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Research

How is Experimentation Carried Out by Companies? A Survey of Three European Regions

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A survey was carried out to characterize experimentation in three different European regions: the Baden-Wurttemberg region, The Basque Country and the rest of Spain. Results of the survey show that even though experimentation is a frequent activity, almost 95% of companies conduct experiments; the strategies used to carry them out are primitive. The one-factor-at-a-time strategy is used by 75% of companies far more than the 23%, which apply design of experiments (DoE). Results show that this may be due to the current lack of knowledge of DoE in these regions, where only 33% are familiar with the technique. Finally, the rate of applications of DoE among Six Sigma users is 40%, twice that of non-users, which stands at 19%. Copyright © 2008 John Wiley & Sons, Ltd.

KEY WORDS: design of experiments; European industry; experimentation; survey

1. INTRODUCTION

Manufacturers engage in a variety of activities such as developing new products, improving previous designs and maintaining them, controlling and improving ongoing manufacturing processes, among others. Experimentation is frequently carried out in unison with such activities. Therefore, since variation is ever present in these activities, statistics ends up being used, regardless of the user's background in it. Therefore, the issue is not whether statistics is used or not, but how well it is used[1].

Lye[2] defined design of experiments (DoE) as a methodology for systematically applying statistics to experimentation. More precisely, it can be defined as a series of tests in which purposeful changes are made to the input variables of a process or system so that one may observe and identify the reasons for these changes in the output response[3]. Based on this definition, DoE is defined throughout this article as a broad subject, encompassing methods such as the response surface methodology, the robust parameter methodology (RPM) or Taguchi methods (TM).

'Unfortunately, engineers and scientists rarely use statistics. It is argued that statistics has been overly influenced by mathematical methods rather than the scientific method. Consequently, the subject has been greatly skewed towards testing rather than discovery'[4].

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Gremyr[5,6], in 2003 as part of a European project, focused on the use of the RPM in five countries, The Netherlands, Germany, Ireland, Spain and Sweden, revealing that this technique is rarely used by companies. More recently, in 2006 Bergquist and Albing[7] analyzed the use of statistical methods at the companies where alumni of The Lülea University of Technology (Sweden) had worked. The survey showed that 23% used DoE, although only 4% of companies apply it to their most relevant processes.

In addition, we carried out a survey among manufacturers in The Basque Country to characterize industry experimentation in that region[8]. Conducted in 2006, the survey was sent only to companies with a workforce greater than 50. Results showed that although experimentation was frequently carried out by Basque companies, DoE was not frequently used. Furthermore, the majority of respondents were unfamiliar with DoE, which considerably hinders the application of the technique.

The purpose of this research is to obtain first-hand information from other European regions to generalize the results obtained in the previous survey. Firstly, the survey was carried out throughout the rest of Spain in order to build on the results obtained from The Basque Country. Secondly, a survey of the industrial region of Baden-Württemberg (B-W) was conducted with a 'Studienarbeit', made possible by the collaboration between Technische Universität Berlin and the University of Navarra. This region was selected based on its industrial significance in Germany and apparent similarities to The Basque Country. Unfortunately, other regions were not surveyed due to constraints in the budget. Consequently, this research will present a comparison of these three regions.

The characteristic of the surveys carried out is depicted in Section 2, as well as the details regarding respondent characteristics. Next, the analysis of survey results is presented in Section 3. Finally, conclusions and direction for future research are given in Section 4.

2. SURVEY CHARACTERISTICS

The same questionnaire was used for all three surveys[‡] and was sent to manufacturing companies with over 50 employees. It had 20 questions, consisting mostly of multiple-choice questions and a few open questions. It was designed to be completed in approximately 10 min and was divided into three sections. The main part of the questionnaire, 'use and knowledge of experimentation', had 11 questions mainly related to the way in which experimentation was carried out. The following section, 'use of statistics', had four questions about the usage of statistics in industry. Finally, a section called 'use of DoE' was included to characterize its applications, and it was meant to be responded to by only those who had applied DoE.

As recommended in survey literature[9,10], initiatives for obtaining a higher response rate were made, such as a letter of introduction, a web page, sending the participation many times, assuring anonymity, and sending a post-survey summary with results and conclusions.

The following sections present details of each of the survey's methodologies and characteristics of the responses received. We received a total of 285 valid responses. Table I highlights the response details of each survey.

2.1. *The Basque Country*

The questionnaire was sent by post in April 2006 to over 760 companies in The Basque County, a region in the Northeast of Spain. Although the geographical area of The Basque Country may be modest, The Basque industry is recognized throughout Europe for its quality and prestige[§]. Manufacturing firms were selected from The Basque industrial and export company catalogue (CIVEX).

[‡]The survey was originally conducted in Spanish, and thus all references to specific questions have been translated. Moreover, for Baden-Wurttemberg region it was translated into German.

[§]Basque Country was the highest-awarded region in Europe from 2000 to 2007, wining 18 European Quality Awards (finalist, prizes and awards)[11].

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Table I. Survey characteristics

	The Basque Country	Baden-Wurtemberg	Rest of Spain
Responses	138	70	77
Response rate	18.2%	6.5%	5.5%
Sample-error*	7.7%	11.3%	10.9%
%SME response	74%	64%	77%

*With $p=q=0.5$ and a significance level of 95%.

A total of 138 completed questionnaires were received, 74% of which were from small and medium enterprises (SMEs, less than 250 employees) and 26% were from large companies (more than 250 employees). The survey response rate was 18.2%, leading to a survey-wide sample error rate of 7.7%.

2.2. *Baden-Württemberg region*

The industrial region selected was that of Baden-Württemberg (B-W), which is one of the most important industrial regions in Germany[¶]. The abbreviation B-W will be used throughout the paper to refer to this region. Manufacturing firms were selected from a mailing list provided by The Commercial and Economic Office of the Spanish Embassy in Berlin. An invitation, which asked recipients to complete an online questionnaire[‖], was sent to 1080 companies in October 2007.

We received a total of 70 completed questionnaires, 64% of which were from SMEs and the remaining 36% were from large companies. The survey response rate was 6.5%, leading to a survey-wide sample error rate of 11.3%. We received fewer responses from B-W than in The Basque Country, since budget constraints made it unfeasible to send the questionnaire by post.

2.3. *The rest of Spain*

Finally, the survey was extended throughout the rest of Spain's autonomous communities (excluding The Basque Country). Manufacturing firms were selected from a directory of governmental companies available on the web. An invitation asking recipients to complete an online questionnaire[**] was sent to 1412 manufacturing companies in November 2007.

We received a total of 77 completed questionnaires, 77% of which were from SMEs while the remaining 23% hailed from large companies. The survey response rate was 5.5%, leading to a survey-wide sample error rate of 10.9%. We also received fewer responses than in The Basque Country, due to budget restrictions.

3. *SURVEY ANALYSIS*

Every response yielded from the surveys conducted in all the three regions was analyzed for a possible correlation to industry size, using tables of contingency. In the cases where correlations are statistically significant for at least one region, the results are shown to be stratified by industry size. On the other hand, when there is no correlation, there is consequently no stratification.

3.1. *Status of experimentation*

Industries engage in a variety of activities where experimentation is carried out in unison with other activities. After a brief explanation of the definition of experiments, the questionnaire tried to ascertain if

[¶]According to 2007 official data[12]; Baden-Württemberg, Bayern and Nordrhein-Westfalen are the most important industrial region with similar number of employees and sales.

[‖]www.tecnun.es/personal/mtanco/umfrage.asp.

[**]www.tecnun.es/personal/mtanco/encuesta.asp.

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experimentation and data analysis are an integral part of their company's activities. Figure 1 shows that almost 95% of companies carry out experimentation and 51% of which do it frequently. The rate of experimentation by Basque companies is strongly correlated to their size: 100% of large companies conduct experiments (83% frequently), while only 92% of SMEs conduct experiments (40% frequently). Surprisingly, there is almost no difference between the rest of Spain and the B-W region when it comes to frequency of experimentation and company size.

Montgomery[3] suggests that strategies for experimentation can be divided into three main groups: Best guess, one-factor-at-a-time (OFAT) and statistical designed experiments (DoE). The first strategy, sometimes called trial and error, consists in carrying out experiments under conditions where only prior knowledge and intuition are depended upon to predict good results. Figure 2 shows that 44% of companies use this primitive strategy for some of their projects. In addition, almost 75% of companies conduct experimentation using the OFAT strategy, commonly known in business as the 'scientific method'. This strategy consists in modifying one variable at a time, which requires many experiments, but does not precisely estimate the

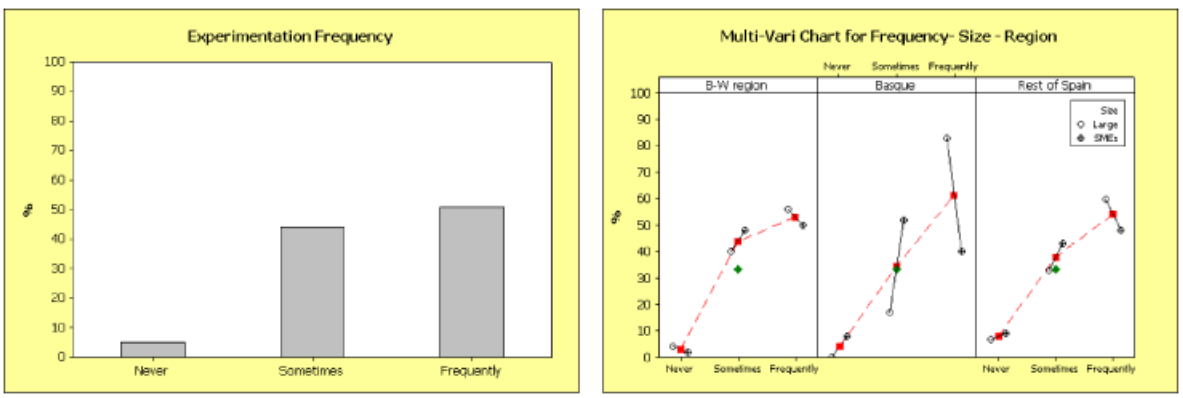

Figure 1. Frequency of experimentation in industries. No. of respondents: 275

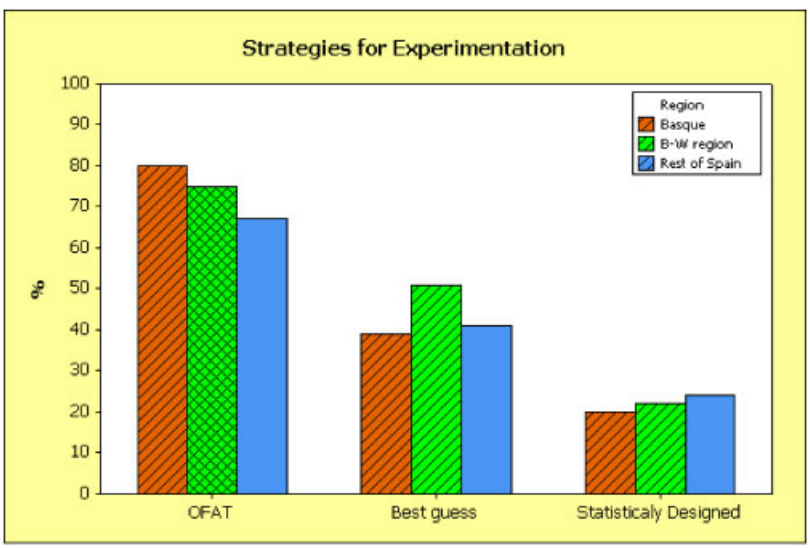

Figure 2. Strategies for experimentation in industries. No. of respondents: 265

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effects or allow the systematic estimation of interactions[13]. Unfortunately, only 23% of companies carry out experimentation with a pre-established statistical methodology. The strategies used by companies are correlated neither to industry nor to county size.

In the questionnaire, companies were asked whether they needed a methodology to carry out their experiments. Results show that 80% of the respondents believed that a methodology is indeed needed. Moreover, large companies have slightly different needs (83%). Surprisingly, those companies that had previously applied DoE reported needing the methodology the most (88%). These results seem to show that existing methodologies are not widely used by companies.

3.2. Knowledge and usage of DoE

Akin to our description in Section 1, we clearly defined DoE in the questionnaire as a broad subject. Next, respondents were asked to describe their knowledge of DoE on a scale of 1(not at all) to 5 (mastery). Responses to this question, as illustrated in Figure 3, show that only 33% of companies claimed to know at least '3-Something' about DoE. Moreover, industry size plays a large part in DoE awareness, since only 24% of SMEs are familiar with DoE: 22% of Basque companies, 20% of B-W companies and 32% in the rest of Spain. On the other hand, almost half of large companies (47%) are familiar with DoE (57% of Basque companies, 36% in the B-W region and 47% in the rest of Spain). Results show that the W-B region is the least knowledgeable when it comes to DoE.

Once the knowledge of DoE was determined, the respondents were asked to rate the extent to which their company used DoE on the following scale: 1 (never), 2 (sometimes) and 3 (frequently). The results shown in Figure 4 illustrate that, on average, only 23% of companies have applied DoE to solve their problems and less than 5% of those apply it frequently. The rates of DoE application presented in the previous papers[5,7,8] do not significantly differ from the results of this survey. However, DoE is still gravely underused.

Again, there is a significant difference in the application rate when it comes to industry size: the application rate for SMEs is 17%, whereas for large companies it is almost 40%. The only significant difference among the countries studied is the frequency of application of DoE in the rest of Spain. About 40% of DoE applicants apply it frequently compared with 15% of Basque companies and 13% of B-W companies.

Recently, a structured initiative for business improvement, known as Six Sigma, gained relevance mainly in quality-control literature. Similar to quality management in general, Six Sigma has penetrated most sectors of today's business world and continues to be one of the most popular philosophies in the business world. A key difference between Six Sigma and other approaches is the integration of a highly disciplined process with one that is both quantitative and data oriented[14]. Experimentation is promoted mainly in the analysis and improvement phases of the well-known five-step DMAIC methodology. By constituting the bulk of these

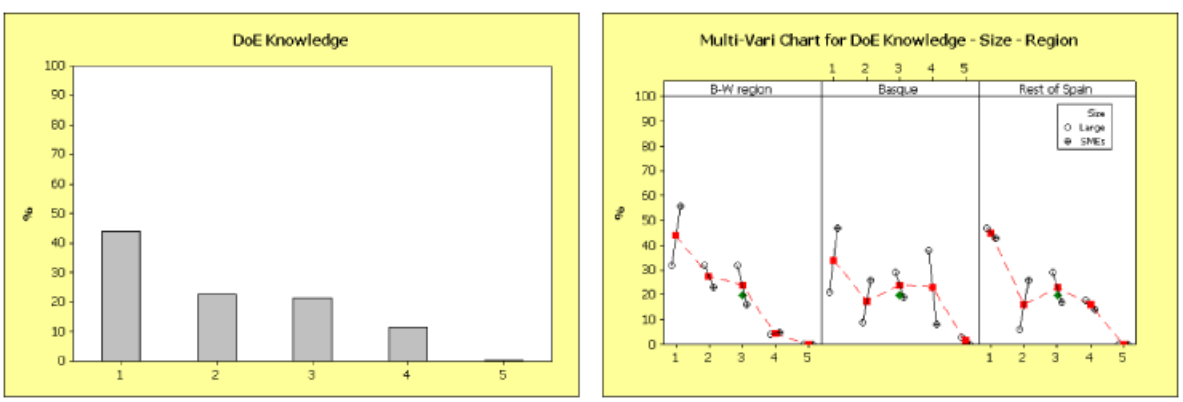

Figure 3. Knowledge of DoE within industries: 1-not at all to 5-mastery. No. of respondents: 277

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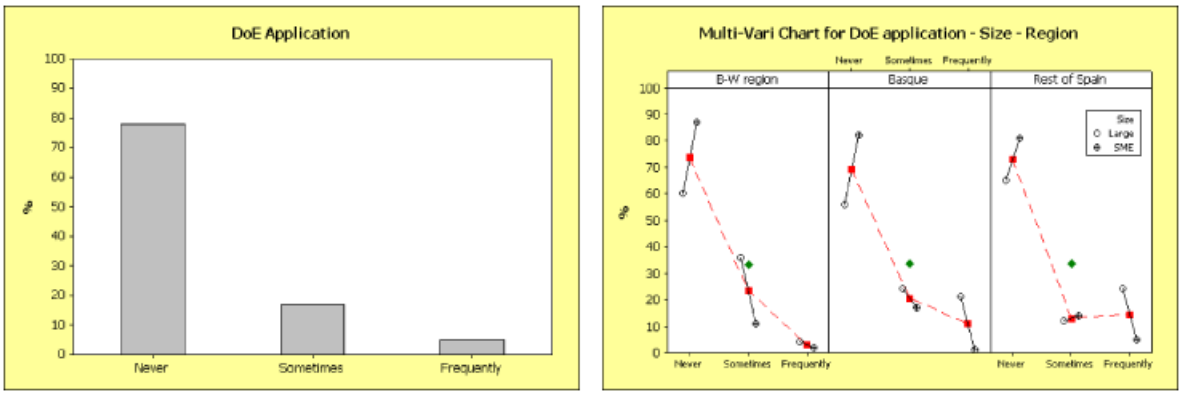

Figure 4. Extent of application of DoE in industries. No. of respondents: 277

important phases, DoE proves itself to be an efficient and critical technique for experimentation. Moreover, an increased emphasis has been placed on DoE in Six Sigma literature during this period[15].

Respondents were asked how often (never, sometimes or frequently) concepts of Six Sigma methodology were applied to their company's projects. Results showed that 22% of companies have recently carried out Six Sigma projects, although only 4% use it frequently. The application of Six Sigma differs significantly from region to region: 30% of Basque companies use it compared with 14% in the Rest of Spain and 22% in the B-W region. The higher results of The Basque Country may be due to the support, funding and training provided by the government for the business sector, especially with regards to the application of new methodologies aiming at company excellence.

Results also showed that Six Sigma practitioners have a greater knowledge of DoE since they state higher values in the knowledge of DoE (1–5) presented previously. This may be probably due to Six Sigma belts training. Moreover, the rate of application among Six Sigma users is 40%††, twice that of non-users, which stands at 19%. Consequently, more than 50% of DoE applications are executed by Six Sigma users.

The questionnaire also included some questions related to TM. Even though they were pioneered in the 50s, these methods became popular among engineers in Europe and the U.S. in the 80s. Although TM have gained proponents in industry, they have also been subjected to considerable critical review[17–19].

In spite of the fact that TM is part of DoE, many bibliographies treat them as separate methods, creating confusion among users[20]. In an effort to gauge the extent of this confusion among respondents, a question regarding TM was included. Survey results show that significant confusion does exist, since 25% (31 responses) of companies familiar with TM rate their knowledge of DoE as 'not at all'.

The results presented in Table II show that, on average, many companies (43%) are familiar with TM. Although it is well-known throughout manufacturing companies, only 7% apply it. This means that 30% of the applicants of DoE have had experience with TM. We have noted that knowledge and application of TM are not correlated to industry size, possibly due to the simplicity of its experimental design methods.

3.3. Characteristics of DoE applications

Next, we have included the analysis of only those questions from Section 3 of the questionnaire, which were directed towards companies having previous DoE experience. Since only 66 companies have applied DoE in all the three regions, results will be shown without stratification of company size.

Firstly, respondents were asked whether they have failed in the application of DoE and then were asked to describe the reason for their failure (various option could be chosen). Table III shows a breakdown of

††Results does not differ from previous results of DoE application among Six Sigma users[16].

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Table II. Knowledge and use of TM. No. of respondents: 278

	N	%	Knowledge (%)	Application (%)
Basque responses: *132*				
Do not have knowledge of TM	68	51	51	93
Have knowledge of TM but do not apply it	55	42	49	
Apply TM	9	7		7
W-B region responses: *69*				
Do not have knowledge of TM	38	55	55	91
Have knowledge of TM but do not apply it	25	36	45	
Apply TM	6	9		9
Rest of Spain responses: *77*				
Do not have knowledge of TM	51	66	66	95
Have knowledge of TM but do not apply it	22	29	34	
Apply TM	4	5		5

Table III. Reasons for failure in the application of DoE. No. of respondents: 65

Failures	% Basque	% W-B	% Rest of Spain	% Average
Mistakes in the pre-experimental stage	30%	40%	38%	36%
Absence of theoretical knowledge	13%	30%	62%	35%
Lack of time and economic resources	17%	20%	31%	23%
Could not identify the reason	30%	20%	15%	22%
Others	22%	20%	15%	19%

these failures. 'Mistakes in the pre-experimental stage' (36%) and 'Absence of theoretical knowledge' (35%) were the most significant ones. This comprised 71% of the failures, echoing the lack of knowledge of DoE shown in Section 2.2. The high failure rate in the rest of Spain, caused due to the absence of theoretical knowledge of DoE, is surprising. Although DoE is presented in books and journals as an effective tool for experimentation, results indicate that only 30% of companies have not failed in it.

All types of industries and areas of a company, including services, can benefit from applying DoE. However, surveys show that Research and Development (R+D) and the supply chain make up 93% of DoE applications: 59 and 34%, respectively. Only five companies applied DoE to other areas such as marketing, sales and distribution.

About 41% of companies were assisted by consultants, R+D centers or universities in their DoE endeavors. Regrettably, 44% of those companies report failing to reach their expectations even with assistance. Moreover, 53% of companies are supported by statistics software, which help them with experiment design and analysis.

4. CONCLUSIONS AND FUTURE RESEARCH

The characteristics of experimentation of three different European regions were analyzed in this paper. Besides the existing cultural differences throughout quality-control management[21], the characteristics of experimentation in these regions are similar in the level of experimentation usage and in the number of companies that apply DoE.

Summarizing the survey results, we can conclude that although experimentation is frequently used, the generally inefficient OFAT strategy is the most common one used to carry out experiments. Most respondents are also unfamiliar with DoE, which hinders its application. Results also show that Six Sigma practitioners

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have a higher rate of applications of DoE, almost twice that of non-users. Furthermore, confusion exists about TM, since many people do not consider them as part of DoE.

Our survey confirms that a wide gap exists between DoE and industry. Different alternatives must be analyzed in order to eliminate the biggest challenge when it comes to applying DoE: the lack of DoE awareness. This may be due to the fact that DoE is poorly taught to engineers in universities[22–24] (sometimes not even taught[1]). Engineers frequently avoid statistics courses because of the theoretical way in which they are taught[24]. Therefore, the promotion of DoE must be a priority to bridge that existing gap.

There is a real need to elaborate an experimental design methodology to develop the information necessary for good planning, design and analysis. Our survey shows that 80% of the respondents believed that a methodology is truly needed. Therefore, unless DoE is developed into easily understood strategies for solving specific problems and made widely available through teaching material and software packages, we cannot expect it to be widely used.

There are some promising areas for future research. Firstly, the study of the barriers that hinder the application of DoE would be worthwhile. Furthermore, analyzing the reasons why industries use primitive strategies for experimentation could be useful to identify pitfalls and limitations. Finally, the causes of failures in DoE application or the economical impact of successful application could also be further analyzed.

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Martin Tanco is an assistant professor at the Engineering School of the University of Navarra. He received his PhD in Industrial Engineering from the University of Navarra. He holds an Industrial Engineering degree from the University of Montevideo and is now working on statistical methodologies for applying DoE to industry. He has authored several publications in Design of Experiments and in Quality Management.

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Laura Ilzarbe was lecturer in Quality Management at TECNUN (University of Navarra). She studied industrial engineering at the University of Navarra and she holds a PhD degree in the Chair of Quality Management from the Technical University of Berlin. Her research interests include quality management, customer satisfaction and design of experiments. She is now the Quality Manager of Transabadell.

María Jesús Álvarez holds a PhD degree in Agricultural Engineering from the UMP (Technical University of Madrid). She is a lecturer in Operational Research at TECNUN (University of Navarra) in the Management Industrial Engineering Department. Her research activities are in Operations Research applied to logistics and to the improvement of the productivity of systems.

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