CONCURRENT ENGINEERING:
THE MODERATING EFFECT OF UNCERTAINTY ON NEW PRODUCT DEVELOPMENT SUCCESS

Daniel Vázquez-Bustelo
Sandra Valle

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AUTHORS

Daniel Vázquez-Bustelo[*]
Universidad de Oviedo
Facultad de Ciencias Económicas y Empresariales
Avda. del Cristo s/n, 33071 Oviedo- SPAIN
Phone number: + 34 985106216
e-mail: dvazquez@uniovi.es
Fax: +34 985103708

Sandra Valle
Universidad de Oviedo
Facultad de Ciencias Económicas y Empresariales
Avda. del Cristo s/n, 33071 Oviedo- SPAIN
Phone number: +34 985103697
e-mail: svalle@uniovi.es
Fax: +34 985103708

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[*] Corresponding author

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ABSTRACT

This work analyses, using linear regression, the link between concurrent engineering and success in the new product development (NPD) process under varying uncertainty conditions. The results indicate that, in environments of low or moderate uncertainty, overlapping of activities, inter-functional integration and teamwork positively affect the NPD performance in terms of development time, quality and success in launching new products. Conversely, such effects are not seen in conditions of high uncertainty. Therefore, the conclusion is that the use of concurrent engineering must depend on the context or specific conditions in which the innovative process of the company is managed.

KEYWORDS: *Product development; concurrent engineering; uncertainty*

1. INTRODUCTION

In order to increase effectiveness in new product development (NPD) –shorter time and development costs and superior products–, firms have reorganised their innovative processes and they have come forward from a sequential approach to an integrated one, described as concurrent engineering.

Since its first applications, this new organisational design sparked off important improvements in the performance of new products, such as cost reduction, better quality, knowledge creation and development time shortages (Rosenblatt and Watson, 1991; Shenas and Derakshan, 1992; Lawson and Karandikar, 1994; Prasad, 1996; Brookes and Backhouse, 1998; Pawar and Haque, 1998; Barba, 2001; Umemoto *et al.*, 2004). However, in reality, empirical evidence show that the use of this methodology does not always achieve those benefits. In other words, employing concurrent engineering does not always produce positive results, and it is argued that its success in improving innovation capabilities depends on the context in which it is applied, on the level of competitive and technological uncertainty.

This fact has led researchers to be focused on identifying which is the most suitable context for concurrent enginerring to be effective. However, it has been observed that a consensus in this topic does not exist, mainly due to the different results achieved. So, it can be concluded that there is actually a lack of unanimity about which circumstances concurrent engineering is suited to and thereby lead to greater success in the NPD process.

Consequently, the main aim of this study is to shed some light on the conditions in which a company should opt for a concurrent approach. To do this, the impact of this methodology on the NPD process results is analysed in a large sample of Spanish manufacturers, distinguishing different scenarios as a function of the level of uncertainty in which the process is being managed.

With this in mind, the work is structured in the following way. First, a review of the literature on concurrent engineering is done. Second, the empirical contradictions on the results of applying this methodology are described and the work hypotheses are formulated. Third, the research methodology is set out. Fourth, the statistical analyses which have been carried out and the results obtained are presented. Finally, the conclusions of the work and the main implications for the company's management are given.

2. THEORETICAL FRAMEWORK

Definition of concurrent engineering

One of the widest known definitions of concurrent engineering is the one given by the American Institute for Defense Analysis, which considers this methodology as "a systematic approach to the integrated, concurrent design of products and related processes, including manufacturing and support. This approach is intended to cause the developers to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements" (Winner *et al*., 1988: 2).

Therefore, concurrent engineering can be seen as "integrated problem solving" (Wheelwright and Clark, 1992), where all activities necessary for the introduction of a new product are considered simultaneously (Shenas and Derakhshan, 1992). This is done in such a way that all factors and questions "downstream" of product development are incorporated into the "upstream" phase of the development (Lee, 1992).

Concurrent engineering versus sequential engineering

Concurrent engineering emerged as opposition to the method followed traditionally by innovative companies, “over the wall”, in which progress moves along a structured process with clearly defined sequential phases, through which the product is defined, designed, transferred to the factory and then to the market (Iansiti, 1995). Each one of these activities only starts when the one before has completely finished, which results in an increase of time and cost (Takeuchi and Nonaka, 1986; Cordero, 1991). In this sequential process there is a lack of integration of the functional areas involved in the process. Each function carries out its work in isolation with minimum reference to the needs of others and without reflecting on or practising the all-important interrelation and co-ordination between different functional contributors. All this translates into continuous retracing of steps in each of the different phases of the project to correct the mistakes made, thereby resulting in very long development times. Each one of these iterations also adds cost to the design process. Similarly, many quality problems arise, basically owing to a lack of communication and understanding between product design, production and the needs of the consumers.

The integrated approach to product development, on which concurrent engineering is based, where all those involved work in parallel and establish suitable connections between the activities of different departments[1], has the exact aim of preventing these problems and improving, therefore, the performance of the NPD process compared to a traditional sequential focus. The objectives are to speed up the process, increase flexibility, adopt a more strategic perspective with more sensitivity to change in the

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[1] Using a sports metaphor, Takeuchi and Nonaka (1986) called the traditional system the “relay approach”, because each phase of the development process is clearly separated and the baton is passed from one group to another. Likewise, these authors called concurrent engineering the “rugby approach”, in which the overlap extends across several phases and team members “run together, pass the ball left and right, and reach the goal as a united body” (Nonaka and Takeuchi, 1995).

environment, oriented at solving problems as a group, developing diverse skills and improving internal communication (Barba, 2001).

The basic elements of concurrent engineering

To achieve all of the objectives, concurrent engineering is founded on three basic elements (Koufteros *et al.*, 2001): (1) concurrent work-flow, thas is to say, the simultaneous realisation of different product development activities which until now have been developed sequentially, (2) early involvement of all participants and groups contributing to product development and (3) team work. In other words, concurrent engineering is the early involvement of a cross-functional team to simultaneously plan product, process and manufacturing activities (Hartley, 1992).

The first basic element stimulates parallel development, total or partial, of those activities that form part of the NPD process. In this way, for example, product and process engineering is managed simultaneously or product planning starts to take place long before the design study is finalised. This does not reduce the duration of each activity, but it does decrease the overall development time (De Meyer and Hooland, 1990). Additionally, this time is also reduced because joint planning of activities means a reduction in redesign and rework. In the same way, there is more chances for smoother production, thus helping to minimise cost and improve quality[2].

The second basic element, early involvement of constituents, means that the different interested groups express their opinions and provide their information inputs right from

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[2] Handfield (1994), for example, observed that products to which concurrent engineering was applied were developed in approximately 60% of the development time required for products developed sequentially. For their part, Bopana and Chon-Huat (1997) quote, as a consequence of the application of concurrent engineering, reductions of between 30% and 60% in development times, of up to nearly 50% in lifecycle costs and between 55% and 95% in engineering requests.

the start of the process. Therefore, a favourable atmosphere for frequent bilateral exchanges of information between the parties is created, so that activities which traditionally occur much later in the product development process benefit from information generated in much earlier activities (Yassine *et al*., 1999). For example, matters referring to fabrication can already be evaluated and incorporated into the final product design, meaning a reduction in uncertainty and the early detection of problems, which will avoid expensive delays later on (Susman and Dean, 1992).

In short, early involvement reduces imbalances or errors between the product characteristics and the capabilities of the process, minimising the probability of problems related to product manufacturability or a failure to adapt to the needs of the client.

Finally, teamwork is established as the other basic element of concurrent engineering. To this end, the participants in the development process are not only involved from the start of the project, openly interacting and exchanging information, as indicated above, but furthermore, they must work closely together, strengthening one another in working towards common goals. In other words, one of the most important characteristics of concurrent engineering is the use of multifunctional teams in which different disciplines can co-ordinate their problem solving efforts to improve product innovation and quality.

Concurrent engineering thus demands a process characterised by a high level of reciprocal interdependence, where functions interact with mutual feedback and share basic principals including common goals, total visibility of the design parameters by all participants, mutual consideration of all decisions, working together to resolve conflicts, continuous improvement and teamwork (Hauptman and Hirji, 1999).

The creation of these multifunctional teams should not be limited to include only the specific functional areas which contribute to product development, but also to cover the participation of agents external to the company. In fact, concurrent engineering is an antecedent, and perhaps a determinant, of a firm´s customer and supplier involvement practices (Koufteros *et al*., 2001). The manufacturing company must work directly and openly with its component or sub-system suppliers, involving them in product design and process planning (Eversheim *et al*., 1997; Hartley *et al*., 1997; Fine *et al*., 2005). Similarly, the inclusion of consumers in the team from the start is crucial for rapid convergence of product specifications and design with consumer needs and expectations (Carter and Barker, 1991; Landeghem, 2000; Pillai *et al*., 2002).

3. EMPIRICAL CONTRADICTIONS AND FORMULATION OF HYPOTHESES

It seems clear, that from the very beginning, concurrent engineering has solved many of the problems derived from traditional product development. In fact, numerous studies back this up. On the one hand, there are those that show that strongly iterative parallel development leads to shorter development times (Takeuchi and Nonaka, 1986; Kusiak and Park, 1990; Clark and Fujimoto, 1991; Millson *et al*., 1992; Wheelwright and Clark, 1992; Karagozoglu and Brown, 1993; Blackburn *et al*., 1996; Calantone and DiBenedetto, 2000). On the other hand, some show that it also leads to reduced development costs (Durand, 1995; Herder and Weijnen, 2000; Barba, 2001).

However, a review of the literature also shows works demonstrating the exact opposite. Thus, for example, in relation to cost, authors such as Takeuchi and Nonaka (1986), Uttal (1987), Aitsahlia *et al*. (1995) and Yassine *et al*. (1999) observe that the application of concurrent engineering brings with it a substantial increase in cost, if compared to sequential development.

In relation to development time, work such as that of Cordero (1991) considers that, although it has been substantially and consistently demonstrated that concurrence may dramatically reduce product development time, there is no evidence that more concurrence is always better. Although it is certain that to accelerate the time to market a degree of overlapping is preferable to sequential development (Krishnan *et al*., 1997), there is a point at which concurrence has limitations (Hoedemaker *et al*., 1999) and an increase in parallelism could be undesirable (Haberle *et al*., 2000).

Datar *et al*. (1997) and Thomke and Fujimoto (2000) also bring to light conflicting findings on upstream planning, a type of functional interaction in which upstream participants anticipate design problems *versus* waiting until the problems appear downstream. Anticipating problems inadvertently causes chaos, and waiting until problems appear leads to design versions. Upstream planning has been found to significantly decrease (Cooper and Kleinschmidt, 1994; Hull *et al*., 1996), significantly increase (Eisenhardt and Tabrizi, 1995) and to have no effect on development time and effort (Datar *et al*., 1997).

In view of all these contradictions, an intense debate has arisen about whether concurrent engineering always produces positive results or whether, depending on the circumstances, it may be inferior to other approaches, including the traditional sequential one. For this reason, some of the research cited, and other, also recent research, directs efforts at trying to answer this question and being able to determine which are the circumstances or situations most suited to the effective application of concurrent engineering. To this end, they distinguish between incremental and radical innovations or, more generically, between environments of high or low complexity and uncertainty[3]. However, with respect to this, there are also many empirical contradictions.

Some authors consider that when companies develop projects characterised by a high level of uncertainty and complexity, i.e. break-off or radical projects, advanced approaches of concurrent engineering are necessary, while for companies developing relatively simple products it is improbable that this methodology provides a viable solution (Shenas and Derakhshan, 1994; Schilling and Hill, 1998; Wheelwright and Clark, 2000). Along the same line, Koufteros *et al.* (2001) show that companies adopt high levels of concurrent engineering when they are faced with highly changing environments, where uncertainty and ambiguity are inherent. These authors believe that, in this type of environment, the concurrent engineering practices allow a better flow of information and facilitate a wider range of solutions, at the same time as reducing ambiguity. Integrated action would reduce uncertainty of information, false starts and design rework (Ettlie, 1997).

However, other authors suggest the opposite and believe that while concurrent engineering can be appropriate for incremental innovations, it is not that suitable for radical ones (Takeuchi and Nonaka, 1986[4]; Handfield, 1994). Furthermore, they believe that when a company is faced with a break-off project that introduces new radical technology, the utilisation of concurrent engineering practices can induce a series of hidden costs which make its use inappropriate. The costs of reducing development time can include an increased probability of committing errors, chaos for the management and unexpected inefficiencies that lead to longer development and delivery times.

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[3] Sutcliffe and Zaheer (1998) cite a group of studies, which have shown that the uncertainty perceived from the environment has a considerable influence on the organisational structure and processes.

[4] These authors also believe that it is possible that concurrent engineering is not applicable to very large scale projects, whose dimensions themselves limit the possibilities for maintaining wide personal contact

(Crawford, 1992; Gaynor, 1993). The concurrent way seems more appropriate for moderate levels of innovation, as is the case with incremental NPD projects (Cordero, 1991; Millson *et al.* 1992), and routine designs where the process characteristics are not critical and fairly insensible to design changes (Cantamessa and Villa, 2000). Hoedemaker *et al.* (1999) also argue that the higher the complexity of the project the higher the limits of concurrent engineering. Therefore, this wave of studies, the most supported, recommends restricting the use of concurrent engineering to environments with low uncertainty. Their results prove that an understanding of the development process through concurrence of activities requires a situation with limited uncertainty, where changes are predictable and can be kept under control. In other words, overlapping can cause substantial reprocessing which would have more weight than the time saved by concurrent engineering (Eisenhardt and Tabrizi, 1995; Ha and Porteus, 1995; Iansiti, 1995; Krishnan *et al.*, 1997; Loch and Terwiesch, 1998; Hoedemaker *et al.*, 1999; Terwiesch and Loch, 1999; Bhuiyan *et al.*, 2004).

In summary, the only clear point is that the effectiveness of concurrent engineering depends on the circumstances in which it is applied and that it is not a valid and viable methodology in every context and possible situation. Taking this fact into account, and following the most supported trend, the following hypotheses have been formulated:

General proposition: Concurrent engineering does not produce positive results in every circumstance or context.

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and can be impractical, similarly, when the product development is conceived and managed personally by an expert who, after creating the invention, imparts a set of precise instructions to his subordinates.

Hipothesis 1: C*oncurrent engineering will lead to reductions in product development times if applied in conditions of moderate or low uncertainty, but not if applied in conditions of high uncertainty.*

Hipothesis 2*: Concurrent engineering leads to superior products if applied in conditions of moderate or low uncertainty, but not if applied in conditions of high uncertainty.*

Hipothesis 3: *Concurrent engineering leads to more success in the launch of new products if applied in conditions of moderate or low uncertainty, but not if applied in conditions of high uncertainty.*

4. RESEARCH METHODOLOGY

Research design and sample characteristics

The information necessary to test the hypotheses above proceeds from a wider study aimed at analysing the main manufacturing policies in Spain. In fact, the data used have been obtained through mail survey aimed at a total of 1234 manufacturers that in 2003 (study reference date), in agreement with the SABI database, were located in Spain and employed more than 100 workers[5]. All of them belong to industrial sectors with SIC codes 25, 28 and 34 to 37, selected for this study for being considered the key segments in the majority of research on themes similar to those treated here (Koufteros *et al.*, 2001, 2002).

The questionnaire used was designed taking as a reference the existing literature and the conclusions of a previous case study. Prior to mailing, the questionnaire was reviewed

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[5] The selection of companies with more that 100 workers was based on criteria similar to those followed in the Encuesta sobre Estrategias Empresariales (ESEE), and is frequently used in previous studies on concurrent engineering (see, for example, Koufteros *et al.*, 2001, 2002).

both by experts in operations management and surveying. Similarly, in order to test its validity and improve its design (facilitate readability, reorder questions, reduce size and eliminate ambiguous questions), a pretest was done on a reduced sample of companies. After making prior telephone contacts, the questionnaires were mailed (performed in phases between November 2003 and July 2004), accompanied by a cover letter in which the objective of the study was indicated and the sending out of the results once obtained was guaranteed.

In total, 286 questionnaires were received, although it was necessary to eliminate three of these because they were not completed suitably or because they contained clearly contradictory responses. So, after review and analysis of the received results, a total of 283 valid questionnaires were obtained, which represented a valid response rate of 22.93% and a sample error of +/-5.21%, for a level of confidence of 95%. This response rate was satisfactory taking into account the scope and extent of the survey carried out, which contained a large number of sections and questions to measure contextual variables, production practices, NPD practices, organisational practices, objectives and competitive capabilities, results or performance measurements and classification variables.

Table 1 summarises the distribution, by sector and size, of the sample of companies studied. Furthermore, in order to evaluate the existence of possible bias in the results, a Chi-squared test was carried out of the differences between the frequencies observed (sample) and expected (population) with respect to the industrial sector and the firm size. This test shows that the distribution of companies in the sample reflects, to a large extent, the distribution of companies in the population according to industry[6]. Similarly, the results obtained show that there are no significant differences between the sample and the population with respect to the distribution of companies by size (Chi-squared=9.154, *p*>0.0573).

Table 1. Distribution of the sample by sector and size

Industrial Sector (According to SIC)	Percentage of companies
SIC-25: Furniture and fixtures	7.64%
SIC-28: Chemicals and allied products	11.64%
SIC-34: Fabricated metal products	32.73%
SIC-35: Industrial and commercial machinery and computer equipment	0.73%
SIC-36: Electrical equipment and components	23.63%
SIC-37: Transportation equipment	20.37%
SIC-38: Measurement, analysing, control instruments and related products	3.26%
Company size by number of employees	**Percentage of companies**
Between 100 y 499 employees	78.9%
Between 500 y 999 employees	10.9%
Between 1000 y 1499 employees	2.55%
Between 1500 y 1999 employees	2.18%
2000 or more employees	5.45%

Consequently, it can be considered that the sample analysed is reasonably representative of the target population as far as size and activity sector is concerned. In other words, the results can be generalised in the field of analysis considered, confirming, therefore, the external validity of the study.

On the other hand, internal validity demands that the information requested be obtained from the most suitable source to provide it. Therefore, before sending out the questionnaire the most suitable person for filling it out was identified through a telephone call. The respondents were mainly the production manager (39.9%), the

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[6] Excluding the electrical equipment and components industry (SIC 36), whose participation in relative terms was

factory manager (20.5%) and the operations manager (14.5%). Furthermore, it was observed that, on average, these people had been working for more than thirteen years in the company and more than six with their current responsibility. Given that the majority of respondents belongs to small size companies and taking into account the selection process, it is reasonable to assume that the people who had participated in the study had adequate information about the NPD implemented in their organisations.

Development of scales and measurement of variables

The scales and variables used in the study were developed on the basis of existing theory, the literature review, the carrying out of previous case studies and the realisation of a formal pretest both with managers and experts on the subject. To measure uncertainty in the environment and concurrent engineering multi-item scales were used. The measurement of each result variable was done on the basis of a single item.

Environment Uncertainty. Researchers have defined the environment as a set of external, contextual elements outside direct control –at least for the short term– which represent a source of opportunities and threats (Bourgeois, 1980) and which are related to the results obtained by the organisation (Duncan, 1972; Swamidass and Newell, 1987; Ward *et al.,* 1995).

Generally, research on the environment has identified the existence of various dimensions among which uncertainty stands out. This dimension has traditionally been highlighted in literature on organisations because of its effect on structure, on strategy or on both (Duncan, 1972).

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higher than expected, a suitable value was obtained in the Chi-squared test ($p>0.063$).

In spite of the many definitions the term can adopt, generally uncertainty has been linked with a level of external dynamism (Duncan, 1972) and it materialises in the absence of an ability to adequately predict the future state of the environment. The dynamism reflects the level of instability in the environment and refers to the existence of unpredictable changes in the conditions affecting the company (Dess and Beard, 1984). Similarly, the stability dimension affects the organisation through the intermediary variable of work predictability (Minztberg, 1979). In other words, a dynamic environment means an organisation is working in a climate of uncertainty or unpredictability. For this reason, dynamism and uncertainty have frequently been considered together in the literature.

In this study, the uncertainty variable has been approximated from the measurement of the level of dynamism in the environment, taking as a reference the works of Miller (1987), Ward and Duray (2000) and Badri *et al*. (2000). For this, a five point scale has been used to measure: (a) the speed of change in the tastes and preferences of the consumers, (b) the frequency of innovation in processes, and (c) the frequency of innovation in products.

Concurrent Engineering. In order to measure concurrent engineering practices, the scale proposed by Koufteros *et al*. (2002) has been synthesised into four items related to its basic elements: (1) the parallel and not sequential development of new products, (2) the early involvement of all the participants in the NPD process and (3) the use of multifunctional teams. To this end, the respondents were asked to indicate, on a five point scale, their level of agreement with the following statements: a) product designs and production processes are developed simultaneously by a group of employees b) various departments or functions (R+D, production, marketing...) are involved from the beginning in the NPD, c) NPD teams are made up of members of different departments or functions and d) the NPD team members work closely together throughout the whole process.

Success of the NPD Process. To measure the performance achieved by using concurrent engineering, measurements of perception on the level of result achieved were used with respect to new product development times, the superiority of the products (measured in terms of functionality and features) and the success of the launch. In every case a five point scale was used.

Dimensionality, reliability and validity

In order to guarantee the suitability of the scales used to measure environmental uncertainty and concurrent engineering an evaluation of their psychometric properties (dimensionality, reliability and validity) was carried out. To study the dimensionality, i.e., whether or not there exists a single factor underlying the set of variables that constitute the scale, exploratory factorial analyses were made first (of main components with Varimax rotation). The results showed in all cases a factorial loading (weight of each variable observed in the factor) over 0.5 and an accumulated explained variance percentage equal to or over 50%. Once the exploratory factorial analyses had been carried out it was followed by confirmatory factorial analyses using structural equations. Robust maximum likelihood was used as an estimation method, as this enabled the problems of non-normality of data to be overcome. The results of these analyses confirmed the dimensions and composition of the scales identified in the previous exploratory factorial analyses.

In order to analyse reliability the calculation of the Cronbach´s alpha coefficient, the Composite Reliability Index and the Average Variance Extracted coefficient (AVE) were used (Table 2). These indexes reflect the degree of internal consistency of the observed variables, i.e., their capacity to represent the common latent variable. The Cronbach`s alpha coefficients obtained for environment uncertainty (0.722) and concurrent engineering (0.905) are over the value of 0.7 recommended by Hair *et al.* (1999). In both cases the composite reliability index was over the minimum level of 0.6 recommended by Bagozzi and Yi (1988) and the Average Variance Extracted coefficient (AVE) over 0.5.

Table 2: First order confirmatory model

Factor	Item	Standardized lambda parameters (t–value)	Reliability			Discriminant validity	
			Cronbach´s Alpha	**Composite Reliability Index**	**AVE**	**Factors**	**Correlation**
Dynamism (F1)	Environ1 Environ2 Environ3	0.493 (7.653) 0.642 (9.712) 0.956 (14.555)	0.722	0.753	0.523	F1–F2	(0.132 – 0.396)
Concurrent Engineering (F2)	ConEng1 ConEng2 ConEng3 ConEng4	0.706 (14.323) 0.823 (16.166) 0.928 (24.996) 0.895 (19.009)	0.905	0.906	0.709		

Goodness of Fit (Robust Solution)

S–B χ^2(13)= 22.5746	**BBNFI**	**BBNNFI**	**CFI**	**IFI**	**MFI**	**RMSEA**
(p< 0.047)	0.975	0.982	0.989	0.989	0.983	0.051

Having studied the dimensionality and tested the reliability, the content, convergent and discriminant validity of the measurement scales were analysed. The content validity determines whether the items contained in the scale are suitable for the concept to be measured. Given that each scale was constructed taking the previous literature as a reference, it incorporates items used in other scales already validated for the measurement of similar concepts and evaluated through a case study and the questionnaire pretest, it is considered that each dimension effectively possesses content validity. The convergent validity measures the degree to which the different scales used to measure a latent factor are correlated. To test the convergent validity the lambda parameters that measure the relation between the observed and the latent variable have been analysed. All the coefficients are statistically significant at least at the confidence level of 95% ($t > 1.96$, weak condition) and are very close to or over the value of 0.5 (strong condition). The discriminant validity measures the degree in which the specified latent factors are different although they are correlated (Hair *et al.*, 1999). In order to check the discriminant validity the confidence interval of the correlation between the scales were calculated. Based on this, the discriminant validity of the scales can be confirmed as the confidence interval of the correlation does not contain the value 1 at the 95% confidence level.

5. ANALYSIS AND RESULTS

With the aim of testing each one of the proposed hypotheses an analysis using linear regression was carried out. In fact, a regression model was tested for each one of the relations included in the hypotheses, considering, in each case, concurrent engineering as an independent or explanatory variable. Prior to carrying out these simple regressions, the companies which make up the sample were classified into three large groups, giving rise to three sub-samples with the same level of uncertainty in the environment: low, medium or high. For this an index of uncertainty was created, as an arithmetic average of the value reached by the three items used to measure the said characteristic. Taking as a reference the average value (χ) and the typical deviation ($S\chi$) of the index created, the sample was divided into three groups: (1) of low uncertainty –97 cases with values in the range $[0, \chi - 0.5S\chi]$–, (2) of medium uncertainty –105 cases with values between [χ- 0.5Sχ, χ+ 0.5Sχ]– and (3) of high uncertainty –81 cases with values in the range [χ+ 0.5Sχ, 5]–, as shown in Figure 1.

Once the sample is divided into sub-samples, the same simple regressions are applied to each sub-sample, whose results are given in Table 3.

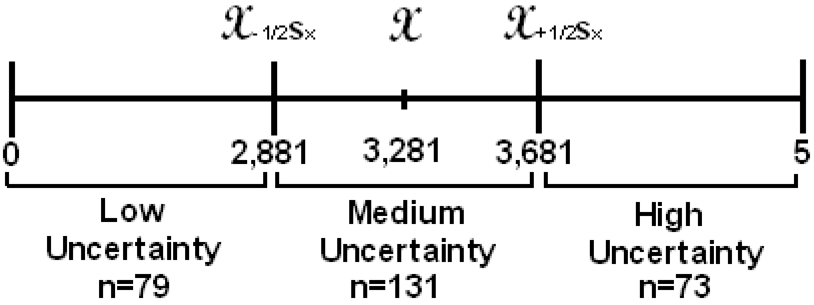

Figure 1. Criteria and segmentation results of the sample

Firstly, the results show that concurrent engineering has a positive and significant influence in the reduction of development time for the products in the sub-samples of companies subjected to medium and low levels of uncertainty. These relations are statistically significant at p=0.002 and p=0.005, respectively. As opposed to the previous result, for the companies included in the sample with high uncertainty a significant relation between the variables studied for a confidence level of 95 % (p<0.05) has not been observed. Taking these results into account, the first hypotheses of this research can be accepted.

Secondly, the results obtained in the statistical analysis show the positive and significant effect of concurrent engineering on the obtaining of superior products (better functionality and features) in conditions of medium and low uncertainty. In this context, significant statistical relations are observed at 95% (p=0.004 and p=0.000) between the considered variables. However, this relation has not been observed for the set of companies that are faced with environments of high uncertainty. Consequently the second hypothesis of the research can be accepted.

Table 3: Results of regressions for the different sub-samples

	Low uncertainty				Medium uncertainty				High uncertainty			
VARIABLES	**Value**	**Beta**	**t-value**	**Signif.**	**Value**	**Beta**	**t-value**	**Signif.**	**Value**	**Beta**	**t-value**	**Signif.**
Dependent Variable: **Development time**												
Concurrent engineering	0.208	0.312	2.883	0.005	0.255	0.272	3.205	0.002	-0.007	-0.007	-0.061	0.952
	(.087)				(.079)				(.114)			
Constant	2.312				2.730				3.971			
	(.291)				(.282)				(.436)			
R^2	0.097				0.074				0.000			
R^2 corrected	0.086				0.067				-0.014			
Statistic F	8.310				10.27				0.004			
Probability of F	0.005				0.002				0.952			
N	79				131				73			
Dependent Variable: **Superior product**												
Concurrent engineering	0.258	0.318	2.943	0.004	0.261	0.332	3.994	0.000	0.057	0.056	0.471	0.639
	(.088)				(.065)				(.120)			
Constant	2.699				2.946				3.762			
	(.292)				(.232)				(.460)			
R^2	0.101				0.110				0.003			
R^2 corrected	0.089				0.103				-0.011			
Statistic F	8.662				15.95				0.222			
Probability of F	0.004				0.000				0.639			
N	79				131				73			
Dependent Variable: **Success in launching new products**												
Concurrent engineering	0.224	0.351	2.291	0.002	0.265	0.357	4.339	0.000	0.164	0.161	1.372	0.174
	(.068)				(.061)				(.120)			
Constant	2.652				2.635				3.171			
	(.227)				(.217)				(.457)			
R^2	0.123				0.127				0.026			
R^2 corrected	0.112				0.121				0.012			
Statistic F	10.83				18.82				1.883			
Probability of F	0.002				0.000				0.174			
N	79				131				73			

Thirdly, the relation between concurrent engineering and success in launching new products presents characteristics similar to those obtained for the relations above. In this way, these results can also support the third hypothesis considered. As can be seen in Table 3, concurrent engineering has a positive and significant effect on the success of launching new products for those companies which operate in conditions of low (*p*=0.002) or moderate (*p*=0.001) uncertainty, but not those companies making up the sub-sample of high uncertainty.

The joint evaluation of all of these results allows, in addition to the validation of the three suggested hypotheses, support of the general proposition introduced as a starting point. In other words, the results support the argument that concurrent engineering does not produce positive results under all circunstances and contexts, making it clear, that the level of uncertainty in the environment in which the NPD takes place is a fundamental moderator variable of the result achieved with this methodology.

6. CONCLUSIONS AND MANAGEMENT IMPLICATIONS

This work investigates the relation existing between the use of concurrent engineering and the success of NPD processes under varying conditions of uncertainty, with the aim of helping to identify which are the most suitable circumstances for effective application of this methodology.

The results obtained show that companies which adopt concurrent engineering practices in conditions of low or moderate uncertainty achieve reductions in the development times of their products, along with superior product quality and, in general, more success in launching new products. Adversely, companies that adopt this methodology in conditions of high uncertainty do not obtain positive results on any of the success indicators of NPD considered. These results are in line with the most supported current wave of studies on this and reinforce the idea that concurrent engineering has serious limitations in conditions of extreme uncertainty.

In accordance with the arguments sustained in this wave of research, it appears that, in situations of this type, where changes are neither predictable nor can be kept under control, concurrence can generate large problems of communication, integration and rework. These inevitably lead to considerable reprocessing, to a greater probability of errors, to chaos in management and, in short, to inefficiency, which ends up converting the positive results derived from concurrent engineering into negative results or penalties, rendering its use inappropriate.

All of these results have an immediate implication for the management of innovative companies: concurrent engineering is not a "recipe" for success. In fact, environments of high uncertainty discourage its implementation. Therefore, management must exercise caution when applying concurrent engineering and not make the common mistake of believing that more concurrence is always better.

In conclusion, this research suggests that adopting concurrent engineering practices *a priori* can be very risky. Companies must first analyse the characteristics of the environment in which they manage their innovative process, and then select the most appropriate method. Specifically, under conditions of low or moderate uncertainty, adopting the concurrent approach appears to be the most suitable, however if companies are faced with high levels of uncertainty, they should consider the possibility of opting for alternative ways without forgetting, even, the traditional sequential way.

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