

Lecture Notes in Management and Industrial Engineering

José Luis Ayuso Muñoz

José Luis Yagüe Blanco

Salvador F. Capuz-Rizo *Editors*

Project Management and Engineering

Selected Papers from the 17th
International AEIPRO Congress
held in Logroño, Spain, in 2013



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Editors

José Luis Ayuso Muñoz
Universidad de Córdoba
Córdoba
Spain

Salvador F. Capuz-Rizo
Universitat Politècnica de València
Valencia
Spain

José Luis Yagüe Blanco
Universidad Politécnica de Madrid
Madrid
Spain

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Preface

The Spanish Association of Project Management and Engineering is pleased to issue this volume. It compiles a selection of the best papers presented at the 17th International Congress on Project Management and Engineering. They are a good sample of the state of the art in the fields of Project Management and Projects Engineering.

After having organized an annual Congress—first at the national and then at the international level—with an array of universities over the last 18 years, by the end of 2008 the AEIPRO Directive Board decided to introduce a two steps procedure to evaluate the papers presented. First the Scientific Committee assess all the papers presented to select the approved ones to the Congress. After the conclusion and taking into account the chairman reports of the session, a second assessment is performed by a reduced Scientific Committee. We hope that the fruit of this process, this volume, contributes to the improvement of project engineering research and enhance the transfer of results to the job of Project Engineers and Project Managers.

The Spanish Association of Project Management and Engineering (Asociación Española de Dirección e Ingeniería de Proyectos—AEIPRO) is a non-profit organization founded in 1992. It is an entity for the professionalization of Project Management and Engineering with the following goals: to facilitate the association of scientists and professionals within the Project Management and Engineering areas; to serve as a tool for improving communication and cooperation amongst these professionals; to improve experts' knowledge in the different fields of Project Management and Engineering; to promote the best professional practices in these fields; to identify and define the needs that may arise in the everyday development of these activities; and finally, to adopt positions in order to orientate society when faced with differences with the fields of action. At present, it is the Spanish Association Member of IPMA (International Project Management Association), an international association that brings together more than 45,000 project management professionals and researchers from 55 countries.

The papers presented in this book, address methods, techniques, studies and applications to project management and all the project engineering areas. The contributions have been arranged in nine chapters:

- Project Management
- Civil engineering, urban planning, building and architecture
- Environmental engineering and natural resource management
- Energy efficiency and renewable energy
- Rural development and development cooperation projects
- Production process engineering
- Product engineering and industrial design
- IT and communications. Software engineering
- Training in project engineering

We want acknowledge our gratitude to all the contributors and reviewers.

Valencia, Spain, May 2014

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Dr. Carlos José Álvarez López, *Universidad de Santiago de Compostela*

Dr. José Luis Ayuso Muñoz, *Universidad de Córdoba*

Dr. Salvador F. Capuz-Rizo, *Universitat Politècnica de València*

Dr. Manuel de Cos Castillo, *Universidad Politécnica de Madrid*

Dr. Ignacio de los Ríos Carmenado *Universidad Politécnica de Madrid*

Dr. Dante Guerrero Chanduví, *Universidad de Piura*

Dr. Jesús Guillén Torres, *Universidad de Zaragoza*

Dr. Adolfo López Paredes, *Universidad de Valladolid*

Jesús Martínez Almela, *Bioagroprojects Biotech*

Dr. Agustín Molina García, *Universidad Politécnica de Madrid*

Dr. Francisco Ortega Fernández, *Universidad de Oviedo*

Dr. Miguel Ángel Sebastián Pérez, *Universidad Nacional de Educación a Distancia*

Manuel Zahera Pérez, *Cotec*

Contents

Part I Project Management

An International Analysis of Project Delivery Systems for Public Works Projects	3
I. De Sande, A. Jiménez-del-Barco, G. Martínez, B. Moreno and F. J. Alegre	
Exploring the Relations between Project Duration and Activity Duration	19
F. Acebes, J. Pajares, J. M. Galán and A. López-Paredes	
Adoption of Project Management Practices and Performance. Non-Governmental Organisations of Navarre–Spain	31
M. I. Montes-Guerra, A. R. De-Miguel, F. N. Gimena, A. Pérez-Ezcurdia and H. M. Díez-Silva	
Quick Planning Using “S” Curves and Cost Based Durations	45
F. Valderrama and R. Guadalupe	
Engineering Projects Assessment Using Earned Value Management with Performance Indexes Evaluation and Statistical Methods	61
J. Rubio, J. I. Muñoz and J. R. Otegi	
Tool Based on AHP and Its Application in the RURENER Local Actions Plan Evaluation	73
A. Paneque-de la Torre, P. Aragonés-Beltrán and J. Martínez-Almela	

Part II Civil Engineering, Urban Planning, Building and Architecture

Comparative Analysis of Calculation of Buildings Drainage Systems.....	87
P. Arrué, A. M Romero and A. C Cárcel	

Innovative Modular Building Manufactured Using Structural Black Poplar Plywood Panels	105
M. Alia-Martínez, J. Fernandez-Ceniceros, J. Antonanzas, E. Fraile-García and R. Urraca	

Part III Environmental Engineering and Natural Resource Management

Multicriteria Decision Making Methodologies Applied to the Selection of Best Available Techniques in the Ceramic Industry: Equalitarian vs Prioritised Weighting	117
V. Ibáñez-Forés, P. Aragonés-Beltrán and M. D. Bovea	

LABWASTE.12: Calculation Tool for the Design of Solid Waste Landfills with Inert Waste Recovery.....	131
J. Esteban, F. J. Colomer, M. Carlos, and A. Gallardo	

Synergy as Strategy for the Energetic Valorisation of Waste Focused in Transport.....	145
J V Álvarez, R. Luiña, F. Ortega and P. Lobo	

Design of an SRF from Refuse from a Municipal Waste Treatment Plant.....	157
A. Gallardo, A. M. Gómez, F. J. Colomer, N. Edo and P. Pascual	

Local Analysis of the Characteristics and Frequency of Extreme Droughts in Málaga Using the SPI (Standardized Precipitation Index)	167
J. L. Ayuso, P. Ayuso-Ruiz, A. P. García-Marín, J. Estévez and E. V. Taguas	

Part IV Energy Efficiency and Renewable Energy

Decision Support System Software Integrating Geographic Information Systems and Soft Computing to Solve Optimal Location Problems of Renewable Energy Plants	183
J. M. Sánchez Lozano, J. Á. Jiménez Pérez, M. S. García-Cascales and M. T. Lamata Jiménez	

Downscaling of Solar Irradiation from Satellite Estimates	197
F. Antoñanzas-Torres, J. Antonanzas, F. J. Martínez-de-Pisón, M. Alia-Martínez and O. Perpiñán-Lamigueiro	

**Self Energy Production by a Floating Photovoltaic System
Covers for Irrigation Reservoirs** 207
 M. Redón-Santafé, C. M Ferrer-Gisbert, J. Ferrán-Gozálvez,
 J. B Torregrosa-Soler, F. J Sánchez-Romero, P. S Ferrer-Gisbert
 and E. Pons-Puig

Part V Rural Development and Development Cooperation Projects

**Leadership Development in Rural Development Projects: A
Case Study in an Aymara Women Organization in Puno (Peru)** 219
 S. Sastre-Merino

Part VI Production Process Engineering

**On-line Soft Sensor Based on Regression Models and Feature
Selection Techniques for Predicting Rubber Properties in
Mixture Processes** 235
 E. Sodupe-Ortega, R. Urraca, J. Antonanzas, M. Alia-Martinez,
 A. Sanz-Garcia and F. J. Martínez-de-Pisón

Part VII Product Engineering and Industrial Design

**Segregation of a Binary Granular Mixture in a Feed Shoe of a
Single Punch Press Using DEM** 249
 L. Martínez-Martínez, E. Sainz-García, J. Muro-Hernández,
 F. Alba-Elías and A. González Marcos

Part VIII IT and Communications. Software Engineering

**Use of Wireless Sensor Network to Control Landslides
Interacting with Infrastructures** 267
 G. Combarros Hernández, A. García Garijo, F. Antoñanzas-Torres,
 E. Alonso García and R. Fernández Martínez

**Evaluation of Clustering Configurations for Object Retrieval
Using SIFT Features** 279
 L. Fernández-Robles, M. Castejón-Limas, J. Alfonso-Cendón and E. Alegre

**A Novel Architecture for Recognising Symbols in a
CAD Environment** 293
 D. G. Fernández-Pacheco, J. Conesa, F. Albert,
 F. Cavas-Martínez and N. Aleixos

Symbolic Computation Applied to Industrial Robots Through SAGE 307
 S. Nájera, C. Elvira, L. F. García-Verde and J. Rico-Azagra

Part IX Training in Project Engineering

Critical Learning in Development Projects and International Cooperation 325
J. Peris, A. Boni, V. Pellicer and S. Fariñas

Competences in Project Management Reachable Before Getting the Engineering Degree 339
D. Guerrero, M. Palma, S. Vegas, V. Quevedo and G. La Rosa

Contributors

F. Acebes Grupo INSISOC, Departamento de Organización de Empresas y CIM, Escuela de Ingenierías Industriales, Universidad de Valladolid, Valladolid, Spain

F Alba-Elías Departamento de Ingeniería Mecánica, Universidad de La Rioja C/Luis de Ulloa 20, Logroño, Spain

F Albert Instituto Interuniversitario de Investigación en Bioingeniería y Tecnología Orientada al Ser Humano, Universitat Politècnica de Valencia, Valencia, España

E Alegre Departamento de Ingenierías Eléctrica y de Sistemas y Automática, Universidad de León, León, Spain

F. J. Alegre Departamento de Ingeniería de la Construcción y Proyectos de Ingeniería, Universidad de Granada, Granada, Spain

N. Aleixos Instituto Interuniversitario de Investigación en Bioingeniería y Tecnología Orientada al Ser Humano, Universitat Politècnica de Valencia, Valencia, España

J. Alfonso-Cendón Departamento de Ingenierías Mecánica, Informática y Aeroespacial, Universidad de León, León, Spain

M. Alia-Martínez EDMANS Group, ETSII, University of La Rioja, La Rioja, Spain

EDMANS Group, ETSII, University of La Rioja, Logroño, Spain

E. Alonso García EDMANS Group, University of La Rioja, La Rioja, Spain

J V Álvarez Universidad de Oviedo, Oviedo, Spain

J. Antonanzas EDMANS Group, ETSII, University of La Rioja, Logroño, Spain
EDMANS Group, ETSII, University of La Rioja, La Rioja, Spain

F. Antoñanzas-Torres Department of Mechanical Engineering, ETSII, University of La Rioja, La Rioja, Spain

P. Aragonés-Beltrán INGENIO (CSIC-UPV) Universitat Politècnica de València, Valencia, Spain

P. Arrué Departamento de Construcciones Arquitectónicas, IT-DIMM, Universitat Politècnica de València, Valencia, Spain

J. L. Ayuso Department of Rural Engineering, University of Córdoba, Córdoba, Spain

P. Ayuso-Ruiz Department of Rural Engineering, University of Córdoba, Córdoba, Spain

A. Boni INGENIO (CSI-UPV), Universitat Politècnica de València, Valencia, España

M. D. Bovea Departamento de Ingeniería Mecánica Y Construcción, Universitat Jaume I, Castellón, Spain

A. C Cárcel Departamento de Ingeniería Mecánica y de Materiales, ITM-DIMM, Universitat Politècnica de València, Valencia, Spain

Departamento de Construcciones Arquitectónicas, IT-DIMM, Universitat Politècnica de València, Valencia, Spain

M. Carlos Departamento Ingeniería Mecánica y Construcción, Universitat Jaume I, Castellón de la Plana, Spain

M. Castejón-Limas Departamento de Ingenierías Mecánica, Informática y Aeroespacial, Universidad de León, León, Spain

F. Cavas-Martínez DEG, Universidad Politécnica de Cartagena, Cartagena, España

F. J. Colomer Departamento Ingeniería Mecánica y Construcción, Universitat Jaume I, Castellón de la Plana, Spain

Departamento Ingeniería Mecánica y Construcción, Universitat Jaume, Castelló, Spain

G. Combarros Hernández University of La Rioja, La Rioja, Spain

J. Conesa DEG, Universidad Politécnica de Cartagena, Cartagena, España

I. De Sande Departamento de Ingeniería de la Construcción y Proyectos de Ingeniería, Universidad de Granada, Granada, Spain

A. R. De-Miguel Projects and Rural Engineering Department, Public University of Navarre, Pamplona, Spain

H. M. Díez-Silva Universidad EAN, Bogotá, Colombia

N. Edo Departamento Ingeniería Mecánica y Construcción, Universitat Jaume, Castelló, Spain

C. Elvira Electrical Engineering Department, University of La Rioja, Logroño, Spain

J. Esteban Departamento Ingeniería Mecánica y Construcción, Universitat Jaume I, Castellón de la Plana, Spain

J. Estévez Department of Rural Engineering, University of Córdoba, Córdoba, Spain

S. Fariñas Grupo de Estudios en Desarrollo, Departamento de Proyectos de Ingeniería, Universitat Politècnica de València, Valencia, España

R. Fernández Martínez ETSI, UPV-EHU, Bilbao, Spain

J. Fernandez-Ceniceros EDMANS Group, ETSII, University of La Rioja, Logroño, Spain

D. G. Fernández-Pacheco DEG, Universidad Politécnica de Cartagena, Cartagena, España

L. Fernández-Robles Departamento de Ingenierías Mecánica, Informática y Aeroespacial, Universidad de León, León, Spain

J. Ferrán-Gozálvez Departamento Ingeniería Rural y Agroalimentaria, Universidad Politécnica de Valencia, Valencia, Spain

C. M Ferrer-Gisbert Departamento Ingeniería Rural y Agroalimentaria, Universidad Politécnica de Valencia, Valencia, Spain

P. S Ferrer-Gisbert Departamento Proyectos de Ingeniería, Universidad Politécnica de Valencia, Valencia, Spain

E. Fraile-García EDMANS Group, ETSII, University of La Rioja, Logroño, Spain

J. M. Galán Grupo INSISOC, Área de Organización de Empresas, Departamento de Ingeniería Civil, Escuela Politécnica Superior, Universidad de Burgos, Burgos, Spain

A. Gallardo Departamento Ingeniería Mecánica y Construcción, Universitat Jaume I, Castellón de la Plana, Spain

Departamento Ingeniería Mecánica y Construcción, Universitat Jaume, Castelló, Spain

A. García Garijo University of La Rioja, La Rioja, Spain

M. S. García-Cascales Departamento de Electrónica, Tecnología de Computadoras y Proyectos, Universidad Politécnica de Cartagena, Cartagena, Spain

- A. P. García-Marín** Department of Rural Engineering, University of Córdoba, Córdoba, Spain
- L. F. García-Verde** Electrical Engineering Department, University of La Rioja, Logroño, Spain
- F. N. Gimena** Projects and Rural Engineering Department, Public University of Navarre, Pamplona, Spain
- A. M. Gómez** Departamento Ingeniería Mecánica y Construcción, Universitat Jaume, Castelló, Spain
- A. González Marcos** Departamento de Ingeniería Mecánica, Universidad de la Rioja C/Luis de Ulloa 20, Logroño, Spain
- R. Guadalupe** Universidad Politécnica de Madrid, Madrid, Spain
- D. Guerrero** Universidad de Piura, Piura, Perú
- V. Ibáñez-Forés** Departamento de Ingeniería Mecánica Y Construcción, Universitat Jaume I, Castellón, Spain
- J. Á. Jiménez Pérez** Departamento de Electrónica, Tecnología de Computadoras y Proyectos, Universidad Politécnica de Cartagena, Cartagena, Spain
- A. Jiménez-del-Barco** Departamento de Ingeniería de la Construcción y Proyectos de Ingeniería, Universidad de Granada, Granada, Spain
- M. T. Lamata Jiménez** Departamento de Ciencias de la Computación e Inteligencia Artificial, CITIC, Universidad de Granada, Granada, Spain
- P. Lobo** Universidad de Oviedo, Oviedo, Spain
- A. López-Paredes** Grupo INSISOC, Departamento de Organización de Empresas y CIM, Escuela de Ingenierías Industriales, Universidad de Valladolid, Valladolid, Spain
- R. Luiña** Universidad de Oviedo, Oviedo, Spain
- G. Martínez** Departamento de Ingeniería de la Construcción y Proyectos de Ingeniería, Universidad de Granada, Granada, Spain
- J. Martínez-Almela** Bioagroprojects, Universitat Politècnica de València-UPV, Valencia, Spain
- F. J. Martínez-de-Pisón** EDMANS Group, ETSII, University of La Rioja, Logroño, Spain
- L. Martínez-Martínez** Departamento de Ingeniería Mecánica, Universidad de la Rioja C/Luis de Ulloa 20, Logroño, Spain
- M. I. Montes-Guerra** Escuela Internacional de Ciencias Económicas y Administrativas, Cundinamarca, Colombia

- B. Moreno** Departamento de Ingeniería de la Construcción y Proyectos de Ingeniería, Universidad de Granada, Granada, Spain
- J. I. Muñoz** University of Castilla–La Mancha (UCLM), Albacete, Spain
- J. Muro-Hernández** Departamento de Ingeniería Mecánica, Universidad de la Rioja C/Luis de Ulloa 20, Logroño, Spain
- S. Nájera** Electrical Engineering Department, University of La Rioja, Logroño, Spain
- F. Ortega** Universidad de Oviedo, Oviedo, Spain
- J. R. Otegi** University of Basque Country (EHU-UPV), Leioa, Spain
- J. Pajares** Grupo INSISOC, Departamento de Organización de Empresas y CIM, Escuela de Ingenierías Industriales, Universidad de Valladolid, Valladolid, Spain
- M. Palma** Universidad de Piura, Piura, Perú
- A. Paneque-de la Torre** Asociación Española de Ingeniería de Proyectos, Valencia, Spain
- P. Pascual** Departamento Ingeniería Mecánica y Construcción, Universitat Jaume, Castelló, Spain
- V. Pellicer** Grupo de Estudios en Desarrollo, Departamento de Proyectos de Ingeniería, Universitat Politècnica de València, Valencia, España
- A. Pérez-Ezcurdia** Projects and Rural Engineering Department, Public University of Navarre, Pamplona, Spain
- J. Peris** Grupo de Estudios en Desarrollo, Departamento de Proyectos de Ingeniería, Universitat Politècnica de València, Valencia, España
- O. Perpiñán-Lamigueiro** Electrical Engineering Department, EUITI-UPM, Madrid, Spain
- E. Pons-Puig** Isigenere S.L, Alicante, Spain
- V. Quevedo** Universidad de Piura, Piura, Perú
- M Redón-Santafé** Departamento Ingeniería Rural y Agroalimentaria, Universidad Politècnica de Valencia, Valencia, Spain
- J. Rico-Azagra** Electrical Engineering Department, University of La Rioja, Logroño, Spain
- A. M Romero** Departamento de Construcciones Arquitectónicas, IT-DIMM, Universitat Politècnica de València, Valencia, Spain
- G. La Rosa** Universidad de Piura, Piura, Perú
- J. Rubio** Dresser-Rand Inc., Miñano, Spain

E. Sainz-García Departamento de Ingeniería Mecánica, Universidad de la Rioja
C/Luis de Ulloa 20, Logroño, Spain

J. M. Sánchez Lozano Centro Universitario de la Defensa, Academia General
del Aire, Universidad Politécnica de Cartagena, Santiago de la Ribera, Spain

F. J Sánchez-Romero Departamento Ingeniería Rural y Agroalimentaria,
Universidad Politécnica de Valencia, Valencia, Spain

A. Sanz-García CDR. University of Helsinki, Finland

S. Sastre-Merino Departamento de Proyectos, ETSI Agrónomos, Universidad
Politécnica de Madrid, Madrid, Spain

E. Sodupe-Ortega EDMANS Group, ETSII, University of La Rioja, La Rioja,
Spain

E. V. Taguas Department of Rural Engineering, University of Córdoba, Córdoba,
Spain

J. B Torregrosa-Soler Departamento Ingeniería Rural y Agroalimentaria,
Universidad Politécnica de Valencia, Valencia, Spain

R. Urraca EDMANS Group, ETSII, University of La Rioja, La Rioja, Spain

F. Valderrama Universidad Europea de Madrid, Madrid, Spain

S. Vegas Universidad de Piura, Piura, Perú

Part I
Project Management

An International Analysis of Project Delivery Systems for Public Works Projects

I. De Sande, A. Jiménez-del-Barco, G. Martínez, B. Moreno and F. J. Alegre

1 Introduction

In the last 20 years, the advancement experienced by the field of Project Management has given rise to new Project Delivery Systems (PDS) that meet today's construction industry's needs in a much more efficient manner. Nonetheless, the development of these PDS has not been a sudden and pervasive phenomenon, but a gradual and localized one. As a consequence, it is hard to apprehend which exactly is the set of PDS that is used around the world. In the current context of globalization, solving this lack of agreement in classification of PDS becomes a critical task. Furthermore, countries such as Spain do not allow the application of certain PDS. This work also aims to serve as a reference so that these countries become more aware of the benefits they can offer and consider the possibility of regulating their use.

I. De Sande (✉) · A. Jiménez-del-Barco · G. Martínez · B. Moreno · F. J. Alegre
Departamento de Ingeniería de la Construcción y Proyectos de Ingeniería, Universidad de Granada, Granada, Spain
e-mail: idspalma@gmail.com

A. Jiménez-del-Barco
e-mail: ajbc@ugr.es

G. Martínez
e-mail: gmmontes@ugr.es

B. Moreno
e-mail: bgmoreno@ugr.es

F. J. Alegre
e-mail: fjalegre@ugr.es

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2 Objectives

This work has two main objectives. On the one side, the development of a classification of PDS, used around the world, studying their names, features, advantages, disadvantages and applications. On the other side, based on this classification, analysing Spain's Public Contracts Law (*Texto Refundido de la Ley de Contratos del Sector Público*-TRLCSP-) and determining some of its various limitations [3].

3 Scope

The scope of this work is limited to those PDS including the design phase and the construction phase of a given project. PDS including phases beyond these two (e.g. operation and maintenance) or alternative financing strategies (e.g. public private partnerships) are not considered in this study. Similarly, besides Spain, only those countries that have a longer tradition in the use of alternative PDS are considered. These countries are the United States of America, the United Kingdom and Australia.

4 Methodology

The methodology followed is been partitioned in four different steps. Firstly, a thorough literature review has been conducted. Elements and variables that take part in the project delivery process have been spotted, and the various PDS used around the world have been identified. Then, these PDS have been contrasted, and four major PDS encompassing the rest of the systems have been defined. Next, PDS regulated by the Spanish legislation have been studied. Finally, these sets of PDS have been compared to the one defined in the first part of the work, and a series of limitations have been ascertained.

5 Project Delivery Concepts

Mark Konchar [6] defines a PDS as the set of relationships, roles and responsibilities of project team members, and the sequence of activities required to provide a facility. As a consequence, it is necessary, before introducing the various PDS that can be found around the world, to define the participants, phases and risks that can be associated to a particular PDS. Besides, every PDS is related to specific contracting methods, procurement methods, and management methods. These methods are also explained in this section

5.1 Project Participants

Each PDS involves a certain group of project participants and assigns a particular role to each of them. Such role entails a series of risks and responsibilities:

- The agency: is the owner of the project. It defines the scope of the work and the basic specifications for design and construction. It usually manages the bidding process and supervises the project.
- The designer: is an entity specialized in the design of infrastructures. It can also act as a supervisor on the constructor.
- The constructor: is an entity specialized in the construction of infrastructures. Most times it will perform the work with its own resources, but sometimes it will subcontract it.
- The designer-constructor: is an entity specialized both in the design and in the construction of infrastructures.
- The construction manager: is an entity specialized in managing construction projects (i.e. project controls, constructability, etc.). Its role and level of authority is different depending on the project [20].

Although the designer may be a private company, in some cases it may be an agency’s in-house team. Similarly, although the constructor refers to one unique entity (generally the contractor), it is also possible to have several constructors working on the same project (Multi-primers).

5.2 Project Phases

Each PDS includes a specific group of phases that occur in a particular sequence. In this work, three project phases are being considered: bidding, designing and building. Materials procurement is embedded into the last two. These phases can occur in linear sequence or can overlap each other (Fast-tracking) [20]. Furthermore, design sub-phases, depending on the level of design complete, can be related to a specific outcome of the designer’s work (Table 1).

Table 1 Design sub-phases and level of design complete. (l.d.c.)

#	According to RD 2512/1977	l.d.c. (%)	According to AGC [16]	l.d.c. (%)
1	Estudio Previo	15	Pre-design	–
2	Anteproyecto	35	Schematic design	15
3	Proyecto Básico	65	Design development	65
4	Proyecto de Ejecución	100	Construction documents	100

5.3 Risk Allocation

Each PDS allocates certain project risks differently between agency and contractor (whoever this is). These risks are: (a) design risks (e.g. errors and omissions) (b) management risks (e.g. mistaken instructions), and (c) financial risks or risk of being the *Final cost* higher than the *Estimated cost*.

5.4 Contracting Methods

A contracting method (or payment method), defines the way in which the *Price of the contract* is set. The *Price of the contract* is the amount of money that the Agency is going to pay to the contractor so that it performs the work. This amount can be equal to the *Final cost* or the *Estimated cost*. The allocation of the financial risk depends on which of these methods is used. Most common methods are the following ones [1, 4, 5, 16]:

- Fixed Price or Lump Sum. This method establishes that the *Price of the contract* is equal to the *Estimated cost* of the project, regardless of what the *Final cost* end up being. This method assigns most of financial risk to the contractor
- Cost Plus Fees or Cost Reimbursable. This method establishes that the *Price of the contract* is equal to the *Final cost* of the project, regardless of what the *Estimated cost* was. The *Final cost* is computed as the sum of two elements, *Reimbursable costs* and *Fees*. This method assigns most of financial risk to the Agency
- Guaranteed Maximum Price (GMP). This method is the same as the previous one, the only difference is that the Price of the contract is capped. This method is usually applied to sharing clauses, both benefits and losses. It assigns the financial risk evenly between Agency and contractor, although at the end of the day is the Agency who bears most of the risk.
- Unit Price. This method establishes that the *Price of the contract* is equal to the *Final cost* of the project, regardless of what the *Estimated cost* was. The *Final cost* is computed as the sum of the products that result when the units of work that define a given scope of work, are multiplied by the price of each of these units. This method assigns the financial risk evenly between Agency (risk of setting the quantities) and contractor (risk of setting the price).

5.5 Procurement Method

A procurement method defines the various criteria that the Agency can follow to select the contractor. Most common methods are the following [16, 17]:

- Low Bid. This method considers the Price of the contract as the only criterion for selection. In the Spanish legislation it is equivalent to what is known as *subasta*.
- Best Value. This method considers a set of criteria for the selection of the contractor. One of these criteria is either the Price of the contract (in which case the method is called Best Value: Total Cost) or the sum of profit and Overhead costs (in which case the method is called Best Value: Fees).
- Qualifications. This method considers a set of criteria for the selection of the contractor. As opposed to the previous method, neither the Price of the contract nor the sum of profit and Overhead costs are parts of these criteria.

5.6 Management Method

When delivering a project, the Agency must decide which management method is going to be applied. A management method is the set of techniques by which construction is administered and supervised [16]. The following two methods are considered:

- In-house Manager. According to this method, it is a group of professionals within the agency who administers the project. This is the most commonly used method.
- Construction Manager as Advisor. According to this method, the agency, due to its lack of in-house resources, hires a construction manager to administer the project. Therefore, the construction manager assumes the management risk.

Understanding the difference between these two approaches is extremely important because many authors consider the Construction Manager as Advisor (CM-Advisor) system as an additional project delivery system (see Table 2). Nonetheless, this concept is mistaken. CM-Advisor is not a project delivery system but a management method, and so, it can be applied to any project delivery method [16].

Table 2 CM-Advisor equivalent names. (Own source)

Country	Name	Abbreviation
United States of America	Agency Construction Manager	Agency CM
	Construction Manager as Advisor	CM-Advisor
	Construction Manager as Agent	CM-Agent
	Construction Manager for Fee	CM for fee
	Pure Construction Manager	Pure CM
	Construction Manager not-at-Risk	CM not-at-risk
	Program Management	PM
	Project Management	PM
United Kingdom	Construction Management	CM
Spain	Construction Manager as Consultor	CMc

6 Results

6.1 Classification

6.1.1 Design-Bid-Build (DBB)

The Design-Bid-Build (DBB) system is a project delivery system where the agency contracts a designer to develop the design and then contracts a constructor to build the project ([7]; Figs. 1 and 2).

Note that the DBB system can be implemented with in-house management or multi-prime constructors. In the last case, design and construction can overlap (Fast-Track) [16, 17].

The DBB system (see alternative names in Table 3) has been the approach most frequently used to deliver construction projects since the beginning of the nineteenth century, when the Industrial Revolution divided design and construction in two completely different fields of specialization [10].

The DBB system is characterized by a lack of construction knowledge applied into the design process and a high degree of agency control over the project [2, 12, 20].

The procurement methods associated to this PDS are the Low Bid method (most common) and the Best Value method [12, 16]. The contracting methods associated to this PDS are the Fixed Price method or the Unit Price method [11, 12]. Both sets of methods apply only to the constructor, who is usually referred to as the contractor.

The risk distribution associated to the DBB system is based on what is known as the Spearin doctrine. According to this doctrine, once the agency accepts the designer's design, the agency becomes responsible of the design to the constructor (*United States v. Spearin, 248 U.S. 132*) [16, 18]. This means that the agency

Fig. 1 DBB participants and contractual relationships [18]

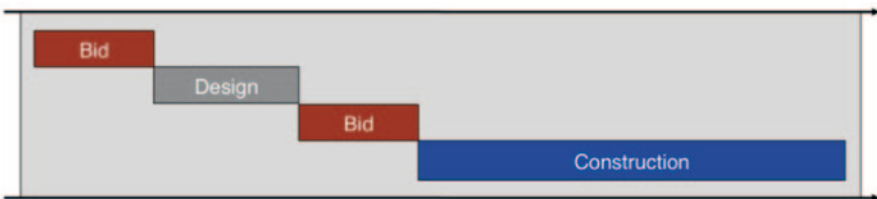


Fig. 2 DBB phases [15]

Table 3 Alternative names for the DBB system. (Own source)

Country	Name	Abbreviation
United States of America	Design-Bid-Build	DBB
	Design-Bid-Construct	–
	Design-Select-Build	–
	Traditional	–
Australia	Design and then Construct	–
	Documented Design	–
	Developed Design	–
	Construct Only	–
United Kingdom	General Contracting	–
Spain	Licitación de contrato de servicios-Proyecto-Licitación de contrato de obra-Construcción	–
	Licitación-Diseño-Licitación-Construcción	LD-LC

assumes the design risk. The management risk is usually assumed by the agency, provided that no Construction Manager is hired as advisor.

Project participants' familiarity with the process, high likelihood of the project outcome meeting the agency's expectations, competition fetching and low tendering costs are the most relevant advantages to this system [11, 12]. On the other hand, some of its most notable disadvantages are the slowness of the process (sequential rather than concurrent phases), the higher number of change orders and disputes between team participants, the lack of construction input in the design and the lack of opportunity for innovation [12, 17].

Finally, the DBB system is usually applied to a wide range of public works projects, mostly because it fills very well the agency's control needs. If the design is one of the agency's major concerns or if the design is expected to change throughout the life of the project, then this is also the system of choice. Nonetheless, this system shall not be applied to significantly large or complex projects [8, 11, 19, 20].

6.1.2 Design-Build (DB)

The Design-Build (DBB) system is a project delivery system where the agency contracts a single entity, the designer–constructor, to perform the design and build the project [7]. The level of design complete at the time of the bid must not be higher than 30% ([12]; Figs. 3 and 4).

The level of design complete is an extremely sensitive variable that many authors seem to obviate. If this aspect is ignored, one will be considering as equal two systems that are going to produce considerably different outcomes (remember that the closer the level of design complete to 100%, the more similar the system to a traditional DBB system).

Fig. 3 DB participants and contractual relationships [18]

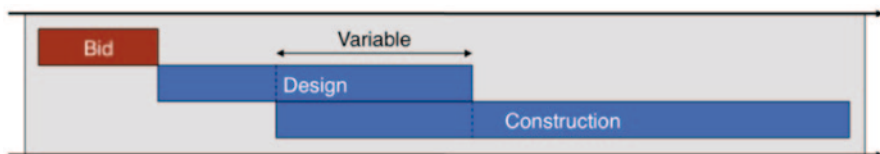
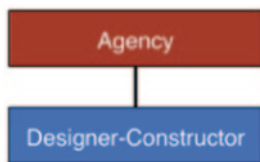


Fig. 4 DB phases [15]

Table 4 Alternative names for the DB system. (Own source)

Country	Name	Abbreviation
United States of America	Design-Build	DB
	Package Deal	–
	Master Builder	–
Australia	Design and Construct	D&C
United Kingdom	Design and Build	DB
Spain	Licitación de contrato de obra-Proyecto-Construcción	–
	Licitación-Diseño-Construcción	LDC

Contrary to what is usually believed, the DB system (see alternative names in Table 4) has been the approach most frequently used to deliver construction projects in history [14, 15]. Nevertheless, as we know it today, this approach only started to be used in the mid 1980s. Many agencies were not comfortable assuming the large amount of risk that the DBB system forced them to bear with. The DB system, which allocates all the risk on one single entity (designer–constructor), offered an attractive alternative to this situation [8, 17, 19].

The DB system, unlike the DBB system, is characterized by the application of construction knowledge into the design process and the low degree of agency control over the project [2, 12, 20]. It is important to note that this loss of control does not necessarily translate into a loss of quality, provided that the agency commits to its inspection duties.

The procurement methods associated to this PDS are the Best Value method (most common) and the Qualifications method [8, 16, 17]. The contracting methods associated to this PDS are the Fixed Price method or the GMP method. Sometimes the Cost plus Fees method is also applied [16, 17].

Regarding the risk distribution, as it has been mentioned above, the DB system assigns most of the design risk to the contractor [2, 12]. Given the loss of agency

control over the project, Management risk is usually assumed by the contractor. It could be fair to assume that, due to the high degree of cooperation between designer and constructor, the magnitude of all these risks for DB projects is lower than its magnitude for DBB projects.

DB system's advantages and disadvantages are opposite to DBB system. Therefore, the advantages can be summarized in the speed of the process (concurrent rather than sequential phases), low number of change orders, low number of disputes between team participants, construction input in the design and opportunity for innovation [12, 18, 19]. On the other hand, disadvantages to the DB system are project participants' unfamiliarity with the process, low likelihood of the project outcome meeting the agency's expectations, limitation to competition and high tendering costs [11, 12].

Finally, the DB system is usually applied to large projects and projects with significant time constraints or with previously allocated budget [8, 12, 20]. It should not be applied to projects which scope is loosely defined or which are likely that many change orders occur. Some authors stated that the DB system should not be applied to complex projects, some others do [8, 10, 11, 17].

6.1.3 Modified Design-Build (Modified DB)

The Modified DB system is a project delivery system very similar to the DB system but where the level of design complete at the time of the bid is between 30 and 80% [8].

Some agencies are not willing to assume the loss of control that the adoption of a DB system entails. Still, these agencies want to transfer some risk to the contractor. This is how the Modified DB system is born [17].

There are two variations of the Modified-DB system; these are the Bridging system and the Novation system. The difference between these two variations is basically the number of designers that contributes to the design. For the Bridging system, there are two designers involved in the project (one before the bidding process, one after), and for the Novation system, however, there is only one.

The Bridging system is a project delivery system where the agency contracts a designer to develop a partial design of the infrastructure, and then contracts a designer–constructor to finish the design and to build the project ([17]; Figs. 5 and 6).

The Bridging system (see alternative names in Table 5) has become considerably popular in countries such as the United States of America. In fact, many agencies which claim to use the DB system are really using the Bridging system. The procurement method associated to this PDS is the Low Bid method [8].

The Novation system is a project delivery system where the agency contracts a designer to develop a partial design of the infrastructure, and then contracts a constructor, who has to partner with the designer, to finish the design and to build the project ([8]; Figs. 7 and 8).

Fig. 5 Bridging participants and contractual relationships. (Own source)

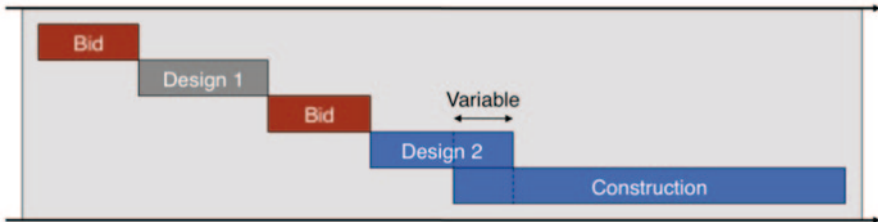


Fig. 6 Bridging phases. (Own source)

Table 5 Alternative names for the Bridging system. (Own source)

Country	Name	Abbreviation
United States of America	Bridging	–
	Design-Build Bridging	–
	Modified Design-Build	–
	Low bid Design-Build	–
	Draft/Detail-Build	–
	Design-Build-Bid	–
Australia	Design Development and Construct	DD&C
	Document and Construct (novate the design only)	–
United Kingdom	Develop and Construct	D&C
Spain	Licitación-Diseño-Licitación-Diseño-Construcción con dos consultores	LD-LDC/2c

The Novation system (see alternative names in Table 6) is widely known in countries such as Australia. In the United Kingdom, many DB projects are actually Novation projects [10].

In short, the Modified-DB system is an intermediate system between the DBB and the DB system; and so are its properties. This means that its properties will be more or less similar to one or another system depending on the level of design complete at the time of the bid. The closer the level of design complete is to 30%, the more similar the Modified-DB system’s properties are to those of the DB system. The closer the level of design complete is to 80%, the more similar the Modified-DB system’s properties are to those of the DBB system. [2, 11].

Fig. 7 Novation participants and contractual relationships. (Own source)

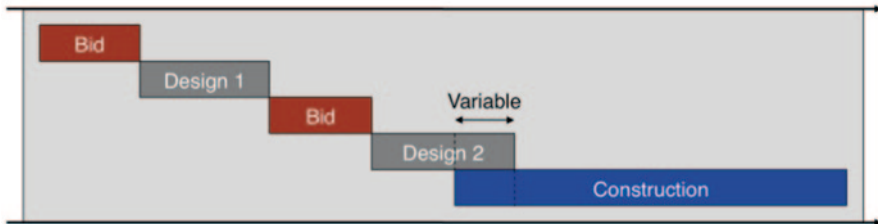


Fig. 8 Novation phases. (Own source)

Table 6 Alternative names for the Novation system. (Own source)

Country	Name	Abbreviation
Australia	Design, Novate and Construct	–
	Document and Construct (Novate design and designer)	–
United Kingdom	Novated Design and Build	–
Spain	Licitación-Diseño-Licitación- Diseño-Construcción con un consultor	LD-LDC/lc

6.1.4 Construction Manager at Risk (CM@Risk)

The Construction Management at Risk (CM@Risk) system is a project delivery system where the agency contracts a designer to develop the design and a construction manager to act first as an advisor during the design phase and as a constructor afterwards. The change of roles occurs when the level of design complete is between 50 and 90% [17]. Usually, the construction manager will only manage the construction process. The construction work will be performed by other subcontractors ([7]; Figs. 9 and 10).

In spite of the above definition, the CM@Risk system can be implemented with no overlapping [17]. Besides, if the construction manager has enough resources, it can also perform the construction works itself [18].

The CM@Risk system (see alternative names in Table 7) is applied for the first time around 1970. Many agencies did not have the resources needed to manage certain types of construction projects (usually larger and more complex) but also

Fig. 9 CM@Risk participants and contractual relationships [18]

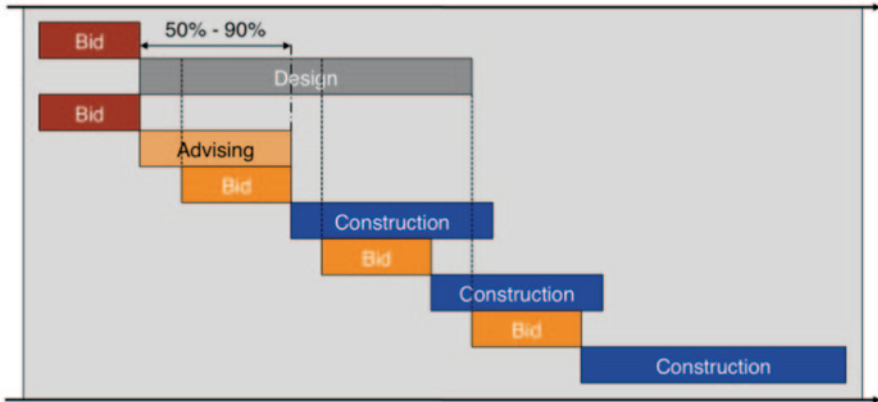
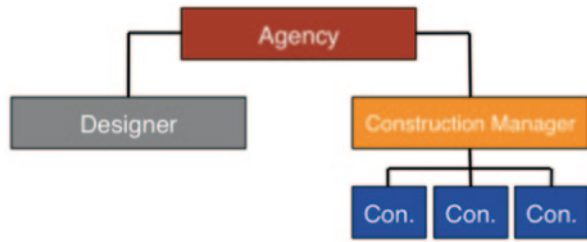


Fig. 10 CM@Risk phases [15]

wanted the construction manager to have more responsibilities than those of an advisor [15, 16]. The CM@Risk system offered a feasible alternative. Nonetheless, this PDS has never become very popular in the construction industry, at least not outside the United States of America [10].

The CM@Risk system is characterized by the application of construction knowledge into the design process and the considerably high degree of agency control over the project [18, 19]. Therefore, the CM@Risk system presents itself as an additional alternative to both the DBB and the DB system.

The procurement methods associated to this PDS are the Best Value method and the Qualifications method. These methods apply to the construction manager. On the contrary, the construction manager usually selects its subcontractors following a Low Bid approach. This combination of procurement methods is frequently seen as one of its biggest strengths [16–18]. The contracting method associated to this PDS is the GMP method (the construction phase will only begin when Guaranteed Maximum Price is been set). Sometimes the Cost plus Fees method is also applied [16, 17].

Regarding the risk distribution, the CM@Risk system assigns most of the design risk to the contractor (Spearin doctrine), and most of the management risk to the construction manager (although this risk can be difficult to allocate if the

Table 7 Alternative names for the the CM@Risk system. (Own source)

Country	Name	Abbreviation
United states of America	Construction Manager as Constructor	<i>CMC</i>
	Construction Manager as Contractor	<i>CMC</i>
	Construction Manager-at-risk	<i>CMR, CM@R</i>
	Construction Manager/General Contractor	<i>CM/GC</i>
	Design Assist	–
	Portland method	–
United Kingdom	Management Contracting	–
Spain	Construction Management as Constructor	<i>CMc</i>

construction manager’s role and authority is not sufficiently well defined [18]. Just as it occurs with the DB system, it could be fair to assume that, due to the degree of cooperation existing between designer and constructor, the magnitude of all these risks for a CM@Risk project is in general lower than its magnitude for a DBB project.

The most significant advantages of the CM@Risk system are the high likelihood of the project outcome meeting the agency’s expectations, the construction input in the design and the opportunity for innovation. On the other hand, limitation to competition and higher overall costs are the most relevant disadvantages to this PDS. It is not clear if the number of disputes increases or decreases [18, 19].

Finally, the CM@Risk system is usually applied to projects with time and/or budgetary constraints, large projects with numerous phases and participants, complex projects, projects with a loosely defined scope of work, projects in which a high number of change orders is expected and projects for which the design is extremely important [11, 19].

6.2 The Spanish Legislation on Project Delivery Systems for Public Works

The *Texto Refundido de la Ley de Contratos del Sector Público* (TRLCSP) is the Spanish Public Contract Law, which derives from the European Directive 2004/18/CE. This Law is the legal frame that regulates the delivery of construction projects in Spain. This Law, however, does not even mention the word *modelo de contratación* (project delivery system). Instead, it focuses on describing the set of contract forms that can be used to deliver a project.

According to this Law, there are two contract forms that can be used to set a DBB, a DB or a Modified-DB project delivery system. These contract forms are

the *contrato de servicios* (services contract) and the *contrato de obras* (construction contract). Nevertheless, the TRLCSP clearly specifies that these two contract forms will be used, in most cases, to set a DBB system. In fact, most of the TRLCSP is focused on these two contract forms as if they were always to be used to set a DBB system. In other words, in Spain the DBB system is the default system to deliver construction projects. The Modified-DB system and the DB system will only be applied under exceptional circumstances. This preference of the DBB system over the Modified-DB system and the DB system was justified about 20 years ago, when these two alternative systems were first regulated in Spain (*Ley 13/1995 de Contratos de las Administraciones Públicas*). Nonetheless, today, the efficiency of these two alternative systems have been demonstrated repeatedly through several empirical studies [13]. Therefore, this biased treatment does not seem logical anymore. In fact, this static regulation contrasts with the ones adopted by several countries within the European Union, such as the United Kingdom or the Netherlands [12], for which the DB system has become the default system. As a consequence, it may be fair to suggest an ease of the conditions that regulate the application of both the Modified-DB and the DB system in Spain.

On the other hand, the CM@Risk system is not regulated by the TRLCSP. This is mainly due to two reasons regarding the selection process of the construction manager. Firstly, the construction manager is usually selected based on criterion that ignores the *Price of the contract* (this is not permitted by the TRLCSP). Secondly, the construction manager is selected at the beginning of the project and automatically switches roles to act as a constructor (for the TRLCSP this is an advantage that breaks the rules of fair competition). Nonetheless, in spite of the obvious risks deriving from this circumstance, and given the set of advantages associated to this PDS, it may also be fair to suggest the inclusion of the CM@Risk system (or a modified version) in the TRLCSP. Some states in the United States apply a slight variation of the CM@Risk system, according to which they have the right to bid the project if the proposed Guaranteed Maximum Price is not low enough [18].

Finally, it is important to mention Love et al. [9], who states that project outcomes do not depend so much on the PDS, but on the contracting method. This observation is interesting because it implies that, besides updating the set of PDS, Spain should also revise the list of contracting methods regulated by the TRLCSP.

7 Conclusions

The present work has grouped the wide spectrum of PDS used around the world into only four different PDS: the DBB system, the DB system, the Modified-DB system and the CM@Risk system. The first two systems represent opposing approaches; the last two represent intermediate approaches between the first two. Each PDS will determine a particular design and management risk distribution, and each

contracting method will determine a particular financial risk distribution, which will have a critical impact on the project outcome in terms of both cost and schedule. The selection of one or another PDS will depend on the project characteristics as well as on the agency's preferences (desired level of control over the project and desired level of construction input in the design) and capabilities (experience and amount of in-house resources). The selection process, however, should not be constrained by the limitations of the legal system in question. It should only be based on efficiency criteria. In other words, the selection process will only lead to the right PDS if the appropriate powers provide the construction industry with the tools it needs to implement them. Nevertheless, whichever the PDS selected, it should be made clear that, in absolute terms, no PDS is better than any other. Instead, each PDS is simply more or less suitable for each project in question.

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Exploring the Relations between Project Duration and Activity Duration

F. Acebes, J. Pajares, J. M. Galán and A. López-Paredes

1 Introduction

A project monitoring and control system is aimed at minimizing the deviations from the initial planning during the execution of the project. This process usually consists of four steps: identifying the status of the project, comparing it with the initial planning, analysing the deviations of the actual execution with regard to planning and proposing, and adopting corrective actions appropriate to redirect the project towards the planned goal.

In this work, uncertainty over the total project duration is referred to the probability that it ends in one or another date depending on the durations of the activities that make up the project.

Monte Carlo simulation is often used to create simulation models of projects [1, 2] which allow estimating uncertainty. If the durations of the activities are modelled using a probability distribution function, Monte Carlo simulation can give as result a probability distribution of the total project duration. This output is useful since it provides a probabilistic support to make predictions about the real duration of projects. However, project Monte Carlo models can be used to obtain additional

F. Acebes (✉) · J. Pajares · A. López-Paredes
Grupo INSISOC, Departamento de Organización de Empresas y CIM, Escuela de Ingenierías Industriales, Universidad de Valladolid, Pso del Cauce S/N, 47011 Valladolid, Spain
e-mail: facebes@yahoo.es

J. Pajares
e-mail: javier@insisoc.org

A. López-Paredes
e-mail: insisoc@insisoc.org

J. M. Galán
Grupo INSISOC, Área de Organización de Empresas, Departamento de Ingeniería Civil, Escuela Politécnica Superior, Universidad de Burgos, C. Villadiego S/N, 09001 Burgos, Spain
e-mail: jmgalan@ubu.es

interesting insights. For instance, we can try to figure out which activities are those with more influence in the duration or variability of the project.

In this article we analyse by means of a case study if shortening, lengthening or reducing the variability of certain activities can produce significant reductions in the expected duration of the entire project, or if the variability of that duration can be reduced. In order to do so, we base our analysis on previous research.

Williams [9] questions the consistency of the criticality index as a single indicator of the importance of each activity in project duration. Criticality is defined as the probability that an activity belong to the critical path of the project. It is usually calculated as a ratio between 0 and 1 of the number of times an activity is on the critical path to the total number of Monte Carlo simulation runs of the project. He proposes the cruciality index as an indicator to complement the analysis based on criticality. Cruciality is defined as the correlation between the duration of an activity and the project duration. In Elmaghraby [4], a short overview addresses the advantages and disadvantages of the sensitivity measures discussed by Williams [8]. He conjectures that the relative importance of project activities should be given by considering a combined version of these sensitivity measures.

Elmaghraby [4] also discusses the uncertainty of the whole project. This uncertainty is measured as the variability of the project duration (statistical variance of the duration), as a function of the expected duration of the activities (average duration). He reviews the research efforts focused on the sensitivity of the mean and variance of project's total duration consequence of changes in the mean and variance of individual activities. Cho and Yum [3] propose an uncertainty importance index to measure the effect of the variability in activity duration on the variability of the overall project duration. Elmaghraby et al. [5] investigate the impact of changing the mean duration of an activity on the variability of the project duration. Gutiérrez and Paul [6] present an analytical treatment of the effect of the activity variance on the expected project duration.

In this work, we explore the relation between the duration of each one of the activities of our case study (both the expected duration and the variability of the duration) with the criticality and cruciality indexes of the activities. We then analyse the influence of these variables on the duration of the entire project (both the expected duration and the variability of the duration). Additionally, we show which activities are the most influential in terms of the previous measures and their associated criticality and cruciality indexes.

We show that this type of analysis gives project managers two interesting additional insights to support decision making. They obtain relevant information to reduce the variability or uncertainty about the total project duration, and at the same time they can determine which are the most influential and decisive activities of the project under different perspectives.

The structure of the paper is as follows: in the next section we describe the project network used as case study in our research. Subsequently we give some brief background to criticality and cruciality concepts. Results and discussions are then provided for each of the variables analysed, and finally, conclusions are presented in the last section.

Table 1 Sequence of project activities of the case study. Durations are modelled as normal distributions; μ represents the mean duration and σ the standard deviation

Previous activity	Activity	μ	σ
	A _i	0	0
A _i	A1	5.5	1.18
A _i	A2	13	3
A1	A3	7	1
A1	A4	16.5	2.5
A2, A3	A5	10	1.34
A4, A5	A _f	0	0

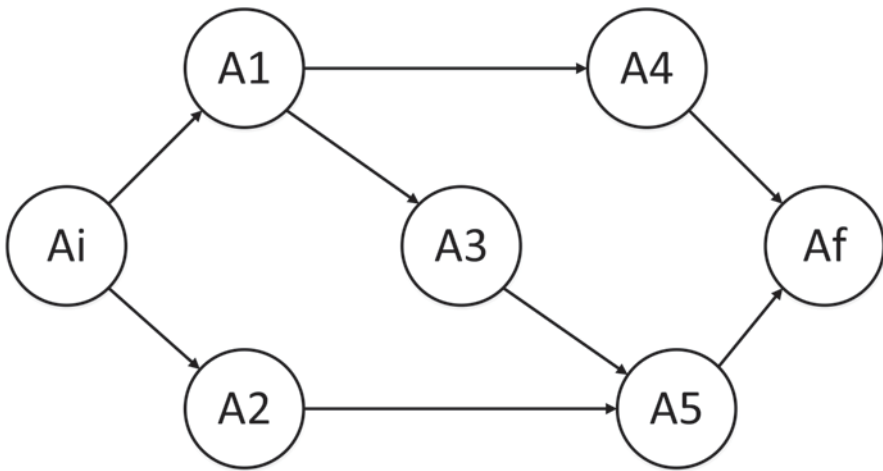


Fig. 1 Activity on node network diagram of the simulated project

2 Case Study

Our analysis is based on a stylized model of a project defined in Table 1 and Fig. 1. This model has been proposed and used by Elmaghraby et al. [5] in previous research. Each one of the activities is assumed stochastic and there are several finish-to-start precedence relationships.

Durations of activities are modelled as Normal probability distribution functions, whose parameters are shown in Table 1.

The used network combines series and parallel networks through the activity 3. Despite being a simple network, this feature increases the diversity of possible outcomes and combinations, which makes it interesting for academic and illustration purposes.

The start and end of the project are represented by two fictitious activities without duration: Initial activity (A_i) and End activity (A_f).

By means of Monte Carlo simulation we have analysed the following relations of the case study:

1. Expected project duration as function of the expected duration of activities.
2. Variability of the project duration as function of the expected duration of the activities.
3. Expected project duration as function of the variability of the duration of activities.
4. Variability of the project duration as function of the variability of the duration of activities.

We use the statistics obtained from the analysis of the total project duration as benchmark to compare the rest of results. Average (expected duration) and variance (measure to assess the variability or dispersion of the duration) are modified for each activity of the project. The results obtained are used to study every one of the cases A, B, C and D and to perform an analysis of criticality and cruciality.

3 Criticality and Cruciality

Criticality and cruciality of the project's activities can both be used as a measure of the influence of the duration of each activity on the duration of the entire project. As consequence, it is important to state clearly the difference between both indexes in order to correctly interpret the information provided for each measure.

Criticality or Criticality Index of an activity is the probability that such activity lies on the critical path or on one of the critical paths of the project. Therefore, using Monte Carlo simulation this measure is calculated as the times over the total number of simulations in which the activity belonged to the critical path.

According to Williams [10] the criticality index should be considered along with other indicators to determine more precisely the influence of the duration of each activity in the whole project. One option is the Cruciality Index.

Cruciality or Cruciality Index of an activity is the correlation between the duration of the activity and the duration of the entire project. Therefore, the influence of the activity duration on the duration of the entire project is measured as the correlation coefficient (Pearson correlation coefficient) between the duration of the activity and the duration of the entire project. In our case study, this information is extracted from the total of the simulations carried out.

This index represents the degree of linear association between the total duration of a project and the duration of a particular activity. In other words, if the total duration of a project is long when a particular activity is long, and the duration of the project is short when this activity is short, then we can say that this activity has a high Cruciality Index.

Both indexes provide complementary information to make decisions. Activities with high Cruciality Index must be carefully managed as consequence of the uncertainty that they create on the project, while activities with high criticality must be shortened, because they are likely to become the "bottlenecks" that hinder reducing the total duration.

4 Analysis of the Results

4.1 *Expected Project Duration as Function of the Expected Duration of the Activities*

Any increase in the duration of an activity will lead to an increase in the project duration, or, at least, the project duration will remain constant. Otherwise, any decrease in the duration of the activity will lead to a decrease in the project duration, or, at least, the project duration will remain constant.

As expected, we can appreciate that increasing the duration of any given activity produce an increase on its criticality and in those which belong to its same critical path (see Fig. 2). Once an activity exceeds a given threshold in its criticality index (95% in this case), the expected project duration increases almost exactly the amount that we have increased in that activity, or in other words, this activity has become practically the only one with influence on the expected project duration.

Given the topology of the network, activity A1 becomes the most critical activity when we increase his duration. We obtain a similar result if we simulate with activity A5. The rest of activities will have minor criticality index.

In the same way, the Cruciality Index of the activities increases if we increase the duration of each one of them. We highlight the results of the activity A1 and activity A4. Increasing the duration of activity A1, increases its cruciality; however due to the long duration of activity A4, which belongs to the same path as activity A1, the cruciality index of both is similar.

4.2 *Variability of Project Duration as Function of the Expected Duration of Activities*

In all cases, the variability of the project duration is stabilized and remains constant from a certain threshold. This happens when the criticality of the activity that we have increased in each case reaches approximately 1.

In this case, if we increase the expected activity duration, we can find three types of activities: (1) those in which an increase in the duration of the activity involves a reduction in the variability of the project duration (see Fig. 3), (2) those in which an increase in the duration of the activity produces an increase in the variability of the project duration and (3) a final set of activities in which, after some oscillations, variability stabilizes at a constant value.

These results are insightful since they illustrate that, if certain activities extend their duration, they may contribute to reduce the uncertainty about the date of completion of the project without delaying it too much.

For networks with paths of more diverse criticality, increasing the more critical activities may reduce even more the uncertainty about project duration. On the other

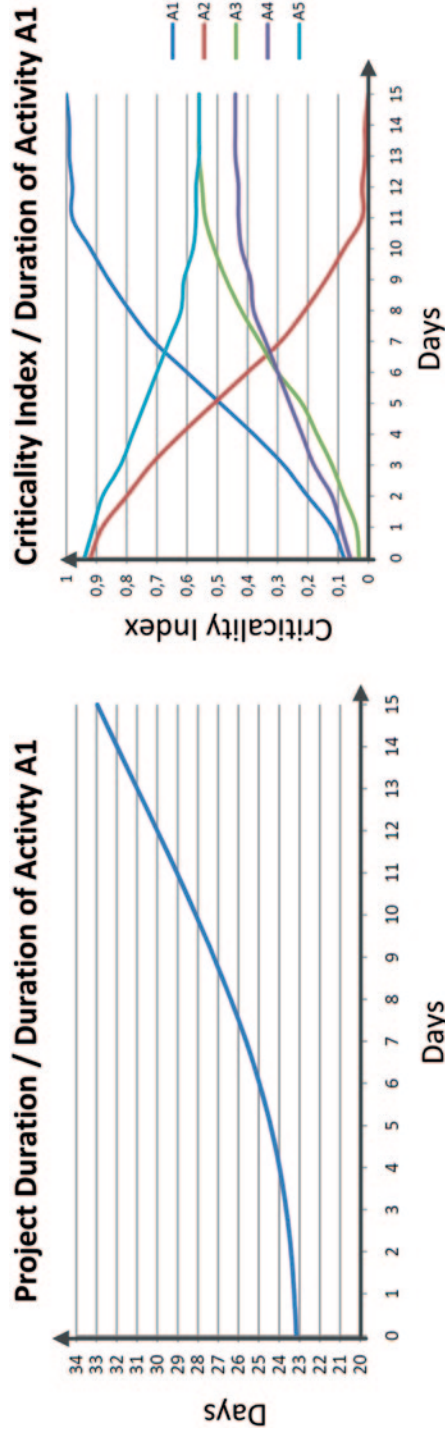


Fig. 2 Average project duration and criticality based on the duration of the activity A1

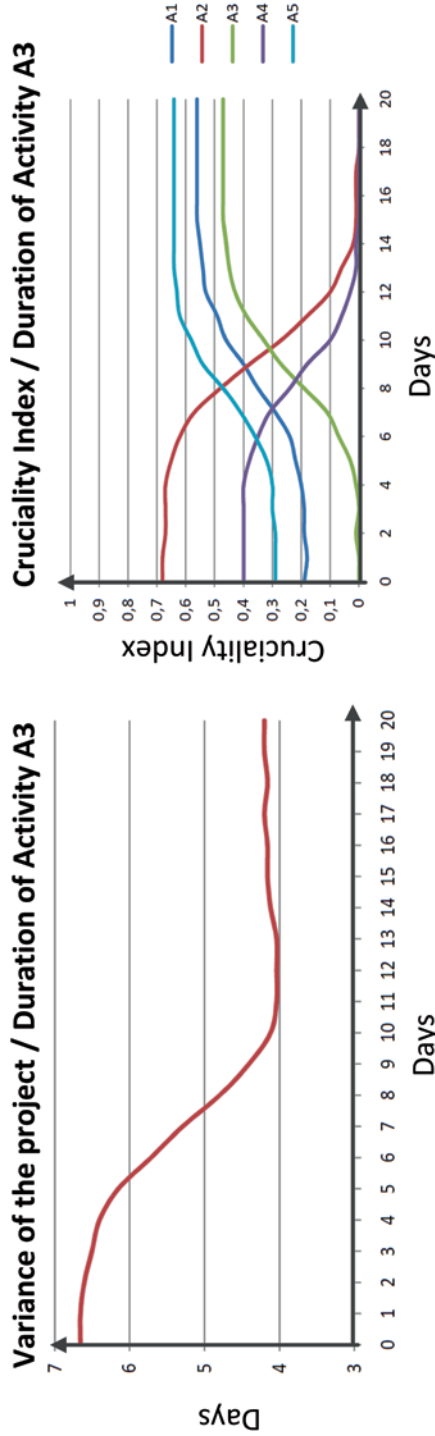


Fig. 3 Variance of the project and cruciality based on the duration of the activity A3

hand, increasing the less critical activities may contribute to raise considerably the uncertainty about the project duration, as the criticalities between the different paths become similar.

In relation to activities that cause oscillations in the variability of the project duration, they are usually the final activities of the project. Initial activities are the cause of an important part of the uncertainty of the project since they are performed in the periods with less information. However, as the project advances, there are more available information and uncertainty about the date of completion is lower, or in other words, final activities generate less uncertainty about the project because they depend on the development of activities that precede them.

Thus, activities which constitute the initial phases of the project are those that generate more uncertainty about the date of completion of the project and consequently they are the activities that project managers should study more carefully, because if they are managed in an appropriate way, uncertainty about the end of the project might be reduced.

Our results suggest that if the goal is to reduce the variability in total project duration, two decisions can be taken: Increase the criticality of the most critical path significantly reduce the variability of the project, i.e., increasing the more critical initial activities or shorten the less critical to reduce uncertainty about the project. A second option is to try to reduce the uncertainty generated by the most crucial activities, particularly the initial tasks.

4.3 Expected Project Duration as Function of the Variability of the Activities Duration

Most of the projects in reality include parallel paths. Our analysis for these projects shows that an increase of the variability in the duration of an activity leads to increase the expected duration of the entire project. This result confirms the conjecture proposed by Schonberger [7] who hypothesized that an increase in the variability of task durations will result in an increase of the expected total project duration.

The criticality is an indicator that does not provide complete information about the expected project duration. Observing Fig. 4, if we increase the variability of the activity, the length of the critical path remains more or less constant, whereas the project expected duration increases lightly. The criticality index remains constant, whereas the cruciality index increases. Therefore, in this case the cruciality index measures better the influence of the uncertainty of the activities on the project.

4.4 Variability of Project Duration as Function of the Variability of the Activities Duration

Instead of focusing our study just on the analysis of cruciality, we have used multiple linear regression to estimate the importance of the uncertainty of the activity.

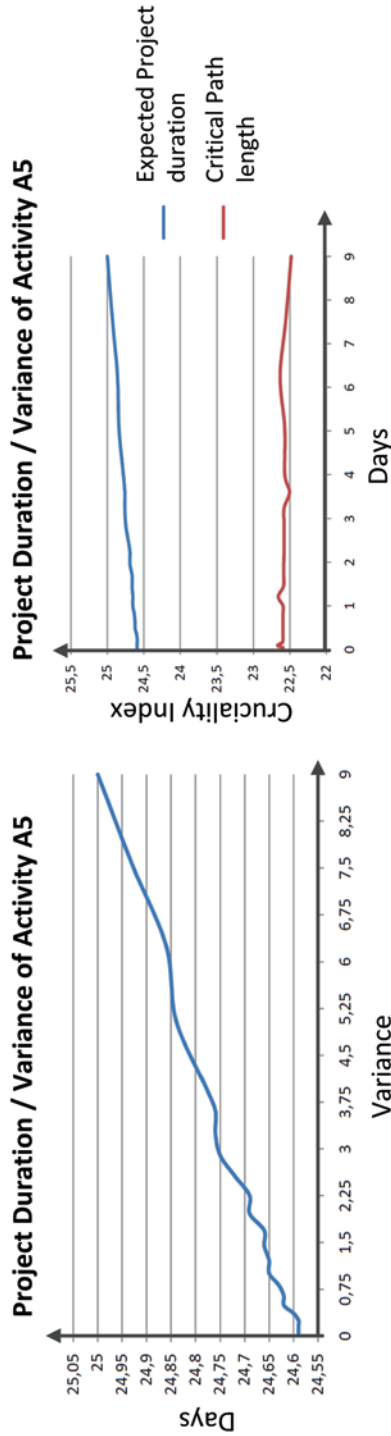


Fig. 4 Average project duration and length of the critical path based on the duration of the activity A5

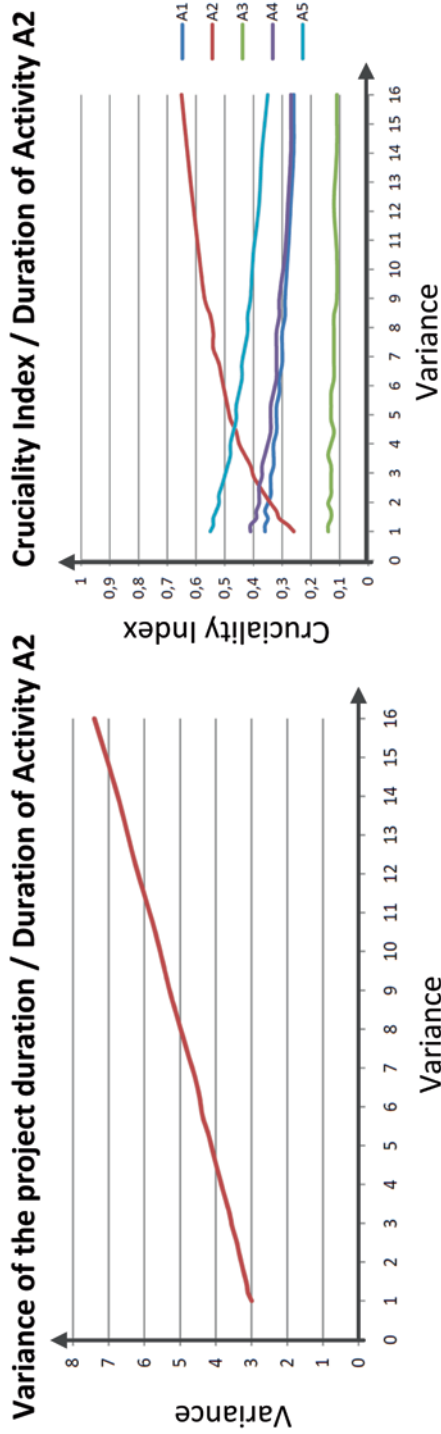


Fig. 5 Variance of the project and cruciality based on the duration of the activity A2

In Fig. 5 we show the evolution of the variability of the project duration as function of the variance of the activity A2. We show also how the evolution of cruciality index is when the variance of that activity is modified.

Our results indicate that all the variables are significant, however, given the parameters of the analysed network there are relevant differences between activities.

Activity A2 is notably the most influential because it creates almost 50% of the variability of the project duration, and the activity A5 origins 35% of this variability. With 85% of variability created over the project duration, the variability in the duration of activities A2 and A5 are considerably the most influential. So these activities are those that project managers should manage more carefully to reduce the uncertainty of the project.

5 Conclusions

We have illustrated with a case study that an analysis of different possible scenarios for the development of the project by means of simulation Monte Carlo may be very insightful to support decision making for project managers.

Once a simulation model of the project is properly formalized, specific characteristics of activities in terms of criticality and cruciality can be identified. This information may allow detecting the key activities which are decisive in the development of the project. These tasks are consequently those in which project managers should pay special attention. We have shown that modifying their expected duration or reducing their duration variability, the uncertainty about the total project duration can be reduced.

In addition, we have confirmed that criticality is not a complete meaningful indicator to assess how a modification in the duration of an activity influences the duration of the total project, and hence cruciality index provides complementary useful information.

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Adoption of Project Management Practices and Performance. Non-Governmental Organisations of Navarre–Spain

M. I. Montes-Guerra, A. R. De-Miguel, F. N. Gimena, A. Pérez-Ezcurdia and H. M. Díez-Silva

1 Introduction

Project orientation arises in the organizational context for the application of knowledge, skills, tools and techniques [41], generating various methodologies [31]. Since the 1960s organizations planned their activities in projects with a worldwide standard applicability; this emerging discipline is being developed in the academic and professional field [49]. The Project Management Institute (PMI), the International Project Management Association (IPMA) and the Association for Project Management (APM) are associations that have advanced the professionalization through various tools to standardize and implement the practices.

Besides being guidelines, standards include methods, techniques, tools and skills for those in the profession, implementing a methodology and a body of knowledge [47, 43], they are voluntary [18], and their adoption as a standard or practice has increased in the organizations [49]. There is also literature about the comparison of their orientations [30, 32, 50].

M. I. Montes-Guerra (✉)

Escuela Internacional de Ciencias Económicas y Administrativas, Campus del Puente del Común. Km 7, Autopista Norte de Bogotá. Chía, Cundinamarca, Colombia
e-mail: maricela.montes@unisabana.edu.co

A. R. De-Miguel · F. N. Gimena · A. Pérez-Ezcurdia

Projects and Rural Engineering Department, Public University of Navarre, Campus Arrosadia, Pamplona, Spain
e-mail: romero.52284@e.unavarra.es

F. N. Gimena

e-mail: faustino@unavarra.es

A. Pérez-Ezcurdia

e-mail: amaya@unavarra.es

H. M. Díez-Silva

Universidad EAN, Sede Principal el Nogal, Carrera 11 # 78 -47, Bogotá, Colombia
e-mail: hdiez@ean.edu.co

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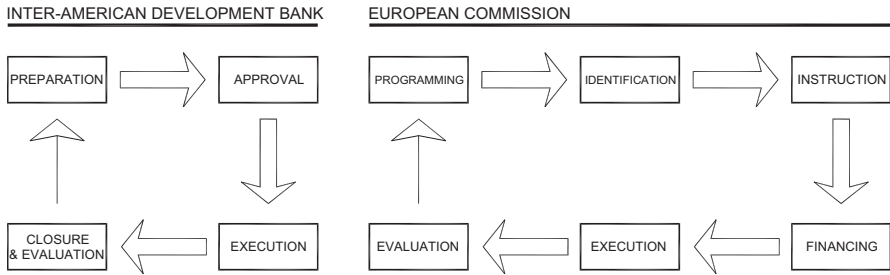


Fig. 1 Project cycle model examples—Inter-American development bank and European Commission

Admission practices and procedures, techniques or tools have been compiled by several studies [7, 30]; studying their application and use in different contexts [7, 15, 26]; or evaluating their use in industry [42]. Standard techniques have been analysed, such as analysis of earned value [3, 8, 22, 37, 39]; critical path method [10], Gantt chart [25]; logical framework [4, 12, 13]; or techniques from the organizational areas; the balanced scorecard [5, 27, 35, 36, 44].

This discipline favours sectors such as international and official aid. This sector mobilizes based on projects [19]; these have been established as a vehicle for providing resources and they refer to the Southern countries [2, 13]. Usually the projects in this area have been characterized as useful alternatives of bilateral intervention [29], directed through institutions and non-governmental organizations from donor countries and counterparts in recipient countries and local population [34].

However, despite the many financial resources in these projects, there are not many studies on the management of cooperation projects [2, 13]. The management of such projects has unified criteria to present, design, evaluate, approve and plan the proposals, but still has shortcomings in implementation processes and methodologies. Inter-American Development Bank (IADB), World Bank (WB), European Commission, Spanish Agency for International Development Cooperation (AECID), the United Nations Development Program (UNDP), Swedish International Development Agency (SIDA), German Technical Cooperation (GTZ), among others, are bodies and governments that have spread their models and management methods, adopting the model of the project cycle [21]. Figure 1 shows two examples of management cycle: the Inter-American Development Bank project and the project cycle of the European Commission.

Since the 1990s official development assistance has been used through the formulation, presentation and management of the project life cycle, which is the process and sequential steps to achieve the overall international cooperation's goals and objectives. The European Commission adopted the cycle as a set of activities, procedures, tasks, roles, responsibilities, key documents and decision making used during the aid's life, in addition to the implementation of the logical framework methodology [9]. The countries at the Paris High Level Forum (2005) have committed to ensuring systems, institutions and procedures, with the implementation of

reforms for effectiveness, transparency and accountability, making progress in the methodology, but with space for improvement in efficiency and quality.

According to Al-Abbasi and Mharmah [1], using project management could provide developing countries improvements in the efficiency of projects and help meeting the goals of their governments. Landoni and Corti [21] consider that the cooperation sector organizations could evolve towards the consolidation of an international standard for managing their projects.

2 Thematic Scope: Measuring Project Success and Performance

The performance evaluation is based on the measurement and monitoring of the projects' performance criteria [6], taking into account time, cost and quality [38, 48]. According to Bjeirmi and Munns [33] there are three external criteria for project success: making a better appreciation of the management's role with external criteria and long-term expectations; the project manager actively interacting with customers in planning and production phases; and acknowledging that success depends on the management techniques used. Measuring project success is complex and subjective, according to the parties involved; and objective indicators are needed, such as the study of completed projects or an intermediate or subsequent audit [14].

There are different opinions about what constitutes "project success". According to Prabhakar [40] project success is measured by the achievement of the objectives of the final product and successful project, based on the variables of time, cost and quality [4, 14]. In this regard, Cooke-Davies [11] distinguishes between success criteria and success factors. Project performance is measured by metrics [23, 24]. The process involves setting goals, choosing a strategy for improvement through success factors, and measuring the difference between what is planned and the results [45, 46].

It would be impossible to generate a universal list of criteria, given the variability from one project to another [20, 24]. In general, most current methods are based on the so-called iron triangle (cost, time and quality) [48]. According to Díez-Silva and others [15], a total of 22 categories can be extracted from the literature to measure project performance, preserving the usual three (time, cost and quality) as well as customer satisfaction, scope and effort, among others. For the development of the empirical work of this research, the three traditional categories have been used as criteria for success, as well as three others taken from the literature and studies related to projects of development cooperation.

It is considered that the area of development cooperation can evolve through the use of the provisions as scope of project management, representing a very interesting field of application for the implementation of practices, lessons learned and methodologies. How can methodologies, techniques and tools of project management be a factor in project performance and success? This is the question posed to define the research.

This paper analyses the impact of the adoption of techniques and tools of project management on the results of projects recently carried out by non-governmental development organizations. The project performance has been analysed through success criteria from the literature. The empirical work provides enhanced importance to the aid sector as a field of applicability, given the large number of projects undertaken and their goals.

3 Territorial Scope: Context Description

In Navarra (Spain), development cooperation (Fig. 2) is planned to address the millennium development goals, addressed to basic social services (especially health and education). For over two decades (1992–2012), this region has implemented projects, executing 2544, with a cost of 238,514,460.17 €, and fostering communities of South America, Central America and Africa, [28]. Figure 2 shows a progressive increase in the budgets for the period of 2003 to 2011 [16].

Projects and instruments are distributed in different modalities and sectors: humanitarian action, economic cooperation, technical cooperation and development education. Aid in Navarra is multilateral, detached and decentralized, with a good budget channelled through NGOs and their local partners; the way to drive it differs from the one executed by the Central Government.

Navarra is a landmark in the international aid funding. For 2012, the reserved budget amounted to EUR 16,604.856 [17], representing 0.6% of government expenditure budget and establishing Navarra as the region making the biggest effort on cooperation across the Spanish state. The contribution by each citizen was 27 € in 2010 [28]. The management is decentralized through support of management organizations and recipient countries. The analysis of the adoption of practices, techniques and tools of project management and its effect on the results of projects in donor countries is a useful contribution to the sector.

4 Study's Methodology

This research aims to determine the use of methodologies, techniques and tools of project management in development cooperation, evaluating the relationship between their use and success. The study uses quantitative and qualitative strategies. With review and interpretive work we found reasons for implementing project management in the field of international cooperation. After reviewing the literature, a questionnaire was designed, structured in 3 parts and 20 questions to gather empirical evidence on the projects and the use of methods, techniques, tools and software, and its relationship with project performance measured through success criteria.

The survey is based on 3 open and 17 closed questions, of which 10 are multiple-choice (about the organizations' general information) and 7 are estimate, which

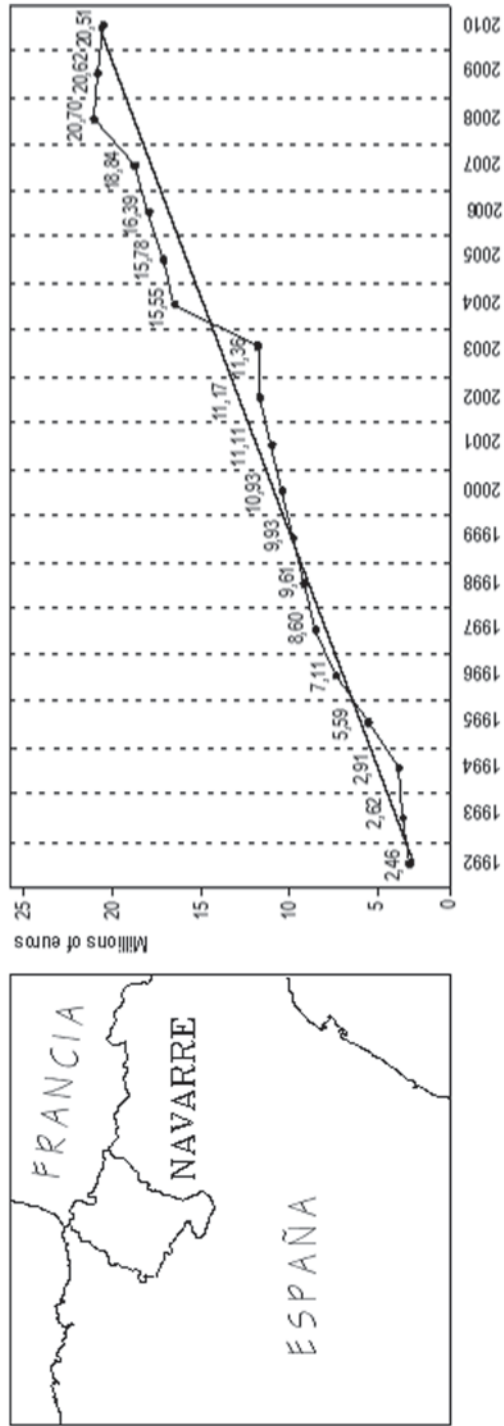


Fig. 2 Evolution of the development official assistance of the Government of Navarre

gather information about the use of methods, techniques and tools in order to check the degree of utilization; 6 questions use the Likert scale and 1 by percentage. The results were presented individually, indicating which were more used, and determining the relation between their use and project performance. We sought to assess the usefulness of the logical frame methodology to establish the weaknesses and the relation with performance.

The frequency with which the northern organizations report to the project funder is important; likewise, such reports are requested to the southern counterpart, local partner, or executor, to determine if the time intervals are similar. For both cases projects were categorized by duration as follows: less than one year, between one and three years, three to five years and more than five years. Similarly, with respect to the progress reports we asked about processes, procedures, measurement indicators and degree of variables measuring project performance. The third and final part, which consisted of 3 questions, explored the final performance of a project that was recently executed by the entity. Based on the literature review six performance criteria were chosen (time, cost, quality, activities, scope and beneficiary satisfaction), specifically in the context of international aid and development cooperation.

The last question of the questionnaire collects information of the percentage of project completion, using performance measurement variables through success criteria. The variables that determined this performance were related to the results of the use of techniques and tools of project management, checking if there is any correlation.

When applying the questionnaire to organizations, individuals with experience in the area of cooperation were selected, to improve the understanding of the questions. The questionnaire was sent to 188 organizations of Navarra registered in the databases of the council government. Efforts were made so that the sample was large enough to ensure somehow the accuracy of statements on the conditions and methods of project management in the NGOs of Navarra (Spain). In that sense, the organizations that participated in the study make up almost 80 % of all organizations analysed in Navarra.

The information obtained was analysed descriptively characterizing the structure of the sector and its organizations in Navarra. Also the application of methodologies, techniques and tools of project management in organizations were studied to determine the degree of applicability. Finally, the correlation of the application of tools with the results of recent projects is analysed. It is showed the most correlated variables and the results are discussed.

5 Analysis and Discussion of Results

The information collected with the questionnaire yielded data whose analysis was focused on various topics of interest, in order to answer the research question posed in the study. We also ranked the basic information of organizations who responded. The sample was characterized by establishing the experience, number of projects developed in 2011, the social base, recipient continents, priority areas

of intervention and the type of projects. Equally we established the most frequent problems with the partners or southern counterparts to determine the possible relation with project performance. Figure 3 shows overall results of the organizations participating in the study.

A large proportion of the sample had experience and a degree of maturity in project management, which can facilitate the implementation of its practices in the sector. The analysis of the overall data indicates that most organizations have experience of 6 to 10 years with 53%, followed by those having from 1 to 5 years with 34%. The vast majority, represented by 63% performed between 1 and 5 projects and 34% between 6 and 10 projects in 2011. This shows that each year the amount of projects executed justifies the implementation of tools to improve both the efficiency of the process and the results, according to the different characteristics of the sector and the impact of resources invested there.

As for the composition or social base, made up by partners, employees and volunteers; 73% had less than 50 people, 11% had between 51 to 99 and 10% had more than 200. According to the data they are relatively small institutions that mobilize countless volunteers, who may be responsible for the monitoring and control of projects, which has implications for project implementation. The executed actions were primarily aimed at the Latin American and African continents, 44% and 43%, respectively.

Information on application areas and types of projects was validated using the classification made by the government of Navarra, who approves the financing. Priority areas focused on projects, micro actions and development education. The types of projects executed were: food safety, awareness, water supply and sanitation, among others. A very heterogeneous typology of projects, focused on economy sectors. There were few management people responsible, compared to the number of projects implemented annually, relying on the volunteers for the improvement of the organizations with project management training. The greatest difficulties arose in meeting deadlines and technical aspects. These two items are greatly related to project performance, since they influence timing and scope (Fig. 3).

The methodologies used are: Project Management Body of Knowledge PMBOK (well known but little applied) and Projects In Controlled Environments PRINCE (less known). A great proportion of organizations used their own methodologies, they did not have a focus on project management. With regard to techniques and tools, they used the logical framework matrix, budget control and monitoring, and reporting systems. Sometimes the GANTT chart was used, whereas critical chain and critical path method (CPM) were never used. The organizations evaluated the logical framework methodology positively at approval and funding stages, and rated stages of implementation, monitoring and control with 3 (nor agree or disagree) on Likert scale (1–5).

As for the preparation of progress reports, it was found that about 69% never use processes and procedures, indicating the low application of traditional methods such as the logical framework in the implementation process. 59% of organizations used indicators to measure performance rarely or sometimes. 55% stated that progress reports were subject to the indicators established and planned when getting

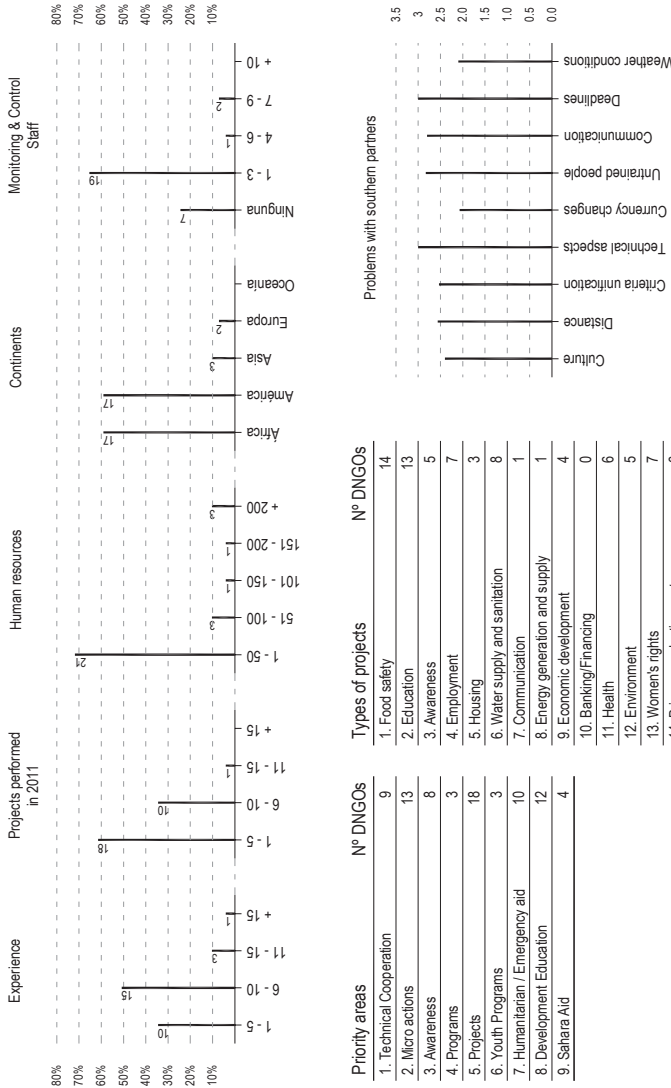


Fig. 3 Overall results of the development NGO's taking part on the study

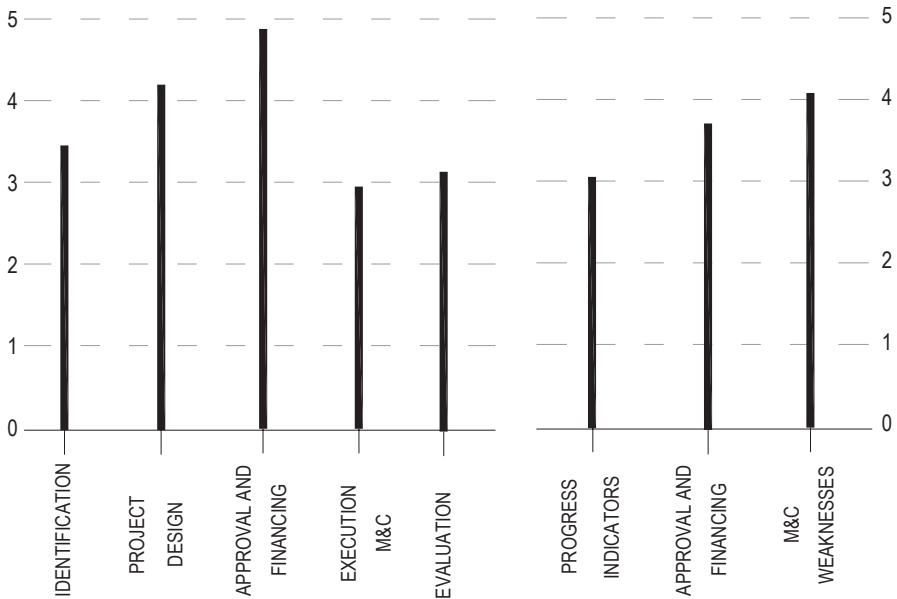


Fig. 4 Usefulness of the logical framework methodology for project implementation and monitoring

funding rarely or sometimes. The presentation of progress reports was not applied, and the most used methodology, the logical framework, did not improve the overall project management.

Figure 4 shows the description of the variables related to the usefulness of the MML, with the average rate of their results.

It was found that northern organizations require progress reports from funding agencies more frequently than southern organizations. The methodology should allow equal or more constant relationship between the northern organization and its southern partner, the latter being the one running the project and working at a more operational level. Currently there is no standard schedule for progress reports, which does not allow a controlled coordination of the implementation process (Fig. 5).

The results related to the measurement of performance variables which are evaluated with progress reports, show that the cost is measured the most in projects (average rate of 4.26) followed by the scope (rate 3.86). This shows that in this type of projects the variables involved in measuring project management are a priority, but extended metrics could improve project execution (see Fig. 5).

In the correlation analysis we selected the variables that influence (positively or negatively) the results of the projects, measured by the selected success criteria. Regarding the use of methodologies and project performance, the performance variables with the highest correlation are quality and activities, the less correlated variables are the cost and scope, although they remain positive. This indicates that the use of management tools improves project performance. In development

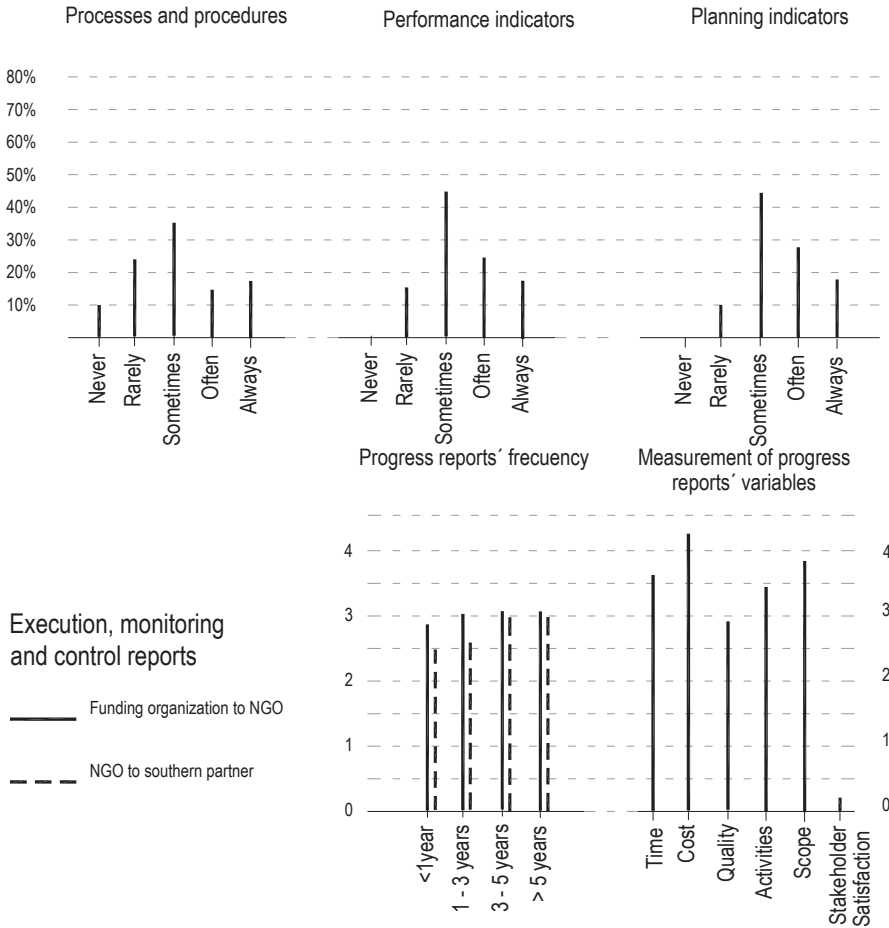


Fig. 5 Description of progress reports' characteristics

cooperation projects these two variables are critical. Techniques and tools have a great impact on the results. Regarding tools, it was confirmed that the most widely used software is the electronic spreadsheet, and although there were other information applications of project management these were little used.

Figure 6 shows the average correlation for methodologies and techniques and tools of project management. It also shows the positive correlations, and the variables with the greatest impact. The positive impact is on key variables of project management, which confirms the usefulness of the tools. Although the use of these tools is low in development cooperation and its projects, the organizations using them show the positive effects on the performance of their activities, which is of great value for the general purposes in this sector and the potential aid and benefits financing.

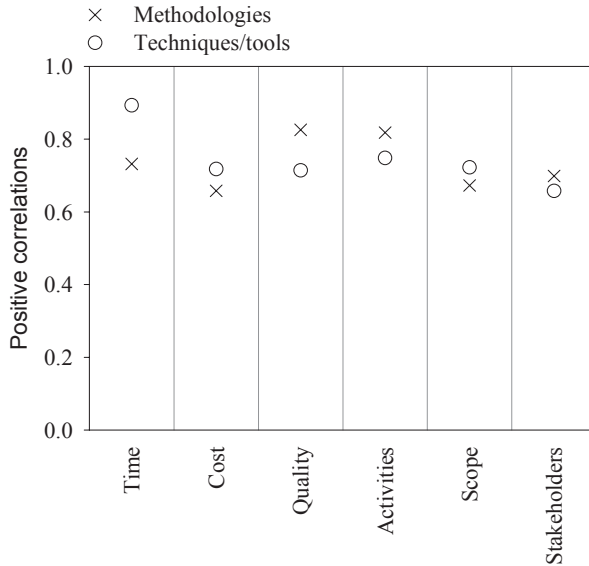


Fig. 6 Correlation between variables and project performance

6 Conclusions

Project management impacts development cooperation when the organizations execute their actions according to it. However it can be complex, due to the large network of people involved and the specific requirements, like the managing process and the life cycle that requires monitoring and control. To improve the projects and meet the objectives, it is necessary to use tools that provide efficiency. This research provides empirical evidence on the use of methodologies, techniques, tools and software in projects of international cooperation and development; it establishes the relation between their use and the final performance.

The literature on development cooperation and its relation to project management as a vehicle to implement interventions is inconclusive. Some input can be found regarding the treatment and importance given to the management and control tools used in the projects in this sector. However, the results of the empirical work show that project management with its tools is a factor that directly affects the performance and success. It was found that in the cooperation sector there is little application of project management tools, although the use of these can have a positive impact on project performance. This demonstrates the need for efforts in spreading the discipline as a means to improve and benefit cooperation organizations and all involved.

The empirical work shows high impact of tool use on sensitive variables for the performance of development projects, such as quality and activities. This may allow a future integration of methodologies, techniques and tools for such projects, and extend the range of measurement variables to the field of management. Taking

as a reference the various agents involved in projects, two lines of future action are proposed: (1) The development of a public use methodology for the cooperation sector that includes the requirements of all the agents in the process, and addresses the needs of each. (2) Improving the design and planning of methodologies, covering the needs of these projects to improve project monitoring and control as well as aid effectiveness and efficiency, facilitating accountability of all involved.

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Quick Planning Using “S” Curves and Cost Based Durations

F. Valderrama and R. Guadalupe

1 Introduction

Miscalculated estimates of building work duration made during initial project stages often lead not only to construction cost overruns as such, but also affect implementation and therefore the entire balance of income and expenses and financial planning.

This paper proposes a fully automated model for the quick estimation of the time required to finish a proposed building or civil work, using a work unit based cost estimate and including not only the total duration, but also the duration of each activity and its sequence.

As it is the case with existing parametric cost estimating systems based on averages and statistics, the result here as well is always a rough estimate, but enough to make decisions in the early project stages. Results are obtained with much less effort than that entailed by traditional detailed planning, which should be done, of course, eventually.

Specifically, this method allows for analysing the funding required to implement the project, and makes a very good approximation from the developer’s standpoint and somewhat so less from the construction company’s standpoint.

F. Valderrama (✉)
Universidad Europea de Madrid, Madrid, Spain
e-mail: fernando.valderrama@presto.es

R. Guadalupe
Universidad Politécnica de Madrid, Madrid, Spain
e-mail: rafael.guadalupe@upm.es

2 Estimating Total Duration

The first step in this model, determining the expected works duration before performing detailed planning, can be done in two ways:

- Based on expert judgment
- By applying historical data

These criteria are based on the assumption that a future project will behave similarly to projects in the past.

When the determination is based on expert judgment, data deriving from experience is combined relatively intuitively, and the relevant parameters for each case are chosen without any formal procedure.

Often, due to the “fallacy of control”, the initial expert estimate is more accurate than that which has been subsequently adjusted. Predictions about events with which we are able to interact, such as task duration, are usually less accurate than those made about what is beyond our control, such as weather predictions.

The second methodology is based on the collection and use of statistical data on similar projects. The work described in Martin et al. [10] was carried out in United Kingdom where the relationship was sought between construction duration and the following set of parameters, based on information collected by the BCIS (Building Cost Information Service) in 2700 new buildings completed between 1998 and 2006:

- Contract amount
- Type of building (housing, warehouse, hotel, etc.).
- Sector (public/private, residential/ non-residential).
- Procurement and payment system (traditional, design and build, etc.).
- Contractor selection method (one or two stages, negotiated, etc.).
- Type of client (local or stage, cooperative, private developer, etc.).

The proposed model consists in a relationship between the duration and the logarithm of the construction cost, of the form:

$$Y \text{ (time in weeks)} = A \log X \text{ (cost in 2005 pounds)} + B \quad (1)$$

The coefficients A and B depend only on the type of use. The construction cost, including all execution costs, except fees and taxes, are adjusted with regional differences and inflation between dates.

Based on this work the BCIS developed a computer program [2] which takes into account the remaining parameters, although their impact is irrelevant for practical purposes.

The coefficients have been adjusted later with projects in Spain, taken from the Soft collection of actual costs [15], and are calculated within the Presto program (Table 1).

The table below shows the values of the coefficients for some uses, as an example.

Table 1 Cost/Time relationship

Building type	Duration (weeks)
General	$22.4 \times \text{LOG}(\text{€}) - 91$
Collective housing	$33 \times \text{LOG}(\text{€}) - 146$
Single family	$31 \times \text{LOG}(\text{€}) - 131$

A third element may be added to these systems, i.e. the need to meet a preset deadline, which can often be decisive. This occurs in projects with strict deadlines or those linked to political criteria, such as upcoming elections. This can also be used to implement the remainder of this model, with the exception of cases in which any of the former methods prove it to be unfeasible.

3 Cost Allocation over Time

The overall project cost and also the cost of many resources is not distributed evenly throughout the building work. Cost is reflected by a roughly asymmetric, somewhat bulging bell or Gaussian-like curve. Expenditure or consumption of these resources accumulated or integrated at origin, also take on a characteristic “S” curve. The Gaussian bell integral is also known as the *logistic curve*.

The first work on this subject was done by Hudson for the British Department of Health and Social Security [8]. This study, limited to hospitals, provided cubic curves whose parameters were solely a function of the total cost. Instead of a single function, different coefficients were obtained for each range of amounts.

Howes [7] performed a comprehensive study on the subject and provided his own parameters for Hudson’s curves.

Other authors have put forward different expressions and parameters together with their coefficients and application ranges:

- Inverted cubic function [3, 4].
- 4th degree Polynomial regression [12, 13].
- Logit curve [9].
- Trigonometric function [11].
- Trilineal or trapezoidal [17].

Other authors Banki and Esmaeili [1] and Skitmore [14] have researched and compared much of this work and applied the results to real cases to detect the prediction accuracy (Fig. 1).

One example is Lara and Dinsmore’s most recent function published by Dórea [5]. The cumulative percentage from origin for each period, using an Excel notation, is (Eq. 2):

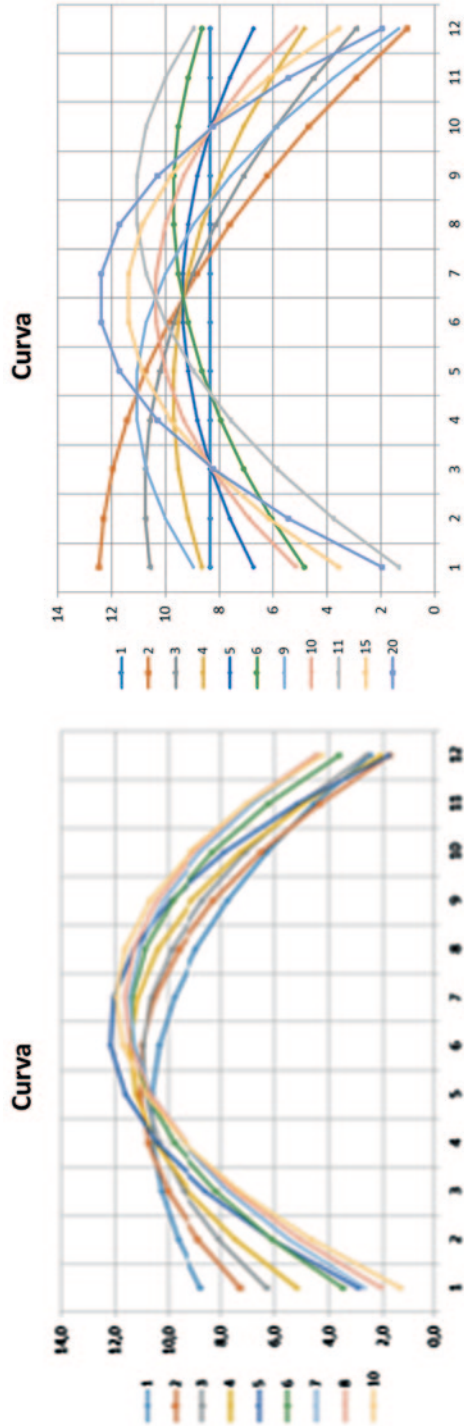


Fig. 1 Expenses by periods (Hudson and Howes)

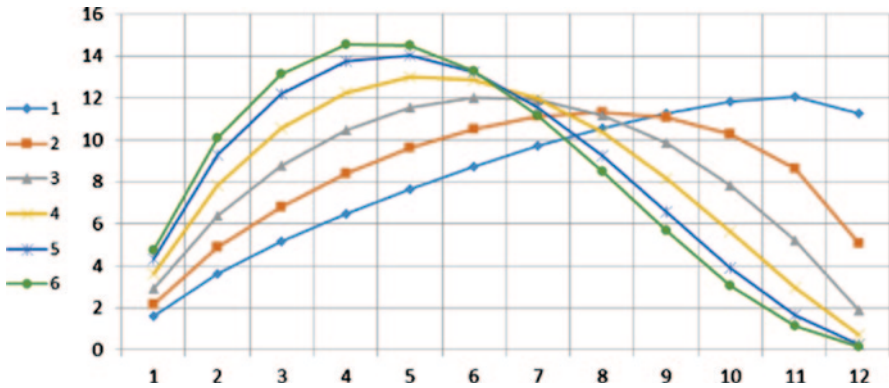


Fig. 2 Expenses by periods (Lara and Dinsmore)

Table 2 Percentages for Lara and Dinsmore curve number 6

Month	1	2	3	4	5	6	7	8	9	10	11	12
Weight	04.76	10.12	13.15	14.53	14.49	13.27	11.16	8.50	5.67	3.07	1.13	0.14
Acc. weight	4.76	14.88	28.03	42.56	57.05	70.33	81.49	89.99	95.65	98.73	99.86	100.00

$$\%Origin = 1 - (1 - (n / N)^L OG(I))^S \tag{2}$$

Where:

n = period number

N = number of periods

I, between 0 and 100 (in practice between 30 and 70) indicates the asymmetry of the curve, i.e., the point at which maximum spending is reached.

S, between 1.1 and 3.3, (in practice between 1.5 and 2.5) indicates the kurtosis or bulge.

The Fig. 2 above shows various curves following this pattern, obtained using different parameters while the table below indicates the percentages for curve number 6 (Table 2).

Any period may be used, although months are most common and will be used in the rest of this article.

4 Defining Activities and Sequencing

Once time allocation is obtained, by using either any of the previously described curves or a customized method, activities should be assigned using this spending pattern.

In order to apply this model, a work unit based estimate must be available although it may not be entirely definitive. Even in very early project stages, current

digital systems are able to generate automatic cost estimates accurate enough for this purpose.

Traditionally, chapters and work units estimates are arranged roughly in the order they are executed, so that the work units are located in the right sequence and only minor adjustments will be necessary.

The allocation procedure is done with a simple assignment algorithm and successive work units are assigned to each certification period until all the planned spending is covered. If an activity has to be split into two periods, certain measures should be taken in order to maintain the building work rationale and avoid overly fragmenting work units that by their nature are inseparable (Fig. 3).

The estimated work units are indicated by billable work to be paid by the client, and therefore are suitable for analyzing both the developer's cost and the construction company's revenue.

However, these work units do not always match the activities used for scheduling. Therefore, from the construction company standpoint, further fine-tuning is required, and site overhead and its breakdown over time must be explicitly defined, including mobilization and demobilization. Proportional costs and home office overhead, as defined by the corporate policy, must be assigned [16]. Hereinafter, elements used in planning, whether or not they are work units, will be referred to as "activities".

Naturally, depending on the approach taken, either contract prices or estimated costs will be used and may be obtained from each other, if desired, using an overall markup.

Revenues and costs are assumed to be incurred in at the end of each period, although for obtaining cash flow simulations, in order to situate them accurately over time, they must be assigned to the expected payment terms.

When price breakdowns are available, the same system calculates resource consumption over time vis-à-vis the work units where required. If these resources are allocated to their respective payment terms, which are at times very far from the end of the period, a very accurate cash flow plan may be prepared, enabling full financial analysis of the works to be done from the construction company's standpoint.

5 Activity Duration

In principal, this model assumes there is a proportional relationship between the cost of each activity and the total cost of the building work including its respective durations (Eq. 3).

$$\text{Activity duration} = \text{Duration of the work} \times \text{Activity cost/Cost of the work} \quad (3)$$

When both the machinery and labor costs are used together instead of merely the activity cost, this assumption becomes very accurate because these figures affect

	NatC	Code	Description	Qty/Tgt Unit	1: Plan 31-Jul-12	2: Plan 31-Aug-12	3: Plan 30-Sep-12	4: Plan 31-Oct-12	5: Plan 30-Nov-12	6: Plan 31-Dec-12	7: Plan 31-Jan-13	8: Plan 28-Feb-13	9: Plan 31-Mar-13	10: Plan 30-Apr-13
1/0	-	0	Housing project	1	81,819.57	94,631.40	107,592.89	120,252.72	132,122.19	142,700.30	151,509.33	158,132.48	162,244.74	163,639.07
2/1	+1	E01	Preliminaries	1	3,981.85									
3/1	+2	E02	Earthwork	1	48,877.31									
4/1	+3	E03	Sewage	1	10,072.11									
5/1	-4	E04	Foundations	1	18,888.30	46,181.73								
6/2	+4.1	E04CN040	HA-20/P/20/l concrete cleaning	34.58 m3	2,119.68									
7/2	+4.2	E04CE020	Wood formwork footings, trenches, beams f...	48.08 m2	778.39									
8/2	+4.3	E04CA060	HA-25/P/40/l/a concrete, footings	220.88 m3	15,990.23	10,714.16								
9/2	+4.4	E04SA020	HA-25 concrete slab reinforced, e = 15 cm	698.35 m2	9,059.47									
10/2	+4.5	E04SE020	Limestone 40/80, e = 20 cm	658.35 m2	4,437.43									
11/2	+4.6	E04MA010	HA-25/P/20/l in concrete wall 25 cm, 1-sided	88.57 m3	21,970.67									
12/1	-5	E05	Structures	1	48,449.67	107,592.89	120,252.72	132,122.19	41,794.27					
13/2	+5.1	E05HFA020	Salb self-supporting beam 20 +5 cm, 60 cm bas	4,272.72 m2	48,449.67	107,592.89	114,778.28							
14/2	+5.2	E05AG010	Lintel galvanized steel, 250x4 mm	365.45 m			5,474.44	986.72						
15/2	+5.3	E05AW040	Angle of 60 mm	108.00 m				2,066.04						
16/2	5.4	E05HSA00_01	Formation of hollow slab	181.37 m2				8,705.76						
17/2	+5.5	E05HLA030	HA-25/P/20 concrete, formwork slabs 5kg/m3	11.66 m3				2,775.08						
18/2	+5.6	E05HSA010	HA-25/P/20/l concrete, pillars, metal formwork,	205.16 m3				47,619.69						
19/2	+5.7	E05HVA030	Concrete girders with wood framing HA-25/P/2	230.18 m3				69,968.90	1,888.69					
20/2	+5.8	E05HVA075	HA-25/P/20/l concrete with flat bands	107.65 m3				39,905.58						
21/1	+6	E07	Walls and divisions	1				100,906.03	151,509.33	77,457.39				
22/1	+7	E08	Cladding and suspended ceilings	1				80,675.09	89,886.69					
23/1	+8	E09	Covers	1				40,090.04						
24/1	+9	E10	Insulation and waterproofing	1				32,268.01	59,251.19					

Fig. 3 “S” Curve-based Activity Allocation (Presto). Total duration obtained by Martin et al. [10] for a housing development with an estimated contract value of 3,083,000 €. The spending pattern displays a Gaussian bell curve

time consumption and factor out the cost of materials. In any event, this article will use the generic term “cost”.

However, the direct application of this direct proportionality generates an unrealistic schedule that places one activity immediately after the other, as if there were start–finish links between them. Furthermore, the durations provided for all of them are too short. When we know the number of simultaneous activities, a better expression is (Eq. 4),

$$\text{Activity duration} = \text{Duration of the work} \times \text{Activity cost} \\ \times \text{Number of simultaneous activities} / \text{Cost of the work} \quad (4)$$

In this estimation, one should bear in mind that the number of activities executed simultaneously on the site is related to the total number of activities. When there is a single activity, only one activity may be performed at the same time. When there are thousands of activities, dozens of them may be running simultaneously. This observation suggests the following potential relationship (Eq. 5):

$$\text{Number of simultaneous activities} = \text{SQRT} (\text{Number of activities}) \quad (5)$$

This criterion can be improved by making two successive corrections.

First, activities having greater economic impact on the site usually receive more attention and more resources, while the opposite occurs with more minor activities. This is not reflected in the equation above, which compresses all like activities.

To take this into account, the total estimated number of activities used to calculate the duration of any single activity should be calculated as if they all had the same cost. This leads the number of simultaneous activities to differ for each activity (Eq. 6):

$$\text{Number of simultaneous activities for activity A} \\ = \text{SQRT} (\text{Cost of the work} / \text{Activity A cost}) \quad (6)$$

A simplification of the expression above could be (Eq. 7):

$$\text{Activity A duration} = \text{SQRT} (\text{Activity A cost} / \text{Cost of the work}) \\ \times \text{Duration of the work} \quad (7)$$

This method also frees the duration of each activity from the total number of activities, whose calculation becomes superfluous.

Certain adjustment factors for durations that the scheduler can freely modify are desirable for greater accuracy.

Since the square root of a value is equal to raising that value to the power 0.5, we can replace this with a variable exponent V (Eq. 8):

$$\begin{aligned} & \text{Number of simultaneous activities for activity A} \\ & = (\text{Cost of the work/Activity A cost})^V \end{aligned} \quad (8)$$

Further simplification gives rise to the final expression (Eq. 9):

$$\begin{aligned} \text{Activity A duration} & = (\text{Activity A cost/Cost of the work})^{(1-V)} \\ & \times \text{Duration of work} \end{aligned} \quad (9)$$

V, which may vary between 0 and 1, is actually a simultaneity coefficient.

- Coefficient V “zero” indicates no concurrent activities. Activities are performed one after the other and their duration, the shortest possible, it is strictly proportional to the work duration.
- Coefficient V “one” indicates that simultaneity is absolute. All activities start and finish at the same time and have the same duration as the building work overall.

V values between these extremes, close to 0.50, allow obtaining practical durations.

For example, the calculated duration for an activity whose cost is 4% of the cost of building work to take 52 weeks is (Eq. 10):

$$\text{Activity duration} = (4/100)^{(1-0.5)} \times 52 = 10.40 \text{ weeks} \approx 47 \text{ working days} \quad (10)$$

When cost elements are groups of activities such as traditional trade divisions, the overlap is clearly higher and coefficient V is closer to 0.60. When cost elements are work units, V values should be closer to 0.40

5.1 Number of Crews

Crew durations give rise to a reasonable total time. When resource breakdown for the activities is available, a different duration may be calculated by multiplying the quantity of the main resource by the total work unit quantity. This duration is expressed in hours or days of work for a single crew or piece of equipment. Therefore, the ratio between durations obtained from both methods allows for a quick estimate of the number of crews or the equipment required to perform the task within a period consistent with the total duration of the building work (Fig. 4).

$$\text{Number of crews} = \text{Duration based on breakdown/Cost based duration} \quad (11)$$

The durations obtained can be used to get fast planning, as described above, and also can serve as quick references for traditional planning activities based on precedents. A Gantt chart can quickly be generated before a detailed analysis is performed.

	Code	NatC	Description	QtyTgt	AmntTgt Unit	Equip...	DurTime	DurCostRes	DurCost
1/0 ▶	0	▲	Housing project	1	2.465.650,18	1	0	428	428
2/1	+ 1 E01	▲	Preliminaries	1	3.981,85	1	0	8	5
3/1	+ 2 E02	▲	Earthwork	1	48.877,31	2	0	50	28
4/1	+ 3 E03	▲	Sewage	1	10.072,11	3	0	9	9
5/1	- 4 E04	▲	Foundations	1	65.070,03	1	0	29	34
6/2	4.1 E04CM040	■	HM-20/P/20/l concrete cleaning, manually Poured	34,59	2.119,66 m3	1	3	2	3
7/2	4.2 E04CE020	■	Wood formwork footings, trenches, beams and pile c	48,68	778,39 m2	1	3	2	2
8/2	4.3 E04CA060	■	HA-25/P/40/l/a concrete, footings, Poured by crane	220,88	26.704,39 m3	1	6	13	18
9/2	4.4 E04SA020	■	HA-25 concrete slab reinforced with wire mesh, e =	659,35	9.059,47 m2	1	0	6	9
10/2	4.5 E04SE020	■	Limestone pitching 40/80, e = 20 cm	659,35	4.437,43 m2	4	21	6	5
11/2	4.6 E04MA010	■	HA-25/P/20/l in concrete wall 25 cm, 1-sided, hand	88,57	21.970,67 m3	1	0	17	16
12/1	- 5 E05	▲	Structures	1	450.211,74	1	0	128	130
13/2	5.1 E05HFA020	■	Forged from self-supporting beam 20 +5 cm, 60 cm l	6.277,72	270.820,84 m2	3	273	83	91
14/2	5.2 E05AG010	■	Lintel of hollow galvanized, 250x4 mm	365,45	6.461,16 m	2	14	8	7
15/2	5.3 E05AW040	■	Angle of 60 mm at auction	108,00	2.066,04 m	2	7	3	3
16/2	5.4 E05HFS400_01	■	Formation of hollow forged hoop attached Edge	181,37	8.705,76 m2	1	0	0	9
17/2	5.5 E05HLA030	■	HA-25/P/20 concrete, formwork slabs of wood Inclin	11,66	2.775,06 m3	1	1	4	4
18/2	5.6 E05HSA010	■	HA-25/P/20/l concrete, pillars, metal formwork, 80 k	205,16	47.619,69 m3	1	7	32	27
19/2	5.7 E05HVA030	■	Concrete girders with wood framing hang HA-25/P/	230,18	71.857,59 m3	1	5	37	36
20/2	5.8 E05HVA075	■	HA-25/P/20/l concrete with flat bands, With woodie	107,85	39.905,56 m3	1	2	31	24

Fig. 4 Automatic activity duration (Presto). DurTime calculation is based on labor rates. DurCostRes (resource cost based durations) and DurCost (total cost based durations) follow the method described in the text and have a V=0.3 simultaneity coefficient

6 Case Studies

6.1 Shopping Center with Office Space and Parking

The planning of the shopping center is broken down and valued by trade division, meaning that the simultaneity coefficient to be used must be in the upper range. Here the value $V=0.6$ (Table 3).

The variables chosen to evaluate the accuracy of the resulting durations were the difference in days and the percentage change. The table shows the sum, the mean

Table 3 Planned vs. calculated durations

Trade division	Cost	Resources	Planned duration	Calculated duration	Difference	Change
	€	%	d	d	D	%
Preliminaries	10,640	87	20	29	9	44
Earthwork	300,843	81	45	106	61	136
Water disposal	27,470	37	30	30	0	0
Waterproofing	23,768	39	52	29	-23	-45
Foundation	810,562	34	63	112	49	77
Grounding	10,192	31	50	19	-31	-63
Concrete structure	2,026,690	37	80	167	87	109
Facade	1,422,344	50	140	163	23	17
Finishes	318,173	66	93	100	7	8
Suspended ceilings	298,917	58	62	93	31	50
Roof	400,127	28	101	78	-23	-23
Thermal & moisture prot.	277,577	34	78	73	-5	-7
Flooring	880,285	39	87	122	35	40
Internal divisions	700,194	64	72	136	64	89
Electrical wiring	399,788	40	108	90	-18	-17
Plumbing	202,562	34	160	64	-96	-60
Air conditioning	225,979	19	112	53	-59	-53
Ventilation	96,539	23	146	41	-105	-72
Lifting equipment	303,080	12	107	50	-57	-54
Fire protection	104,806	17	145	37	-108	-74
Painting	477,654	55	53	110	57	107
Special facilities	107,568	27	85	45	-40	-47
Total	9,425,758	43	327	-	-142	164
Mean	-	-	-	-	-6	7
Standard deviation	-	-	-	-	56	65

The resource cost is estimated based on total cost and using a trade division specific average percentage taken from Soft [15]

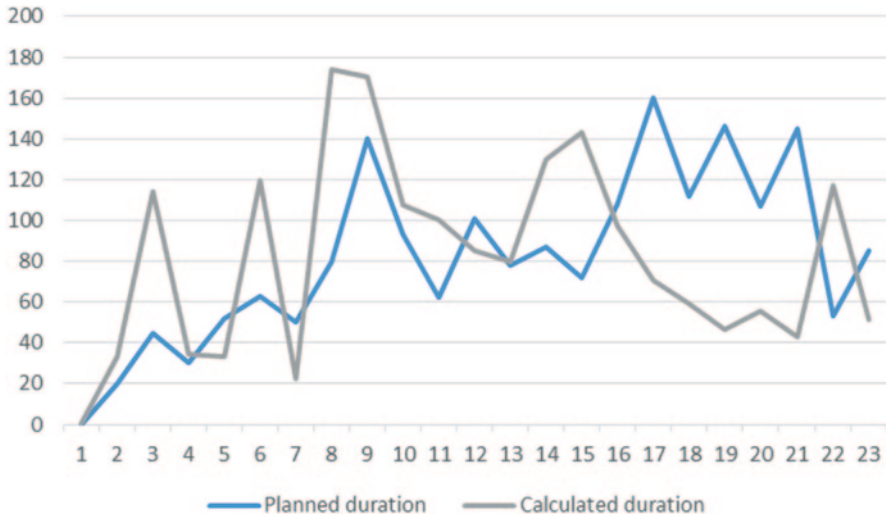


Fig. 5 Planned vs. calculated durations

and standard deviation for both series of values. High standard deviation and fairly low averages for both series point towards an interesting path for further research (Fig. 5).

It should be noted that the significant differences observed in the last trade divisions, mechanical and electrical facilities, are due to their being widely separated over time, with idle time in between.

6.2 Residential Buildings

Because the project estimate is detailed by work unit, the simultaneity coefficient should be taken at the lower end of the range, i.e. $V=0.40$, while the table also shows results for $V=0.30$, $V=0.50$ and the direct proportional duration, where $V=0.00$.

The total duration is obtained by applying the BCIS formula to the total cost and using housing type coefficients. Planned durations were calculated based on resource efficiency, as published in GTP [6]. The total number of days is adjusted for the number of crews appropriate for each stage of construction, as listed in the following table (Tables 4 and Table 5)

The resulting duration for $V=0.40$ shows a well-compensated estimation, with a low standard deviation as well. The comparison between the different V values suggests that when the proper value for the typology is ascertained, estimates can be very accurate, while differences increase as the coefficient moves away from this value.

The value obtained with $V=0.00$ reflects the simple hypothesis that duration could be directly proportional to cost. The amount of the differences with the

Table 4 Crews used in the planning

Trade	Num. of crews
Foundation, structure	2
Brickwork, painting	3
Finishes, facilities	2
Other activities	1

Table 5 Calculated durations for different V values

Work unit	Resource cost	Planned duration	V	Dif.	V	Dif.	V	Dif.	V	Dif.
	€		0.00		0.30		0.40		0.50	
Trench refinement	4921	19	2	-17	9	-10	15	-4	27	8
Excavation	4354	16	1	-15	8	-8	14	-2	25	9
Transport to landfill	38,013	30	13	-17	37	7	52	22	74	44
Forged joist	127,127	137	43	-94	85	-52	107	-30	135	-2
Brickwork, 1'	106,786	124	36	-88	75	-49	97	-27	124	0
Id. 1/2'	27,717	32	9	-23	29	-3	43	11	63	31
Id. single int. partition	38,539	44	13	-31	37	-7	52	8	74	30
Id. double int. partition	26,806	31	9	-22	29	-2	42	11	62	31
Final cleaning	12,199	31	4	-27	17	-14	26	-5	42	11
Plaster finish	171,322	191	57	-134	105	-86	128	-63	157	-34
Inverted flat roof	14,109	21	5	-16	18	-3	29	8	45	24
Sound insulation	21,373	26	7	-19	24	-2	37	11	55	29
Tile flooring	16,399	29	5	-24	20	-9	31	2	49	20
Oak flooring	79,356	75	27	-48	61	-14	81	6	107	32
Continuous flooring	5707	10	2	-8	10	0	17	7	29	19
Ceramic tiles	11,328	20	4	-16	16	-4	25	5	40	20
Natural ceramic tiles	11,378	16	4	-12	16	0	25	9	40	24
Doors	9485	16	3	-13	14	-2	23	7	37	21
Front cabinets	12,808	22	4	-18	17	-5	27	5	43	21
Steel fence	10,286	37	3	-34	15	-22	24	-13	38	1
Base plug	10,269	18	3	-15	15	-3	24	6	38	20
10 A circuit	6788	12	2	-10	11	-1	18	6	31	19
15 A circuit	6701	12	2	-10	11	-1	18	6	31	19
20 A circuit	8525	15	3	-12	13	-2	21	6	35	20

Table 5 (continued)

Work unit	Resource cost	Planned duration	V	Dif.	V	Dif.	V	Dif.	V	Dif.
	€		0.00		0.30		0.40		0.50	
25 A circuit	10,656	18	4	-14	15	-3	24	6	39	21
Radiator elements	8262	14	3	-11	13	-1	21	7	34	20
Paint	61,541	74	21	-53	51	-23	69	-5	94	20
Total	1,276,293	428	-	-801		-321		2		479
Mean	-	-	-	-30		-12		0		18
Standard deviation	-	-	-	30		20		17		15

All durations are in days

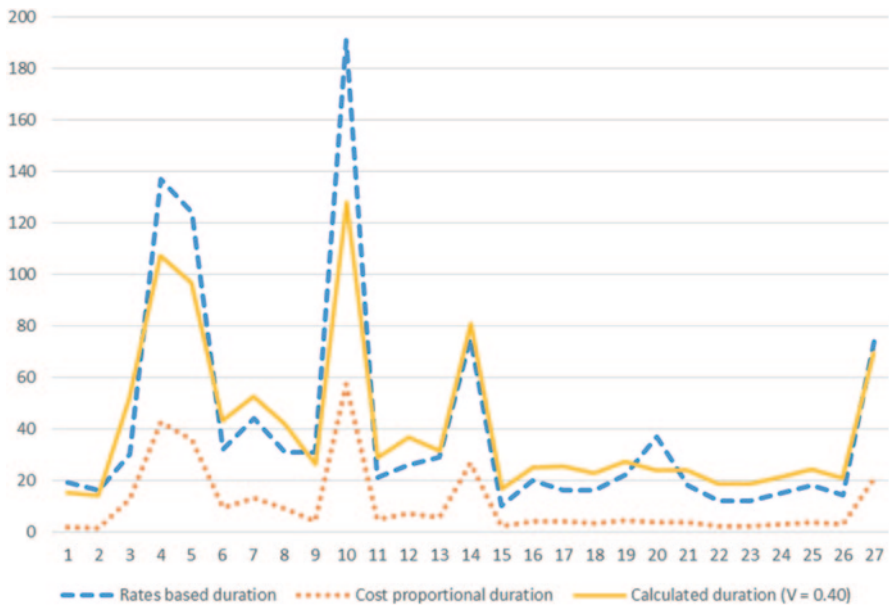


Fig. 6 Planned, proportional and calculated durations

calculated duration proposed in this article is a good measure of this procedure’s potential (Fig. 6).

7 Conclusions

The model described in this article allows for defining the cost allocation over time from early project stages before more precise traditional planning is done (Fig. 7).

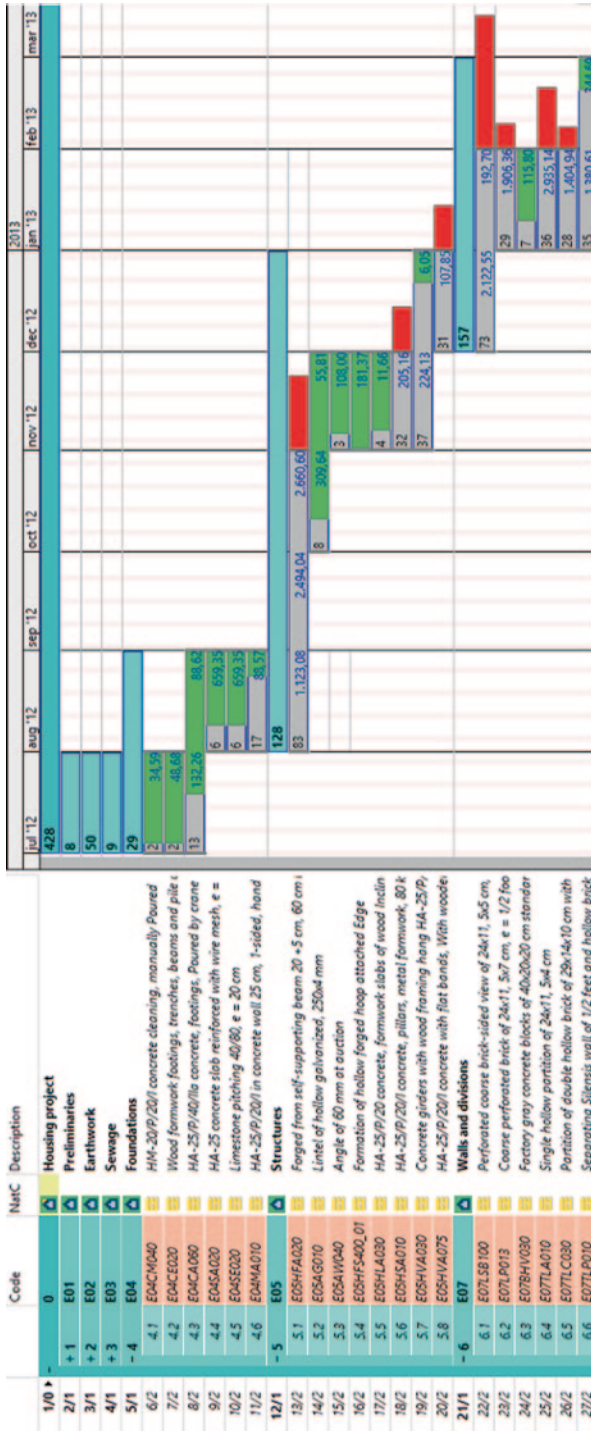


Fig. 7 Final results (Presto). Note: resource cost based duration, at the left end of the bar, is shown in grey. The red portion indicates activities where resource cost based duration is longer than the period indicated by the “S” curve. The amount allocated to the financial period appears in blue

Starting from a work unit based estimate, or even trade division based estimate, the procedure is completely automatic, and entails the following decision points:

- Establishing the BCIS coefficients for the total duration
- Establishing the right sequential order in the estimate
- Selecting the most suitable “S” curve for the project
- Establishing the simultaneity coefficient.

When labor resource and machinery unit price breakdowns are available, and this is commonly found in Spanish construction price databases, both greater accuracy and an estimate of the number of crews needed during execution will be obtained.

Looking towards the future, a comprehensive set of projects must be collected and analyzed in order to refine and further validate the method, and V coefficients must be ascertained for different typologies or new parameters, as required, in order to provide a quick, reliable time estimating procedure for professionals and construction companies alike.

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Engineering Projects Assessment Using Earned Value Management with Performance Indexes Evaluation and Statistical Methods

J. Rubio, J. I. Muñoz and J. R. Otegi

1 Introduction

It is increasingly requested by project manager's crystal clear project status indicators, especially in engineering projects. These indicators should be reliable, easy to manage and capable to show objectively project deviations from the initial planning in order to take better decisions and to define corrective actions as soon as possible. That is the reason because the Earned Value Management (EVM) has been widely introduced in these types of projects, as it integrates the management of project scope, cost and schedule and gives deviations calculation, performance indexes, as well as final project duration and cost forecasting.

Commonly, in the engineering projects where the EVM technique is used, the basic formulas of EVM are applied, which are comprehensively collected in the standard ANSI EIA-748-1998 [1]. Nevertheless the EVM has been considerably developed during the last 10 years and new research lines have been appeared in the literature that should be taken into account for say an "updated EVM". Among the main EVM research lines could be highlighted the followings: reliability assessment of the EVM indexes and forecasting methods of project final duration and cost [18]; the EVM extension called Earned Schedule [7]; the integration of the technical performance in the EVM [14–16]; the consideration of project risks [11]; and the use of fuzzy techniques [9] and analytical curves [19] for the EV determination.

J. Rubio (✉)
Dresser-Rand Inc., Miñano, Spain
e-mail: jrubio@dresser-rand.com

J. I. Muñoz
University of Castilla–La Mancha (UCLM), Albacete, Spain
e-mail: josegnacio.munoz@uclm.es

J. R. Otegi
University of Basque Country (EHU-UPV), Leioa, Spain
e-mail: joserra.otegi@ehu.es

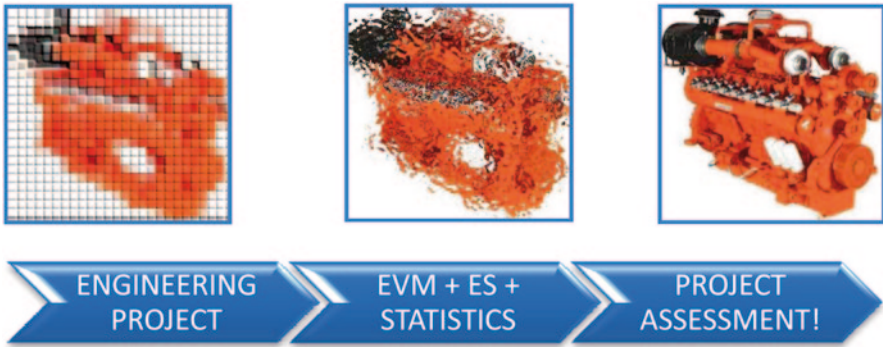


Fig. 1 Engineering projects assessment using updated EVM

In engineering projects some of these latest researches have a direct interest, such as, the integration of the technical performance in the EVM, referenced in some studies [10] since engineering projects have intrinsically technical outputs. Moreover, the research findings about EVM recent extension, the Earned Schedule, has a great interest in engineering projects, as well as, the reliability of the EVM indexes in order to have a robust EVM methodology to be applied throughout the project control process.

Actually, in this work, the Earned Schedule will be applied to a real engineering project of engine development in order to check the practice in use in this type of projects. Also, it will perform a sensitivity analysis of the cost performance index from the EVM and the schedule performance index from the ES, by means of statistical methods which helps to generate probable situations of the real project to evaluate the effect over the indexes. Looking at the results, we will be able to check whether in the engineering projects is already practical the use of ES and the stability of the performance indexes of the EVM and ES for the engineering projects assessment (Fig. 1).

2 Objectives

The objectives of this work are two-fold. The first one is to evaluate the practical application of the Earned Schedule (ES), the recent extension of the EVM, in engineering projects using real project data. And secondly, to analyse the behaviour of the performance indexes from the EVM and ES in a real engineering project applying statistical methods. The consecution of the objectives will lead to a better assessment of the engineering projects control management.

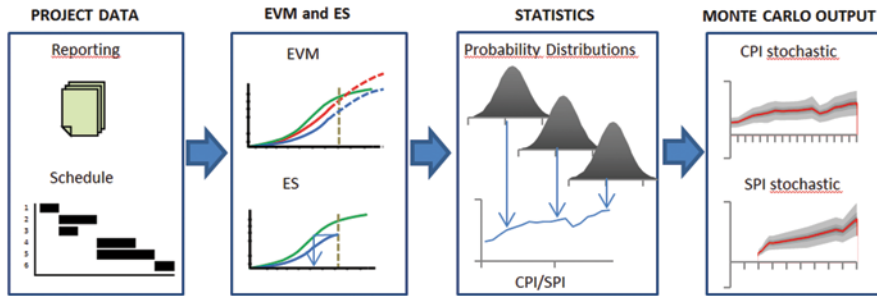


Fig. 2 Applied methodology overview

3 Methodology

The methodology used in this work in order to evaluate the performance indexes in a real engineering project has three steps. The first step consists in applying the EVM formulas to the real engineering project data with the aim of obtaining the Cost Performance Index (CPI). Secondly, the Earned Schedule formulas are also applied to the same real project data to obtain the Schedule Performance Index in terms of time (SPI(t)). And finally, Monte Carlo simulations are run with the previous results to study the trends of the CPI and SPI(t) in the project. The following points explain in detail these three steps. Analogous methodology is used in the literature with some differences. For example, some authors also use statistics to analyse the performance indexes but with the objective to obtain confidence limits [8]. Other authors also use Monte Carlo simulations but with fictitious project data mainly [17] (Fig. 2).

3.1 Applied EVM

The EVM is a methodology used to measure and communicate the real progress of a project, integrating the scope, time and cost, in monetary terms. The EVM is widely explained in literature [2, 4, 5, 12, 13]. For an overview, the EVM is based on three basic metrics, Planned Value (PV), Actual Cost (AC) and Earned Value (EV) from which they are constructed performance indexes and forecasting formulas.

From the EVM we will focus on the CPI. According to the research [6], the CPI gives a reasonable good result of project cost performance. In the case study we will follow the CPI trend and it will be compared with the findings from the literature [3], coming from large projects of the US Department of Defense where the cumulative value of CPI stabilizes by the time the project is 20% complete. Stability is defined by mean that the final CPI does not vary more than 0.10 from the value at 20% complete.

Table 1 EVM metrics

PV	Planned value
AC	Actual cost
EV	Earned value
CV	Cost variance ($CV=EV-AC$)
SV	Schedule variance ($SV=EV-PV$)
CPI	Cost performance index ($CPI=EV/AC$)
SPI	Schedule performance index ($SPI=EV/PV$)
CR	Critical ratio ($CR=CPI*SPI$)
BAC	Budget at completion
IEAC	Independent estimate at completion (the forecasted final cost)

For convenience, the terminology EVM is used to portray project status, and forecasting is shown in Table 1.

3.2 Earned Schedule in Practice

The EVM schedule indicators, SPI and SC, are broadly recognized for failing when projects continue execution past the planned end date. For late finish projects, SPI converges and concludes at the value 1, while SV behaves similarly, converging and concluding at 0. With this flaw schedule, prediction cannot be performed reliably using SPI. A recent extension from EVM has emerged which provides reliable, useful schedule performance information. This extension is Earned Schedule (ES). Briefly, this method yields time-based indicators, unlike the cost-based indicators for schedule performance offered by EVM. The ES measure identifies when the amount of EV accrued should have occurred. ES is further explained in literature [7].

From the ES we will focus on the SPI(t). Notice that the nomenclature with (t) refers to a metric from ES to differentiate it from the same metric from EVM. According to the research the SPI(t) gives a reasonable good result of project schedule performance [8].

For reference, the terminology of ES is shown in Table 2

Table 2 ES metrics

AT	Actual time
ES	Earned schedule ($ES=C+I$)
C	Number of whole time increments of PMB for condition $EV \geq PV$
I	Portion of PMB increment earned ($I=(EV-PV_c)/(PV_c+1-PV_c)$)
SV(t)	Schedule variance (time) ($SV(t)=ES-AT$)
SPI(t)	Schedule performance index (time) ($SPI(t)=ES/AT$)

3.3 Statistics for Performance Indexes Sensitivity Analysis

Statistics allow considering the probabilities in the project and therefore proposing different situations and their effects. In this work, the initial step to apply the statistics requires the construction of a deterministic baseline schedule given the project network data. In a second step, the deterministic data of earned value and earned schedule in this baseline schedule are put into question by adding stochastic elements on them. Pre-defined normal distributions are assigned to the deterministic data from which numbers will be drawn in the third Monte Carlo simulation step. In this step, different scenarios of the project are simulated and its performance is compared to the deterministic baseline point of reference. In a final step, sensitivity information about the CPI and the SPI(t) is reported as measured during the different simulation runs.

In the case study, the probabilistic function applied to the deterministic values is a Normal distribution. This distribution and the Monte Carlo simulations are performed with a software program named @RISK. This is an Excel based application that allows the use of different probabilistic functions and simulation options. In the case study 10,000 iterations have been run in the Monte Carlo simulations.

The following figure shows the PALISADE @RISK[®] framework and the Normal distribution type applied to the deterministic data (Fig. 3).

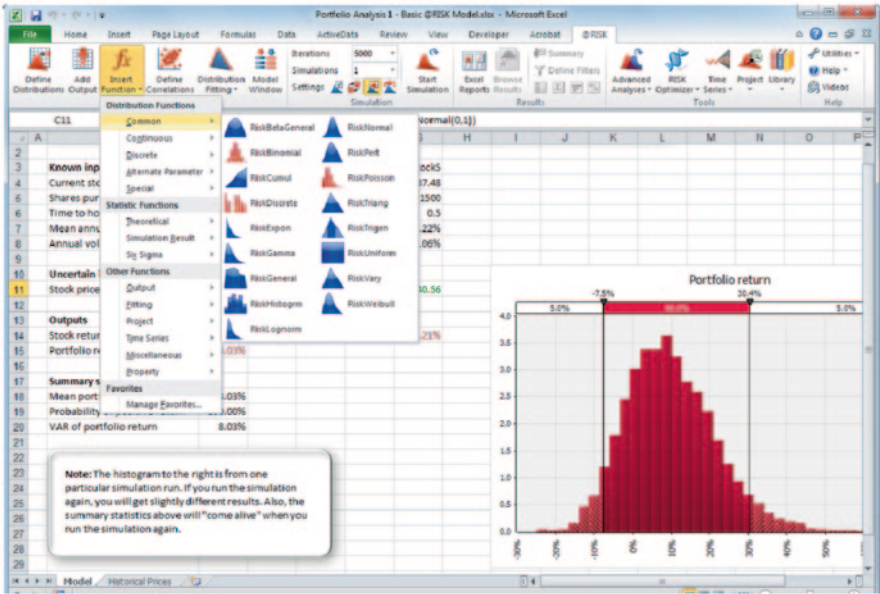


Fig. 3 @RISK software used for Monte Carlo simulations

4 Case Study

4.1 *Description of the Selected Project: Engines Engineering Project*

A real-life engineering project of combustion engine development for energy generation has been analysed. This project has been performed between 2005 and 2008 by a company dedicated to the development and manufacturing of combustion engines for power generation.

These projects are characterized by including the typical phases of the industrial engineering projects, such as, the concept design, detailed design, simulations and calculations, prototyping, testing and launch mass production, where the level of compliance of the technical objectives is strongly important, besides the cost and scheduling control. The project analysed is also featured by the fact that it is a large project in the energy field, as it has a budget of several million Euros, duration between 2–4 years and the risk of putting a new product into the market. The large size of the project makes the breakdown structure of the tasks (WBS) to be also quite large.

The project consists in the development of a new engine of higher efficiency and power than the existing ones in the company. Figure 4 shows the type of engine developed in the project.



Fig. 4 Engineering projects assessment using updated EVM

4.2 Project Data Analysed

In the analysed project, the available information for tracking all the project life cycle was the following documents:

- The initial baseline schedule in MS Project software. It is detailed with multiple tasks levels, and including the starting and finishing dates, as well as, the dependences between them.
- The total budget of the project made at the beginning of the project and its breakdown in six general cost issues, are as follows: material costs, tooling investments, engineering hours, outsourcing expert consultancy support hours, testing costs and trips.
- A monthly report with the technical, economical and scheduling tracing. The technical part of the report includes a list of all manufacturing drawings and the testing results. The economical part of the report included monthly cost figures of the general spending issues collected from the invoices. The scheduling part of the report includes approximate deadlines for the critical tasks but not a detailed scheduling tracking.
- The general accounting of the project with the invoiced costs per month. There are available monthly figures of six general cost issues as it is shown in Table 3.

Table 3 Project data

Project cumulative cost data (Thousands of Euros)							
Date	Materials	Investment	Labour	Testing	Engineering out	Trips	Total
Dec-05	178	206	55	14	425	10	889
Jan-06	148	206	74	22	678	10	1139
Feb-06	152	206	96	32	678	10	1175
March-06	159	206	118	43	678	10	1215
April-06	174	219	131	50	678	10	1263
May-06	177	219	143	60	678	11	1288
June-06	180	228	162	68	678	11	1326
July-06	248	259	172	75	679	11	1444
Aug-06	252	259	178	78	679	12	1457
Sept-06	283	260	184	85	679	12	1503
Oct-06	308	260	197	93	679	12	1549
Nov-06	316	260	208	101	679	12	1576
Dec-06	383	262	211	104	995	12	1967
Oct-07	417	279	309	176	1443	13	2637
June-08	444	279	401	242	1522	16	2905
Aug-08	445	279	425	261	1523	16	2950
Nov-08	472	279	475	281	1526	23	3056
Dec-08	473	279	488	281	1526	23	3070

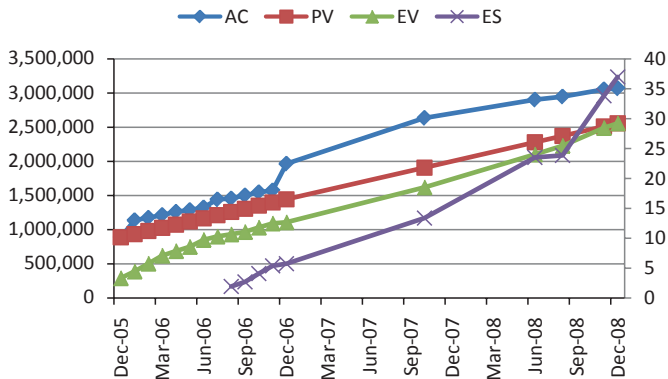


Fig. 5 EVM and ES metrics throughout the project

5 Results

5.1 EVM and ES Results

EVM and ES have been applied to the data of the case study and the basic metrics of both techniques have been successfully obtained, such as, the AC, PV and EV from EVM and the ES, and their cumulative values have been plotted throughout the project in Fig. 5.

The total budget is equally distributed in the project periods to obtain the PV as used by some authors [2].

5.2 Performance Indexes Results

From the calculated basic metrics of EVM and ES, the variances and performance indexes can be obtained. We will focus on the results of the CPI, SPI, SPI(t) and CR. The Fig. 6 shows the CPI throughout the project. As can be seen, the CPI has significant variations in the first third of the project, and then it tries to maintain a stable trend. This result matches with the findings in large projects of the US. DOD described in the literature.

Also the SPI and SPI(t) values have been plotted, in this case, in Fig. 7. A quick look shows the differences between the two indicators. The SPI behaviour at the end of the project tends to 1 independently of the real status of the project. On the other hand, the SPI(t) behaviour is more realistic according to the project information. In the first third part of the project the SPI(t) shows a worst schedule situation than the SPI, which matches better with the project information, thus the SPI could be too optimistic. The SPI(t) at the end of the project shows variations that indicate that it is still working independently of the fact that it has to reach the value 1. Actually, in

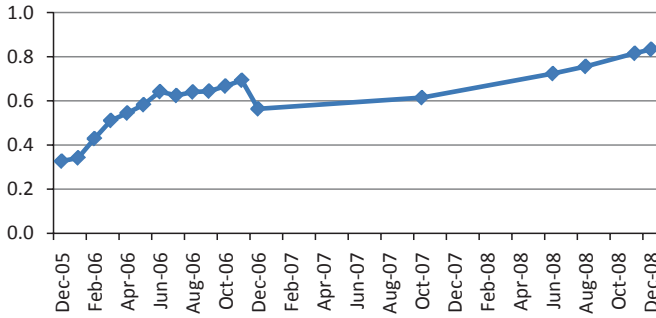


Fig. 6 CPI throughout the project

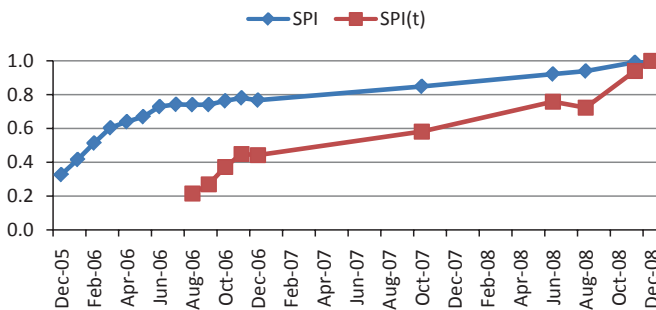


Fig. 7 SPI and SPI(t) throughout the project

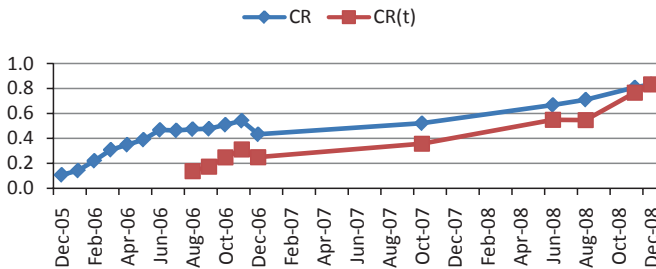


Fig. 8 CR and CR(t) throughout the project

this project the final value of the SPI(t) should be 1 because in the project the earned schedule and earned work was equal to the planned one, but the SPI(t) could catch delays in the project.

Finally, the CR indicator is monitored in Fig. 8, and as it is the product of the CPI and SPI it behaves like them, so the CR(t) collects better the real status of the project.

5.3 Monte Carlo Simulations Results

Once the performance indexes values CPI and SPI(t) are obtained, which are deterministic, it applies a Normal distribution to each of them and a Monte Carlo simulation is run up to 10,000 iterations to generate probable values of the CPI and SPI(t) throughout the project.

The Fig. 9 shows the statistical values of the CPI and their probability percentages.

For this job, we have been considered as confidence limits the maximum and minimum values (100%), as well as, the 95, 50% confidence intervals and the mean. These values are plotted for both the CPI and SPI(t).

The Fig. 10 shows the statistical values of the SPI(t) and their probability percentages. In the case of the SPI(t), there are no values available at the beginning of the project, because there is no result from the ES formulas, until there is an integer number of whole time increments where $EV > PV$.

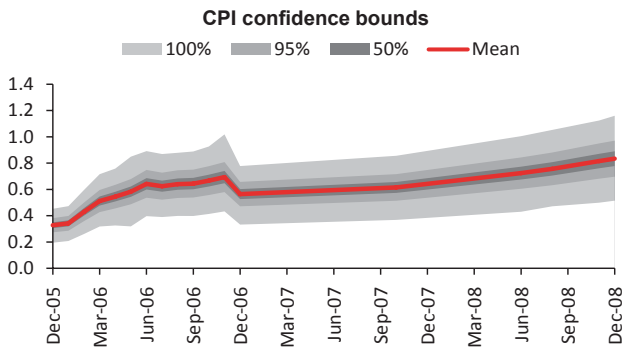


Fig. 9 CPI range of probable values with normal distribution

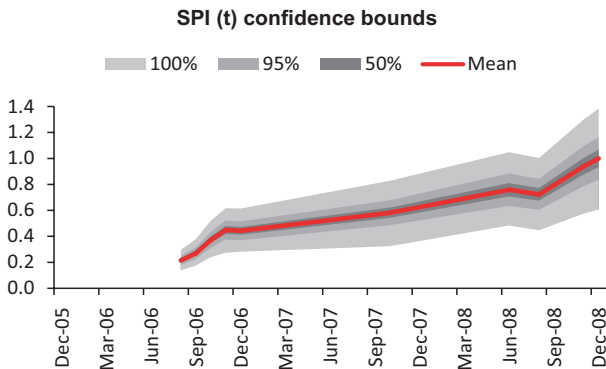


Fig. 10 SPI(t) range of probable values with normal distribution

As it can be seen in the results plots, the CPI and SPI(t) change with the Normal distribution values so that they are sensible enough to the changes in the EV and ES to catch different project situations.

On the other hand, looking at the results, the standard deviation remains stable which can be interpreted as the CPI and SPI maintain the trends even when the values of the EV and ES change with a normal distribution, which may be considered as the behaviour of the CPI and SPI(t) is stable and representative of the project behaviour.

6 Conclusions

Once applied the described methodology in this work to real engineering project data as in the practical case, the following conclusions can be extracted:

- The CPI stability after 20% of project execution observed in several large projects is also confirmed for this type of engineering projects.
- The Earned Schedule, the recent extension of the EVM, can be applied in practice in the engineering projects with the project data usually managed in this type of projects with the exception, and this is a remarkable finding, in case of the condition $EV > PV$ is not accomplished which often occurs at the beginning of the projects.
- It is also been confirmed that, at the end of the project, the SPI(t) obtained from ES is more accurate than the SPI from EVM, because it does not tend automatically to 1.
- In the engineering projects the CPI from the EVM could be applied during the entire project. On the other hand, SPI from EVM should be applied at the beginning of the project and the SPI(t) from the ES should be applied at the end of the project in order to get reliable performance indexes.
- Regarding the sensitivity analysis, with just a few cases, deterministic analysis makes it difficult to see which variables impact the outcome of the project the most. In Monte Carlo simulation, it's easy to see which inputs had the biggest effect on bottom-line results.

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Tool Based on AHP and Its Application in the RURENER Local Actions Plan Evaluation

A. Paneque-de la Torre, P. Aragonés-Beltrán and J. Martínez-Almela

1 Introduction

In 2003, the European Commission launched the Intelligent Energy-Europe Programme (IEE Intelligent Energy-Europe). This program, running until 2013, was developed to support EU energy efficiency and renewable energy policies, with a view to reaching the EU 2020 targets (20% cut in greenhouse gas emissions, 20% improvement in energy efficiency and 20% of renewables in EU energy consumption). Intelligent Energy-Europe creates better conditions for a more sustainable energy future in areas as varied as renewable energy, energy-efficient buildings, industry, consumer products and transport. The expectation is that by doing this, Europe will also boost its competitiveness, security of energy supply, and innovation standing for years to come.

The RURENER project is a network of small rural communities (villages and small towns) that want to reach a neutral energy print at the local level. The project is a part of the European Financial Instrument, Intelligent Energy for Europe (IEE), with duration of 3 years (2009–2011), and a budget of € 1,077,250. The main objective is to involve rural areas in the design of energy policies in order to achieve energy neutrality and promotion of innovative development. The EC knows the difficulty that those kind of rural areas have in this sense and with this project

A. Paneque-de la Torre (✉)
Asociación Española de Ingeniería de Proyectos, Valencia, Spain
e-mail: anpade@dpi.upv.es

P. Aragonés-Beltrán
INGENIO (CSIC-UPV) Universitat Politècnica de València, Camino de Vera s/n, CP 46022
Valencia, Spain
e-mail: aragones@dpi.upv.es

J. Martínez-Almela
Bioagroprojects, Universitat Politècnica de València-UPV, Valencia, Spain
e-mail: jma@bioagroprojects.com

Europe supports the creation of a European Network to share experiences related to energetic neutrality [2].

The specific objectives of the project are:

- Advancing in an energetic neutrality concept amongst the small rural communities
- Offering technical and methodological support to small towns and villages in rural areas in order to reach energy-neutrality
- Sharing experiences and tools throughout this active network
- Promoting public and private investments in renewable energetic resources (RES) and the rational use of energy (RUE) in rural communities
- Encouraging the use of local resources, such as biomass; wind, solar and hydro-electric energy
- Promoting energetic neutral towns as a model and innovative local development in Europe
- Expanding the European network with new members during project life
- Organizing local, national and European events in which members can share information and experiences

The number of rural communities that have joined RURENER has been increasing since its creation. In March 2012, 47 local communities from eight EU countries were members of RURENER (Fig. 1). Despite coming from different countries, some of these communities have similar or complementary characteristics in terms of their environmental conditions and available renewable energy sources. This allowed for cooperation and mutual support between communities through mentoring and twinning activities, thus improving energy efficiency strategies and exploitation of local renewable energy sources, considered as an indicator of success.

In 2009 RURENER Charter was signed by the 14 rural communities listed in Table 1. Next to them is the name of the “partner” organizations that support each of the rural communities.

Fig. 1 Rural communities that are RURENER members. March 2012 (source: www.rurener.eu)



Table 1 Signatories rural communities of the RURENER founding charter

Country	Rural community		Partner
Spain	Atzeneta del Maestrat	A	INTERCOOP
Romania	Calimanesti-Caciulata	B	UBC
	Slanic-Moldova	C	
	Tasca	D	
Greece	Keratea	E	CRES
	Nikiforos-Dramas	F	
Hungary	Nagypali	G	BZAKA
	Perkupa	H	
France	Peyrelefade	I	ADIMAC
	St. Etienne de Lugdares	J	
Germany	Schladen	K	EMT
	Schöningen	L	
	Wesendorf	M	
Italy	Tirano	N	IREALP

2 RURENER Roadmap

The way for small rural communities to reduce their carbon footprint and work towards energy neutrality is presented as a road map. It consists of 6 steps, each of which offers advice and tools that have been tested by RURENER pilot communities, and useful case studies illustrating how communities have put theory into practice.

STEP 1: Local Action Plan: It allows rural communities to anticipate, coordinate and share short and long term visions about how to drive a comprehensive energy policy, based on their resources and available external support.

STEP 2: Communication and Participation: The RURENER network encourages community participation in sustainable energy initiatives and promotes good communication. Good communication and having citizens and local players participating in, or at least, supporting energy strategies is essential for success. This step will provide tips on what to communicate, who the target audience is, when to communicate, who should participate and what role the citizens or the stakeholders play.

STEP 3: Local Diagnosis: A local diagnosis shows the first step, “point 0” or a “baseline”, that allows small communities to identify their current energy sources and energy use before planning future energy strategies and plans.

STEP 4: Capacity Building: This step deals with finding project partners, twinning with other communities, accessing specialist advice and finding out about financial support possibilities.

STEP 5: Concrete Actions: RURENER provides case studies on how communities have adopted particular renewable energy technologies to reduce their carbon footprint, and links to sources of help and advice.

STEP 6: Evaluation: To know how successful a local energy policy is it is necessary to evaluate the impacts it may have on energy saving, energy neutrality and the community's sustainable development.

The implementation of RURENER roadmap has led to the development of short-, medium- and long-term Local Action Plans (RLAP) in certain pilot communities (Table 1). RLAPs can be divided into four groups or categories depending on their specific or main goal:

- Renewable energies: actions aimed at promoting the use of renewable energies in the community.
- Energy saving: actions aimed at achieving greater energy savings in the community or promoting energy savings among users.
- Communication and awareness: actions aimed at disseminating energy saving policies and encouraging the use of renewable sources in the local community, as well as activities for energy-saving awareness rising.
- Control and follow-up: actions aimed at assessing and monitoring the results of RLA plans.

As indicated in step 6 of the roadmap, to determine the effectiveness of such actions and, therefore, local energy policy, it is necessary to evaluate their impact on energy conservation, energy neutrality and sustainable development of each community. This assessment, especially with regard to local sustainable development, is a complex process that requires the study of a large amount of information from different actors and stakeholders in the project, and need tools designed to assess the environmental, social, economic and institutional aspects (Fig. 2).

RURENER project has developed evaluation tools to help local communities to monitor and evaluate the impacts of their local action plans on energy saving, energy neutrality and local sustainable development. In addition, the evaluation tool can also be used to extrapolate the results obtained in the pilot communities to other rural communities, and implement similar initiatives and adapt them to the particular characteristics of their region.

Fig. 2 New LED street lighting in the rural community of Schladen (Germany). Example of energy-saving RLAP



3 Evaluation of Local Action Plans

To analyse the impact of energy neutrality on local economic development and determine which actions have a greater positive impact on the environment, it is necessary to evaluate the results of these RURENER Local Action Plans to promote their implementation, not only in the pilot communities but also in new communities who may be interested in participating in the project or who wish to promote energy saving policies and the use of renewable energy sources to achieve energy neutrality.

A support tool for decision-making based on the Analytic Hierarchy Process (known as AHP) was developed to help identify which projects offer better results and which plans could be adapted for better results from the perspective of the new community.

4 Evaluation Process

According to Bouyssou et al. [1], the selection of a model based on Multi-Criteria Decision Analysis (MCDA) is not easy, as there are several models that can be used in a decision-making process. Some of these techniques are the Analytic Hierarchy Process, ELECTRE and PROMETHEE methods, PRES II, TOPSIS and CODASIS.

The Analytic Hierarchy Process (AHP) allows decision makers to structure the prioritization problem as a hierarchy based on the consistency of relevance judgments. The model is easily understood by the experts who evaluate the reports and allows them to propose and gather information generated individually by each expert in a simple and systematic manner. In addition, the supporting software tools can perform calculations and display the results in a fast and simple way.

The Analytic Hierarchy Process (AHP) developed by Thomas Saaty [4, 5] is a technique for multicriteria decision making that decomposes a complex problem into a hierarchy (see Fig. 3) with each level consisting of a few manageable elements; the top level of the hierarchy is the main goal and the lower levels consist of the criteria and sub-criteria and the alternatives to the problem.

Once the problem has been structured into a hierarchical model, the decision makers will make pair-wise comparisons for each level of the hierarchy so as to obtain the weight of each element in the same level with respect to an element of the next higher level. This weight factor provides the decision maker with a measure of the relative importance of that element.

Fig. 3 Hierarchical structure of the problem according to AHP



Table 2 Criteria and sub-criteria used for LAP prioritization

Criteria	Sub-criteria
01 Energy neutrality (RES)	C11 01 Energy neutrality
02 Energy savings (RUE)	C21 Energy savings
03 Economic impact	C31 Cost efficiency
	C32 profitability
	C33 Investors
	C34 Capacity building
04 Institutional impacts	C41 Institutional impact
05 Social impacts	C51 Employment
	C52 Social involvement
	C53 Avoidance of nuisance to neighbours
06 Environmental impacts	C61 Preferential use of renewable resources
	C62 Minimization of energy, water and material consumption and land utilization
	C63 Minimization of greenhouse gas emissions, land and water pollution
	C64 Maximization of resource re-use and/or recycling
	C65 Maintenance and restoration of ecological diversity

When the number of alternatives is greater than 7 ± 2 the ratings model should be used. It consists in building a category scale for each criterion against which the different alternatives are compared. The prototypes of the categories should avoid ambiguity, because then they may be interpreted differently by different evaluators, and they should be interchangeable to describe two alternatives with different preferential value.

5 First Approach to RLAP Evaluation Tool and Comments Made by RURENER Association

In an earlier paper [3] we described the design of the RURENER evaluation tool. The aim of this tool was to determine which RLAPs were more efficient in terms of environmental impacts according to the different communities involved in the action plans. The main goal was “Prioritization of RURENER Local Action Plans regarding their environmental impact”. Fifteen energetic, economic, social and environmental indicators were used as model criteria (see Table 2). The result was a priority order of the pilot communities participating in the project, the community with the highest LAP score being at the top of the list (Fig. 4).

The results were analysed by the members of the Association but, for political reasons, we decided not to present the priority order of the participating communities. Instead, the different action plans of the communities involved in the project

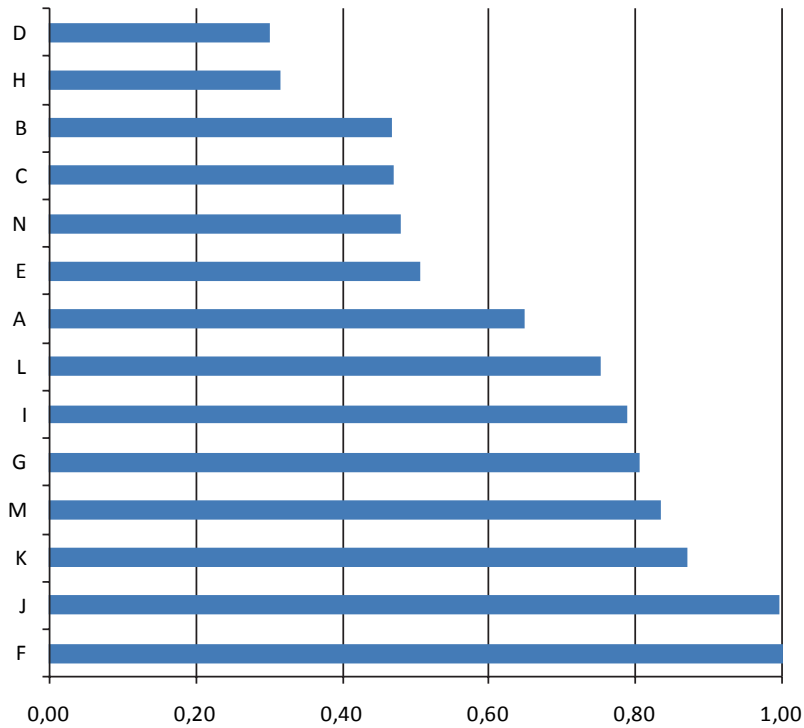


Fig. 4 Prioritization of the alternatives according to the criteria defined by RURENER experts (Priority ideal values)

were compared with each other. Furthermore, to complete the project in time, we used the same responses of the questionnaires though the weighting of criteria and sub-criteria was different from that presented in the initial evaluation tool. The new weighting values were obtained from the opinions of RURENER experts.

The new model was well accepted among the decision makers as it could be adapted to the conditions of other rural communities. The use of the questionnaire was found to be an efficient and motivating tool as it helped new communities interested in joining the RURENER project to better identify which action plans better suit the characteristics of their region. In this way, they could use a simple computer application, e.g. a spreadsheet to evaluate the particular conditions of their region with no need for a more complex computer program.

The initial model was thus modified as follows. First, instead of one analytic hierarchy process (AHP), four AH processes were conducted, one for each category of action plans (Renewable energies, Energy savings, Communication and awareness and Monitoring), so as to obtain more accurate and reliable results. In this way, rather than a rank order of rural communities the new model analyses the action plans or activities developed by a community to reach the goals defined in each category.

This breakdown by category involved assigning values to the actions defined in each category based on the general RLAP questionnaire.

To simplify the use of the tool, Super Decisions software was replaced by a Microsoft Excel spreadsheet, thus avoiding the need for downloading, setting-up and executing a more complex decision-making support tool.

6 Problem Structuring

The new version of the tool was used to determine which action plans or activities are more efficient from the point of view of their impact on rural development. Therefore, the main objective can be defined as the “Identification of priority energy plans in terms of their impact on rural development”. The goal was the same for each AHP in each category. The criteria and sub-criteria used to evaluate the impact of different actions were the same: 15 energetic, economic, social and environmental indicators described earlier. Similarly, the alternatives to prioritize were also the initial 14 RLAPs, but considering only the action plans corresponding to the category under analysis.

7 Evaluation of the Alternatives

As requested by RURENER Association, the new model uses the same values obtained in the initial questionnaires although the weighting of the criteria and sub-criteria for the evaluation or rating of the alternatives is different

8 New Weighting Values of Criteria and Sub-criteria

For the redefinition of the weighting values, the expert panel members had to fill in a form in which they were asked to make pair wise comparisons first among the criteria, and then among the sub-criteria. The global weights were obtained by calculating the mean of the answers given by the experts (Table 3).

As shown in Fig. 5, the Energy neutrality and Energy savings criteria are those best rated by the experts, as could be expected due to the characteristics of the project. The difference between these two criteria and the other criteria is even more clearly observed when the weights of the sub-criteria are represented graphically, in part because these two criteria, i.e. Energy neutrality and Energy savings, do not have sub-criteria.

Table 3 New global weights as defined by RURENER experts

Criteria	Sub-criteria	Weights
01 Energy neutrality (RES)	C11	0.4655
02 Energy savings (RUE)	C21	0.2995
03 Economic impact	C31	0.0174
	C32	0.0073
	C33	0.0283
	C34	0.0205
04 Institutional impact	C41	0.0194
05 Social impact	C51	0.0480
	C52	0.0252
	C53	0.0132
06 Environmental impact	C61	0.0228
	C62	0.0090
	C63	0.0090
	C64	0.0124
	C65	0.0026

9 Application of the Model to the Analysis of Alternatives

As explained above, with the purpose of obtaining the most accurate and reliable results for the action plans and activities developed in each rural area, the different communities were analysed separately by the category which better identified their main goal:

- Renewable energies
- Energy saving,
- Communication and awareness
- Monitoring

All the actions taken by the pilot communities during the initial evaluation period were classified into the four groups mentioned above. As mentioned earlier, for a more accurate and simpler analysis, four models (networks) were built, one for each category. If in a community there is at least one activity that may have some influence on one of the criteria, then the category to which this action belongs will exert some influence on this criterion.

The influences of the individual actions on each indicator were determined from the description of each action (“1” means that the action has some influence on the corresponding criterion). Yet much more accurate results might have been obtained if the influences had been determined directly by representatives of each pilot community.

The process of assigning values to the categories is shown in Fig. 6, which as an illustration presents the case of the community of Slanic-Moldova (Romania) and criterion C41, Institutional impacts.

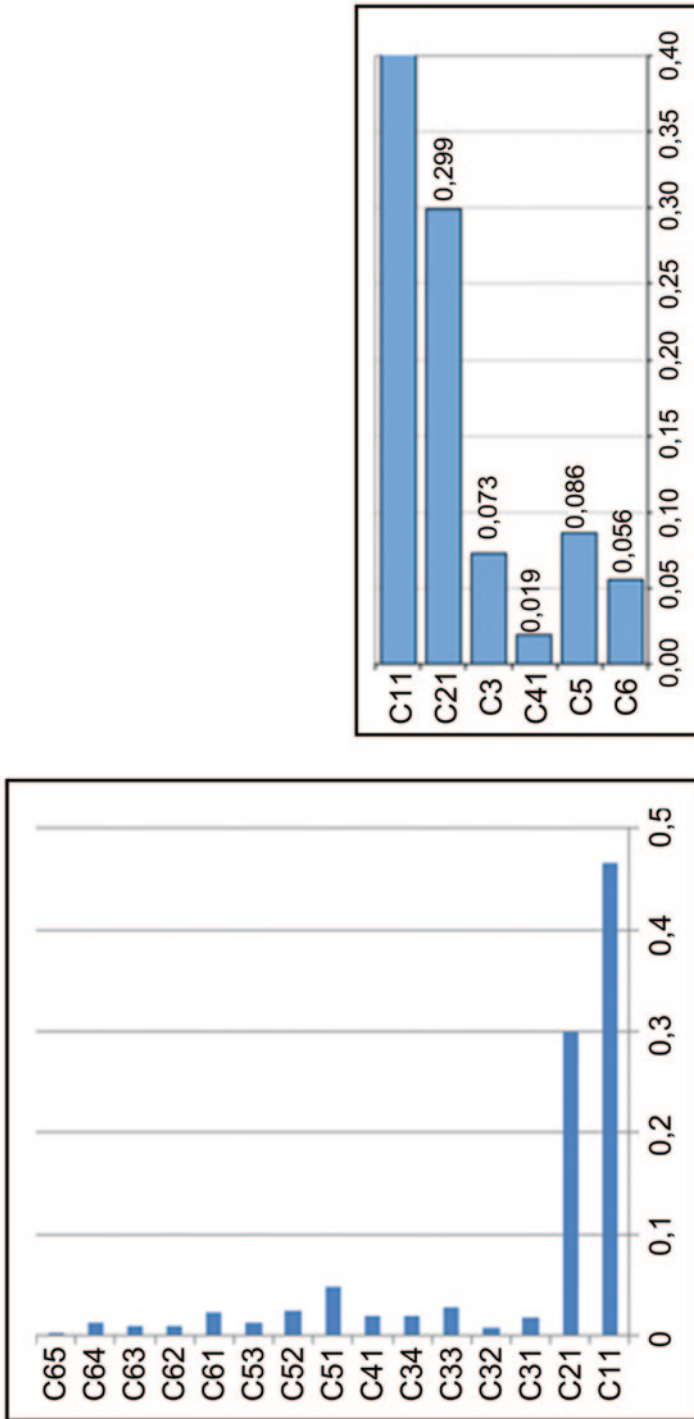


Fig. 5 Graphical representation of the new global weights as defined by the RURENER experts

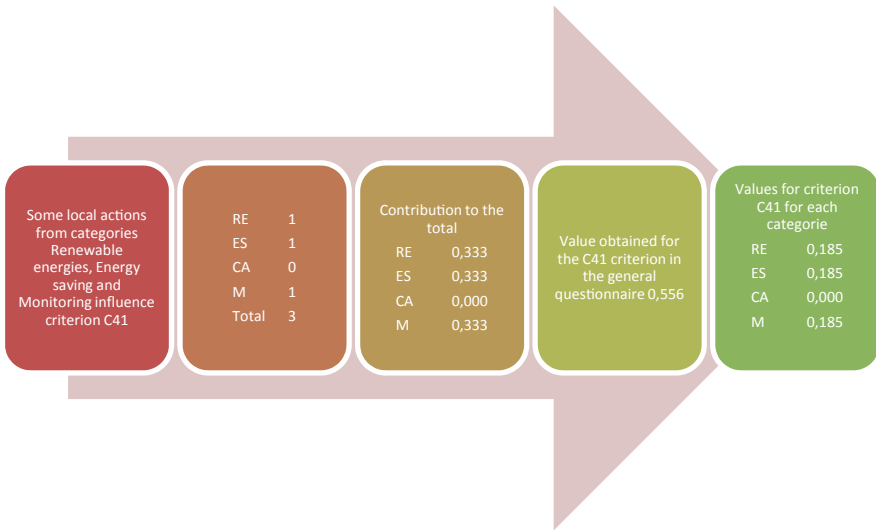


Fig. 6 Example of values assigned to the categories

10 Analysis of Results

The following figures show the ideal values for the different alternatives in each category (Fig. 7).

The modification of the former evaluation tool provides a reliable description of the actions implemented in different rural communities that best meet the expectations of the expert panel, i.e. when the criteria for assessing the success of the action plans and activities are Energy neutrality and Energy savings. If the experts had considered, for example, Institutional impact as the most important criterion, then the results would have been different and other action plans would have been the best rated.

The Excel tool described in this paper can be used as a reliable aid by new rural communities interested in achieving energy neutrality to implement the action plans and activities that best meet their needs and requirements for the achievement of their particular goals. For that purpose, the communities have to answer the questionnaire provided by the tool and indicate the relative importance of the factors to take into consideration when selecting a project. The questionnaire will then generate the weighting of the criteria to be used in each of the four selection processes, one for each category. The results of the proposed tool are more reliable and accurate than those obtained with the process described in Paneque de la Torre et al. [3] for the implementation of action plans in new rural communities.

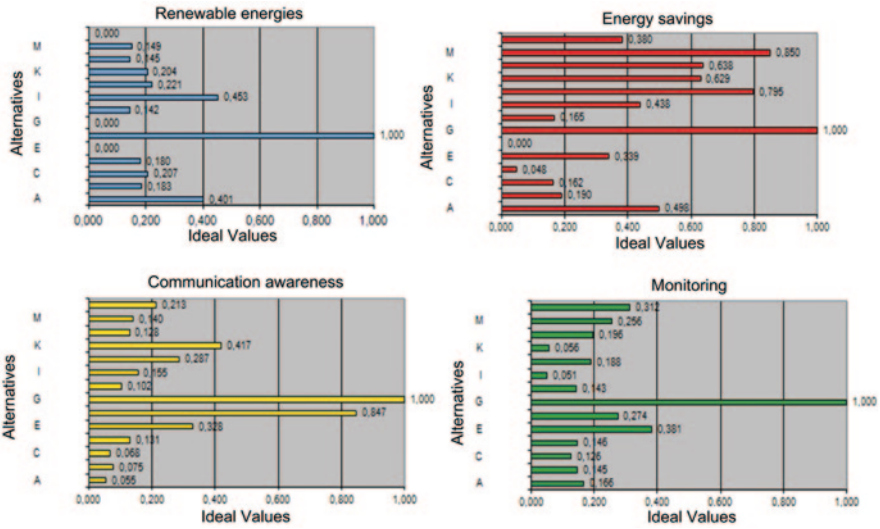


Fig. 7 Results for the alternatives in each category (Ideal values)

11 Conclusions

This paper describes how an AHP method for decision-making can be adapted and tailored to the needs of different stakeholders. In the present case study, a new tool has been developed to help RURENER project team to evaluate positive impacts resulting from the implementation of local action plans on energy neutrality. The tool analyses a set of criteria (energetic, economic, social, legal, environmental, etc.) adapted to the actual needs and requirements of the participating communities, and thus provide more accurate and reliable results.

On the other hand, the classification of action plans and activities into categories (Renewable energies, Energy savings, Communication and awareness, and Monitoring) helps new rural communities select the activities that best meet the particular requirements of the region.

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Part II
Civil Engineering, Urban Planning,
Building and Architecture

Comparative Analysis of Calculation of Buildings Drainage Systems

P. Arrué, A. M Romero and A. C Cárcel

1 Introduction

The Technical Building Code (CTE) in the Approved Document relating to sanitary conditions of health, HS Salubridad, specifically the introduction of the sub-code HS-5 Water evacuation [3], was a major policy change in the field of plumbing for water disposal installations in buildings. Prior to these technicians had to rely on scientific methods to determine the optimal design and sizing of networks, in the absence of mandatory standards. An optimal design and correct sizing involves not only code enforcement but also justifying that the proposed solution ensures smooth functioning and proper sanitary conditions.

To analyse the requirements of HS-5 CTE comparative empirical methodologies and analytical calculations that allow us to determine the degree of security that the application of the HS-5 requirement of CTE represents in downspouts and main sewers have been performed. The most notable contributions were made by Hunter [11], Babbitt [12], Dawson and Kalinske [13], Manning [4], with methodologies based on experimentation and secondly Swaffield and Gallowin [8], Darcy [2], Weisbach [9] and Colebrook and White [1], providing analytical tools grounded in Fluid Mechanics.

This study shows that the HS-5 sub-code has not developed to its full extent, as would be desirable, in two fundamental ways. On one hand, in terms of the

P. Arrué (✉) · A. M. Romero · A. C Cárcel
Departamento de Construcciones Arquitectónicas, IT-DIMM, Universitat Politècnica de València, Valencia, Spain
e-mail: paarbu@csa.upv.es

A. M. Romero
e-mail: aromeros@csa.upv.es

A. C Cárcel
Departamento de Ingeniería Mecánica y de Materiales, ITM-DIMM, Universitat Politècnica de València, Valencia, Spain
e-mail: acarcel@mcm.upv.es

coefficients of simultaneous consumption, as habits have been changing and there has been an increase in water consumption that dictates the design of adequate networks for water evacuation. On the other hand, the sizing proposed by regulations is clearly inferior to the results required by the application of empirical and analytical methodologies. This can lead to serious pathologies, caused by a variation of pressure inside the networks thus causing siphoning phenomena that cause the elimination of water seals and insanitary air entering inside the premises.

2 Materials and Methodology

2.1 Sizing Rainwater Downspouts

With reference to the sizing of rainwater downspouts, the CTE does not specify the typology of rainfall, of short or long duration or chronological rainfall patterns essential to determine the maximum average rainfall intensity and risk of failure, nor the type of material, nor the relationship between the annular surface of the liquid flow and the total section of the pipe, “r”, nor the temperature and physical characteristics of the fluid. These are important variables as they determine the relative height and terminal velocity of the fluid inside the downspout.

The diameters given by the analytical equations are based on the contributions of Swaffield and Gallowin [8], Swaffield and Thancanamootoo [7] and Wise and Swaffield [10] in fluid mechanics, specifying the thickness of the fluid ring as it is expressed in Eq. (1) given by Romero and Arrué [5], taking into account variables such as the rugosity of the material, the kinematic viscosity of the fluid temperature and the thickness of the sheet of water in the downspout.

$$\frac{Q}{\pi \cdot x(D-x)\sqrt{2gx}} = -4 \log_{10} \left[\frac{1}{4x(D-x)} \left(\frac{\varepsilon}{3.71} + \frac{1.26\nu}{\sqrt{2gx}} \right) \right] \quad (1)$$

The diameters given by the empirical Eq. (2) are based on input from Hunter [11], Dawson and Kalinske (1937) and Babbitt (1935), corresponding to vertical flow, corresponding to the fluid ring in the downspout, Fig. 1, it should occupy between 25 and 33% of its cross section, i.e., “r” between 0.25 and 0.33, a constraint that J. A. Swaffield proposes more restrictively to the extent of 15/64.

$$Q = 3.15 \cdot 10^{-4} \cdot r^{5/3} \cdot D^{8/3} \quad (2)$$

Given that the diameter of the air column “d” is the pipe “D” minus 2 times the thickness “x” of the water surface adhered to the wall of the downspout. The limitations of “x” can be expressed according to different authors as:

Hunter [11], Babbitt [12] y Dawson y Kalinske [13]; and Swaffield and Than-canamootoo [7]

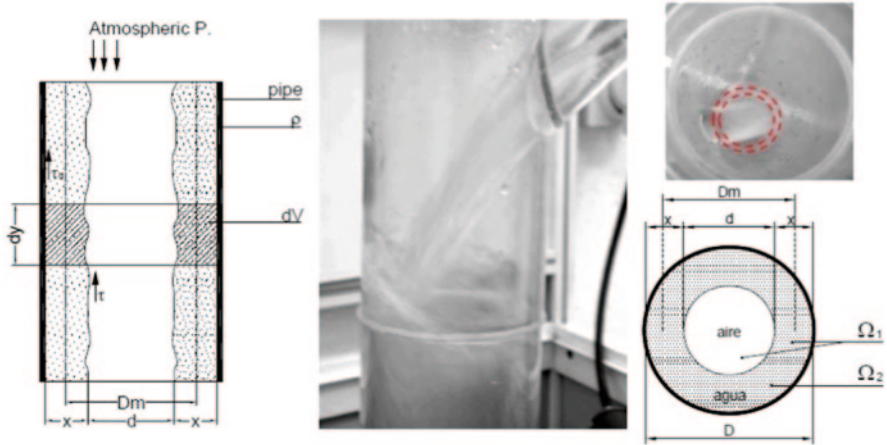


Fig. 1 Flow in a downspout, relation between annular and transversal cross-section of the downspout

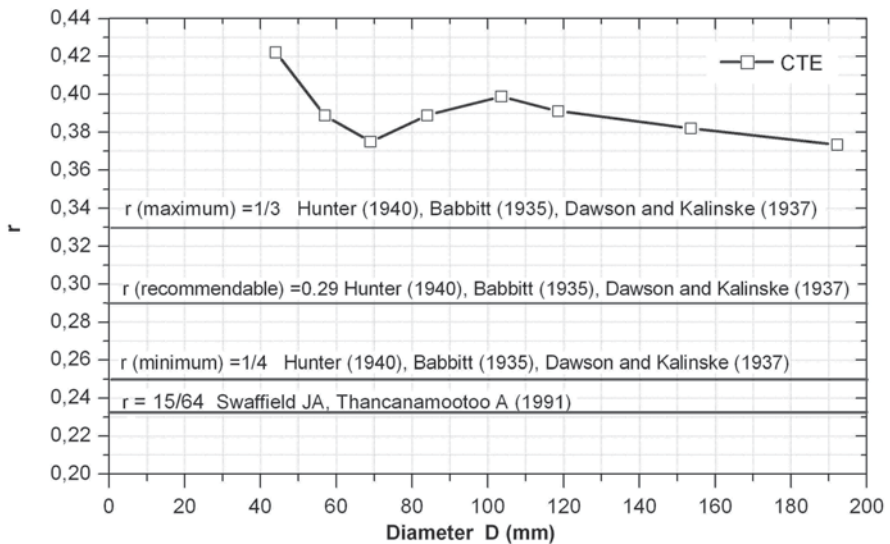


Fig. 2 Correlation between the diameter of the downspout and “r”, for $i=100$ mm/h and PVC-U UNE 1329

$$r \geq 1/4 \rightarrow x \geq D / 14.92$$

$$r \leq 1/3 \rightarrow x \leq D / 10.89$$

$$r \leq 15/64 \rightarrow x \leq D / 16$$

Figure 2 shows the correlation between the “r” parameter representing the relationship between the annular section of the fluid with respect to the total cross section of the downspout and the diameter thereof resulting from the application of CTE compared to the constraints.

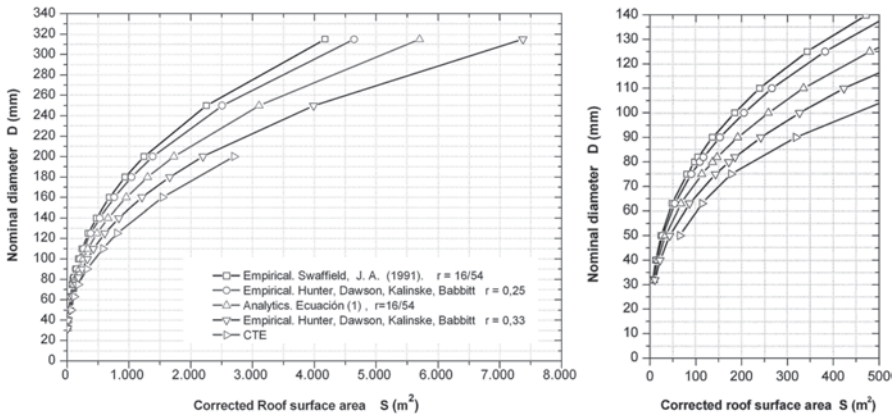


Fig. 3 Correlation between the corrected roof surface area and the diameter of the downspout ($D \leq 350$), for $i=100$ mm/h, according to the CTE, empirical method and the analytical method (PVC-U UNE 1329)

It is observed that in all cases the results indicate the implementation of the CTE values of “r”, which are above 0.37, much higher than those recommended by Hunter [11], Babbitt [12], Dawson and Kalinske [13] of 0.33 maximum and Swaffield and Thancanamootoo [7] of 0.23. The comparison between the CTE and the analytical and empirical equations has been made for a rainfall rate of 100 mm/h and PVC-U UNE 1329.

Figure 3 shows the comparison between the diameters obtained by the model proposed by the CTE, which are clearly inferior to the results obtained empirically by Hunter, Dawson, Kalinske and Babbitt, with values of “r” more than 33% reaching 42%, and less than the analytical model with the constraint “r” proposed by Swaffield and Eq. (1). It is therefore recommended to adopt diameters for downspouts greater than those proposed by the CTE.

2.2 Sizing of Main Rainwater Sewers

The analytical method of calculation is based on the equations of Darcy [2], Weisbach [9] and Colebrook [1] expressing a full pipe flow given by Eq. (3) and at 50% full flow in the Eq. (4).

$$Q_{l\theta=90^\circ} = -\frac{\pi \cdot D^2}{2} \log_{10} \left[\frac{\varepsilon}{3.71 \cdot D} + \frac{2.51 \cdot \nu}{D \sqrt{2g \cdot D \cdot s_0}} \right] \sqrt{2g \cdot D \cdot s_0} \tag{3}$$

$$Q_{\theta=90^\circ} = -\frac{\pi \cdot D^2}{4} \log_{10} \left[\frac{\varepsilon}{3.71 \cdot D} + \frac{2.51 \cdot \nu}{D \sqrt{2g \cdot D \cdot s_0}} \right] \sqrt{2g \cdot D \cdot s_0} \tag{4}$$

To test this full section hypothesis the flow contributed by the areas proposed by the building sub-code DB Table 4.9 CTE HS-5 is taken as a starting point with their respective slopes and applied to circular pipes made of PVC-U UNE 1329, with an absolute rugosity “ε” of 0.025 mm and the kinematic viscosity of water at 4 °C ($\nu=1.562 \cdot 10^{-6} \text{ m}^2\text{s}^{-1}$). The calculation has taken the hydraulic loss (s0) to be approximately equal to the geometric slope (p), and as the pattern is uniform and constant it can be taken as the loss of a unit load, such that, $s_0 \cong p \cong j$, valid for very small pipe slopes. Note that the slopes range between 1 and 4% angle between 0.5729° and 2.2909° and the error produced by this assumption is admissible.

Figure 4, 5 and 6 show the comparison between the diameters given by the CTE and the analytical method for the full and partially full section diameters for the slopes 1, 2 and 4% with an $i=100 \text{ mm/h}$ with pipes made of PVC-U 1329.

It can be seen that the curves for the CTE are between 50 and 100% of the relative flow height, the percentage of section diameter occupied, except DN-315 with a 1% slope, which is less than 50%. Note that the recommended maximum relative flow height of the collecting depth is 50% of the section diameter.

From the empirical Eqs. (5, 6 and 7) Manning [4] flow rate, relative flow height and velocity can be obtained for each pipe diameter and slope,

$$Q_{\theta^{\circ}} = \frac{1}{n} \sqrt{s_0} \frac{D^2}{4} \left[\frac{\pi \cdot \theta^{\circ}}{180^{\circ}} - \text{sen} \theta^{\circ} \cdot \cos \theta^{\circ} \right] \cdot \left[\frac{D}{4} \left(1 - \frac{\text{sen} 2\theta^{\circ}}{\frac{2\pi\theta^{\circ}}{180^{\circ}}} \right) \right]^{\frac{2}{3}} \tag{5}$$

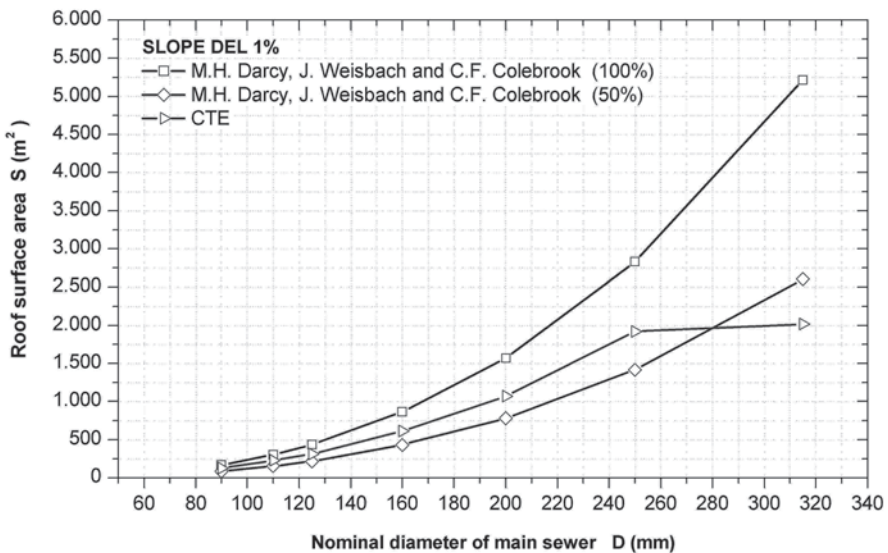


Fig. 4 Nominal diameter of the main rainwater sewer with respect to roof surface area according to the CTE and Fluid Mechanics with full sections and at 50%, with a 1% slope; for $i=100 \text{ mm/h}$ and PVC-U 1329

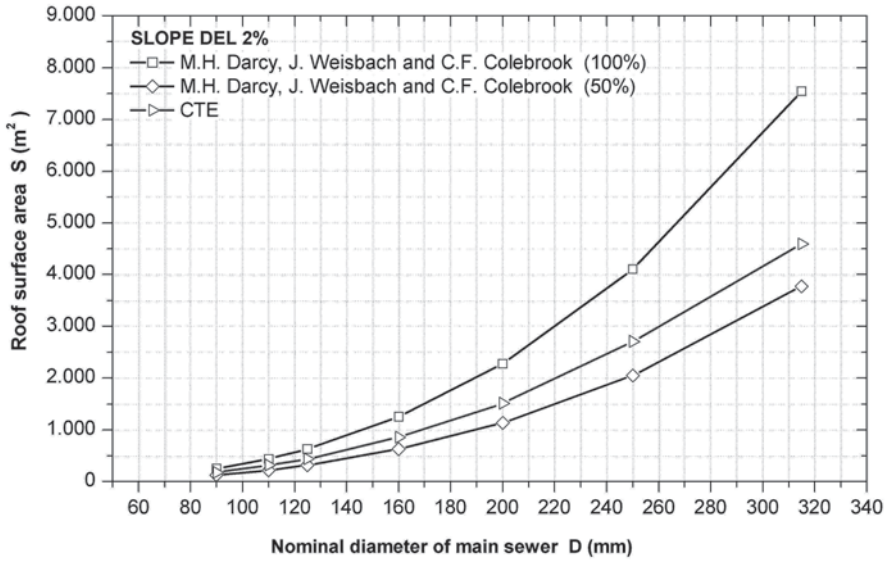


Fig. 5 Nominal diameter of the main sewer with respect to roof surface area according to the CTE and fluid mechanics with full sections and at 50%, with a 2% slope; for $i=100$ mm/h and PVC-U 1329

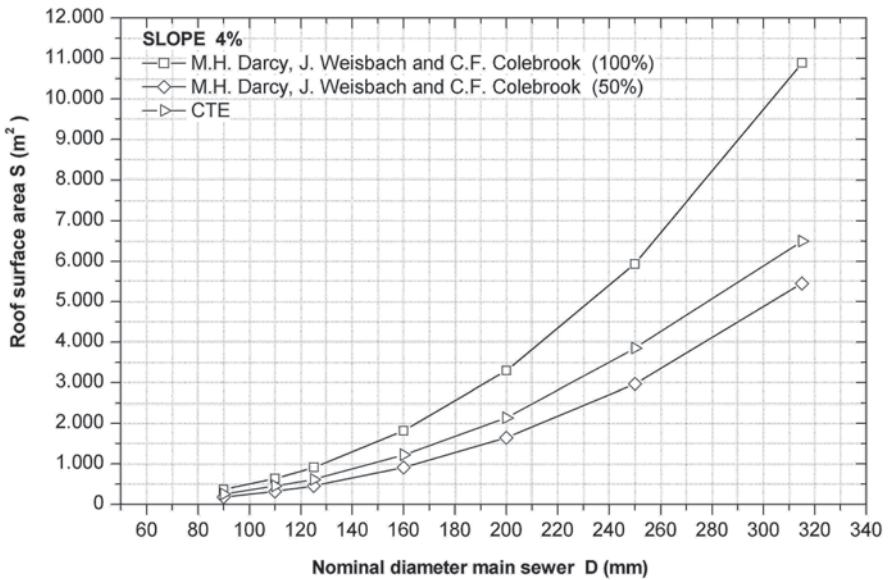


Fig. 6 Nominal diameter of the main sewer with respect to roof surface area according to the CTE and fluid mechanics with full sections and at 50%, with a 4% slope; for $i=100$ mm/h and PVC-U 1329

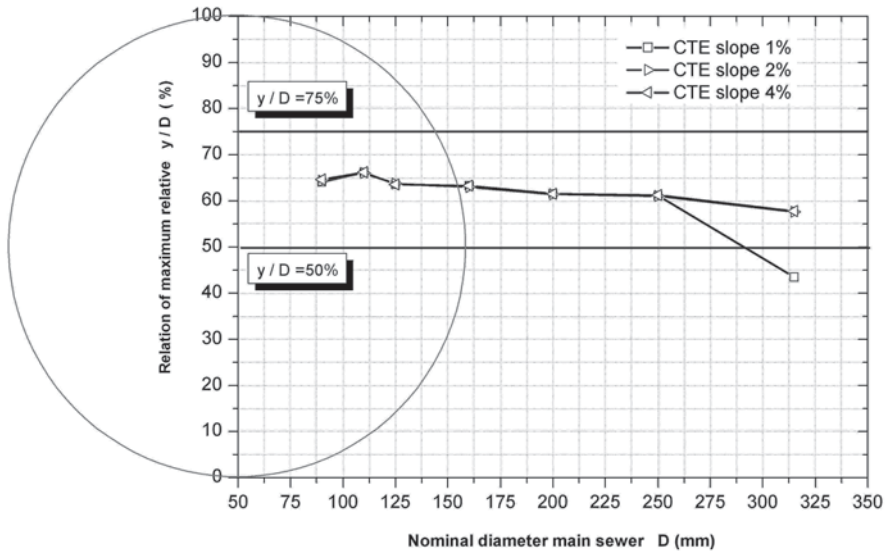


Fig. 7 Correlation between the diameters proposed by the CTE and the relative flow height in main rainwater sewers, $i = 100 \text{ mm/h}$

$$C_{\theta^{\circ}} = \frac{1}{n} \sqrt{s_0} \cdot \left[\frac{D}{4} \left(1 - \frac{\text{sen}2\theta^{\circ}}{\frac{2\pi\theta^{\circ}}{180^{\circ}}} \right) \right]^{\frac{2}{3}} \tag{6}$$

$$y_{\theta^{\circ}} = \frac{D}{2} \cdot [1 + \cos(180^{\circ} - \theta^{\circ})] \tag{7}$$

Analysing diameters proposed by the CTE and considering pipes made of PVC-U UNE 1329 with a coefficient of friction of Manning $n = 0.009$ for new materials, the relative flow height results of Fig. 7 and the flow velocities of Fig. 8 are obtained.

The diameters given by the CTE show the relationship between the relative flow height ranging between 43 and 66 %, with a mean value of 62 % and a velocity ranging between 0.93 ms^{-1} and 4.21 ms^{-1} .

For sizing main sewers fluid velocity values between 0.6 ms^{-1} and 2.6 ms^{-1} are recommended to prevent erosion or sedimentation and a maximum relative flow height of 50 % of the diameter.

The calculations have relied upon the calculation graphics proposed by Romero and Arrué [5] which take into account variables such as the rugosity of the material, temperature and kinematic viscosity of the fluid. For example, The graph corresponding to PVC-U UNE 1329 rainwater sewers with a friction coefficient $n = 0.009$, for a slope of 1 % is shown in Fig. 9.

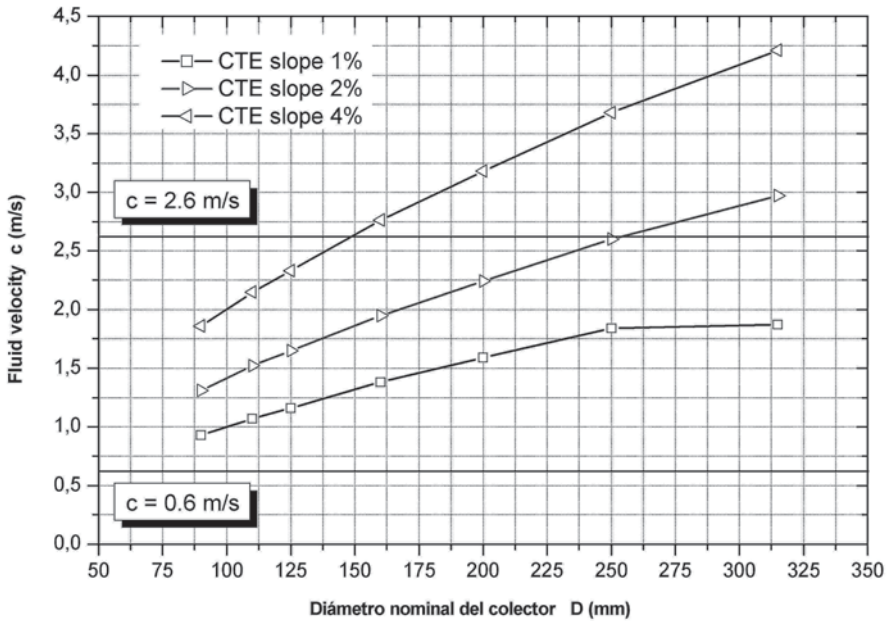


Fig. 8 Correlation between the diameters proposed by the CTE and the fluid velocity in main rainwater sewers, $i = 100$ mm/h

2.3 Sizing Waste-Water Downspouts

Below is a comparison of the diameters given by the CTE for wastewater downspouts with those produced by methodologies based on analytical Eq. (1) and the empirical Eq. (2), Hunter [11], Dawson and Kalinske [13] and Babbitt [12].

From Fig. 10 and 11 it can be seen that the diameters proposed by the CTE are clearly lower than those proposed following the methodology of analytical and empirical calculation.

2.4 Sizing Waste-Water Main Sewers

The CTE sizes the diameter of the main sewers according to the number of units of discharge and the slope of the pipe with the premise that the level of the relative flow height is half the pipe diameter with a maximum of 75% under conditions of uniform flow (art. 4.1.3 CTE HS-5).

Below is a comparison of the diameters given by the CTE with analytical equations shown by Darcy [2], Weisbach [9] and Colebrook [1]. Equations (3 and 4) for slope gradients of 1, 2 and 4%, Fig. 12, 13 and 14, respectively, with the coefficients of simultaneity given by UK model (including toilets) for PVC-U pipes 1329, rugosity “ ϵ ” 0.025 mm and the fluid at 4 °C.

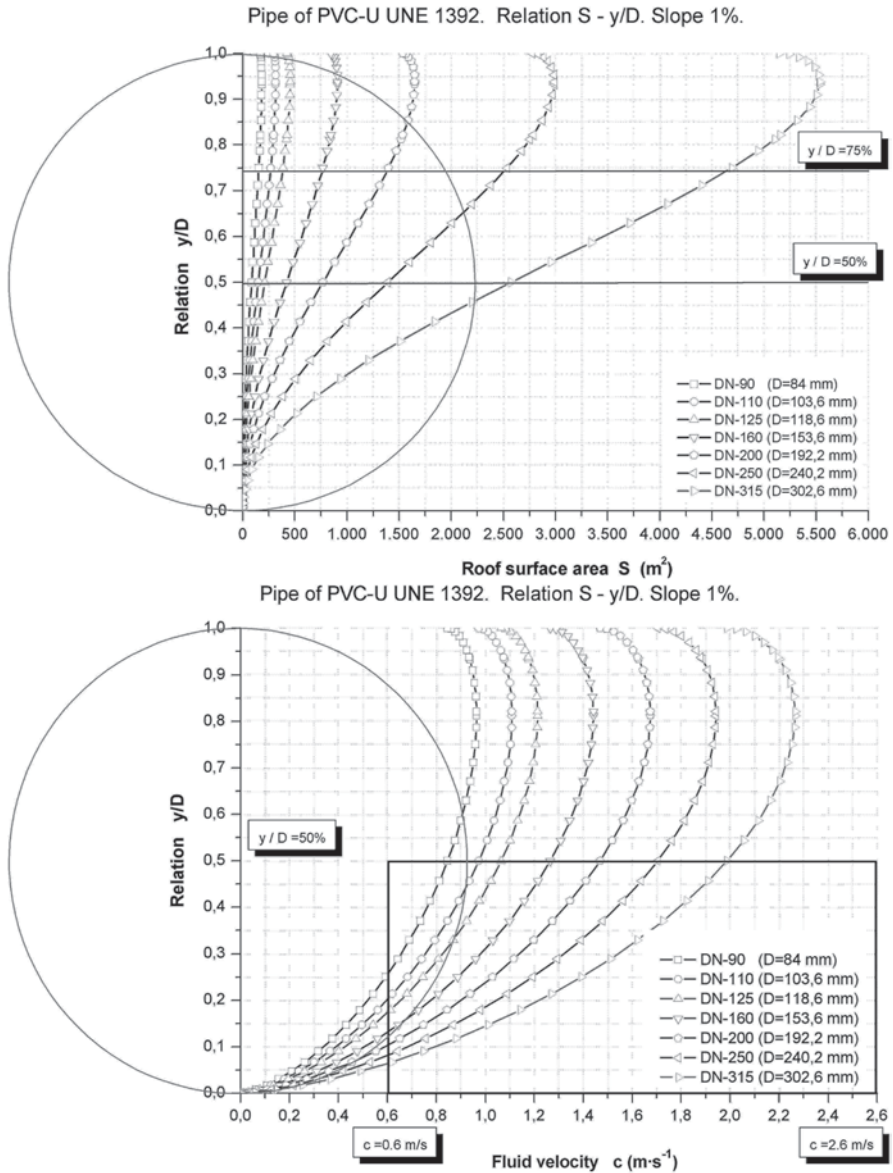


Fig. 9 Correlation between the roof surface area, the relative flow height and the fluid velocity, for $i = 100 \text{ mm/h}$, in pipes of PVC-U UNE 1392 with a 1% slope

It can be seen that up to DN-160 ($D = 153.6 \text{ mm}$, $P = 1\%$) in Fig. 9, DN-125 ($D = 118.6 \text{ mm}$, $P = 2\%$) in Fig. 10 and DN-110 ($D = 103.6 \text{ mm}$, $p = 4\%$) in Fig. 11, the diameters of the CTE are inferior than those of the analytical curve for 100% flow, therefore implying the commencement of a load application to the tube surface.

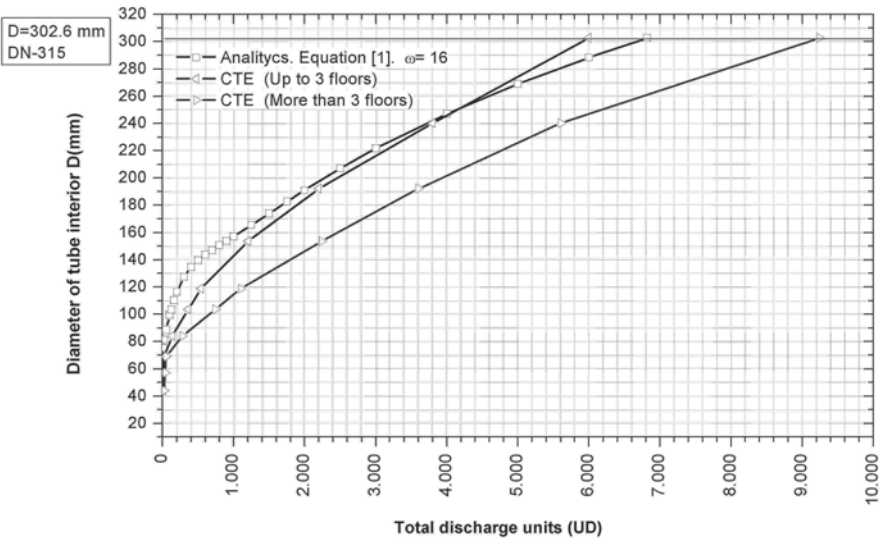


Fig. 10 Correlation D vs. total units of discharge (UD) according to the CTE and fluid mechanics K (UK includes WC usage), $x=D/16$, $\epsilon=0.025$ mm and PVC-U 1329

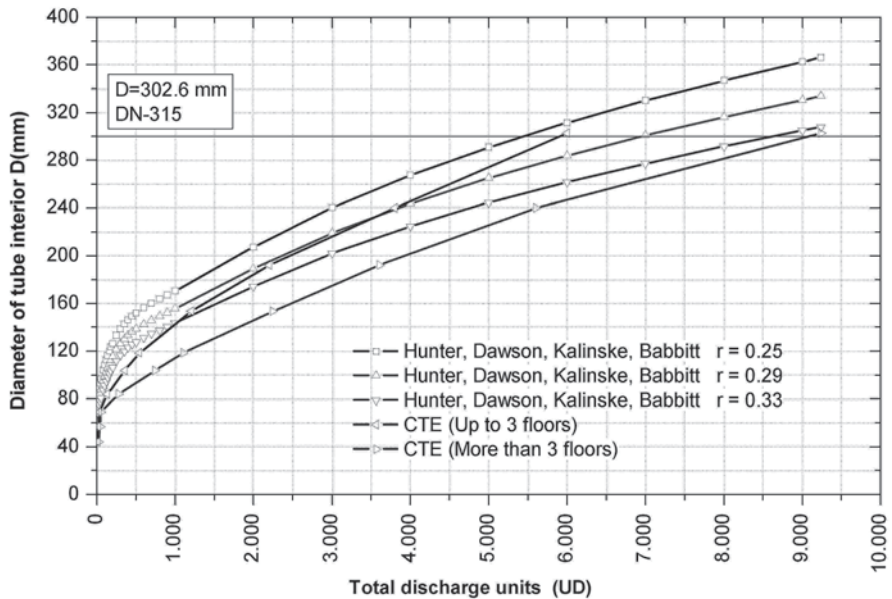


Fig. 11 Correlation D vs. total UD according to the CTE and the empirical equations K (UK includes WC usage), $r=0.25, 0.29$ y 0.33 y PVC-U 1329

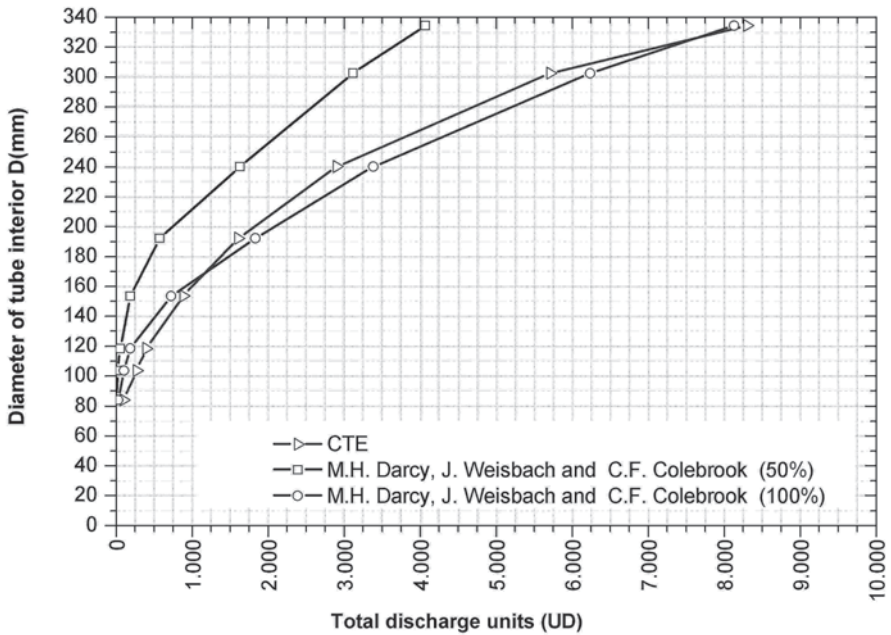


Fig. 12 Diameters of waste-water main sewers vs. total UD according to the CTE and fluid mechanics, for a 1% slope, K (UK includes WC usage) and PVC-U 1329

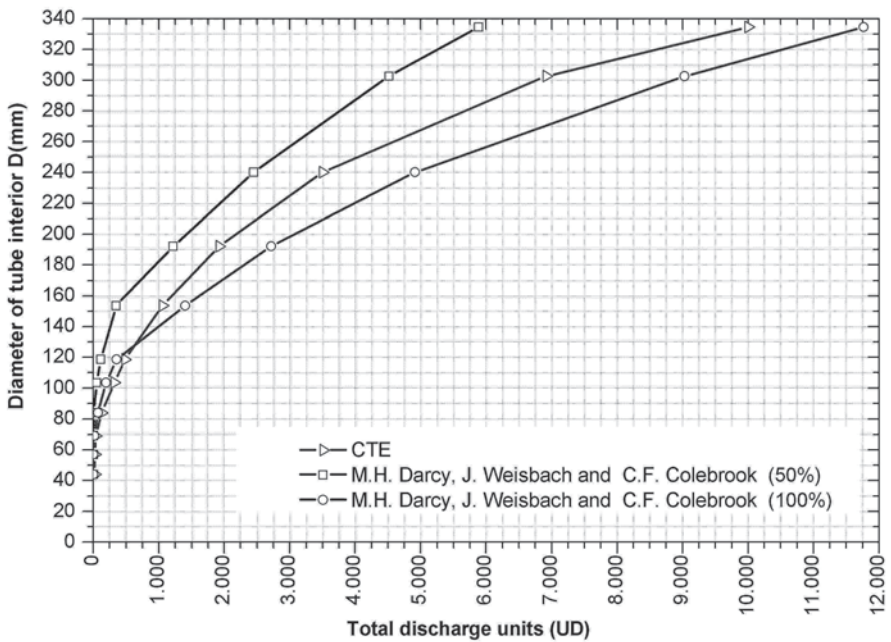


Fig. 13 Diameters of waste-water main sewers vs. total UD according to the CTE and fluid mechanics, for a 2% slope, K (UK includes WC usage) and PVC-U 1329

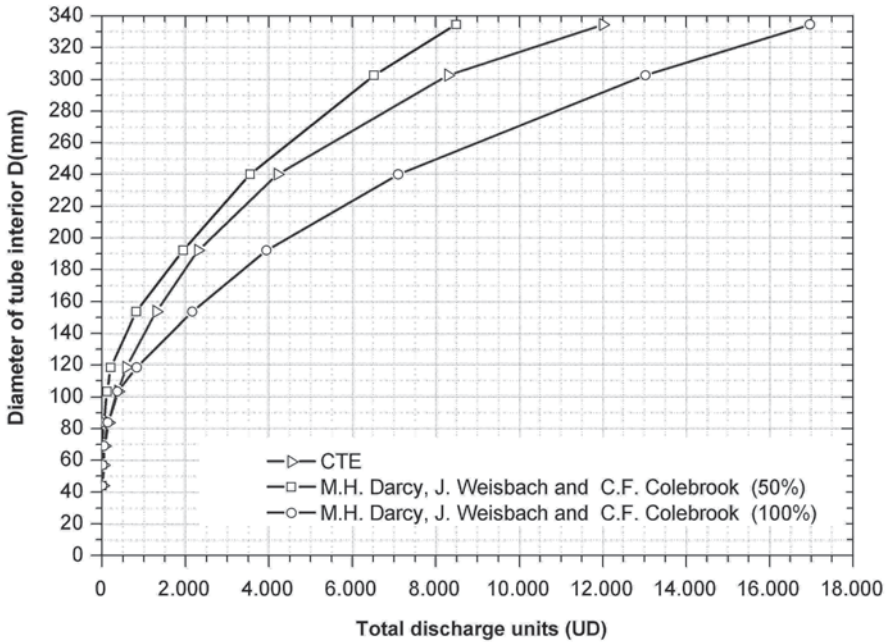


Fig. 14 Diameters of waste-water main sewers vs. total UD according to the CTE and fluid mechanics, for a 4% slope, K (UK includes WC usage) and PVC-U 1329

Bearing in mind that the commencement of a load application is not an acceptable solution as described in the art. HS-5 CTE 4.1.3, the conclusion that the simultaneity coefficient implicitly used by the CTE is much lower than used by the UK standard (including toilets) follows. For diameters greater than those indicated the relative flow height would fall between 50 and 100%.

Below is a comparison of the diameters given by the CTE with those given by the empirical equations proposed by Manning (Eq. 5) [4], for a gradient of 1, 2 and 4%, Fig. 15, 16 and 17, respectively, with the coefficients of simultaneity derived from the UK model (including toilets) for pipes made of PVC-U 1329, $n=0.009$ and relative flow heights of 50, 75 and 100%.

As shown in Fig. 15, 16 and 17 up to the diameter DN-160 ($p=1\%$), DN-125 ($p=2\%$) and DN-110 ($p=4\%$), the diameters given by the CTE are lower than the empirical curve for 100% of relative flow height, implying the commencement of load application. Furthermore, in most cases the CTE curve is similar to the empirical of 75% of maximum relative flow height. The same conclusions are obtained as in the case of analytical analysis which shows that the simultaneity coefficient implicitly used by the CTE is well below the standard used by the UK (including toilets). It is therefore recommended to size the main sewers to a maximum relative flow height of 50% of the diameter and flow velocity between 0.6 ms^{-1} y 2.6 ms^{-1} , the diameters given by CTE being thus considered as a regulatory minimum.

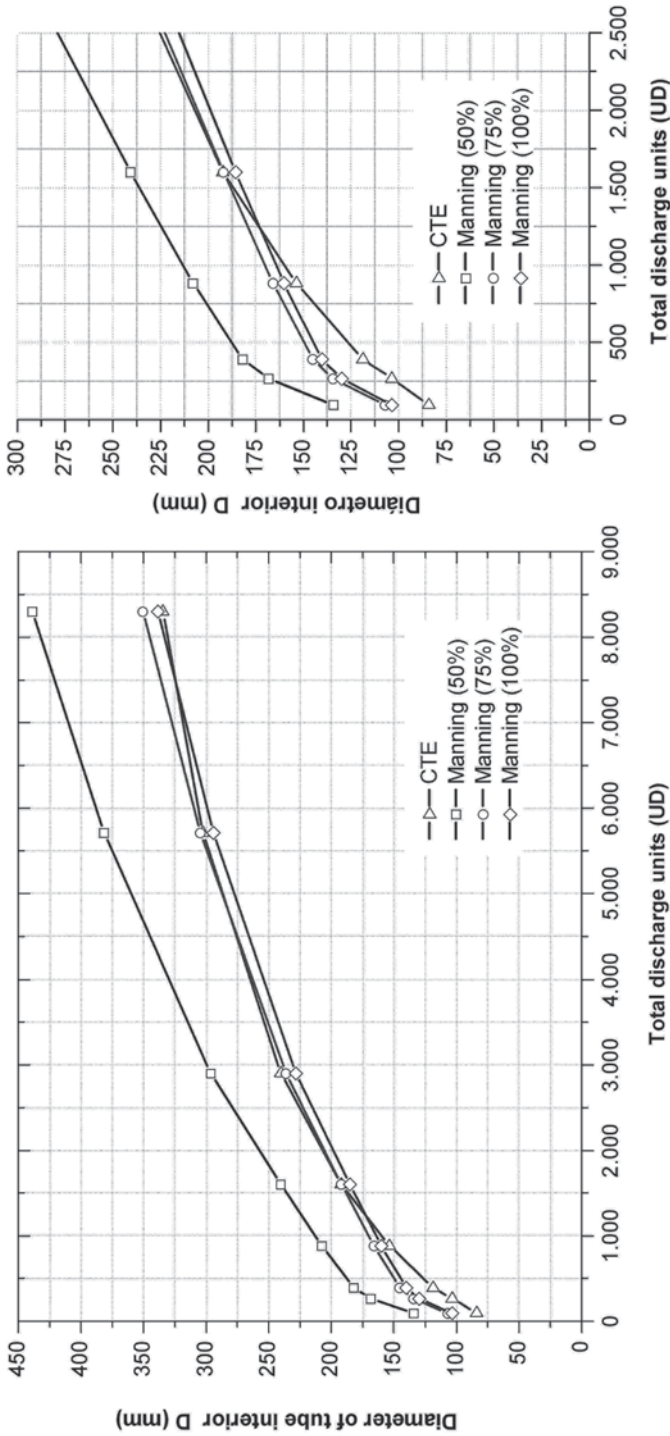


Fig. 15 Diameters of waste-water main sewers vs. total UD according to the CTE and the empirical method, for a 1% slope, K (UK includes WC usage) and PVC-U 1329

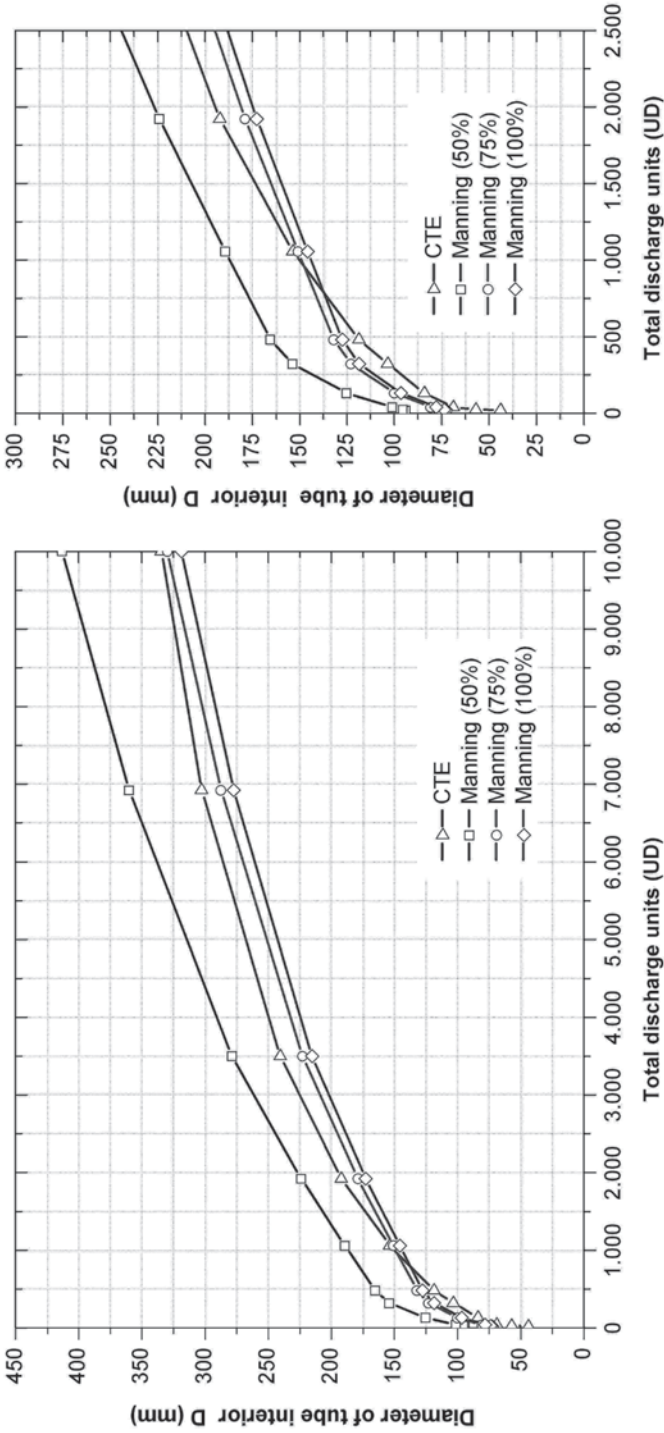


Fig. 16 Diameters of waste-water main sewers vs. total UD according to the CTE and the empirical method, for a 2% slope, K (UK includes WC usage) and PVC-U 1329

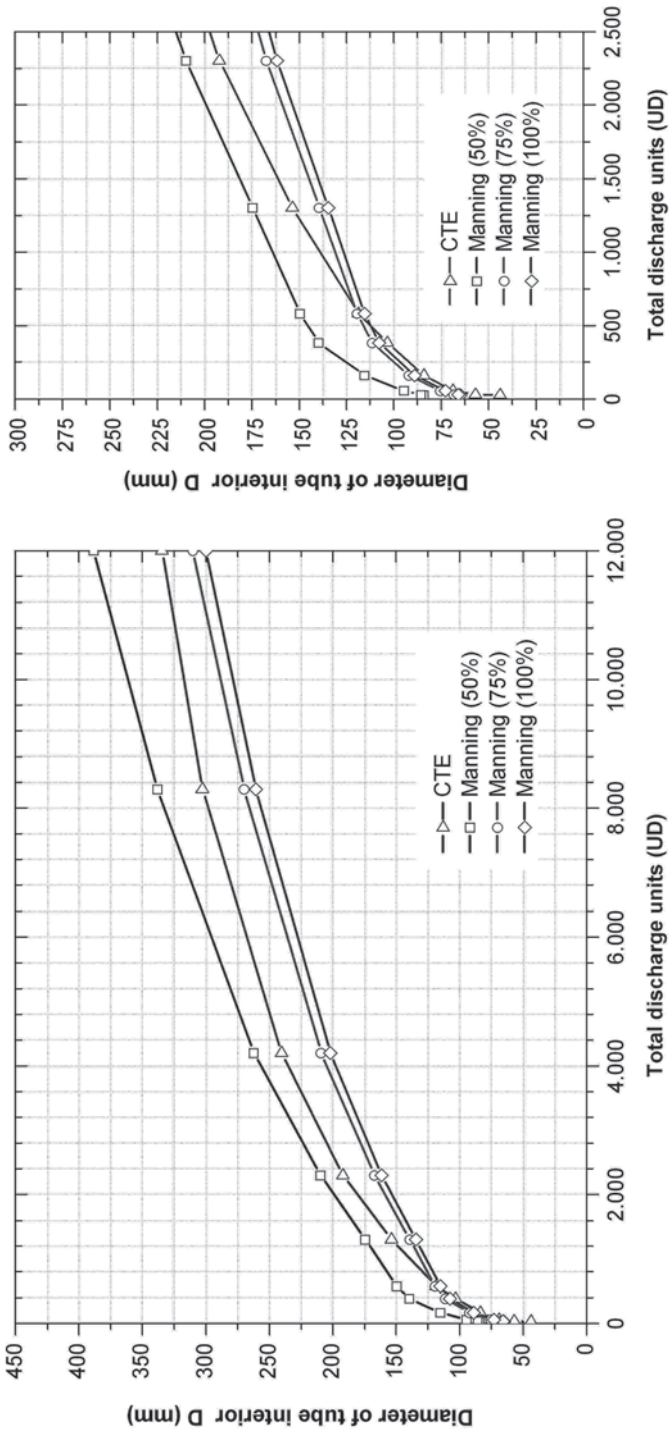


Fig. 17 Diameters of waste-water main sewers vs. total UD according to the CTE and the empirical method, for a 4% slope, K (UK includes WC usage) and PVC-U 1329

3 Results

The diameters given by the CTE are inferior to those obtained by the empirical and analytical equations, framing the results in the context of the boundary constraints imposed. In the downspouts proposed by the CTE values of “r” averaging at 0.39 equivalent to 118% of the recommended maximum. In the case of the rain-water downspouts CTE diameters are lower than those obtained by empirical methods (90%, $r=0.33$; 76%, $r=0.25$; 73%, $r=15/64$) and the analytical ones (83%, $w=16$), as well as in the CTE case for waste water “up to 3 floors” by empirical methods (93%, $r=0.33$; 78%, $r=0.25$) and analytical ones (85%, $w=16$) and with “more than 3 floors” by empirical methods (79%, $r=0.33$; 67%, $r=0.25$) and analytical ones (73%).

The diameters of the rain water drains given by the CTE show a high average relative flow height of 62% and velocities ranging between 0.93 and 4.20 ms^{-1} . Furthermore, in the case of wasted water the average relative flow height is 82% with speeds between 0.93 and 3.41 ms^{-1} . Notably diameters up to DN-160 ($p=1\%$), DN-125 ($p=2\%$) and DN-110 ($p=4\%$) begin to receive pressure loads, which shows that the simultaneity coefficient used implicitly by the CTE is lower than the model used by the United Kingdom (including toilets), as well as the AFNOR standard modified according to activity, which is an aspect to be considered as existing sanitary habits have changed.

The equations proposed through Fluid Mechanics allow for sizing to be undertaken, guaranteeing correct operation under more specific constraints than the CTE, such as the type of material, geometry, physio-chemical properties of the air and water at working temperature, thickness of the fluid layer and the pressure variation. The analysis of this article did not take into account the influence of air on the network by direct comparison with the CTE which would require further study [6].

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Innovative Modular Building Manufactured Using Structural Black Poplar Plywood Panels

M. Alia-Martínez, J. Fernandez-Ceniceros, J. Antonanzas, E. Fraile-García and R. Urraca

1 Introduction

Nowadays, plate's theory is one of the most relevant theories in Structural Engineering. It is able to model the structural behaviour of plates, which exhibit one of the most complex behaviour among the existing resistant elements.

Plates are flat structural elements, which may be approximated by a two-dimensional surface and normally work with bending forces. In elasticity terms, a plate is known as a sheet. Sheets are cylindrical bodies characterized by having a short height compared to its base. A sheet is considered thin when the relationship between thickness and one of the characteristic dimensions (x or y) of the base is much smaller than one. Contrary to plane strain state, loads are essentially normal to the median plane, which is defined by the points equidistant from both external surfaces of the plate. In this study, the median plane is assumed to be a continuous surface with only a smooth variation.

M. Alia-Martínez (✉) · J. Fernandez-Ceniceros · J. Antonanzas · E. Fraile-García · R. Urraca
EDMANS Group, ETSII, University of La Rioja, Logroño, Spain
e-mail: manuel-julian.aliam@unirioja.es

J. Fernandez-Ceniceros
e-mail: julio.fernandezc@unirioja.es

J. Antonanzas
e-mail: antonanzas.javier@gmail.com

E. Fraile-García
e-mail: esteban.fraile@unirioja.es

R. Urraca
e-mail: ruben.urraca@unirioja.es

The following assumptions are undertaken to implement plate's theory:

- Movements of the median plane of a surface plate are smaller than the thickness of the plate, so the vertical displacements of the points of the median plane do not depend on z direction.
- After flexural stress, every straight-line prior normal to the median surface will remain straight. This implies that median plane points will only suffer from vertical displacement.
- Normal stresses exhibit low values compared with other stresses. Hence, they can be neglected.

Spain and France are two important black-poplar wood producing countries [4]. In both countries, plywood panel is the most well known product derived from black-poplar wood. However, so far plywood panels have mostly been used with decorative purposes, such as boards for construction processes. The use of plywood panel in other fields such as construction still remains a challenge. This study will focus on testing the applicability of plywood panels as load-bearing walls for small constructions, which arises as a promising market for European companies [7]. Specially, Spanish and French enterprises can take advantage of this situation due to their black-poplar wood production capacity [4].

Previous work Alía et al. [1] showed several methods that can be used for obtaining plywood panel properties. The aim of this study is to implement sandwich plywood panels as structural element in order to test if plywood panel properties can be improved by combining it with other materials. This will be evaluated using the structural checks required to use these materials for small constructions applications.

Loads are calculated using Spanish CTE, taking into account that edification can be placed anywhere in Spain. Thus, the most unfavourable situation is considered. Besides, all different combinations of loads will be checked. Two checks must be performed. The first one verifies the last resistance of the board and the second one focuses on the visual aspect of the building, establishing maximum displacements for each resistive elements. Floor, wall and roof will be individually checked.

2 Methodology

2.1 Materials

Hybrid materials combine two or more compounds in order to develop new characteristics that individual materials don't have by themselves. Some examples of hybrid materials are fiber composites or sandwich materials. This study will focus on the last one. Both, the combination of different raw materials and the different fabrication methods, allows getting new materials with many diverse typologies.

A structural plywood panel is a sandwich material that combines two materials in a defined geometry. This geometry is configured using two plywood faces and a polystyrene core. Flexural rigidity increase and weight reduction are some advantages of this combination. Besides, with the introduction of a polystyrene core, the inertia moment of the section gets higher, improving the final flexion and buckling properties. A high performance in terms of thermal and acoustic isolation can be obtained with this hybrid material.

2.1.1 Elasticity Modulus

The resistant capacity of both materials in consonance is obtained using the Eq. 1 from Ashby [2].

$$\frac{1}{E_{f,0}} = \frac{1}{E_f \left[(1 - (1 - f)^3) + \frac{E_c}{E_f} (1 - f)^3 \right]} + \frac{B_1}{B_2} \left(\frac{d}{L} \right)^2 \frac{(1 - f)}{G_c} \tag{1}$$

Where T is the thickness of the faces, d is the normal thickness, c is the soul thickness, L is the panel length, E_f is the elasticity modulus of the faces, E_c is the elasticity modulus of the core, G_c is the shear modulus of the core, f can be obtained using $f = \frac{2t}{d}$ and B_1 and B_2 are coefficients that depend on the boundary conditions. In case of a fixed ended panel, $B_1 = 384$ and $B_2 = 8$. If all sides of the panel are simply supported, $B_1 = 384/5$ and $B_2 = 8$.

2.1.2 Flexural Strength

The flexural strength of the panel is computed with Eq. 2 from Ashby [2]:

$$\sigma_{flex} = (1 - (1 - f)^2) \sigma_f + (1 - f)^2 \sigma_c \tag{2}$$

Where σ_f is the strength of the faces and σ_c is the strength of the core.

2.1.3 Compressive Strength

The compressive strength is again obtained using an equation from Ashby [2] for hybrid materials (Eq. 3). The equation takes into account the volumetric friction of each individual material.

$$\sigma_{comp} = f_f \cdot \sigma_f + f_c \cdot \sigma_c \tag{3}$$

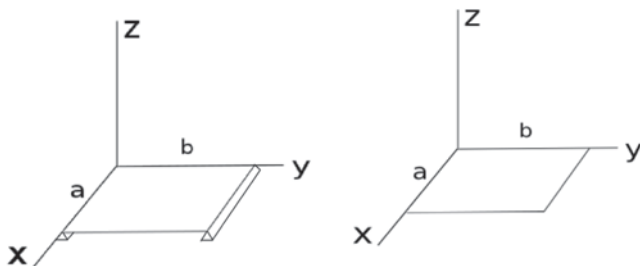


Fig. 1 Navier Solution (left) and Levy Solution (right)

2.2 Plate's Theory

2.2.1 Navier

Navier method solves plate's theory equations by using the double Fourier series [3]. Conditions required for the series coefficients are obtained from the differential equation of the plates. In this section, only rectangular plates under simply supported boundary conditions will be considered. The originally developed solution by Navier in 1820 will be studied (Fig. 1).

A four sides simply supported plate is assumed. These sides are defined by $x = 0$, $x = a$, $y = 0$ and $y = b$. Over the plate a transversal charge $q_z(x, y)$ appears. This charge will be named $p(x, y)$. The final equation to be solved is Eq. 4.

$$\nabla_w^4 = \frac{\partial^4 w}{\partial x^4} + 2 \cdot \frac{\partial^4 w}{\partial x^2 \cdot \partial y^2} + \frac{\partial^4 w}{\partial y^4} = \frac{p}{D} \quad (4)$$

Three boundary conditions must be satisfied:

1. $w=0$
2. $x=0$ and $x=a$ is $\frac{\partial^2 w}{\partial x^2} = 0$
3. $\frac{\partial^2 w}{\partial y^2} = 0$ in $y=0$ and $y=a$

The real plate is supposed as part of another fictitious plate four times greater and it is submitted to an odd charge: $p(x, y) = -p(-x, y) = -p(x, -y) = p(-x, -y)$. This conditions implies that movements can be also considered as an odd function, $w(x, y) = -w(-x, y) = -w(x, -y) = w(-x, -y)$. The period in the x direction is $T = 2 \cdot a$, and $T' = 2 \cdot b$ in the y direction. In order to solve the problem using

Fourier series, $w = \frac{\pi}{a}$, $w' = \frac{\pi}{b}$ is imposed and it is considered that the charge can be decomposed as shown in Eq. 5.

$$w(x, y) = \sum_{m=1}^{\infty} \sum_{n=1}^{\infty} c_{mn} \cdot \sin \frac{m \cdot \pi \cdot x}{a} \cdot \sin \frac{n \cdot \pi \cdot y}{b} \tag{5}$$

2.2.2 Levy

Initially, Levy method uses a two-sides simply supported plate $y = 0$ and $y = b$ [3]. Free displacement is imposed to the remaining boundaries. Charge is defined by Eq. 6.

$$p(x, y) = g(x) \cdot h(y) \tag{6}$$

Here $h(y)$ is derived using Fourier simply series to odd functions. A double plate is obtained by extending the plate along the y negative direction. This extended part is also named the fictitious part. In this fictitious part, a $p(x, -y) = -p(x, y)$ charge is applied.

$$h(y) = \sum_{m=1}^{\infty} b_m \cdot \sin \frac{m \cdot \pi \cdot y}{b} \tag{7}$$

2.3 Structural Checks

Two verifications are carried out for each element:

1. Element strain has to be lower than the ultimate strain resistance of the material.
2. Element displacement has to be lower than the maximum displacement allowed by the structural standard.

2.3.1 Ultimate Strain Check

Bearing Wall

Two different checks are carried out. The first one following CTE code (buckling effect is neglected). The second one using the criterion established by the Engineered Wood Association (including buckling effect). After stress computation, maximum moments are obtained using plate's theory (Eqs. 8 and 9)

$$\sigma_c = \frac{N}{A} \tag{8}$$

Where N is the compressive charge and A is the resistive area.

$$\sigma_f = m \cdot \frac{6}{t^2} \quad (9)$$

Where m is the maximum moment and t the thickness of the plate.

CTE

The equations supplied by the CTE are Eqs. 10 and 11.

$$\left(\frac{\sigma_c}{\sigma_{comp}} \right)^2 + \frac{\sigma_{f,0}}{\sigma_{flex,0}} + k_m \cdot \frac{\sigma_{f,0}}{\sigma_{flex,0}} \leq 1 \quad (10)$$

$$\left(\frac{\sigma_c}{\sigma_{comp}} \right)^2 + k_m \cdot \frac{\sigma_{f,0}}{\sigma_{flex,0}} + \frac{\sigma_{f,0}}{\sigma_{flex,0}} \leq 1 \quad (11)$$

Where σ_c is the maximum compressive stress generated, $\sigma_{f,0}$ is the maximum parallel flexural stress generated, $\sigma_{f,90}$ is the maximum normal flexural stress generated and k_m is a coefficient that takes into account the stress redistribution. For the present study, we assume k_m equals 1.

Engineered Wood Association

First, the maximum admissible charge must be obtained with Eq. 12.

$$P_{max} = \frac{3.619 \cdot E \cdot I}{144 \cdot L^2} \quad (12)$$

Where I is the inertia moment, L is the length of the panel and E is the elasticity modulus. Second, Eq. 13 has to be evaluated.

$$\frac{N}{P_{max}} + \frac{\sigma_{f,0}}{\sigma_{flex,0}} + k_m \cdot \frac{\sigma_{f,0}}{\sigma_{flex,0}} \leq 1 \quad (13)$$

Ceiling and Floor

Ceiling and floor plates are checked against flexural stresses. Moments and stresses are obtained from the equations of previous sections. All sides of roof panels are simply supported. This check is carried out using Eqs. 14 and 15 from the CTE.

$$\frac{\sigma_{f,0}}{\sigma_{flex,0}} + k_m \cdot \frac{\sigma_{f,0}}{\sigma_{flex,0}} \leq 1 \quad (14)$$

Table 1 Plywood panel properties

Property	Value (N/mm ²)
Parallel elasticity modulus: E_0	4320
Normal elasticity modulus: E_{90}	5542
Parallel strength: σ_0	19.14
Normal strength: σ_{90}	25.88

Table 2 Polystyrene properties

Property	Value (N/mm ²)
Elasticity modulus: E_p	12
Shear modulus: G_p	8
Strength: σ_p	0.5

$$k_m \cdot \frac{\sigma_{f,0}}{\sigma_{flex,0}} + \frac{\sigma_{f,0}}{\sigma_{flex,0}} \leq 1 \quad (15)$$

2.3.2 Maximum Displacement Check

First, the maximum permissible displacement is computed according to Eq. 16.

$$\delta_{max} = \frac{L}{300} = \frac{250}{300} = 0.83 \text{ cm} \quad (16)$$

Second, the maximum displacements in the structure are obtained using the plate's theory.

3 Results

3.1 Data of Raw Materials

The properties of the source materials are shown in Tables 1 and 2.

3.2 Sandwich Panel properties

Properties obtained for the sandwich panels applying the described methodology are shown in Table 3.

Table 3 Sandwich panel properties

Property	Simply supported sides N/mm ²	Fixed ended (N/mm ²)
Parallel elasticity modulus: E_0	1650	526
Normal elasticity modulus: E_{90}	613	613
Parallel flexural strength: $\sigma_{flex,0}$	13.29	13.29
Normal flexural strength: $\sigma_{flex,90}$	17.92	17.92
Compressive strength: σ_{comp}	7.3	7.3

Table 4 Structural results

	N (kN)	Pmax (kN)	σ_c $\left(\frac{N}{mm^2}\right)$	$\sigma_{f,0}$ $\left(\frac{N}{mm^2}\right)$	$\sigma_{f,90}$ $\left(\frac{N}{mm^2}\right)$	Charge max. displacement check	Result Ultimate strain check	Maximum displacement (cm)
Bearing wall (CTE)	–	–	3.48	0.6	0.85	3.97	0.32	0.6
Bearing wall (CTE)	0.29	3.97	–	0.6	0.85	–	0.17	–
Ceiling	–	–	–	0.6	0.19	2.17	0.11	0.19
Floor	–	–	–	1.25	1.77	3.52	0.19	0.81

3.3 Case Study

Structural verification results are depicted in Table 4. Ultimate strain check values for every structural part are lower than 1. All justifications meet safety standards. The critical scenario appears when flexural and compressive stresses act together. Besides, maximum displacements in the structure are lower than the ones specified by the standards. Nevertheless they are closer to the limit, especially in the floor case.

4 Conclusions

The previous study proves that plywood panel has the required properties to be implemented in small constructions. The proposed material has passed both, the Spanish CTE and the American Wood Association criteria, showing this composite opens up a wide range of possibilities for the development of new construction methods. Besides, related to the non-resistant face, the results show that plywood plates possess much less resistance if combined flexural and compressive stresses are applied in this face. Thus, it is crucial to correctly set the position of the panels

in the building to optimize their structural capacity. Finally, the distribution of wood fibers conforming the plate has to be carefully studied to obtain a symmetrical board and consequently increase the total flexural capacity.

To conclude, in this study only the combination of poplar plywood with polystyrene has been taken into account due to polystyrene isolation properties. However, future studies can be oriented on testing materials with other combinations that fulfill a special required structural property

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Part III
Environmental Engineering and Natural
Resource Management

Multicriteria Decision Making Methodologies Applied to the Selection of Best Available Techniques in the Ceramic Industry: Equalitarian vs Prioritised Weighting

V. Ibáñez-Forés, P. Aragonés-Beltrán and M. D. Bovea

1 Introduction

Traditionally it has been considered that technological development is a competitive advantage among companies, further promoting the economic growth and social benefit of countries [3, 4, 15].

Nowadays, one of the most common aims of the introduction of new technologies in industrial systems is the minimization of their negative effects on the environment [16]. This fact is being strengthened by the increasingly stringent environmental requirements imposed by European Commission through the continued implementation of environmental legislation (Directive 96/61/EC and Directive 2008/1/EC) [6, 7] (Integrated Pollution Prevention and Control–IPPC) and Directive 2010/75/EU [8] (Industrial Emissions Directive–IED)).

Specifically, in order to improve the sustainability of industries, the IED strengthens the application of Best Available Techniques (BAT). However, the numerous BAT that can be applied to the same sector make difficult to identify which is the optimal one for each industry. The BREF document (Reference Documents on Best Available Techniques) include all the BAT proposed by the European Commission which may apply to a particular industrial sector.

Over the last years, many studies were focused on the identification of the optimal technology options by using sustainability assessments and comparisons of

M. D. Bovea (✉) · V. Ibáñez-Forés
Departamento de Ingeniería Mecánica Y Construcción, Universitat Jaume I,
Av Sos Baynat s/n, 12071 Castellón, Spain
e-mail: bovea@uji.es

V. Ibáñez-Forés
e-mail: vibanez@uji.es

P. Aragonés-Beltrán
INGENIO (CSIC-UPV) Universitat Politècnica de València,
Camino de Vera s/n, C.P. 46022 Valencia, Spain
e-mail: aragones@dpi.upv.es

alternatives. Along this line, countless technology assessment methods have been created in order to support the decision-making processes [24].

On one hand, many authors considered that all sustainability indicators have the same relative importance and hence, they are equally weighted. Then, they directly compare the alternatives on the bases of their attributes, either numerically or graphically.

However, on the other hand, the technological choices are mostly multidimensional problems which have different demands, preferences or requirements in each one of its dimensions. Therefore, in order to identify the best option, it is needed to use multi-criteria methodologies which are based on the prioritization of the analysed indicators [5].

The most appropriate methodology to be applied in multi-criteria decision making varies almost exclusively with the characteristics of the problem [12]. As a consequence, choosing the best approach (equal weighting vs priority weighting) is a difficult decision.

The aim of this study is to analyse and compare both approaches by applying them to the identification of the most preferable BAT for the ceramic industry from an environmental, economic, technical and social perspective. To do so, two methodologies representing both approaches are applied to 13 alternative scenarios which were made up of different combinations of BAT. These combinations depend on the aim of each scenario: to improve energy efficiency, to mitigate particulate matter or acid gas emissions and to reduce noise. The selected multicriteria decision making methodologies are: an own methodology based on equal weighting of criteria and the Analytic Hierarchy Process (AHP), which is a widespread method based on priority weighting.

2 Configuration of Alternative Scenarios

Based on the standard process of manufacturing ceramic tiles in Spain (baseline scenario) 13 alternative scenarios are proposed, considering different combinations of BAT options and their optimum placement within the installation of the baseline scenario. Table 1 details the 9 BAT under study, which have been selected from the reference document for the ceramic industry [10].

The Fig. 1 shows the combination of BAT that constitute each alternative scenario. The details related to the scenarios configuration process, including all factors and physical parameters taken into account to optimize the combination of BAT, such as gas flow rates, operating temperatures or acid dew points, can be found at Ibáñez-Forés et al. [14].

Table 1 BAT options

Hot spot	BAT option	Type
Energy efficiency	1	1a Heat recovery from dirty flue gasses (Heat exchangers)
		1b Heat recovery from clean flue gasses (Heat exchangers)
Particulates (stack emissions)	2	2a Traditional bag filters with pressure-pulse regeneration
		2b High-temperature synthetic filter with pressure-pulse regeneration
	3 Electrostatic precipitator	
Particulates (diffuse emissions)	4	4a Full enclosure of bulk storage areas
		4b Dust valves with suction and bag filter in bulk storage areas
		4c Water spraying
Acid gases	5	5a Cascade-type packed-bed adsorber with CaCO ₃
		5b Cascade-type packed-bed adsorber with a combination of CaCO ₃ and Ca(OH) ₂
	6 Module adsorber with several honeycomb modules made of Ca(OH) ₂	
	7	7a Dry flue gas cleaning with Ca(OH) ₂
		7b Dry flue gas cleaning with NaHCO ₃
	8	8a Wet flue gas cleaning with Ca(OH) ₂ or CaCO ₃
8b Wet flue gas cleaning with Na(OH) ₂		
Noise	9	Enclosure of the noisiest units with noise-protection walls

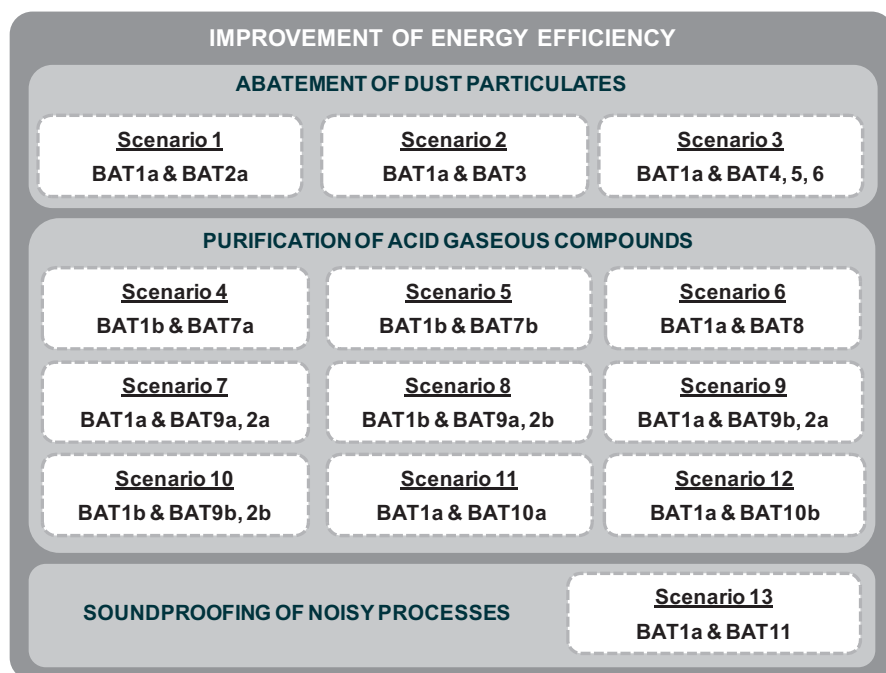


Fig. 1 Configuration of alternative scenarios

3 Sustainability Indicators

Table 2 describes the selected sustainability indicators which are grouped into environmental, economic, technical and social indicators. Moreover, Table 2 shows the scale and linearity of each indicator.

LCA software SimaPro v7.3.2 [23] and the Eco-Indicator 99 method [11] have been used to estimate the environmental indicator by modelling the inventory data.

Economic and technical indicators are based on secondary data, that is to say, data obtained directly from the literature, mainly from the reference document for the ceramic industry [10]. On the other hand, social indicators are obtained from primary data gathered by surveying different stakeholders related to the ceramic industry.

It should be noted, that the qualitative scoring method used for obtaining the qualitative indicators is based on scales shown in Table 3.

Furthermore, as there are two or more BAT in each scenario, the overall score of a scenario is calculated, for economic and technical indicators, as the average of the scores for all the BAT options that make up that scenario and, for social indicators, as the sum of the scores for the individual BAT options.

All information related to the calculation of the sustainability indicators, as well as the literature sources from which the relevant information were obtained, are detailed in Ibáñez-Forés et al. [14].

Below, Table 4 shows the sustainability indicators obtained for the alternative scenarios proposed (see Fig. 1).

4 Methodology Based on Equal Weighting of Criteria

The methodology applied to the identification of the most preferable scenario(s) based on equal weighting of criteria is divided in two stages: an initial screening which is carried out by comparing the scenarios on their economic performance and a graphical comparison of alternatives on all the sustainability indicators calculated.

4.1 Screening of Alternatives: Economic Viability Analysis

According to Schoenberger [21] the techniques that fulfil the requirements to be a BAT, but whose implementation is not economically feasible are called “*beyond BAT*” and they should only be applied to test scenarios aimed at developing them further to bring down their price.

Furthermore, according to the BAT costing methodology in the BREF on Economics and Cross-Media Effects [9], an investment is considered profitable when the pay-back period is equal to or shorter than 3 years, since it entails a quick recovery of investment and hence, it leads to a reduction in the risk of economic loss taken by the investor. Conversely, an investment is considered not profitable if the

Table 2 Description of the sustainability indicators selected

Indicators		Description	Unit	Linear
C1 Environment	C1.1 Eco-Indicator99	Eco-Indicator99 quantifies the overall environmental impact of a system by means of a single value that integrates the environmental impact for different impact categories	Points	Yes inverse
C2 Economic	C2.1 Investment Cost	Investment Cost (IC) is a quantitative measure which represents the initial payment needed to start up the equipment. Includes acquisition and installation costs and ancillary items such as insulation, connections, etc	€	Yes inverse
	C2.2 Total Annual Cost	The Total Annual Cost (TAC) incorporates the IC and operation and maintenance costs which include energy, materials and service expenses and fixed maintenance costs	€/year	Yes inverse
	C2.3 Net Annual Savings	Net Annual Savings (NAS) are calculated as the difference between TAC and the Avoided Costs (AC), which represent cost savings in raw materials, energy, labour, etc. owing to the implementation of BAT	€/year	Yes direct
C3 Technical	C3.1 Maintenance	Qualitative indicator that considers the requirements for maintenance, including the frequency and complexity involved as well as the related staff skills and training needed for the effective operation of the equipment	Qualitative	Yes inverse
	C3.2 Noise	Qualitative indicator that assesses the variations in noise level due to the application of BAT	Qualitative	Yes inverse
C4 Social	C4.1 Level of knowledge	Qualitative indicator that assesses the perception and predisposition of industry to adopt BAT through the knowledge that relevant experts have over them	Qualitative	Yes direct
	C4.2 Accessibility of BAT	Qualitative indicator that measures how reasonably accessible are the BAT and/or if they are applied relatively widely in industry	Qualitative	Yes direct

Table 3 Scores for different maintenance requirements, noise and level of knowledge/accessibility of BAT

Maintenance		Noise		Knowledge/accessibility	
Low	1	Reduction	-1	No application/no knowledge	1
Medium	2	Small or no change (<3 dBA)	0	Some application/some knowledge	2
High	3	Increase	1	Reasonable application/general knowledge	3
Very high	4			Wide-spread application/extensive knowledge	4

Table 4 Sustainability indicators

		Indicators								
		C1		C2			C3		C4	
		C1.1 (Pt)	C2.1 (€)	C2.2 (€/year)	C2.3 (€/year)	C3.1	C3.2	C4.1	C4.2	
		(qualitative)								
Alternative scenarios	1	0.066	406,000	318,000	142,000	3	1	3.542	2.681	
	2	0.067	3,150,000	620,000	-132,000	2	0	3.208	1.689	
	3	0.065	348,000	157,000	331,000	1	1	3.743	2.645	
	4	0.113	554,000	212,000	302,000	2	1	2.889	1.514	
	5	0.115	554,000	246,000	279,000	2	1	2.889	1.514	
	6	0.095	750,000	443,000	45,000	3	0	2.375	1.514	
	7	0.068	959,000	378,000	82,000	3	1	3.181	1.764	
	8	0.069	950,000	474,000	51,000	3	1	2.861	1.546	
	9	0.068	959,000	419,000	41,000	3	1	3.181	1.764	
	10	0.068	959,000	515,000	39,000	3	1	2.861	1.546	
	11	0.068	1,817,000	548,000	-60,000	4	0	2.778	1.569	
	12	0.069	1,817,000	553,000	-65,000	4	0	2.778	1.569	
	13	0.069	196,000	119,000	369,000	1	-1	3.639	2.778	

pay-back period is greater than the plant lifetime which, in this case, is assumed to be 15 years.

The pay-back period is defined as the period of time that the company needs to recover the initial Investment through the profits it generates and it can be calculated as the quotient between the initial Investment and the Net Annual Savings.

Therefore, to assess the profitability of each scenario in order to reject the non-profitable options, the pay-back periods are calculated for all scenarios and compared in the bar graph shown in Fig. 2. This graph includes two horizontal lines which represent the limit for the maximum profitability (green line) and for the economic unfeasibility (red line), respectively.

As it can be seen in Fig. 2, scenarios 1, 3, 4, 5, 7 and 13 are cost effective solutions since they have enough economic benefits to pay back the investment before ending their lifetime (15 years). At the other end, scenarios 6, 8, 9 and 10

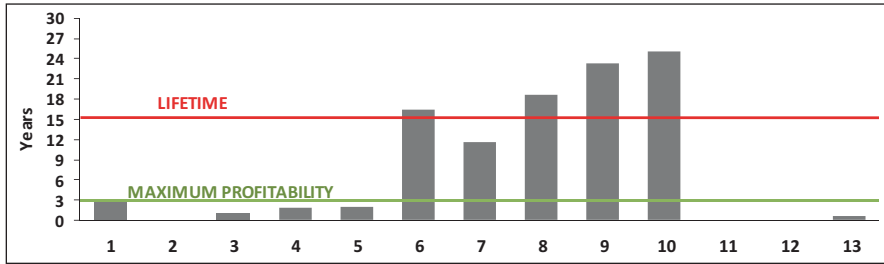


Fig. 2 Pay-back periods

have a pay-back period longer than their lifetime and hence they cannot be considered as economically feasible since the investment may be deemed irrecoverable. Therefore, those scenarios cannot pass to the next stage of the methodology and are screened out.

As shown in Table 4, scenarios 2, 11 and 12 have higher costs than the benefits of implementing them, therefore, they do not provide any Net Annual Savings for recovering the investment and consequently are also screened out from the analysis.

4.2 Comparison of Alternatives: Graphical Representation

Once the unprofitable scenarios have been rejected, the remaining options are compared for all the sustainability indicators considered. The different units in which the sustainability indicators are expressed (see Table 4) make it necessary to normalise them before comparing the alternatives, in order to ensure that all of them are in the same numeric order. To do so, the following approach has been adopted [2, 17, 20, 25]:

<p><i>If a lower value of indicator is better:</i></p> $z_{ij} = \frac{x_{ij} - x_{imin}}{x_{imax} - x_{imin}}$	<p><i>If a higher value of indicator is better:</i></p> $z_{ij} = \frac{x_{imax} - x_{ij}}{x_{imax} - x_{imin}}$
<p><i>Where:</i></p> <ul style="list-style-type: none"> $i = 1, 2, \dots, n$ – number of sustainability indicators $j = 1, 2, \dots, m$ – number of alternative scenarios z_{ij} – normalised value of ith indicator for the jth scenario x_{ij} – value of ith indicator for the jth scenario (no normalised) $x_{imin} = \min(x_{i1}, x_{i2}, \dots, x_{im})$ – minimum value of ith indicator for all scenarios $x_{imax} = \max(x_{i1}, x_{i2}, \dots, x_{im})$ – maximum value of ith indicator for all scenarios 	

In the following, the normalised values of the indicators for each scenario are plotted on a *spiderweb* graph, as it is shown in Fig. 3. These graphs represent the environmental, economic, technical and social behaviour of each alternative. As it is shown in these graphs, the scenario 13, followed by 4, 5 and 3, represent the most sustainable alternative since they have a better performance (smaller area) for all the considered indicators.

5 Analytic Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) methodology, which was developed by Thomas Saaty in the 1970s [19], is a widely used technique to solve decision making problems involving multiple criteria. The AHP is one of the most used methods in that field due to its capacity to simplify complex decisions [18].

First of all, the Decision Maker (DM), the agent which holds the responsibility for making the final decision, has to be selected. In this case, the DM is a team of three industrial engineers with extensive experience in the ceramic industry. Although these experts have a deep knowledge of BAT due to their long experience in preparing Integrated Environmental Authorizations for ceramic industry, prior to beginning the process of decision making, they were fully informed about all the characteristics of the BAT considered.

It should be noted that the identification of the preferred scenarios is based on criteria/indicators which are linear and independent of each other (see Table 2), as it is assumed that there is not any interaction or influence between each other for any given property. These criteria have been agreed and considered by the DM as suitable for identifying sustainable scenarios.

Figure 4 shows the hierarchy structure which represents the decision-making problem, by representing the relationship established between the different criteria taken into account.

As it is described in Table 2, some of the criteria under consideration are qualitative, such as maintenance, noise, level of knowledge and accessibility of BAT. To configure the assessment matrix of the scenarios, the DM has to assess the scenarios with regard to each criterion based on their own knowledge and experience.

To do so, the individual preferences of the experts regarding the alternative scenarios for each criterion are measured by pair-wise comparison on the basis of the Saaty 1–9 scale [19].

Later on, from the results obtained from the pair-wise comparison, the assessment matrix is configured according to the methodology described by Saaty [19] (red box in Table 5). The different nature of data included in the assessment matrix (qualitative and quantitative), makes it needed to normalise them in a distributive manner to allow data comparison. It should be noted that these data reflect the preferences of DM, so it means that preferences are proportional to the values assigned to the alternatives for each criterion.

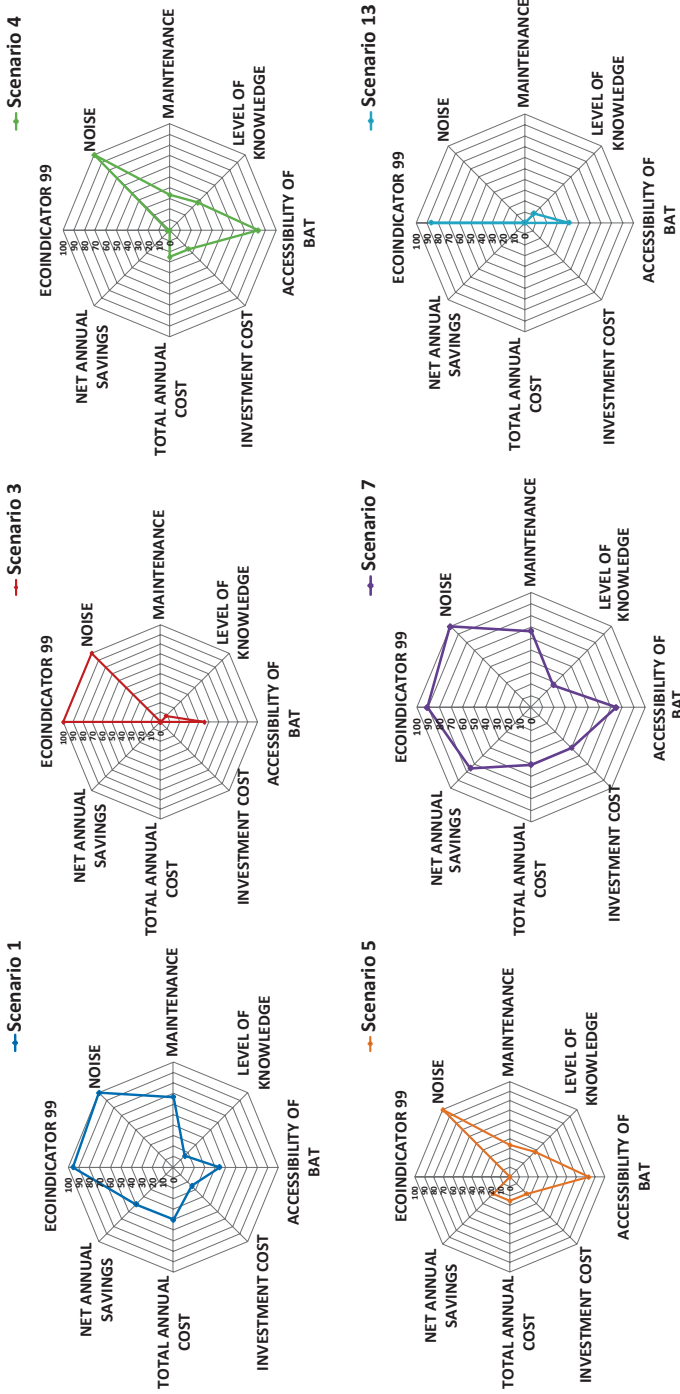


Fig. 3 Sustainability analysis (After normalisation, lower values are better for all indicators so that the smaller area bounded by the connecting lines on the diagram indicates a better scenario)

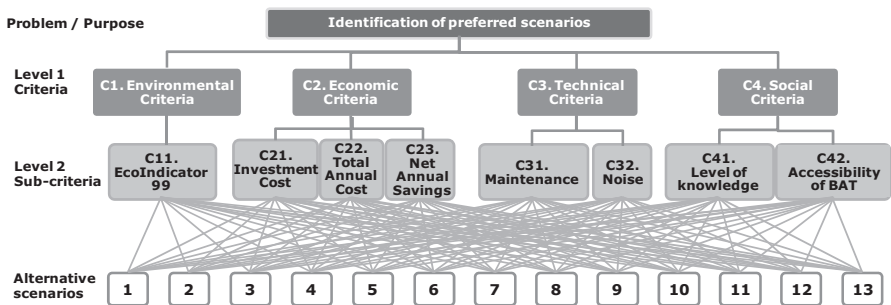


Fig. 4 Hierarchical decision model

Table 5 Final priority matrix of scenarios for decision making

		Criteria								Priority
		C1		C2			C3		C4	
		C11	C21	C22	C23	C31	C32	C41	C42	
Sub-criteria global priority		0.064	0.080	0.340	0.171	0.040	0.190	0.047	0.068	
Alternative scenarios	1	0.066	0.117	0.073	0.100	0.031	0.045	0.095	0.109	0.077
	2	0.067	0.015	0.037	-0.093	0.117	0.095	0.062	0.087	0.034
	3	0.065	0.137	0.147	0.232	0.031	0.203	0.098	0.115	0.157
	4	0.113	0.086	0.109	0.212	0.031	0.095	0.067	0.067	0.114
	5	0.115	0.086	0.094	0.196	0.031	0.095	0.067	0.067	0.107
	6	0.095	0.064	0.052	0.032	0.117	0.045	0.073	0.046	0.054
	7	0.068	0.050	0.061	0.058	0.031	0.045	0.077	0.082	0.058
	8	0.069	0.050	0.049	0.036	0.031	0.045	0.065	0.057	0.048
	9	0.068	0.050	0.055	0.029	0.031	0.045	0.077	0.082	0.051
	10	0.068	0.050	0.045	0.027	0.031	0.045	0.065	0.057	0.045
	11	0.068	0.026	0.042	-0.042	0.117	0.019	0.075	0.056	0.029
	12	0.069	0.026	0.042	-0.046	0.117	0.019	0.075	0.056	0.029
	13	0.069	0.243	0.194	0.259	0.287	0.203	0.105	0.119	0.197

Subsequently, according to Saaty [19], in order to weight the criteria, DM has to compare the relative importance of each criterion and sub-criterion on the basis of the Saaty scale. To do so, comparison matrices are filled by comparing pair-wise elements at each level of the hierarchy with respect to the upper-level element, based on the judgments of the DM. Therefore, according to Fig. 4, four matrices need to be filled: one for comparing the first level criteria (C1-environmental criteria, C2-economic criteria, C3-technical criteria and C4-social criteria) and three for comparing the sub-criteria within the same sub-criteria group (C21, C22 & C23; C31 & C32; and C41 & C42).

Since the DM is made up by a team of experts acting as a whole, the individual judgments were aggregated using the geometric mean [1, 13, 22].

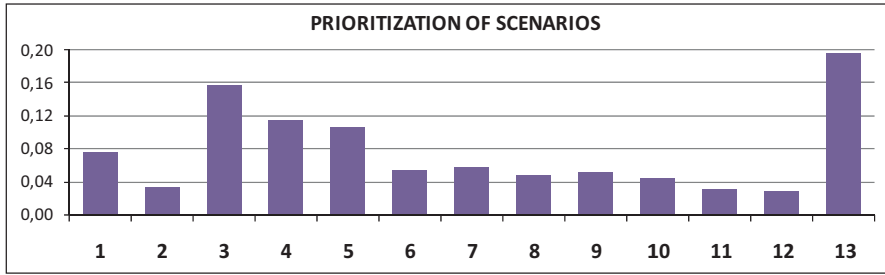


Fig. 5 Priority of scenarios based on the preferences of the decision maker

Note that the consistence ratio is $< 5\%$, so the pair-wise comparison matrices, both individually and once aggregated, are regarded as consistent enough.

The overall priorities for each sub-criterion are shown in Table 5, in the row called “sub-criteria global priority”.

Lastly, the final priorities of the scenarios have been calculated by aggregating the individual priorities in additive way (weighted sum). These priorities are included in the last column of Table 5 and form the global priority vector for the lowest level of the hierarchy (see Fig. 3).

To facilitate the interpretation of the scoring resulted from the preferences of the DM, the global priority vector is represented in a bar graph which is shown in Fig. 4.

As it can be seen in Fig. 5, the preferable scenarios are, in order of priority, the 13, 3, 4 and 5.

6 Discussion and Conclusions

Comparing the results obtained from the application of the two methodologies considered, it can be found that the results obtained are similar in both cases.

Note that with the method based on equal weighting of criteria, although the results may vary depending on the interpretation of the output or graphs obtained, this method helps to identify the behaviour of each alternative for each indicator individually considered.

The AHP method is a more systematic method which allows better traceability. Furthermore, an order of priority of the alternatives is obtained by applying AHP. So, if the preferred option may not be applied, it would be known which is the next best option. However, the results obtained depend on the DM and hence, they are not generally applicable since if the DM varies, the preferred options may vary as well. In addition, as a consequence of the participation of the DM, which is usually made of to a group of experts with extensive knowledge in the involved field, the AHP method is a more costly and time-consuming process.

Regarding the case study, based on the results obtained from the application of both methodologies, it has been found that the most sustainable scenarios for the Spanish ceramic tiles industry combine heat recovery from flue gas with the abatement of its dust particulates (scenario 3) or with the soundproofing of noisy processes (scenario 13). Furthermore, to reduce the acid gaseous compounds from emissions, the most recommended sustainable scenarios include heat recovery from flue gas and its clean-up with CaCO_3 and/or $\text{Ca}(\text{OH})_2$ (scenarios 4 and 5). These results are consistent, as have been obtained from the application of both multicriteria decision methodologies under study.

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LABWASTE.12: Calculation Tool for the Design of Solid Waste Landfills with Inert Waste Recovery

J. Esteban, F. J. Colomer, M. Carlos, and A. Gallardo

1 Introduction

Regional and national plans on waste usually refer to construction and demolition waste (C&DW). In fact, the Spanish Integrated National Plan on Waste (PNIR 2009) includes a National Plan for C&DW (2008–2015). There is also a law called Real Decreto 105/2008, dated 1st February, which regulates the production and management of C&DW. This law establishes the minimum requirements in order to accomplish the European Union guidelines on prevention, reutilization, recycling, and valorization. On the other hand, the Valencian Integrated Plan on Waste (PIR 2010) reports a deficit in the number of C&DW classification plants and, as a result, the regional government is going to build more of this sort of plants in the future, in addition to the seven that currently exist.

Nevertheless, a large part of the aggregates from C&DW have no commercial outlet and therefore have to be deposited in landfills, without being put to any good use. In addition, in recent years, this problem has been exacerbated by the economic situation in Spain. The decline in the construction activity has reduced further still the number of C&DW products that could be marketed. One possible application would be to use debris in landfill construction, since the structure of most existing national landfills includes aggregates extracted from mines. In

J. Esteban (✉) · F. J. Colomer · M. Carlos · A. Gallardo
Departamento Ingeniería Mecánica y Construcción, Universitat Jaume I,
Av. Vicent Sos Baynat s/n, 12071 Castellón de la Plana, Spain
e-mail: altabell@uji.es

F. J. Colomer
e-mail: fcolomer@uji.es

M. Carlos
e-mail: mcarlos@uji.es

A. Gallardo
e-mail: gallardo@uji.es

many cases thousands of tons of such material are used and could be replaced by equivalent amounts of aggregates from C&DW.

2 Rationale and Objectives

The main goal of this work is to determine the technical and economic viability of recycling inert waste from C&DW in the construction, operation, and closure of landfills. To this end, each activity and their relationships in the different phases of landfills have been analysed. Furthermore, economic viability depends on many factors, such as the price of aggregates and their shipping. This study proposes the creation of a tool that takes all these factors into account.

This tool is called LABWASTE.12, and it presents the construction, operation, and closure of landfills at a draft level, so that the user (construction company, public administration, etc.) knows the amounts of materials (aggregates and others) needed in the construction and exploitation phase. Initially, the tool is limited to the Spanish territory but in the future its applications could be extended to include other regions in different countries around the world.

3 Methodology and Results

The calculation tool LABWASTE.12 was developed using the software application Excel®, and it was designed in 12 “chapters”. These, in turn, were split into different items that define the mathematical relationship between different variables and unify the information by themes. The results obtained by means of this relationship will allow a draft and a budget of a landfill project to be presented. The tool provides some data, but the user can also define his or her own information. The methodology that makes up each chapter will now be detailed in the following items.

3.1 General Data

In this chapter, a general database is established and will be used automatically in the different chapters depending on calculation necessities. The main goal of the tool is to determine whether the use of aggregates from recycled C&DW can be suitable or not. To do so, it is essential to know the location of the landfill and the C&DW classification plant. The tool then calculates the cost of transporting aggregates from the C&DW recycling plant or quarry and advises on the cheapest option. Consequently, in this chapter the user has to insert general data (Table 1).

Table 1 General data about the landfill required by the tool in Chapter 1. These data can be obtained from a website (plot identifier of the Spanish Ministry of Agriculture, Food and Environment. (<http://sigpac.mapa.es/feqa/visor/>))

Data required	Options
Region	The user has to define the region
Type of landfill (according to physical geography)	Area, trench or head of gully
Type of landfill (according to deposited waste)	Inert waste (IW), industrial non-hazardous waste (NHW), municipal waste (MSW), refuse from composting plants (RCPW)
Affected population (inhabitants)	Data supplied by the user
Daily generation rate of waste	The tool supplies a figure by means of statistical data, but the user can select his or her own figure
Density of waste in the landfill	200–1100 kg/m ³ . User can select another amount
Perimeter of the landfill surface	Figure supplied by the user*
Area available for the landfill	Figure supplied by the user*

*These data can be obtained from a website (plot identifier of the Spanish Ministry of Agriculture, Food and Environment: sigpac.mapa.es/feqa/visor/)

Table 2 Climate data

Data required	Data provided	Units
Period of data collection	By the user	years
Average annual maximum rainfall in 24 h	By the user	L/m ²
Standard deviation of maximum rainfall in 24 h	By the user	–
Monthly average rainfall (P)	By the user	L/m ²
Monthly real evapotranspiration (ETPr)	By the user	L/m ²
Monthly average temperature	By the user	°C
Reserve variation = (P–ETPr)	LABWASTE.12	L/m ²

Furthermore, the following data are also required by the tool:

- Composition and moisture content of waste: From statistical data, the tool shows a figure for MSW landfills, such as at a regional or national level, or the user can choose the value. These data classify the different fractions (%) of MSW into biowaste, paper/cardboard, plastic, glass, metals and others, and the tool also provides a value for their average moisture content. The above-mentioned data were extracted from the PNIR (2009), PIR (2010), Gallardo et al. [9, 10]. From these data, the tool calculates the volume of leachate generated by the landfill.
- Climate data: The user must introduce into the tool the information required to dimension the stormwater dam, the perimeter channel, the internal gutter, the leachate dam, etc. (Table 2).
- Data from C&DW classification plant: The user must enter the necessary information about the types, characteristics, and costs of aggregates that are processed

Table 3 Properties and characteristics of the C&DW classification plant

Data required	Options
Region	User must select the region
Name of the C&DW classification plant	By the user
Distance from C&DW classification plant to landfill (km)	By the user
Types of aggregates manufactured by C&DW classification plant	Recycled concrete, recycled ceramics or a mixture
Characteristics of the sand from C&DW classification plant	Grain size (mm), density (t/m ³) and cost (€/t)
Characteristics of the graded material from C&DW classification plant	Grain size (mm), density (t/m ³) and cost (€/t)
Characteristics of the gravel from C&DW classification plant	Grain size (mm), density (t/m ³) and cost (€/t)

Table 4 Characteristics of the transport of aggregates

Data required	Options
Types of transport used for the transportation of aggregates	By the user
Capacity of the vehicle (m ³)	By the user
Estimated cost of transport (€/km)	By the user

in the C&DW classification plant. These data will allow the user to calculate the economic viability of using aggregates from C&DW with respect to materials from a quarry. The tool requires the following data (Table 3).

- Quarry aggregates data: The user must introduce information about the types of aggregates, their characteristics, and the cost of the quarry aggregates. The variables analysed are the same as those in Table 3.
- Transport general data: The user must indicate the type of transport used to cover the distance between the plant and the landfill (Table 4).
- General data about the types of aggregates used: The user must introduce information about the types of aggregates and grain sizes to be used (Table 5).

3.2 Landfill Vessel Area to be Filled

This chapter gathers information about the characteristics of the area to be filled. Some data from the previous chapters such as the type of landfill, the perimeter of the area, etc. are used in this chapter, but other data are also required to complete the design of the area to be filled with waste.

- General data about the area to be filled: In addition to the data provided in the preceding chapters, this chapter also requires other data (Table 6). In many types

Table 5 Application of aggregates in the landfill

Activities	Type of aggregate required	Options
Construction of the drainage layer	Gravel	Origin of the aggregates (C&DW classification plant/quarry), grain size (mm)
Construction of the drainage layer	Graded	
Construction of the cells/covering layer	Sand/graded	
Construction of storm drainage collection system	Graded/gravel	
Construction of the leachate collection system	Gravel	
Construction of the leachate pond drainage system	Gravel	
Construction of the biogas collection system	Gravel	
Drainage and closure layers of the landfill	Gravel	

Table 6 Additional data needed to design the draft of the area to be filled

Data required	Target
Year the area is expected to start being filled with waste	Calculating the lifetime of the landfill and programming activities
Estimated area available to be filled	Knowing roughly the area to be waterproofed, and the structure of the unit cells
Estimated average depth of the area to be filled	Calculating the size of the biogas collection pipes and the definition of the structure of all the unit cells
Permeability coefficient (k) of the natural geological barrier	Whether or not to install an artificial waterproof layer, geomembrane, geotextile and/or geonet
Estimated depth of the natural geological barrier	
Thickness of the leachate drainage collection layer	Calculating the amount of gravel required

of landfills waterproofing the area to be filled is compulsory. LABWASTE.12 considers this requirement, as shown in Fig. 1

From Table 6, on one hand, the tool supplies the estimated area to be waterproofed, the capacity of the area to be filled, and the lifetime of the landfill. On the other hand, it also provides information about whether or not it is necessary to install an impermeable layer in order to meet current regulations (Royal Decree 1481/2001). The drainage layer (Fig. 1) is compulsory in all cases. The tool automatically calculates, according to their densities, the amount of aggregate required to build this layer, both in terms of volume and by weight. Prices and amounts are related, and the economic cost of constructing the area to be filled is also calculated using box prices or an actualized database

Fig. 1 Layers in the bottom of the landfill according to LABWASTE. 12

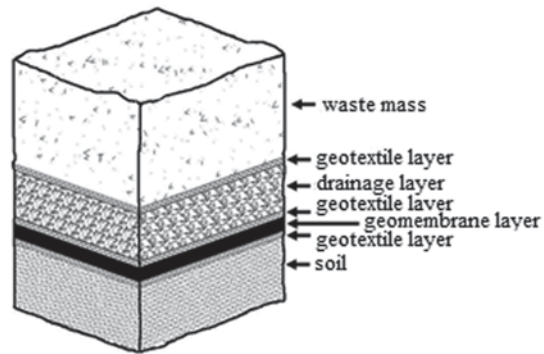


Table 7 Necessary data required by LABWASTE.12 to design the dams

Data required	Target
Section of the dam	The tool applies by default a scalene trapezoid. From these data the final geometry of the dam, the aggregate needed (compacted graded aggregates), and the cost are calculated
Crest width of the dam	
Height of the dam	
Inclination of the upstream slope	
Inclination of the downstream slope	
Length of the dam	

3.3 Dams

This chapter defines the information about the characteristics of the retention dams, as well as the landfill leachate and stormwater ponds waste.

- General data of the toe dam: The user must introduce the information about the general characteristics of the toe dam, that is to say, the dam holding all the slope of the landfill. This item collects data entered in previous chapters, such as the type of landfill, the estimated perimeter of the area, the estimated area available, etc., and requests additional data from the user (Table 7).
- General data about the stormwater pond dam: The user must introduce the information about the general characteristics of the stormwater pond dam. To do so, the tool requires the same data as in the previous item (Table 7), and furthermore the user must decide whether these data are necessary or not, according to the topography of the zone.
- General data about the leachate pond dams: The user must introduce the characteristics of the leachate pond dam. In order to do so, the tool requires the same data as in the previous items (Table 7), and furthermore the user has to indicate whether the dam is necessary or not, according to the topography.
- Data of slope stability: The software application “Estabilidad de taludes” (made by Professor B. Rechea [19] from the Polytechnic University of Valencia, Spain) calculates the slope stability by means of its safety factor (SF). Nevertheless, in

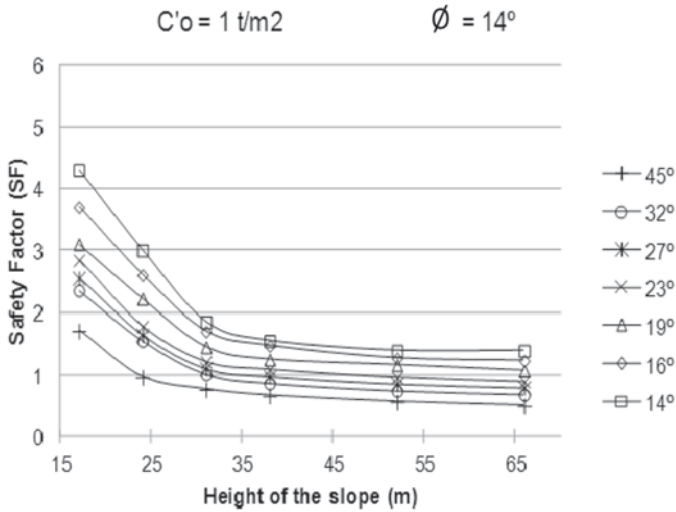


Fig. 2 Nomogram made from the soil mechanics formulas and geotechnical properties of the waste [5]

order to design the nomogram represented in Fig. 2, soil mechanics methods and formulas were applied [1, 13, 21]. The tool calculates the SF value according to the following values: effective cohesion of the material ($C'o$) equal to 1 t/m² and friction angle (ϕ') equal to 14°. These values are very low but they ensure the stability of the slope. Hence, the tool, in accordance with Fig. 2, automatically calculates the SF, which has to be bigger than 1.4 to ensure a safe slope from the geotechnical point of view [2, 15, 23]

From the previous chapters and data, if the user accepts the value of the SF that is supplied, the tool automatically indicates the amount of aggregate needed for each dam together with their cost.

3.4 Unitary Cells

This chapter contains all the information related to the characteristics of the unitary cells [6]. A cell includes the solid waste deposited in it and the cover material (15–30 cm thickness).

- General data about the unitary cells: Besides the data offered in previous chapters, the tool also asks the user about the data shown in Table 8.

With the data from Table 8 and those indicated in previous chapters, LABWASTE.12 automatically provides the area needed to place the waste, the daily, monthly, annual, and total volume/mass of aggregate needed in the cover layers and their cost.

3.5 Stormwater Devices

This chapter contains the data related to the stormwater collection and evacuation structures in landfills [6, 25].

- General data about the stormwater collection perimeter ditch: This ditch collects the landfill upstream stormwater runoff and its main function is to prevent this stormwater runoff from seeping into the landfill body. First of all, the tool asks if this ditch is necessary or not, which depends on the type of topography of the landfill. If the answer is affirmative, the tool collects data from previous chapters, such as maximum precipitations and other data like those shown in Table 9.

Using the Gumbel method, LABWASTE.12 provides information about the maximum flow in the ditch in the estimated return period. With these data and those in Table 9 and using the Manning equation, the tool offers the ditch size and the amount of concrete needed to build it. Knowing that the maximum percentage of the amount of recycled aggregate is 25%, the tool additionally calculates the amount of recycled aggregate that could be used in the ditch construction

- General data about the stormwater collection internal ditch: This ditch collects the stormwater runoff that comes from inside the landfill body and carries it to a collection pond. The way to calculate and design this ditch is the same as the one used previously, but in this case the stormwater collection area is the plot of land where the landfill is placed. Therefore, this ditch will generally be smaller than the perimeter ditch.

Table 8 Data required for the predesign and budget of the unitary cells

Data required	Data provided
Cell average height	By the user
Cover layer average thickness	15–30 cm
Type of aggregate and size	Graded/sand

Table 9 Data needed to size the perimeter stormwater evacuation ditch

Data required	Data provided
Estimated return period	50, 100, 500 years
Basin collection area	By the user
Perimeter ditch geometry	Trapezoidal
Slope inclination in relation to the vertical	30° or by the user
Walls: type of material	Concrete
Manning roughness coefficient	0.013–0.017
Maximum slope of the water line	0.5–2%
Ditch length	By the user (m)
Ditch slope thickness	0.1–0.3 m or by the user

Table 10 Data needed to size the perimeter stormwater evacuation ditch

Data required	Data provided
Number of stormwater ponds foreseen	1, 2 or by the user
Estimated maximum water volume (m ³)	By the user
Pond geometry	Square/rectangular/circular
Pond depth	1–5 m or by the user
Upstream slope inclination	45° or by the user

- General data about the stormwater collection pond: To determine the dimensions of this pond it is necessary to know beforehand the volume to be stored. As this value has already been calculated, the tool introduces it in this chapter, taking into account that the final result will be defined by the number of ponds selected by the user. The tool requires the data shown in Table 10.

With these data and using trigonometric and mathematical equations, the tool provides the slope geometry, the pond capacity, and the amount of geomembrane, geotextile and geonet (in m²) needed to design a permeable whole as well as the aggregate required to build it (graded to build the dam) and its cost.

3.6 Leachate

This chapter contains all the data related to the leachate evacuation and collection structures.

- General data about leachate collection: This chapter collects some previous data (waste compaction, evapotranspiration, waste moisture content, rainfall, etc.) and asks the user about the need to build a leachate pond. If the answer is affirmative, the user must decide the pond geometry and the period of time between one discharge of the leachate and the next. With these data, the tool uses the Swiss method [14] and shows the leachate flow value generated in the landfill (L/day).
- Leachate evacuation system data: The tool includes this group to know the characteristics of the pipes and the aggregate needed to build the leachate evacuation system. Table 11 shows the information that is needed. The calculations were taken from the works by Carey et al. [3] and Guyer [11].

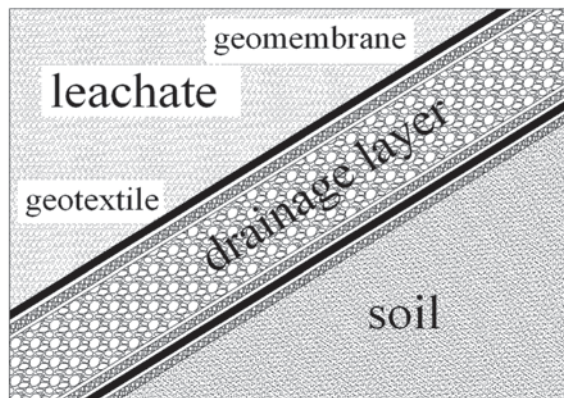
With the previous data, LABWASTE.12 provides the cross-section of the ditch, the total length of the pipe in meters, the amount of aggregate needed, and the cost.

- General data about the leachate pond: The way this pond is calculated is similar to the one used to calculate the stormwater collection pond, but in the case of the leachate pond, the pond needs a drainage system to detect leaks (Fig. 3). The tool

Table 11 Data for designing and calculating the leachate evacuation system

Data required	Data provided
Distance between pipes	10–100 m
Average diameter of the leachate evacuation pipes (mm)	200 or by the user
Leachate evacuation ditch depth (m)	0.5 or by the user
Leachate evacuation ditch width (m)	1 or by the user

Fig. 3 Layers needed for the leachate pond vessel



provides the pond dimensions, the pond capacity, the amount of aggregate, and the number of layers needed, as well as the cost.

3.7 Biogas

This chapter contains all the data about the biogas collection systems in the landfill.

- General data about biogas collection wells: This chapter needs previous data and requires the information shown in Table 12.

With these data, the tool provides information about the number of wells and extraction pipes, the aggregate requirements, and the cost.

- General data about the biogas collection pipes: Once the estimated area available for the vessel is known, the tool automatically shows the ratio between the linear meters of the pipe, and the vessel area in square meters. This information was obtained from several real landfill projects. A statistically significant correlation was established between the dimensions of the landfill and the ratio (pipe length/landfill area), which allows the tool to calculate the amount of piping in linear meters and the cost in the corresponding group.
- Estimation of the biogas collection data: This chapter provides an estimation of the generation and possible collection of biogas. To determine the production

Table 12 Data needed to design the biogas collection and evacuation systems

Data required	Data provided
External collection pipe diameter (m)	0.80 or by the user
Internal collection pipe diameter (m)	0.25 or by the user
Radius of influence of the well (m)	20, 25, 30 or by the user

of biogas of the landfill, some previous factors allowing calculation of biogas valorization cost-effectiveness must be analysed. Therefore, the tool is based on the EPA handbook “Handbook Landfill Gas to Energy Project” [16], which fixes the minimum values that must be reached to consider the valorization of landfill biogas cost-effective.

Other works were based on the first-order model [7, 8, 18], the Afvalzorg multi-phase model, the French EPER model [20], the SWANA Zero-order model, SWANA simple first model [24], the LandGEM US EPA model, the Biogas Mexican model, and the Scholl Canyon model [20].

Estimation of biogas production is based on the SWANA zero-order model (Solid Waste Association of North America), as it provides similar biogas capture results to those measured in known landfills and because it is easy to apply. In this chapter, the tool automatically shows the value provided by this method to calculate the methane generation power. The user must select the year operations are due to start in order to estimate the biogas production and, by means of a mathematical equation that contains previous variables; the tool plots the biogas generation graph and the feasibility of its valorization.

3.8 Landfill Fence

Mandatory installation of a landfill perimeter fence is contemplated in the regulations of several countries [4]. This chapter contains all the data referring to landfill and pond fences. The user must introduce the landfill perimeter as well as the perimeters of the ponds. The user must also decide on the type of fence, taking into account that current regulations establish a minimum height of 1.80 m. The tool provides the total length of the fence in meters, the cost per unit (landfill, stormwater ponds, leachate ponds), and the total cost.

3.9 Closure, Sealing and Integration

The main objective of closure is to create a physical separation between waste and the atmosphere, in order to control environmental impacts. This step includes the final covering of the vessel with or without a impermeability layer. The permeability of the final cover layer will prevent diffuse emissions of biogas (Directive

31/1999) [12, 17, 22] . Additionally, the regulations emphasize the importance of environmental and visual integration, which means that the vessel zone should be integrated within the landscape and the surroundings. For this reason is important to project the landfill post-closure uses. In each case the native vegetation should be replaced following closure, and this will depend on the geographic location. For some types of landfills, the EU requires closure as shown in Fig. 4.

The tool requests the thicknesses of the different layers (Table 13)

From the data shown in the table above the tool provides information about the amounts of materials needed for the cover layer and their cost

4 Conclusions

LABWASTE.12 is a tool capable of providing useful information thanks to some input data and the use of mathematical equations. The main information provided by the tool is:

- A final report with all the input data and the data calculated by the tool. This report summarizes all the data chapters and the final solutions.
- A final budget in each chapter and the total budget from several price databases. Any other price can be introduced

Fig. 4 Graphic representation of the closure, sealing, and reintegration of a non-hazardous waste landfill in compliance with EU regulations

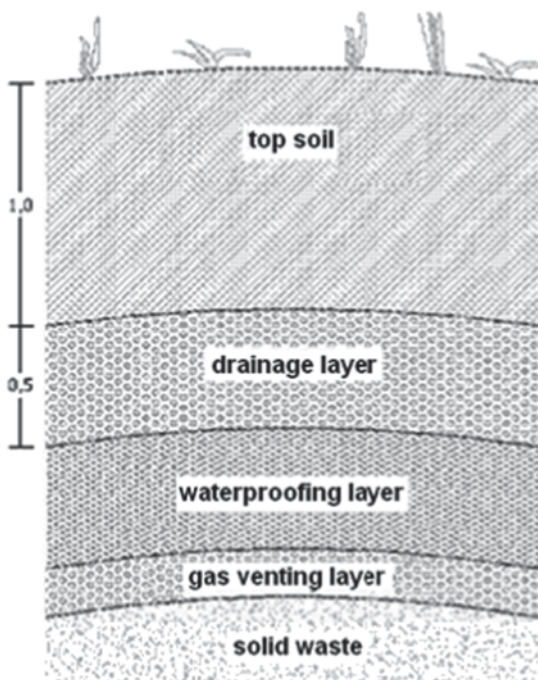


Table 13 Data required by the tool to design the cover layer

Data required	Data provided
Estimated area available for the cover layer (m ²)	By the user
Gas drainage layer thickness (m)	0.30 or by the user
Stormwater drainage layer thickness (m)	0.30 or by the user
Topsoil cover thickness (m)	0.70 or by the user
The topsoil extracted from the vessel is used to create the topsoil cover	Yes/no
Type of aggregate used (size)	Sand/graded/gravel
Geomembrane/geotextile	Yes/no

- An economic viability analysis to allow the user to decide whether it is more cost-effective to use recycled aggregate or quarry aggregate for each chapter and activity

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Synergy as Strategy for the Energetic Valorisation of Waste Focused in Transport

J V Álvarez, R. Luiña, F. Ortega and P. Lobo

1 Introduction

Economic growth based on increasing resource consumption is clearly showing as unsustainable. Thus, in order to encourage sustainable development, it is necessary to optimize energy consumption and resources. It could be considered that different industries when consume and exchange resources are as constituents of an industrial ecosystem, where any waste stream could be considered a resource, in the same way it runs in a natural ecosystem.

The principle underlying By-Product Synergy is that one industry's waste stream can be used by another as a primary resource. It is a simple idea, but one which has enormous potential for reducing waste volumes and toxic emissions to air and water, as well as cutting operating costs [17].

However, to evolve towards a new way of understanding production is a considerable challenge. The traditional industrial linear system begins with the extraction of resources which are then processed until they reach the final consumer, to afterwards become waste and be landfilled.

It is necessary to move from this traditional linear system towards a close loop system, in which environmental issues are taken into consideration and which mimics the natural ecosystems, where a system is defined by a set of internal and external interactions with the surrounding environment.

J. V. Álvarez (✉) · R. Luiña · F. Ortega · P. Lobo
Universidad de Oviedo, Oviedo, Spain
e-mail: valer@api.uniovi.es

R. Luiña
e-mail: rocio.luina@api.uniovi.es

F. Ortega
e-mail: fran@api.uniovi.es

P. Lobo
e-mail: paulalobo@api.uniovi.es

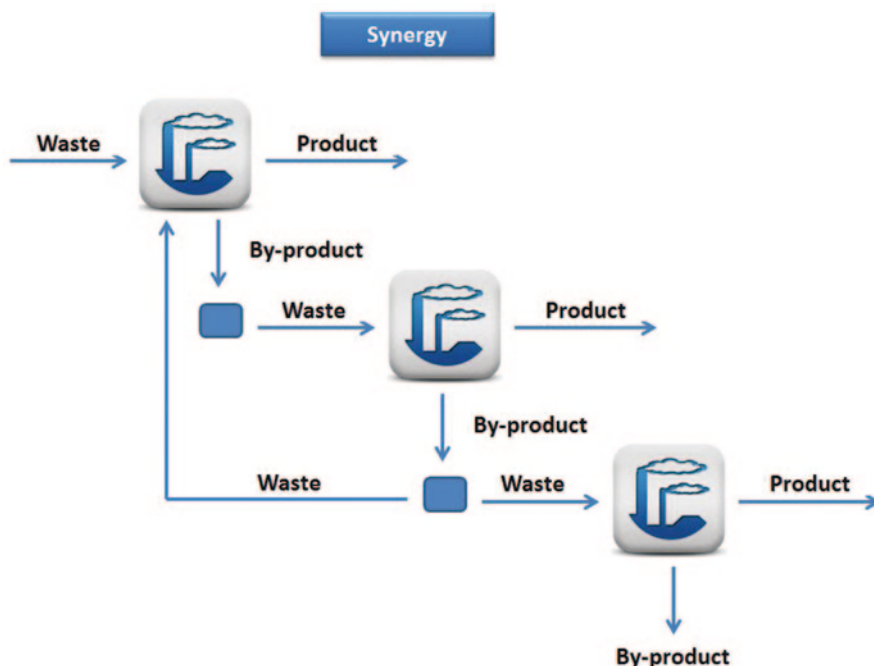


Fig. 1 Scheme of “by-product synergy” philosophy [10]

The aim is to make industrial activities work as ecosystems in order to minimize the environmental impacts, improve the recycling and re-use of materials among industries which have a potential for generating and consuming by-products and to encourage waste trading of all kind of wastes (Fig. 1; [15]).

By-product synergy is the principle which underpins the concept of ‘industrial ecology’—a holistic view of industry in which organizations exchange energy and materials between one another, rather than operating as isolated units. Industrial ecology promotes a shift away from traditional open, linear systems towards closed loops and inter-dependent relationships.

In the report “Industrial Ecology: Some Directions for Research” [23] Industrial Ecology or Ecosystem Ecology is defined as a system in which energy and material consumption is optimized, industrial waste water is minimized and the re-using of by-products as primary resources for other processes is encouraged.

In order to facilitate an exchange of materials and resources, businesses need to work together to determine what unwanted by-products exist, and what their potential applications are. These resources can then be exchanged, sold, or passed free of charge between businesses, thus creating a by-product synergy.

That is the case of the approach taken by a Canadian cement manufacturing plant, which managed to recycle its high CO₂ emissions from production processes into algaculture, which provide a renewable energy source such as biodiesel. Furthermore, this biodiesel could be used to supply part of the strong energetic demand used for manufacturing cement [8].

To date, the best known example of industrial ecology is the Danish industrial town of Kalundborg. However, a recent study by the Environmental Protection Agency (EPA) suggests that there still is a substantial potential for exploiting by-product synergies among co-located industries.

To achieve the Industrial Ecology ideal, it is necessary to decrease the negative environmental impacts, encourage the use of materials for re-use or recycling and improve the technological processes of transformation to increase efficiency in the use of primary resources. It is at this stage where ecodesign comes into play. Therefore, the idea of generating synergy between by-products is an initiative in which the members of different industries are involved through an innovative and entrepreneurial approach of resources and materials management at regional level.

In order to design a by-product synergy project, it is necessary to know the potential site so as to assess the available by-products and how they are processed. Next, to detect any synergy opportunity and the exchange of resources or energy that could be established. Strategies of waste reduction also play an important role.

The benefits of the implementation of a by-product synergy mean new opportunities of selling materials instead of paying to send them to disposal facilities, adapting processes to reduce costs of material use and less space of landfill, developing recycling and reducing wastes, getting involved in profitable exchanges in the present as well as in future times, and having access to technical knowledge and rules and regulations for the assessment of opportunities [17].

2 Objective

One of the most developed options for the exploitation of biomass is the extraction of biogas from waste materials. The use of agricultural and livestock waste opens the possibility of extracting fuel with the same characteristics as natural gas which can be injected in gas grid or used as fuel for transport.

Among the existing technical possibilities, this paper refers to the anaerobic process to produce methane-rich biogas and its further transformation until reaching the demanded characteristics of natural gas.

Though it generates a sustainable fuel, this process generates a large quantity of CO₂ and organic digestate as by-products. According to the principles of the industrial ecology, it would be convenient to find another process which uses those by-products as inputs. As a limitation, such process is intended to generate energy.

The proposed method is algaculture, in which biodiesel is obtained from after the transesterification process. It is taken for granted the proximity of a transesterification plant, in which algae lipids would be an alternative primary resource. The solar drying of the algae biomass is not considered as a possibility, and both algaculture and SNG are made in close installations (less than 50 km).

It is necessary to assess these industrial ecology processes to ensure that they produce an improvement on the sustainability of the combined process. To this purpose, the proposed tool will be the Life Cycle Analysis (LCA). Since it is a process

for obtaining energy, in this case an improvement of the energetic performance will also be assessed by the Energy Return On Investment (EROI). As an addition, it has been decided to include the Carbon Footprint (CF), as it is one of the most widespread and traditional concepts. Therefore, a comparative is performed later, between an Option 0 or initial alternative—the SNG production obtained from anaerobic digestion of agroindustrial waste and its further cryogenic upgrading against a Alternative 1 (proposed) which introduces the concept of industrial ecology, as it combines two complementary processes that can be considered as a closed cycle, as the GNS and biodiesel production from microalgal growth.

3 Obtaining SNG Through the Energetic Exploitation of Agroindustrial Waste

The proposed method for SNG production has two stages: biogas production and upgrading. They will be described separately.

3.1 Biogas Production

The biogas production plant uses organic and dairy waste to obtain 60% purity biogas. It is the proper mixture of these materials and its homogenization what will ensure a stable process with an acceptable performance [16].

In this particular case, the average supply of cattle manure is 19,000 kg per day, 1000 kg of animal by-products from slaughterhouse and 600 kg of dairy waste. With these average inputs, 533 Nm³ of biogas will be produced per day, with a composition of 60% CH₄, 37% CO₂, 3% N₂ and trace amounts of sulphur [20].

The treatment of these waste materials avoids environmental impacts, which should be considered as something positive for the process. According to the values provided by [13] this means 2.04 kg of CO₂ prevented for each m³ of biogas produced.

It is expected a useful life of the plant of 25 years and 10 years for machinery. During normal operation in the plant, a consumption of 1.3 GJ of electric energy is produced and 2.22 GJ of heat.

Along with biogas, the digested is obtained with a ratio of 20.010 kg per day. This by-product of anaerobic digestion can be used directly as fertilizer or be used in a production process to obtain a chemical fertilizer [6].

3.2 Biogas Purification and Upgrading Process

The upgrading process of biogas is aimed to produce a fuel with the characteristics of natural gas (higher than 96% of methane) removing H₂S and water to avoid corrosion which that combination would provoke in the gas supply pipes. [18].

In this case, it is proposed a cryogenic air separation. It is based on the liquification of H_2S and the other gas pollutants at different pressure and temperature levels, which make it possible to separate them from methane. Its advantage is the storage of all the resulting gases, therefore avoiding the emission into the atmosphere of the resulting CO_2 . However, it is an energy-intensive process, since it requires very low temperatures (closer to $-100\text{ }^\circ\text{C}$) and high pressure (40 bars) for the separation to occur [11].

The process requires a series of exchangers and compressors placed in line. The biogas passes through a heat exchanger which cools the gas temperature to approximately $70\text{ }^\circ\text{C}$. Next, compressors and heat exchangers in a cascade system cool the gas to $-100\text{ }^\circ\text{C}$ and 40 bars of pressure. Then, it passes through a distillation column that separates methane from pollutants. It can be used to treat high quantities of gas, guaranteeing gas of the purest quality, at an energy cost of $0.505\text{ kWh per Nm}^3$ of GNS produced (data obtained in a prototype installation) [9].

The plant should treat 823 annual tons of biogas (considering a density of 0.6 kg/m^3). The plant installations are complex and demanding. It is assumed to be located in the same site available for the biogas installation; therefore there is no need to occupy new land. The plant has an estimated useful life of 15 years.

4 Biodiesel Production from Microalgae Cultivated in Ponds

Microalgae grow spontaneously in aquatic and humid environments and moist conditions. However, despite its abundance in nature, they need to control cultivation in solid ground plants in order to be able to produce biofuel [1].

The reference installation has a system for algaeculture in high performance ponds provided with greenhouse covering. The selected algae to be produced are the *Chlorella Vulgaris*, which has a growing rate of 25 gm-2d-1 [14]. The installation contains 3 ponds of 1500 m^2 of useful area, which means a total land of 4500 m^2 , with a total production of 112.5 kg of biomass per day.

The algaeculture is determined by several factors such as light, temperature and nutrients. The algae necessities are fulfilled by CO_2 injection and adding fertilizers. Their needs are calculated according to algae composition shown in [3]. As regards the amount of CO_2 required, it doubles the algae mass and it is pressurized into the whole pond.

Besides, in order to prevent bacteria propagation and avoid toxic accumulations or inhibitors, water cleaning is required. This is performed in situ by a primary wastewater treatment, with a 750 W pump [12]. Water losses due to evaporation and harvesting processes are estimated in 0.5 mm per day [3].

All the cultivation method is under constant agitation using paddlewheels which generate an horizontal flow of 20 cm/s and vertical oscillations on the surface [21].

Since algae are diluted in the water, harvesting comes in two steps: natural decantation followed by centrifugation. With the first step, a 65% biomass concentration pulp is generated, with 20 times higher concentration than in the water stream

after 2 h of residence time [3]. An electric consumption in the pump of 0.1 kWh/m³ is required, pumping at 45 kWh per harvest.

Once the decanting process is completed, then comes the centrifugation process through the spiral plate technology, which generates an output flow with 50 kg of algae concentration. According to [5], the electricity consumption of the centrifugation is 3.000 kWh/t dry algae.

The output flow passes to the drying stage to reach 90% of solids concentration, which according to [19] permits the assimilation of the algae paste to the process followed by soya seeds to produce biodiesel. Therefore, the process of creating biodiesel from soya seeds is taken as reference from the Ecoinvent database [4].

To reach that level of concentration is used a drying belt that uses both gravity and mechanic pressure and an input of heat [22]. Despite being one of the least demanding methods, it requires 400 kWh of electricity and an input of 13.8 MJ of heat by kg for dry processed material to reach a final 90% concentration [7], which means a high energy consumption.

The algae paste is sent to a transesterification plant located 60 km away, where the pressed oil is obtained by circulating solvent upstream. The outputs of the finishing mill are crude oil and pulp. It is calculated that 87% of the total product is methyl ester and 13% glycerin. Once the oil is obtained, it has to be esterificated with alcohol to be transformed into biodiesel.

5 Integrated Process for a Closed Cycle

As it was previously mentioned, the production of GNS generates CO₂ and fertilizers as by-products, which can be used utilized in the microalgae culture as nutrients. Thus, there is no need to use any mineral fertilizer. On the other hand, biodiesel production generates glycerin and pulp remaining from extraction, which is carried into the biodigestor stream, increasing its performance. [13].

Besides, the energetic inter-dependence of the two processes is quite clear, specially the algae drying. Therefore, it is proposed to dispatch part of the generated biogas to cogeneration, in order to produce the heat needed for the processes and a certain amount of electricity, which will probably be invested into the system. Flue-gas is obtained as a by-product, and then washed in microalgae ponds, functioning as CO₂ resource.

To do so, it is considered an increase in wastes to be treated, in order to have a fraction of biogas exclusively for supplying the heat demands in the system (digestion and drying) by its combustion, in a cogeneration process which also generates energy.

This will generate 86% increase in wastes, obtaining a total of 1130.19 Nm³ of biogas (considering a 14% increase in biogas production due to the glycerin obtained in the transesterification process), 458.39 Nm³ of which are destined to

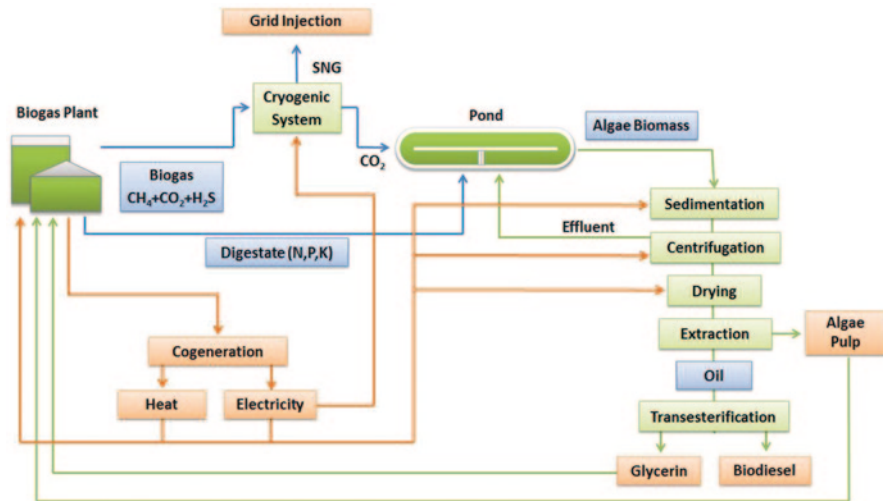


Fig. 2 Scheme of the alternative proposed

generate the heat needed during the waste digestion process and drying of algae biomass and 677.79 Nm³ to SNG production. It is estimated a performance of 55 % for heat in cogeneration and 32 % for electricity according to Ecoinvent database, which the cogeneration process is taken from. Losses in transport and heat inter-changers up to 40 % are expected as well. Therefore, 4215.35 MJ and 1703.17 kWh are obtained from this stage, 1552.47 MJ and 1158.9 kWh of which will be destined to cover the biodigester energy consumption, whereas the rest of the heat will be used in the drying process of algae biomass. The surplus of electricity obtained in cogeneration, apart from meeting the electricity needs of the biodigester, 324.03 kWh will be used in the cryogenic upgrading and 212.22 in the cultivation and harvesting of algae biomass.

To improve the system by implementing the By-products synergy philosophy, the combustion gas is washed and bubbled in the ponds to supply the CO₂ demand. Given an estimated fixation rate of CO₂ which doubles the amount of algae produced, and that the bubbling produces a minor water dilution than injection, it is necessary to count the emissions to the atmosphere from the ponds.

Balancing the CO₂, the calculation of the emissions during biogas combustion in the cogeneration engine are 4 kg for every m³ of biogas, which means 3200 kg of CO₂ per day. Whereas the microalgae installation only absorbs 226 kg of CO₂ per day. Therefore, the bubbling of combustion gases into the pond supposes an approximately 7% saving.

However, bubbling combustion gas instead of pressurizing CO₂, as in the combination with the cryogenic upgrading, supposes an energetic cost of approximately 6.5 times higher (Fig. 2) [2].

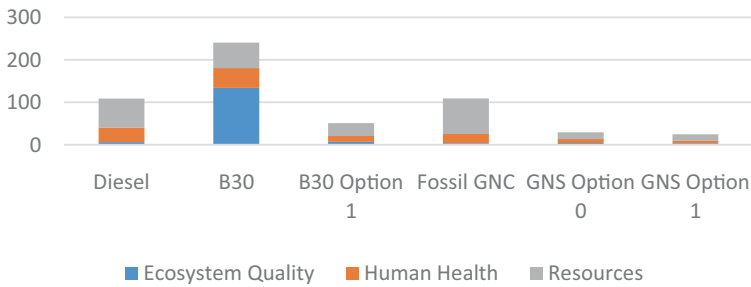


Fig. 3 Comparison of only score EI99 HA of complete cycle of a bus at 1 km according to the different mobility systems (mili-pt)

6 Analysis

Since these processes generate different forms of energy, it is necessary to compare them within a common framework. Therefore, the functional unit of evaluation will be the transport: 1000 km run by an urban bus according to conditions exposed in [13]. A natural gas engine bus consumes 740 Nm³, while a biodiesel engine bus consumes B30 504 kg.

6.1 LCA

To perform the LCA, the ecoindicator99 methodology is selected due to its widespread use. Calculations are made using GaBi software and both the European Life Cycle Databases (ELCD) and Ecoinvent are employed.

The option 0, SNG production, generates an impact of 49.2 milipt by tkm if we take the reference of 1000 km run (1 tkm). However, if we do not take into account that the CO₂ separated from biogas is bottled, but emitted, the global score would be higher.

As for the production of biodiesel from microalgae, it supposes an impact of 94.72 milipt for tkm. From this global score, 39.38 pt. correspond to biodiesel. Therefore, this scenario allows us to obtain a B30 biofuel with a quite lower score than that obtained from colza oil (245 milipt) [13] and even similar to scores obtained from recycled oils.

In the case of a close cycle system, there is an improvement in the score, with 61 milipt/tkm, 13 of them corresponding to NGS and 29.5 pt. to Biodiesel. These results are an improvement of nearly 8 pt as compared with the previous case exposed.

Figure 3 represents the score obtained for the different types of buses. It includes the values of some reference fuels and the ones obtained in each synergy, reflecting thus what the improvements are in each of them. The values of option 0 and the Proposed Alternative or option 1, are then compared with the score obtained by other forms of mobility in [13].

Table 1 Energy balance of GNS production process expressed in m³

Process	Input	Output
Transport	31.73	–
Electricity digestion	15.57	–
Heat digestion	42.81	–
Electricity upgrading	34.60	–
SNG production	–	303.81
Total	124.721	303.81
EROI	–	2.43

6.2 Energy Return On Investment (EROI)

The evaluation of energetic efficiency and the environmental impact analysis are important to test the suitability of the system. To this purpose, the Energy Return on Investment (EROI), which assesses the amount of energy demanded and produced by the system, is analysed.

The calculation of the EROI is made through a primary energy balance, in which inputs and outputs are accounted for and expressed in m³ of NGS. To make this conversion, a performance of 0.8 in the transformation of chemical energy into heat is taken into account, and this is taken as the value for the transformation of 1 m³ of NG is 41.8 MJ.

Table 1 shows the EROI of the production process of SNG, which gives us an optimum result, since the inversion of energy in waste treatment for obtaining biogas and its further upgrading permit to obtain a profitable energy vector.

However, after the promising results obtained for the SNG production, while analysing the energy balance of biodiesel production from microalgae cultivated in ponds, it shows a negative performance, since the system requires more energy than that it can produce. It can only be suitable if it were analysed from a perspective of offering energetic independence (Table 2).

Next, it is presented the EROI calculation for the production of 458 Nm³ of biogas destined to cogeneration for the generation of electric energy and heat. It shows an excellent performance, obtaining a value of 6.248. In this case, the cogeneration is energy-efficient, as the heat produced will be used in the same installation to supply the demand of anaerobic digestion and algae drying. However, if there is no process on which to apply the heat, the performance will not be as good (Table 3).

Once the EROIs of each process are analysed individually, the EROI of option 1 is evaluated. It is remarkable how the performance of the SNG production decreases while biodiesel production improves (Table 4).

Table 2 Energy balance of the biodiesel B30 production process

Process	Input	Output
Flue gas	7.487	–
Paddlewheels	5.102	–
Transport fertilizer	0.658	–
Harvesting	3.903	–
Centrifugation	21.347	–
Dry Heat	46.471	–
Electricity drying	40.371	–
Transesterification	0.283	–
Biomass transport biomass	0.825	–
Diesel	93.996	–
Biodiesel production	–	125.242
Total	220.442	125.242
EROI	–	0.568

Table 3 Energy balance of the biogas and cogeneration production process

Process	Input	Output
Transport	31.731	–
Electric digestion	13.397	–
Heat digestion	36.788	–
Heat cogeneration	–	12.565
Electricity cogeneration	–	385.878
Total	81.916	511.929
EROI	–	6.248

Table 4 EROI of alternative proposed scenario

Process	Input	Output
GNS	133.499	380.190
Cogeneration	81.916	511.829
B30 (treatment and transport digestat)	22.100	125.242
Total	436.415	1017.261
TRE	–	2.331

6.3 Carbon Footprint

To calculate the carbon footprint, it is used the CML2001 methodology in equivalent kg of CO₂. Taking as reference a production of SNG of 303.8 Nm³ and 112.5 kg of algae biomass, with a performance of 25.6 kg of biodiesel, we obtain a negative CF of –140 and –70 kg-CO₂ equivalent respectively, mainly due to the CO₂

fixation in both the anaerobic digestion and algae cultivation. It is important to remark that the negative value appears as a consequence of not taking into account the gas emissions during the combustion of these energy vectors. Another factor which determines the negative value of this CF is the fact that, during upgrading, the separated gases are perfectly isolated and that their purpose is different from that of being emission to the atmosphere

However, unlike LCA or EROI, the value of the Alternative Proposed, equivalent 228.77 kg-CO₂, is worse than in the previous cases. That is caused by the co-generation process, due to its important CO₂ emissions to the atmosphere.

7 Conclusions

From these results, one can affirm that the industrial ecology provides a more sustainable management.

From the energy assessment of livestock waste, it is proved that the SNG production (option 0) has less environmental impacts, which can even improve if all generated by-products are exploited.

The microalgae cultivation process for biodiesel production has proved to be a complementary process to that of SNG production. Once both processes are studied, we can see that the inputs of one process can be supplied by the outputs generated by the other one.

Therefore, the analysis on the environmental sustainability of each of the individual processes and the different connections proposed reflect that there is a clear improvement in score reached as it moves towards a closed cycle. It does not apply to the results of EROI and carbon footprint.

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Design of an SRF from Refuse from a Municipal Waste Treatment Plant

A. Gallardo, A. M. Gómez, F. J. Colomer, N. Edo and P. Pascual

1 Introduction

Up until a few decades ago, municipal waste management consisted in the disposal of municipal solid waste (MSW) on monitored landfills. However, management assessment has quickly evolved to adapt to the principles of sustainable development. European Union legislation, by means of Directive 2008/98/EC on waste, establishes a policy for member states designed to develop cleaner technologies, waste minimization, material re-use and recycling, and energy recovery from waste. Thus there is a need for a MSW management plan based on these principles that should be applied not only in legislation but also in management policies.

In Spain, over 17 million t of MSW are disposed of in landfills every year [12]. Yet not only waste that complies with the Spanish law R.D. 1481/2001 on waste disposal in landfills is deposited in monitored landfills, they also receive those fractions that are rejected at waste management facilities, for instance from material recovery plants, composting plants or mechanical biological treatment (MBT) plants. This represents a large volume of waste to be disposed of and gives rise to problems related to a shortage of sites.

In 2009 Spain had 120 recovery and composting facilities [12] and, as described in the National Plan on Waste 2008–2015, the number of recovery and composting

A. Gallardo (✉) · A. M. Gómez · F. J. Colomer · N. Edo · P. Pascual
Departamento Ingeniería Mecánica y Construcción, Universitat Jaume I, Av. Vicent Sos
Baynat s/n, Castellón de la Plana, CP. 12071 Castelló, Spain
e-mail: gallardo@uji.es

A. M. Gómez
e-mail: aparra@uji.es

F. J. Colomer
e-mail: fcolomer@uji.es

N. Edo
e-mail: al272620@uji.es

P. Pascual
ppascual@tetma.com

plants will have to be increased in this waste management system. The National Plan includes a strategy for reducing the landfill of bio-waste. Thus, biodegradable MSW will be treated by means of biological processes (composting or digestion) in order to treat the bio-waste in a way that meets a high level of environmental protection, while also ensuring environmentally safe materials are produced from bio-waste, prior to disposal on landfills. In addition, the modification of packaging waste legislation [19] includes stricter recycling targets for each specific type of waste material and, consequently, more recovery plants will be necessary.

However, despite of the amount of reject fraction (RF) generated during MSW management, few research studies have been conducted in this field of recovery [14]. Some papers have developed models to estimate the potential energy that could be obtained from rejection [1]. Other authors study its use as a fuel for incineration plants with energy recovery [2, 13] or the chemical composition of RF as fuel in order to reduce the heavy metal content and comply with the legislation on incineration [17].

One alternative for reject valorization purposes is its conversion into solid recovered fuel (SRF). The European Union estimates that the total amount of SRF produced per year from MSW is over 4–5 million t [8]. This production capacity is growing due to the construction of new MBT plants. Moreover, some industries and power generation facilities are becoming increasingly interested in using alternative fuels, which are cheaper and offer the same specific, homogeneous quality as that of the SRF derived from the reject fraction of MSW plants.

Nowadays this kind of facilities already exist in Spain: in the Zona Franca in Barcelona there is one of the most modern SRF production plants in Europe [21]; Madrid has the Environmental Complex of Valdemingómez, where the SRF produced is energetically valorised on-site [10]. However, the rate of substitution of fossil fuels by SRF, although it is growing year after year, is still relatively low in Spain compared to other European countries where MSW management systems have been focused on disposal minimization and energy recovery for decades.

To determine whether the SRF derived from the reject fraction of MBT plants is suitable as fuel for different technologies, specific information such as its physical–chemical properties and thermal behavior must be known [9]. Sulphur and chlorine contents produce combustion problems on the furnace walls, such as deposits formation or inner layer oxidation [16]. High concentrations of potassium produce undesirable deposits in recovery boilers that form an insulating layer [15]. The design and control of the furnace depends on the calorific value of the fuel materials [3]. But another important problem associated to bio-waste combustion is the content and composition of the ashes, which determine the combustion technology to be applied, the characteristics of the furnace, the temperature conditions, and the method for extracting the ashes [20].

2 Objective

The aim of this research work is to design an SRF with a high market value, according to European standards, using material from a recovery and composting plant. With this goal in mind, physical–chemical analyses of refuse were performed.

Furthermore, a set of enhancements in the mechanical, electromechanical, and optical separation processes were proposed.

The following secondary objectives are proposed to help reach the main goal:

- A review of the previous studies on this subject, and also the quality standards that apply to this type of project.
- Check the legislation and the parameters that define the quality of this material as well as the field of application.
- Chemical and physical characterization of the refuse. Refuse from a municipal waste management plant was analyzed in the laboratory at the Universitat Jaume I (UJI).

3 Materials and Methodology

3.1 Description of a Waste Recovery and Composting Plant

The main goal of a municipal waste recovery and composting plant is to separate and process all those feasible components of mixed municipal waste to be valorised [5]. These facilities consist of two different parts: pre-treatment–recovery and composting.

At the pre-treatment–recovery stage, the rest-waste fraction of MSW (that not previously sorted at origin) enters the plant. This stage in turn has two phases: primary and secondary selection. Once the waste stream has been received, it is fed into the trommel, where the first selection is carried out according to size: the fine fraction composed of the organic matter in the MSW, and the coarse fraction. In some plants a plastic bag opener precedes the trommel.

The coarse fraction is carried to the secondary selection process, which consists in manual selection and magnetic, optical, and Foucault separation. Recyclable materials such as aluminium, ferrous metals, plastics, and liquid packaging board LPB (cartons) are recovered, and the remaining material is the reject fraction.

The fine fraction stream is taken to the composting plant, where compost, a soil fertilizer, is produced by means of a biological treatment followed by a maturation phase. A stage of refinement by size and weight methods must be performed to achieve the properties required to be able to market the compost and comply with agricultural specifications. In this refinement process a ferrous and a reject fraction are also obtained.

3.2 Quality Specifications of SRF

Solid recovered fuel is a solid fuel prepared from non-hazardous waste, e.g., municipal waste or the reject fraction from a recovery and composting plant, which is then processed and homogenized to meet a certain standard of quality [6] so that

Table 1 Classification system for SRF: UNE-EN 15359:2012

Classification property	Statistical measure	Unit	Classes				
			1	2	3	4	5
Net calorific value (NCV)	Mean	MJ/kg	≥ 25	≥ 20	≥ 15	≥ 10	≥ 3
Chlorine (Cl)	Mean	%	≤ 0.2	≤ 0.6	≤ 1.0	≤ 1.5	≤ 3
Mercury (Hg)	Median	mg/MJ	≤ 0.02	≤ 0.03	≤ 0.08	≤ 0.15	≤ 0.5
	80th percentile	mg/MJ	≤ 0.04	≤ 0.06	≤ 0.16	≤ 0.30	≤ 1.0

it can be utilized for energy recovery. The SRF from MSW is composed mainly of textiles, wood, plastics, paper, and so forth. Producing SRF from MSW pursues two objectives: to reduce the volume of the reject fraction disposed of on landfills, and to obtain an alternative fuel for those energy-intensive industries like cement, power generation or boilers.

However, the physical and chemical properties of SRF may be very heterogeneous due to the characteristics of the input waste and the treatments applied. A well-defined classification and specification system for this group of fuels is therefore of great importance. The physical and chemical quality of the fuel has to comply with the regulations to ensure the protection of the environment and the furnace process, as well as the quality of the product, if this is the case, as happens for cement products. Furthermore, the calorific value and mineral content should be stable enough over time to guarantee optimal furnace feeding. And the physical form must be such that manipulation, storage and supply under safe working conditions are ensured.

For this purpose, the European Committee for Standardization (CEN) published the standard EN 15359: Solid recovered fuels—specifications and classes. This standard aims to serve as a tool to enable efficient trading of SRFs by promoting their acceptability on the fuel market and increasing public trust in these products. The classification system is based on three important parameters: an economical parameter (net calorific value), a technical parameter (chlorine content), and an environmental parameter (mercury content). The parameters have been chosen to give a stakeholder an immediate but simplified picture of the fuel in question.

Each property is divided into five classes with limit values (Table 1). The SRF will be assigned a class number from 1 to 5 for each property. A combination of the class numbers makes up the class code. The parameters are of equal importance and thus no single class number determines the code. In addition to the class code, the following properties of SRFs must be specified, in accordance with the template in Annex 1: origin, particle form (pellets, briquettes, flakes, and so on), particle size, ash and moisture content, NCV, and chemical properties (chlorine and heavy metals content).

3.3 Laboratory Analyses

The procedure for the characterization of the refuse obtained at a recovery and composting plant was as follows:

1. Sampling: for a period of 5 months, one sample was taken from the plant every month. We started with a representative sample of 10 kg, which was sequentially quartered to obtain a final test sample of 500 g.
2. At the waste analysis laboratory, the sample was dried to obtain the moisture content.
3. Determination of chemical properties: net calorific value, chlorine, mercury, and ash content. With the results obtained, the SRF is classified under the criteria of the standard.
4. Physical determination of the composition of the sample. Any of the components of the refuse that can be separated by hand were expressed as a percentage by weight, e.g., paper, textiles, plastics, rubber.
5. Chlorine content determination of all the separated components.

The following standards were used to analyze the samples:

- UNE-EN 15414-3:2011. Solid recovered fuels. Determination of moisture content using the oven dry method. Part 3: Moisture in general analysis sample.
- UNE-EN 15400:2011. Solid recovered fuels. Determination of calorific value.
- UNE-EN 15408:2011. Solid recovered fuels. Methods for the determination of sulphur (S), chlorine (Cl), fluorine (F), and bromine (Br) content.
- UNE-EN 15411:2012. Solid recovered fuels. Methods for the determination of the content of trace elements (As, Ba, Be, Cd, Co, Cr, Cu, Hg, Mo, Mn, Ni, Pb, Sb, Se, Tl, V y Zn). Mercury was analyzed directly on the solid sample, following EPA method 7473, which is based on a thermal decomposition, subsequent amalgamation and atomic absorption spectrometry. A total mercury analyzer AMA-254 LECO model was used for this purpose [11].
- UNE-EN 15403:2011. Solid recovered fuels. Determination of ash content.

4 Results and Discussion

4.1 Chemical Characterization of Refuse

The resulting samples, five in all, were dried to determine the moisture content. The mean value obtained for this parameter was 22.71 %. The methodology used to analyze the chemical properties was as follows: once the sample was dried, it was quartered to obtain a 25-g subsample. It was then crushed in a knife mill and sieved through a 1 mm-mesh size sieve. Later the NCV, ash, Cl, and Hg content were calculated. These results are shown in Table 2 (σ : standard deviation).

The NCV values obtained vary from 5596.9 kcal/kg (23.4 MJ/kg) to 6045.9 kcal/kg (25.3 MJ/kg), which are higher than those obtained from other waste-derived fuels like dried timber or woody biomass [7]. The low variability of the values registered may indicate that a possible SRF from this refuse would be energetically uniform. Under the standard classification property, NCV, the refuse generated was classified

Table 2 Refuse classification

Classification property	Statistical measure	Value (dwb)	σ	Class
Net calorific value (MJ/kg)	Mean	24.28	0.85	2
Cl (%)	Mean	1.22	0.19	4
Hg (mg/MJ)	Median	0.003	–	1
Ash content (%)	Mean	12.08	0.19	–

as belonging to class 2. This property has a low capacity for improvement due to its dependence on the composition of the waste. Only eliminating the lower calorific components could allow the NCV of the SRF to increase.

With regard to mercury values, the results obtained were very low, so the refuse classification under this property was class 1, i.e., the best.

Chlorine content is the parameter that yielded the worst results. The differences between the five samples vary from 1.02 to 1.47%, on a dry basis. This variation may be due to the small amount of sample needed to perform the analyses (0.7–1.0 g). The sample, although crushed and mixed uniformly, is a blend of different materials and components, and the presence of chlorinated plastics, like polyvinyl chloride (PVC), introduces a great degree of variability in the percentage of chlorine content. The classification of the refuse under the chlorine content property established it as belonging to class 4. To improve this class number of the SRF, it would be desirable to reduce the amount of this parameter (Cl%).

The ash content is not a property included in the standard for classifying an SRF, but nevertheless its importance in combustion processes is something to be taken into account. The mean value obtained for the refuse samples studied was 12% (dwb), a value that is slightly high for heat generation processes.

4.2 Physical Characterization of Refuse

The aim of a physical characterization of the refuse is to know the weight percentage of the main components (on a dry basis). The five dried samples were characterized, with an average weight per sample of 475 g. Initially the sample was sieved through a 1 cm-mesh size sieve, the fraction passing through the sieve being called fines <1 cm, and the upper fraction was separated by hand into eight components: liquid packaging board LPB (cartons), rubber/leather, foam, wood, paper/board, plastic film, rigid plastic and textiles/cellulose. The results are shown in Table 3. The weight percentage refers to the sum of the fractions for each of the samples. Plastic film is the main component, followed by paper/board and the fines. Fines are composed of inert material and a mixture of all the eight components.

With the aim of establishing which fraction made the largest contribution to the chlorine content, this parameter was analyzed for every single component (Table 4). The results showed that both types of plastics, textiles, and fines were the main

Table 3 Average composition of refuse

Fraction	(%)
LPB	2.40
Rubber/leather	1.23
Foam	0.53
Wood	1.89
Paper/board	20.00
Thin plastic (film, bags, etc.)	23.87
Rigid plastic	13.37
Textiles/cellulose	17.90
Fines < 1 cm	18.81

Table 4 Chlorine content in refuse fractions

Fraction	(%) Chlorine content (dwb)	
	Mean	σ
LPB	0.15	0.00
Rubber/leather	2.18	–
Foam	0.26	–
Wood	0.36	–
Paper/board	0.44	0.13
Thin plastic (film, bags, etc.)	0.46	0.41
Rigid plastic	0.72	1.10
Textiles/cellulose	0.72	0.22
Fines < 1 cm	0.56	0.12

contributors. The chlorine content of rigid plastic had a mean value of 0.72%, with a high standard deviation. This may be due to the presence of PVC in this fraction. When this material was not observed in the analyzed samples, the chlorine content was much lower; on the other hand, when its presence was detected, the chlorine content increased considerably.

A characterization of the main types of plastics present in the municipal waste samples was performed (Table 5). It was observed that PVC was the main contributor to chlorine content in refuse, although the textile fraction, due to its synthetic origin, may also contain an important amount of chlorine. The plastic film component showed a chlorine content value of 0.46%, while the content in rubber/leather was the highest (2.18%), even though this fraction only represented 1.23% of the refuse by weight. The chlorine content in this fraction may be due to the presence of shoe soles and pieces of sports shoes, which are partially composed of chlorine-containing materials. The fines fraction was a mixture of the composition of refuse, so the chlorine content could be explained as being an average value of each component.

Table 5 Analysis of chlorine content in different types of plastic

Type of plastic	% chlorine (dwb)
HDPE	0.06
PET	0.05
PP	0.12
PVC	38.40

5 Conclusions

In the present work the possibility of producing an SRF with an acceptable quality from refuse has been studied. The classification parameters NCV and mercury content, included in European Standard EN 15359, were suitable while chlorine and ash content should be reduced in order to improve the quality of the SRF produced in a municipal waste treatment plant.

A process to analyze the refuse from a treatment plant has been designed, and can be used to study this type of materials systematically. Moreover, it has been applied in a practical case to characterize several refuse samples.

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Local Analysis of the Characteristics and Frequency of Extreme Droughts in Málaga Using the SPI (Standardized Precipitation Index)

J. L. Ayuso, P. Ayuso-Ruiz, A. P. García-Marín, J. Estévez and E. V. Taguas

1 Introduction

Droughts lead to ecological disasters and they have received much attention from environmentalists, ecologists, hydrologists, meteorologists, geologists and agronomists. Drought is one of the most important natural hazards and it strongly influences human activities and economic development [2]. In the twentieth century, droughts have been the natural disaster that has caused most detrimental impacts [21]. Drought is a regular and recurring feature of the climate, which occurs in all climate regimes and refers mainly to the reduction in the amount of precipitation over an extended period of time, such as a season or a year. It is a temporary anomaly, in contrast to aridity, which is a permanent feature of the regional climate and limited to areas characterized by a low amount of rainfall [30].

In recent years, severe droughts all over the world have been observed on all the continents, affecting large areas. A study on a continental scale of the potential impacts of global change on future flood and drought frequencies in Europe carried out by Lehner et al. [14] under the proposed scenarios of global change indicates a significant increase in the frequency of droughts in the south and southeast of Europe. During the last three decades, many important droughts have occurred in Europe, the most severe one being in 1976 (North and Western Europe), and in 1989

J. L. Ayuso (✉) · P. Ayuso-Ruiz · A. P. García-Marín · J. Estévez · E. V. Taguas
Department of Rural Engineering, University of Córdoba, Córdoba, Spain
e-mail: ir1aymuj@uco.es

P. Ayuso-Ruiz
e-mail: patri_ayuso@hotmail.com

A. P. García-Marín
e-mail: amanda.garcia@uco.es

J. Estévez
e-mail: jestevez@uco.es

E. V. Taguas
e-mail: ir2tarue@uco.es

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and 1991 (over the whole continent). Recently, the most severe drought of the past 60 years occurred in the Iberian Peninsula in 2005 [18].

There is no single definition of drought. In an excellent review of the fundamental concepts of droughts, Mishra and Singh [18] fully described its many definitions. In general, it can be agreed that drought is a natural phenomenon that occurs when there is a period of time with a sustained and extended rainfall deficiency, compared to normal levels in that period. In addition, drought can be defined in terms of meteorological, agricultural, hydrological and socio-economic factors [2, 31]. Meteorological droughts are based on a rainfall deficit compared to what is considered “normal” and express a major cause of drought; agricultural droughts are based on a deficit of water available to plants; hydrological droughts are based on a deficit of streamflow; and socioeconomic droughts are based on a deficit in water supply over demand. Different types of drought have led to the development of a variety of indices to quantify them. In works reported by Heim [10] and Mishra and Singh [18], a list of the various indices used is described. All drought indices usually employ precipitation either individually or in combination with other hydro-meteorological variables (e.g., evapotranspiration), depending on the requirements. Historical difficulties in quantifying these hydro-meteorological variables in combination with precipitation limit the use and application of these indices. In fact, indices based only on rainfall data give good results in comparison to more complex indices [8].

Since it was proposed by McKee et al. [16, 17], the Standardized Precipitation Index (SPI) is widely and universally used to study meteorological drought (e.g. [3, 5, 8, 9, 23, 25, 28]) and it has proven to be a useful tool for estimating the intensity, magnitude and duration of drought events.

The work proposed here focuses on the analysis of meteorological drought in Málaga (Southern Spain) using the SPI to quantify the severity, magnitude and duration of droughts. To carry out this work, monthly precipitation data series from Málaga Airport observatory were used. We have extracted the maximum annual events from the SPI time series selected for different time scales, forming the series of annual maximum drought values. Subsequently, they have been used for conducting a frequency analysis to determine droughts quantiles for different return periods, providing an assessment of the risk of local drought.

2 Study Area and Precipitation Data Source

Monthly precipitation data from 1945 to 2011 recorded at Málaga Airport observatory (36° 40′ 00″ N, 04° 29′ 17″ W; 7 m above sea level) were used in the present study. This station belongs to the Spanish Meteorological Agency (AEMET in Spanish). This area is characterized by a Mediterranean climate, with 18 °C of mean annual temperature. Málaga province is historically subject to flood and drought cycles, due to the irregularities in this type of climate. Mean annual rainfall in Málaga airport is 553 mm (1945–2011 period) and 80.8% of this rainfall occurs from early October to late March (autumn and winter), highlighting the predominance

of precipitation in winter (43.6% of the annual rainfall). It is worth noting the high interannual erratic rainfall, which alternates very rainy years with extremely dry years. Therefore, in keeping with this high variability, numerous extreme rainfall events (default and excess) are recorded.

3 Methodology

In this section, the methods applied to carry out the analysis of meteorological droughts by using SPI are expounded. Also, the methods for applying the frequency analysis of the intensity and severity of droughts using the L-moments technique are described.

3.1 Monthly Precipitation Time-Series

The first step toward calculating the SPI was to form the accumulated monthly precipitation time series at various temporal scales considered: 1, 3, 6 and 12 months. For each of the 12 months, cumulative rainfall was calculated separately for each selected scale. The accumulated precipitation for a given year i and month j , depends on the temporal scale chosen, m . Therefore, the total rainfall in the month j of year i in $m-1$ previous consecutive months with $m \leq 12$, was calculated as [4]

$$P_{i,j}^m = \sum_{k=13-m+j}^{12} p_{i-1,k} + \sum_{k=1}^j p_{i,k} \quad \text{if } j < m \quad (1)$$

$$P_{i,j}^m = \sum_{k=j-m+1}^j p_{i,k} \quad \text{if } j \geq m \quad (2)$$

Where $p_{i,k}$ is the precipitation for the first month of year i (mm).

The precipitation time series for the different time scales (monthly, seasonal, annual, etc.) do not follow the normal distribution but, rather, distributions skewed toward higher precipitation values (right skewed distributions). This implies that the mean rainfall for a given time period is greater than the median. Thus, over half of the time, total precipitations are below the mean. For example, Fig. 1 shows the histogram of the frequency distribution of total rainfall at Málaga airport from March (time scale of 3 months: January, February and March) for the period 1945–2011. The bias of the frequency distribution of precipitation, and the fit to gamma and normal distributions can be observed. The mean value was higher than the median value and the bias coefficient was greater than zero, indicating that the frequency distribution was skewed to the right and did not follow the normal distribution.

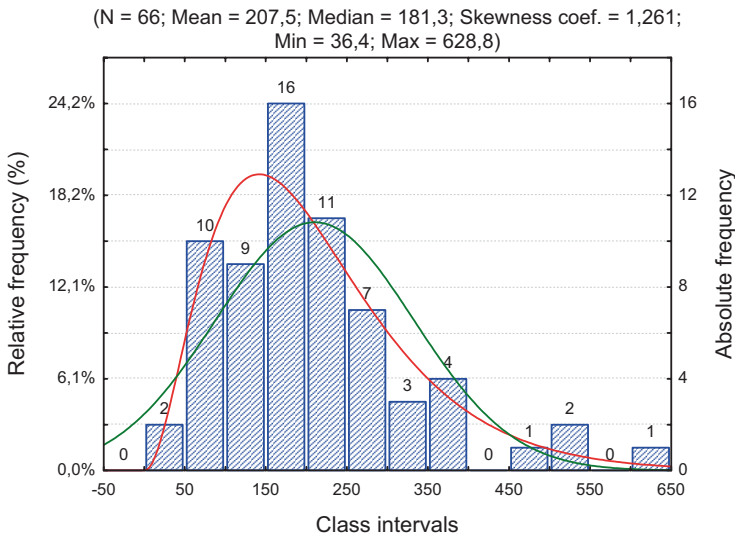


Fig. 1 Frequency distribution of 3 month precipitation (mm) for the month of March (totals for January, February and March) for Málaga from 1945 to 2011

3.2 Drought Evaluation by Using the Standardized Precipitation Index (SPI)

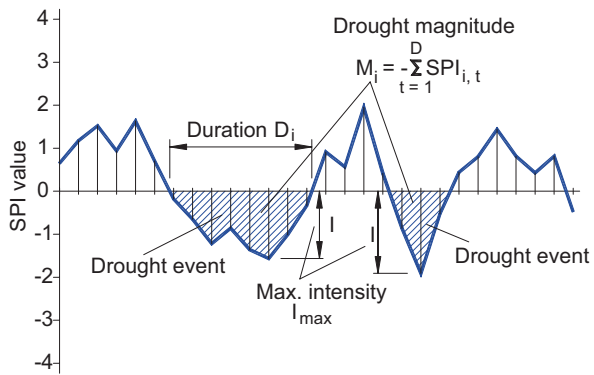
Precipitation is the primary factor that controls the formation and persistence of drought along with other variables such as evapotranspiration. In order to identify, characterize and quantify the attributes of the various components of the drought, different indices have been proposed. Among these, the relatively recent Standardized Precipitation Index (SPI) proposed by McKee et al. [16, 17], is considered to be the most reliable one for measuring the intensity, duration and magnitude of drought (Table 1) [8, 12, 15].

The characterization of a drought event involves identifying the start and end time, its intensity and its magnitude [16]. A drought event is assumed as being a

Table 1 Drought classification by SPI value and corresponding event probability [15]

SPI value	Drought category	Probability (%)
≥ 2.00	Extremely wet	2.3
1.5 to 1.99	Very wet	4.4
1.00 to 1.49	Moderately wet	9.2
-0.99 to 0.99	Near normal	68.2
-1.00 to 1-1.49	Moderately dry	9.2
-150 to -1.99	Severely dry	4.4
≤ -2.00	Extremely dry	2.3

Fig. 2 Definition of drought properties based on the SPI



number of consecutive months in which the SPI values remain negative. According to the range of values of the SPI, the drought events can be classified from moderate to extreme (Table 1). The duration of a drought event, D_i , is the time period between the start of the drought and its end. This is assumed as being the number of consecutive time intervals (months) with negative SPI values. Since the drought event is defined as aggregation at the monthly time scale, the minimum duration is 1 month. The drought intensity is the highest SPI value during the drought event, I_i . The magnitude of the drought is the cumulative sum of the SPI values during the drought event (Fig. 2). For convenience's sake, the magnitude of drought event i , M_i ($i=1, 2, \dots, n$) is taken to be positive, which is given by [16]

$$M_i = -\sum_{t=1}^{D_i} SPI_{i,t} \tag{3}$$

3.2.1 Calculation of SPI

The SPI calculation requires knowledge of the frequency distribution of the data of the time series of monthly precipitation accumulated at various temporal scales, considering at least 30 years of data. A gamma distribution is fitted to each empirical frequency distribution of the rainfall cumulative time series established for the selected temporal scales by applying the methodology described in Sect. 3.1.

Subsequently, equiprobability transformation of the gamma distribution into the normal distribution is performed. The negative values of the normal standardized variable are compared to the limits of the different drought types in Table 1. This last step identifies the severity of a drought event.

The probability density function of the Gamma distribution is

$$g(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \tag{4}$$

Where α is the shape parameter ($\alpha > 0$), β the scale parameter ($\beta > 0$), x the amount of precipitation ($x > 0$), and $\Gamma(\alpha)$, the gamma function. The fit of the data to the distribution needs the estimation of the parameters α and β for each time scale (1, 3, 6 and 12 months) and for each month of the year. The cumulative probability distribution function $G(x)$ is given by [22]

$$G(x) = \frac{1}{\beta^\alpha \Gamma(\alpha)} \int_0^x t^{\alpha-1} e^{-(t/\beta)} dt \tag{5}$$

This equation cannot be solved directly. If the change $y = x/\beta$ is done, this yields

$$G(y) = \frac{1}{\Gamma(\alpha)} \int_0^y y^{\alpha-1} e^{-y} dy \tag{6}$$

The estimation of α and β using the L-moments methodology, needs the following steps: [11]

1. Arrangement of the data series in ascending order
2. Obtaining the probability weighted moments b_0 and b_1 of the arranged data series by using the expressions

$$b_0 = \frac{1}{n} \sum_{j=1}^n x_j \quad b_1 = \frac{1}{n} \sum_{j=2}^n \frac{(j-1)}{(n-1)} x_j$$

3. Estimation of L-moments, $l_1 = b_0$ $l_2 = 2b_1 - b_0$ and the L-Variation Coefficient, $t = l_2 / l_1$
4. Estimation of the parameters α and β of the Gamma distribution by the following expressions

If $0 < t < 1/2$ then $z = \pi \cdot t^2$ and $\alpha = \frac{1 - 0.3080z}{z - 0.05812z^2 + 0.01765z^3}$ (7)

If $1/2 < t < 1$ then $z = 1 - t$ and $\alpha = \frac{0.7213z - 0.5947z^2}{1 - 2.1817z + 1.2113z^2}$ (8)

Finally, the parameter β is given by

$$\beta = l_1 / \alpha \tag{9}$$

Since the data samples can contain various zero precipitation values, in order to consider the probability of the value zero, and considering that the Gamma distribution is not defined for $x=0$, the cumulative probability function of the Gamma distribution is modified as:

$$H(x) = q + (1 - q)G(x) \tag{10}$$

Where q is the probability of zero precipitation. If m is the number of zero values in rainfall data series, then q can be estimated as m/n . The Gamma distribution is transformed into a standard normal distribution with an average value of zero and variance one, the SPI value being the result of the transformed probability. The probability transformation is made by the following expressions [1] that convert the cumulative probability distribution into a standard normal distribution, Z

$$Z = SPI = - \left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \quad \text{for } 0 < H(x) \leq 0.5 \quad (11)$$

$$Z = SPI = + \left(t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right) \quad \text{for } 0.5 < H(x) \leq 1 \quad (12)$$

Being:

$$t = \sqrt{\ln \left(\frac{1}{(H(x))^2} \right)} \quad \text{for } 0 < H(x) \leq 0.5 \quad (13)$$

$$t = \sqrt{\ln \left(\frac{1}{(1 - H(x))^2} \right)} \quad \text{for } 0.5 < H(x) \leq 1 \quad (14)$$

$$C_0 = 2.515517; \quad C_1 = 0.802853; \quad C_2 = 0.010328 \\ d_1 = 1.432788; \quad d_2 = 0.189269; \quad d_3 = 0.001308$$

Once the precipitation values have been normalized, the kind of drought can be derived from Table 1. Positive SPI values indicate higher values than the average rainfall (wet period), and negative values indicate less rainfall than the average (dry period).

For the study of droughts by using the SPI, monthly rainfall data series of at least 30 years is needed [16]. Later, Guttman [7] investigated the effect of sample size on the distribution of rainfall fitted by using L-moments. He found that 40–60 years of records are needed in order to obtain a steady estimation of the parameters in the central side of the distribution, and from 70 to 80 years of records to obtain stability in the tails. Those requirements are important to the correct use of the SPI. In this work, 67 years of monthly rainfall records have been used.

As an example for March and for a time scale of 3 months, Fig. 3 shows the transformation of the values given by the Gamma distribution into the standard normal distribution to obtain the corresponding SPI values. The left side of the plot shows the empirical cumulative probability distribution of 3-month cumulative rainfall data (January–February–March) corresponding to the months of March in the time series from 1946 to 2011. It also shows the theoretical cumulative probab-

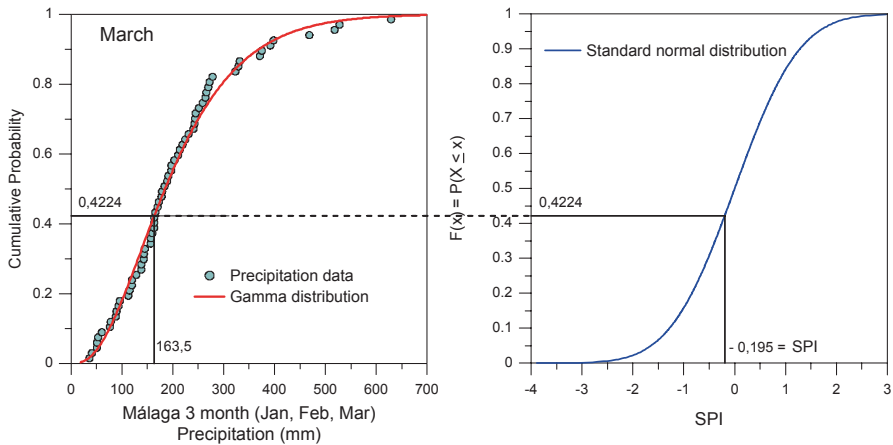


Fig. 3 Example of equiprobability transformation from fitted gamma distribution to the standard normal distribution

ity distribution Gamma function fitted. The right side of Fig. 3 shows the standard normal distribution.

To transform a certain precipitation datum into its SPI value, the amount of rainfall has to be located over the x-axis of the left plot. Then, a perpendicular line is drawn to intercept the theoretical fitted distribution (Gamma distribution). The theoretical probability of the amount of rainfall can then be read. If a horizontal line is drawn by this value until the standard normal distribution is reached, a point is obtained whose projection over the x-axis of the normal distribution gives the value of the SPI of the precipitation considered. From Fig. 3 it can be seen that to a precipitation value of 163.5 mm corresponds a SPI of -0.195 .

The SPI has the ability of quantifying the precipitation deficit for different time scales, reflecting the impact of drought on the availability of water resources.

4 Results

A software in Visual Fortran has been developed in order to carry out SPI calculations and drought analysis. The software includes the calculations of 1, 3, 6 and 12-month SPIs, the fitting of these temporal series to gamma distribution of the precipitation and then, its transformation into the standard normal distribution. As a graphic output of these operations, it shows the cumulative probability versus precipitation values. Additionally, duration, intensity and magnitude of drought events are described.

In Fig. 4, a graphic sample of SPI calculation for the selected temporal scales by gamma distribution fitting and the later equiprobability transformation into the standard normal distribution can be found.

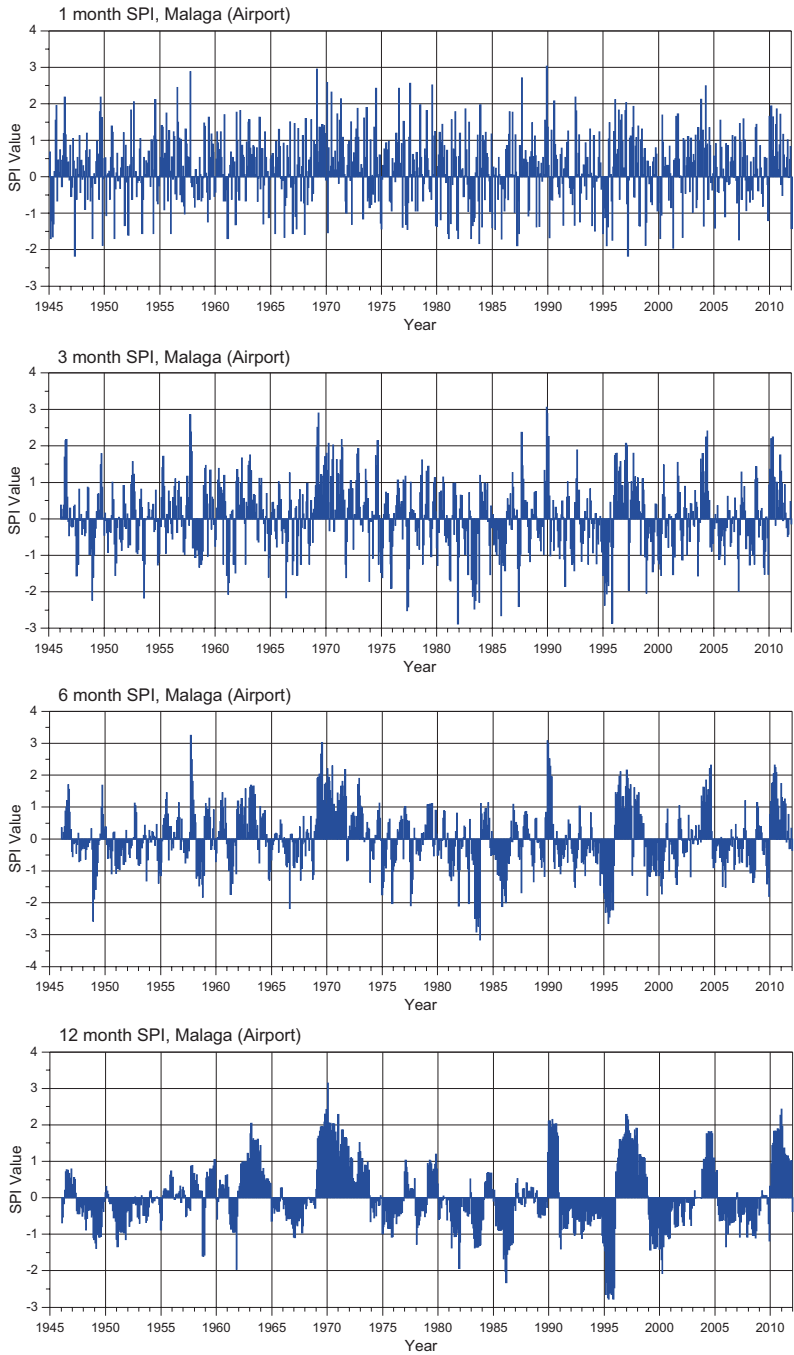


Fig. 4 SPI-values for the temporal scales of 1, 3, 6 and 12 months

Table 2 Severe and extreme drought events properties. (*) % of total drought events recorded at corresponding scale

SPI	N° Events	Duration (month)			Intensity			Magnitude			% (*)
		Min	Mean	Max	Min	Mean	Max	Min	Mean	Max	
SPI-1	48	1	2.71	8	0.74	1.53	2.17	1.51	2.69	7.76	29.8
SPI-3	61	2	4.82	14	0.46	1.52	2.88	1.51	4.31	15.23	55.4
SPI-6	46	2	8.15	24	0.55	1.40	3.17	1.68	6.30	32.14	60.5
SPI-2	23	3	18.43	61	0.52	1.26	2.77	1.67	12.8	62.77	63.9

Once the drought events were identified under the different temporal scales, they were classified as very serious or extreme according to their magnitude. The values obtained of drought features, duration, intensity and magnitude are shown in Table 2

4.1 *Frequency Analysis of Annual Extreme Values of the Drought Intensities and Magnitudes*

Information on magnitudes and frequencies of extreme droughts is essential for water resource planning and management. For this purpose, it is important to analyze the annual extreme values of the drought intensities and magnitudes for different temporal scales. Consequently, the frequency analysis of these extreme values—formed by annual maximum series (AMS) of drought intensities and magnitudes—by the selection and fitting of the most suitable probability distribution functions (PDF) have to be performed for the different temporal scales using L-moments methodology.

The most appropriate selection of PDF for each temporal step is carried out by the graphic procedure derived from diagram of L-moment ratios [29]. They are widely used in the frequency analysis as is illustrated by authors such as Hosking and Wallis [11], Kumar et al. [13], Modarres [19], Saf [24], Núñez et al. [20] and Eslamian et al. [6].

In Fig. 5, the coefficients of L-Skewness and L-Kurtosis of the AMS of magnitude and intensity of droughts at each temporal scale are shown. These values and their theoretical relationships with the distributions generalized logistic (GLO), lognormal (LN3), Pearson type III (P-III), generalized extreme-value (GEV), generalized Pareto (GPA) and Wakeby (WAK) are displayed. It can be observed how the GEV distribution is the most suitable one for fitting AMS of drought magnitudes for 1, 3 and 6-month SPI, and the P-III distribution is the best fitting for 12-month SPI due to the proximity of the curves to L-Cs and L-Ck points of the SPI temporal scales, respectively. With regard to the AMS of drought intensities, it can be observed that GEV distribution is the most appropriate one for the analysis of 1 and 6-month SPI, and P-III distribution the best fit for 3 and 12-month SPI series.

When using AMS, a substantial portion of drought event magnitude and intensity values are those reported as zero, i.e., in wet years. These data sets are censored samples because these zeros have been removed or censored. In the AMS analyzed, one zero was observed in series obtained with SPI-1, four zeros in series SPI-3, 15

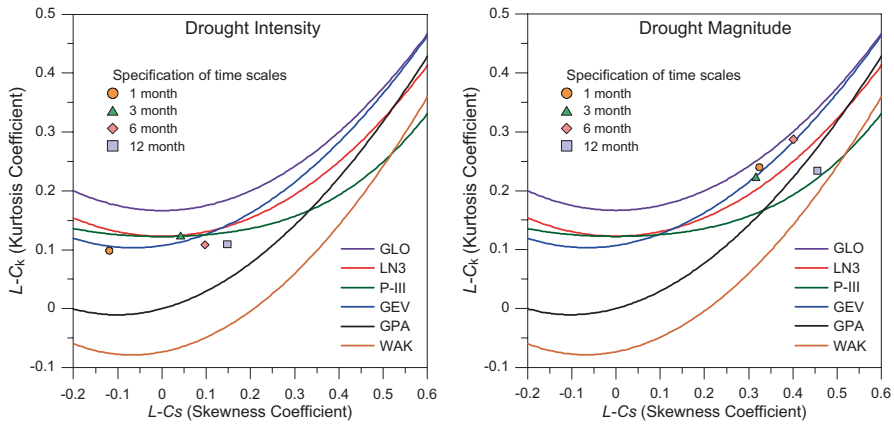


Fig. 5 Diagrams of L-moments SPI annual maximums corresponding to steps 1, 2, 3, 6 and 12 months

zeros in the series SPI-6 and 36 zeros in SPI-12. In the fitting of the censored samples to the selected distribution functions an extra parameter describing the probability q that an observation is zero was considered. The adequate distribution function $G(x)$ was derived for the strictly positive non-zero values using L-moments methodology. The unconditional cdf $F(x)$ for any value $x > 0$ is, then, [26]

$$F(x) = q + (1 - q)G(x) \tag{15}$$

After identifying the most appropriate PDF fit, the SPI-quantiles, expressed as positive values, for different return periods are shown in Fig. 6. These quantiles can be used to characterize the drought features (intensity and magnitude) according to distinct return periods.

5 Conclusions

Natural drought phenomena in Málaga have been analysed by the standard precipitation index SPI, which is the most popular and simplest indicator for the identification and characterization of drought. Although other alternative indexes are available, none presents the universal usefulness of SPI [27]. Its probabilistic features determine its suitability in the risk management and decision analysis.

In this work, the SPI has been calculated for the temporal steps of 1, 3, 6 and 12 months in order to identify the drought events occurring between 1945 and 2011 in Málaga. In addition, durations, intensities and magnitudes of drought events were quantified. The application of the frequency analysis methodology with L-moments allowed to the identification of the most appropriate distributions for the fits of annual extreme values of SPI. The estimation of intensity and magnitude quantiles of drought events for different return periods permit one to evaluate the drought risk,

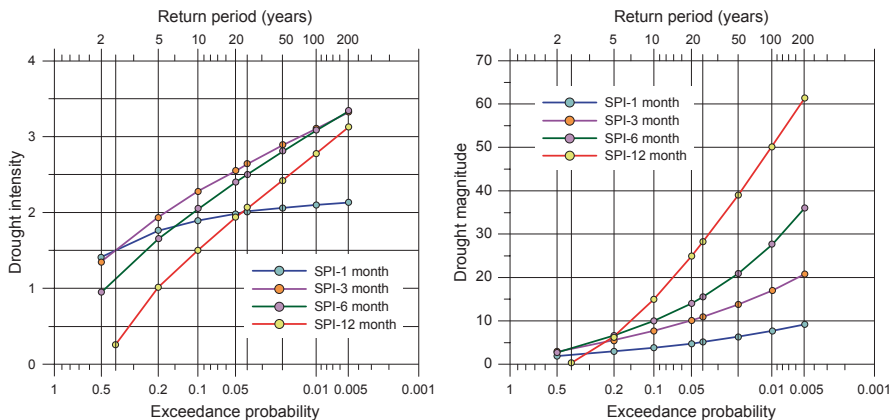


Fig. 6 Quantiles of drought intensity and magnitude

which is of great help with a view to improving water resource policies and management in the study town, Málaga.

Although in this work the statistical modeling of drought event durations was not done, a bivaried frequency analysis will be needed to evaluate the relationships between the magnitude and duration of droughts due to their random nature and high degree of correlation.

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Part IV
Energy Efficiency and Renewable Energy

Decision Support System Software Integrating Geographic Information Systems and Soft Computing to Solve Optimal Location Problems of Renewable Energy Plants

J. M. Sánchez Lozano, J. Á. Jiménez Pérez, M. S. García-Cascales
and M. T. Lamata Jiménez

1 Introduction and Objectives

The main purpose of this paper is to develop a Decision Support System (DSS) into a tool which integrates all the methodology proposed in [5, 7] for solving the optimal placement of renewable energy facilities.

Therefore, it is proposed to apply Multiple Criteria Decision Analysis (MCDA) and Geographic Information Systems (GIS) to find optimal locations for renewable energy installations on the coast of Murcia, by relying on the free software GIS gvSIG 1.10, so as to develop a Decision Support System (DSS) that combines and integrates these disciplines. That is to say, software created serves the mathematical models used in decision making and uses the GIS technology as the database.

With these premises, Optimal Locations v1.0 was born, the name given to the DSS presented in this paper and which has been developed as a software desktop application for Microsoft Windows Operating Systems. The fundamentals of the basic operation of the system, as well as the presentation of the solution to a problem of optimal location, are included in the following sections.

J. M. Sánchez Lozano (✉)

Centro Universitario de la Defensa, Academia General del Aire, Universidad Politécnica de Cartagena, Santiago de la Ribera, Spain
e-mail: [juanmi.sanchez@cud.upct.es](mailto:juanmi.sanchez@ cud.upct.es)

J. Á. Jiménez Pérez · M. S. García-Cascales

Departamento de Electrónica, Tecnología de Computadoras y Proyectos, Universidad Politécnica de Cartagena, Cartagena, Spain
e-mail: joseangel.jp@gmail.com

M. S. García-Cascales

e-mail: socorro.garcia@upct.es

M. T. Lamata Jiménez

Departamento de Ciencias de la Computación e Inteligencia Artificial, CITIC, Universidad de Granada, CP 18071, Granada, Spain
e-mail: mtl@decsai.ugr.es

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2 Optimal Location v1.0

We have developed a Decision Support System (DSS) for the location of renewable energy facilities. Its structure is as shown in Fig. 1. Named Optimal Location v1.0, it is formed by three sub-systems [8]

- Data handling sub-system: Contains information about the problem. In this case, the Data Base is obtained by means of a Geographical Information Systems (GIS).
- Models' handling sub-system: Mathematical models that are used to solve the problem. Optimal Location v1.0 uses AHP and the TOPSIS method with or without fuzzy logic. The weights of the criteria are obtained by means of AHP.
- User interface sub-system: It is the environment in which the user controls the DSS. The interface has been completely designed for the development of Optimal Locations v1.0.

2.1 DSS Data Entry

As already mentioned, one of the elements to be integrated into the DSS object of this paper is the GIS, which will create a database with which to run the DSS. Therefore, Optimal Locations v1.0 uses GIS technology to obtain all the information necessary to deal with the problem of decision making.

The application starts with a file format ESRI Shapefile (.Shp) [10] to perform all functions. This file must have been previously published and analysed in professional GIS software, Optimal Location v1.0 does not have enough power and capabilities to produce geo-referenced information that helps to create new layers, calculate distances, determine areas etc... These tasks must be performed by appli-

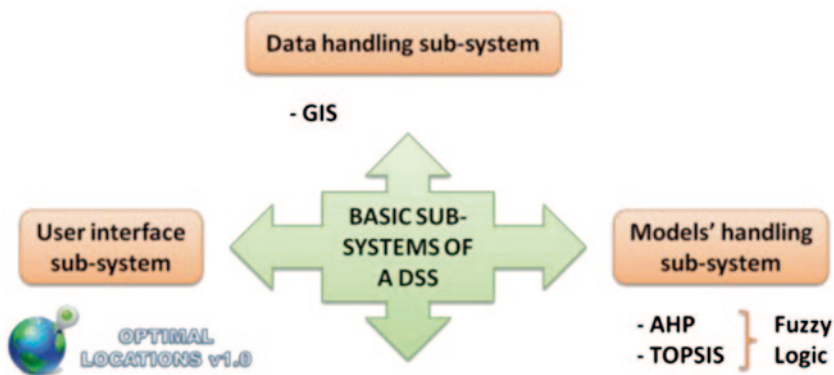


Fig. 1 Structure of decision support system (DSS)

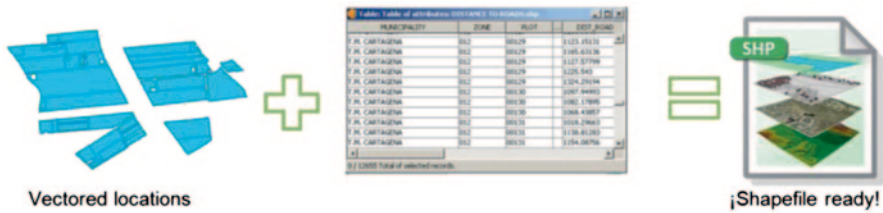


Fig. 2 Composition of a Shapefile for use in optimal locations v1.0

cations such as ArcGIS, gvSIG, Grass, etc. In this particular case, the gvSIG (www.gvsig.org) tool has been employed because it is free software.

While at first sight this may seem a weakness of the program, it may actually be seen as a strength, as it is an aspect that enables flexibility in the type of problem to be solved. The user can create a digital map of any territory and build thematic layers that influence their specific decision making problem.

The idea of starting from a prepared Shapefile can be simplified in the following steps:

1. The user vectorizes the geography of an area, i.e., one that hosts all alternatives influencing the decision making problem of a location. Hence a layer with the representation of the locations that are the subject of decision (eg, plots of a municipality) will be obtained.
2. Subsequently, in the database of the edited layer at least as many attributes as there are criteria involved in the problem should be evaluated. Quantifiable attributes represent criteria in the decision making problem. For example, attributes can be created that include the distance of a particular point from roads or villages, areas of environmental regulations, meteorological parameter, etc. In short, variables affecting the calculation of decision making.
3. With this, a Shapefile is obtained which is ready to be used in Optimal Locations v1.0 (Fig. 2)

On the other hand, for the optimization it is necessary to establish the relative importance that each decision criterion will have by calculating them. Optimal Locations v1.0 allows for such importance offering three ways:

- All criteria have the same weight
- The criteria weights are assigned manually
- Configuring perspectives based on the opinion of a group of experts

The first two are clear; the third one corresponds to the methodology used to conduct the Analytic Hierarchy Process (AHP) [4]. It refers to establishing the pair-wise comparisons required by this method from different surveys by experts in the field of the decision-making problem concerns. It is a pseudo-Delphi technique, in which several independent members without mutual interaction with each other will perform value judgments for pair-wise comparisons. Thereby we aim to obtain



Fig. 3 Input data for the assignment of weights for expert perspectives

a vector of weights of the criteria by each expert and then a single significant vector is obtained by the arithmetic mean of them all.

Calculation of the assignment of weights is done using the AHP method, so the user must enter the program settings of the AHP hierarchy problem. This is explained in greater detail in the following section (Fig. 3).

2.2 *Mathematical Models Implemented*

Optimal Locations v1.0 is based on the TOPSIS method (Technique for Order Performance by Similarity to Ideal Solution) [3] and on the TOPSIS method based on linguistic variables [1] to solve decision making problems. In turn, when calculating the coefficients of importance or weights of the criteria is required, we resort to the use of AHP method. Furthermore, these calculations can be performed using classical logic (crisp) or fuzzy logic [9]. For the latter case, Optimal Locations v1.0 is able to introduce triangular fuzzy numbers. The type of logic configured affects the final result of the problem, which will be closer to reality in the case of fuzzy logic. The user of the program should not worry about it when assigning value judgments, as this is done by linguistic labels.

2.2.1 AHP Method

The program calculates the AHP method to obtain the weight vector of the criteria. The calculation is only required when this vector is not formed manually or by direct assignment of weights: cases in which all weights are equal or keyed in one by one.

The DSS supports two different ways of calculating the AHP, which are called complete AHP and bounded AHP (Fig. 4).

It has been previously suggested that the idea is to follow the path of study in which different experts question through surveys, for value judgments to resolve the problems of decision making in the most accurate way possible. The questions

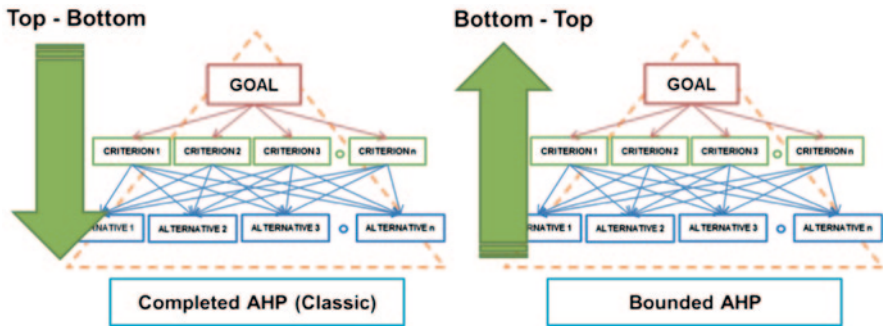


Fig. 4 Assigning weights in the complete AHP and bounded AHP methods

in such surveys are made corresponding to the classical AHP judgments. This is the method of AHP implemented conventionally (Top–Bottom) and has been called the complete AHP method [4].

Moreover, the bounded AHP method [2] can be employed, which sets the value judgments following a Bottom–Top order in AHP hierarchy. This presents two advantages: firstly, it simplifies the number of questions asked by the decision maker surveys, and secondly as a result of the first, inconsistencies in the calculations due to contradictions in the allocation of the judgments by the decision maker are minimized.

Whichever methodology is used, Optimal Locations v1.0 will obtain as many weight vectors as there are perspectives configured. A vector of weights would normally be a compromise among all experts. This is simply the mean of the vectors of the experts.

2.2.2 TOPSIS Method

Once the program knows all the data and configuration information of the problem, it builds a decision matrix and proceeds to execute the steps of the TOPSIS method [3].

Whether the calculation logic is crisp or fuzzy, the end result will be a vector of values, which is the ranking of alternatives or suitable locations with high to low suitability. This will always be according to the configuration of the problem; it should be remembered that this is a subjective process (Fig. 5).

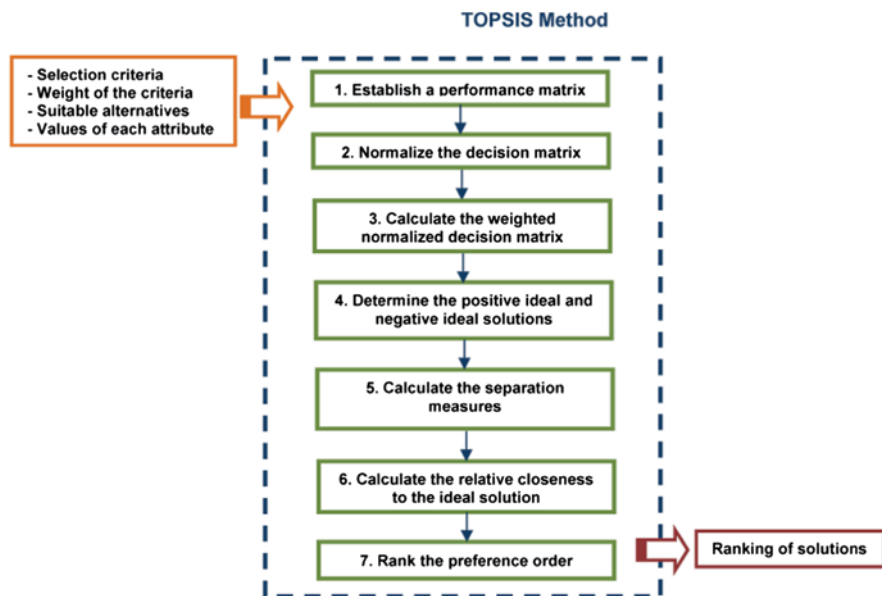


Fig. 5 TOPSIS method execution steps

2.3 Output Results

To show the results of its calculations, Optimal Locations v1.0 is supported on two different forms of representation: through reports (in Pdf and Xls) and using a map viewer.

2.3.1 PDF Results

During the development of the application it was taken into account that the user should have access to intermediate results obtained through the AHP and TOPSIS methods. Thus, the idea was that the user could not only analyse and compare intermediate results, but also had the opportunity to correct inconsistencies in the calculations.

Optimal Locations v1.0 presents the results in PDF because it is a very common format, fully standardized and its license is free. It additionally offers the possibility of transporting information in small files [6].

It should be mentioned that the presentation of results will differ depending on the options the user has configured to solve the problem. For example, graphics that provide the weights of the criteria are presented with bars for crisp logic, whereas for fuzzy logic, series that shape triangular fuzzy numbers are used (Fig. 6).

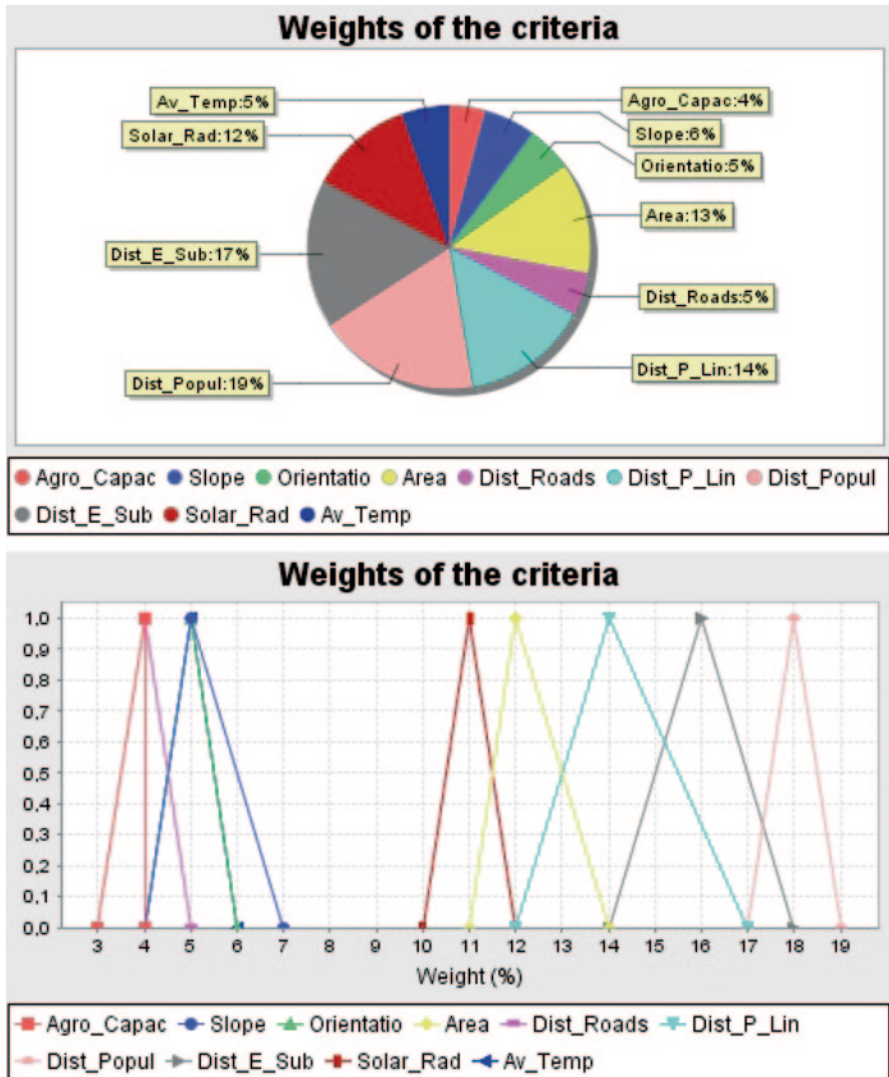


Fig. 6 Graphics to PDF reports for crisp logic (top) and fuzzy logic (bottom)

2.3.2 Xls Reports

Besides the results of weights, the most representative graphics, the relative proximity, etc. the user may need to access and export intermediate calculations performed at each step of the methods implemented. This may prove useful to check the veracity of the results, and to make or obtain more comprehensive analysis indices and graphics. Optimal Locations v1.0 does not do this a priori. This application provides the possibility to generate files in spreadsheet format, specifically with

the Xls, natively used by *Microsoft Excel* in version 2003. It is the most extended format for creating spreadsheets and currently almost all programs for working with this information read this extension. Currently, there are free software distributions which can read and edit these files, such as *Apache OpenOffice*, so this format complies with the initial idea of this project to develop free software.

Therefore, the DSS can export files.Xls for the results of intermediate calculations from the application of the AHP and TOPSIS methods.

2.3.3 Map Viewer

The map viewer allows the user to show the results of the ranking of alternatives graphically that have been obtained by the TOPSIS method. This is possibly the most important feature of *Optimal Locations v1.0*, and which concludes solving the decision-making problem, taking advantage of the powerful tool map display with all Geographic Information Systems (GIS). It is therefore the culmination of combining the Decision Support Systems (DSS) and Geographic Information Systems (GIS).

In the representation of the solution, the system colours locations or plots according to a colour code. Colourless locations (when all layers are visible) correspond to unsuitable locations that have been filtered before performing all calculations (Fig. 7).

It is also of interest for the user to know all the information regarding a location map. This viewer has an *info* button, with a selection pointer that displays data from a particular location: attributes relating to Shapefile data and results related to the TOPSIS method are enabled.

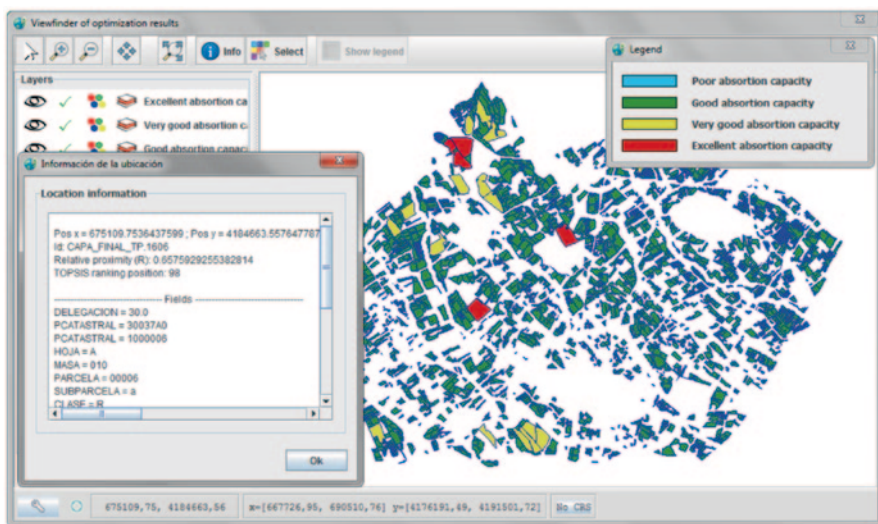


Fig. 7 Representation of the solution of the problem with the map viewer

3 Example of Solving a Problem with Optimal Locations v1.0

3.1 Problem Data

As a test of the power of the program, a problem solution is discussed below.

The resolution of a case study consisting in finding optimal locations is proposed to implement facilities for photovoltaic solar plants on the coast of Murcia (South-east of Spain). To do so, the factors that influence the absorption capacity of such facilities in that geographic area will be assessed.

The starting point is therefore a map in ESRI Shapefile format, composed from different thematic layers obtained through official government agencies. In this map cadastral parcels are shown, where it would be physically and legally possible (once all restrictions have been imposed) to locate renewable energy installations (Fig. 8).

To obtain the suitable surface map the restrictive criteria listed in Table 1 were used [7].

The Shapefile was built with the gvSIG 1.10 free software. This file contains the database or attribute table constructed from thematic layers of the selection criteria.

Similarly, the AHP hierarchy of the decision problem is constructed with the criteria for grouping categories, as defined in Fig. 9.

In addition, to establish the weights of the criteria and solve the problem, a survey was given to three independent experts in the field, who provided the value judgments shown in Table 2.

Finally, the problem is formulated taking into account that:

- The best locations are sought for the installation of solar photovoltaic plants.
- It is to be resolved by the bounded AHP method
- Fuzzy logic is used

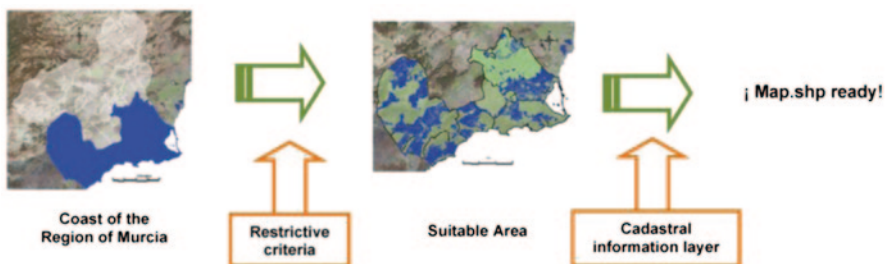


Fig. 8 Composition of the map with cadastral parcels suitable for installing photovoltaic solar plants

Table 1 Restrictive criteria

Category	Criteria
Land typology	Urban land
	Areas of high landscape value
	Protected and undeveloped lands
Communications	Road network
	Railroad network
Infrastructures	Water infrastructures
	Military zones
Orography	Mountains
Hydrology	Watercourses and streams
Patrimony	Archaeological sites
	Paleontological sites
	Cultural heritage
Protected areas	Community interest sites (LICs)
	Areas of special protection for birds (ZEPAs)
	Mediterranean coast
	Cattle trails

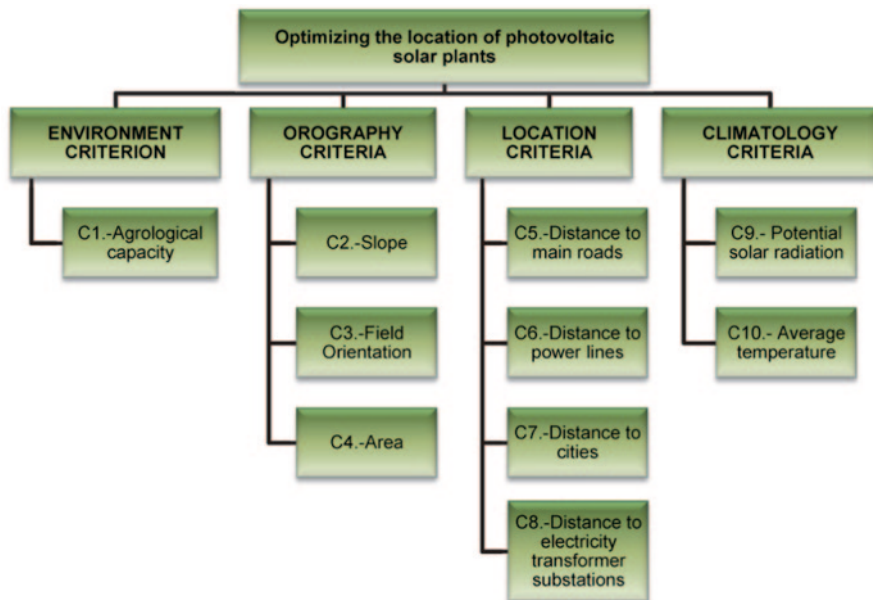


Fig. 9 AHP hierarchy problem location for solar photovoltaic plants

Table 2 Experts valuations

Expert 1		Expert 2	Expert 3
<i>Order of importance of the criteria</i>			
C8		C7	C9
C6		C2	C6
C4		C3	C4
C10		C5	C2
C2		C10	C8
C3		C6	C5
C9		C8	C10
C5		C1	C3
C7		C4	C7
C1		C9	C1
<i>Pairs evaluations of each criterion relative to the greater importance</i>			
1st–2nd	S+I	VS+I	II
1st–3rd	+I	VS+I	II
1st–4th	+I	Ex+I	+I
1st–5th	VS+I	Ex+I	+I
1st–6th	VS+I	Ex+I	+I
1st–7th	VS+I	Ex+I	Ex+I
1st–8th	Ex+I	Ex+I	Ex+I
1st–9th	Ex+I	Ex+I	Ex+I
1st–10th	Ex+I	Ex+I	Ex+I

Linguistics labels: II equally important, S+I slightly more important, +I strongly more important, VS+I very strongly more important, Ex+I extremely more important

3.2 Results

After inserting all the data presented in the previous section, Optimal Locations v1.0 calculates a ranking of alternatives from the best to the worst solution. It will also generate the reports with the information required by the user, Fig. 10.

Finally, the Optimal Locations v1.0 map viewer shows the best solutions using GIS technology. In Fig. 11, we can see that the DSS has found a plot of the municipality of Lorca as the best of all alternatives.

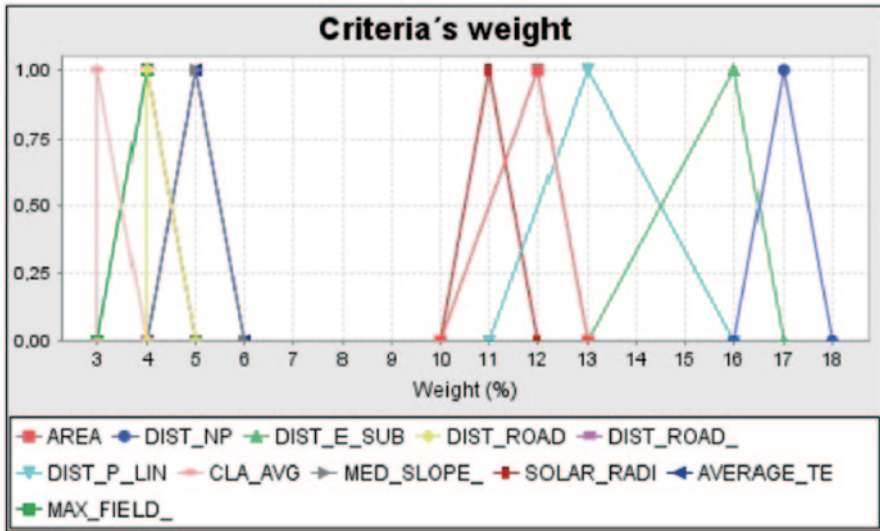


Fig. 10 Graph with the weights of the criteria shown in a PDF report

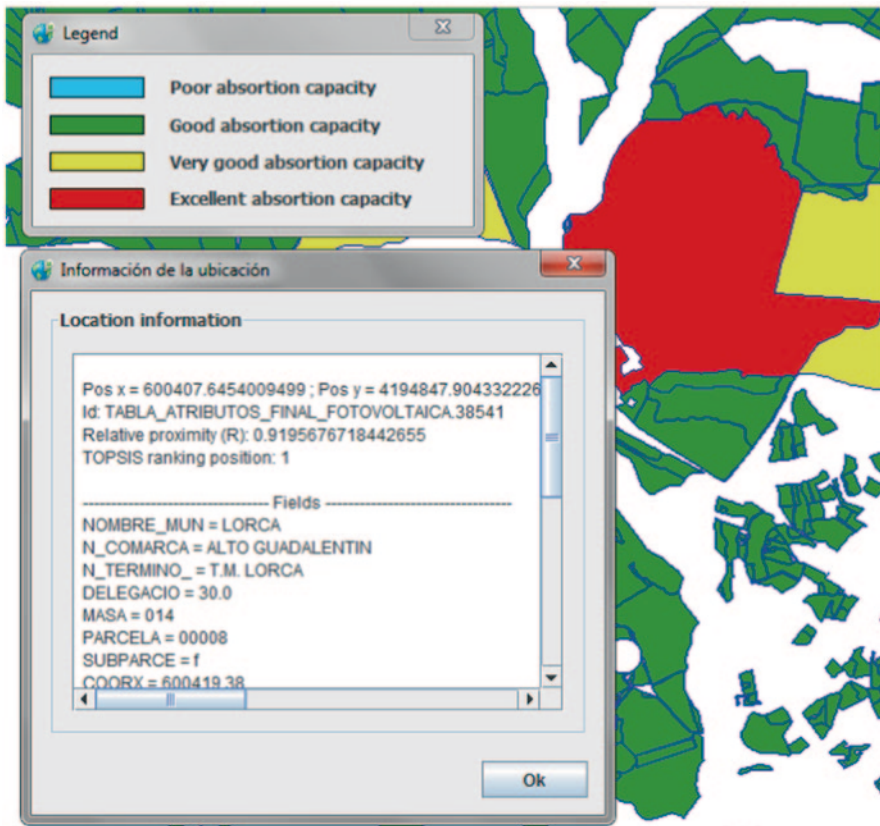


Fig. 11 Graph with the weights of the criteria shown in a PDF report

4 Conclusions

The problem discussed clearly demonstrates the power and effectiveness of Optimal Locations v1.0 to solve location problems. The problem was resolved in less than 10 min with more than 73,000 alternatives as possible solutions. In addition, the operating philosophy of the program leaves the door open to locate facilities of any kind. Therefore, good performance has been obtained with the concept of flexibility, without over complicating the development of the program and its use at the user level.

The importance of a good configuration of the Shapefile should be highlighted because the success of the results produced by Optimal Locations v1.0 totally depends on it. This task is not simple, and in fact may be the most complicated part of the resolution process, because the attributes are constructed from thematic layers that can be difficult for the user to access. Also, the greatest drawback when developing GIS information, which is the constantly changing real world, should be added, entailing a high cost to ensure that the data are always current.

Finally, we must highlight the strong component of subjectivity that affects the resolution of any problems with these tools. From the first step, in which the selection criteria for decision making are chosen, it is introducing a partiality which will affect the final result. To compensate for the possible lack of user objectivity Optimum Locations v1.0 allows different views of experts to be entered. However, who confers the title of “expert” to an individual? Would such an “expert” contextualize the problem correctly? These are questions that the user of the program should always bear in mind.

Likewise, the evaluation of the results is an impartial process. Therefore, to conclude, Optimal Locations v1.0 should be understood as a powerful tool for decision support but never as a substitute for a decision maker, as they will provide good experience and lead to the success of a decision making problem according to the environment under which it is posed.

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Downscaling of Solar Irradiation from Satellite Estimates

F. Antoñanzas-Torres, J. Antonanzas, F. J. Martínez-de-Pisón,
M. Alia-Martinez and O. Perpiñán-Lamigueiro

1 Introduction

Solar photovoltaic energy has experienced a remarkable development in the last few years in some areas of the planet with high solar resource. In many occasions, the access to reliable solar resource data supposes a truly challenge during the promotion, design and risk management stages of the development of a new solar photovoltaic power plant. In those areas without any pyranometer installed nearby to the location selected and with solar irradiation derived from satellite estimates with low spatial resolution, the intra-pixel variability can be excessively high as a consequence of micro-climatic variables and complex topography. Given the high cost of the installation and maintenance of a meteorological station, it usually postponed its installation until the final stage of design or construction, using in the promotion stage satellite estimates and therefore, incurring in a high uncertainty with the consequent risk on the project.

The effect of variability on solar irradiation related to the distance amongst pyranometers has been previously analysed in Spain via estimates obtained with ordinary and universal kriging, concluding that stations further in distance to 40 km

F. Antoñanzas-Torres (✉) · J. Antonanzas · F. J. Martínez-de-Pisón · M. Alia-Martinez
EDMANS Group, ETSII, University of La Rioja, Logroño, Spain
e-mail: antonanzas.fernando@gmail.com

J. Antonanzas
e-mail: antonanzas.javier@gmail.com

F. J. Martínez-de-Pisón
e-mail: fjmartin@unirioja.es

M. Alia-Martinez
e-mail: manuel-julian.aliam@unirioja.es

O. Perpiñán-Lamigueiro
Electrical Engineering Department, EUITI-UPM, Ronda de Valencia 3, CP 28012, Madrid, Spain
e-mail: oscar.perpinan@upm.es

in areas with complex topography are not sufficiently relevant to elaborate accurate solar resource maps [2]. Topography supposes a significant attenuator of solar irradiation, due to the straightforward effect of relieve shades on solar irradiation. Nevertheless, the effect of topography is not usually considered in numerous studies of solar irradiation due to the high computational cost and also the necessity of generating solar irradiation [1, 9, 10] with high temporal resolution, preferable hourly. However, during the last years new solar irradiation databases from satellite estimates have been released with global coverage and with temporal resolution in the range of days or even hours, but with low spatial resolution ($0.25^\circ \times 0.25^\circ$, in the range of 40 km in latitudes of 40°). In other areas of the planet, such as Europe and northern Africa, there are data with spatial resolution of $0.03^\circ \times 0.03^\circ$. The fact that some of these databases are provided on an hourly basis eases the quantification of the topographic effect and reduce it significantly.

In this study it is proposed using the downscaling to increase the spatial resolution of solar irradiation and reduce their errors associated to intra-pixel uncertainty due to topography. Downscaling has been previously described in other disciplines such as hydrology [3], agriculture [16] and also in solar resource evaluation in the Mont Blanc massif [5] and Sierra Nevada [15], being an alternative to geo-statistical interpolation when spatially continuous data is available.

A digital elevation model (DEM) is used as exogenous known variable with higher resolution in order to develop the downscaling. Results are validated with on-ground measured data with pyranometers in three meteorological stations with hourly registers. The study is performed in an area of high complex topography as the Iregua Valley in La Rioja is, with elevations ranged between 400 and 2000 m

2 Data

Solar irradiation data is freely obtained from the climate datasets provided by the Climate Monitoring Satellite Application Facility [4], a satellite-derived irradiation database in which several European meteorological institutes cooperate using Meteosat images.

The spatial resolution in the area studied is $0.03^\circ \times 0.03^\circ$ (equivalent to 3.5×3.5 km) with hourly resolution. The analysis is performed with data of 2005, as per Fig. 1, since it is the year with higher solar irradiation from the period available of CM SAF (1983–2005) and more similar to a typical meteorological year as per what it has occurred during the period 2006–2012. Climate datasets corresponding to global horizontal irradiation (SIS) and beam horizontal irradiation (SID) are selected.

Eventually, selecting the study area from Fig. 1, it is derived the global horizontal irradiation, whose range oscillates between 1498 and 1606 kWh/m²/year (Fig. 2).

Measured data from three meteorological stations (Logroño, San Román de Cameros and Moncalvillo) with complete hourly global horizontal irradiation time series for the year 2005 are used as external validators. In these three stations

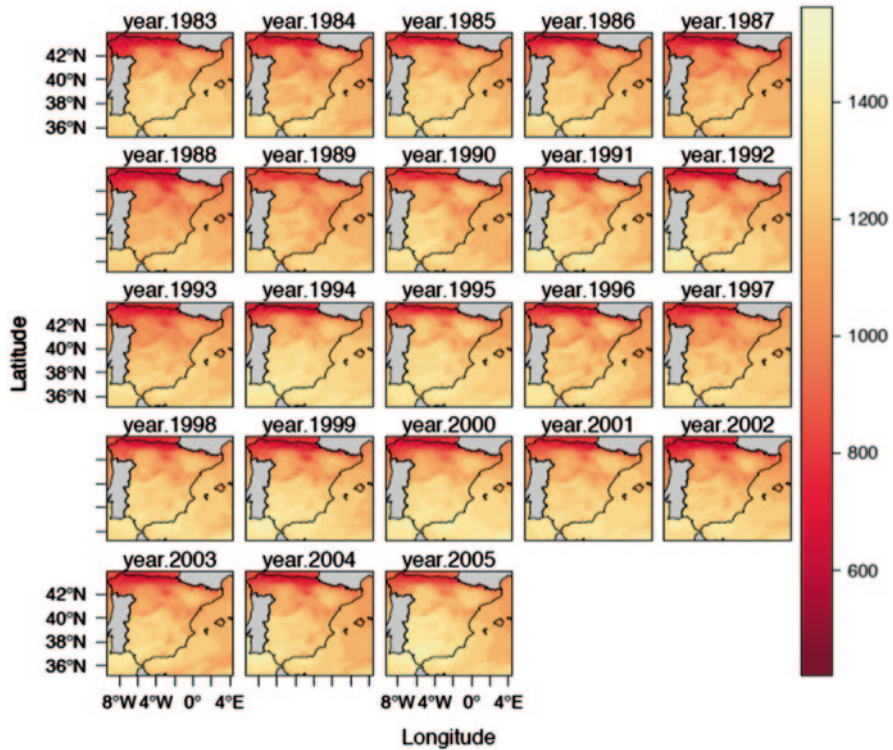


Fig. 1 Beam horizontal irradiation- SID climate dataset from CM SAF

the sky view factor (SVF) is close to the unit (absence of horizon blocking). These meteorological stations have First Class (ISO9060) pyranometers with a maximum error of 5%.

The DEM is freely obtained from the Spanish National Institute of Geography [8] with a spatial resolution of 200×200 m. As it can be appreciated in Fig. 3, the Iregua valley follows a South-North orientation and therefore, it generates significant shades during the sunrises and sunsets.

3 Methodology

The software used is R-Project [14] and the specific libraries raster [7] for spatial calculations and analysis, solar [12] for solar geometry calculations, parallel for parallel computing and rasterVis [13] for spatial visualization of results.

The methodology proposed in this study is shown in Fig. 4. Beginning from global horizontal (GHI) and beam horizontal irradiation (BHI) data, diffuse horizontal irradiation is obtained (DHI). DHI is decomposed into its main components,

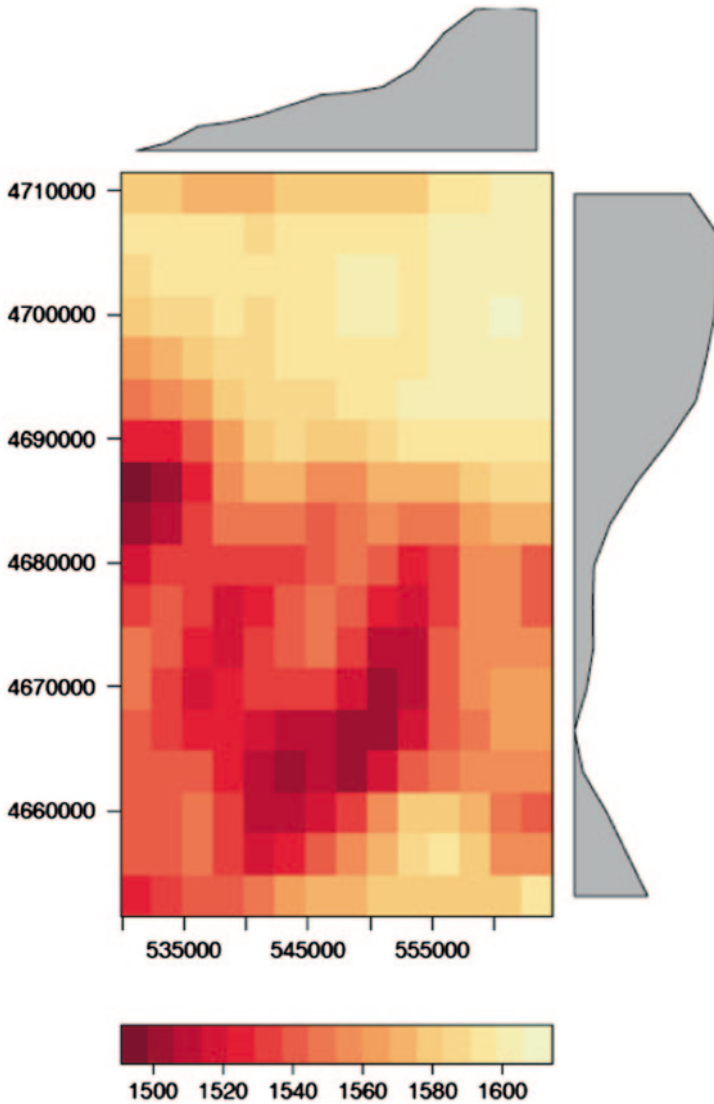


Fig. 2 Annual global horizontal irradiation (kWh/m²) in the area studied

isotropic diffuse irradiation (DHI_{iso}) and anisotropic (DHI_{ani}), as per the anisotropic model by Hay and McKay [6], Eqs. (1–3). This model is based on the anisotropy index (k_t) defined as the ratio beam irradiation to extra-atmospheric irradiation. DHI_{iso} stands for the portion of diffuse irradiation incoming from an isotropic sky and has higher importance in those overcast days. DHI_{ani} or circumsolar is the one incoming from the circumsolar region and can be analysed as beam irradiation [11].

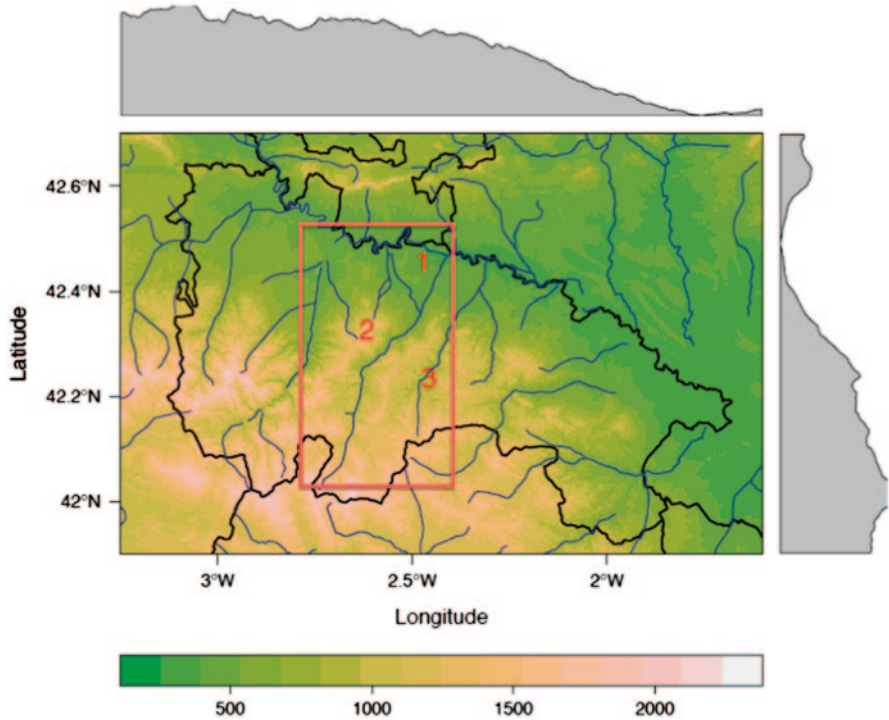


Fig. 3 Digital elevation model of the area studied (within the red box). Numbers correspond to meteorological stations: Logroño (1), Moncalvillo (2) and San Román de Cameros (3)

$$DHI = DHI_{iso} + DHI_{ani} \tag{1}$$

$$DHI_{iso} = DHI \cdot (1 - k_1) \tag{2}$$

$$DHI_{ani} = DHI \cdot k_1 \tag{3}$$

Both diffuse irradiation components and also the beam irradiation are disaggregated into the DEM’s resolution (UTM 200 × 200 m). Nevertheless, given that the DEM’s and irradiation resolutions are in different scales with different geometry, a post-processing is performed denoted as resample, using bilinear interpolation [7]. This process is computationally expensive and can be avoided selecting a DEM with similar geometry to the solar irradiation source.

From this point onwards, it begins the topographical interactive analysis with each of the components disaggregated of solar irradiation. DHI_{iso} is limited by the visible sky portion in each point analysed, denoted as the sky view factor (SVF), as per Eq. (4) defined by Ruiz-Arias et al. [15].

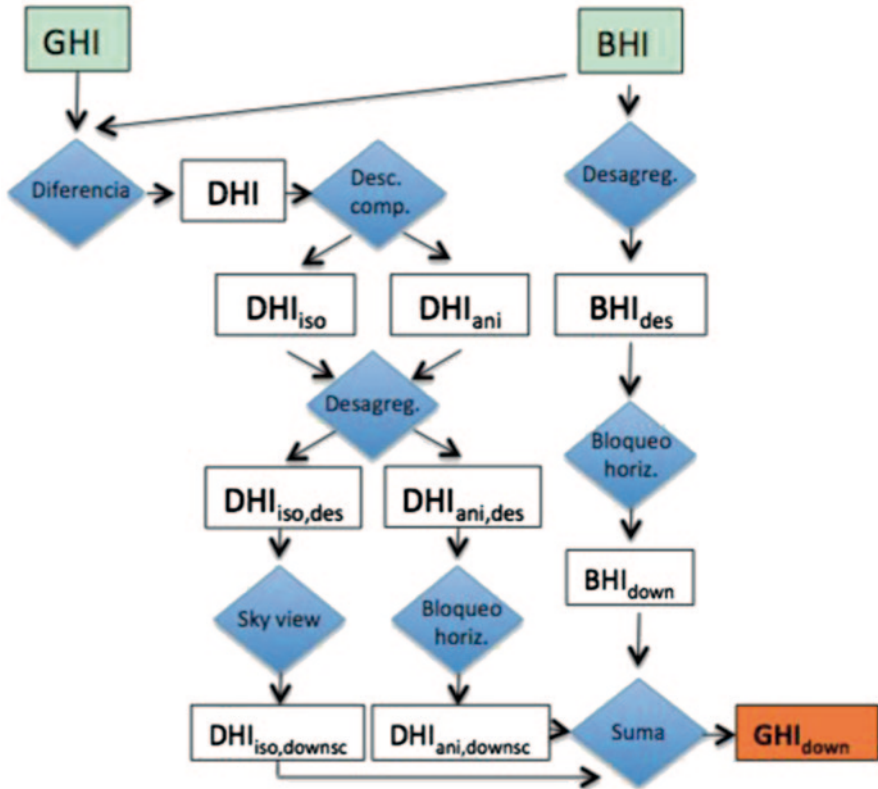


Fig. 4 Methodology proposed in the downscaling

$$SVF = \int_0^{2\pi} \text{sen}^2(\theta_{hor}) d\theta \tag{4}$$

Where θ_{hor} is the horizon angle between the zenith and the horizon. The SVF is calculated using 5° intervals of θ_{hor} around the 360° of sky sphere.

Eventually, the DHI_{iso} incident is defined with Eq. (5).

$$DHI_{iso,downs} = DHI_{iso} \cdot SVF \tag{5}$$

Afterwards, the horizon blocking analysis is performed on DHI_{ani} and BHI. The solar geometry is calculated in 10-min values, particularly, the solar elevation angle and the solar azimuth for the region studied with the spatial resolution of irradiation raster files and afterwards the hourly average of those 10-min values. As a result, spatial rasters are later disaggregated and post-processed with *resample* and bilinear interpolation. The decision of developing the disaggregation once the solar geometry has been calculated leads to a drastic computational time reduction without penalizing results. θ_{hor} corresponding to solar azimuth is compared with the complementary angle of solar elevation (zenith angle). If the zenith angle is greater than

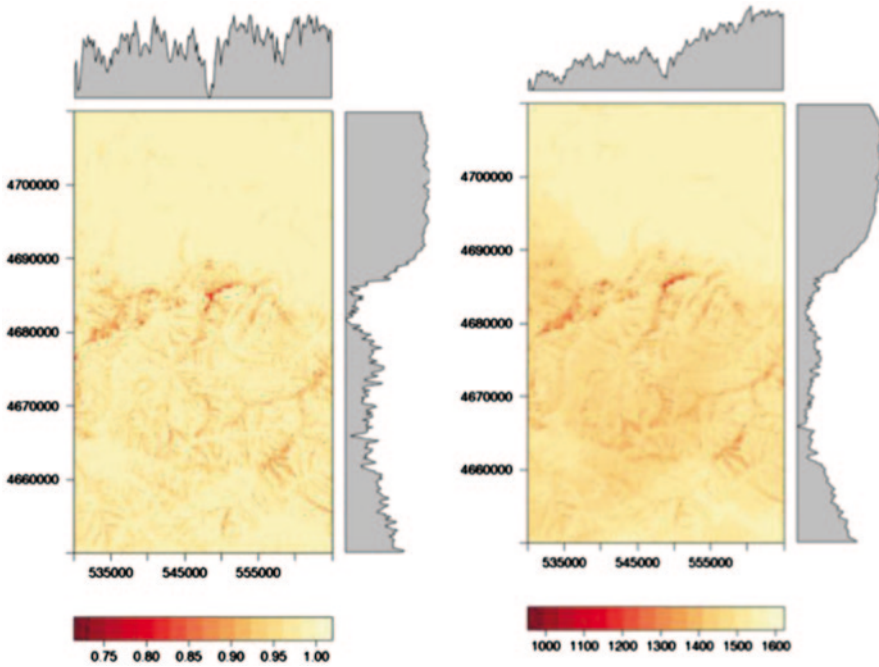


Fig. 5 Left: SVF. Right: Downscaling of annual GHI in kWh/m²

θ_{hor} , it implies that horizon blocking exists and therefore, no BHI either DHI_{ani} is received. Eventually, the sum of components $DHI_{ani, downsc}$, $DHI_{iso, downsc}$ and BHI_{downsc} constitutes the downscaled global horizontal irradiation.

4 Results

The sky view factor is an indicator that leads a better numerical understanding, on which sense DHI_{iso} is reduced. In Fig. 5-left, it is visualized the orography of the region studied, which is distinguished between the north part of the figure (corresponding to the Ebro river) and the south part (relative to the Cameros mountains) with a range of SVF between 0.73 and 1. Those areas with a darker color imply a lower portion of visible sky.

Figure 5-right shows the annual sum of global horizontal irradiation downscaled with spatial resolution of 200×200 m. The variation of GHI in the area studied is in the range of 994–1580 kWh/m²year.

Table 1 shows the estimates of GHI by CM SAF without downscaling (GHI_{cmsaf}), and after the downscaling (GHI_{down}). It selected the relative error as statistical indicator for validation of results as per Eq. (6)

Table 1 Comparative of results

Estación	SVF	GHI _{med}	GHI _{cmsaf}	GHI _{down}	rE _{cmsaf}	rE _{down}
Logroño	0.9985	1504	1592	1559	5.8%	3.6%
Moncalvillo	0.9995	1330	1498	1473	12.6%	10.7%
San Román	0.9754	1504	1537	1488	2.2%	-1.1%

$$rE = \frac{GHI_{est} - GHI_{med}}{GHI_{med}} \quad (6)$$

Errors are reduced in the positions of the three meteorological stations even though the SVF in these positions is very high. In the case of Logroño station, error is indeed reduced below the tolerance of the pyranometer (5%).

5 Conclusions

The high importance of estimating solar irradiation with precision in a location or geographical area is fundamental for the promotion and development of solar photovoltaic technology. In general, the access to reliable solar irradiation data measured with pyranometers in meteorological stations is very complicated and requires the proximity of these stations to the location selected and a correct calibration of their sensors. Estimates obtained from satellite images supposed an alternative to on-ground pyranometers, being their spatial resolution very gross in wide areas of the planet, but not their temporal resolution that can be up to hourly.

The downscaling supposes a very useful tool to reduce errors between satellite-derived estimates and measurements with pyranometers in the Iregua valley, taking into account the horizon blocking and the SVF. It is remarkable that meteorological stations in which the study is validated are located in areas with high SVF and even though, the annual relative error has been reduced in average 2% (Moncalvillo and Logroño), as a consequence of a better adjustments of DHI_{iso} .

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Self Energy Production by a Floating Photovoltaic System Covers for Irrigation Reservoirs

M. Redón-Santafé, C. M Ferrer-Gisbert, J. Ferrán-Gozálvez, J. B Torregrosa-Soler, F. J Sánchez-Romero, P. S Ferrer-Gisbert and E. Pons-Puig

1 Introduction

Solar pumps have become common since the development of photovoltaic technology and have been favoured by a growing awareness of the environmental benefits of renewable energies [2]. However, the seasonality inherent in irrigation lengthens the repayment period for these investments. Given this fact, the possibility of selling the energy produced during inactive periods is a promising approach for facilitating the development of these facilities.

The elimination of premiums for the installation of photovoltaic systems has aroused considerable interest in the ‘own use’ of generated power by installers and developers. Although the legislation governing such facilities is currently confusing

M. Redón-Santafé (✉) · C. M Ferrer-Gisbert · J. Ferrán-Gozálvez · J. B Torregrosa-Soler ·
F. J Sánchez-Romero
Departamento Ingeniería Rural y Agroalimentaria, Universidad Politécnica de Valencia,
Valencia, Spain
e-mail: miresan@agf.upv.es

C.M Ferrer-Gisbert
e-mail: caferrer@agf.upv.es

J. Ferrán-Gozálvez
e-mail: jjferran@agf.upv.es

J.B Torregrosa-Soler
e-mail: jbtorreg@fis.upv.es

F.J Sánchez-Romero
e-mail: fcosanro@agf.upv.es

P.S Ferrer-Gisbert
Departamento Proyectos de Ingeniería, Universidad Politécnica de Valencia, Valencia, Spain
e-mail: pferrer@dpi.upv.es

E. Pons-Puig
Isigenere S.L, Alicante, Spain
e-mail: ponspuig@isigenere.com

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and regulation of the ‘net balance’ of energy is needed, the current regulatory framework in Spain supports total or partial own use of energy [5].

Under these two assumptions—solar powered irrigation and own use—this paper examines the technical and economic feasibility of investing in a floating photovoltaic system (FPS) and using the energy produced to operate irrigation pumps.

The FPS system is designed to simultaneously obtain the advantages of covering the surface of a reservoir and feeding electricity into the grid (if existing premiums economically discourage the alternative of own use). A description of this system was presented at last year’s AEIPRO International Congress on Project Management and Engineering [4]. In this current paper, the feasibility of the system is studied from the perspective of own use, and several design enhancements are described.

2 Methodology

To analyse the feasibility of using the energy generated by an FPS, a scheme of work is proposed based on powering a set of pumps managed by a farmers’ association of irrigators. The following points are addressed:

- Description of the current situation of the irrigation network.
- Technical development of the FPS system.
- Determination of the hydraulic variables and energy characteristics in the current irrigation network.
- Determination of hydraulic and energy variables when generating energy through the FPS
- Energy cost comparison between two scenarios.

2.1 Case Study

The Virgen de las Nieves irrigation association in Aspe (Alicante, Spain) has an irrigation area of about 3520 ha. In recent years, thanks to national and regional modernisation programs, an on-demand drip irrigation system has been installed throughout the irrigated area.

The principal hydraulic scheme of the irrigation network serves five sectors (Fig. 1): (i) three areas are irrigated by gravity from sufficiently sized reservoirs (*Rollo, Federal, Rabosero* sectors); (ii) the other two sectors are irrigated by direct injection pumping (*Tolomo Cota Alta* and *Rollo Cota Alta* sectors).

An analysis of each of the sectors is performed following the Clement [1] model for calculating flows. The network was designed using a system of multiuser hydrants. A pressure equal to or greater than 30 mca is guaranteed at each of the hydrants and outputs lead to the farmers’ fields.

The studied case (in the *Tolomo Cota Alta* sector) is fed from the *El Tolomo* reservoir. Table 1 and Fig. 2 summarise the main features.

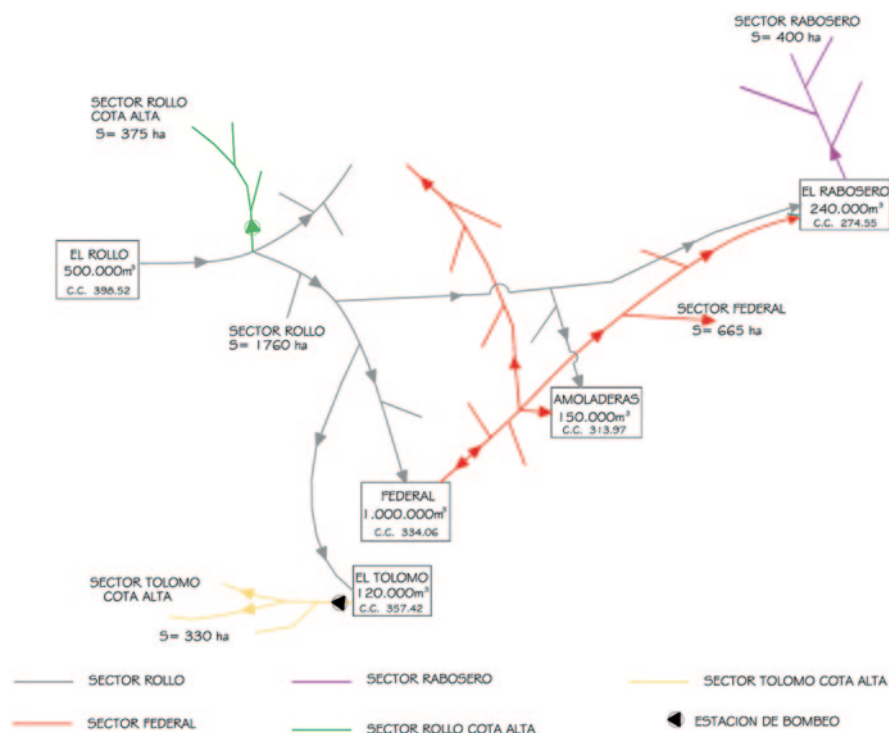


Fig. 1 Hydraulic diagram of the Virgen de las Nieves network

Table 1 Main characteristics of El Tolomo irrigation sector

Irrigation network	
<i>Supply from El Tolomo reservoir using injection pumps and filter station installed near reservoir</i>	
Irrigation surface	330 Ha
Total multiuser hydrants	49
Pressure range of pumps	60–90 mca
Flow range	0–345 l/s
Pumps	3 variable electric pumps
<i>El Tolomo reservoir</i>	
Type	Loose material waterproofed with geomembrane
Maximum height	357 msnm
Bottom	340 msnm
Reservoir depth	12 m
Inner slope	2.2 H/1V
Reservoir capacity	122.000 m ³
Surface	16,300 m ²



Fig. 2 Tolomo Cota Alta irrigation sector

2.2 Technical Development of the FPS

The FPS involves the creation of a structure floating on the water surface that consists of polyethylene units each housing a single PV panel. This concept is the primary difference from the design presented in Ferrán et al. [4]. The polyethylene floats measure $1850 \times 1200 \times 250$ mm with inclinations of $0\text{--}5^\circ$ (see Fig. 3). The entire surface is anchored along the perimeter and openings are arranged to enable the modules to fit within the concave profile of the reservoir if the level of the water varies.

In contrast to the previous version, this system does not require a metal support structure, elastic mooring, or articulated metal anchors. The reduced profile of the PV panels ($5\text{--}10^\circ$ less) reduces wind loads and therefore the size and cost of the perimeter foundations (Table 2).

Fig. 3 Floating unit



Table 2 Main FPS characteristics

Geometric characteristics: El Tolomo reservoir	
Useful depth	11 m
Water surface (11 m)	15,166 m ²
<i>Key photovoltaic cover features (FPS)</i>	
Dimensions of floating MDPE module	1.85 × 1.20 m ²
Number of floating modules	6831
Number of floating modules in corridor	683
Number of useful floating modules (with PV panel)	6148

3 Results

3.1 Calculation of Current Energy Consumption and Costs

Table 3 shows energy costs of the direct injection system for one, two, or three pumps according to the 3.1.A tariff rate [6]. Costs for power and energy are calculated for each operating scenario when considering an equal spread of operating hours for each period.

Table 4 summarises the hydraulic characteristics of the calculation model and the energy costs of the direct injection system used in the Tolomo Cota High irrigation sector for the three operating scenarios (one, two, or three pumps) and at maximum demanded water pressure.

3.2 Calculation of Current Energy Consumption and Costs

Table 5 summarises the PV calculations for a complete coverage of the water surface with the FPS. Peak power of the PV system is shown. Radiation data and annual production data for a south-facing system with a 5° tilt and a PR of 75% for the location of the reservoir [3] are obtained. The theoretical nominal power for the total own use scenario is also calculated—observing that the resulting power is much less than when the reservoir is totally covered.

Table 5 shows that the total energy produced by the FPS is about four times greater than the power required by the injection pumps. There is therefore a surplus production of slightly more than 1467 MWh/year and this opens the possibility of selling the power to the grid or using it in other installations managed by the irrigation association.

Finally, we estimate the economic viability considering the total cost of the FPS as 1.55 €/Wp as shown in Table 6.

Table 3 Calculation of energy costs

Pump station			
Number of pumps	3	2	1
Total Q (m ³ /s)	0.35	0.25	0.13
Annual volume (m ³)	1,650,000	1,650,000	1,650,000
Operation time (h/year)	1328.50	1833.33	3666.67
Operating months	8	8	8
Daily operation time (h/day)	5.54	7.64	15.28
Power (kW)	406.27	294.40	147.20
Consumption (kWh/año)	539,733.33	539,733.33	539,733.33
Supply voltage (kV)	20	20	20
Rate tariff	3.1.A	3.1.A	3.1.A
<i>Power (€/kW year)</i>			
Period 1—P1	25.59	25.59	25.59
Period 2—P2	15.78	15.78	15.78
Period 3—P3	3.62	3.62	3.62
<i>Energy (€/kWh year)</i>			
Period 1—P1	0.13	0.13	0.13
Period 2—P2	0.12	0.12	0.12
Period 3—P3	0.08	0.08	0.08
<i>Operating time per period (h/year)</i>			
Period 1—P1	442.83	611.11	1,222.22
Period 2—P2	442.83	611.11	1,222.22
Period 3—P3	442.83	611.11	1,222.22
<i>Energy consumed (kWh/year)</i>			
Period 1—P1	179,911.11	179,911.11	179,911.11
Period 2—P2	179,911.11	179,911.11	179,911.11
Period 3—P3	179,911.11	179,911.11	179,911.11
Total energy consumed	539,733.33	539,733.33	539,733.33
<i>Total power cost (€/year)</i>			
Period 1—P1	10,395.96	7533.31	3766.65
Period 2—P2	6410.91	4645.59	2322.79
Period 3—P3	1470.09	1065.29	532.64
Total power	18,276.97	13,244.18	6,622.09
<i>Total energy cost (€/year)</i>			
Period 1—P1	22,974.65	22,974.65	22,974.65
Period 2—P2	21,049.60	21,049.60	21,049.60
Period 3—P3	14,752.71	14,752.71	14,752.71
Total energy	58,776.96	58,776.96	58,776.96
<i>Total energy costs (€/year)</i>			
Total energy cost	77,053.93	72,021.14	65,399.05
Other concepts (3.262%)	2513.50	2349.33	2133.32

Table 3 (continued)

Pump station			
Electricity tax (4.864%)	3870.16	3617.38	3284.77
Reactive charges and excess power	7705.39	7202.11	6539.90
VAT (21 %)	19,140.03	17,889.89	16,244.98
Total energy cost (€/year)	110,283.00	103,079.85	93,602.03
Total energy cost (€/m ³)	0.07	0.06	0.06
<i>Other ratios</i>			
Energy cost (€/kWh)	0.20	0.19	0.17
Volumetric energy cost (kWh/m ³)	0.33	0.33	0.33
Water cost (€/m ³)	0.07	0.06	0.06

Table 4 Summary of hydraulic calculation and energy costs

System: Direct injection	3 pumps	2 pumps	1 pumps
Area (ha)	330	330	330
Flow (l/s)	345	250	125
Manometric suction (m.c.a)	90	90	90
Pump power (kW)	406.27	294.40	147.20
Flow (m ³ /h)	1242	900	450
Annual volume per ha (m ³ /ha year)	5000	5000	5000
Total volume (m ³ /year)	1650,000	1650,000	1650,000
Annual operating hours (h/year)	1328.50	1833.33	3666.67
Annual consumption (kWh/year)	539,733.33	539,733.33	539,733.33
Consumption months	8	8	8
Monthly operational hours (h)	166.06	229.17	458.33
Daily operating hours (h)	5.54	7.64	15.28
Annual cost (€)	110,283	103,079.85	93,602.03
Energy cost (€/kWh)	0.20	0.19	0.17
Water cost (€/m ³)	0.066	0.062	0.056

Table 5 Calculation of energy costs

Concept	Number
Number of PV modules (units)	6148
Power of single PV panel (kWp)	235
Total peak power (kWp)	1440
Annual production: (kWh/year)	1390
Nominal PV power (1kWp)	–
Nominal power: 100% of energy demanded by injection pumps (irrigation system) (kWp)	388.3
Annual FPS energy production (kWh/year)	2,007,160
Own consumption: injection pump energy demanded (kWh/year)	539,733.33
Difference (kWh/year)	1,467,426.67

Table 6 Estimated FPS investment

Concept	(€/Wp)
Photovoltaic modules	0.55
Inverter	0.18
CC/CA installation	0.06
Monitoring system	0.01
Floating system	0.50
Total	1.30
Overhead+ Industrial profit (19%)	0.25
Total investment	1.55

Table 7 Economic study

	Scenario 1 $P=1440$ kWp	Scenario 2 $P=507$ kWp
Savings (€)	103,079.85	103,079.85
Income (€)	73,371.33	8,249.83
Total (€)	175,415.19	111,329.69
Investment (€)	2,238,200	785,850
Repayment period	12.68	7.06

Table 7 summarises the economic study performed considering two scenarios for PV panel installations on the surface of the reservoir:

1. Complete coverage with a maximum installed capacity of 1440 kWp. Part of the energy is used for own consumption with the energy saved priced at 0.19 €/kWh (middle price from the scenarios calculated for Table 3). The surplus power is fed into the grid for an income of 0.05 €/kWh.
2. Partial covering of the reservoir which is sufficient to produce power required for direct pump injection in the irrigation network. A real power calculation of 1.25 times the nominal power is used to consider the transient effects of start-up. Prices for energy saved and generated are the same as in the previous scenario.

Table 7 shows the repayment period for the investment at constant prices and the relative advantageousness of Scenario 2 is clear—thanks to a better fit for the energy needed for own use and a smaller initial investment that substantially reduces the repayment period.

However, if we project that energy prices rise constantly at 5% per annum then the two scenarios draw closer—given that the investment will be recovered in year 11 in Scenario 1 while Scenario 2 remains the same as under constant prices. Finally, the internal rate of return of the investment for a horizon of 25 years is 9% for Scenario 1 and 21% for Scenario 2.

4 Conclusions

This article calculates the energy costs for three scenarios for the conventional energy consumption (using existing electrical tariffs) of a group of irrigation pumps in the Tolomo Cota Alta sector of an association of irrigators (Virgen de las Nieves de Aspe) near Alicante in Spain.

The potential for generating sustainable energy by designing a floating photovoltaic system (FPS) on the water surface of El Tolomo reservoir is calculated—including the infrastructure costs for the accumulation and regulation systems that feed the injection pumping station.

Completely covering the water surface would generate slightly more than 1467 MWh/year—and the pumps would only demand some 25% of this energy. Accordingly, the saving produced by the production of power for the pumps can be added to the income generated by selling excess power to the grid. Extremely attractive static repayment periods for the investments are thus produced for the scenario of completely covering the water surface, as well for the scenario of only partially covering the surface and just meeting the needs of irrigation system. Economic viability is further enhanced if energy prices are projected to rise: with a resulting rate of internal return of 9% for complete coverage and 21% for partial coverage.

From the point of view of the management of the irrigation network, it should be noted that power production scenarios using only PV would require modifying the irrigation timetables to concentrate activity around daylight hours. Future studies on this issue will consider integration with other renewable energies, or the use of conventional energy reserves during periods of little or no sunlight.

Finally, the energy and economic scenarios created by the generation of energy using FPS are very attractive given that the association of irrigators has other nearby installations that could use the excess generated power and so enjoy substantial savings in power costs.

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Part V
Rural Development and Development
Cooperation Projects

Leadership Development in Rural Development Projects: A Case Study in an Aymara Women Organization in Puno (Peru)

S. Sastre-Merino

1 Introduction

The focus of development projects in rural areas has undergone significant changes in recent decades, from a technocratic and top-down vision (which led in many cases to conflicts and lack of social integration in communities) to one in which local people acquire a fundamental role in the management of their resources and projects. In this context, the new models of planning and management of development projects rely on local people and often include among their objectives the development of local capacities and leadership. Both are considered essential for enhancing the sustainability of the actions, as they improve the confidence to develop local initiatives and the decision-making process about managing natural, human and cultural resources [15]. With the right skills and good leadership, endogenous and sustainable development can be generated. According to Adebo [1], for community development projects in rural areas to be successful, influential local leaders must be involved, or otherwise, they may undermine the progress of these projects. Once involved, the process of developing leadership collectively understood begins, which some authors have considered as a similar concept to empowerment [16, 44].

In that vein, in Europe, the LEADER rural development model included among its strategies, leadership development in the territory to generate rural development. It was considered that the added value of projects in rural areas was not only the wealth generated but capacity building and leadership development in the territory. This comprehensive approach, focused on the territory as a unit, contributes to economic and social development of rural areas, since it produces a commitment of the population to the future of their territory, favouring the development of

S. Sastre-Merino (✉)
Departamento de Proyectos, ETSI Agrónomos, Universidad Politécnica de Madrid,
Avenida Puerta de Hierro, 2. CP 28040 Madrid, Spain
e-mail: susana.sastre@upm.es

local institutions that integrate different groups and take into account the different resources [11]. Thus, this approach aligns with the definition of sustainable development. Other worldwide institutions have also considered the importance of leadership and capacity building for rural development, such as United Nations Development Programme (UNDP) [43].

Leadership development has been conceptualised from individual approaches, focusing on the attributes or capabilities of the leader, or from a more collective perspective, taking both the leader and the followers. Hence there is a difference between leader development (at the individual level, focusing on his/her personal leadership skills, behaviours, values, etc.) and leadership development (conceptualised as a process that includes connections between leaders of a system, interpersonal relationships, social influence processes, team dynamics, context, etc.) [6, 17]. According to this latter view, both the leader and the followers have important roles in the leadership process, although, usually, we overestimate the role of the former and underestimate that of the latter [26].

In the case of the leader-centered approaches, their conceptual origin corresponds to the Great Man theories [38], trait and skills theories [25, 28, 30]; behavioural theories—they lead to leadership styles: autocratic, democratic and “laissez-faire”—(developed by the University of Ohio and Michigan, Blake and Mouton (managerial matrix); Rensis Likert, Tannenbaum and Schmidt [39]); situational leadership—they consider that the leader changes style depending on the situation—(Hersey and Blanchard) or contingency theories—probabilistic models that propose behaviours with higher probability of success depending on a wide range of contingencies (Fiedler; Hersey and Blanchard), including the path-goal theory—according to which effective leaders must motivate subordinates to accomplish their goals at work [22].

In the case of approaches that are more focused on process and relationships, various theories support them, such as transactional leadership theory—the leader guides or motivates, by reward and punishment, his followers in the direction of the set goals [12] and the leader–member exchange theory—he does not exercise a single leadership but depends on the interaction with each subordinate [40]; transformational leadership—promotes a relationship of mutual stimulation between a leader and the followers, resulting in a transformation in the scale of values, attitudes and beliefs of their followers, for which the leader must have charisma [5, 8]; authentic leadership—process related with values, purpose and integrity, that generates in leaders and followers a positive behaviour and encourages self-development [4, 29]; complex leadership—defined by interrelationships, stimulates creativity, learning and adaptive capacity with a bottom–up approach to find solutions to complex problems [41]; relational leadership—process of social influence through which an emerging coordination and a change are constructed and produced [40]; or distributed leadership—leadership is exercised by the whole group and not just the leader [10, 21, 34, 37].

Traditionally the dominant approach was the individual, focusing on building intrapersonal skills, although as Bartol and Zhang [7] indicated, an effective leader

needs to develop interpersonal and relational capabilities that allow, not only, to accumulate human capital but also social and systemic or relational capital. The capital is accumulated from direct links with various people on the basis of reciprocity and social exchange. When positive and support relationships are built, including those between leaders and followers, a flow of goodwill and changing attitudes and behaviours is generated. The system capital refers to the ability to appeal to and exploit a network of relationships to access, not only, to the resources provided by direct links but indirectly to those given by the ties of others, in a broad sense of the network. Therefore, networking is an important way to improve the social and system capital of an organization, since much of the capital is embedded within networks of mutual knowledge [7].

In this study the focus is on leadership as a collective process, in which both leaders and followers can develop their leadership skills [7] (according to Kellerman [26], these skills are not that different), which are considered of interest to rural development. In this context often the authority and power of the leaders are not given for formal positions, as in business organizations, but by their social relationships, through which they create common goals to improve the welfare of the community [2]. Even in many rural communities, leadership is shared and elected through decisions in assemblies, so that approaches that include the relationships between leaders and followers in their analysis are considered appropriate in such context. As a result of rural development projects with a focus on leadership development, it is expected to help members of the community to develop the necessary skills to design and implement their own programs to improve the community welfare. The authors note that in many cases, communities have the resources necessary for their well-being but lack the leadership capacity necessary to properly utilize these resources [2].

Leadership development and its relation to capacity development is discussed in the case study of a project to develop leadership skills with an organization of Aymara women artisans in six districts of Puno (Peru), formed by 21 groups and 300 women. The project has been underway since 2008 through the collaboration of GESPLAN group from the Technical University of Madrid, the NGO “Design for Development” and the Aymara Women Coordinator (CMA). The overall project objective is “to increase the technical and entrepreneurial capacity of women entrepreneurs of Aymara communities in the region of Puno (Peru) to improve their level of independence becoming leaders in the sustainable development of their communities and relief of poverty” [14]. For this, and in agreement with the local organization, they are developing two main priority lines: support in the development of the craft activity and the establishment and management of a revolving fund to finance their activities and other innovative projects. The model considered in the project planning, Working With People (WWP) [13], with a focus based on the central role of local people, their values and culture, favours a distributed and transformational leadership style, through which women are developing their skills to lead the process of improving the welfare of their families and communities.

2 Leadership Development and Its Relationship with Capacities Development

The relationship between leadership and capacity development is essential, according to UNDP [43], since the promotion of good leadership maximizes and protects investments in capacity building at the individual and organizational level in a given context. Others, such as UNDP [42], Odeh and Bruning [32], James [24], Davies [16] and Allen and Lachapelle [2] also point out that leadership is essential to the development and growth of capacity. According to UNDP [43] and James [24], bad leaders can spoil decades of effort and serve their own interests, while successful leadership is based on relationships and trust, mobilizes energies and resources in a sustainable manner, generates commitment and ownership of the goals and this result in an improvement of relations and effectiveness among teams. Davies [16] defines good leadership in terms of building the capacity of rural communities to develop sustainable futures at a social and economic level.

Many studies have associated certain skills with leadership, different according to theories upon which they rely, and which determine the design of leadership development processes. Theories of the great man and traits associate intelligence, self-confidence, determination, integrity and sociability to the leader. As for the theory of skills, McCall and Lombardo [30] identify four traits associated with success or failure: emotional stability and composure, recognition of errors, good interpersonal skills and intellectual breadth. Kouzes and Posner [28] in turn, determined the seven characteristics most admired by followers of their leaders, and these are: honesty, look ahead, be competent, inspiring, intelligent, fair and tolerant [33]. Katz [25] suggests that effective leadership requires three basic personal skills: technical, human (team work, work with other groups, effective communication) and conceptual (analysis capability of the whole system and its context), with different relevance depending on the job (senior management, management or supervisors).

Within behavioural theories, Battilana et al. [9] consider that there are two different but related groups of skills: task-oriented or people-centered. In the first case, the effectiveness is related to the ability to clearly define the requirements and structure of tasks around the mission and goals of the organization, and in the second case, it is based on the ability to show consideration to others and consider their own and others emotions. Kets de Vries, Vriegnaud and Florent-Treacy [27] indicate twelve dimensions considered essential for exemplary leaders: vision, empowerment, promotion, design and control, reward and give feedback, team building, orientation of external actors, global mindset, tenacity, emotional intelligence, life balance and stress resistance.

Goleman [20], in line with the transformational authors, indicates that traditionally skills associated with leadership that include intelligence, firmness, determination and vision, are not sufficient for success, but must be accompanied by other “soft skills” related to emotional intelligence and self-awareness (self-control, appreciation of values, ethics, honesty, self-confidence), autoregulation (reliability

and integrity, openness to change) motivation (strong achievement orientation, optimism, even in the face of adversity; commitment to the organization), empathy and social skills (effectiveness in leading change, persuasiveness, expertise in building and leading teams) [20]. UNDP [42, 43] and Avolio and Gardner [4] also stand out as significant leader skills, aspects considered “soft” as strong ethical convictions, self and others knowledge, confidence, optimism, hope and resilience. They also stress the importance of knowing the context in which the leader operates. The relationships established between the leader and his followers are then of trust, respect and affection and both are developed in the process.

This implies, according to Odeh and Bruning [32] and UNDP [43], that to be a leader there is a need to acquire, not only, the “hard” skills and expertise to manage projects (such as critical and analytical thinking, negotiation and teamwork skills), but to develop “soft” skills through reflection and introspection, for a real change. These ideas correspond to the authentic leadership style, based on the leader’s values and his/her ability to positively influence followers. Therefore, since the change in the leader is critical for organizations to evolve and increase their capacity, the processes of leadership development included in projects must be based on personal values, vision, family, social and cultural context and not just on training in management skills [24]. The author proposes the combination of different methodologies to promote the change, so that it encourages personal growth, conceptual understanding, feedback and skills building. However he warns that through a list of competencies a full leader cannot be developed because there are aspects that cannot be taught, as they depend on individuals, such as energy, perseverance and emotional resilience. Meanwhile the followers also play an important role as part of the process, with their own roles and responsibilities.

Other authors, such as Davies [16] analyse the most suitable leadership styles for capacity development in rural communities, concluding that those styles similar to Burns [12] transformational leadership are best suited to enhance the adaptive capacities. This type of leadership is often described in the programs and policies, although the most common application is transactional, top-down, focused on promoting local leaders as capable of proposing ideas and solutions and implementing strategies to solve these problems. The author believes that the skills learned in leadership training programs (planning and project management, finance, conflict resolution, team building) are necessary, but by themselves are unable to improve the resilience of rural communities, and must be supplemented by the transformational approach that promotes participation, community support and capacity building. Hence, he argues that while projects may begin with a top-down approach, they should end up being transformational, to receive the support of the community and be sustainable over time. Transformational approach implies that leaders and followers work together to achieve common goals. In the process changes occur (transformations) in both the group and the people involved [16]. Einstein and Humphreys [18] suggest that transformational leadership for rural development is about building the capacity of rural people to effectively respond to future challenges that may arise.

3 Case of Study in an Organization of Aymara Women in Puno (Peru)

This case study is based on a project to develop the leadership skills of an association of Aymara women in the region of Puno, on the Peruvian altiplano around Lake Titicaca. This region is characterized by extreme poverty, with a poverty rate of 60.8% and extreme poverty between 51 and 70%, according to the National Institute of Statistics and Informatics (INEI) [23]. The main reasons are the extreme weather conditions [36] that greatly limit the development of agricultural activities, communications infrastructure and poor transport, low technological level of agricultural activities, the fragmentation of land and lack of irrigation systems [3], as well as a poor products marketing system, sold at low prices through intermediaries [19].

The mainstay of the economy of the region is based on the production of sheep and alpaca wool, cattle breeding and growing potatoes, quinoa and barley. The craftsmanship appears in this context as an alternative productive activity, which becomes important in the rural economy since the 1980s and is mainly carried out by women [19], using wool of different qualities and origins, as alpaca, to make products and sell them in local markets or through intermediaries. Due to the low prices obtained by these means, some of the women have been grouped into organizations to improve market access and conditions of sale and have received support from different NGOs, religious organizations and public entities, focusing primarily on knitting techniques training [31]. However, in many cases the lack of integration of business vision in such projects has caused that once these are finished, due to lack of capacity building in this regard, many of these organizations do not continue with their activities and return to work as before, leaving markets achieved and maintaining their situation of poverty and exclusion. In these cases, the sustainability of these projects is questioned, for not being able to generate the necessary change from the development project to the business entity [31].

In response to the situation described, the Pastoral Coordination of Women (CPM) of the Prelature of Juli, the group GESPLAN from the Technical University of Madrid and the NGO “Design for development” (DPD), proposed a development project in 2007 to promote leadership skills development. It was launched in 2008 and through it the women of the association are developing the skills to turn their craft into a successful business venture. The CPM emerged in 1982 as a union of support groups for women, associated with the Catholic Church. Although its origins are related to evangelization activities, women’s rights and domestic violence support, eventually other goals such as individual and organizational development, health improvement and training in some activities, such as crafts and agriculture were incorporated. Currently, the women’s organization is legally established as Coordinadora de Mujeres Aymaras (CMA), and brings together 300 women organised in 21 groups, divided into six districts (Huancané, Moho, Vilquechico, Platería, Chucuito and Juli). Each group is led by a president and a secretary. Groups belong to three zones, each with a zone leader. Finally, there is a board of directors, consisting of two women from each area, which is renewed every 2 years.

The support from GESPLAN group occurs through a local technician who works continuously with the women, and coordinates with the rest of the team, which travels regularly to the area. The philosophy is based on WWP model that puts people at the center of actions, promotes the participation and social learning and provides a framework for the analysis of capacity development through three components: ethical-social, technical-entrepreneurial and political-contextual.

4 Methodology

The methodology consisted in analysing the issues addressed in the literature review to answer two research questions: (1) what leadership styles are being promoted by the project in the CMA, and (2) how the leadership development relates to capacity building and the development of the organization.

To perform the analysis, the secondary sources of information available were first studied, including: (1) the initial diagnostic reports of the area and of the organization, made in 2007, (2) periodic reports by local technician from 2007 to 2012, (3) reports prepared to funding agencies, and (4) the conference papers and articles related to the project written by members of the research group GESPLAN in the same period.

Then primary data was analysed through qualitative methods, including: (1) key informant interviews, made to all the technical team from GESPLAN, consisting of five people, between the months of November 2012 and January 2013. The aim was to evaluate the evolution of the local organization within 5 years of the project, in terms of leadership development (and analysis of leadership styles identified in the period) and technical, organizational, relational and contextual skills, as well as gender issues, and prospects for the future and sustainability of the project; (2) participant observation, in October and November 2011 and November 2012; and (3) autobiographic stories to eight leaders of the organization, including the leaders who formed the women's Association in 1982 and the most active leaders. Information was gathered about their family, community and personal history, the beginning of their craft activities and their involvement in work groups, support received, the style of leadership in groups, ways of marketing, perception of changes with the project, gender issues and future prospects.

Also the results of a midterm evaluation survey were taken into account (see description and analysis of surveys in Sastre-Merino and De los Ríos [35]). They were considered useful for their focus on skills development, under the project management model of the International Project Management Association, IPMA. These results indicate that there has been a breakthrough in the development of technical skills and that in the case of behavioural skills they have made good progress since the internal organization has been strengthened, common values and a shared vision are maintained, although they should continue to work on conflict management, commitment and motivation. Finally, in relation to the contextual skills, it is considered to be the area that develops last, once the above are consolidated, and therefore it becomes paramount objective of the project from now on.

5 Results

The results of the analysis are organized around the study of the leadership styles associated with the organization and promoted by the project, and the relationship of leadership development with capacity building and the development of the organization.

5.1 Styles of Leadership in the CMA and Favoured by the Project

First, the history of the organization in relation to leadership is analysed. Since its origin, support groups for women were formed with the support of a religious order. They were led by themselves, and they received training and catechesis. The leaders were trained, and then they often went alone to other communities to support and train other groups on topics such as natural medicine and leadership. Thus a number of community leaders were enhanced and remain today in the organization and are often the ones who held positions on the board.

The group's structure, which in turn belongs to a large regional structure, has fostered a series of relationships, both within the groups and between groups, forming a network of friendship or social support at regional level. This is seen as an element that has generated a lot of unity among women and according to the biographic interviews, it has changed their ways of relating to each other, because according to them, their fear of public speaking, to say what they think, has decreased and their self-esteem has been reinforced. That unit also translates into empowerment of all women, not just the leaders, because decision making is done through meetings, trainings are conducted by women from one group to another and when only a number of women from each group attends a training activity, they are committed to replicate in their groups. It is therefore considered that leadership in the CMA has generated characteristics of transformational and distributed models.

As for the project, its design was done under the WWP model, which includes the focus of social learning, so the participation of the CMA in every decision has been promoted from the beginning. The aim was to empower the organization through continuous exchange with the GESPLAN group to become leaders of their own development. This was done through assemblies, board meetings, visits to communities, and empowerment evaluation workshops, among other activities, to define the mission, training activities, norms, etc. In this regard, the local team believes that this is the big difference with other craft projects in the area, the prominence given to the women in all decision-making processes. It can be considered that there is a shared leadership among GESPLAN and CMA.

The challenge of the CMA is to successfully combine their social leadership with a business-like one and take advantage of friendship networks to become networks that are also related to the craft they perform. Experts interviewed consider that business leadership would not necessarily coincide with the social one, mainly because there are young women with more training for business issues than natural leaders,

that are usually older, but it is difficult to create a different hierarchy and that it is respected. This coincides with the consideration of Allen and Lachapelle [2] regarding the difference of leadership in formal organizations or communities. The differences in the requirements between a business organization and the previous social organization imply new situations that the entire organization slowly has to adapt to, starting with the need to speed up decision-making, without marginalizing women without formal positions. For this it is essential that leaders maintain a climate of trust, effective communication and good will in the CMA.

5.2 Relationship of Leadership Development with Capacity Development and Development of the Organization

Leadership development in the CMA, set as the target of the project, has been associated since its inception with capacity building in order (according to Davies [16]), to develop sustainable social and economic futures. The approach to this target is based on the principles of WWP planning model, that promote respect and primacy for the rights, traditions and culture of the people, and bottom-up, endogenous and integrated approaches to strengthen the skills and knowledge of people [13]. Therefore actions aimed at capacity building, have relied on the values of the leaders and other women (social-ethical component of the WWP model) in line with that pointed by James [24].

It is considered that the exercise of leadership fosters the development of a number of competencies and that, in turn, the development of these competencies promotes the leadership of women. These competencies are technical, but also interpersonal and contextual, similar to those proposed by Katz [25], related to the development of human, social and relational capital, although the approach also seeks the transformation, through the participation of all women in defining common goals and increasing their commitment to support the project.

As for the relationship between leadership and capacity development, it has been observed through the results of the intermediate surveys and interviews with experts from GESPLAN that in the three areas that make up the CMA, the leaderships have been different and that has influenced the different groups. In the south, the existence of a strong leadership causes a high commitment of these groups and a major influence on capacities development. By contrast, in the north, a conflict between the leader and those of other areas has meant that almost the entire area lost ties with the organization, reducing their involvement and commitment, and that explains the low levels obtained in the assessment. This points out the key role of leaders in the involvement and motivation of their groups and in keeping values like trust and reciprocity. It also infers the difficulty of combining social and business leadership.

Major advances in capacity development generally are at the level of technical skills, but it is also remarkable the effort to integrate the specificities of each area on a common project, through relational capacities. In any case, relational and contextual aspects are those that need greater attention in the future, although not

necessarily with training, but accompanying the process of internalization by women. Other aspects of leadership, such as improved self-esteem were also improved with the project, with increased income at the household level, which women valued for the independence they gain and the opportunity to improve nutrition and education of their children.

Regarding the evolution of the organization, experts indicate that the collective leadership that is developing is generating significant changes, with progressive involvement and appropriation of women in the process at the enterprise level. This change in their mentality has been important because they were used to top-down approaches that did not involve them in decision-making. This is reflected in the steps taken by women since the beginning of the project, including the establishment of internal rules, the legalization of CMA, the reorganization of the training activities and the production structure to respond more equally to all areas, the implementation of an internal training system, and ownership of the processes of quality control and benefits management. However, it is a long process that the organization should go, to continue to learn together and become true leaders in the development of their communities.

6 Conclusions

The change in the approach to rural development projects, from top-down models to endogenous models, in which local people should be responsible for managing their resources and projects, in turn implies that it is necessary that local actors develop a number of capacities. Leadership development has been considered in the context of rural development projects a key factor in developing the capacities of local people to adapt to changes that occur in their communities.

On this premise, the definitions and the different styles of leadership have been analysed, concluding that in rural contexts the leadership styles that best promote sustainable development are the relational ones, as transformational, distributed and authentic, which consider both the role of the leader and the followers and leadership as a process. These approaches take into account interpersonal and relational skills (social capital) of communities, as well as human capital. The drawback of these approaches is that they require long periods of time, in which the local population not only develops management skills, but must internalize the change, and this implies a time period which cannot always be assumed by the project, so many end up working with a more transactional approach.

With regard to capacities, the most commonly associated with leadership are technical capacities, aimed at the effective management of projects. However, these skills must be supplemented with other considered “soft”, such as ethics, values or trust in the other, through which a process of respect, trust and affection with followers is generated. That helps to create a sense of process ownership and the development of all the actors collectively.

The case study analysed corresponds to a leadership development project of an organization of women artisans, in which the WWP planning model philosophy has been applied, giving a major role to women and following the characteristics of transformational, distributed and authentic leadership development models. The project has been supported by the social leaders of the organization to further the process of capacity development. The capacities have been approached through three components: technical-entrepreneurial, ethical-social and political-contextual. These allow to both develop the hard skills to manage the business project, and the soft skills, through which social and relational capital are enforced, creating an atmosphere of trust, involvement in the project and shared vision of all women, not just the leaders. In this environment a change of women mentality is promoted, from being part of a development project to become main actors in a social-business organization.

The project results indicate that there is a process of leadership development, both of the leaders and the other women, which results in the progressive acquisition of capacities. These are technical capacities, related to the management of their craft enterprise, but they are also building the capacities to adapt to change, as the organization is faced with conflicts and tensions of the combination of the logic of a social organization with a business organization. The style of distributed leadership is favouring the process, although there is a long way to go and the role of leaders is essential to maintain motivation from other women, and overcome the problems encountered, that generate envy and resentment, which can undermine the achievements reached so far.

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Part VI
Production Process Engineering

On-line Soft Sensor Based on Regression Models and Feature Selection Techniques for Predicting Rubber Properties in Mixture Processes

E. Sodupe-Ortega, R. Urraca, J. Antonanzas, M. Alia-Martinez,
A. Sanz-Garcia and F. J. Martínez-de-Pisón

1 Introduction

In automotive industry, many different types of long rubber profiles with complex section shapes are traditionally used for the opening and shutting regions of vehicles. They sealed off vehicles reducing noise and vibration and preventing air and water from getting into vehicle interior. Extrusion lines perform the manufacturing of these long rubber profiles with complex cross-section shapes. The extrusion is an unstable and changing process that involves a high variability on its working conditions. It is difficult to control and readjustments are continuously needed.

There are two main sections in rubber extrusion lines: the mixing and the extrusion phases. Both play a key role to obtain good quality final profiles, but research on rubber mixing is not so wide than on the other. Variations occurred when mixing the raw materials is decisive to avoid wasting raw materials, decreasing production costs. Nowadays, higher quality standards are required by automotive industries and more stringent controls have been implemented. To assure quality of final

E. Sodupe-Ortega (✉) · R. Urraca · J. Antonanzas · M. Alia-Martinez · F. J. Martínez-de-Pisón
EDMANS Group, ETSII, University of La Rioja, La Rioja, Spain
e-mail: enrique.sodupeo@unirioja.es

R. Urraca
e-mail: ruben.urraca@unirioja.es

J. Antonanzas
e-mail: antonanzas.javier@gmail.com

M. Alia-Martinez
e-mail: manuel-julian.aliam@unirioja.es

A. Sanz-Garcia
CDR, University of Helsinki, Finland
e-mail: andres.sanz-garcia@helsinki.fi

F. J. Martínez-de-Pisón
e-mail: fjmartin@unirioja.es

products, profile manufacturers are constantly improving the control of the rubber properties. As much on-line information about rubber conditions could be provided to plant engineers, as more reliable and ease is the control of the extrusion line.

The rheological curve of the rubber mixture is an important factor in the extrusion process. Two main factors have direct impact on the rheological curve of the rubber. On one hand, the input conditions and the properties of the raw materials used for the mixing process; and on the other hand, the mixer setting points, which need to change in case of new batches of raw material are loaded. Each time a new batch of raw material is loaded to the machine, the operator needs to change all the setting points of the mixer in order to readjust its proper behaviour. This is mandatory to keep the same rheological properties that the quality department establishes for each rubber profile.

The rheological curve is really difficult to determine during the mixing phase. It is defined by a parameters set that can only be obtained by means of a series of laboratory tests. The tests can be performed only after the rubber compound has been extruded. Therefore, these results are not useful to rapidly detect failures during the extrusion process or constantly monitoring the quality of the extruded product. These large delays in the acquisition of the rheological curve are creating big problems to plant engineers.

The paper proposes the development of new on-line soft sensors to predict the parameters that define the rheological curve. This proposal have been widely used in industry [4] and several authors have demonstrated that can provide useful knowledge for controlling setting points of rubber mixers. Currently, this process entirely depends on the good eye and experience of plant operators. However, this does not guaranty that the adopted decisions will lead to the expected results. So, plant operators need more help for the decision making process concerning the mixing phase.

Using historical data from the mixing process, a data-driven prediction model based on a wrapper scheme is proposed. The wrapper is mainly composed of a regression model and a feature selection routine. The aim of the feature selection is to improve predictor performance and the understanding of the underlying process that generated the data, and also provide faster and more cost-effective prediction models [2]. In fact, many types of regression models have already been developed to the extrusion phase, but not to rubber mixing process. The later is under the influenced of a high number of heterogeneous variables, which create an inherent complexity [11].

The opportunity to collect other alternative measures from the extrusion and the mixing process is the main reason because data-driven prediction models are preferred to this application [1, 7, 10]. Many approaches have recently implemented data-driven black-box models to achieve a better interpretability of results without losing accuracy. However, our proposal is based on four types of linear regression models: classical multiple linear regression and three types of regression trees: recursive partitioning (rpart), separate-and-conquer strategy (M5Rules) and an extension of Quinlan's M5 model tree (cubist). A better understanding of the most important process variables could be obtained by using a data-driven white-box approach. Models should be able to point out what process variables have more influence to the parameters that define the rheological curve. Subsequently, an on-line soft sensor in the mixing process will help operator with the decision making process and will avoid the lack of information during the time period that the laboratory test results are not available.

2 Database Characteristics and Input/Output Variables

The training and test database used to develop the four prediction models selected and also to measure their performance was obtained from a real rubber extrusion line. The production line belongs to Standard Profil S.A. and it is located at one of its factories on the northern of Spain. The database includes a total of 20 variables. A number of 15 were selected as inputs for training the four models. The rest of the variables were the outputs and correspond to the parameters that define the rheological curve to be predicted.

The names of the input variables are the following: “dureme”, “pocom”, “predu1”, “predu2”, “prerci1”, “prerci2”, “terefi”, “terein”, “vca1”, “vca2”, “vca3”, “vexten”, “vne1”, “vne2” and “vne3”. On the other hand, the outputs (rheological curve parameters) are “ml”, “ts1”, “tc50”, “tc90” and “mh”. The database was created with data collected from six different rubber compounds or formulae. The data were pre-processed and filter to remove spurious and zero values. The final database corresponds to a total of 1240 samples. Further explanations about the database or its composition and the nature of the variables selected can be found in previous works [4, 6].

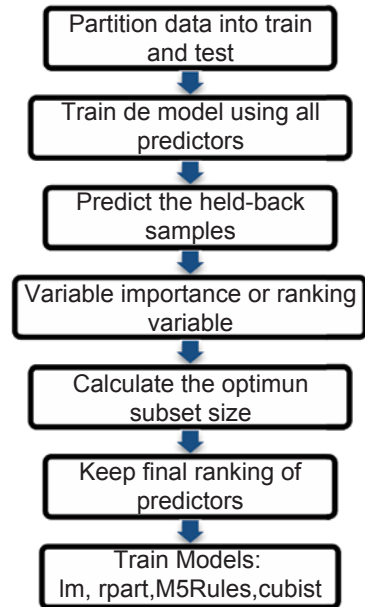
3 Methodology

In industrial processes, many parameters can be measured. However, this does not mean that all these variables are necessary to train the best prediction models. This is due to the fact that some variables may not explain the issue under study. Using these irrelevant variables as inputs, model accuracy can be reduced. For that reason, a reduction of the number of inputs should be carried out before the training phase. Here is where the parsimony concept comes into play: finding models where a variable reduction technique is applied and its loss of accuracy is feasible to respect the original model, will lead to better understanding of the problem. In addition, a reduction of the resources involved such as industrial process sensors and measuring times can be achieved.

Another important factor that directly affects the correct behaviour of models and selection of the proper subset size is variable importance. Usually, to determine the importance of input variables is a hard decision process and depends on the experience of plant engineers. The problem is that not always these advices are available and decisions about which inputs are included in the model must be taken.

Due to the high variability of rubber extrusion process, it is very important to acquire as much information as possible. A feature selection routine was used as a “wrapper” in order to know the optimum subset size of variables used in the linear models. Indeed, variable importance was also analysed in order to know which variables have a greater influence in the predicted outputs. A scheme about wrapper steps can be seen in Fig. 1. Four linear models were implemented in order to predict output variables of rheological curve: multiple linear model, rpart, M5Rules and cubist.

Fig. 1 Basic procedure to set up wrapper scheme



The performance of the models was measured using the following performance measures. First the root means squared error (RMSE):

$$RMSE = \sqrt{\frac{\sum_{k=1}^n (y(k) - \hat{y}(k))^2}{n}} \tag{1}$$

Where $y(k)$ is the target output, \hat{y} is the prediction of the model and n is the total number of instances. To obtain a robust estimation of the goodness of the RMSE, we included an additional measure, the mean absolute error (MAE):

$$MAE = \frac{\sum_{k=1}^n |y(k) - \hat{y}(k)|}{n} \tag{2}$$

Finally, the coefficient of determination or r-squared (R^2) was also computed to use as a comparative to other similar studies:

$$R^2 = 1 - \frac{\sum_{k=1}^n (y - \hat{y})^2}{\sum_{k=1}^n (y - \bar{y})^2} \tag{3}$$

Where \bar{y} is the mean of the observed data. These performance measurement values were calculated in both training and testing. An m repeated k -fold cross validation (CV) technique was used to generate a larger number of estimates and a more reliable measure of the model performance.

Wrapper used consists on a recursive featuring elimination (RFE) with a backwards selection routine. The RFE algorithm gives the best number of variables to use and which of these variables have more significant importance. A re-sampling method (bootstrap) was used inside the wrapper in order to have a greater amount of data to analyse. Wrapper structure can be described as follows:

1. Partition data into train and test.
2. Model is tuned with the training set of data using all inputs.
3. Calculate variable importance or variable ranking.
4. Backwards selection routine is applied in order to know the optimum subset size of the model. Algorithm starts training the model with all the p available inputs. For each iteration, the input with a lower score is excluded and model is trained again with $(p-1)$ inputs. There will be as many iterations as inputs to be analysed. An optional recalculation of variable rankings can be done after each predictor is excluded.
5. Best subset size is determined by some measure performance. In this study RMSE was used to adjust models performance. RMSE is computed over all models with different number of inputs. A tolerance is chosen by the client in order to determine the acceptable subset size to be picked. This tolerance determines the acceptable difference percentage between the best subset size and the reduced one. This tolerance is calculated according to the Eq. (4). Optimum RMSE ($RMSE_{opt}$) corresponds to the minimum error obtained for a specific subset size.

$$RMSE_{tol} = 100 \cdot \frac{RMSE - RMSE_{opt}}{RMSE_{opt}} \quad (4)$$

6. Once the best subset size is determined, next step is to select the list of inputs to keep in the final model. This selection is carried out according to the previous variable ranking.

Two previous steps are carried out before the execution of wrapper code, normalization of the original database and partition of data into train and test. The first step is needed when there are different scales in the database. In the second step, training dataset is used for tuning models, but testing dataset is not used in order to check the generalization ability of models predicting new data.

Once the wrapper scheme calculates the best subset size and which inputs should be included, this information is used in order to train the four models studied. In order to be able to compare the performance of all models, same inputs should be used and the same wrapper was applied to all of them. Once the four predicted models are obtained, a denormalization of data is applied.

4 Models Overview

Models implemented to predict output variables of rheological curve are described below:

- Rpart is an iterative process of splitting data into separate sub-groups, using a two stage procedure. The algorithm recursively chooses the split that partitions the data into two parts such as to minimize the sum of the squared deviations from the mean in the separate parts. This partition process is done until a minimum size is achieved or no improvement can be made. After the complete tree is built a cross validation technique is applied in order to prune or simplify it. A further explanation of rpart can be found in [9].
- M5rules is a method to generate rules from model trees. It is a basic separate-and-conquer strategy for learning rules. However, instead of building a single rule, a full model tree at each stage is built and taking its best branch as a rule. All instances covered by the rule are removed from the dataset. The process is applied recursively to the remaining instances and terminates when all instances are covered by one or more rules. This avoids potential for over-pruning. In contrast to PART (Partial Decision Trees), which employs the same strategy for categorical prediction, M5'Rules builds full trees instead of partially explored trees [5].
- Cubist is a rule based model that is an extension of Quinlan's M5 model tree. A tree is grown where the terminal leaves contain linear regression models. These models are based on the inputs used in previous splits. Also, there are intermediate linear models at each step of the tree. A prediction is made using the linear regression model at the terminal node of the tree, but is smoothed by taking into account the prediction from the linear model in the previous node of the tree (which also occurs recursively up the tree). The tree is reduced to a set of rules, which initially are paths from the top of the tree to the bottom. Rules are eliminated via pruning and/or combined for simplification. A further explanation can be found in [8].

5 Results and Discussion

Mathematical and statistical analyses were carried out with the open source software R-project 2.15 (<http://www.r-project.org>), running on a dual quad core Opteron server with Linux SUSE 11.2. The pre-processing and post processing of data were also carried out with the same statistical software and all models were implemented using the following R-project packages: "Cubist", "rpart" and "RWeka". Finally, the wrapper approach was integrated in the design process using "caret" package.

Figure 2 shows a visual explanation of subset size selection and tolerance technique carried out. Tolerance used for all the experiments was 10% and calculated

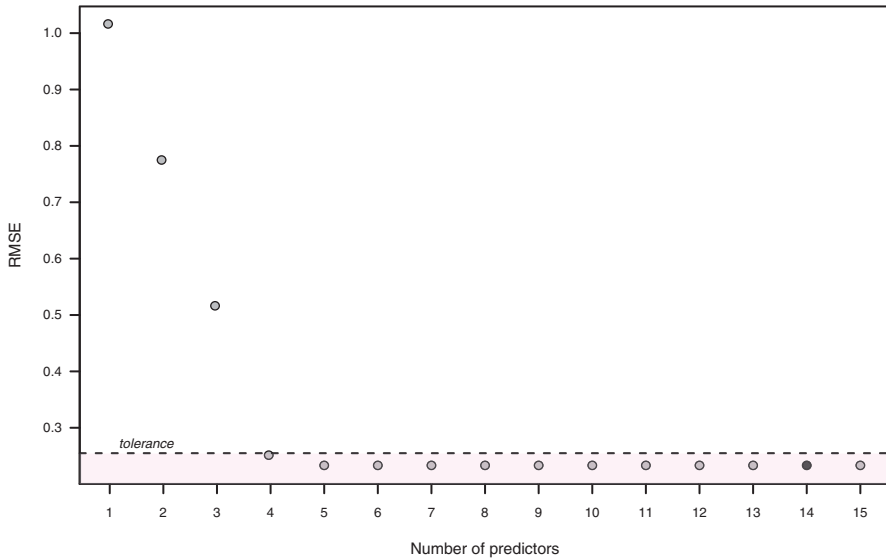


Fig. 2 Selection of best subset size

according to Eq. (1). Each point of the figure represents a model with a specific number of inputs in abscises axis and RMSE performance in ordinates axis. The point with the black background represents the model with a specific number of inputs that has a lower RMSE or optimum RMSE. This graphic does not remain constant, each new iteration tolerance value and best subset size are computed.

Those models located under the tolerance line have a similar accuracy to the optimum model, with a lower use of inputs and less complexity. For instance, choosing only five inputs at least 90% of accuracy can be achieved with respect to optimum model (see Fig. 2). A further explanation of this technique can be found in [3]. Those models within assumed tolerance, with lowest number of inputs, were chosen to form the best subset size.

In Table 1 is shown the subset size used to train models for each output variable of the rheological curve. A considerable reduction of the original number of inputs is achieved. Most used subset sizes have five and six inputs. Therefore, a simplification of models can be achieved without a significant loss of accuracy.

Tables 2, 3, 4 and 5 show the performance of four models (lm, rpart, M5Rules and cubist) for each output variable represented. Both tables provide mean values of the 100 × 10-fold cross validation technique carried out. The feature selection was not applied in Tables 2 and 3. It is clear that only test results for both tables are represented. Results obtained within the framework of this study reveal cubist as the model with the highest accuracy, followed by M5Rules and lm. As expected, models trained with the complete set of inputs have better accuracy than models which wrapper approach is applied. This tendency is reflected in the four models studied and all rheological parameters predicted. Despite there is a reduction predicting

Table 1 Subset size used for each model

	Number of predictors																																							
	ml						ts1						tc50						tc90						mh															
	4	5	6	7	8	9	4	5	6	7	8	9	4	5	6	7	8	9	4	5	6	7	8	9	4	5	6	7	8	9										
lm	0	843	156	1	93	670	236	1	3	692	289	16	0	478	522	0	551	449	20	793	186	1	213	663	122	2	51	650	282	17	7	766	227	0	656	344				
M5Rules	7	851	141	1	193	702	104	1	59	608	316	17	2	704	293	1	698	302	28	822	150	0	185	731	83	1	43	659	280	18	2	713	285	0	691	309				
Cubist	28	822	150	0	185	731	83	1	43	659	280	18	2	713	285	0	691	309																						

Table 2 Mean errors of the output variables ml, ts1 and tc50 without feature selection

	ml			ts1			tc50		
	RMSE	MAE	R ²	RMSE	MAE	R ²	RMSE	MAE	R ²
lm	0.2312	0.1796	0.9690	1.9807	1.5593	0.9484	2.2663	1.7575	0.9513
rpart	0.2577	0.2019	0.9625	2.2052	1.6301	0.9505	2.3787	1.8113	0.9530
M5Rules	0.2287	0.1674	0.9797	2.0176	1.4571	0.9489	2.3120	1.6808	0.9460
cubist	0.2228	0.1646	0.9558	1.9597	1.4287	0.9744	2.2776	1.6359	0.9790

Table 3 Mean errors of the output variables tc90 and mh without feature selection

	tc90			mh		
	RMSE	MAE	R ²	RMSE	MAE	R ²
lm	1.4801	1.1563	0.9586	1.5716	1.2368	0.9653
rpart	1.5655	1.1535	0.9588	1.7302	1.3702	0.9537
M5Rules	1.4266	1.0677	0.9547	1.5596	1.1811	0.9691
cubist	1.4469	1.0646	0.9656	1.5665	1.1380	0.9809

Table 4 Mean errors of the variables ml, ts1 and tc50 with feature selection

	ml			ts1			tc50		
	RMSE	MAE	R ²	RMSE	MAE	R ²	RMSE	MAE	R ²
lm	0.2334	0.1804	0.9686	2.0933	1.6425	0.9423	2.3039	1.7751	0.9522
rpart	0.2747	0.1930	0.9602	2.0581	1.5910	0.9487	2.3534	1.7905	0.9521
M5Rules	0.2282	0.1722	0.9495	2.0775	1.5886	0.9294	2.3625	1.7715	0.9351
cubist	0.2260	0.1709	0.9622	2.0792	1.5783	0.9495	2.4338	1.7537	0.9637

Table 5 Mean errors of the output variables tc90 and mh with feature selection

	tc90			mh		
	RMSE	MAE	R ²	RMSE	MAE	R ²
lm	1.6380	1.2654	0.9524	1.5961	1.2499	0.9609
rpart	1.5511	1.1492	0.9565	1.7427	1.3760	0.9518
M5Rules	1.4445	1.1139	0.9487	1.5335	1.1998	0.9625
cubist	1.4821	1.1163	0.9570	1.5428	1.1965	0.9705

accuracy using wrapper scheme, this reduction mostly is not observed until the second decimal. In addition, this loss of accuracy is offset by a higher parsimony of models and a higher interpretability of results.

Wrapper approach can provide useful information as shown in Table 6, where influence of inputs for each output variable is represented. It can be observed which variable have a more direct effect explaining rheological parameters and which variables are irrelevant in order to understand its behaviour. For example, variables “predul” and “vne3” are always included as inputs for all models.

Table 6 Percent (%) of use of each input variable for prediction the output variables

Input variables								
Output variable	dureme	pocome	predu1	predu2	prerci1	prerci2	terefi	
ml	0	0	100	100	0	2	0.2	
ts1	18.4	0.6	100	100	25.1	71.5	23.1	
tc50	16.5	0	100	100	0	4.8	99.7	
tc90	45.6	100	100	99.9	0	7.5	99.2	
mh	0	100	100	3.5	14.7	10.5	0.8	
Input variables								
Output variable	terein	vca1	vca2	vca3	vexten	vne1	vne2	vne3
ml	0.1	0	0	49.4	100	65.1	0	99
ts1	18.3	0	100	0	0	57.5	0	100
tc50	10	0	100	0	1.2	99.7	0	99.9
tc90	0	0	100	0	0	0	0	100
mh	0	0	0	84.5	100	32.8	0	98.1

These results show that more strict control of the setting points in the mixture machine will lead to a better control of the output parameters. This is not the case with those variables that were excluded or not included in any models.

6 Conclusions

A better understanding of the underlying process of rubber mixing phase in extrusion lines is crucial to improve product quality. Our proposal is to use new on-line soft sensors based on data-driven regression models to explain the complex behaviour of the rubber mixing processes. A wrapper scheme was implemented to obtain better regression models on the basis of the parsimonious criterion. The wrapper showed a dimensional reduction in models without generating a significant reduction on accuracy. In fact, model performance measures only showed a variation in the number of the second decimal. This demonstrates the proposal accuracy and that the use of regression models in wrapper schemes is an interesting technique for modelling soft sensors. Finally, the developed wrapper additionally provided higher interpretability of the results and a better understanding of the most relevant process variables (inputs). We consider this approach a promising technique that can be used in many other industrial applications.

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Part VII
Product Engineering and Industrial Design

Segregation of a Binary Granular Mixture in a Feed Shoe of a Single Punch Press Using DEM

L. Martínez-Martínez, E. Sainz-García, J. Muro-Hernández, F. Alba-Elías and A. González Marcos

1 Introduction

This paper discusses the application of the discrete element method (DEM) to study segregation phenomena that occur in the feed tank (moving shoe) of an eccentric compression machine.

The discrete element method is framed in the family of numerical methods to simulate parameterized models of granular solid systems and discontinuous materials. Specifically, the software that is used is EDEM[®] (DEM Solutions), which can implement the geometry of the elements to simulate, or import it from a CAD tool.

In order to study the segregation of a binary mixture (two ingredients) produced inside a feed tank by the DEM method, it was necessary to first adjust the parameters of the simulated model (mainly friction coefficients) in accordance with the results of empirical tests carried out with a tank constructed with a transparent material (polycarbonate) and dimensions similar to those of a real feed tank.

Segregation is affected by various factors, such as particle size [3], density [2], and shape [7], and is governed mainly by the “Brazil nuts” effect [4, 8].

F. Alba-Elías (✉) · L. Martínez-Martínez · E. Sainz-García · J. Muro-Hernández · A. González Marcos

Departamento de Ingeniería Mecánica, Universidad de la Rioja C/Luis de Ulloa 20, CP 26004 Logroño, Spain
e-mail: fernando.alba@unirioja.es

L. Martínez-Martínez
e-mail: laura.martinezma@alum.unirioja.es

E. Sainz-García
e-mail: elisa.sainzg@unirioja.es

J. Muro-Hernández
e-mail: jorge.muroh@alum.unirioja.es

A. González Marcos
e-mail: ana.gonzalez@unirioja.es

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The study of the processes of segregation in the feeder tanks of a compressor has great importance, particularly for the pharmaceutical industry, where the composition of each tablet should be perfectly executed. The model permits to identify segregation mechanisms produced in this kind of machine to be identified. It also aids future researches to study the changes required to mitigate segregation without a need for numerous and costly laboratory tests.

2 Objectives

The objectives of this work are:

- To study the segregation phenomena produced in a direct compression machine based on empirical tests and simulations by the discrete elements method DEM.
- To determine the simulation parameters necessary to adjust the simulation to the actual empirical evidence.
- To study the segregation phenomena produced during the compression process.

3 Compression of Granular Material

3.1 Compressor Machines

There are two main kinds of compressors machines or presses:

- Eccentric and hydraulic (“alternative,” “mobile hopper,” “single punch tablet press” and “single stroke tablet press”): The eccentric machines have a single die (“die cavity”) and one or more cameras of compression. The machine is inserted into a piece that is called a platen (“die platform” or “die plate”). The platen remains stationary, while the tank feeder with an alternative movement expels the excess material from the feed and then discharges the tablet with an upward stroke of the lower punch (Fig. 1a).
- Rotary (“rotary tablet machine”): Rotating machines have several dies and punches. The hopper remains fixed, but the dies move within a mobile circular steel plate. The punches are controlled by the rollers of a metal wheel track (“pressure wheel”). The hardness of the table is adjusted by adjusting the spacing between the two rollers with a screw (“die lockscrew”).

3.2 Feeding Tank

The feeder tank of an eccentric compression machine (Fig. 1b) is an element that performs two functions: (1) It fills the array with an established product before the tablet and punches are conformed. (2) It pushes the tablet after it has been formed.

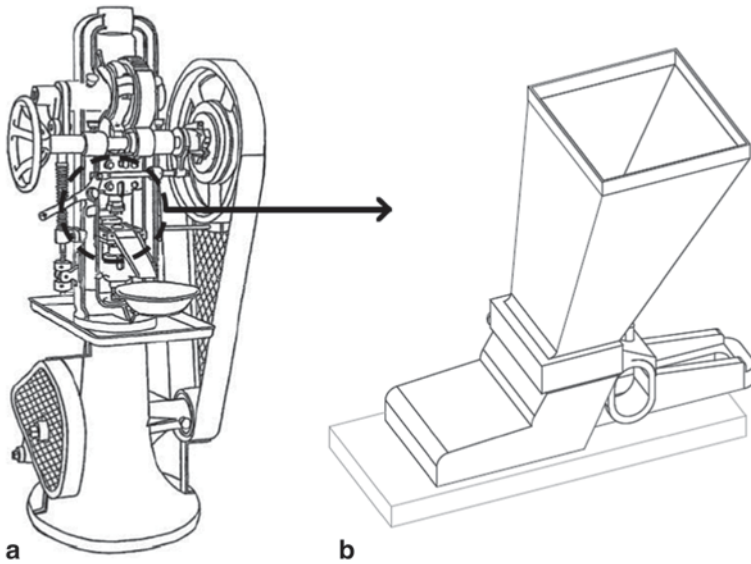


Fig. 1 a Eccentric compression machine. b Feeding tank

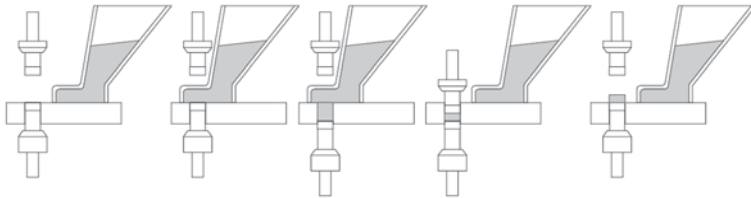


Fig. 2 Tablet compression sequence in an eccentric machine

The feeder tank is a mobile component that is synchronized with the other components of the compressor. It is usually attached by a flexible conduit to another fixed hopper (with more capacity). The second hopper replaces the contents of the feed tank while the latter fills the matrix. This alternative movement generates a vibration. This causes the ingredients in the segregated mixture to be compressed to form a tablet that is not good (Fig. 2).

4 Segregation of Granular Materials

It is believed that a granular material has undergone a process of segregation when it presents significant variations in the distribution of particles within it. For various reasons, some particles are separated from the others, leading to a non-homogeneous

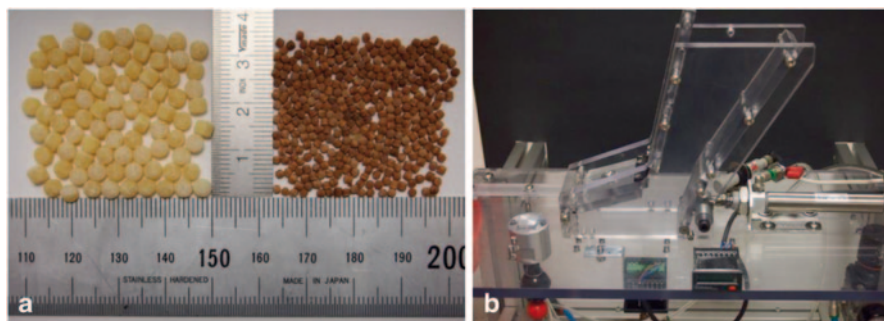


Fig. 3 **a** Ingredients I1 and I2. **b** Eccentric compression machine simulator

mixture of the product. There are several types of mechanisms for segregation. Some of them are:

- Convection: occurs in granular mixtures with ingredients of different sizes that are subjected to conditions of vibration. They accumulate separately in localized regions [10].
- Percolation: caused by the input of small particles into the voids generated by the large particles until the granular structure tends to consist of equal particles locally. It is known as segregation by size.
- Segregation path: this is a thin line of particulate material with movement that is caused by the reduction in the size of smaller or more angular particles due to the effect of friction on their speed.

5 Methodology

5.1 Experimental Materials

5.1.1 Mixture Ingredients

The ingredients of the tablets that can be manufactured in a compression machine are varied. These ingredients include active pharmaceutical tablets; preservatives; flavourings and general additives used in the food industry such as salt, citric acid, and ascorbic acid; detergent tablets for washing machines and dishwashers; chlorine tablets and swimming pool additives.

For this project we have used a binary mixture (two ingredients) that by its nature permit the study of several of the above mentioned segregation mechanisms of different size, density and coefficient of friction (Fig. 3a).

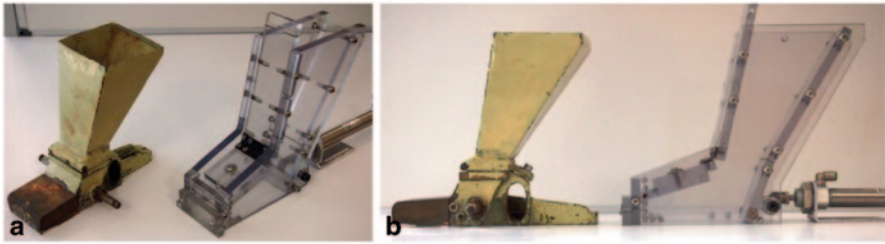


Fig. 4 **a** Isometric view. **b** Profile of conventional tank and polycarbonate tank “3D” (51 mm)

- The major ingredient, I1 (85% by weight) corresponds to the larger or “coarse” and lower density form of pasta (semolina) with a substantially spherical shape of 3.8 mm diameter and a density of 1335 kg/m^3
- The minor ingredient, I2 (15% by weight) is the smaller or “fine” and higher density: form of pasta with a substantially spherical shape of 1.6 mm diameter and a density of 1730 kg/m^3

5.1.2 Compression Machines Used

- Set simulator eccentric tableting machine:
The machine is constructed of polycarbonate (tank and platen). The alternative movement of the tank is caused by an air cylinder that has a displacement of 10 cm. The movement of the punch is caused by the displacement of the air cylinder 2 cm. Two cameras take photographs of the profile and the bottom of the simulator and two counters record the number of pills that have been produced. These are reflected in the images above (Fig. 3b).
- Tank feeder simulation:
In order to observe and study the movement of the particles inside the feeding tank, a polycarbonate tank with dimensions similar to those of an actual compression machine was constructed. This “simulator” tank consists of two side plates bolted to other panels, front and rear, to form a rigid assembly. The front and rear plates are interchangeable so that the width of the tank can be modified (Fig. 4a and b). In this study, the configuration of a tank (tank “quasi-3D”) of 20 mm inside width was studied.

5.1.3 Software Used

For CAD, Catia V5R20 and for DEM simulations, EDEM ® Academics 2.3 DEM Solutions (Edinburgh, UK) are used.

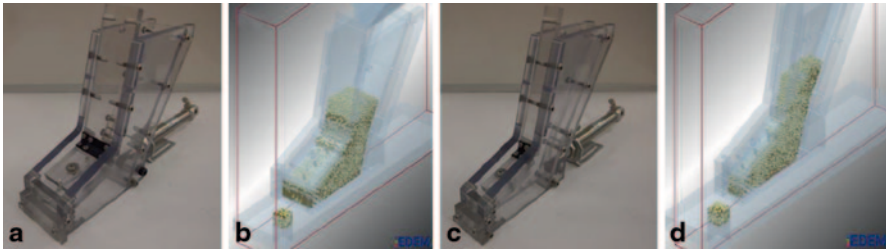


Fig. 5 a and b “real” tank (51 mm) and simulated tank. c and d “quasi-3D” real and simulated tank

5.2 Simulation of the Compression Process

5.2.1 Simulator of Tank Feeder “Quasi-3D”

In the preliminary simulation tests in which the tank model of 51 mm (with dimensions similar to those of a conventional tank, Fig. 5a and b) was used, it was found that the computational cost was excessive for the process of determining the optimal parameters. The computation time needed to simulate the total discharge of the feeder tank (8860 particles and 16163 particles I1 I2) was 65 h, using eight servers in parallel. In this circumstance, and embodying the experience of other authors [3, 5], a model tank of 20 mm of internal width was constructed and then later simulated it by computer. It is described as “quasi-3D” (Fig. 5c and d). The tank model of 51 mm was subsequently used to validate the model obtained from the quasi-3D model. This validation is not described in this communication. The cited authors used in their works “slices of elements” to simulate the tank. Although not for this reason, they obtained results that differed significantly from those obtained by the actual tank with actual dimensions. In our case, the simulation time for the 20 mm tank was reduced from 65 to 6 h.

5.2.2 The Model Used to Stimulate the Tank and the Ingredients in the Mixture

The EDEM® software simulates real particles using a model based on spherical particles. To consider the irregularities of real particles, EDEM can use particle models in which different numbers of spheres are used [6] or modify the simulation parameters, such as the rolling resistance (“rolling friction”). The latter permits to reproduce precisely the “difficulties” to roll (particle-particle and particle-wall) of non-spherical particles. Due to the practical sphericity of the ingredients, it was used the latter approach in this project. The characteristics of the ingredients (Fig. 3a), that have been found unchanged in the simulations were the following:

Table 1 First values of the parameters of simulation

	Poisson coefficient	Density (kg/m ³)	Shear module (Pa)
I1	0.4	1000	1×10^5
I2	0.4	1000	1×10^5
Material tank–Matrix–Punch	0.3	7850	8.4×10^5

Table 2 First values of the parameters of interactions

	Restitution coefficient	Static friction coefficient	Rolling friction coefficient
I1–I2	0.8	0.5	0.01
I1–I1	0.8	0.5	0.01
I1–Wall	0.8	0.15	0.01
I2–I2	0.8	0.5	0.01
I2–Wall	0.8	0.15	0.01
Wall–Wall	0.8	0.15	0.01

- The major ingredient, I2: 1 sphere of 3.8 mm diameter and density of 1335 kg/m³. It is the 85% by weight of the total mixture.
 - Tank “3D”: 4430 particles
 - Tank “quasi-3D”: 8860 particles
- The minor ingredient, I1: 1 sphere of 1.6 mm diameter and density: of 1730 kg/m³. It is the 5% by weight of the total mixture.
 - Tank “3D”: 8082 particles.
 - Tank “quasi-3D”: 16163 particles.

5.2.3 Initial Value Used in the First Iteration

The initial values of the variables in the simulation of the first iteration were obtained from the database simulation software [1] and references from other works [9]. Likewise, the possible range of variations of each of these variables, depending on the limitations of the software used (Tables 1 and 2), were defined. The most significant variables in simulating the filling/emptying of the tank were:

After defining the initial values of the parameters of the simulation iteration process, an iteration process to adjust these values began. This ensured that the results of the simulations would converge into the results of the “real” empirical evidence (tank). For this iteration process, the percentage by weight of ingredient I2, served as a reference (the smaller (fine) and minority (15% weight)).

Figure 6 shows the percentage by weight of ingredient I2 obtained in each of the 30 tablets. A complete cycle of 30 tablets (starting with the filled tank until the tank

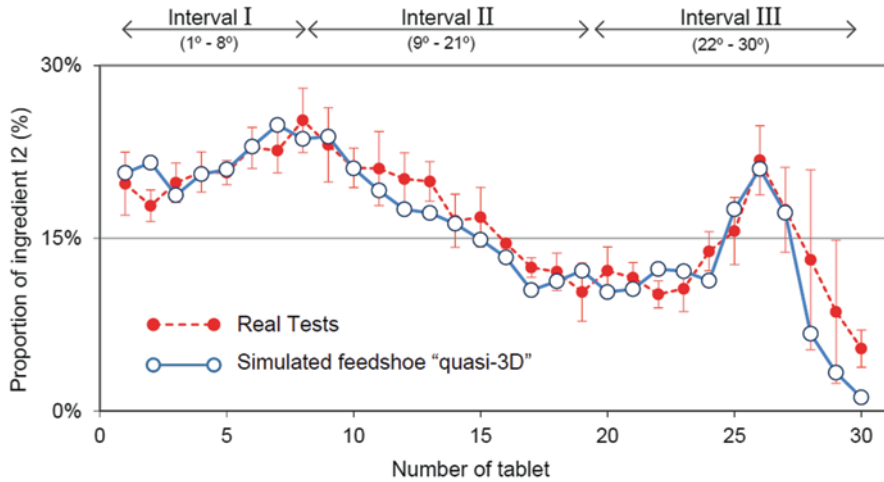


Fig. 6 Percentage of minority ingredient (15% by weight) obtained in the actual tests (an average of five tests conducted that indicate the confidence interval for $\alpha=0.05$) and in the final simulation. Both results correspond to those of tank “quasi-3D”

was empty) that corresponds to half of the actual tests and a final simulation, related both to tank “quasi-3D.” In this iterative process, the parameters of the simulation values are changed within the predetermined range (Tables 1 and 2). The RMSE of the error (Root Mean Squared Error) was used to determine the adequacy of each of the simulations. Subsequently, the adjustment process was able to reduce the initial error by 16.5–4.05%. During the iteration process, 27 simulations were conducted.

5.2.4 Complete Cycle of Real and Simulated Tests

A complete cycle for the tested truck model “quasi-3D” (both actual and simulated tests) begins with filling a hopper at the top of the tank with 200 g of “perfect” binary mixture (Fig. 7a). In order to reduce as much as possible the segregation in filling this interim storage, the loading of 200 g in actual testing was divided into 20 portions of 10 g. They were subsequently added to the hopper in as orderly a manner as possible. Then, the lower base plate, which contains the mixture in the hopper, is pulled back, pouring the contents out of the tank (Fig. 7b). The typical arrangement of the ingredients of the mixture can be seen in Fig. 7c. The upper surface of the mixture has a cone similar to the silo discharge inclination.

Using the displacement of the tank and punch as origin, the configuration in which the tank is filled, the following coding FxPyTz was used to describe the different configurations of the tank-punch assembly for each of the significant instants of the cycle. The “Fx” letters indicate the position of the feed or tank (“Feedshoe”), with F0, the coding corresponding to the position in the origin and F100, corresponding to the position of the tank 100 mm from the origin (above the matrix).

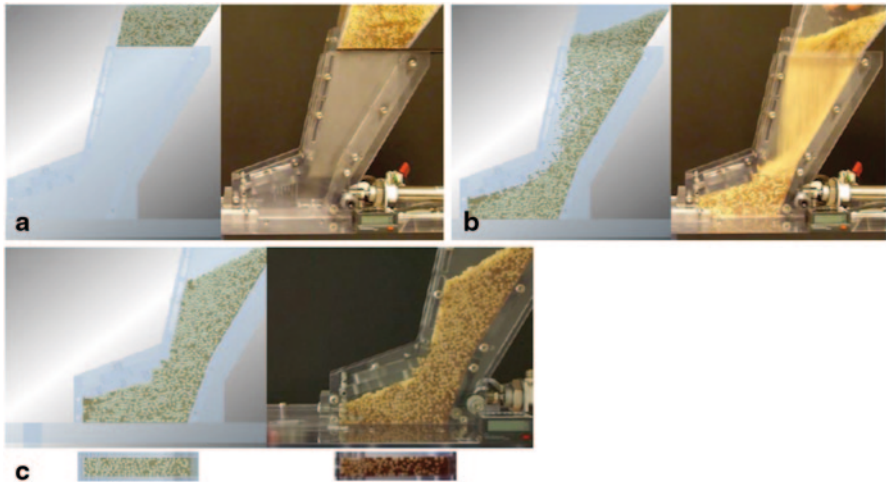


Fig. 7 Filling the tank from a hopper

Similarly, “Py” serves to designate the position of the lower punch (“Punch”), where P0, the initial position (upper position flush with the platen) and P20, the position of the punch as it travels 20 mm downwards to accommodate the mixing portion from the tank. The letters “Tz” designate the number of tablets (“Tablets”) formed so far. For quasi-3D simulations (actual and simulated), “z” varies between 0 and 30. Accordingly, the configuration in which the tank is filled corresponds to the FOP0T0 code. To show the production sequence of a tablet by example in Fig. 8, the production of compressed No. 8 is shown.

After the tank has been filled and the ingredients of the mixture have become stable (Fig. 8a), the tank moves forward for 100 mm at a speed of 0.32 m/s, placing the tank above the matrix (Moment F100P0T8, Fig. 8b). After the ingredients are completely motionless, the punch is moved downward at a speed of 1 m/s (instant F100P20T8, Fig. 8c). Then, the tank returns to its initial position at a speed of 0.32 m/s (instant FOP20T8) and the particles that are in the matrix are counted after the punch has returned to its initial position (FOP0T9 instant, Fig. 8d). This cycle is repeated 30 times at which time the minor ingredient I2, will have virtually disappeared.

6 Results

6.1 Final Values of the Simulation Parameters

The values finally obtained in the iteration process permitted the adjustment of the actual simulation tests with the accuracy level shown in Fig. 6 (RMSE of 4%). These values are presented in Tables 3 and 4.

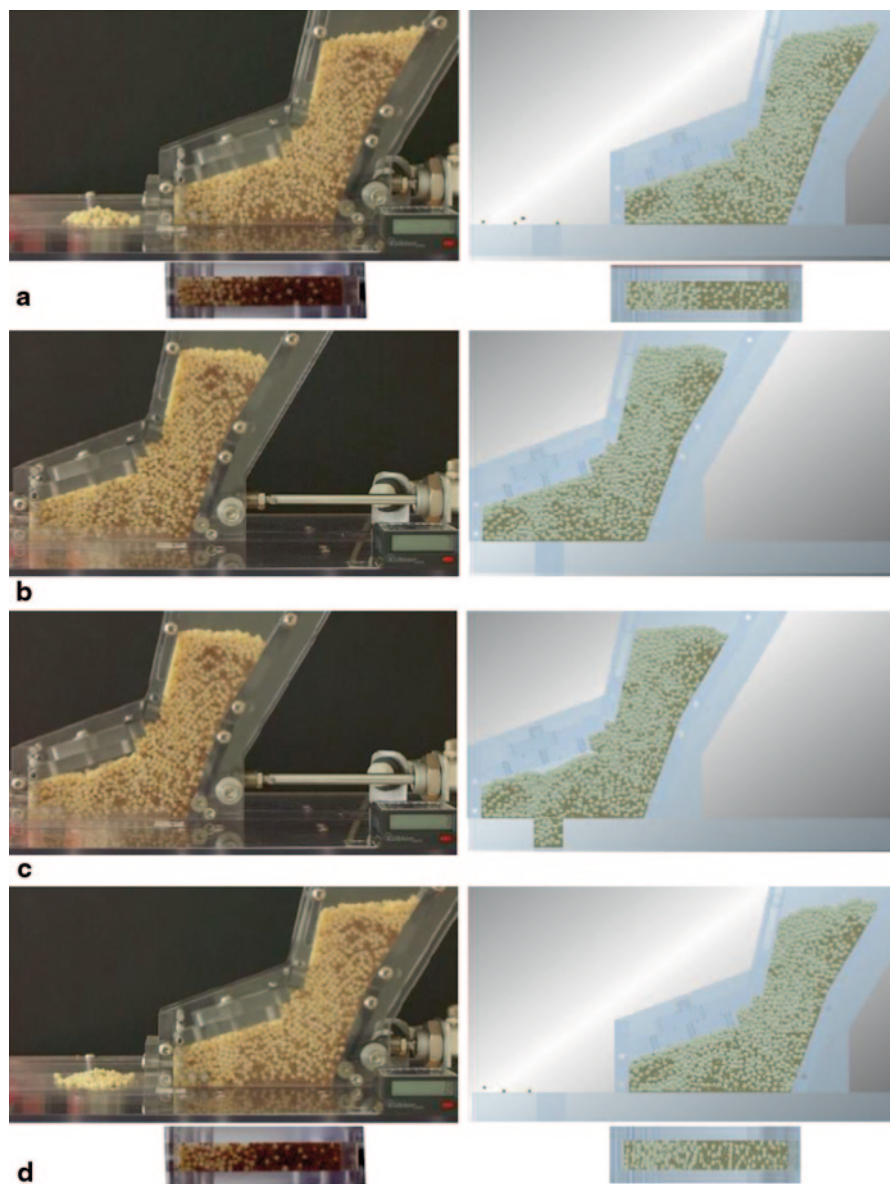


Fig. 8 Example of a tablet's production sequence: N° 8

Table 3 Final values of the simulation parameters. Parenthetically, the ranges of variations used in the final model that we obtained with our iterations

	Poisson coefficient	Density (kg/m ³)	Shear module (Pa)
I1	0.4 (0–1)	1335 (750–1500)	3.6×10^6 (1×10^4 – 1×10^8)
I2	0.4 (0–1)	1730 (750–1900)	3.6×10^6 (1×10^4 – 1×10^8)
Material tank–Matrix–Punch	0.4 (0–1)	7850 (7850)	1×10^5 (1×10^4 – 1×10^{13})

Table 4 Final values of the variables related to the interactions. The ranges of variation used in the fit model appear in brackets

	Restitution coefficient	Static friction coefficient	Rolling friction coefficient
I1–I2	0.9 (0–1)	0.05 (0–1)	0.01 (0–1)
I1–I1	0.8 (0–1)	0.4 (0–1)	0.1 (0–1)
I1–Wall	0.9 (0–1)	0.3 (0–1)	0.1 (0–1)
I2–I2	0.9 (0–1)	0.1 (0–1)	0.1 (0–1)
I2–Wall	0.9 (0–1)	0.05 (0–1)	0.01 (0–1)
Wall–Wall	0.8 (0–1)	0.15 (0–1)	0.01 (0–1)

6.2 Analysis of Segregation During the Filling of the “quasi-3D” Tank

When the tank is filled with the mixture to compress (Fig. 7), a first separation takes place by the deposition of the particles at different speeds. The different way in which particles bounce off each other and against the walls of the tank, determines their magnitude. This segregation depends on the following factors: the properties of the particles (density, size, shape, etc.), the coefficients of friction (static and “rolling”), the restitution in the particle–particle and particle–wall contacts (of the tank) and the tank geometry (slope, inserts, etc.). This segregation ensured that fine particles are deposited in a higher proportion of the theoretical percentage (15%) at the base of the tank (pictures of tank base in Fig. 7c). For this reason, the first tablet had a percentage of 20.7% fines.

6.3 Analysis of Segregation while the “quasi-3D” Tank Empties

Over a full cycle test (real and simulated) it is possible to identify all segregation mechanisms mentioned in paragraph 4. Although whenever a combination of all segregation mechanisms is produced due to the particular geometry of the feeder tank, the incidence of each varies over one complete cycle. Taking into account the segregation identified along the cycle (Fig. 6), segregation mechanisms have

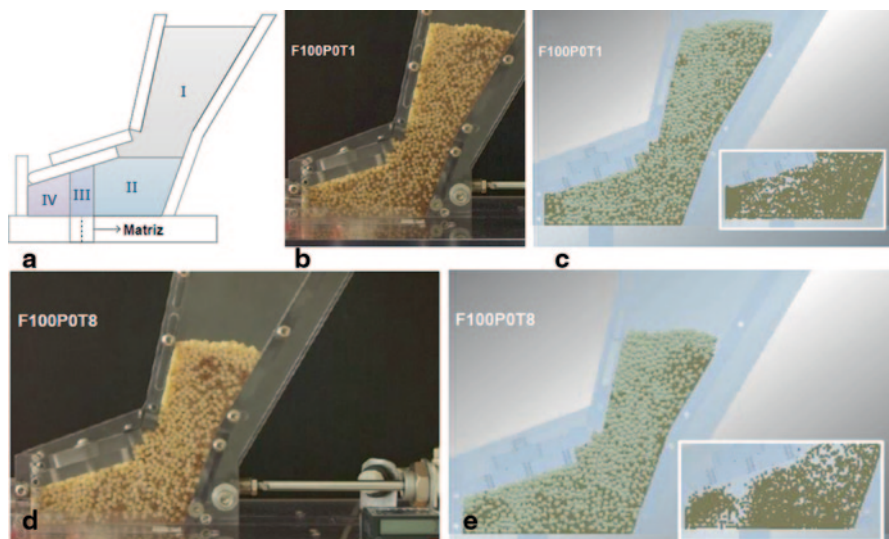


Fig. 9 Divisions of the contents of the tank and real images and simulated moments in F100P0T1 and F100P0T8

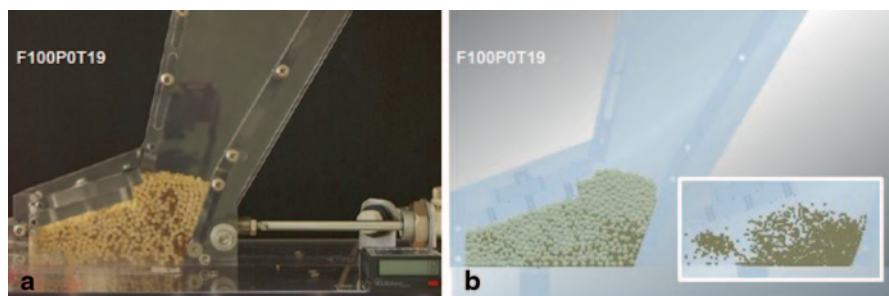


Fig. 10 Real and simulated images in F100P0T19

been analyzed in three intervals tableting. Figures 9, 10 and 11, correspond to the pre-filling of the matrix (instant F100P0Tz) that will produce tablets N° 1, 8, 19, 22, 26 and 30. These tablets correspond to the three identified intervals Zones I, II, III and IV, into which the contents of the tank have been divided and which allow a better explanation of the mechanisms segregation that arises during the complete cycle appear in Fig. 9a. For each tablet, a profile image of the compressed actual test is shown (in which one can see that the counter shows a number corresponding to the above compressed, $z-1$), as well as the simulation. In addition, to facilitate an understanding of the mechanisms of segregation, there is a detailed image of the simulation. Only particles of I2 ingredient (ingredient of size or fine) appear in it.

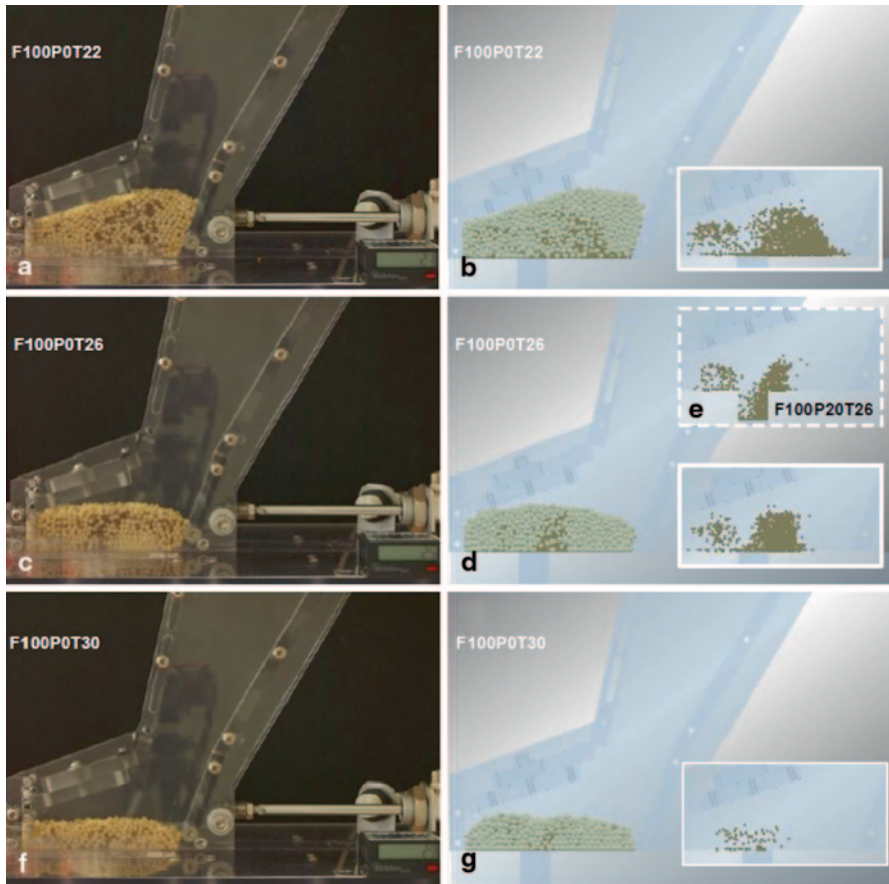


Fig. 11 Real and simulated images of F100P0T22 moments F100P0T26 and F100P0T30

- Interval I (tablet N° 1 to N° 8): Smaller or fine particles (I2) fill the spaces between larger or coarse particles (I1) providing that these particles go scrolling down and accumulate at the base of the tank. This segregation by percolation (by difference in size) increases until the tablet reaches the N° 8 a percentage of fines of 24%. In the image detail (which is fine only) in Fig. 9e, one can note that the fine particles have disappeared from zones III and IV (tip tank). This has resulted in a higher percentage of the tablets produced in this range. Fine particles located in the base of Zone III (located just above the matrix) are discharged from each filled matrix. Their place will be occupied by the thin particles located in the upper part of zone III. When the tank moves backwards, the fine particles of Zone IV are “trapped” in the spaces created by coarse particles that just entered the matrix. Finally, and by percolation, the quantity of particles in the top area of zone I is reduced by their move to lower parts of zone I (Fig. 9d, e).

- Interval II (compressed N° 9 to N° 21): The segregation mechanisms identified in interval I continue, but in running out of fines, the percentage of these decreases from 23.9% of tablet N° 9 to 10.6% of tablet N° 21 (Fig. 6). The detailed image of Fig. 10b, shows that the disappearance of fine particles in zones III and IV has accelerated. However, unlike what happened in interval I, this has not led to a higher percentage of fines from the upper parts of these zones. Also, the images show that there has been a reduction in fine particles (actual and simulated) in the top of the zone I.
- Interval III (tablet N° 22 to N° 30): During intervals I and II, the main segregation phenomenon was related to the percolation of fines (vertical movement in the direction of gravity). The particle movement was severely limited by the geometry of the tank and the horizontal displacement that was due to the alternative movement of the tank was virtually nonexistent. Since N° 22 compressed, having consumed the particles in zone I, the mixture begins to have space in which can move horizontally within the tank due to inertia that gives it in its alternative movement. At this point, a segregation mechanism by convection (or vibration) begins to occur. As the free space increases in the tank base, particles move horizontally between zones II, III and IV. This displacement (also maintaining percolation identified in the above ranges) explains the sudden increase in the proportion of fines that occur in the compressed No. 26 (21.0%). In the detailed image of Fig. 11b one can see how the coarse particles from the area I (free of fines), take up the right half of zone II. This and the virtual disappearance of fine in zones III and IV are responsible for a “bag of fines” that moves horizontally to the left half of area II (detailed image in Fig. 11d). This bag of fines is “consumed” in the production of tablets N° 25, 26 and 27 (Fig. 6) when it is positioned in zone III, just above the matrix. In the detailed image of Fig. 11e (only fine particles), the sequence F100P20T26 (just after the F100P0T26) shows how lowering the punch causes many of the fine particles to fall into the bag matrix. After this event, in compressed after N° 27, the percentage of fines decreases dramatically to almost zero in the compressed N° 30 (detailed image in Fig. 11g).

7 Conclusions

The present paper shows an application of the discrete element method (DEM), which has been used to simulate the complete emptying of the feeder tank of an eccentric compression machine.

The optimal values of the process variables have been determined through an iterative process, for which there was an acceptable (4.0%) level of errors (RMSE).

With the model obtained it has been possible to analyze in more detail the process of segregation that occurs in this type of machine. This model is the starting point that will, in future research, lead to improvements in the design of the elements of these machines that will mitigate the problem of segregation.

Acknowledgements This work has been made possible by the support of EDEM Solutions (Edinburgh, UK) and Rioja Plan I + D of the Autonomous Community of La Rioja, through project FOMENTA 2010/02.

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Part VIII
IT and Communications. Software
Engineering

Use of Wireless Sensor Network to Control Landslides Interacting with Infrastructures

G. Combarros Hernández, A. García Garijo, F. Antoñanzas-Torres,
E. Alonso García and R. Fernández Martínez

1 Introduction

The occurrence of landslides in slopes, more common in areas under harsh environmental conditions, suppose a high-risk danger for infrastructures located close to the risky point and to the people that live around. In order to minimize this risk, in this work it is proposed a real-time monitoring of landslides with high risk of geological disaster, such as ones formed by easily erodible rocks with water contact, or geographical areas with hard weather conditions along the whole year (water, snow, ice, wind, etc.).

An example where one of these danger areas can be found is the N-634 road, included in the Spanish national roads system, placed in Vizcaya, in the North of Spain, between the cities of Getaria and Zarautz. This road supports a high level of traffic. In this area there is a high risk of landslide according to the literature [2–5]. It is a road which extends along the north face of the Cantabrian Mountain Range, isolated by the Cantabrian Sea and this mountain range. There is a very

G. Combarros Hernández (✉) · A. García Garijo
University of La Rioja, La Rioja, Spain
e-mail: gocombar@gmail.com

A. García Garijo
e-mail: tpvalfaro@hotmail.com

F. Antoñanzas-Torres
Department of Mechanical Engineering, ETSII, University of La Rioja, La Rioja, Spain
e-mail: antonanzas.fernando@gmail.com

E. Alonso García
EDMANS Group, University of La Rioja, La Rioja, Spain
e-mail: eduardo.alonsoga@gmail.com

R. Fernández Martínez
ETSI, UPV-EHU, Alameda Urquijo s/n. C.P., 48013 Bilbao, Spain
e-mail: roberto.fernandezm@ehu.es



Fig. 1 Overview of Km 22 in N-634 road

unstable weather conditions the whole year due to the peculiar location. In general, the weather conditions are characterized by high relative humidity, copious rains in spring and autumn and abundant snow in winter. Besides, the stratification of this ground is composed by limestones, sandstones and black slates, especially sensitive materials that can be eroded by water and snow. For these reasons, there are frequent landslides in this area during the rainy season.

The stretch road covers a total surface of 9 km long, nevertheless this study is just focused on the km 22, which is near a tunnel between Zarautz and Getaria (Fig. 1), where a high risk slope of 100 m is located with a surface of 22.25 ha.

During last years it has been quite common these kind of problems in this spot. The 6th of December of 2008, there was a huge landslide causing the close of the road for a couple of days. The effect of the landslide can be seen in Fig. 2, showing that the damage was quite significant.

To provide security and environment protection, currently many techniques can be used to measure the inclination of a slope: from classical methods, such as cracking detectors made of two wood boards, to modern techniques like new inclinometer sensors, which can measure vertical inclination at several axis.

Another common problem in this scenario is the monitoring on real time, mainly because landslides are unpredictable. It is necessary to know the conditions of the slope at every time, checking if the displacement has not changed in each point. Thus, one of the most effective solutions is the arrangement of a wireless sensor network (WSN), in such way it will be able to place several nodes in different points along the slope. Each node sends obtained measures to the gateway, so that the communication among nodes allows a continuous flow of information to make possible control the situation on real-time.

Fig. 2 Landslide occurred in the studied spot on 2008



To sum up, the final aim of this work is the implementation of a WSN that measures the inclination of high risk spot through inclinometers [7, 14].

2 Objectives

The goal of this study lies on the development of a capable system of monitoring a slope with high risk of landslides. To that end, it is proposed the implementation of a WSN, working on real time and autonomous enough to run without human intervention in long periods of time.

With regards to the WSN, its tasks to accomplish are:

- Collect the information that comes from the previous fixed spots, by storing all the measures within a database.
- The design of a sustainable source of energy able to provide power to the nodes during long periods of time.
- Reduce costs, either on setting in and maintenance.
- Make possible to cover a large area through long distance communication between nodes.

3 Materials and Methods

3.1 *Inclinometer*

The LCF196 is a biaxial inclinometer packed in a 22 mm diameter stainless steel case, very hard and appropriate for adverse weather conditions (Fig. 3). This family of inclinometers has three different devices, depending on their maximum

Fig. 3 LCF196 inclinometer

inclination measure range: 14.5, 30 and 90°. In this study after analysing the possible scenarios, it has been used the 14.5° model.

The sensor works with an output voltage between +5 V and -5 V, depending on the inclination angle. The main and starting position is 0 V, which usually takes place on a vertical arrangement. When the inclinometer detects a voltage over ± 5 V, the manufacturer of the product cannot ensure a reliable linearity of these values, and therefore the angle of inclination may be incorrect.

3.2 *Wireless Sensor Network*

A WSN is a group of small devices, called nodes, equipped with sensors [1, 11, 13]. These nodes can communicate with each other by wireless communication protocols, which allow them to monitor any kind of scenario easily and quickly. The main features of a WSN are its energy-saving and its adaptation to the field.

A WSN is formed with two different types of nodes:

- A central node or gateway: its task consists in receiving all the information data from the sensor network and storing it in a database. It is also the gateway to the outside network, since it is possible to send and receive data from other networks.
- Sensor nodes or motes: they are placed in pre-studied important spots of the slope to make measurements during certain periods of time and they send the information collected to the gateway node. Besides, these nodes are totally autonomous and they don't need any kind of wire connection to run.

Table 1 ZigBee vs Bluetooth

	ZigBee	Bluetooth
Consumption transmitting	30 mA	40 mA
Consumption in sleep mode	0.3 μ A	0.2 mA
Data transfer rate	250 Kbps	3 Mbps
Maximum length	75 m	10 m
Maximum number of nodes	65353	8

The topology used in this study is based on a star topology, which fits perfectly with the needed requirements of this work. The star topology consists in several sensor nodes placed around a central node or gateway, which is the responsible of receiving messages from the nodes and storing the useful information in a database. In this topology, the key element is the gateway due to the management of all data sent by the nodes. Furthermore, when data is compiled and organized on the gateway, useful information is sent out to a PC connected with the gateway through an internet connexion. In that way, gathered information is available from everywhere and the system is more useful.

Besides, this nodes system follows a fail-safe design, because it might present a fault in any node but the rest of the network would run properly. Although, on the other hand, if the problem lies at the gateway, the whole system will stop working completely and information will not be kept.

3.3 *Communication Protocol*

The used protocol is ZigBee [8, 9] due to the fact that presents many advantages in regards to other wireless protocols, such as Bluetooth.

Table 1 shows the main differences between Bluetooth and ZigBee. Besides, it is needed to remark that the way Bluetooth works requires a permanent communication, thus devices have to be active most of the time. On the contrary, ZigBee only requires being active during the sending task. Once it finishes, the node automatically enters in a sleep mode which lasts until the next sending operation.

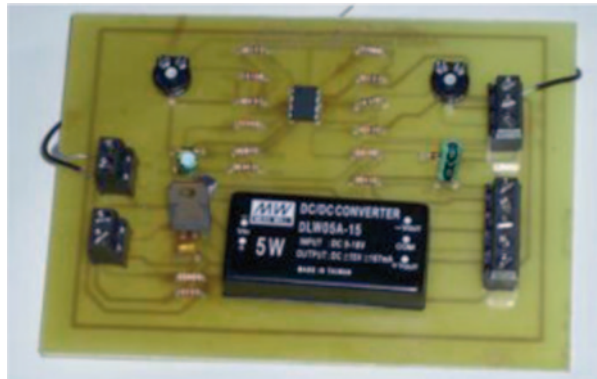
3.4 *Imote2*

Nowadays Imote2 (Fig. 4) is considered one of the most advanced nodes in market for carrying out this process. Imote2 is an advanced node developed by Memsic, Inc. and specifically designed for WSN. This design is based in a low power consumption CPU, PXA271 XScale from Intel, which works with a very low voltage (0.85 V) and low frequency (13 MHz). A radio frequency (RF) antenna is also integrated within, which allows communication under the IEEE802.15.4/Zig-Bee standard. The final goal of this device is to work with a low voltage and high performances in a small space, giving it a great versatility.

Fig. 4 Imite2



Fig. 5 Signal adapter and source power board



Furthermore, its work possibilities are endless due to several additional boards that can be added to the device and improve the features of the node, thanks to the modular and expandable design based on the expansion board connectors. Besides an operating system (OS) can be installed on it, which is a great help to design and program new applications.

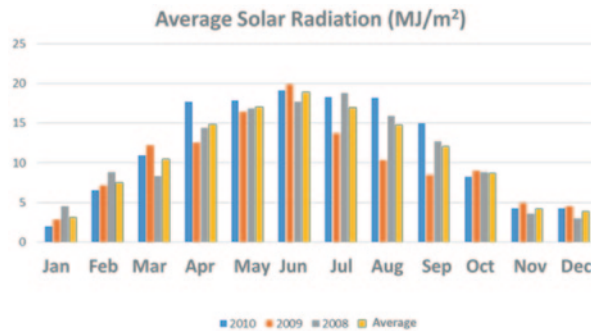
3.5 Signal Adapter and Power Supply Board

Each mote must be equipped with an additional circuit for signal adaptation and for power supply, this is necessary to feed each device installed in the spot (both inclinometer and Imote2). This fact is also totally necessary because the output range of the inclinometer (± 5 V) does not match with the input range of the ADC integrated on Imote2 (0–3 V). Thus, it was performed a small design capable of converting the inclinometer output voltage into the input voltage of the Imote2 ADC. The final result is shown in Fig. 5.

Table 2 Electrical features of each one of the sensor nodes

Feature	Values
Working voltage	12 V
Average current	0.165 A
Nominal power	1.98 W
Daily use time	24 h
Daily current demand	3.96 Ah
Daily power demand	47.52 W

Fig. 6 Solar radiation data from Zarautz during 3 years (2008–2010)



The final conversion is given by Eq. (1).

$$V_{ADC} = 0.3 \cdot (V_{sensor} + 5)V \tag{1}$$

In this way, the voltage obtained can be received by the ADC, without losing any resolution.

3.6 Power Supply

The power supply design represents a critical part of this study, mainly because this power supply reinforces the autonomy of the system without any human intervention [10]. An estimation of the main features of each node, related with the power used by the nodes is shown in Table 2

The implementation of a small size solar panel has been chosen to supply the necessity of power of each node and to provide them total autonomy, so that the results comparing to use regular batteries are improved [6].

Previously to the design of this power supply, it is necessary to carry out a solar radiation analysis of the area where the WSN will be located. This analysis was made with data collected from the meteorological station of Zarautz, a city close to the study spot, which has measured its solar radiation for several years. Data obtained from this weather station during 3 years (2008–2010) are shown in Fig. 6.

As it can be seen in Fig. 6 during the winter solar radiation is less intense than in summer. Taking this into account, the total sun energy in a year was calculated in order to estimate the life of the batteries, trying to avoid any kind of uncharged element during the project life. This analysis estimates that a power of at least 27 W can be obtained from the solar panel. Therefore, a solar panel of nominal power equal to 30 W was the chosen, being these 30 W more than enough to supply energy to each mote, and using solar panels of small dimensions to reduce the environmental impact as much as possible.

3.7 Software

Imote2 can work under different operating system (OS); in this study, after analysing advantages and disadvantages, the OS Linux was chosen. The main reason was the versatility and simplicity to program under C language. Moreover, the programming methodology is very similar to the required in a desktop computer, with only one difference, it is necessary a cross compiler due to the Imote2 micro-processor architecture.

The developed software is based on four different processes: acquisition, sending, reception and register.

- Acquisition: process that reads measures from the sensor through the ADC; subsequently these measures are collected by the mote. It is advisable to bear in mind the relation between the digital value and its proportional inclination, this value is given by Eq. 2, where “D” responds to the data measured.

$$\text{Angle} = 7.08 \cdot 10^{-2} \cdot D - 14.5^{\circ} \quad (2)$$

- Sending: process that transmits data from the mote to the gateway.
- Reception: the gateway accomplishes this action, where is constantly alert to receive data coming from the motes.
- Register: this action is accomplished by the gateway, where the received data is converted to readable information and stored for further interpretations. Besides, this function keeps the gateway always alert, waiting for the request of sending data from a PC.

3.8 Position of Nodes and Inclinometers in the Field

The last step of this work is the positioning of each node in their exact position, according to Suarez [12].

- It is really important a good positioning of the nodes at a medium height, between the road and the highest point of the slope, otherwise the measurement will not be accurate (Fig. 7).



Fig. 7 Comparison between different nodes location along the slope

Fig. 8 Location of each node



- Furthermore, there must be a distance of 20 m between the measurement spots. The most convenient location of the nodes is in line, with equidistant distances between them (Fig. 8), in a way that finally the system can cover around 100 m.

4 Results

This system has not been implemented in the suggested area yet, but the laboratory experiments were very successful. Sending and reception between sensor nodes and the gateway work correctly, and data measurements registered match perfectly with the inclination of the inclinometer (Fig. 9).

The power supply provides energy to the inclinometers, which measure the inclination on each location, and the wireless nodes, which are in charge of the transmission to the gateway. Once information is obtained from the sensor, the signal is treated to adjust the real value in each mote. Each mote processes the measure and sends messages to the network without losing packets. Besides, the gateway receives the messages sent by the motes and redirects them to a central station, where all the information will be stored.

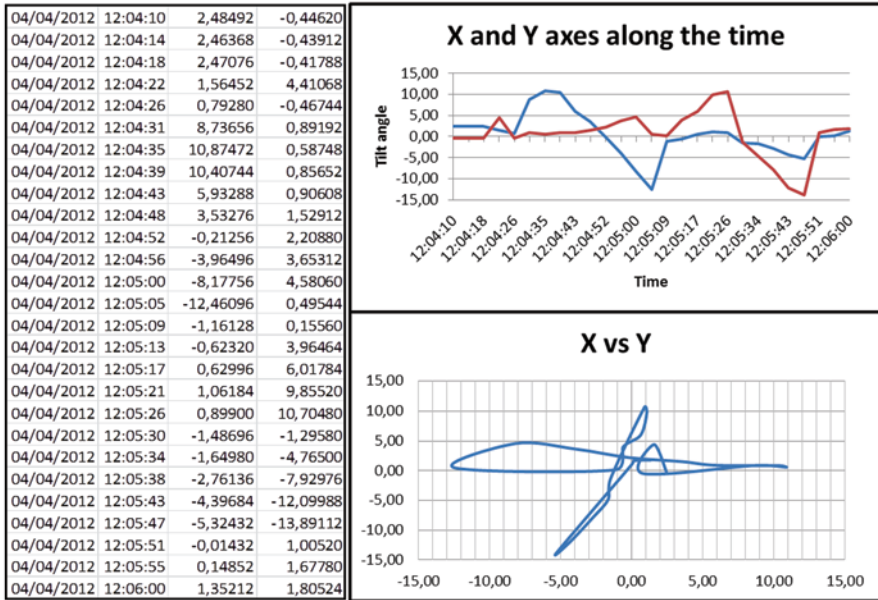


Fig. 9 Example of gathered information and graphs of obtained measures in laboratory

And finally, the stored information is used to show the inclination of the two axes measured by the inclinometer. In each message, the time and date of when the signal was read, and the identifier number of each node are sent. Through this information, a proper monitoring of the network can be performed with the aim of prevent future possible landslides in the area.

5 Conclusions

A WSN has great potential benefits in this kind of scenario, mainly because it is based on a group of spatially distributed autonomous sensors that monitor physical or environmental conditions. Therefore this kind of systems, more specifically the one proposed, can be applied to situations where inclination measures are required, such as different kind of infrastructures or areas with seismic activity.

These networks can be placed in areas where wired networks cannot be situated or where the installation costs become too expensive, thanks to their special features like scalability, ease of use, nodes heterogeneity, adaptation to the environment, power awareness, among others. Moreover, according to the work carried out in this study, it is possible to add new nodes anytime without any kind of reprogramming, just copying to the new nodes the code developed, what means an advantage for further scalability of the system.

To sum up, this work has shown through reliable data and several tests, the multiple advantages that these networks based on autonomous nodes have and how can monitor uneasy locations with accurate and affordable results.

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Evaluation of Clustering Configurations for Object Retrieval Using SIFT Features

L. Fernández-Robles, M. Castejón-Limas, J. Alfonso-Cendón and E. Alegre

1 Introduction

Object retrieval aims at retrieving images that contain objects similar to the query object captured in the region of interest (ROI) of a query image. When the object retrieval system is based on query by example, the user chooses an image of interest and then selects a bounding box in that image, which conforms the ROI, holding the query object or object of interest. Straightaway, the ROI has to be described and this feature representation is used to match images or videos in an image or video database. Changes in pose, scale, orientation, illumination, rigidity, cluttered background or occlusion, among others, makes object retrieval a challenging task (see Fig. 1).

Recent object description approaches rely on local features rather than in global descriptors, since local description can reliably detect highly distinctive keypoints of an image. Therefore, a single feature can be correctly matched with high probability against a large database of features, providing a basis for object and scene recognition. Another advantage is the capability for still retrieving images with occluded query objects. The development of image matching by using a set of local

L. Fernández-Robles (✉) · M. Castejón-Limas · J. Alfonso-Cendón
Departamento de Ingenierías Mecánica, Informática y Aeroespacial,
Universidad de León, León, Spain
e-mail: l.fernandez@unileon.es

M. Castejón-Limas
e-mail: manuel.castejon@unileon.es

J. Alfonso-Cendón
e-mail: javier.alfonso@unileon.es

E. Alegre
Departamento de Ingenierías Eléctrica y de Sistemas y Automática,
Universidad de León, León, Spain
e-mail: enrique.alegre@unileon.es



Fig. 1 Example of images containing the same object, a *blue* toy car

interest points was definitively efficient when Lowe [13] presented SIFT, introducing invariance to the local feature approach. Later, Bay, Tuytelaars and Van Gool [3] outperformed previously proposed schemes with respect to repeatability, distinctiveness, robustness and speed. Recently, Ozuysal et al. [16] showed a fast key point recognition method using random Ferns which avoids the computationally expensive patch pre-processing by using hundreds of simple binary features. Following this idea, and due to the need of running vision algorithms on mobile devices with low computing power and memory capacity, new approaches are being developed. The Binary Robust Independent Elementary Feature (BRISF) [4], the Oriented Fast and Rotated BRIEF (ORB) [18], the Binary Robust Invariant Scalable Keypoints (BRISK) [12] and the Fast Retina Keypoint (FREAK) [1] are good examples. Their stimulating contribution is that a binary string obtained by simply comparing pairs of image intensities can efficiently describe a keypoint, for example an image patch.

In order to rank all the images of the dataset, one possibility would be to take into account the distance of the closer match between the ROI and every image in the dataset. However this could lead to two kinds of errors. First, the local surroundings of two keypoints could be very similar even when they belong to different objects. Secondly, unfortunately, a bounding box selection makes that together with the query object, there could be other (partial) objects or cluttered background in the ROI. These non-interest regions can produce non-relevant keypoints that could lead to closer matches. Lowe [14] suggests to consider at least 3 features correctly matched from each object for reliable object retrieval using a Hough transform to identify clusters belonging to a single object, and finally performing verification through least-squares solution for consistent pose parameters.

ASASEC (Advisory System Against Sexual Exploitation of Children) is a European research project whose goal is to provide a technological solution to help the fight against child pornography. One of the most challenging tasks in this kind of environments consists in retrieving objects from huge amounts of image and video datasets that are proven to come from images or videos containing scenes of children exploitation. Relating different scenes could help to understand and demonstrate complex legal cases. Object matching interpretation becomes then a crucial task. In this paper we compare the performance when retrieving images, using just the distance of the closest pair of keypoints, and when using Lowe's [14] proposal, using the vote of at least three points by means of the Hough transform and least-squares verification.

The rest of the paper is organized as follows: After reviewing object recognition using Invariant Local Features (ILF) and the main ideas related with model fitting in Sect. 2, we introduce our experiments and discussion in Sect. 3. Section 4 brings the most important conclusions and recommendations for future work.

2 Object Recognition Using Invariant Local Features

2.1 *Invariant Local Features (ILF) and Object Recognition*

As it has been pointed out in the introduction, since the Lowe's paper [13], the computer vision community has been very active presenting improvement after improvement based on SIFT method. Although over a decade, Lowe's algorithm has proven very successful in a number of applications using visual features and mainly objects recognition. The main problem associated with it has been the large computational burden imposed by its high dimensional feature vector that, in recent years, led to the emergence of new proposals mainly focused on obtaining equally robust descriptors but more computationally efficient. The first of a series was FAST [17] who uses a machine learning approach to derive a feature detector similar to Harris, SUSAN or DoG but much more faster than them, but with the disadvantage that is not very robust to the presence of noise.

A step farther was proposed by Calonder et al. [4]. They use binary strings as a feature point descriptor, called BRIEF that is highly discriminative, even when using a few bits, and can be computed using simple intensity difference test. Another big advantage of BRIEF is that the matching can be performed by using the Hamming distance, which is more efficient to compute than the Euclidean distance employed in most of the invariant local features detectors. Both aspects convert BRIEF in a faster descriptor in construction and matching, but as it is not invariant to large in-plane rotations, it is not suitable for object recognition task that are similar to the problem we are facing in the ASASEC project.

Another faster than the classical SIFT and SURF [3] but comparable at matching performance is the BRISK detector [12]. BRISK relies on a configurable circular sampling pattern from which it computes brightness comparison to form a binary descriptor string. Its detection methodology is inspired in the adaptive corner detector proposed by Mair [15] for detecting regions of interest in the image. Their AGAST is essentially an extension for FAST [17], proven to be a very efficient basis for feature extraction. With the aim of achieving invariance to scale, BRISK goes a step further by searching for maxima not only in the image plane, but also in scale-space using the FAST score s as a measure for saliency.

An evolution of the above-mentioned methods is the ORB descriptor [18] that builds its proposed feature on FAST and BRIEF, standing its name for Oriented FAST and Rotated BRIEF (ORB). Their authors address several limitations of these techniques, mainly the lack of rotational invariance present in BRIEF. They add

a fast and accurate orientation component to FAST and, at the same time, they present an efficient way to compute the oriented BRIEF features. Furthermore, the ORB descriptor uses a learning method for de-correlate BRIEF features under rotational invariance, leading to better performance in nearest-neighbour applications. ORB was evaluated using two datasets: image with synthetic in-plane rotation and added Gaussian noise, and a real-world dataset of textured planar images captured from different viewpoints. As their authors pointed out, ORB outperforms SIFT and SURF on the real-world dataset, both the outdoor and the indoor, what make this method a good choice for object recognition.

As this work is based in the SIFT descriptor, next section elaborates on describing the main steps that are necessary to obtain a SIFT keypoint vector.

2.2 *Scale Invariant Feature Transform (SIFT)*

In his seminal paper, Lowe [13] presented a method for image feature generation called the Scale Invariant Feature Transform (SIFT). The advantage of this approach is that it transforms an image into a large collection of local feature vectors, each of which is invariant to image translation, scaling, and rotation.

The scale-invariant features are efficiently identified by using a staged filtering approach.

1. Identification of key locations in scale space

The first stage identifies key locations in scale space that are invariant to image translation, scaling and rotation, and also robust to noise and small distortions. To achieve rotation invariance SIFT selects key locations at maxima and minima of a difference of Gaussian function applied in scale space that is computed by building an image pyramid with resampling between each level.

2. Stability of the key features

The stability of the previous keypoints is obtained through different operations. Image gradients and orientations are used to characterize the image at each key location. The gradient is computed as the pixel differences and robustness to illumination change is enhanced by thresholding the gradient magnitudes at a value of 0.1 times the maximum possible gradient value.

To ensure invariant to rotation, to each key location a canonical orientation is assigned. The orientation for each key point is determined by the peak in a histogram of local image gradient orientations. The orientation histogram is created using a Gaussian-weighted window whose weights are multiplied by the thresholded gradient values and accumulated in the histogram at locations corresponding to the orientation.

3. Description of the local regions surrounding the key points

Given a stable location, scale and orientation for each key, SIFT describes the local image region in an invariant manner to these transformations. This method repre-

sents the local image region with multiple images representing each of a number of orientations (orientation planes). Each orientation plane contains only the gradients corresponding to that orientation, with linear interpolation used for intermediate orientations. Each orientation plane is blurred and resampled to allow for larger shifts in positions of the gradients.

SIFT implements this approach in a very efficient way by using the same pre-computed gradients and orientations for each level of the pyramid that were used for orientation selection. For each keypoint, they used the pixel sampling from the pyramid level at which the key was detected. The pixels that fall in a circle of radius 8 pixels around the key location are inserted into the orientation planes. The orientation is measured relative to that of the key by subtracting the key's orientation. In his experiments, Lowe uses 8 orientation planes, each sampled over a 4×4 grid of locations, with a sample spacing 4 times that of the pixel spacing used for gradient detection.

In order to sample the image at a larger scale, the same process is repeated for a second level of the pyramid one octave higher. This time, SIFT uses a 2×2 sample region; therefore almost the same image region is examined at both scales, avoiding in this way undesirable effects coming from occlusions. The final SIFT feature vector comes from a 4×4 array of histograms with 8 orientation bins in each, having a length of $4 \times 4 \times 8 = 128$ element feature vector for each keypoint.

2.3 *Model Fitting*

The following step after obtaining the data around the key points and their local features might be to extract useful information by using data-mining techniques [8]. This approach seems to be fitted for this scenery due to the large amounts of information that, quite soon, a medium size collection of pictures might provide. Moreover, there is hidden information within the bulk of key points and their descriptors that might be extracted in order to achieve a better knowledge of the nature of the objects captured in the analysis. That seems to be mandatory for decision-making processes based on evidence criteria, as recommended by ISO standards.

Amongst the different procedures that these data may undergo, we consistently find the greatest usefulness of the following stages:

- Exploratory data analysis
- Outlier identification
- Variable selection
- Robust model building
- Model testing with new data from fresh images

The former might summarise a general data-mining scheme for computer vision and pattern recognition, at least, to the degree where reliable higher information might be obtained.

The first step, *exploratory data analysis*, provides a visual comprehension of the difficulties that the numerical algorithms might have to tackle in order to discern

the number of different behaviours -in computer vision, different objects-, occurring in the pictures data set. A well-trained practitioner might find suggestive elements that might support later results as provided by the numerical algorithms or, on the contrary, help them search further with different techniques should the results be inconclusive, proving that a particular technique is not accurate enough for the purpose intended.

The second step, *outlier identification*, highlights those samples that do not follow the pattern of the majority. Traditionally, these outliers have been nominated for removal in order to simpler algorithms manages to obtain the model representing the majority of the cases recorded. Nevertheless, it is sensible to investigate the origin of these outliers, as many times that will provide knowledge about particular events of special relevance. A more coherent approach in model fitting integrates those outliers in the model definition ensuring that the model building process is robust enough to manage this information.

The third step, *variable selection*, plays a central role in computer vision for pattern recognition. Given the various and sundry different descriptors proposed by researchers in computer vision during the last decades, the practitioner must select those that will perform the particular task at hand more efficiently. Variable selection can be performed by traditional ways: adding and removing the input variables and checking whether that improves the results according to some indicator; or following more powerful approaches where evolutionary computation, e.g. genetic algorithms, are especially useful.

The fourth step, *robust model building*, is responsible for providing a prediction model that works well, not only with the training data, but also with new data from fresh images not considered on the determination of the parameters of the model. As different behaviours are to occur in real case studies, cluster analysis techniques will be of much help on isolating different populations for determining better their characteristics. The use of those varies on the model fitting technique applied later on, but in general terms, having acquired such degree of knowledge about their distribution empowers the successive analyses for more accurate results. Classification analysis techniques can be classified in two large groups: supervised classification -also known as discriminant analysis- and non-supervised classification -also known as clustering.

Discriminant analysis techniques [2] are useful in those contexts where a finite number of classes are known to exist and to follow a known probabilistic model. Their purposes are two-fold:

- Describe the differences amongst occurring classes, and define which are the features that best determine or predict the class to which one sample belongs to. These variables are names discriminant variables, and the analysis is considered as descriptive.
- Define rules that allow assigning the observed samples to the occurring classes. This is the predictive analysis.

The purpose of cluster analysis [6], on the other hand is to identify groups of differentiated behaviour within the samples obtained, as they are supposed to have been

generated by different populations, or different states of the generating process. That could be a general definition that, in the context of computer vision, can be translated to identify different groups of elements pertaining to different objects, images, textures, etc. Predominant clustering techniques can be classified mainly in hierarchical techniques and partitioning techniques.

The fifth step takes advantage of the clustering characterization obtained in step number 4. By considering the differences in the data, a robust model can be obtained. For such a purpose, traditional techniques [7] for model fitting are especially useful in computer vision, as far as they provide results efficiently requiring small computing efforts and affordable times. This is especially important when analysing big data sets of images containing several objects per image, and describing a considerable amount of key point on each image. Complexity of the algorithms is, thus, one of the more severe requirements for any application supposed to work on large sets of images.

For smaller sets where more computing power can be spent, neural networks are found especially useful for predictive purposes. Given that multilayer perceptrons can be considered universal function approximators [10], they soon appealed the attention of researcher in need of a tool for model fitting where non-linearities could be assumed, and where second order effects are not necessary neglected for the sake of tractability.

Multilayer perceptron neural networks (MLPNN) consist of a set of units, called neurons, which are grouped into successive layers [9]. Each of these neurons is endowed with a particular behaviour, described by their activation function; typically either a hyperbolic, threshold or linear function, their nature depends on their function on the network, which is typically defined by their location on the different layers. These, the layers, are commonly classified into three categories: input layer, hidden layers and output layer. Neurons in a MLPNN are generally fully connected, which implies that the outputs of the input neurons point towards the inputs of the first hidden layer, the output of the neurons of the first hidden layer point towards the inputs of the second hidden layer, or to the inputs of the output layer, if the MLPNN is only defined with one hidden layer.

MLPNN are trained with samples from the data set in an iterative manner until some stopping criterion is applied. The choice for the stopping criterion has an impact on the capability of the neural network to generalize well the learned patterns when new data is entered.

2.4 Hough Transform for Object Recognition

The Hough transform [5] is a popular technique in the computer vision area. Amongst its numerous advantages robustness can be highlighted. Moreover, it is a fairly efficient algorithm suitable for situations like this where a large set of pictures might be involved. Though originally it was defined for identifying simple shapes in images, like lines and circles, its use has been extended to more general shapes,

allowing for detection of multiple instances of an object that might even be partially occluded. The complexity relies on the number of parameter chosen to represent the complex shape, with search times increasing in exponential order. Fortunately, the Hough transform can be easily implemented on parallel computing systems as each image point can be treated independently [11] using more than one processing unit.

Essentially, the Hough transform converts sets of points in an image to a parameter space. Thus, two points can be represented in the parameter space as a point in a two dimensional space whose axes represent the two parameters needed to define the line over those two original points in the image. Similarly, the points of circles, ellipses and parabolas in the image can be transformed to points in a new space of parameters. Shape parameterization extends this idea further by means of high-dimensional parameterization that can be decomposed into smaller sets of parameter to determine sequentially.

One of the complexities that appear when using the Hough transform is that for a single image, many points can be chosen to belong to a single line, and thus many lines can be adjusted with the whole data set. Model fitting comes to the rescue in order to choose the best model to use. Additionally, by using the Hough transform a voting scheme can be adopted [11], which is one of the most common manners of applying the algorithm.

3 Experiments and Results

3.1 Dataset

For the purpose of our goal, retrieving query objects from a dataset containing child pornography, we have created our own dataset. It is composed of 614 frames of 640×480 pixels that come from 3 videos recorded under different conditions. All videos were recorded in different bedrooms with different distributions, illumination, textures, etc., making the object retrieval a challenging task. Nevertheless, some objects are present in all videos, such as two toy cars, some clothespins, a stuffed bee, some pens, some cups or a child book together with a big doll. The doll is usually the principal actor in the videos, and helps us to simulate partial occlusions of the objects and a more realistic scenario. Although these objects are present in every video, they do not appear in every frame. As query objects, we have used the book, the blue and yellow car, and the pink, blue and green clothespin shown in Fig. 2. The total number of query objects present among the 614 frames that we used in this paper can be found in Table 1.



Fig. 2 Regions of interest of the query objects. (The dataset is available at <http://pitia.unileon.es/varp/galleries/>.)

Table 1 Number of objects in the dataset

Object	Book	Blue car	Yellow car	Pink clothespin	Blue clothespin	Green clothespin
Number of objects	115	102	138	125	92	42

3.2 Results and Discussion

When dealing with object retrieval, it is important that the retrieved images are ranked according to their relevance to the query object, instead of just being returned as a set. The most relevant hits must be in the top few images returned for a query. Recall and precision are measures for the entire hitlist and do not account for the quality of ranking the hits in the hitlist. Relevance ranking can be measured by computing precision at different cut-off points, this is technically called Precision at n or $P@n$.

Let $h[i]$ be the i th hit in the hitlist, and let $rel[i]$ be 1 if $h[i]$ is relevant and 0 otherwise. Then precision at hit n is:

$$P@n = \sum_{k=1..n} rel[k] / n \quad (1)$$

In order to analyse the retrieval performance of the query objects, we have compared results when relying on the match with the smaller distance, and when verifying the location, scale and orientation of the matched keypoints.

In the first case, after matching individual features of the ROI to the features of an image of the dataset, using a fast nearest-neighbour algorithm [14], we chose the match with the smaller distance. Since the smaller distance is considered, this pair of keypoints is the most similar one among all pairs of keypoints matched with the nearest-neighbour algorithm, and, therefore, this match has the highest probability of being correct. We use the distance of the closest pair of keypoints as a measure of the similarity (distance) between the ROI and the consulted image. The ranking of the retrieved images will be done sorting the images by this distance in ascending order. We will refer to this case as “no clustering”.

In the second case, after matching individual features to a database of features from known objects, using a fast nearest-neighbour algorithm, we use a Hough

Table 2 Precision at 5, 10 and 20 of the query objects using different clustering parameters. (Note: Lowe’s clustering uses 30 degrees for orientation, a factor of 2 for scale, and 0.25 times the maximum projected training image dimension (using the predicted scale) for location. Half and quarter clustering settings use 60 and 90° for orientation, factor of 4 and 6 for scale, and 0.5 and 0.75 times the maximum projected training image dimension for location, respectively.)

	Book			Blue car			Yellow car		
	P@5	P@10	P@20	P@5	P@10	P@20	P@5	P@10	P@20
No clustering	1	1	1	1	1	0.75	1	0.9	0.75
Quarter clustering	1	1	0.5	1	1	0.6	1	0.8	0.45
Half clustering	1	0.9	0.8	0.2	0.3	0.35	1	1	0.7
Lowe’s clustering	0.8	0.7	0.7	0.6	0.4	0.3	1	0.8	0.7
	Clothespin Pink			Clothespin Blue			Clothespin Green		
	P@5	P@10	P@20	P@5	P@10	P@20	P@5	P@10	P@20
No clustering	0.8	0.4	0.25	1	0.7	0.35	1	0.5	0.3
Quarter clustering	0.2	0.1	0.05	0.4	0.2	0.1	0.2	0.1	0.05
Half clustering	0.2	0.3	0.25	0.6	0.3	0.15	0.6	0.3	0.15
Lowe’s clustering	0.2	0.3	0.25	0.8	0.4	0.2	1	0.6	0.35

transform to identify clusters belonging to a single object, and finally we perform verification through least-squares solution for consistent pose parameters, as suggested by Lowe [14]. Each of SIFT keypoints specifies 4 parameters: 2D location, scale, and orientation, and each matched keypoint in the database has a record of the keypoint’s parameters relative to the training image in which it was found. Therefore, we can create a Hough transform entry, predicting the model location, orientation, and scale from the match hypothesis. Lowe’s clustering uses broad bin sizes of 30 degrees for orientation, a factor of 2 for scale, and 0.25 times the maximum projected training image dimension (using the predicted scale) for location. Here we present results with different configurations of the parameters. In this way, half and quarter clustering settings use 60 and 90° for orientation, factor of 4 and 6 for scale, and 0.5 and 0.75 times the maximum projected training image dimension for location, respectively. We computed the average of the distances of the matches of every cluster in an image and used the maximum average to rank the retrieved images.

Results for the four clustering types: no clustering, quarter clustering, half clustering and Lowe’s clustering showing the precision at hit 5, 10 and 20 can be seen in Table 2.

Since SIFT is not invariant to colour and the shape of the cars and the clothespins are very similar, it could be assumed that there are three different kinds of objects: books, cars and clothespins. Examples of the second, fifth and tenth hit in the hitlist for the yellow car with the different clustering approaches can be seen in Fig. 3.

The ROI of the book is a 350×334 image with well-defined corners that should be quite easy to detect and match among the images of the dataset. Table 2 shows a perfect retrieval for the first 20 matches when no clustering approach is used. Results get worse as a clustering more similar to Lowe’s one is performed. In fact, precision at 5 is 1 (all 5 first hits were relevant), except for Lowe’s clustering in

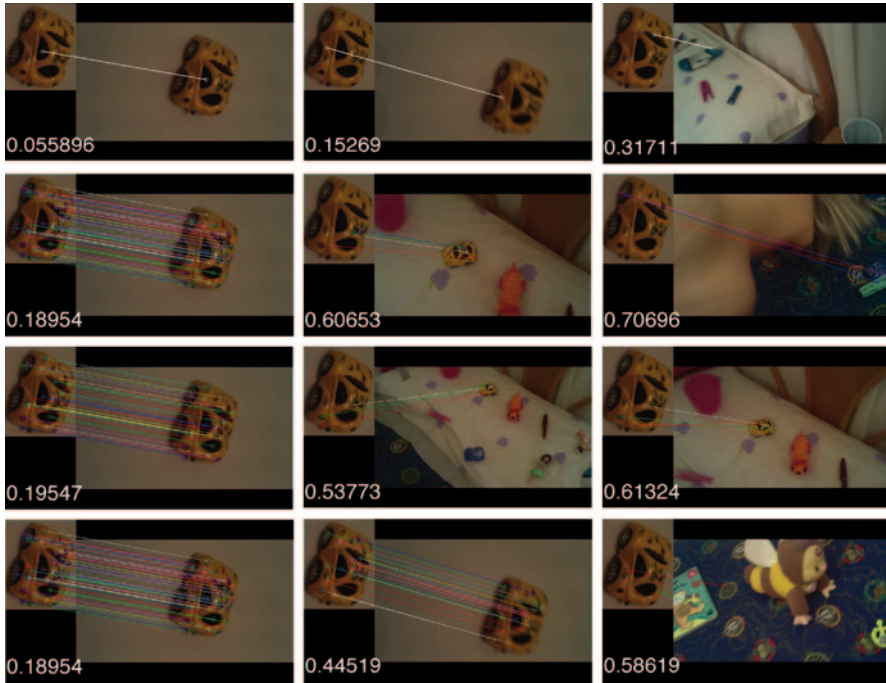


Fig. 3 Second, fifth and tenth hits using different clustering parameters for the *yellow car*. (Rows No clustering, quarter clustering, half clustering and Lowe's clustering. Columns second, fifth and tenth hit in the hit list. The number indicates the distance of the match or the average distances of the matches.)

which one hit is not relevant. Moreover, using the no clustering approach retrieves first 51 images correctly, considering that there are 115 images containing the book in all 614 dataset images, this is a very promising result.

For the car queries, we used a ROI of 285×258 for the blue one, and a ROI of 208×265 for the yellow one. Although SIFT method computes the descriptors using gray level images, there are small differences in shape and patterns between the two cars that can help the algorithm to distinguish them. The blue car retrieval is perfect for the first 5 and 10 hits, either using no clustering or quarter clustering approaches. Precision at 20 increases when less restrictive clustering is used, being $P@20$ equals to 0.75 with a no clustering approach. In regard to the yellow car, we observed that the first 5 images were well retrieved, no matter the clustering configuration used. Precision at 10 is 1 for half clustering approach followed, whereas precision at 20 is better for no clustering configuration achieving a value of 0.75.

As for the clothespins, we used ROIs of 146×132 , 85×145 and 68×59 for the pink, blue and green one, respectively. Clothespins present a more difficult task since less distinctive keypoints are present. Most of the keypoints are found in the metal wire, near the holes or in the outlines. Precision at 20 only reaches 0.25, 0.35, and 0.35, respectively. No clustering configuration is proved to work better

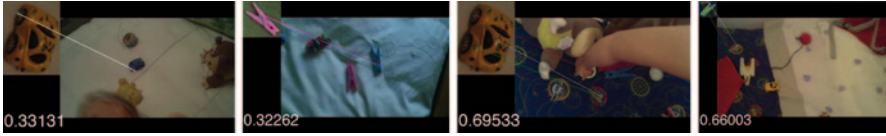


Fig. 4 Mismatches produces by similar objects (*first two*) and pattern duvet (*second two*)

for retrieving the pink and blue clothespins, while Lowe's clustering performs better for the green clothespin.

In order to show how similar objects with different colours can lead to mismatches, in Fig. 4, (first two images) we present examples of misclassified query objects. Only two mismatches, among different cars, appeared over all our experiments for the first 20 hits of the hitlist, but up to 10 in the case of the clothespins. Background is also another source of mismatches. The pattern duvet of one of the settings lead to many non-relevant but distinctive keypoints that look similar to other objects. We found out that some of the patterns of the duvet are similar to the patterns of the yellow car. Figure 4 (second two images) shows some examples of this fact.

Finally, we would like to make a comment about the number of hits found with each configuration. No clustering approach retrieves all images of the dataset in the hitlist, unless there are some images with very few keypoints, which is unusual. On the contrary, when considering clusters to vote for the same object, more images in the dataset do not produce a hit. Quarter clustering configuration obtains the fewest hits, followed by half clustering and Lowe's clustering approaches. For example, the number of hits for the green clothespin was 614, 18, 4 and 1, with no clustering, Lowe's clustering, half clustering and quarter clustering, respectively. This becomes a restriction in our application field since we prefer false positives rather than false negatives in order not to lose information of possible child abuses sceneries.

4 Conclusions

In this paper, we have presented and compared four different clustering approaches to carry out the retrieving of different query objects in a 614-image dataset. After applying SIFT descriptors, and a fast nearest-neighbours matching, Hough transform with three configurations of the parameters, and least squares refinement were used to make clusters vote for the object pose, orientation and scale. Also, we evaluated a simpler case that relies on the closest match of the nearest-neighbours matching. Results are not conclusive, but show some interesting facts. Most of the times, no using a clustering outperforms the rest of the configurations. One reason we have observed is that the closest match between a ROI and an image can be lost, because there are not, at least, other three points agreeing with the objects pose, scale and orientation. Another thing to be considered is the fact that fewer images are retrieved, when using a softer configuration of the clustering parameters. Besides, similar objects and cluttered background have led to quite a few misclassifications.

All in all, this technique could help to retrieve images from child pornographic datasets, which is a huge improvement, since it is a task usually manually performed nowadays. In future work, we will perform evaluation with a bigger number of query objects, and apply different techniques of clustering such as RANSAC.

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A Novel Architecture for Recognising Symbols in a CAD Environment

D. G. Fernández-Pacheco, J. Conesa, F. Albert, F. Cavas-Martínez and N. Aleixos

1 Introduction

Studies promoted by the Engineering Design Graphics Division of the American Society for Engineering Education [2] and by the American Society of Mechanical Engineers [11] have demonstrated that the two most highly valued skills that engineering students should be competent in, are mainly the abilities “to produce free-hand sketches of engineering objects” and “to create solid 3D models on a computer”. Other studies, such as the ones carried out by Plimmer and Apperley [10] or Tversky [12], have analysed the important role played by the use of sketches during the process of developing new industrial products.

The arrival of CAD (Computer Aided Design) supposed an enormous change on the lately phases of the product design process, but had a poor impact on the conceptual design phase, where sketches with pencil and paper are still necessary. In the current practice, the designer only starts to create a 3D CAD model from scratch after obtaining a final sketch. The main reason for this is due to the lack of CAS (Computer Aided Sketching) tools provided by CAD applications at both commercial and academic level. In addition, it has been revealed that using CAS tools is, at least, as

D. G. Fernández-Pacheco (✉) · J. Conesa · F. Cavas-Martínez
DEG, Universidad Politécnica de Cartagena, C.P. 30202 Cartagena, España
e-mail: daniel.garcia@upct.es

J. Conesa
e-mail: julian.conesa@upct.es

F. Albert · N. Aleixos
Instituto Interuniversitario de Investigación en Bioingeniería y Tecnología Orientada al Ser Humano, Universitat Politècnica de Valencia, Valencia, España
e-mail: fraalgi1@dig.upv.es

F. Cavas-Martínez
e-mail: francisco.cavas@upct.es

N. Aleixos
e-mail: naleixos@dig.upv.es

useful as conventional pencil and paper for developing spatial vision skills in novel engineering students [5]. However, CAS tools have not been developed as expected due to, first, the hardware necessary to implement them has not been available in the market until the recent appearance of Tablets and other tactile portable devices; and second, the limited capabilities they offer do not improve the traditional sketching, that is still carried out nowadays with conventional tools (pencil and paper).

These new devices have emerged as standard drawing tools and have supposed an important advance in the development of new user interfaces, also known as calligraphic or natural Interfaces. CIGRO system, proposed by Contero et al. [4], is the proof of this fact. In this system, authors present a calligraphic interface with a set of reduced instructions to create geometrical objects using digital sketches.

The improvements provided by the use of these interfaces enable the development of a wide variety of applications, like the application proposed by Wu et al. [13] to define 3D shapes from a unique view using shape palettes. Or the Plushie interactive system, developed by Mori and Igarashi [8], to design ragdolls by using sketches and some gestural commands in order to crop or extend the parts of the existing model. Also the FiberMesh system, presented by Nealen et al. [9], uses sketched 3D curves to design free-form surfaces.

However, one important application of calligraphic interfaces is to provide CAD systems with the capability of automatically recognising hand drawn sketches as commands, instead of the slower and less intuitive use of complex menus.

Automatic gesture recognition is a complex task, and even more if it is taken into account that different users can draw the same symbols with different shapes, sizes or orientations. In addition, the personal way each user draws influences the final result of the recognition. Furthermore, users often produce quivering strokes during sketching, or end the strokes with hooks when they lay down or lift the pen from the screen (so called outliers). Due to all these and other inconveniences, many recogniser algorithms are not robust or present ambiguity in their decisions, what usually requires user intervention.

For this reason, a change is needed in the methodology recogniser's implementation in order to distinguish and classify sketches like a human would do, that is to say, using context information and being flexible at middle and final decisions. This way of behaviour can be achieved by the use of expert systems, object based systems, and agent-based systems, among others.

In the case of agent-based systems, they have been widely used in applications for process simulation, process control, management, traffic control, navigation, etc., although its use is being extended more and more to processes in artificial vision environments, image analysis, and recognition tasks, such as sketch interpretation for supporting natural interfaces. For instance, Juchmes et al. [6] justify the use of multi-agent systems for free-hand sketch interpretation in the conceptual stage of architectural design. The system is able to capture lines and interpret them in real time, constructing progressively the technological and functional models of the building that is being designed. A similar structure is presented by Azar et al. [1], who propose and implement a multi-modal interface for architectural sketches interpretation based on a multi-agent architecture. In this case, the system is composed of several graphic agents which are in charge of recognising basic graphic elements (such as lines and

circles), and other more complex ones (such as doors or stairs), all of which belong to the architectural design. Other authors such as Mackenzie and Alechina [7] choose to apply a multi-agent architecture to a recogniser for child-like sketches of animals.

The ambiguity problems can be solved if the context information is considered and thus obtaining a correct recognition. This is precisely the case of the recogniser of UML Use Case Diagrams, which is based on an agent-based framework [3]. The recognition process is carried out by means of a series of a kind of intelligent agents, which are in charge of recognising the sketched symbols and coordinating among themselves to get an efficient and precise interpretation of the sketch introduced.

However, the previous described systems do not take into consideration other essential symbols used to create 2D sections or 3D geometry (e.g. geometric and dimensional constraints). For this reason, in this work it is defined a multi-agent architecture that permits to recognise hand-drawn sketches, as part of a higher level software, detecting simple entities (lines, arcs, circles, curves, ellipses, etc.), gestural commands (extrusion, revolution, symmetry and erasing) and geometrical/dimensional constraints (annotation, concentricity, parallelism, perpendicularity, etc.). The use of agents also permits to easily extend the field of application by creating new agents, which can be integrated following a modular structure.

2 Materials and Methods

2.1 *The Recognition System*

Previously to the development of the multi-agent architecture, a paradigm that permitted to accomplish the sketch recognition was defined. In this paradigm, a comparison between the graphical and spoken languages was performed, matching each symbol (primitive or combined) with a word, in such a way that a symbol was made up of one or several simple strokes, which are considered as the phonemes that made up a word, which in turn form a dictionary.

For instance, the symbol for the gestural command of revolution (see Fig. 1) can be sketched drawing three strokes or phonemes that conform the symbol (as two lines and one arc) or two phonemes (as one arc and one angle) or even a unique phoneme (if the symbol is drawn with a single stroke and if that possibility makes sense). In the case of the symbol for the geometric restriction of, for instance, the tangency (see Fig. 1), it makes no sense to sketch the symbol by means of one simple stroke, so this possibility is not considered and the symbol can only be constituted by two phonemes (as one line and one circle). In the same way, the cross-out word is always drawn as a simple stroke.

When designing the paradigm, all those strokes that can be drawn with only one unique stroke and that can be part of the symbols or words that form the dictionary, have been chosen as phonemes, so called primitive symbols (see Fig. 2). Furthermore, those symbols that form a minimal set that is able to create, to edit or to customize basic 2D geometry, have been considered as words, so called combined symbols (see Fig. 2).

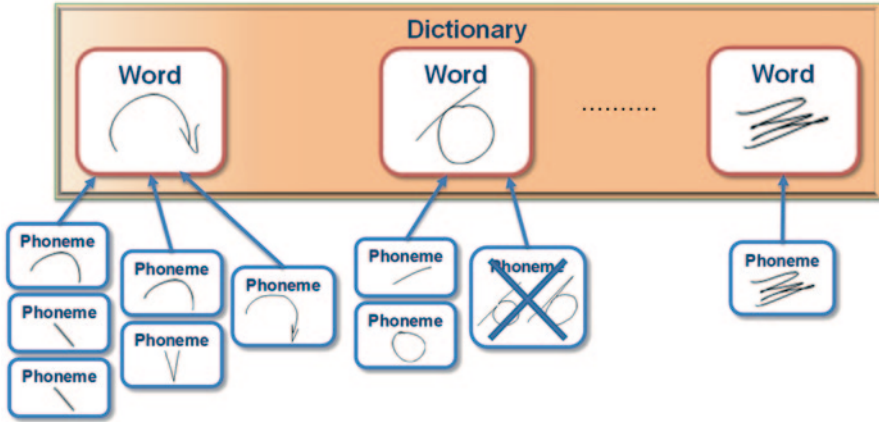


Fig. 1 Recognition system

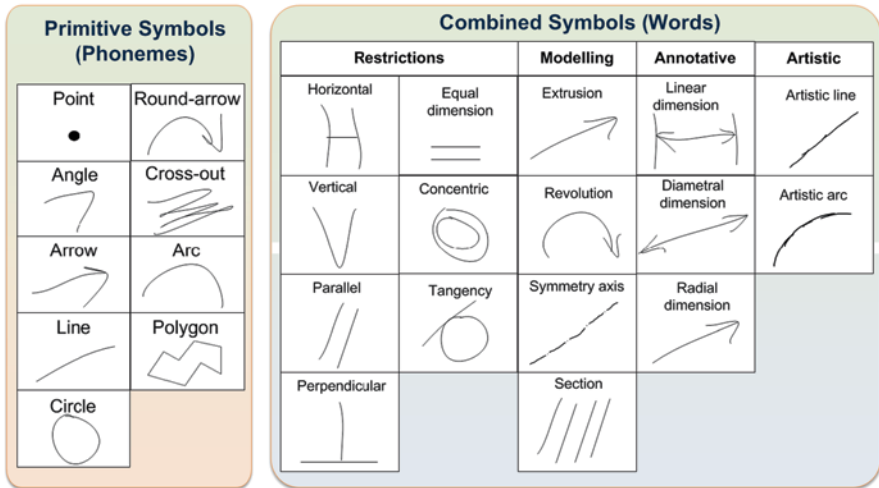


Fig. 2 Symbols (primitive and combined) of the dictionary

2.2 Multi-Agent System Architecture

The multi-agent architecture proposed here offers the possibility that the recognition task focuses on a specific group of symbols that are particular of different fields of engineering. For instance, we can sketch symbols which allow modelling operations like extrusion or revolution, symbols associated with the restrictions of the design like parallel or concentric, and annotation symbols like radial dimension or diametral dimension.

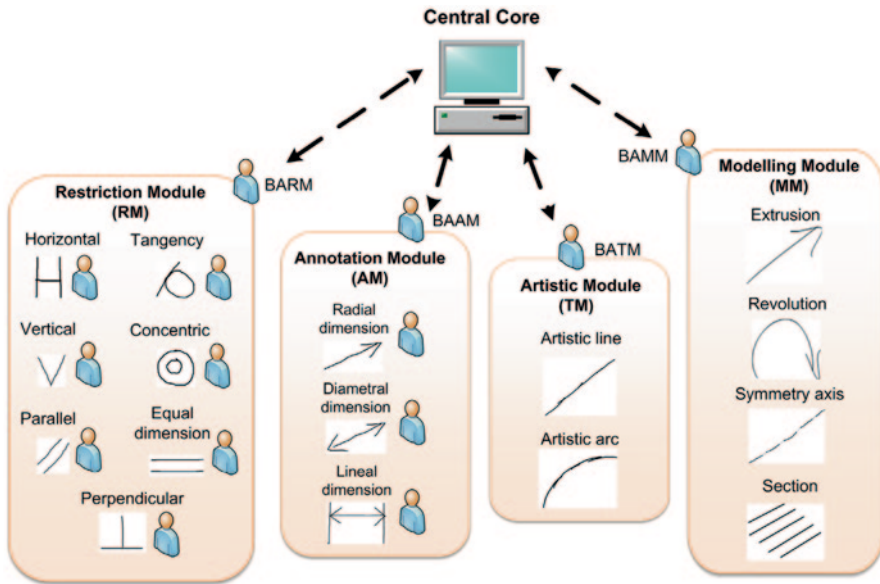


Fig. 3 General scheme of the agent-based sketching platform

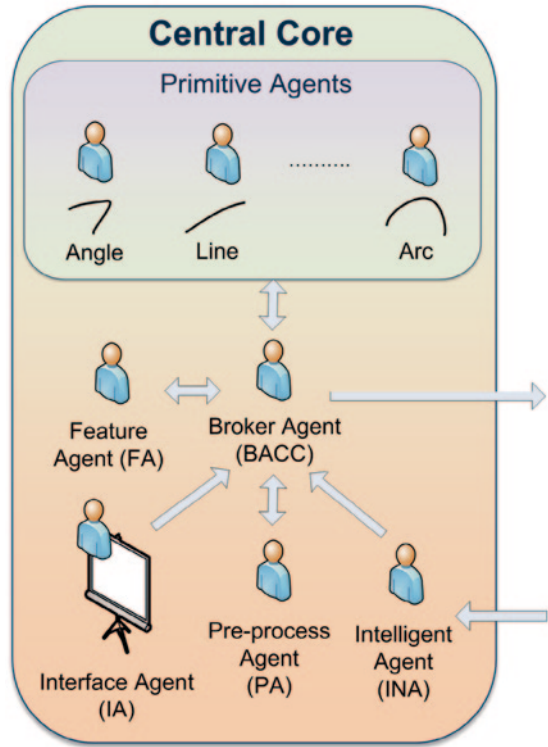
The proposed platform presents a two level structure. In one level resides a central core that controls the interaction of the system with the user. Also in this level reside the agents responsible for the basic tasks of recognition, all they controlled by the Broker Agent (BACC); In the other level, there are different modules assigning tasks to their combined agents that are responsible for the recognition of the symbols assigned to the module, and each module is managed by its own broker agent (BAM), which informs the central core of the result of its own agents in order to make the final decision for recognition (see Fig. 3).

2.3 The Central Core

The Central Core (see Fig. 4) performs the final recognition of the user input. In this work a total of nine strokes have been classified. These strokes are named primitive symbols and can be used to obtain all the symbols defined in the different modules. In order to identify each primitive symbol, a primitive agent has been defined (see Fig. 2).

When a user draws a stroke, the Interface Agent (IA) shows it and sends the digitised points through a data structure to the Broker Agent of the Central Core (BACC). The BACC receives this notification and sends the digitised points of the stroke to the Pre-processing Agent (PA). These points should be ideally uniformly distributed, nevertheless, the faster the stroke is drawn, and the fewer points are digitised, causing a variation in the concentration of the points. Besides, the

Fig. 4 Structure of the central core



drawing can be trembling and halting. The Pre-processing Agent (PA) must filter and eliminate all this noise in order to get a perfect stroke ready for the recognition.

Once the pre-processing has been completed, the BACC requests the Feature Agent (FA) to extract the features of the sketched entity. The FA agent performs a sequential execution, distinguishing two well differentiated processes. In the first process, the segmentation of the stroke is carried out extracting its primitive geometrical forms, and providing information about them, information that will be used in the ulterior decision stages. In the second process, a series of features or basic “cues” of the stroke are extracted. Once the FA agent has finished, it sends back those features to the BACC, which will send all this information to the corresponding primitive agents.

2.4 The Primitive Agents

All the primitive agents will use the information received in order to find relevant clues which allow them to recognise their corresponding primitive symbol. The primitive agent will perform a recognition based on the geometry of the stroke, obtaining a positive or negative match after the syntactic analysis obtained from the segmentation performed by the FA agent (see Fig. 5).

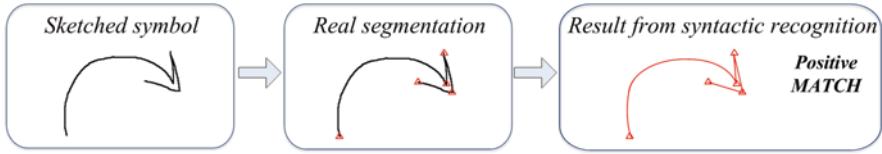


Fig. 5 Matching of vertices and primitives found

The primitive agents evaluate and quantify the degree of the coincidence of a stroke with its corresponding primitive. The result of this evaluation is sent to the BACC agent, which will decide if the syntactic recognition has a valid candidate (primitive symbol) and will inform the BAM agents of all the modules and the Intelligent Agent (INA) agent. Then the second recognition process starts.

The information provided by the primitive agents and the analysis performed by the BACC agent will establish the starting point to try to guess the symbol that is being sketched by the user, or on the contrary, if it is part of the geometry of the sketch. The INA will be in charge of taking the final decision, but this will depend on both, the information provided by the BACC agent and the information that every module of the system sends to the INA agent.

2.5 The Modules of the System

All the modules that are part of the platform have a similar structure (Fig. 6). Inside each module, an agent has been dedicated for each symbol. These symbols are denominated “combined symbols”, and each agent responsible for their recognition will be designated as its “combined agent”. The combined agents will compete with each other in order to recognise the combined symbol, using previous recognition from primitive symbols.

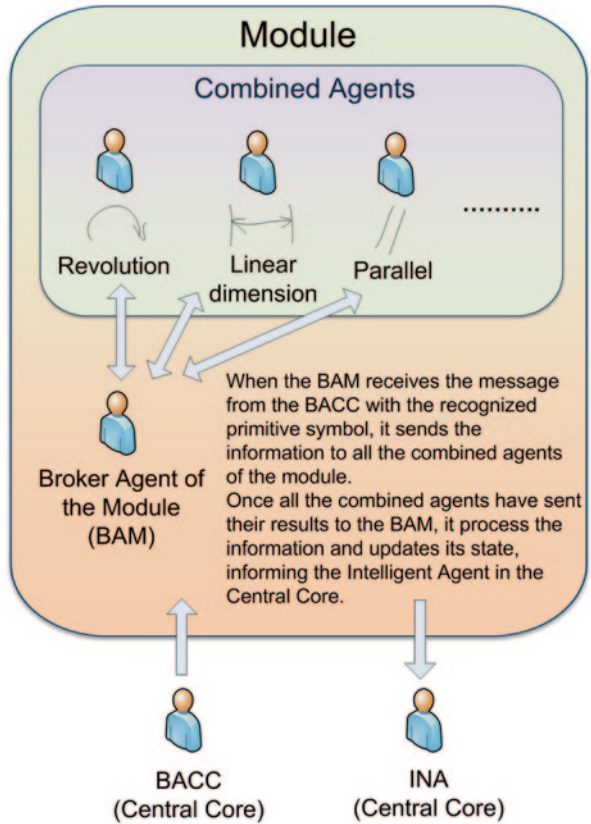
Each module is controlled by its corresponding Broker Agent (BAM). The BAM sends the information of the recognised primitive symbol from the BACC in the Central Core to the combined agents of its module. The BAM also sends the results of its corresponding module to the Intelligent Agent in the Central Core (INA), once this information is processed by all the combined agents.

2.6 The Combined Agents

In general, the combined agents look for the recognition of their combined symbol, using the information they receive of the analysis carried out previously by the primitive agents. This process is performed at three levels:

1. The Contextual Analysis: this analysis is based on the relative position between the different recognised primitive symbols and other features as for instance the proportions between them.

Fig. 6 Structure of the modules



2. Postulations for the symbol to have a complete meaning: that is, the combined agents can be classified in three groups:
 - Modelling agents (extrusion and revolution): these agents are executed on a previously existing geometry, and designate an immediate action. If no prior selection of a surface (like a closed outline) is introduced by the user, the Broker Agent of the central core will inform the combined agents, and thus other possibilities will be considered for the recognised symbol.
 - Agents with references (parallelism, perpendicularity, equal dimension, tangency and concentricity): these agents establish a relationship between two geometric entities, so the symbols they look for have to be recognised twice consecutively.
 - Independent agents (vertical, horizontal, cross-out, radial dimension, linear dimension, diametral dimension, symmetry axis, section, artistic line and artistic arc): agents are considered independent when no previously introduced symbol or selected surface is needed, and thus its recognition supposes an immediate action, as for modelling agents.

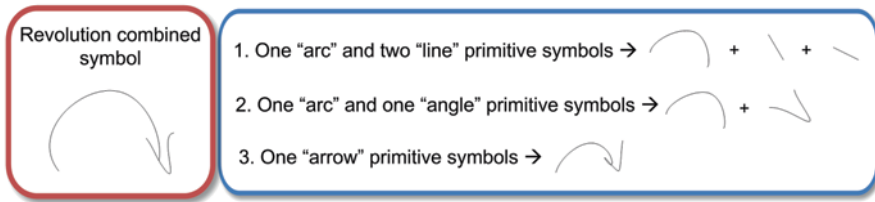


Fig. 7 Possible configurations for the revolution command combined symbol

3. Semantic interpretation: a stroke can either represent a symbol by itself or can be part of a more complex symbol, which is made up by different primitive symbols, with no matter the sequence in which they are introduced. As an example of this, the revolution command combined symbol that can be recognised from one of the three configurations of primitives shown in Fig. 7.

Using the information received from the analysis performed by the primitive agents, the combined agents search the recognition of its combined symbol executing a contextual analysis that makes the combined symbol independent of the order in which the primitive symbols have been introduced. This manner, the primitive symbols that were sent to the combined agent, are added to a list. Later, the combined agent will analyse whether the set of primitives in the list identifies its combined symbol, or if it is able to identify the symbol with the subsequent primitives. In this case, the primitive symbol will be kept in the list, otherwise it will be rejected.

After performing these analyses, the combined agents update their status using a flag, which can take three possible values:

- Rejected: if the primitive symbol cannot be part of the combined symbol.
- In process: if the primitive symbol, by itself or together with the primitives symbols in the list, is capable of constituting the combined symbol.
- Accepted: if the primitive symbol, by itself or together with the primitives symbols in the list, identifies the combined symbol.

The change in the status will be passed to the broker agent of the module, by each of the combined agents of the module.

2.7 The Broker Agents

The Broker Agents (BAMs) are in charge of two principal functions. One function is to send the information (the recognised primitive symbol) from the BACC to the combined agents of the module. The other function is to manage the results given by each of the combined agents and to inform the Intelligent Agent in the Central Core about the status of the module. This status depends on the flags of the combined agents of the module.

When a BA of a module receives a new primitive symbol, this one is sent to the combined agents of the module whose status flag is "in process" or "accepted".

Once all the status flags of the combined agents are received, the BA sends a report to the INA. This report can contain three states:

- Rejected: if the flags of all the combined agents of the module indicate “rejected”.
- In process: if, at least, a flag of a combined agent of the module indicates “in process”.
- Accepted: if one flag of a combined agent indicates “accepted” and the rest have the “rejected” status.

2.8 *The Intelligent Agent*

The Intelligent Agent (INA) is in the central core and is responsible of managing the reports coming from the broker agents of the different modules, and responsible of taking the final decision about the recognition of the symbol, establishing a kind of negotiation between the INA and the BAM agents of the different modules. The procedure carried out by the INA is based on the information given by the primitive agents and the state of the flags of the BAM agents in the different modules. At the beginning of a recognition process, the BAM agents are initialized to the “in process” state.

Firstly a list structure is defined. In this list all the strokes sketched by the user are stored. Every time a new stroke is introduced, and after a pre-processing, the BACC agent sends its features to the BAM agents of the active modules (those whose status flag is “in process” or “accepted”). Then, each BAM agent contacts with its active combined agents and update its flag according to their status. Later BAM agent informs of its status to the INA agent.

Once the INA agent has received the information from all the active BAM agents, it decides if a full semantic recognition has been achieved taking into account the following considerations:

1. If the stroke is not recognised by any of the primitive agents:
 - 1.1. If any of the BAM agents with “in process” state contains a combined agent whose state is “accepted”, its symbol is recognised and the new stroke is considered as geometry.
 - 1.2. Otherwise, the content of the list and the new stroke are considered as geometry.

Once the verification is finished the elements are erased from the list.

2. If the stroke is recognised by some of the primitive agents:
 - 2.1. If the stroke is recognised by the cross-out primitive agent:
 - 2.1.1. If any of the BAM agents has a combined agent whose state is “accepted” its symbol is recognised.
 - 2.1.2. Otherwise, the content of the list is considered as geometry.

In any of the previous cases, and a posteriori, the cross-out primitive symbol is recognised and the list is erased.

- 2.2. Otherwise, the stroke is stacked in the list and the updating of the BAM agents is awaited:
 - 2.2.1. If the state of all the BAM agents is updated to “rejected”:
 - 2.2.1.1. If any of the BAM agents, before adding the last stroke, had a combined agent whose state was “accepted”, its symbol is recognised, the list is erased, all the modules are initialized with the “in process” state and the last stroke is newly introduced in order to initialize the recognition process again.
 - 2.2.1.2. Otherwise, the list is considered as geometry and its content is erased.
 - 2.2.2. If there is any BAM agent whose flag has the “in process” state, the next stroke is awaited.
 - 2.2.3. If all the BAM agents have the flag in the “rejected” state, except only one that keeps its flag in the “accepted” state, it is assumed that the list is recognised as a combined symbol. The combined agent, whose flag is kept in “accepted” state, indicates the kind of the recognised symbol. Once the verification is finished, the list is erased.

Every time the list is erased, the INA agent sends a reset message to the BACC, which in turn will send the request to the BAM agents of the modules, causing the broker agents and each one of the combined agents to initialize their flags to the “in process” state.

For a better comprehension of the operation of the multi-agent platform, in Fig. 8 the recognition of a revolution command symbol is analysed, going into detail on the states through which the flags of the combined and BAM agents are set during the recognition process

3 Results

The proposed architecture has been evaluated at two different stages. In a first stage, the syntactic recognition carried out by the primitive agents has been evaluated. In a second stage, the semantic and final recognition by the combined agents and the intelligent agent of the system has been also rated.

For the first stage evaluation, 10 CAD users have introduced several occurrences of each of the primitive symbols of the dictionary, and a total of 2440 primitive symbols with different orientations and sizes have been used for the evaluation. The results of the first recognition stage are shown in Table 1, which shows a success ratio in the classification for each phoneme (primitive symbol) in the diagonal cells, and the percentage of misclassification in the rest of the cells. As it is evident from these results, the average success ratio achieved in the recognition of the primitive symbols was of 97.21 %.

For the evaluation of the second recognition stage, and thus for the final evaluation of the natural designed interface, the tests were conducted with the same 10 CAD users, who introduced several occurrences of each combined symbol (a total of 2770 symbols) with different orientations and sizes. The implemented interface classified them obtaining an average success ratio of 98.11 % as shown in Table 2

Table 2 Results of the recognition by the combined agents (in %)

	Recognised symbols																
	Restriction module						Modelling module				Annotat module		Artistic module		Central core		
	Con-centric	Tan-gent	Ver-tical	Hori-zontal	Parallel	Perpen-dicular	Equal dimen	Sec-tion	Sym-metry axis	Revo-lution	Estrus/rad dim	Lineal dimen	Diam-etal dim	Artis-tic line	Artis-tic Arc	Geom-etry	Cross-out
Concentric	98.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0
Tangent	0.0	99.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0
Vertical	0.0	0.0	98.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0
Horizontal	0.0	0.0	0.0	96.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.3	0.0
Parallel	0.0	0.0	0.0	0.0	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Perpendicular	0.0	0.0	0.0	0.0	0.0	98.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0
Equal dim	0.0	0.0	0.0	0.0	0.0	0.0	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Section	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Symmetry axis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	96.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.0
Revolution	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.4	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
Extrus/Rad. dim	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	99.6	0.0	0.0	0.0	0.0	0.0	0.4	0.0
Lineal dim	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	93.6	0.0	0.0	0.0	0.0	6.4	0.0
Diametral dim	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	98.7	0.0	0.0	1.3	0.0	0.0
Artistic line	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	95.9	0.0	4.1	0.0	0.0
Artistic arc	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	94.4	5.6	0.0	0.0
Geometry	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100	0.0	0.0
Cross-out	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	98.2	0.0

4 Conclusions

The paper presents an agent-based architecture for the recognition of sketches based on the paradigm of syntactic and semantic meaning, which has been structured in primitive and combined symbols in order to be implemented in a CAD environment. The recognition process has been supported by two levels of agents: a first level where the “Primitive Agents” reside and are in charge of the syntactic recognition, and a second level where the “Combined Agents” remain and carry out the semantic recognition using contextual information. The proposed architecture has been designed in order to be easily extensible by means of new primitive agents or new combined agents.

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Symbolic Computation Applied to Industrial Robots Through SAGE

S. Nájera, C. Elvira, L. F. García-Verde and J. Rico-Azagra

1 Introduction

Technological advances in computing hardware and new software developments have led to a great development of symbolic computation programs in recent decades. Sage (Software for Arithmetic and Geometry Experimentation) was created in 2004, by William Stein, as a project to develop an open-source software CAS (Computer Algebra System) released under GPL (General Public License). The mission of the project was to provide a viable free open-source alternative to Magma, Maple, Mathematica and Matlab. From the beginning, there has been integrated several free software packages (PARI, GAP, Maxima, Singular, Pynac, GNUpLOT, etc.) in Sage, and nowadays includes about 100 packages on your system [12], which are currently in continuous development.

While other CAS systems use their own programming language, Sage has been developed in Python language. Such language is object-oriented, and its learning and use has spread in academic environments. One of the reasons of its success is that Sage can be used in many different hardware platforms, and besides, python is a general-purpose, easy-to learn and readable scripting language.

There are many symbolic applications which can be computed with this software. At this point, it is worth highlighting some educational applications aimed at mathematical courses [2], as well as those aimed at teaching engineering subjects [8, 9].

S. Nájera (✉) · C. Elvira · L. F. García-Verde · J. Rico-Azagra
Electrical Engineering Department, University of La Rioja, c/San José de Calasanz 31, 26004
Logroño, Spain
e-mail: silvano.najerac@unirioja.es

C. Elvira
e-mail: carlos.elvira@unirioja.es

L. F. García-Verde
e-mail: luis-fernando.garcia@unirioja.es

J. Rico-Azagra
e-mail: javier.rico@unirioja.es

1.1 Main Features of Sage

In order to access the application, the user has to be registered with a username and password. The administrator is the user who may register manually other users to use the application, although it can be configured to do it automatically so new users may register themselves using an e-mail.

It is recommended to install Sage on a computer with a free and open-source distribution (Ubuntu, Fedora, OpenSuse, etc.). There are compiled binary packages for these distributions, although it is advisable to perform the compilation of source code by following the instructions [11]. It is worth noting that there are other alternatives to install the application on other operating systems (MAC OSX, Solaris, and Windows OS). In the case of installing it on a Windows operating system, the available choice is to work on a virtual machine, with the resulting loss of performance.

One of the application highlights is its client-server feature. On one hand, the software application is installed on a server computer and, on the other hand, multiple clients may be running it simultaneously on different machines. These clients access using a web browser, just typing the server web address. In summary, it is cross-platform software and it can be used with any web browser. Access to the application is restricted to users working on the same private network, unless a public internet address is assigned to the computer server. In this last case, it is possible to access the server from any physical location that has Internet access (Fig. 1).

In addition to the client-server feature, it is possible to work directly on the local computer, eliminating the latency caused by network communication. Through a network connection, users can work without the graphics user interface used in web browser, just typing sentences in the command line interpreter. In this way, it saves time by eliminating latencies due to the transcripts of code used by HTML.

Once the user has logged into the software with an internet explorer, a graphic environment is available. This is known as the notebook and it is used to program spreadsheets just typing programming instructions. Each user can manage their spreadsheets (Fig. 2), which can be classified in three different ways according to their states: active, archived or deleted (sent to the trash). Note that the sheets are ASCII files with SWS extension and coded in HTML and XML. The user can create and open new spreadsheets, download spreadsheets to the client computer in compressed format, or upload from the local client to the remote server. The application has another important feature which is a collaborative working environment. In order to achieve this, each user can share any of their spreadsheets in the notebook with other users (called collaborators) and work together with them.

At the same time, each spreadsheet is divided into cells where the user interacts with the application. These are the following types of cells it can be used:

- Input cells for mathematical computation, allowing the user to enter programming statements, and afterwards send them to the server which carries out the execution.
- Output cells of computation. The user receives them from the server with the result of programmed instructions (mathematics results, graphics, etc.).

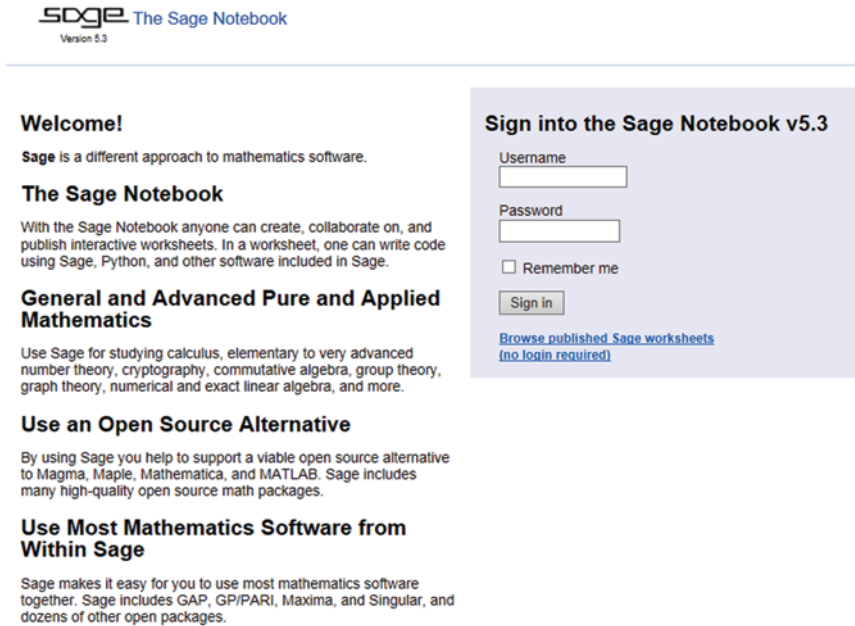


Fig. 1 Sage login screen to access the server

- Cells with no computation that cannot type mathematical programming instructions. They are cells with HTML code which can be used to add a set of example problems, user manuals, discussion forums, etc.

As in any CMS, management lies on a higher privileged user available on the application. The privileges held by the administrator of the application include:

- User account management: account creation (with username and password) and maintenance (suspension, deleting), resetting password
- Graphic interface settings: language and appearance, etc.
- Security settings: access port, authentication type, reCAPTCHA configuration, etc.
- Worksheets parameters configuration
- Server settings: maximum history length, etc.

1.2 Client-Server Infrastructure in the Electrical Engineering Department, University of La Rioja

There are many courses offered by the Electrical Engineering Department that uses simulation software. Some teachers of the department can use the Matlab and Mathematica software because the university has proprietary licenses. The main impediment why this software cannot be used is the unavailability of some ad-

SDGE The Sage Notebook
Version 5.3

admin | [Home](#) | [Published](#) | [Log](#) | [Settings](#) | [Help](#) | [Report a Problem](#) | [Sign out](#)

[New Worksheet](#) [Upload](#) [Download All Active](#) [Search Worksheets](#)

[Archive](#) [Delete](#) [Stop](#) [Download](#)

Current Folder: [Active](#) [Archived](#) [Trash](#)

	Owner / Collaborators	Last Edited
<input type="checkbox"/> Active Worksheets		
<input type="checkbox"/> TX60-PCD_DH	admin Share now	Mar 25, 2013 9:20:19 PM by admin
<input type="checkbox"/> EjemploVectores	admin Share now	Mar 25, 2013 9:19:08 PM by admin
<input type="checkbox"/> Untitled	admin Share now	Jan 18, 2013 2:49:03 AM by admin
<input type="checkbox"/> EjemploGraficos	admin / cesar.gonzalez, cristina.hernandez, oscar.elexpe, ramon.rico, ruben.saenz Share now	Dec 14, 2012 11:19:01 AM by ruben.saenz
<input type="checkbox"/> EjemploInteraccion	admin / cesar.gonzalez, cristina.hernandez, oscar.elexpe, ramon.rico, ruben.saenz Share now	Dec 14, 2012 11:15:47 AM by ruben.saenz
<input type="checkbox"/> TX60-MH	admin Share now	Nov 22, 2012 5:07:22 AM by admin
<input type="checkbox"/> ControlCinematicoInterpoladorGrado5	admin Share now	Nov 22, 2012 5:00:14 AM by admin
<input type="checkbox"/> ControlCinematicoInterpoladorCubico	admin Share now	Nov 22, 2012 4:58:48 AM by admin
<input type="checkbox"/> SageVigo6	admin Share now	Nov 20, 2012 3:32:57 AM by admin
<input type="checkbox"/> TX60_CinematicaPinzaMovierendeArticulacion1	admin Share now	Nov 19, 2012 2:51:41 PM by admin
<input type="checkbox"/> TX60_AceiAngularPinza1Articulacion	admin Share now	Nov 19, 2012 2:21:53 PM by admin
<input type="checkbox"/> TX60_VeAngularPinza1Articulacion	admin Share now	Nov 19, 2012 10:48:19 AM by admin
<input type="checkbox"/> TX60-PCD_DH_muneca	admin Share now	Nov 16, 2012 4:31:19 AM by admin
<input type="checkbox"/> TX60-PCD_DH_brazo	admin Share now	Nov 16, 2012 4:13:29 AM by admin

Fig. 2 Screen user's notebook in Sage

Table 1 Sage servers in the Electrical Engineering Department

Model	Hardware μ P	Memory (GB)	Hard disks (GB)
HP DL585 G1	4 \times Opteron DC	24	3 \times 300 (Raid5)
IBM xSeries 360	4 \times Xeon 2.0 GHz	4	2 \times 32.6 (Raid1)

ditional packages (toolboxes) needed in some cases. Since there was no symbolic programming package available, an economical alternative for teaching purposes was needed. Sage software met all the requirements to be selected.

The first infrastructure was created in 2010 at the Electrical Engineering Department of the University of La Rioja, which included three obsolete server computers that gave support to teachers and students inside and outside the university [7]. Since then, the equipment has been improved to guarantee an uninterrupted service for all users.

Nowadays, the available infrastructure consists of two computers servers running the software. One of them is connected to the Public Internet, and the other one only allows access to certain private computers on a VLAN (Virtual Local Area Network). This network was created to be used in the laboratories available in the university for teaching purposes. Table 1 shows the main characteristics components of the server computers.

Both server computers have hardware features and the elements necessary to provide continuous operation. In this way, Sage software can run in the fault-tolerant equipment with:

- Redundant power supply units connected to independent distribution lines with the help of an uninterruptible power supply.
- Redundant disk storage system. Using a main controller card we connect local physical disks and create logical disks in RAID1 or RAID5 environments.
- Software configured by the administrator to automatically make local disk backup or remote backup.

In addition to the servers listed above, it is worth noting that there are other public servers [13] for this software application, with high performance computing and high speed communication network. This option is recommended when the institutions do not have material and human resources to install, configure and manage their own servers (with the minimum requirements).

2 Applying Symbolic Computation to Robots with Sage

A robot is an open kinematic chain which consists of a sequence of links interconnected by joints. Each joint q_i provides a relative motion between two links. If the motion is lineal, the joint d_i is called prismatic or translational, whereas if the motion is rotational, the joint θ_i is called revolute or angular.

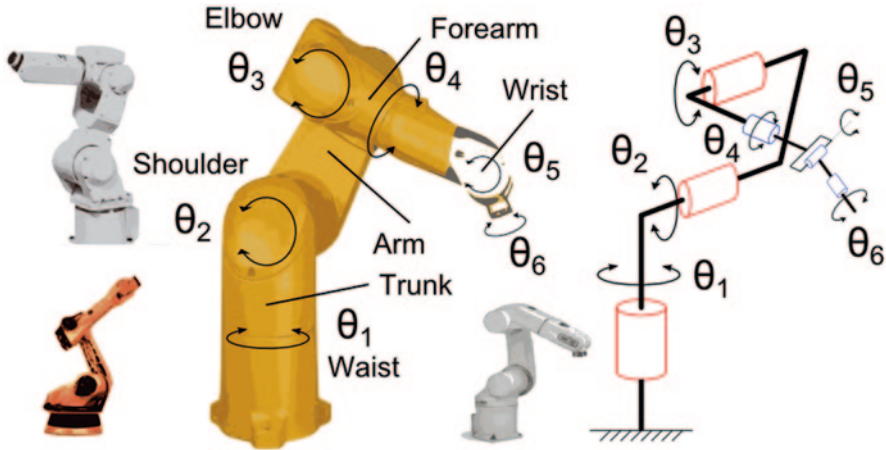


Fig. 3 Anthropomorphic industrial robot. Symbolic representation

The anthropomorphic mechanical structure (Fig. 3) is one of the most widely used, and consists of an arm with three revolute joints $\{\theta_1, \theta_2, \theta_3\}$, connected to the wrist with another tree revolute joints $\{\theta_4, \theta_5, \theta_6\}$. Similarity to human structure is noticeable on the first three links (shoulder, forearm and arm) with relative motion produce by the first joints (waist, shoulder and elbow). The main task of the whole arm is the end-effector (hand) positioning, and the wrist determines the final end-effector orientation. The combined motion of the six joints allows positioning the end-effector according to the particular application (material handling, welding, painting...)

Due to many industrial robots have the same structure (anthropomorphic, SCARA, cylindrical, cartesian), some authors [14] use a symbolic representation (Fig. 3).

2.1 Orientation Study Using an Euler Wrist

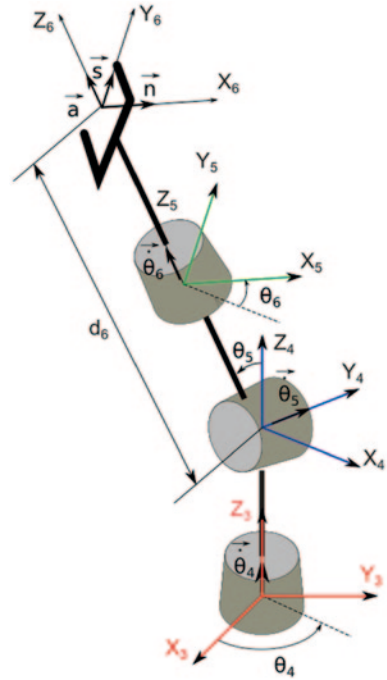
The robot described in the previous section has a wrist with an Euler type compound joint (Fig. 4) with three angular motions [15]:

- One rotation by an angle α about axis Z.
- Another rotation by an angle β about current axis Y.
- Final rotation by an angle γ about current axis Z.

All the three elementary rotations are made with the actual reference frame, and the set of three Euler angles $[\alpha, \beta, \gamma]^T$ constitutes a minimal representation of orientation of any solid body.

$$R = R_{Z,\alpha} \cdot R_{Y,\beta} \cdot R_{Z,\gamma} = \begin{bmatrix} c_\alpha c_\beta c_\gamma - s_\alpha s_\gamma & -c_\alpha c_\beta s_\gamma - s_\alpha c_\gamma & c_\alpha s_\beta \\ s_\alpha c_\beta c_\gamma + c_\alpha s_\gamma & -s_\alpha c_\beta s_\gamma + c_\alpha c_\gamma & s_\alpha s_\beta \\ -s_\beta c_\gamma & s_\beta s_\gamma & c_\beta \end{bmatrix} \quad (1)$$

Fig. 4 Euler wrist with three degrees of freedom



In Fig. 5, we can see the script programmed in Sage [5] in order to compute three-dimensional symbolic matrices using some basic algebraic operations.

In addition to the previous example where we made a representation of orientation using Euler angles, there are other ways to describe orientation in the three-dimensional space, changing the order of the rotations, changing the selected rotation axis and finally composing the elementary rotations using a fixed frame. Lastly, noting we can compute other models based on two-dimensional matrices in any of the principal planes XY, YZ, ZX .

2.2 Kinematics Analysis Applied to the End-Effector Moving One Joint of the Robot

According to mathematical methods used in classic mechanics, the following example proposes the study of position, velocity and acceleration vectors through direct derivation. On one hand, the complete kinematics motion of the end point in the robot is studied, (Fig. 6) computing vectors using a fixed or static frame $\{X_0, Y_0, Z_0\}$. On the other hand, the same vectors are computed using a mobile frame $\{X_1, Y_1, Z_1\}$ which changes its orientation due to the first joint movement θ_1 .

```

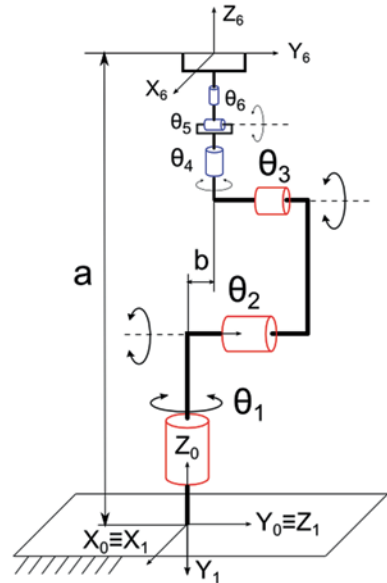
var('alpha','beta','gamma');
Rot1=MatrixSpace(SR,3,3);Rot2=MatrixSpace(SR,3,3);Rot3=MatrixSpace(SR,3,3);
Rot1=matrix([[cos(alpha),-sin(alpha),0],[sin(alpha),cos(alpha),0],[0,0,1]])
Rot2=matrix([[cos(beta),0,sin(beta)],[0,1,0],[-sin(beta),0,cos(beta)]])
Rot3=matrix([[cos(gamma),-sin(gamma),0],[sin(gamma),cos(gamma),0],[0,0,1]])
MunecaEuler=Rot1*Rot2*Rot3;
html('<font color="blue">Euler matrix: S\mathbf{R}_((\alpha,\beta,\gamma)) = %s</font>'%latex(MunecaEuler))

```

$$\text{Euler matrix: } \mathbf{R}_{(\alpha,\beta,\gamma)} = \begin{pmatrix} \cos(\alpha)\cos(\beta)\cos(\gamma) - \sin(\alpha)\sin(\gamma) & -\cos(\alpha)\cos(\beta)\sin(\gamma) - \cos(\gamma)\sin(\alpha) & \cos(\alpha)\sin(\beta) \\ \cos(\beta)\cos(\gamma)\sin(\alpha) + \cos(\alpha)\sin(\gamma) & -\cos(\beta)\sin(\alpha)\sin(\gamma) + \cos(\alpha)\cos(\gamma) & \sin(\alpha)\sin(\beta) \\ -\cos(\gamma)\sin(\beta) & \sin(\beta)\sin(\gamma) & \cos(\beta) \end{pmatrix}$$

Fig. 5 Calculation of symbolic Euler matrix using Sage

Fig. 6 Symbolic representation of the robot just moving the first joint θ_1



If we use the fixed frame, we can calculate the velocity ${}^0\mathbf{v}_p$ and acceleration vectors ${}^0\mathbf{a}_p$ just with direct derivation of position vector ${}^0\mathbf{r}_p$, [4]. Since this last vector is not constant and it depends on the first joint value θ_1 .

$${}^0\vec{r}_p = \begin{pmatrix} -bs_1 \\ bc_1 \\ 0 \end{pmatrix} \quad {}^0\vec{v}_p = \begin{pmatrix} -b\dot{\theta}_1 c_1 \\ -b\dot{\theta}_1 s_1 \\ 0 \end{pmatrix} \quad {}^0\vec{a}_p = \begin{pmatrix} -b\ddot{\theta}_1 c_1 + b\dot{\theta}_1^2 s_1 \\ -b\ddot{\theta}_1 s_1 - b\dot{\theta}_1^2 c_1 \\ 0 \end{pmatrix} \tag{2}$$

However, the position vector ${}^1\mathbf{r}_p$ of the end-effector will be constant, if we consider a mobile reference frame $\{X_1, Y_1, Z_1\}$. The calculation of the velocity ${}^1\mathbf{v}_p$ and the acceleration vector ${}^1\mathbf{a}_p$ is made, adding the cross product between the angular velocity vector of the mobile reference frame and the vector that is being derived [16].


```

var('theta,t,r,a,b,omega,alpha')
tita(t)=function('theta',t); # Definición de la variable de articulación tital = f(t) en función del tiempo
dita(t)=derivative(tita,t); # Velocidad de la variable de articulación tital = f(t) en función del tiempo
ddtita(t)=derivative(dita,t); # Aceleración de la variable de articulación tital = f(t) en función del tiempo
def Rot01(a):
    var("alpha");alpha:=a;
    R=MatrixSpace(SR,3,3);
    R1=matrix([[cos(alpha),0,-sin(alpha)],[sin(alpha),0,cos(alpha)],[0,-1,0]]);return R1
R01=Rot01(tita(t))
show('Matriz de cambio de orientación entre la referencia móvil SR1 y la referencia fija SR0')
html('<center><font color="green">$^0\mathbf{R}_1 (\backslash\theta)= %s</font></center>'\latex(R01))

Omega0=vector(SR,[0,0,0]);Omega1=vector(SR,[0,-dita,0]);
dita(t)=omega;
show('Vector de velocidad angular de la referencia móvil expresado en ella misma SR1');
html('<center><font color="green">$^1\mathbf{\Omega}_1 (\backslash\theta)= %s</font></center>'\latex(Omega1.column()))

rP1=vector(SR,[0,-a,b]);
show('Vector de posición en la referencia móvil no inercial SR1')
html('<center><font color="green">$^1\mathbf{r}_P (\backslash\theta)= %s</font></center>'\latex(rP1.column()))
show('Vector de posición en la referencia fija SR0')
rP0=R01*rP1 # Vector de posición en la referencia fija inercial SR0
html('<center><font color="green">$^0\mathbf{r}_P (\backslash\theta)= %s</font></center>'\latex(rP0.column()))

vP0=derivative(rP0,t)+Omega0.cross_product(rP0);
show('Vector de velocidad en la referencia fija SR0');
html('<center><font color="green">$^0\mathbf{v}_P (\backslash\theta)= %s</font></center>'\latex(vP0.column()))
vP1=derivative(rP1,t)+Omega1.cross_product(rP1);
show('Vector de velocidad en la referencia móvil SR1');
html('<center><font color="green">$^1\mathbf{v}_P (\backslash\theta)= %s</font></center>'\latex(vP1.column()))

# Cálculo de los vectores de aceleración en ambas referencias
aP0=derivative(vP0,t)+Omega0.cross_product(vP0);
show('Vector de aceleración en la referencia fija SR0');
html('<center><font color="green">$^0\mathbf{a}_P (\backslash\theta)= %s</font></center>'\latex(aP0.column()))
aP1=derivative(vP1,t)+Omega1.cross_product(vP1);
show('Vector de aceleración en la referencia móvil SR1');
html('<center><font color="green">$^1\mathbf{a}_P (\backslash\theta)= %s</font></center>'\latex(aP1.column()))
    
```

Fig. 7 Input cell with the code to compute kinematics movement of the end-effector just moving the first joint

$$\begin{aligned}
 {}^1\vec{r}_p &= \begin{pmatrix} 0 \\ -a \\ p \end{pmatrix} & {}^1\vec{v}_p &= \frac{d^1r_p^T}{dt} + ({}^1\Omega_1 \wedge {}^1r_p) = \begin{pmatrix} -b\dot{\theta}_1c_1 \\ -b\dot{\theta}_1s_1 \\ 0 \end{pmatrix} \\
 {}^1\vec{a}_p &= \frac{d^1a_p^T}{dt} + ({}^1\Omega_1 \wedge {}^1v_p) = \begin{pmatrix} -b\ddot{\theta}_1 \\ 0 \\ -b\dot{\theta}_1^2 \end{pmatrix}
 \end{aligned}
 \tag{3}$$

Both results are directly related through the matrix which computes the change of orientation between the mobile reference frame $\{X_1, Y_1, Z_1\}$ and the fixed frame $\{X_0, Y_0, Z_0\}$, according to the following mathematical expression:

$$\begin{aligned}
 {}^0r_p &= {}^0R_1(\theta_1) \cdot {}^1r_p \\
 {}^0v_p &= {}^0R_1(\theta_1) \cdot {}^1v_p & \text{donde: } {}^0R_1(\theta_1) &= R_{Z,\theta_1} \cdot R_{X,-90^\circ} \\
 {}^0a_p &= {}^0R_1(\theta_1) \cdot {}^1a_p
 \end{aligned}
 \tag{4}$$

Figure 7 shows the program code in Sage [5] to compute all the symbolic vectors. Note that you can type LaTeX coding to format the output mathematical expressions in the same way as you edit expressions with LaTeX syntax.

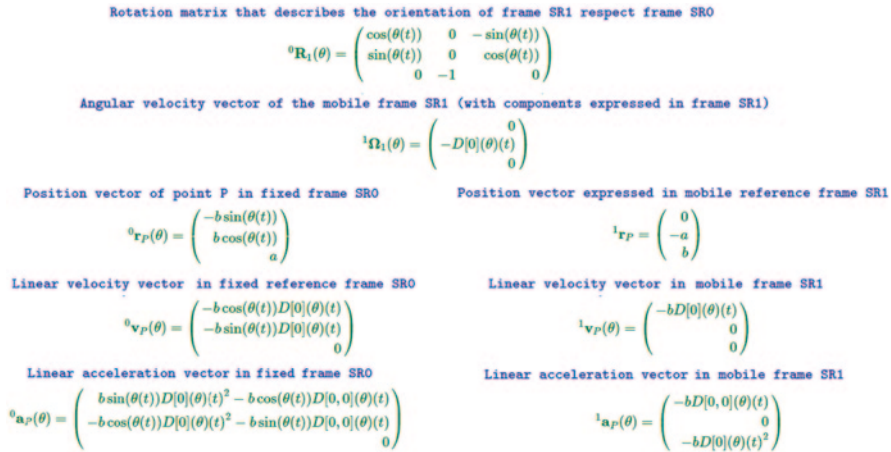


Fig. 8 Output cell showing the symbolic results of the kinematics movement of the end-effector just moving the first joint

Figure 8 shows a Sage worksheet with the graphics results in an output cell. The web explorer provides these results based on the previous input cell code.

2.3 Calculation of the Homogeneous Transformation Matrix Between Two Frames

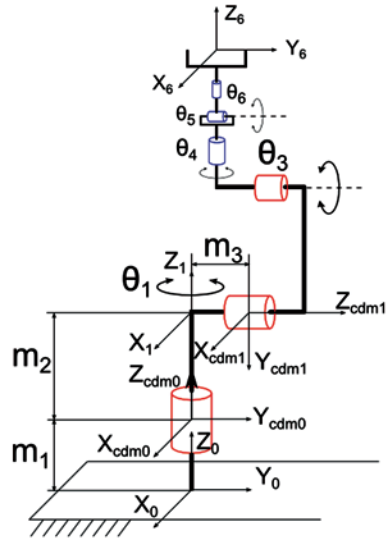
The Homogeneous Transformation Matrix is a mathematical model that describes the following solid features: position, orientation, perspective projection and scaling [6]. When we describe solids (joints and links) in a robot, we just get two features that allow to obtain the position and orientation, leaving a unitary scale factor and cancelling the three components of the perspective projection vector.

$$H = \begin{bmatrix} r_{11} & r_{12} & r_{13} & d_x \\ r_{21} & r_{22} & r_{23} & d_y \\ r_{31} & r_{32} & r_{33} & d_z \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

According to the geometrically robot dimensions showed in the Fig. 9, we compute the following homogeneous matrices:

- Homogeneous transformation matrix that describes the reference frame located at the center of mass of the fixed link 0 with respect to the fixed reference frame $\{X_0, Y_0, Z_0\}$: ${}^0H_{\text{cdm}0}$.

Fig. 9 Representation of the reference frames in link 0 and link 1 of the robot



- Homogeneous transformation matrix that describes the reference frame located at the center of mass of the mobile link 1 with respect to the reference frame located at the center of mass of the fixed link 0: ${}^{cdm0}H_{cdm1}$.
- Homogeneous transformation matrix that describes the reference frame located at the center of mass of the mobile link 1 with respect to the reference frame $\{X_0, Y_0, Z_0\}$: ${}^0H_{cdm1}$.

The results of the program (Fig. 10) show the usage of Sage in the construction and manipulation of symbolic 4×4 matrices, and some simple algebraic operations. We can add HTML coding in the Sage programs in order to get better displayed results.

2.4 Calculation of the Homogeneous Transformation Matrix According to the Denavit-Hartenberg Convention

In robotics, a fixed reference frame $\{X_0, Y_0, Z_0\}$ attached to the absolute reference (ground) is used. In the kinematic chain that forms the robot structure, we associate a mobile reference frame $\{X_i, Y_i, Z_i\}$ to every link i -th. We describe the position and orientation of two adjacent links with one homogeneous transformation matrix in which these following two conditions are met [10]:

- The X_i axis is perpendicular to the Z_{i-1} axis.
- The X_i axis intersects the Z_{i-1} axis.

```

var("theta,m1,m2,m3") # Symbolic variables
H0cdm0=matrix(SR,[[1,0,0,0],[0,1,0,0],[0,0,1,m1],[0,0,0,1]]);
show('Homogeneous transformation matrix that describes SRcdm0 respect SR0')
html('<center><font color="green">S^0\mathbf{H}_{cdm_0}= %s</font></center>'\latex(H0cdm0))

R01=matrix(SR,[[cos(theta),0,-sin(theta)],[sin(theta),0,cos(theta)],[0,-1,0]]);
rcdm0cdm1=matrix(SR,[[1,-m3*-sin(theta)],[m3*cos(theta)],[m2]]); # Position vector (column)
Fila=matrix(SR,[[0,0,0,1]]) # Definition of last row [0 0 0 1] of the homogeneous transformation
Hcdm0cdm1=R01.augment(rcdm0cdm1) # Insert position of the homogeneous transformation matrix
Hcdm0cdm1=Hcdm0cdm1.stack(Fila) # Insert last row [0 0 0 1] of the homogeneous transformation matrix
show('Homogeneous transformation matrix that describes SRcdm1 respect SRcdm0')
html('<center><font color="green">S^1\mathbf{H}_{cdm_1}= %s</font></center>'\latex(Hcdm0cdm1))

H0cdm1=H0cdm0*Hcdm0cdm1;
show('Homogeneous transformation matrix that describes SRcdm1 respect SR0')
html('<center><font color="green">S^0\mathbf{H}_{cdm_1}= %s</font></center>'\latex(H0cdm1))
    
```

Homogeneous transformation matrix that describes SRcdm0 respect SR0

$${}^0\mathbf{H}_{cdm_0} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & m_1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Homogeneous transformation matrix that describes SRcdm1 respect SRcdm0

$${}^{cdm_0}\mathbf{H}_{cdm_1} = \begin{pmatrix} \cos(\theta) & 0 & -\sin(\theta) & m_3 \sin(\theta) \\ \sin(\theta) & 0 & \cos(\theta) & m_3 \cos(\theta) \\ 0 & -1 & 0 & m_2 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Homogeneous transformation matrix that describes SRcdm1 respect SR0

$${}^0\mathbf{H}_{cdm_1} = \begin{pmatrix} \cos(\theta) & 0 & -\sin(\theta) & m_3 \sin(\theta) \\ \sin(\theta) & 0 & \cos(\theta) & m_3 \cos(\theta) \\ 0 & -1 & 0 & m_1 + m_2 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Fig. 10 Input and output cells for computing the homogeneous transformation matrices of the links

We obtain the Denavit-Hartenberg matrix:

$${}^{i-1}H_i(q_i) = \begin{bmatrix} c_{\vartheta_i} & -s_{\vartheta_i}c_{\alpha_i} & s_{\vartheta_i}s_{\alpha_i} & a_i c_{\vartheta_i} \\ s_{\vartheta_i} & c_{\vartheta_i}c_{\alpha_i} & -c_{\vartheta_i}s_{\alpha_i} & a_i s_{\vartheta_i} \\ 0 & s_{\alpha_i} & c_{\alpha_i} & d_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{6}$$

Figure 11 shows the program in Sage. It is important to highlight in this example that we have programmed functions and control structures for the trigonometric simplification using Python language.

Both reference systems are related by the two above conditions, using only four parameters, instead of six that are necessary to describe an orientation and a position in a generic way. Three of these four Denavit–Hartenberg parameters are constant and one of them is the variable, θ_i in case we have a rotational joint or d_i in case we have a prismatic joint. There are other representations for the description of two adjacent links [3].

Table 2 Denavit-Hartenberg parameters of the arm robot

θ_i (°)	d_i	a_i	α_i (°)
θ_1	d_1	0	90
θ_2+90	$-d_2$	a_0	0
θ_3-90	0	0	-90

```
def MMH(titai,alfai,ai,di):
    var("alpha,theta,a,d"):alpha=alfai;theta=titai;a=ai;d=di;
    H=MatrixSpace(SR,4,4);
    H1=matrix([[cos(theta),-sin(theta)*cos(alpha),sin(theta)*sin(alpha),a*cos(theta)], [sin(theta),cos(theta)*cos(alpha),-cos(theta)*sin(alpha),a*sin(theta)], [0,sin(alpha),cos(alpha),d],[0,0,0,1]]);
    for k1 in range(4):
        for k2 in range(4):
            if H1[k1,k2]<> 0:
                H1[k1,k2]=H1[k1,k2].full_simplify()
    return H1;
var('theta1,theta2,theta3,d1,d2,a2');
H01=MMH(theta1,p1/2,0,d1);
H12=MMH(theta2+p1/2,0,a2,-d2);
H23=MMH(theta3-p1/2,-p1/2,0,0);
H02=H01*H12;
for k1 in range(4):
    for k2 in range(4):
        if H02[k1,k2]<> 0:
            H02[k1,k2]=H02[k1,k2].full_simplify()
H03=H02*H23;
for k1 in range(4):
    for k2 in range(4):
        if H03[k1,k2]<> 0:
            H03[k1,k2]=H03[k1,k2].factor();
            H03[k1,k2]=maxima(H03[k1,k2]).trigreduce().sage()
html('<center><font>S</font>^0\mathbf{H}(3) (\theta_1,\theta_2,\theta_3)= %s</font></center>'\latex(H03))
```

$${}^0\mathbf{H}_3(\theta_1, \theta_2, \theta_3) = \begin{pmatrix} \cos(\theta_2 + \theta_3) \cos(\theta_1) & -\sin(\theta_1) & -\sin(\theta_2 + \theta_3) \cos(\theta_1) & -\frac{1}{2} a_2 \sin(-\theta_1 + \theta_2) - \frac{1}{2} a_2 \sin(\theta_1 + \theta_2) - d_2 \sin(\theta_1) \\ \sin(\theta_1) \cos(\theta_2 + \theta_3) & \cos(\theta_1) & -\sin(\theta_2 + \theta_3) \sin(\theta_1) & -\frac{1}{2} a_2 \cos(-\theta_1 + \theta_2) + \frac{1}{2} a_2 \cos(\theta_1 + \theta_2) + d_2 \cos(\theta_1) \\ \sin(\theta_2 + \theta_3) & 0 & \cos(\theta_2 + \theta_3) & a_2 \cos(\theta_2) + d_1 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Fig. 13 Input and output cells for calculating the forward kinematics of the arm robot

Figure 13 shows the results programmed in Sage. In this program we have simplified the trigonometric expressions, calling directly to procedures belonging to Maxima package

3 Conclusions

Sage is a tool to support the teaching of any subject in the field of engineering that requires symbolic formulation. It is attractive because it is open source software, it allows programming in a compact and readable Python language, and it can be used with any web browser regardless of the hardware.

Teachers can pose sets of examples and exercises to the students. They can also pose laboratory homework (in certain subjects). Students can use Sage to solve academic activities (exercises, practices, etc.) proposed by the teacher, to check complex handwritten mathematical developments, as well as to find the errors made. Throughout the learning process, students enrich themselves with a proper use of the application.

All users (teachers and students) who use the software can work collaboratively by sharing worksheets corresponding to the tasks entrusted to them. Finally, if the implementation of Sage is installed on a server to centralize all information on a single computer, thereby it facilitates the access and sharing of results

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Part IX
Training in Project Engineering

Critical Learning in Development Projects and International Cooperation

J. Peris, A. Boni, V. Pellicer and S. Fariñas

1 Introduction

The official Master's degree in Development Cooperation of the Polytechnic University of Valencia started out in the 2011–2012 academic year with a program specialization course in Project Management and Development Processes which rest on the experience acquired over the four previous years of the UPV's master's degree in Development Policies and Processes. It's a Master organized by the Department of Engineering Projects (DPI) with the impetus provided by the Research Group on Development, Cooperation and Ethics (GEDCE).

Since its beginning, the Master has been conceived and developed on the basis of principles such as critical learning, participation and the connection between local and global problems. These principles have been integrated in both the contents as well as in its own teaching process giving place to a series of teaching–learning practices which go beyond the classroom space and contribute to define a very specific profile in project management and development processes.

The present article starts with a presentation of the Master's degree in Development Cooperation in terms of objectives, structure and academic program as well as its most distinctive elements. After explaining the meaning of what we understand

J. Peris (✉) · V. Pellicer · S. Fariñas

Grupo de Estudios en Desarrollo, Departamento de Proyectos de Ingeniería, Universitat Politècnica de València, Camino de Vera s/n 46022, Valencia, España
e-mail: jperisb@dpi.upv.es

V. Pellicer
e-mail: vicpelsi@gmail.es

S. Fariñas
e-mail: saraifarinas@gmail.com

A. Boni
INGENIO (CSI-UPV), Universitat Politècnica de València, Camino de Vera s/n 46022, Valencia, España
e-mail: aboni@dpi.upv.es

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to be critical learning, the analysis discusses the main elements that contribute to its development, delving into its methodological innovations developed at the teaching level in the Master and also in the evaluation and follow up areas that have been created in order to incorporate students' active participation and that of other external stakeholders. The analysis explores the major difficulties encountered as well as the main supporting factors for critical teaching practices in the field of development projects and international cooperation. Finally, the above is contrasted with the view of the students on the basis of information from the various evaluations that have been carried out.

2 The Master in Development Cooperation

The complexity and increasing concern over issues of development and poverty requires qualified professionals with specialized and interdisciplinary training. The University Master in Development Cooperation responds to the need to offer, by the public universities of Valencia, high standard development cooperation training.

This Master is the outcome of a coordinated effort of the five Valencian public universities that provide a total of eight specializations which are: Co-development and Migratory Movements (UVEG), International Humanitarian Action (UJI), Comprehensive Local Development Planning (UVEG), Health in Developing Countries (UVEG and UMH), Development Cooperation and Policies (on-line) (UJI), Environmental Sustainability (UA), Project Management and Development Processes (UPV). The UPV University Master in Development Cooperation has its origins in the previous UPV Master in Development Policies and Processes, offered during the period 2007–2011.

First, the student takes the Main Core Curriculum of the Master, where the conceptualization of the development concept is undertaken and the international cooperation system is discussed. Next, the specialization in Project Management and Development Processes is studied from an applied perspective, addressing the question of how cooperation programs and projects can constitute an adequate instrument to support and promote development processes and social change.

The Master has two academic courses: the first one of an educational nature and the second of a tutoring one. The first academic course runs from September to July and has 60 ECTS. Within it, the core subjects and those of the Specialization in Project Management and Development Processes are studied. The second academic year is devoted to the performing of internships and the Master Final project. It covers the period from September to February.

The main objectives of the Master are the following:

- To increase the knowledge of economic, social and political forces which explain and cause the existence of poverty and inequality.
- To provide analysis criteria of political, social, economic and cultural reality in which approaches and themes of the new culture of cooperation are contextualized.

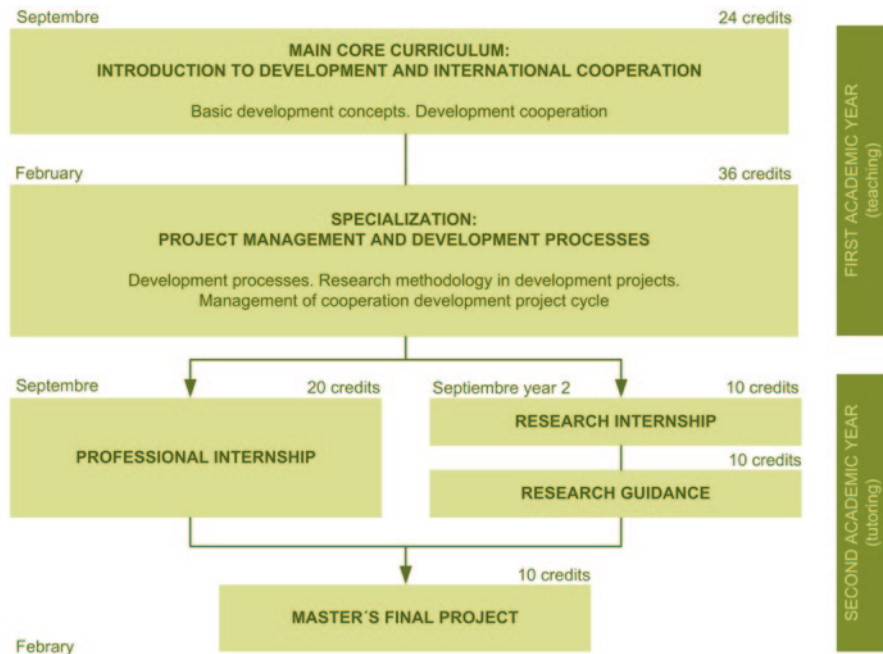


Fig. 1 Structure of the master in development cooperation

- From a critical perspective, to examine the operational strategies for the quality and effectiveness of the concept of development cooperation in depth.
- To develop skills for designing, planning, management and evaluation of development interventions at the levels of policies, plans, programs and projects.

The general structure of the course is illustrated in the Fig. 1:

2.1 Main Core Curriculum

From a critical approach, the Main Core Curriculum aims to introduce the operational strategies of development cooperation. It also seeks to increase knowledge of the economic, social and political forces that explain and cause the existence of poverty, inequality and development issues from a global perspective.

Through critical analysis of different authors, different theories of development and concrete regional experiences are studied. From which, an in-depth analysis of the stakeholders, characteristics, instruments, policies, international agreements and sectors of intervention is carried out, intending to provide students with a critical and informed international cooperation and development discourse.

2.2 Specialization: Project Management and Development Processes

Through discussion of planning and development management theories as well as the study of concepts, methodologies and techniques of the project cycle management, it is intended to give students the theoretical basis and concrete tools to allow them to address project management of wide and long-term processes of human and sustainable development, in addition to the ability to consider and influence the structural causes of inequality, poverty and underdevelopment.

Furthermore, the different epistemological approaches underlying the methods of social research, the basic concepts of research methodologies, methods and their characteristics, as well as participatory research tools are studied.

2.3 Internships

Students have the opportunity to apply the knowledge achieved by doing internships in the government sector, NGOs, international organizations and other entities in the field of development. For the professional itinerary, the internship adjusts to the training needs of each student so as to specialize in the professional area of his/her interests (field work, office management, knowledge of international organizations...). For the research itinerary, it adjusts to the needs of specialization in the subjects that most interest the students, providing the students who wish to be in the field of research a direct knowledge in situ and the chance to perform the necessary field work for his/her research.

In both cases, the tutoring of the internships is a very direct process and has a strong teacher involvement. In the research itinerary, this follow up with the students becomes even more visible, the person who is academically responsible accompanies the intern closely so as to insure that the final research be original and to provide interesting contributions to the field of research in development.

2.4 Introduction to Research

The end purpose of this module, which is compulsory for students who choose the area of research, is to further develop the students' abilities in seeking information, processing, analysis and synthesis in addition to obtaining specialized training in a specific topic.

2.5 Master's Final Project

The Master Final Project is mandatory and, depending on the chosen orientation, is comprised of a dissertation research or a more technical and professional project on

a relevant issue related to what has been studied throughout the training process. In both cases, the work must maintain academic rigor, be performed individually and then be defended in an academic tribunal. As pointed out above, the tutor places special emphasis on the support of this process in order to get revealing evidences that are applicable to the field of development cooperation.

3 What Do We Mean by Critical Learning?

A central feature of the Master in Development Cooperation has been its concern to offer an oriented training to what Clarke and Oswald [3] define as a critical development practice. This is characterized by positioning the principle of social justice at the heart of the values and practices, and takes on the complex and political nature of development processes that are understood to be crossed by power relations [3].

This approach goes hand in hand with the idea of professional skills developed by Walker et al. [11], which argued that a university committed to human development and poverty reduction must address the training of development professionals from the perspective of their contribution to social change.

This leads us to that, beyond learning the essential skills for project development management, it is essential to work on the ability to adapt to an environment that is changing, complex and not without conflicts. It deals with “being able to operate within the complexity and unpredictability that are inherent of social systems” [12]. In order to “better cope with complexity but not to control it, while acting with conscience and resolution” [10].

In this line, the Master tries to build an action-oriented critical learning within the training of development projects. For that, it incorporates Brookfield’s [2] approaches in several aspects. On one hand we stress the confrontation and questioning of values, ideas and hegemonic practices in the field of development to assess their implications in terms of power relations between actors involved in the processes. Furthermore, reasoning skills and analysis to form their own judgments in a rigorous manner, knowing how to contrast viewpoints based on available information. Finally, learning to construct and deconstruct the experiences and their own meanings in complex intercultural contexts to enable a strategy oriented to promoting changes of a social nature.

In line with this, one of the key notions which the Master has been based upon is the idea of participation understood as agency in public space [4], which allows people to have influence on the processes that affect their own lives [8] in an institutional framework that enables and constrains the forms of action [7] and is associated with notions of empowerment and democratic consolidation of institutional systems of governance [5] in terms of accountability and real exercise of rights [9]. In this context, the construction of global and local relationships becomes a key element to sustain a critical practice of development.

4 Elements for Critical Learning in the Master

In the next sections we present how the different facets are oriented to building this critical learning.

4.1 *In Relation to Contents*

The first relevant field to promote critical learning is the Master's own content. In that sense, the Master is not conceived from a single point of view on development and the implications of interventions or projects, but also incorporates a variety of perspectives that allow contrasting approaches with the aim of making possible a critical elaboration of knowledge by students themselves.

In the general teaching on the conceptualization of development, the economic vision is complemented with the fundamentals of human and sustainable development from the perspective of Amartya Sen's capabilities, which opens the door to considerations of social, cultural, environmental and political nature. In particular, issues such as participation, citizenship and rights, democratic development, ethics or gender are emphasized.

From the University Master in Development Cooperation standpoint, it is understood that the processes of change for a more just society must undergo to re-examine, from a critical perspective, the world in which we live to create transforming action strategies towards the world in which we want to live. For this purpose, the contents in the educational area feed from the research practice of teachers who test the theory presented in the classroom, nurturing it with the research done by the research groups to which they belong.

EL GEDCE¹ is, in this sense, the 'connecting point' of reality in the development of master's teaching, creating and reworking theory based on alternative approaches that lay the groundwork for cooperation practices to be more critical and just. Rights Based Approach, Theories of Education Development, Theories of Social Change, Human Capabilities Approach, Gender and Development Approach are, among others, the theoretical basis on which the teaching lies.

In the specialization course in project management and development processes, dominant approaches and tools such as logic models and the essential of project management (scheduling, quality, risks, human resources...), are given while at the same time other alternative models are stressed from participatory approaches (participatory planning, action research, gender planning...) or from the rights based approaches and political advocacy that offer different visions of development processes. In particular, the role of participatory tools for future application in the workplace is emphasized, for which we have created a web of specific resources².

¹ <http://www.upv.es/contenidos/GEDCE/>.

² <http://www.planificacionparticipativa.upv.es>.

4.2 In Relation to Teachers, Speakers and Experts

Regarding teaching, the faculty of the UPV is complemented with the participation of guest speakers and experts with a wide range of profiles, career paths and geographic areas that enrich the teaching by giving different views and conceptualizations. In this regard, it stresses not only the role of academics from different universities but also professional experts from organizations and various development agencies.

In addition, some thematic units include the participation of ex-students contributing, on a firsthand basis, their personal experience after finishing their training. In this way, the ways that the everyday reality of the organizations takes that critical practice in development work and what are the main barriers it faces are discussed in the classroom firsthand.

In this sense, and because of the social changes that have been experienced in these last few years, classroom participation of people from grassroots movements has become essential to shed light on certain processes of change that cannot be explained without including the emergence of social movements on the world stage. Thus, the Master has opened the door for discussions, in first person, of men and women who have organized themselves to give voices and names to change. Understanding that development processes are to create a fabric that is conducive to social justice, and that this network should form itself connecting local demands from various geographical areas of the world, the Master promotes the participation of stakeholders in the classroom that are agents of change. For that reason, it encourages the participation of neighbourhood representatives in Valencia, as well as grassroots movements in Peru through videoconferences.

4.3 In Relation to the Student Profile

The profile of the students is also relevant in terms of providing critical learning. In that sense, the elements of intercultural and interdisciplinary groups of students are relevant, as they enrich the construction of shared classroom knowledge. It becomes a way to illustrate, with examples in the classroom, the dialectics between different worldviews and the complexity of implementing development processes and projects. However, this has led to significant challenges in terms of integration and group dynamics as well as in teacher planning.

4.4 Regarding the Methodology

Regarding the pedagogical approach, there are teachers who develop a more conventional education, mainly based on the transmission of knowledge through master lectures and where the students' role is, at best, to work and present study cases.

This coexists with other riskier approaches which seek not only to bring about spaces for dialog but also that these spaces become meaningful for learners, that is to say, to be based on daily situations, conflicts and interests that have been experienced through dynamics that simulate real situations and problems. It is through participatory teaching methods that knowledge is built on a network of shared relationships between students, teachers and external organizations.

In this regard it is noteworthy that the faculty works consciously to modify the spatial conception of the classroom. The class arrangement is changed, putting the students in a circle and encouraging dialogue between participants and at the same time bridging the gap between the teacher, thus contributing to the blurring of the existing power relations between students and lecturer.

We can say that a large number of the Master teachers share this pedagogical approach although its realization is not always easy. Undoubtedly, the strengthening of teaching practices based on the constructivist paradigm and meaningful learning opens a very suggestive channel for teacher training in the Master.

Listed below are the methodological elements developed in the teaching practice. In the first place, the Workshop on Designing a Local Intervention through Participatory Action-Research methodology. During the specialization term, students come in contact with a social organization of the city of Valencia and make a project related to it. Through a series of meetings, an initial question is formed and over a period of three months the students should use the knowledge and tools learned in the course to make a project that responds to the question proposed by the organization (Fig. 2).

Secondly, applied works are developed in different subjects of the course, such as the drafting of an actual research that later is developed into the Master Final Project, the writing of a cooperation project proposal for an NGO, or conducting a simulated participatory planning exercise in the classroom in relation to issues of the course itself.

As a complement, activities related to self-deliberation are done in which students should think about their own career path and vital experience and relate it to what is being outlined in the classroom. They should think about the aspects that have led them to pursue this degree, the types of social change they have lived,



Fig. 2 Scenes illustrative of participatory teaching methods

attitudes, skills and knowledge they are learning and the barriers they believe they will find as critical professionals, the role of gender in their daily lives, etc.

Moreover, the practices and the Master Final Project is a space to put into practice the knowledge, skills and attitudes developed in the master, build real partnerships in a real professional environment and systematize an in-depth thought whether it is a researching or professional nature.

Finally, research seminars related to GEDCE and open to students are carried out to enrich teaching education with research practice.

4.5 In Relation to the Management of the Master

If at the beginning of this article we concretely defined what we mean by critical development practice, the daily management of the Master could not ignore these approaches and therefore has tried to incorporate elements that constitute key innovations to contribute to critical learning.

Firstly, we emphasize in the participatory design process of the Master. Since the first year in 2007 to the subsequent upgrades and modifications for conversion into an official degree, the design of the Master has had the participation of various actors of international cooperation in defining both its content and its teaching approach. Through participatory workshops and other on-line work tools, knowledge, skills and values expected of a professional trained to work on development projects from a critical perspective were defined. In relation to this, in the course 2012/2013 a complete module was designed in a participatory manner, gathering in two workshops professionals from NGOs, researchers and teachers to form the entire curriculum of the subject. Through this initiative it is intended that the design of the degree has a dynamic relationship with the living realities of cooperation and development.

This initial participatory design has been complemented with a continuous evaluation also of a participatory character incorporating different elements. Firstly, each thematic unit is evaluated in person in the classroom by the students together with the teacher. Secondly, at the end of each course a monitoring committee is organized which is composed of the management of the Master, the technical secretariat, the lecturers of the subject and two students representatives. At these meetings the strengths and weaknesses of the course are discussed in order to introduce improvements in successive courses. Finally, an annual participatory evaluation is conducted by an external professional introducing a complementary view of the group (Fig. 3).

Additionally, the Master has an Advisory Board composed of development organizations, mainly Development NGOs. Its main objective is to give feedback of the training process of the Master and ensure teaching quality, adapting the contents to the needs and demands of professionalism in an ever changing and dynamic context.

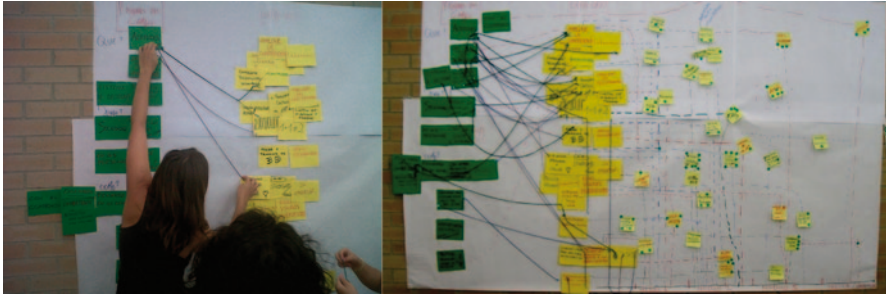


Fig. 3 Master's evaluation workshop

Moreover, during the year 2012, an Innovation Team for Educational Quality was formed by lecturers to enhance participation and action orientation in the teaching–learning process. Among other things this has contributed to the publication of educational and research materials which are available on the website of the Master.

Finally, a thorough process of internship selection is done according to the profiles and motivations of the students, understanding that each person has some interests, some preferences, and particular skills that should be strengthened.

5 An Assessment from the Students

Below, we offer the students' assessment of the issues raised so far. They are the results of two evaluation activities carried out in the Master so as to discuss their scope in terms of critical learning.

The first one is an exploratory study conducted in 2011 which aimed to find out to what extent the students of the Master had acquired skills for a critical practice in development [1]. The methodology consisted in conducting semi-structured interviews with 13 students who had completed the Master. This information was supplemented by the reading of dissertations and internship reports. The second is the evaluation of the Master [6] conducted in 2012 and aimed at assessing how the critical view developed in the course was reinterpreted and adapted to the actual work in the development organizations in which graduates worked. To that end, 17 semi-structured interviews were carried out, some of them in groups.

It is important to clarify that when the interviews were conducted, the only graduates were those who had completed the Master in Development Policy and Process (the precursor of the current Master in Development Cooperation). It seemed to us also that it was relevant to interview people who had graduated from the Master so as to explore the learning space of the internships and the final research project.

We organize below the results of these studies in terms of: (1) learning and change, (2) Critical view and (3) Critical practice and action orientation.

5.1 *In Relation to Learning and Change*

The first question is about how people learn, from what, and what factors have made people learn critically about the issues addressed in the Master. Through the exercise of ‘rivers of learning’ developed in the interviews that were part of the 2012 evaluation, each participant identified those factors.

The first thing that stands out is the combination of formal and informal elements in their educational path. The type of formal education received marks the decisions that students make in relation to the type of postgraduate training. In a very particular way, those students who come from primarily technical or scientific careers (such as engineering, biology or architecture) highlighted the need for a reorientation of the basis of their professional career. So they assert things like, “I don’t want to be just a technician”, “engineers tend to be fairly square”, “I want to stop working so much with things and work with people”, “I realized that humanism was missing in the way that architecture is understood.”

Secondly, they consider that participating in children and youth association initiatives of different stamps has awakened or strengthened their concerns for ‘the social’. These are experiences that, according to participants, marked a basis in their learning for different reasons like “to learn to socialize”, “to meet people different from me”, “to get to know other realities” or “to get close to poverty in my city”.

A third moment of learning and change refers to periods of crisis and ethical conflicts in which they have had the feeling that what they did made no sense or were not in the right place to fulfill themselves, feel good or make sense:

- “At one point, I began to feel that architecture was too individualistic, like a work of art, a finished object with copyright. I felt that architecture should be more human, more people-centered. I started working as an architect in the community, allowing me more contact with the user of architecture. That raised new ethical conflicts in me concerning power relations that were created and I decided to leave it”
- “I worked in a company that built race cars, as an engineer. I liked the job, but not so much the people. At one point I asked myself, ‘what am I contributing to the world?’ From there on I started working more seriously in the social area”

In this process, what the Master has provided has to be framed in a dynamic and continuous learning process that goes beyond the training environment itself. In most cases, people bring these experiences with them, which in one way or another, the course helps them to make sense of, and in some cases, to ‘verbalize’ what they already felt or knew or as two participants mentioned “to give a name to things that I had already thought, felt or sensed”. Along these lines, participants say things like:

- “The Master gave structure to that other way of seeing the world. I was critical and the Master made me even more critical”, “The Master helped me to click on a lot of things, but I also realized that the puzzle began to fit” “The Master gave support in building other lenses and looking with them, with more consciousness”

The participants make a clear reference to collective learning; this is to say, to what is learned by the interaction of students, rather than by the interaction with teachers or the course content. In the analysis' exercises on learning during the course a student said, "I think obviously it has a collective dimension and in the Master those clicks, that happen a lot, happen together [...] there are moments in which it "floats in the environment"". Thus, the spaces that the course dedicates to knowledge and collective learning are highly valued.

In the evaluation, the issues of internships and Master final project were identified as an important input for the learning experience and as a space for building relationships and creating networks. For some the internships were riddled with 'clicks' and moments of linking theory and practice: "My internship was based on my work in Morocco with NGO X, whenever I came to Valencia, the classes would be full of issues that I'd noticed and put into practice in my work there. That process gave me a lot of strength, a lot of activity." For some people, the Master Final Project was more like a 'closing cycle', a time of ending a loop of learning.

Other learning factors arising from the stories collected in the evaluation of the Master refer to ideas, readings, key authors and teachers.

5.2 *Regarding the Critical View*

From the aforementioned analysis on learning, it seems clear that the 'critical view' is something that is built from various experiences that the Master helps to make sense of and conceptualize. That is to say that critical thinking is not something that comes with the experience in the Master but is (re) activated or conceptualized by this experience.

Thus, there are numerous testimonies that claim that the Master strengthens critical thinking among participants although just having critical capacity is also one of the motives that drives them to study this Master.

This critical vision takes shape in the rejection of a 'hegemonic thinking' that has manifested itself in different ways, at different times and in different fields such as education, or professional associations.

Regarding the critical view, students emphasize the role of taking 'consciousness' in how the 'system in which we are engaged' works, 'the AECID', 'the University', 'the relationship between donors and implementing organizations' or 'the logical positivism' associated with project management tools for development.

This is complemented with the idea of 'skepticism' in the sense that adopting a 'critical view' involves maintaining certain "prudence and suspicion, in the use and consumption of terms" (Participant). Therefore, it is essential in the world of development interventions to continually question where the initiatives come from, who says the things and from what position.

Finally, it emphasizes the ability to understand the power relations that occur in actual work situations in development. Thus, the combination of power, politics and

critical thinking is present in many responses from students when assessing their learning in the Master “Yes, as far as seeing the different types of power... beginning to see the different kinds of power, the visible, invisible and hidden, especially the issue of hidden power... Because the visible one, we criticize and we have more tools to criticize it, the invisible one, well you know it’s there as it is, but the hidden one is more complicated because you have to get a hold of it.” This analysis of power seems to contribute to a better understanding of relationship networks that occur between people and organizations in the daily work in development.

5.3 Regarding Critical Practice and the Action-Oriented Approach

When implementing this critical view of development and moving it to everyday work in organizations, evaluations show obvious difficulties. Through discussion with graduates of the Master three typical situations come up which correspond to three different attitudes or states when facing the question.

The first would correspond to questions such as “What do I do now, where do I start, how to continue? This state corresponds to those times when taking a ‘critical look’ turns out to be paralyzing due to it clashing with the reality of this sector that is described as bureaucratic, hierarchical and even authoritarian by the students themselves. This creates confusion and generates some frustration in the ‘real practice’, it just doesn’t adjust to that set of concepts and ideas that shaped the critical view of the work in development.

This can lead to the second state, according to which, the best for development is not working on development. In those moments this confrontation with reality leads to consider or even decide not to work in development.

Finally, the third stage would correspond to an expression like there is light at the end of the tunnel, characterized by greater optimism and greater acceptance of the difficulty of implementing a committed and conscientious work. Here, each one handles his/her ethical conflicts differently in order to achieve a more proactive state and act accordingly: “For me the critical practice is to try to propose alternatives to the mainstream development practice.” In these lines, the importance of the knowledge acquired in the Master is highlighted:

- “You have to know how the system logic works to propose a change. To me the management module seems very important... I think the Master is giving us tools to deal with the dominant discourse and also to expand this critical vision. For example, the tools I learned from the workshops (...) are used very often and I feel that they work and transform”

These three positions, moments or states are changeable and are subject to stress and balances. They are attempts to address the relationship between reflection and action, in the search for coherence with that critical vision.

6 Conclusions

Throughout this paper we have presented a training experience in Project Management and Development Processes in the framework of the Master in Development Cooperation of the UPV. We have tried to discuss the elements that support an education oriented to building a critical view that leads to a critical practice of development work.

To do this, we have formulated what we mean by critical learning and we have discussed the different elements of the program that in a particular way are intended to contribute to it. These include aspects related to the contents, faculty and external speakers, the profile of students, teaching methodology and the management of the Master.

Finally, we have captured the outcomes of an exploratory study and the evaluation made in 2012 to illustrate how the Master students express their vision in terms of the critical learning processes they have experienced, what meaning they have given to this critical vision that they have attempted to construct and how they transfer it to a critical practice in the organizations where they work.

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Competences in Project Management Reachable Before Getting the Engineering Degree

D. Guerrero, M. Palma, S. Vegas, V. Quevedo and G. La Rosa

1 Introduction

Engineering is a profession in which the knowledge of basic sciences is used in order to efficiently use materials and the forces of nature in order to meet the growing needs of human beings [17].

Engineering students live in a world where it helps them to have experience, to find more than one solution to a problem and to have an open attitude, thus allowing them to work from different approaches and perspectives. Engineering teams require professionals to have self-confidence and self-control, and to be able to use the most advanced technologies in order to be able to access information and communicate with others. An education in engineering must provide students with an awareness and understanding of how to work in a team and the ability to solve problems, in contrast to what the curriculum offers [8, 19, 20].

This work demonstrates the impact of the Project-Based Learning (PBL) methodology in improving the project management competences among two groups of industrial engineering students, one from the 2011 semester, and another from the 2012 semester. Sect 2 gives an overview of the PBL methodology and the project management competences of the International Project Management Association

D. Guerrero (✉) · M. Palma · S. Vegas · V. Quevedo · G. La Rosa
Universidad de Piura, Piura, Perú
e-mail: dante.guerrero@udep.pe

M. Palma
e-mail: martin.palma@udep.pe

S. Vegas
e-mail: susana.vegas@udep.pe

V. Quevedo
e-mail: valeria.quevedo@udep.pe

G. La Rosa
e-mail: gerson.larosa@udep.pe

(IPMA). Sect 3 describes the characteristics of the project management course and proposes it as a case study. Sect 4 presents the results obtained and the statistical evidence that supports the conclusions given in Sect 5.

2 Project Based Learning and IPMA Competences

Project Based Learning (PBL) is a teaching methodology that integrates teams of people with different profiles; students are organised into groups and acquire, use and apply the concepts of the course throughout their research. They also develop skills in planning, implementing and evaluating projects which are being executed in the real world [7, 3, 6, 9].

The results of various investigations [1, 7, 11, 13, 22, 21, 12], Mergendoller and Thomas 2005 show that PBL promotes the development of abilities, such as self-teaching learning, communication, self-confidence, organisation and project structure. It also improves the students' commitment and motivation, teamwork, conflict and crisis management, and problem-solving, thereby allowing better academic performance.

In PBL, the role of the teacher is fundamental as well, designed projects need suitable platforms. This teaching support should facilitate resources and learning guidance, give additional training on key skills and feedback on the progress of projects, provide examples of good practice, give in-class workshops that allow students to share knowledge and develop a positive approach [2, 15].

The PBL structure can be determined in 4 phases [5]:

- Information: in this phase students gather the information necessary for the task.
- Planning: the plan is developed, the methodology is given a structure and a strategy is selected.
- Realization: this includes research and experimental work and the analysis of the plan.
- Evaluation: the results are reported and discussed by the students and the teacher.

A final written project report is submitted and the teams present their results to the teacher, classmates, and guests. This assessment should examine the knowledge of the students regarding the project and its academic content.

The evaluation phase may include a self-assessment, allowing the students to reflect on their competency levels at the beginning and end of the course. This phase also allows the students to reflect on their performance in the project, their contribution to their team, their negotiation abilities and the trust generated with other team members [2].

The Universidad Politécnica de Madrid (Polytechnic University of Madrid) promotes the fundamental competences in project management as defined by the International Project Management Association (IPMA). These are adapted to facilitate training in technical, personal, and contextual competences. This connection allows



Fig. 1 Eye of competence of IPMA

higher education to be linked to a professional certification system and so opens up opportunities for students [4].

IPMA through the ‘eye of the competence’ (see Fig. 1) shows the three dimensions of competences: technical, behavioural and contextual.

Within the three dimensions there are 46 elements of competence (Table 1) which are required for a person to gain the entire benefit from the project, programme or portfolio and so meet the expectations of all interested parties [10].

Technical competences describe the elements necessary to implement, manage and complete a project. Behavioural competences include elements of personal attitude which are relevant to the management of projects. These elements can be applied to the project manager, team members and the parties involved. Contextual competences describe the concept of the project, programme or portfolio, as well as the link and organization(s) involved in a project [10].

The dimensions of the competences proposed by the IPMA follow the holistic approach of professional competences, and are suitable for engineering students [16]. This is because they are professionals who use a complex mix of knowledge, skills, abilities, attitudes and values. Depending on the situation, they use particular attributes to make intelligent decisions, thus allowing a place for ethics, values, and reflective practice.

The global certification system IPMA has four levels A, B, C, and D. IPMA Level D® entitled ‘Technical in Project Management’ does not require experience in project management. One only needs to show a level of knowledge required in all its elements. Table 2 shows the importance of the areas of competences and the minimum score of knowledge and experience one must obtain in order to earn a certification in IPMA Level D®. Being certified at IPMA level D® means that the person can apply their knowledge in project management when participating in projects of any size and thus ensuring that the person has a sufficient level of knowledge to perform their role with a satisfactory level of competence.

Table 1 Code of competences of IPMA

1 Technical competences	2 Behavioural competences	3 Contextual competences
1.01 Successful management of projects	2.01 Leadership	3.01 Focus on projects
1.02 Parties involved	2.02 Commitment and motivation	3.02 Focus on programs
1.03 Project requirements and objectives	2.03 Self-control	3.03 Focus on portfolios
1.04 Risks and opportunity	2.04 Self-confidence	3.04 Implementation of projects, programmes, and portfolios
1.05 Quality	2.05 Relaxation	3.05 Permanent organisation
1.06 Project organisation	2.06 Open attitude	3.06 Commerce
1.07 Teamwork	2.07 Creativity	3.07 Systems, products, and technologies
1.08 Troubleshooting	2.08 Focus on results	3.08 Personnel management
1.09 Project structure	2.09 Efficiency	3.09 Safety, health, and the environment
1.10 Scope and deliverables	2.10 Consultation	3.10 Finances
1.11 Time and project phases	2.11 Negotiation	3.11 Legal
1.12 Resources	2.12 Conflicts and crisis	
1.13 Cost and financing	2.13 Reliability	
1.14 Provisioning and contracts	2.14 Appreciation of values	
1.15 Changes	2.15 Ethics	
1.16 Controls and reporting		
1.17 Documentation and information		
1.18 Communication		
1.19 Release		
1.20 Closing		

Table 2 IPMA Level D

Scope of competence	IPMA level D® (%)
Technical	70
Behavioural	15
Contextual	15
Competence components	IPMA level D® (0–10)
Knowledge	4
Experience	(not applicable)

3 Project Course

The objective of the course is to provide students with the tools required by the methodology within the body of knowledge of the general theory of the project and the development of competences in project management. Furthermore, it seeks to boost the capacity of management and the execution of operations, processes, and production projects and services, with an emphasis on information systems.

The course was designed on the 'Basis for Project Management Competence, NCB Version 3.1' [10] and the 'Guide of Fundamentals of Project Management' [18]. The course consisted of 16 weeks of classes, totalling 50 h of theoretical lectures, 8 h of practice sessions and 128 h of studying.

3.1 Course Evaluation

The assessments given during the course are of three types: tests, the semester project and general participation.

The exams are based on the MOODLE platform and consist of multiple choice questions. These follow the style of the written examination for IPMA Level D® and are classified according to the code of competences (Table 2). The exams account for 20%.

The semester project is group based, with a maximum of five people per group. The formation of the groups and the topic of the project are decided by the students. Each group is assigned a monitor certified in project management by IPMA, who answers questions about course content and provides advice on the formulation, design and implementation. The monitor also accompanies the team when it presents its final report.

The approval of the project determines the approval of the course and is worth 60% of the total evaluation.

Evaluation of participation is continuous and taken on participation in workshops, the project, evidence of the acquisition of competences and a formal submission of deliverables. These deliverables are: the project idea, project charter, statement of scope, project management plan and a closing report. Participation accounts for 20% of the total evaluation.

4 Results

In order to acquire an indication of the students' improvement in the competences during the courses of 2011 and 2012, two types of evaluations were made, one at the beginning of the process and another at the end. These were the students' self-assessments and written examinations.

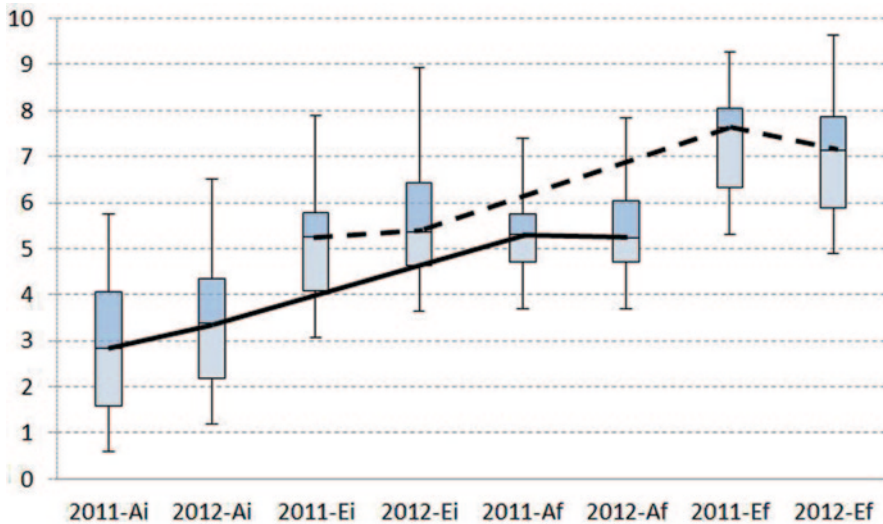


Fig. 2 Descriptive statistics of technical competences

Self-evaluations were done following the model proposed by the IPMA in NCB version 3.1. Self-evaluation sheets were sent to students at the beginning and at the end of the course.

The written examinations mentioned earlier are given throughout the learning process. There are four of them. They are based on written examination for the IPMA Level D®. The results of the first and final exams of the course are used as a reference point. The graph in Fig. 2 shows the improvements in technical competences.

The self-evaluations done by the two groups of students (2011-Ai, 2012-Ai) are similar to their final self-evaluations (2011-Af, 2012-Af) where it can be noted that there is a 50% improvement in competences, going from a range score of 0.5–3.5 and another of 3.5–5.5.

The box-and-whisker graphs for the written examinations for the course show that 50% of the students in both groups had an initial range score between ranges 3 and 5.5 (2011Ei, 2012Ei) which then improved to a range score between 5 and 7.5 (2011Ef, 2012-Ef).

In Fig. 3 some improvements can be seen in the behavioural competency of students from the 2011 and 2012 semesters. Students develop their behavioural competences during their college careers before starting the course in project management. This is seen in the box-and-whisker charts corresponding to the initial self-assessments and examinations (2011Ai, 2012Ai, 2011Ei, 2012Ei), where 75% of the students considered themselves to have a score higher than 4 in behavioural competences in the initial self-evaluations (2011Ai, 2012Ai). However, 100% of the 2011 and 2012 semester students proved to have a score higher than 4 in the initial evaluations (2011Ei, 2012Ei).

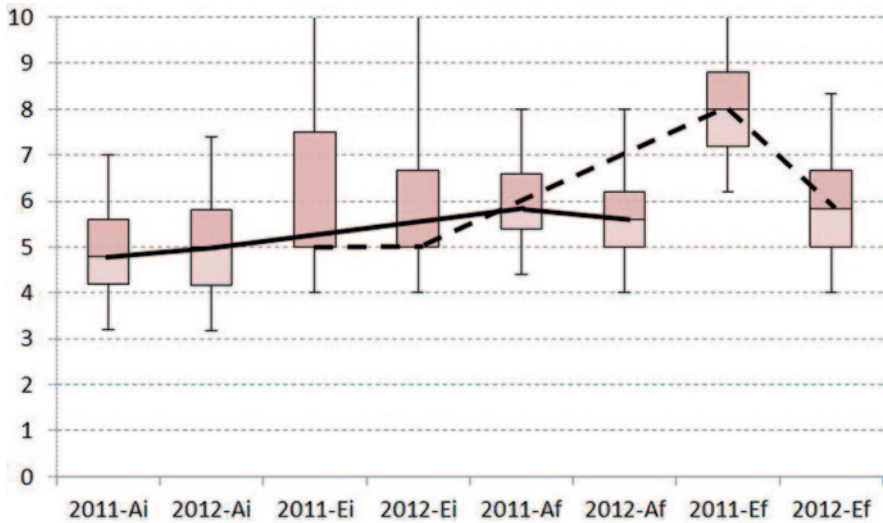


Fig. 3 Descriptive statistics of behavioural competences

By looking at the box-and-whisker charts for the exams and final self-assessments (2011-Af, 2012-Af, 2011-Ef, 2012-Ef), we see that 50% of students believed their behavioural competences had improved, reaching a score higher than 5.5 (2011-Af, 2012-Af). In the written final exam 100% of students from 2011 semester and approximately 50% from 2012 improved their behavioural competences, reaching a score higher than 6 by the end of the course (2011-Ef, 2012-Ef).

In Fig. 4, we can see the improvement in contextual skills for the students of both the 2011 and 2012 semesters. This is shown by the lines that cross through the medians of the box-and-whisker graphs. These correspond to the self-assessments (2011Ai, 2012Ai, 2011Af, 2012Af) and the written examinations (2011Ei, 2012-Ei, Ef-2011, 2012-Ef).

Evaluating the initial and final self-evaluations of the students of 2011 and 2012 individually (2011Ai, 2012Ai, 2011Af, 2012Af) shows that 50% of students below the median considered they had improved their behavioural competences, by moving from a score between a range of 2.5–0.5 to a range of 2.5–4.5.

Looking at the box-and-whisker graphs of the written examinations of students from 2011 and 2012 (2011Ei, 2012Ei, 2011Ef, 2012Ef) shows that students from semesters 2011 and 2012 improved their contextual competences from a range of 0.5–8.5 (2011Ei, 2012Ei) to a range of 3.5–10 at the end of the course (2011-Ef, Ef-2012). Finally, about 75% of students of 2012 (2012Ef) and 100% of students of 2011 (2011Ef) reached a score greater than 5 with respect to contextual competences by the end of the course.

The questions crafted for the written exams were based on the written examination for the IPMA Level D®. Therefore, we can align the results obtained with the rating level required for the IPMA Level D® certification. The final written exami-

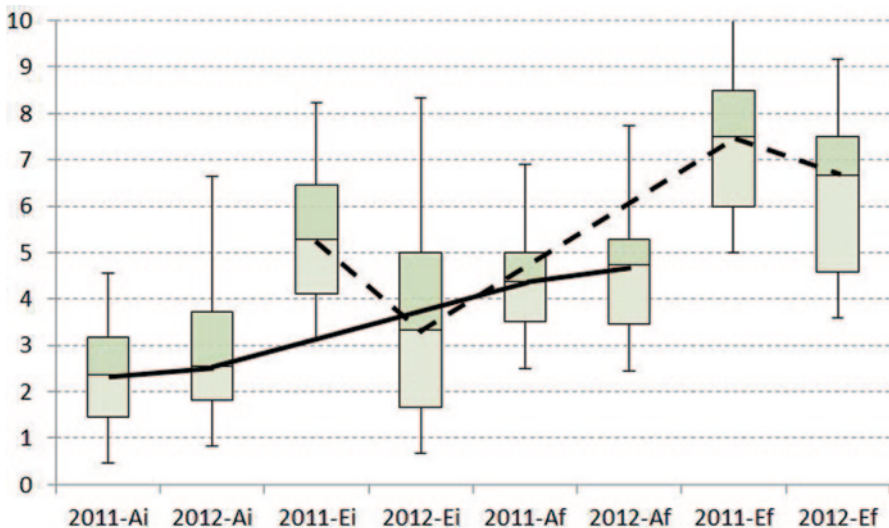


Fig. 4 Descriptive statistics of contextual competences

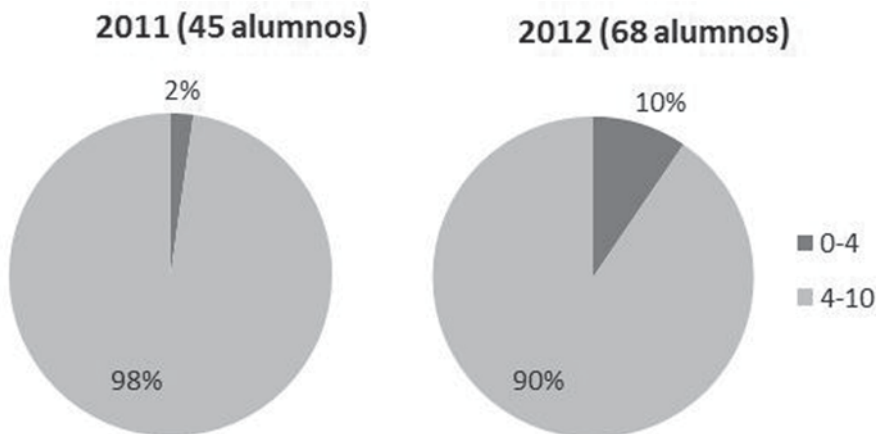


Fig. 5 Descriptive statistics of scores obtained at the end of the course

nation contains 100 questions covering the whole content of the course. Figure 5 shows the percentage of students that achieved an average score of competences higher than 4 at the end of the course for both groups. In conclusion, 93% of the 113 students who took the Project Management course in 2011 and 2012 proved to have the minimum level of knowledge required to obtain the IPMA Level D® certification.

Figure 6 highlights the similarities between the averages of specific competences corresponding to the three dimensions of competences in project management from

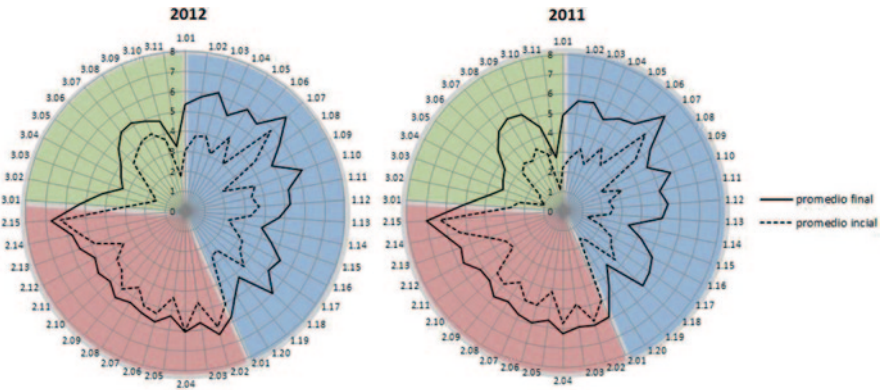


Fig. 6 Improvements of competences in project management

students of 2011 and 2012 semesters. Here a significant improvement in technical and contextual competencies occurs in both groups. However, some of the behavioural competences stay the same when comparing the initial and final averages, as in the case of commitment and motivation competences (2.02), ethics (2.15) and self-confidence (2.04). These had an average minimum score of 5. Ethics had an average score of 7. This can be attributed to the values that the Universidad de Piura instills during its teaching.

In order to test if the results of the descriptive analysis were statistically significant, a comparison was made using software STATA 11.1 and the test ‘T-Student’ where the null hypothesis is the equal of the means and which is rejected if the level of significance observed is less than 0.05.

Table 3 shows results obtained by the test of ‘T’ student. Firstly, the results of the initial self-assessment and the initial exam in each of the dimensions of competences in project management for both groups of students (2011 and 2012) are compared. We can infer the invalidity of the null hypothesis. Therefore, it can be said that the initial exam and self-assessment do not show the same result, except for that obtained in the behavioural competence of students from 2012. It can also be concluded that there is an inequality between the results obtained in the final exam and the final self-assessment in each of the dimensions of competences of project management for both student groups (2011 and 2012), except for the behavioural competences from the students of 2012. This shows that students judge themselves strictly. This could possibly be explained by their lack of confidence and lack of professional experience.

Verifying the hypothesis of equality of means between initial self-assessment and final self-assessment shows that the significance of the two queues is less than 0.05, thus demonstrating the invalidity of the hypothesis. The same result is seen with the significance of the two queues between the initial and final exam. This supports that there is an improvement in the competences of Project Management between 2011 and 2012. This can be attributed to the learning methodology. How-

Table 3 Results of the test “T-Student”

		Assessment of competences (0–10)							
		Initial self-assessment (Ai)	Initial assessment (Ei)	Final self-assessment (Af)	Final assessment (Ef)				
2011									
	Initial technical C. (CT11)	2.84 (1.45)	4.82 (1.43)	4.84 (1.80)	7.05 (1.65)				
	Initial behavioural C. (CC11)	4.75 (1.12)	5.61 (2.39)	5.44 (1.98)	7.65 (1.77)				
	Initial contextual C. (CCT11)	2.30 (1.08)	5.12 (1.64)	3.65 (1.90)	6.90 (1.99)				
	Score IPMA level D®	3.04 (1.27)	4.98 (1.37)	4.75 (1.72)	7.12 (1.66)				
2012									
	Initial technical C. (CT12)	3.28 (1.50)	5.28 (1.71)	5.04 (1.61)	6.27 (2.40)				
	Initial behavioural C. (CC12)	4.91 (1.18)	5.37 (2.15)	5.33 (1.65)	5.27 (1.96)				
	Initial contextual C. (CCT12)	2.81 (1.53)	3.55 (2.21)	4.11 (1.60)	5.61 (2.51)				
	Score IPMA level D®	3.46 (1.36)	5.04 (1.60)	4.94 (1.57)	6.02 (2.22)				
	CT11 = CT12	0.127	0.130	0.541	0.061				
	CC11 = CC12	0.477	0.578	0.755	0.000				
	CCT11 = CCT12	0.055	0.000	0.168	0.005				
Global									
	Initial technical C.	3.10 (1.49)	5.10 (1.61)	4.96 (1.68)	6.58 (2.16)				
	Initial behavioural C.	4.85 (1.15)	5.46 (2.24)	5.37 (1.78)	6.22 (2.21)				
	Initial contextual C.	2.61 (1.39)	4.18 (2.14)	3.93 (1.73)	6.13 (2.40)				
	Score IPMA level D®	3.29 (1.33)	5.02 (1.51)	4.87 (1.63)	6.46 (2.08)				
2011									
	Assessment of competences (0–10)					Significance of two queues			
	ΔA	ΔE	Af = Ei	Af = Ef	Af = Ai	Ef = Ei	ΔA = ΔE		
	Initial technical C. (CT11)	2.01 (1.84)	2.23 (1.91)	0.000	0.000	0.000	0.662		
	Initial behavioural C. (CC11)	0.69 (1.80)	2.04 (2.82)	0.031	0.000	0.015	0.025		
	Initial contextual C. (CCT11)	1.36 (2.02)	1.78 (2.18)	0.000	0.000	0.000	0.418		
	Score IPMA level D®	1.71 (1.71)	2.13 (1.37)	0.000	0.000	0.000	0.361		

Table 3 (continued)

	ΔA		ΔE		$A_i = E_i$	$A_f = E_f$	$A_f = A_i$	$E_f = E_i$	$\Delta A = \Delta E$
2012									
Initial technical C. (CT12)	1.75 (1.98)		1.03 (3.02)		0.000	0.000	0.000	0.011	0.1.08
Initial behavioural C. (CC12)	0.42 (1.70)		0.10 (2.36)		0.175	0.853	0.048	0.920	0.368
Initial contextual C. (CCT12)	1.30 (1.81)		1.29 (2.96)		0.043	0.000	0.000	0.007	0.981
Score IPMA level D®	1.49 (1.81)		2.24 (3.03)		0.000	0.001	0.000	0.001	0.088
CT11 = CT12	0.503		0.020		-	-	-	-	-
CC11 = CC12	0.426		0.000		-	-	-	-	-
Global	ΔA		ΔE		$A_i = E_i$	$A_f = A_i$	$A_f = A_i$	$E_f = E_i$	$\Delta A = \Delta E$
CCT11 = CCT12	0.847		0.347		-	-	-	-	-
Initial technical C.	1.85 (1.92)		1.51 (2.69)		0.000	0.000	0.000	0.000	0.280
Initial behavioural C.	0.52 (1.74)		0.87 (2.72)		0.016	0.002	0.002	0.008	0.286
Initial contextual C.	1.32 (1.89)		1.48 (2.68)		0.000	0.000	0.000	0.000	0.635
Score IPMA level D®	1.58 (1.77)		2.20 (2.62)		0.000	0.000	0.000	0.000	0.053

ever, there is an equality of means in the results of the assessments of behavioural competences for students from 2012.

If the equality between the variation of self-assessments and the exams is analysed, the validity of the hypothesis can be seen. Therefore both tools reflect, in the same degree, the improvement of competences in Project Management. The hypothesis was only not supported by the results of the assessment of behavioural competences for the students of 2011.

If the results obtained in the self-assessment and the initial exam between students of 2011 and 2012 are compared it can be seen that students from both semesters start at the same level for the competences, except for the contextual competences.

The results obtained in the final exam prove that students from the 2011 semester obtained a higher score in the behavioural and contextual competences in relation to the final results obtained from students of 2012. This can be attributed to the fact that the 2012 students had to submit their final project and final written exam on the same day. This should be taken into account when scheduling activities for the upcoming semesters.

Finally, it can be seen that the students' perception of improvement in 2011 and 2012 has no relation to the development of each of the dimensions of competences in Project Management. This is shown in the analysis of the significance of queues that exist between the 2011 and 2012 groups with respect to the variation of self-assessment score (ΔA).

Once the improvement in professional competences between the 2011 and 2012 students has been proved, it is convenient to list specific competences that have shown improvements greater than 15%. Table 4 shows that the majority here correspond to contextual and technical competences. However, it must be noted the improvement in the behavioural competence "conflicts and crisis" evidenced during the presentation of the semester projects, where students expressed the existence of conflicts and crisis among different people and the parties involved. Applying the 'T-Student' test, it can be observed that the significance of queues shows that the level of competences reached at the end of the course is the same in both groups in spite of a different starting level in the following competences: "parties involved", "time and project phases", "resources", "cost and financing", "provisioning and contracts", "closing" and "permanent organisations".

5 Conclusions

Through self-assessments it is possible to confirm that the students believe the methodology used helped them to improve and acquire the important competences such as success in Project Management (25%), management of parties involved (24%), project organisation (27%), scope and deliverables (26%), time and project phases (22%), as well as management of conflicts and crisis in the project team (20%).

Table 4 List of competences in project management

Code Competence	Improvement of competences (%)			Significance of two queues			Overall improvement (Final = Initial)
	2012 (Final-Initial)	2011(Final-Initial)	Global (Final-Initial)	Initial status (2012 = 2011)	Final status (2012 = 2011)		
1.01	23	27	25	0.051	0.115	0.000	
1.02	20	29	24	0.023	0.812	0.000	
1.03	23	25	24	0.156	0.240	0.000	
1.04	21	25	23	0.202	0.702	0.000	
1.05	16	18	17	0.231	0.288	0.000	
1.06	26	27	27	0.987	0.793	0.000	
1.09	28	26	28	0.953	0.828	0.000	
1.10	25	27	26	0.197	0.304	0.000	
1.11	19	26	22	0.023	0.484	0.000	
1.12	16	28	21	0.009	0.761	0.000	
1.13	15	27	20	0.044	0.413	0.000	
1.14	17	21	19	0.014	0.290	0.000	
1.15	19	22	21	0.063	0.378	0.000	
1.16	21	23	22	0.281	0.577	0.000	

Table 4 (continued)

Code	Competence	Improvement of competences (%)			Significance of two queues			Overall improvement (Final = Initial)
		2012 (Final-Initial)	2011(Final-Initial)	Global (Final-Initial)	Initial status (2012=2011)	Final status (2012=2011)		
1.17	Information and documentation	18	24	21	0.331	0.453	0.000	
1.18	Communication	20	19	20	0.385	0.310	0.000	
1.19	Implementation	17	16	17	0.143	0.078	0.000	
1.20	Closing	22	29	25	0.020	0.402	0.000	
2.12	Conflicts and crisis	16	24	20	0.664	0.051	0.000	
3.01	Orientation to projects	21	24	23	0.273	0.612	0.000	
3.02	Orientation to programs	22	16	20	0.613	0.374	0.000	
3.03	Orientation to portfolios	18	23	20	0.093	0.916	0.000	
3.04	Project implementation	17	21	19	0.127	0.689	0.000	
3.05	Permanent organizations	16	23	19	0.023	0.564	0.000	

A comparison shows that technical, behavioural and contextual competences of the students improved by the end of the period. This supports that the methodology used on the course is effective in helping the students achieve the objectives of the course. Therefore, it can be asserted that more than 90% of students can apply to the certification process and gain the level D for technical competences in Project Management.

In general, the students have improved by the time of the final presentations, they have learnt to present in a clear, concise and informative manner, using the language of Project Management. They are therefore able to support their proposals, answer questions from the public, and so present the conclusion they have reached during their project.

It is considered feasible to integrate this experience in other Engineering courses. For this it will be necessary to reinforce the tutoring role of the teacher, define assessment criteria in accordance to the objectives and to identify and evaluate the improvement of competences during the learning process.

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