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Ensaios sobre Flexibilidade da Cadeia de Abastecimento

Uma abordagem de opções reais

Essays on Supply Chain’s Flexibility

A real options approach

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Doutor em Gestão Industrial, realizada sob a orientação científica do Professor Doutor Joaquim José Borges Gouveia, Professor Catedrático do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro e sob a co-orientação do Professor Doutor Joaquim Carlos da Costa Pinho, Professor Auxiliar do Departamento de Economia, Gestão e Engenharia Industrial da Universidade de Aveiro.

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palavras-chave

Incerteza da procura, flexibilidade da cadeia de abastecimento, opções reais, desempenho da cadeia de abastecimento, cadeia de abastecimento multi-estádios, inventários, estratégia de oferta de produto, decisões de investimento, gestão de turnos, integração vertical, planos de negócio flexíveis.

resumo

A presente tese investiga o processo de tomada de decisão na gestão de cadeias de abastecimento, utilizando um quadro de análise de opções reais. Especificamente, estudamos tópicos como o nível de inventário ideal para protecção contra a incerteza da procura, o momento para implementação de capacidade flexível em mercados onde existe complexidade no mix de produtos, o tempo para o reforço do factor trabalho visando requisitos de serviço ao mercado, e as decisões entre integração e outsourcing num ambiente de incerteza. Foram usadas metodologias de tempo discreto e contínuo para identificar o valor ideal e o calendário das opções a adoptar, quando a procura é estocástica. Além disso, foram considerados os efeitos dos requisitos dos mercados, como a complexidade na oferta de produtos e o nível de serviço. A procura é representada recorrendo a diferentes processos estocásticos, o impacto de saltos inesperados também é explorado, reforçando a generalização dos modelos a diferentes condições de negócio. A aplicabilidade dos modelos que apresentamos permite a diversificação e o enriquecimento da literatura sobre a abordagem de opções reais, no âmbito das cadeias de abastecimento. Níveis de inventário flexíveis e capacidades flexíveis são característicos das cadeias de abastecimento e podem ser usados como resposta à incerteza do mercado. Esta tese é constituída por ensaios que suportam a aplicação dos modelos, e consiste num capítulo introdutório (designado por ensaio I) e mais seis ensaios sobre factores que discutem o uso de medidas de flexibilidade nas cadeias de abastecimento, em ambientes de incerteza, e um último ensaio sobre a extensão do conceito de flexibilidade ao tratamento da avaliação de planos de negócio.

O segundo ensaio que apresentamos é sobre o valor do inventário num único estádio, enquanto medida de flexibilidade, sujeita ao crescente condicionalismo dos custos com posse de activos. Introduzimos uma nova classificação de artigos para suportar o indicador designado por overstock. No terceiro e quarto ensaio ampliamos a exploração do conceito de overstock, promovendo a interacção e o balanceamento entre vários estádios de uma cadeia de abastecimento, como forma de melhorar o desempenho global. Para sustentar a aplicação prática das abordagens, adaptamos o ensaio número três à gestão do desempenho, para suportar o estabelecimento de metas coordenadas e alinhadas; e adaptamos o quarto ensaio à coordenação das cadeias de abastecimento, como auxiliar ao planeamento integrado e sequencial dos níveis de inventário.

No ensaio cinco analisamos o factor de produção “tecnologia”, em relação directa com a oferta de produtos de uma empresa, explorando o conceito de investimento, como medida de flexibilidade nas componentes de volume da procura e gama de produtos.

Dedicamos o ensaio número seis à análise do factor de produção “Mão-de-Obra”, explorando as condicionantes para aumento do número de turnos na perspectiva económica e determinando o ponto crítico para a tomada de decisão em ambientes de incerteza.

No ensaio número sete exploramos o conceito de internalização de operações, demarcando a nossa análise das demais pela definição do momento crítico que suporta a tomada de decisão em ambientes dinâmicos. Complementamos a análise com a introdução de factores temporais de perturbação, nomeadamente, o estádio de preparação necessário e anterior a uma eventual alteração de estratégia.

Finalmente, no último ensaio, estendemos a análise da flexibilidade em ambientes de incerteza ao conceito de planos de negócio. Em concreto, exploramos a influência do número de pontos de decisão na flexibilidade de um plano, como resposta à crescente incerteza dos mercados. A título de exemplo, usamos o mecanismo de gestão sequencial do orçamento para suportar o nosso modelo.

A crescente incerteza da procura obrigou a um aumento da agilidade e da flexibilidade das cadeias de abastecimento, limitando o uso de muitas das técnicas tradicionais de suporte à gestão, pela incapacidade de incorporarem os efeitos da incerteza. A flexibilidade é claramente uma vantagem competitiva das empresas que deve, por isso, ser quantificada. Com os modelos apresentados e com base nos resultados analisados, pretendemos demonstrar a utilidade da consideração da incerteza nos instrumentos de gestão, usando exemplos numéricos para suportar a aplicação dos modelos, o que claramente promove a aproximação dos desenvolvimentos aqui apresentados às práticas de negócio.

keywords

Demand uncertainty, supply chain flexibility, real options, supply chain performance, multi-stage supply chain, inventory, product mix strategy, investment decisions, shifts management, vertical integration, flexible business plans.

abstract

The present thesis researches the process of decision making in supply chain management using a real options analysis framework. Specifically, we address issues regarding the optimal inventory level to hedge against demand uncertainties; the timing for equipment capacity implementation under market product mix complexity; the timing for workforce capacity reinforcement aiming market service requirements; and the decisions between integration and outsourcing in an uncertainty environment. Discrete and continuous time methodologies were used to identify the optimal value and timing of the options to adopt, when the demand is stochastic. Additionally, the effect of market requirements, such as product mix complexity and service level, were also taken into consideration. The demand is modelled under different stochastic processes; the impact of unexpected shocks is also explored, which enhances the generalization of the models to different business conditions. The applicability of the models enables the diversification and enrichment of the literature on the real options approach, within supply chain concept. Flexible inventory levels and the flexible capacity are supply chain features that can be used to deal with demand uncertainty. The thesis is organized by essays that support the application of the models, and consists of an introductory chapter (essay I) and six trials on factors that enhance the use of supply chain flexibility measures in uncertainty environments and an extended essay on the concept of flexibility to the evaluation of business plans.

The second essay we present refers to the inventory value in a single echelon, as a measure of flexibility, subject to cost constraints. We introduce a new items' classification to support the indicator designated as overstock. In the third and fourth experiments we extend the concept of overstock, promoting the interaction and balance between supply chain echelons in order to improve overall performance. For a practical application of the approaches, we adapted the third essay to the performance management, to support the establishment of coordinated and aligned goals, and used the fourth essay to the coordination of supply chains, supporting the integrated and sequential inventory planning. In the fifth essay we analyse manufacturing technology features in connection with the company's product mix, exploring the concept of investment as a flexible measure to deal with uncertain demand volume and product range flexibility.

We dedicate the sixth essay to the analysis of the input "workforce", exploring the economic conditions for increasing the number of work shifts and determining the critical point for decision making in uncertainty environments. In the essay number seven, we explore the concept of internalisation of operations, focusing our analysis in the trigger moment that supports decision making in dynamic environments. We complement the analysis by introducing temporal factors that could disturb the change, including the preparation stage prior to any strategic alternative.

Finally, in the last essay, we extend the concept of flexibility in uncertainty environments to the business plans analysis. Specifically, we explore the influence of the number of decision points in the flexibility of a plan in response to increasing market uncertainty. As an example, we use the mechanism of sequential budget to support the model.

The increasing uncertainty in demand has promoted supply chains agility and flexibility, limiting the use of many of the traditional management techniques, because of their inability to incorporate the effects of uncertainty. Flexibility is clearly a competitive advantage that companies should have and therefore must be quantified. With the models developed and results that are presented, this thesis aims to demonstrate the usefulness of considering the uncertainty impact in management tools, using numerical examples to support the application of the models and the interpretation of the results, which clearly seek to bring the developments to the actual business practices.

ESSAYS ON SUPPLY CHAIN‘S FLEXIBILITY

A real options approach

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ESSAY IV: INTEGRATED INVENTORY VALUATION IN MULTI-ECHELON PRODUCTION/DISTRIBUTION SYSTEMS

-This paper has been re-submitted to the International Journal of Production Research, Special Issue "Optimisation Approaches for Distributed Scheduling Problems", with Borges Gouveia and Carlos Pinho. Final results in August 2012.

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ESSAY I: INTRODUCTORY ESSAY TO THE THESIS

1. PROBLEM FORMULATION AND GUIDANCE

The goal of this thesis is to study the effects of uncertainty in management enhancing the supply chains' flexibility. The purpose is to develop new models to support supply chain resources application; explore the effects of market uncertainty in the decision process; explore the effects of uncertainty in the supply chain performance; to perceive and quantify flexibility using options; and to test the applicability of proposed concepts and methodologies using illustrative examples. In particular, this thesis presents solutions to minimize disruptions in fulfilling the uncertain market demand, caused by upstream problems, triggered by inadequate or unbalanced inventory buffers, lack of downstream technological or human capacity, or delays in running new operations.

In this section, the motivation and research objectives that lead to the research questions to be analysed on the subsequent related essays, organization of the research topics and the main research questions, will be presented. A general background on the issues we address, specifically, related with demand uncertainty treatment in supply chains, flexible supply chains and the background on the methodologies based on real options will be presented and discussed. Furthermore, we will explore the main topics and questions, which will be expanded into sub-problems to be analysed in the following chapters. Problem definitions, methodologies, conclusions and directions for future research are going to be made explicit for each essay to be presented in the form of research paper. Each paper incorporates all the improvements and suggestions from the forums or journals at which it was presented for discussion.

2. MOTIVATION

In recent years, due to increased market uncertainty, some companies began to restructure their supply chain concept and management tools. In the past, when production did the push to the market, up streaming the inventories for sale, any decision to scale-up capacity was justified based on forecasting sales and positive marginal returns. Today the world is different, the evolution of markets has been characterized by uncertainty and many markets even show extremely high volatility levels. Following this, companies must be more flexible than ever before, using different tools to incorporate such high levels of uncertainty. New approaches are needed to support the changes during the execution of strategies and plans.

From the explored literature, we conclude that the real options methodology enhances the company value by incorporating opportunities and appears as a solution to support decisions in a high uncertainty context.

In this context, not only academics (e.g. Dixit, 1989 and Pindyck, 1991), but also companies, are using the real options reasoning in their decision processes (e.g. Moel and Tufano, 2002; Smit, 2003). Despite this trend and context, the use of the approach is still far from required disclosure. Although the discussions on demand uncertainty treatment in supply chain optimisation have been addressed, it is still a relatively new problem and the methodologies are still scarce. Most of the literature have been applying the stochastic programming technique (e.g. Gupta and Maranas, 2000; Salema et al., 2007).

Using the complexity of real environments, we are able to add a practical overview of the most important theoretical background about the supply chain and business management problems in uncertain environments.

We aim to adapt real options methodology within the context of supply chains to fill gaps between the traditional tools and market uncertainty, through new models, tested by numerical examples, also as providing possible directions for future research. As the issue related to the flexibility of the supply chains under uncertainty is complex and extensive, we can not address all the perspectives in this thesis. However, we suggest some solutions that can be used or even modified by future students or practioners. In particular, the essays we present explore flexible solutions for different problems.

The main objectives are to stress the role of flexibility in managing supply chains, providing the means to adjust to the consequences of risks, to define and value options as a way to create flexibility, and to focus on timing frame to support management decisions. We want to outline that managers need more and more flexibility to respond to unexpected changes in the market. This concept implies changes in the way managers frame the reasoning to support the decisions, from designing supply chain systems to specify circumstances to planning within a wide variety of possibilities. Considering that an option is a formal way of defining flexibility which allied to the options fundamental posts an interesting challenge on supply chain flexibility framework.

An option is a right, but not an obligation, to undertake some action, now, or in the future, for a pre-defined price; in this sense, the cost of the action is split from the value of option. Real options for managing the supply chain can arise in different forms, such as inventories motivated by disruptive events, capacity investments, prioritisation contracts with manufacturers to insure supply, improving cycle-time of products, or faster response to market requirements.

Both suppliers and customers need flexibility to deal with unexpected changes from the market, like product modularity, plants design or distribution centers. One way to analyse flexibility is to capitalize all the possible opportunities. Flexibility requires the capacity to face complex problems, to optimise situations, to take advantage of opportunities (buy options); or to avoid relevant losses (selling options).

Our motivation relies on flexibility that represents a real challenge for supply chain management and the tools used to support the decisions. Nowadays, instead of planning to a target specification, companies should plan for possible levels of performance under target boundaries. In this line of reasoning we find two interesting challenges: How worth is flexibility? - Flexible capabilities allow managers to recover from disruptions and to take advantage of coming opportunities, maximizing the potential outcomes – there is a value to explore; and how much companies have to pay for flexibility? - Costs are related with the use of resources within a specific goal which, when applied to supply chains, refer to issues like inventories, investments in capacity or sequential decisions implementation.

3. RESEARCH TOPICS

We will list the main research topics that support this thesis. The first topic is about volume and mix flexibility. The agility to manufacture a product, despite changes to volume and mix, is explored by Braunscheidel and Suresh (2009), also van Donk and van der Vaart (2005) explored dedicated or multiple production facilities, and Miller (1992) studied the impact of multi-skilled workers. The process flexibility will also be explored. The flexibility of the resources, workforce or equipment, enables a company to cope with uncertainty caused by market demand or product mix complexity, which causes frequent product changeovers on the shop floor. Miller (1992) explored labour flexibility and Ulrich (1995) analysed the implementation of general purpose machines, equipment and technologies. These topics will be explored in essays five and six. The literature refers to strategic stocks as those that are used to buffer against uncertainty (Davis, 1993; Helms et al., 2000; Wong and Arlbjorn, 2008). To better illustrate the effect of uncertainty, different items classifications are critical, for this purpose an item classification is suggested and corresponds to a single product family within a certain market position, according to product life cycle. The classification of the items considers the sales performance but also the product life cycle evolution, stressing the importance of the launching and phasing-out periods. These topics are explored in essays two to four. Lee (2002) and later, Sun et al. (2009), explored logistic outsourcing, and Harrison (2001) discussed the infrastructure for new products or processes. The integration versus outsourcing will be explored on essay number seven. For Miller (1992), vertical integration is as a way to control supply or demand uncertainties also as partnership with collaboration and information sharing (Christopher and Peck, 2004; Muckstadt et al. 2001).

Peidro (2009), defended the importance of forecasting, simulation, or mathematical modelling, to reduce, or at least, quantify the impact caused by uncertainty. The use of performance measures, mainly key performance indicators, to detect uncertainty is referred by Geary et al. (2002). This is a topic explored in multi-stage models. A framework will be presented to resume the metrics that will come from the proposed models.

4. RESEARCH QUESTIONS

A relevat issue in supply chain management is the consideration of market uncertainty. This is a critical topic to support most of the decisions regarding resources and capacity efficiency (Papageorgiou, 2009). In the literature, several authors agree that demand cannot be fully explained by deterministic parameters, due to changes in the market requirements that are not controlled by the supply chain, mainly customer preferences. Markets are becoming more unpredictable, which creates the need for complex demand's stochastic models.

According to the literature explored, the most used strategies to coop with supply chain uncertainty are: orders postponement, volume/delivery flexibility, process flexibility, customer flexibility, alternative suppliers, strategic stocks, integration and collaboration, and lead-time management. Most of the strategies are related with flexibility. In fact, flexibility provides a competitive advantage to the firm. The question then becomes as how valuable is such flexibility? The goal of real options valuation is to address this question in an environment of high volatility. As so, we intend to use the real options methodology to address the problem of market demand uncertainty and value the firms' flexibility in such environments.

The researches we present in this thesis will discuss a group of management problems emerging in supply chain management due to the increasing demand uncertainty. We aim at providing answers to the problems, using techniques derived from real options, with advantages and limitations that will be discussed later. The cases we present are important to support the applicability of the models; nevertheless, the assumptions and limitations will be discussed to assure the generality of the models and the required adequacy to knowledge increase in the explored topics.

The main research question is how to value flexibility, comparing uncertain returns with costs? And secondary questions are related with the flexibility metrics presented in each essay, mainly: what is overstock? What is the optimal value of overstock? What is the distortion effect of non-optimal overtstock values in multi-distribution channels? How can a company value a product mix flexible investment? How sensible is workforce planning to service level changes and flexible to demand changes? How valuable is an integration option compared with outsourcing? And how valuable is a rolling plan concept?

For each question we point flexibility metrics such as: overstock, multi-echelon overstock, flexible investment acquisition value, service level improvement value, integration option and business rolling plan value.

5. GENERIC TERMS AND CONCEPTS

5.1. SUPPLY CHAINS EVOLUTION

According to Bosman (2006), we can split the context of the supply chains in three moments. Till 19th century, companies used simple supply chains, developed as a consequence of the physical flow. After the 20th century, companies started to develop vertical integration in order to control the nodes of the chain. When companies were not able to acquire or joint with relevant partners, they promote some risk minimization simply by reinforcing the safety stock or implementing dual sourcing strategies. The globalisation came in the 80's and with it an aggressive competition. The concerns on lower resources broadened the supply chain within different countries. This period can be characterized by three main goals: speed, cost and outsourcing of the non-core activities.

In the 90's, supply chain concept became a very important issue in the business management. Some changes in the previous two decades affected the concept. Companies became specialized in their core activities and put their non-core activities under the management of low cost suppliers, partly due to the need of cost decreasing. The development of lean practices, within internal processes, to avoid waste, increased the fragility of the chain and diminished the capacity to answer to eventual disruptions. Also the procurement, looking for lower purchase prices, reduced the number of suppliers. With the geographic spreading and the increasing dependency on suppliers, the concept of network and the goal to improve performance, reinforced the need of a global chain management, recognizing the links in the chain as a relevant value driver.

The increase of competition forced to special attention on quality, speed and prices. Besides these three vertices, also shortages, surpluses, environmental, safety and health issues became part of the customer decision process (Stokes, 2008).

Some facts have been changing the behaviour of the demand. One of them is the product life cycle that is becoming shorter and consequently, it's crucial to speed up product launch and decrease the time-to-market. In this innovation context, companies face high levels of diversification and the demand is focalised on customized products.

The answer to the client’s requested speed is normally done using inventories spread all over the chain. The decision to use and abuse of inventories in a growing number of articles began to be seen as a risky option, because it is difficult to predict customer choice. On top of product mix variety, the trend of low prices challenged the option of using funds in low rotating items. The just-in-time practices, going to the limit of the inventory required value, reduced the buffers and developed the need of a faster reaction based on timely and accurate information.

The network concept is also the consequence of the need to analyse the global supply chain performance and not only each part. With more partners along the supply chain, information sharing has become even more relevant as well as the synchronization of the supply chain to understand the relationship between the links.

5.2. SUPPLY CHAIN MANAGEMENT

Hutchins (2003) outlined five concerns in managing the supply chain, such as the identification of core activities, outsourcing non-core activities to the "world class" partners, acquire and integrate the processes, existence of a performance culture, innovation and improvement on an ongoing basis. Cavinato (2004), besides the traditional three network flows (cost, material and information), added the existence of the relational and innovative flow. Norrman and Jansson (2004) also considered the ability to respond (as the link between quality and time), leanness (as the link between quality and costs), agility (which links the time and cost) and risk management.

The adaptation to new situations requires planning and knowledge. In this sense, collaboration between the players in the chain is very important, as the parts can increase the global value by respecting the down and upstream nodes. Costs are still a key issue in supply chain management and the need for cost adaptation has become a strategic competitive issue. Also, service level appears as a relevant issue, considering customer needs, an oriented service and product customisation.

The supply chain management intends to increase performance. In this sense, performance can be evaluated considering efficiency, productivity, scale, time, diversity and flexibility metrics. This is a possible way to organize the performance metrics – highlights that call the manager’s attention to reflect, analyse, plan, decide and act, according to the strategic challenge of the organization, facing aspects such as price competition, volume, commodities, innovation, knowledge, service level, design, time or flexibility.

Efficiency metrics are based on a relation of the resources usage, assuming a standard target for orientation.

Productivity metrics provide a relation between output and input resources. The productivity measures should be associated with limited capacity of the available resources. One of the main difficulties to assure the calculation and the interpretation of productivity is the possibility of having a single metric, able to aggregate multiple resources.

Scale metrics intend to measure the installed capacity. These metrics should be as aggregated as possible, which requires the use of homogenisation mechanisms of the possible output existing measures. When this is not possible, or the products range is very significant, these measures have a poor interpretation only applicable to the isolated elements within a supply chain.

Time metrics are flow measures, not single task metrics. Time is one of the service level components and should be seen as a strong competitive advantage.

Diversity metrics account for the variety of existent products. When the strategy is focused on client, the customisation of services and products is highly complicated and diversified mixes are developed. In this line, as fast as companies introduce new features and products, new processes emerge and their position in the market place among competitors increase. As so, innovation increase risk but, at the same time, assures a competitive advantage in the market.

The flexibility is part of supply chain managers' skills and can be analysed as a group of options regarding opportunities. It's the incremental value resulting from a decision review, considering the changes in the assumptions that guide the initial decision to a new one. Following this, the use of real options approach can support the calculation of flexibility measures. If it's possible to measure, it is also possible to influence and to manage.

The common initiatives to influence flexibility, according to Olhander (1993), Chambers (1992) and Slack (1988), are the set-ups reduction, multi-functions machinery investment, additional investment in machinery or outsource flexible work, like temporary workers to answer for scale flexibility need, and qualified workers to answer for process flexibility.

5.3. FLEXIBILITY

The production systems evolution was the bases for the organizations development, going through the standard model (production in series), the diversity/variety models and finally the reactive models (Cohendet and Llerena, 1999). These last models are characterized by the ability to reconfigure the resources to respond to consumer demand.

We analyse the flexibility under two points of view, the side of relevance, which means that the company has the capacity to adapt to environmental constraints; and the side of consistency, highlighting the existence of internal coordination. Flexibility is, for several decades, an important target for organizations and, according to Swamidass and Newwell (1987) it is a possible way to minimize the impact of environmental uncertainty.

Following studies of Beamon (1999), the advantages of a flexible supply chain are associated with the increased customer satisfaction, the ability to react to changes in demand volume and mix, the capacity to adjust the internal performance due to the disturbances, and the ability to introduce new products and develop new markets.

For Lummus and Vokurka (1999), the operations and logistic processes, supply network, organizational design and information system are relevant components of the supply chain flexibility. Traditionally, flexibility is defined considering time, market variety and capacity, for which Duclos and Vokurka (2003) added the market flexibility (approach to customer requirements).

For Rice and Caniato (2003) resilience is the ability to react to an unexpected disruption or failure, due to supply, transportation, production, communications or human resources. For Sheffi (2005) resilience can be seen as a competitive advantage, which relies on the ability to promote a fast recovery from any disruption. Resilience can be reinforced considering the supply chain design and questions like which parts, make or buy, make to stock or to order, configure or design to order, the process management, the information visibility and accuracy, supplier/customer relationship management and the culture of the chain partners.

5.4. RISK MANAGEMENT

For Bosman (2006), for risk management purpose, the supply chain should be considered a network with a special concern in the links of all the parts and should include the sharing of information and the goals clarification. Christopher and Lee (2004) argued that the cycle time of a request, the status of the orders, the demand forecasting, responsive and capable suppliers (also defended by Finch, 2004), product quality and reliability of services and transportation are the relevant parts that can minimize the risk. The lack of trust increases the buffers (Giunipero and Eltantawy, 2004), resulting in longer pipelines, causing lack of visibility and ending in the lack of confidence. Faisal et al. (2006) stressed the importance of sharing information to minimize risks. Later, Manuj and Mentzer (2008) showed flexibility, organizational learning, information systems and performance metrics as key risk management issues. At that, Jones (2008) added the visibility of supply chain activities encompassing the source-to-pay life cycle.

Overall, the risk management process considers the risk identification, the risk analysis, the risk-reducing measures and the risk monitoring (Bandyopadhyay et al., 1999).

5.5. THE REAL OPTIONS AND SUPPLY CHAINS

The use of options in supply chain management intends to promote and value the flexibility of all the partners and resources involved. The capacity to deal with uncertain environments is based on hedging instruments to smooth the potential negative effects, due to market or resources volatility. Through time, the arrival of new relevant information can help managers adapting their decisions within a conceptual framework of the possible alternatives to follow.

Cohen and Huchzermeier (1999) analysed the advantages of using options in global supply chains under uncertain demand. They found that real options can have a significant impact on the value of the firm and in reducing the downside risk. Supply chain can be seen as a group of related and coordinated options, considering the sources of uncertainty, the expected return, committed real resources and the right time for implementation (Cohen and Huchzermeier, 1998). There are a number of uncertainty sources affecting the business environment that justify the use of real options in managing the supply chain, such as the exchange rates, market demand, market prices, the supplier capacity / capability, resources' pricing, income generation, product updates and process technology, competitors' actions or policy changes.

6. GENERAL REAL OPTIONS FRAMEWORK

We begin this section by describing, in general terms, the arguments behind the real options approach, noting its basis on the capacity to learn and the ability to act. Real options thinking recognise that multiple scenarios to the future are a better way to manage risks and opportunities than a single view of the future. Real options consider the timing of information arrival and the sequence of decisions over time; the practice typically involves careful framing of an investment decision problem in order to improve the project, and enhance the shareholder value. This section shows how real options can add value and the subsequent section provides details on real options valuation techniques.

Real options are an important mechanism to measure the impact of risks in the decision process. The philosophy behind the concept reinforce the management ability in dealing with risk, making possible the transformation of potential threats into opportunities, or anticipating abandonment options to minimize undesired impacts. During the last two decades, researchers have been discussing the analysis of discounted cash flow techniques, considering the calculation and the interpretation of the results within a decision process context. One of the most controversial and critical element to support the discounted cash flows is the choice of the interest rate to be applied (Gertner and Rosenfield, 1999). Another limitation is that the discounted cash flows ignore the dynamic flexibility that exists in almost all decisions, because there is uncertainty in long-term. Investment analysis has been criticized for not taking into account the dynamics of decision-making (Chirinko, 1993). According to Dixit and Pindyck (1994) the dynamic should reflect the irreversibility (total or partial), the uncertainty and the timing of decisions. The term option refers to the philosophy of risk coverage. Risk is the probability of a loss and appears as the main reason for the use of options. According Trigeorgis (1991), real options should be seen as an extension of the discounted cash flows (expanding the net present value). Bernhard (2000) reinforced the work of Trigeorgis in 1991, considering that the net present value should include an option premium. Allesii (2006) introduced a new method in the presence of real options, using the internal rate of return.

In short, the application of real options approach relies on three main conditions, such as the existence of uncertainty, flexibility and irreversibility in the decision process.

Flexibility in supply chains is desirable, allowing managers to adapt their decisions to changing market conditions. Real options may increase the value of a project by allowing managers to improve flexibility, which will turn into additional benefits. Optimal managerial decision-making, therefore, requires a choice between one of several possible alternatives, which can be valued using a real options framework. According to real options theory, the managerial decisions imply the creation and then the possible exercise of options.

The explored literature supported several examples of real options applications. We will start by referring Trigeorgis (1996), who categorized real options in postponement, expansion/contraction, switching, and abandonment. McDonald and Siegel (1985) and Brennan and Schwartz (1985) approached the option to temporarily shut down. Majd and Pindyck (1987), McDonald and Siegel (1986), and Paddock et al. (1988) examined options to defer. Brealy and Myers (2006), Kandel and Pearson (2002), Kester (1984), Myers (1977), Siegel, et al. (1987) and Tiwana et al. (2007), amongst others, explored growth options. Growth options are the most prevalent type of real option, and are analogous to financial call options, specifically, Trigeorgis and Mason (1987) and Pindyck (1988), analysed options to expand; also Fichman et al. (2005) explored scale options on projects regarding expansion.

Myers and Majd (1990) and Hubbard (1994) studies aimed abandonment options. Kensinger (1987), Kulatilaka (1988) and Kulatilaka and Trigeorgis (1994) concentrated on switch options; Triantis and Hodder (1990) valued the option to change the outputs of a project, while Kulatilaka (1993) valued the option to change the inputs, regarding the resources. We also found studies on staged investments using sequential options (e.g. Carr, 1988; Majd and Pindyck, 1987). Majd and Pindyck (1987) also pointed the relevance of the impact of new information in the decision process.

Hodder and Triantis (1993) presented a general framework for modelling investments considering flexibility to switch between alternatives. Kogut and Kulatilaka (1994) modelled the operating flexibility to change production between two manufacturing plants, located in different countries; also Dasu and Li (1997) studied the structure of optimal policies for a firm operating plants in different countries.

Kogut and Kulatilaka (1994), and Mello et al. (1995) explored global production network that allows production to be moved from one node to another over time (see also Billington et al., 2002). Huchzermeier and Cohen (1996) developed a stochastic dynamic programming formulation for the valuation of global manufacturing options with switching costs, emphasizing the concept of operational hedging. Smith and McCardle (1998) used the integrated option pricing and decision analytic approach. Tsitsiklis and Van Roy (1999) modelled an optimal stopping problem.

In 2000, Nembhard et al. suggested the need for modelling the flexibility in manufacturing operations using real options; Tsitsiklis and Van Roy (2001) provided theoretical results that help explaining the success of approximate dynamic programming methods. Focused more specifically on manufacturing systems, Triantis and Borison (2001) concluded that real options help managers making better investment decisions. Courtney (2001) suggested the use of contingent road maps, option portfolio management and strategic evolution principles. Wilson (2002) gave an illustration of the use of system dynamics, by developing a general simulation model to assess the impact of transportation disruptions under different scenarios. Brach (2003) incorporated decision-making operational concerns into the real options framework. Nembhard et al. (2003) studied the option value to switch between the states of producing or outsourcing an item. Boyabatli and Toktay (2004) reviewed the operational hedging literature and options on production decisions. McGrath and Nerkar (2004) used real options to analyse firm’s investments in technology. For Milner and Kouvelis (2005), in the same line as Fisher and Raman (1996), the use of real options reasoning in the supply-chain literature emphasizes postponement or switching options. Tiwana et al. (2007) found that managers relate scale, switch use, and abandonment options to the perceived value of a project more under conditions of high uncertainty than under low uncertainty. Ding et al. (2007) studied the capacity allocation option by delaying the commitment of capacity to specific markets uncertainties.

In 2008, Oriani and Sobrero used real options to analyse firms’ investments in areas such as research, development or knowledge (Wang and Lim, 2008). Hult et al. (2010) posted two important contributes on using options to perceive value under conditions of high supply chain risk uncertainty, and on suggesting that some options operate differently in supply chains than they do in firms. Xihui and Liang (2011) demonstrated the performance improvement of purchasing using real option contracts. Sting and Huchzermeier (2012) explored the impact of correlated supply and demand uncertainty on optimal multiple-sourcing decisions.

Though previous studies differ in the options they value and the way they solve the problems, they generally assume that the underlying stochastic variable are governed by a single geometric diffusion, which allows the use of analytic solutions.

Through the real options theory, the management can firstly judge the strategies to adopt when, inside the supply chain, decisions are made under uncertainty, and secondly make the right decision to give more flexibility to the production process.

7. GENERAL DECISION METHODOLOGY AND REAL OPTIONS VALUATION TECHNIQUES

We will describe the general decision frame that has been used in the decision support models we present. The first step is to build a database with historical data regarding the variables and parameters under analysis. At a second level a data analysis should be done in order to allow the interpretation of data (important to discuss the stochastic process that best fits with demand behaviour) and to support the estimation of the parameters. In the next step an optimisation model is required to solve the problem (after the objective function being identified). We explored the real options model, using the possible techniques, according to their advantages and limitations, which are discussed in this chapter. The employed technique will retrieve the optimal value, under a closed formula or a simulation process, after which the decision can be taken considering the results and the flexibility to go or wait.

Real options theory has been widely explored. Options' value is derived from an underlying asset. Consequently, changes in the value of the underlying asset will affect the value of the corresponding options. Since calls options provide the right to buy the underlying asset at a fixed price, an increase in the value of the asset will increase the value of the call options. Put options, on the other hand, become less valuable as the value of the asset increase. The buyer of an option acquires the right to buy or sell the underlying asset at a fixed price. The higher is the variance in the value of the underlying asset, the greater the value of the option. A key characteristic used to describe an option is the strike price. In the case of call options, where the holder acquires the right to buy at a fixed price, the value of the call option will decline as the strike price increases. In the case of put options, where the holder has the right to sell at a fixed price, the value will increase as the strike price increases. Options become more valuable as the time to expiration increases. This is because a longer time to expiration provides more time for the value of the underlying asset to move up. Since the buyer of an option pays the price of the option up front, an opportunity cost is involved and quantified. This cost will depend on the level of interest rates and the time to expiration.

The deterministic cash flow valuation, relates the value of an asset to the present value of the expected future cash flows. Sensitivity analysis involves applying sensitivity simulations to the deterministic discounted cash flow model. Monte Carlo risk analysis came in the 1980s. Instead of single values for each input parameter (as in sensibility analysis), the Monte Carlo algorithm repeatedly samples values from the probability distributions of each of the input parameters – to produce a probability distribution of the net present value. The main limitation of the Monte Carlo technique is that it does not take into consideration the fact that management can adapt the strategy according to changing conditions. Real options recognise not only that the future is uncertain but also the inherent flexibility associated with an asset value.

Valuation techniques	**Considers multiple futures**	**Models risks**	**Values Flexibility**
Deterministic discounted cash Flow	No	No	No
Sensitivity analysis	Yes	No	No
Monte Carlo risk analysis	Yes	Yes	No
Real option valuation	Yes	Yes	Yes

Table 1: Valuation techniques

To quantify the value of an option, the first step is to value the discounted cash flows and the uncertainty of each possible result (Copeland and Antikarov, 2003; Trigeorgis, 1996). Forecasting the possible results enables managers to overview all the potential benefits from the investment. The problems under a real options analysis can be solved using closed formulas or numerical methods. The closed formulas are based on analytical expressions, such as the Black and Scholes (1973) formula. Numerical methods apply for simulation techniques, decision trees, and finite differences method (Hull, 2005; Willmott, 2000).

The Black and Scholes formula is particularly useful for problems with simple structures, such as a single source of uncertainty and a single decision. Binomial trees and Monte Carlo simulation are more general and powerful techniques that can be used in more complex settings. While the three techniques differ somewhat in terms of assumptions and structure, all of them reflect the same valuation principles. The three methods are illustrated and compared below in the context of the valuation of a growth option.

The closed solutions models are exact, fast and easy to implement (Mun, 2002). We will make a reference to two of the most used models in the literature: the Black and Scholes model (Black and Scholes, 1973), and McDonald and Siegel (1986). Black and Scholes (1973) used a closed formula, considering several parameters but assuming that the only stochastic variable is related with the asset value under evaluation. The advantage of the Black and Scholes model, relative to other valuation techniques, is that it simply requires de identification of six inputs into a formula to support the calculation of the option value: 1) the initial value (S) of the underlying asset; 2) the time (T) until maturity of the option; 3) the investment, or exercise price (X), that is required to exercise the option; 4) the difference between the capitalization rate and the percentage expected change in the value of the underlying asset; 5) the continuously compounded annual risk-free rate of return; and 6) the volatility of the underlying asset, which is the standard deviation of the rate of return on the underlying asset. While this is an attractive feature, there are some important limitations to the Black and Scholes formula. First, it assumes that options can be exercised only at the maturity date. Second, it assumes that the underlying asset value has a lognormal distribution, which implies that the (continuously compounded) rate of return on the underlying asset price is normally distributed with a constant standard deviation over time. Third, the formula lacks in transparency and intuition as it is too much mathematical oriented. Why do these parameters affect the value of a real option and how are they captured within the Black and Scholes model? The value of the option depends on the likelihood that the asset will in fact be developed, and on how profitable such development might be. As volatility increases, there is a larger probability that the asset development will be very profitable, thus increasing the value of the option.

The use of Black and Scholes model (1973) and Merton (1973) can be found in several works (e.g. Angelis, 2000; Titman, 1985; Trigeorgis, 1996). Later on, in 1986, McDonald and Siegel developed a model to calculate the value of an investment option, considering the delaying alternative, which represented a significant step to support the calculation of the optimal timing to invest. For that, they assumed that the investment option is perpetual. One disadvantage of this model is the fact that the optimal moment is not known, which may be considered a limitation in the presence of options with a defined maturity date.

Numerical solutions are based on simulation processes using approximations to the final solution. Their use is extended to time discrete models or time continuous models, but subject to an initial discretization and are normally used when closed solutions are not possible.

Binomial trees are possible graphical representations of intrinsic values that an option can take at different periods in time. The value in any of the nodes depends on the probability that the underlying asset value will either increase or decrease at any given period of time or node of the tree. An advantage is the simplicity of the use (Smit, 2003). While the Black and Scholes model assumes that the value of the underlying asset is log-normally distributed, the binomial model assumes that in each period of time, the value of the underlying asset can take only one of two values. By allowing a sequence of periods with such binomial movements, a large set of paths (called a tree) can be generated to approximate all possible value changes that could occur, to the underlying asset during the life of the option. The steps of the binomial method in the valuation procedure are described below. The first step is the generation of the binomial tree. The standard way of establishing a binomial tree is to assume that, during each time period of length ΔT, the value of the underlying asset either increases, by a factor of $u = e^{\sigma\sqrt{\Delta T}}$, or decreases by a factor of $d = e^{-\sigma\sqrt{\Delta T}}$, where σ stands for the volatility ; starting with the initial value of the asset, and multiplying it by the return factors u and d, two possible values at the end of time interval are obtained. Once the values of the underlying asset have been generated, the next step is to calculate the value of the option at the maturity date, considering each of the simulation steps. This requires subtracting the exercise price from the asset value at the end of each time interval, if the asset value is higher that the exercise price, or else setting the option value equal to zero if the asset value is lower that the exercise price. The next step requires working backwards through the tree to first calculate the option value at the end of the first time interval, under each of the two possible value scenarios, and then to calculate the option value at the initial date. The expected value of the option is adjusted to account for the option's risk, and is then discounted at a risk-free rate. Limitations of these methods are related to key assumptions: there was only one source of uncertainty, this uncertainty had a lognormal value distribution, and a single decision to be made (develop or not), and there was a finite horizon of time.

An alternative to binomial trees is the use of finite differences for solving the valuation equation. Schwartz (1977) proposed the finite difference procedure of discretizing all state variables. Finite difference methods are used to price options by approximating the (continuous-time) differential equation that describes how an option price evolves over time, by a set of difference equations. The discrete difference equations may then be solved iteratively to calculate a price for the option.

Monte Carlo simulation is an alternative real option valuation technique. Simulation techniques like Monte Carlo, despite requiring a large number of simulations, are flexible, mainly allowing the use of several variables. Boyle (1977) introduced Monte Carlo simulation method for asset pricing of European options. The technique consists, first, in a number of different values for the underlying uncertainties that are generated based on distributions (probabilities) and adjusted for systematic risk. The expected value of the option is then calculated, and a risk-free rate is used to discount this expected value back to the initial date. The principal advantage that Monte Carlo simulation provides, over the other valuation techniques, is its ability to deal with multiple uncertainties, in particular, if they have non-standard distributions and may be correlated with each other. However, Monte Carlo simulation presents two limitations: first, the solution procedure is less clear to management, when compare with a tree model where one can trace along the few paths that are generated. Second, standard Monte Carlo simulation technique has been unable to solve option problems where early exercise is involved, or more generally where decisions at a point in time depend on decisions made at a future point in time (e.g. dynamic programming problems). The use of Monte Carlo simulation to value real options is likely to grow over time, given its power and the development of informatics' systems to support such applications.

Let us consider a (possibly multidimensional) random variable X, having probability mass function, or probability density function $f_X(x)$, which is greater than zero on a set of values χ. Then the expected value of a function g of X is: $E(g(X)) = \sum_{x \in \chi} g(x) f_X(x)$; if X is discrete, then $E(g(X)) = \int_{x \in \chi} g(x) f_X(x) dx$; if X is continuous, then we computed the mean of $g(x)$ over a defined sample within χ, then the Monte Carlo estimate is $\tilde{g}_n(X) = \frac{1}{n}\sum_{i=1}^{n} g(X)$.

8. MAIN LIMITATIONS ON THE USE OF REAL OPTIONS

A detailed discussion about the difference between real options and discounted cash flow risk adjustments and their value effects is found in Jacoby and Laughton (1992), Salahor (1998), Samis et al. (2006), and Laughton (2007).

One of the first limitations pointed in literature is the imperfect quantification of the asset value (Dixit and Pindyck (1994); Copeland e Antikarov, 2003; Merton, 1998). Despite, Cox e Ross (1976) assumed that an option can be simulated using an alternative equivalent asset, Howell et al., 2001, Majd and Pindyck, 1987, posted some difficulties on defining the appropriate equivalent asset. Since the underlying asset is not traded, it is difficult to get either of these inputs from the market; therefore a Monte Carlo simulation can provide both values.

Amram and Kulatilaka (1999) pointed the use of stochastic models to represent some specific realities as another limitation. In fact each industry faces different demand behaviours. The use of historical data to estimate the parameters and uncertainty behaviour can have some limitations due to dramatic and unexpected changes that can occur (Copeland e Antikarov, 2003; Kallberg e Laurin, 1997; Smit, 2003). This can be a limitation as some of the proposed real options techniques are based on a singular stochastic process. To overpass this limitation a study on the adequacy of the stochastic models to real data should be done. Other limitations are linked with competition influence and limited information in the market (Grenadier, 2000); the complex formulas (Amram and Kulatilaka, 1999; Kemna, 1993; Nichol, 1994); the requested effort (time) to apply the techniques (Rose, 1998; Trigeorgis, 1988).

Nevertheless the limitations presented, the explored literature pointed that by using the real options methodology the decisions are better sustained than those supported on the traditional techniques. (e.g. Dixit and Pindyck, 1994; Merton, 1998; Trigeorgis, 1996). The limitations of traditional methods are mainly due to the fact that they ignore long-term effects; ignore uncertainty effects; do not capture option value of delay, scalability, and agility (for example a change in the product mix).

For Copeland e Antikarov (2003) there are four basic drivers for the success of a methodology like real options: being a better solution than the existent ones, clarification about the main assumptions and limitations, low complexity and be able to be tested using real data. Contributions as the one of Gupta and Maranas (2004) that presented a multi-period supply chain planning model under demand uncertainty, based on real option values, or Rogers and Maranas (2005) that applyed real options to research and development licensing, have been invocated in literature. There are two main contributions from academic developments in the application of real options methodology: the use of simple structures and explanations (e.g. Bjersund and Ekern, 1990); and the capacity to spread the use for different real life problems.

Considering the definitions around real options methodology, its application to supply chain problems requires a clarification of concepts as flexibility, uncertainty, irreversibility and timing of the decisions. In the further section a discussion on these topics will be provided.

9. DISCUSSION ON REAL OPTIONS ASSUMPTIONS

From literature, any investment on assets, must consider the flexibility, irreversibility, uncertainty, timing and the associated future expected value. We will discuss each of the main assumptions to support the methodologies to be used in the present thesis. First, we will refer to the flexibility, as the capacity to change the initial requirements and costs, in order to maximize the future potential values from an actual resource allocation. As so, the flexibility has more value as the uncertainty increases and the management team take decisions in order to use all the available information aiming to maximize the potential of the present decisions (Copeland et al., 2000; Jones and Ostroy, 1984; Trigeorgis, 1996). Uncertainty reflects the unpredictable variables that can affect the course of the decision, including the information that is and will be available at each moment in time. Demand uncertainty treatment in supply chain models has received significant attention in the literature: Snyder (2006) regarding optimisation under uncertainty applied in facility location problems; Taskin and Fuat (2007) about multi-echelon inventory management in supply chains, with uncertain demand and lead times; Papageorgiou (2009) stressed the importance of systematic consideration of uncertainty within supply chain optimisation problems; and Klibi et al. (2010) reviewed supply chain networks design problems under uncertainty.

The management flexibility can affect the probabilities applied to the demand behaviour, as the decisions to be taken should count with additional available information (Trigeorgis, 1993), also as the timing of the decisions. These effects are not treated in traditional mechanisms to evaluate decisions regarding the use and application of the real assets. The time to decide a project, anticipation and flexibility are relevant management skills (Eccles et al, 1999) and can determine the success of a project (Baldwin and Clark, 1992).

Considering this concepts, supply chain flexibility can be analysed as a group of options that are available, at each moment, and make part of a strategic frame (Kulatilaka and Marks, 1988), nevertheless if the frame reflects all the supply chain or a single company perspective.

Traditionally, one problem has been raised about real options methodology concerning the assumption about the irreversibility of costs to support the decisions. The application of this assumption tends to be discussed, mainly on resources that, due to the actual manufacturing evolutions and lean practices, are becoming more and more variable, which may violate the assumption about the irreversibility behind the application of resources within real options approach. Considering this reasoning, and to avoid that the assumption appears as a potential critical limitation to the application of real options methodology in the models we propose, we follow Henry (1974) for whom, the irreversibility can be total or partial and can be seen as a limitation for the application of the resources within an extended period of time. This definition deserves a deep analysis. First irreversibility is not a closed concept; instead it can be used to explain that a present resource allocation cannot be fully recovered if the decision is reverted, because of future market conditions (Kogut e Kulatilaka, 1994; Kulatilaka and Perroti, 1998; Pindyck, 1991). Second, the irreversibility normally can also be discussed in traditional techniques as it tends to create protectionism, by increasing the expected return, mainly under conditions of high uncertainty (Henry, 1974). Third, the irreversibility allows the quantification of postponing decisions and the investment to a future moment, where new information can add a better support on the decision process (Dixit and Pindyck, 1994; Quigg, 1993). Fourth, the irreversibility concept is more relevant to the decision process when traditional techniques (such as free discounted cash flow) present small payback values, which are highly dependent on future conditions. Such a situation reinforces that uncertainty is not a barrier in the decision process (Ingersoll and Ross, 1992; Kulatilaka e Perroti, 1998); which is also supported by Trigeorgis (1996), for whom, an option gives the right to obtain future values, but not the obligation to assume potential losses.

There are two types of uncertainty that can be explored: the economic (external) one that cannot be influenced by the company, and the technical one that can be influenced by the company (Brealey et al., 2006). The economic uncertainty is correlated with the general movements of the economy. As so, it is exogenous to the decision process (e.g. prices evolution, when a company is a price taker). The increase of external uncertainty threats the increase of the costs associated with the decision, mainly due to the timing when to apply for such decision (Dixit and Pindyck, 1994; Trigeorgis, 1996). On the other hand, the internal uncertainty that is intrinsic to the decision process can be minimized, by splitting investments or diversifying the possible alternatives (Brealey et al., 2006; Neves, 2002). So, investing step-by-step provides valuable information and reduces the variance of the uncertainty by the possibility of revising the expected value, what Pindyck (1993) define as the shadow value. The timing frame for the decisions can influence the value of the opportunity, because new information will be available as time runs and can be used (Dixit and Pindyck, 1994).

Two questions arise with respect to the size and behaviour of assets volatility. What happens when volatility is small? This question is critical in cases where the use of the binomial model is considered. And, what happens when volatility is not constant? We consider the most likely case to be one in which volatility declines over time, when the option life is significant relative to the life of the underlying asset. This behaviour in volatility could also be relevant when the market stops growing, after an initial period of explosive growth (introduction or after a marketing campaign). As volatility is lost, and the expected outcome becomes predictable, option pricing becomes less attractive.

Assumptions about the option's exercise time. What is the moment when it is optimal to exercise an option? The answer to this question relates to the ability to calculate the value of the option on, or before its expiration date. With the standard Black and Scholes model, finding the time would require repeating the option pricing analysis for various entry points, within the time frame. However, some advanced variations of Black and Scholes, such as the analytical model developed by McDonald and Siegel (1986), enable to determine optimal investment timing. The binomial model may also be attractive because it can easily calculate the option value, on, or before expiration. The mechanism used is to calculate the option for every node in the binomial tree, thereby allowing the decision maker to identify time corresponding to a node where option assumes the maximum value.

10. THE STRUCTURE OF THE THESIS AND RELATION BETWEEN ESSAYS

All seven papers are within the topic of demand uncertainty. Paper 1 (essay II) contributes to the inventory mechanism in uncertain markets. In general, inventory control concerns balancing demand and supply where, in order to do that in a smooth fashion, some stocks are needed. Most often, buffers exist to profit from economies of scale and to protect from uncertainties in demand or in supply. Economies of scale dictate that because of existing fixed costs, the procurement or production orders should be dimensioned to some reasonable minimum batch sizes. Market demand uncertainty concerns both quantities and the timing. This give rise to stocks, an excess buffer to be kept to provide the adequate customer service requirements. In this thesis the economies of scale will be ignored and our focus is the uncertainty element, specifically, the demand uncertainty.

In essay II, we propose the use of overstock as a new supply chain key performance indicator to define the optimal stock value, according to different demand uncertainty levels. To support this concept and for a better adaptation, regarding the models used to represent the demand, a new methodology to support the items' classification is presented; following the classification frame, different items should have different approaches regarding inventory management. We use a combination between the traditional ABC's adapted classification, considering the sales performance (fast movers, movers and slow movers); the market segmentation and the product's life cycle evolution. The results point out the relevance of three internal factors in the flexibility of the supply chain, which are the lead time, the phase-out activities and the subsequent obsolescence risk in items management, and the cost function related with warehousing activities and with the invested capital. The overstock model shows the link between demand uncertainty and supply chain inventory flexibility, for different item groups.

Based on the work of essay II, we extended the contribution to the attribute of uncertain demand, considering the inventory sequential mechanism between different echelons in a chain. The extended research comprise five major scopes: (1) the effect of demand behaviour on multi-echelon overstock value; (2) the influence of lead-time changes; (3) the influence of service level changes; (4) capital restrictions on inventory value and the (5) influence of non-optimal overstock values. An additional scope is related with the influence of the network design stocking points on overstock value. Simultaneously, we study the application of the model using an illustrative example.

In essay III, we explore the concept of target setting in a multi-echelon supply chain, considering the demand uncertainty penetration through the different echelons. We use the overstock indicator to propose a balanced and integrated supply chain approach for each node. From the retail perspective, we suggest for a specific moment, the overstock to be targeted in upstream echelons, based on the demand uncertainty, existing stock level, lead time, agreed service level and cost function. With this methodology, managers can define their targets linked with down and upstream echelons and identify the most critical parameters to be monitored. The main results show the importance of the downstream stocks in the protection of the supply chain against the demand uncertainty effect, also as the link between echelons when non optimal values are considered. We propose a corrective factor that can be used in the target setting process, to close the gap between realistic targets under uncertain environments and performance evaluation.

In essay IV, we employed a sequential decision frame applied to inventory management, considering the dynamic of supply chain nodes interaction. We base our reasoning in the right sequence and value of inventory in a multi-echelon supply chain. In each stage the management team decide the overstock level and, at the same time, they judge whether to exercise it or not. The decisions are optimised using a sequential approach. The analysis considers that the overstock value at one echelon depends heavily upon the overstock availability at other nodes. Only when the overstock goal of downstream echelon is defined, the overstock of the previous stage can be planned. But, on the other hand, in real terms, if the upstream overstock target is not achieved, it is not possible to increase stocks in the next stage, considering a capacity balanced supply chain. Based on the results, we support integration and alignment in inventories decision process to protect the supply chain from the market uncertainty. We conclude that the overstock is more sensible to lead time and service level changes in the downstream echelons, where the changes are more expressive with higher implications. We use the concept of a multi-echelon overstock as a flexible inventory planning technique in uncertain environments. We extended the application for different stochastic processes.

In the same line of research on uncertainty impact in supply chain management, valuing the flexibility, we explore the capacity problems. First we incorporated capacity restrictions on the multi-echelon overstock model. Second we study options value on technology capacity. Our approach is close to value an investment decision regarding an asset acquisition. The novelty is the consideration of demand uncertainty together with a complex frame, including the product mix variety. Supply chain decisions should account for demand uncertainty on products' portfolio. The product mix is an actual problem for most of the companies operating in markets where the products life cycle is becoming shorter and the need of innovation is rising, corresponding to the customer needs, balancing quality and prices.

The essay V investigates the manufacturing flexibility in the context of product mix strategy. We study the product mix strategy impact in the investment decisions process, especially by quantifying the investment decisions under demand uncertainty, examining the impact of different equipment features on investment flexibility value and incorporating product mix between standard and customized items. The motivation for this essay is driven by firms' desire to satisfy customer specific needs yet respond to them quickly, under uncertain demand. Indeed, the challenge presented in this study is timely. Today's firms are constantly trying to figure out better ways to exploit economies of scale, while satisfying an increasing demand for highly customized products. Such an article, with a well sustained case study, might prove useful and inspirational to firms who are looking to implement such decision frameworks, in order to evaluate the opportunity to invest in flexibility enabling technology. Overall the study looks at standard and customized production systems and the decision to invest in a set of resources that will enable the choice.

Paper number five (essay VI) is devoted to workforce capacity problem. A model is presented to support changes in workforce, considering a complex formulation covering most of the actual workforce planning issues. The novelty concerns to the incorporation of demand uncertainty and service level. In this paper we model the timing decision in adding labour shifts to respond to stochastic demand. A numerical experiment is provided to illustrate the proposed method. This study deals with the decision on creating or not a new work shift, which is a relevant decision point to the management of production systems. We consider that the introduction of a new work shift implies an investment that is not fully reversible and we use real options theory to deduct the optimal time to implement the decision. We explore the link between the service level target and the variable decision for an additional shift. For the generality of the model we used two stochastic processes to represent the demand behaviour. We incorporated in the model many parameters used for planning purposes, such as overtime, but also with strategic concerns regarding the workforce composition. We used the service level improvement value concept as a flexibility measure to quantify the workforce shift changes, according to a service level target.

Paper number six (essay VII) is about supply chain network design, considering the option to integrate or outsource activities. There are a large number of studies on outsourcing, which consider the variability of the costs as the main hedging tool to deal with the market uncertainty, yet often penalizing the profit function of the company. The change from vertical integration to outsourcing creates a loss of direct access to information and integrated control throughout the entire supply chain.

As a result, in the past at least, some of the expected gains from outsourcing have failed to materialize due to the lack of accurate and shared information. A flexible supply chain can respond efficiently to real-time changes in the cost, quantity, or mix of products that the market demands, only if there is accurate real-time information about supply and demand conditions. In this essay we explore the integration strategy, to help managers deciding to change from outsourcing to integration and defer commitment until future uncertainties are partially solved. The major concerns are related with the moment for the change, under demand uncertainty and considering the profit function prior and after the decision, which can be full or partial. The change in the strategy can imply additional resources, for which a preparation stage is required, triggering irreversible costs.

At the end we explore the design of business plans models, mainly referring to the number of planning periods. Companies need to plan their activities and to establish targets for their performance, for which a plan and a budget are required. Most of the times these revision periods represent important information arrival that can be used to correct or adjust forecasting models. We also want to reinforce the difference in the utility of such plan and budgeting periods considering the time that is being projected, from a short term approach to long term estimation. We use essay VIII to develop a dynamic business plan model. A business plan guides the company profitability and helps managing the release of additional investments or resources. The more flexible a plan is in responding to future market changes, the more successful the business evolution is likely to be. The flexibility of a business plan is based on the extent of the milestones used to promote changes in the commitment of resources, considering the analysis of past results, but also the arrival of new valid information. For generality we contribute to the extension of plans analyses, informing the value of a dynamic business plan. We explore the marketing projects to support our reasoning about plans flexibility; nevertheless, the model can be extended to all situations regarding sequential investments or projects.

11. SUMMARY OF PAPERS

This thesis consists of this introductory essay (I), where the problem statement, research objectives and methodologies are discussed, five more essays on supply chain flexibility under uncertainty and a last essay on business plans flexibility. Essay I also provides the summary of the essays, their contribution to the literature and their implications. After each essay (paper) summary (abstract), a brief description will follow about the purpose, methodology, findings, practical implications, originality, limitations and future research.

11.1. ESSAY II: OVERSTOCK – A REAL OPTION APPROACH

In the last decades, firms have been facing a new challenge, considering the increasing uncertainty of the markets and the pressure to achieve better levels of performance within the stake-holders expectations. Three main problems have emerged in dealing with management performance: the increasing pressure to reduce working capital, the growing variety of products and the fulfilment of a demanding service level. Most of the popular indicators have been developed based on a controlled environment. A new indicator is now proposed based on the uncertainty of the demand, the flexibility of the supply chains, the evolution of the products' life cycle and the fulfilment of a required service level. The model to support the indicator is developed using a real options approach.

Purpose – The goal of this paper is to find the optimal inventory excess that is most valuable to the firm, at a certain moment, considering the impact of demand volatility.

Methodology/approach – In order to achieve the aim of this work, we use the real options theory to coverage demand uncertainty risk inside the supply chain, valuing the flexibility and the capacity to decide the exercise of such options.

Findings – A useful theoretical framework has been described, enabling the selection of inventory options to protect the firm against the risk originated from market demand source of uncertainty.

Practical implications – In the paper, a framework providing useful information on inventory management under uncertainty demand within supply chain management, is presented.

Originality/value – The paper attempts to provide an original application to the concept of "overstock", based on a new items' classification that is proposed, able to hedge against market demand uncertainties, as an alternative model for inventory management.

Limitations – This model is a single stage model, which does not count with supply chain echelons interactions. The demand is modelled considering one stochastic process, the impact of capacity constraints and resources availability has not been addressed. These limitations will be solved in the next papers.

Future research –The extension of overstock concept applied to a multi-echelons approach, including several stocking points, will be a plus. This extension will be explored in the next papers.

11.2. ESSAY III: TARGET SETTING UNDER UNCERTAINTY

The main goal of this study is the definition of a key performance indicator, able to measure the impact of the demand uncertainty in a multi-stage supply chain inventory level. Despite the traditional bullwhip effect being normally analysed considering the particular dimension of the demand volatility in the amplification of upstream orders, an endogenous effect can be found and measured using a new indicator, able to help managers understanding the demand uncertainty penetration in the different stages of a supply chain. With this metric, managers are able to establish a more reliable target for their stock level, in each node, according to the risk exposure, promoting the optimisation of the invested capital in an aggregated supply chain analysis. The mathematical model is supported on the real options methodology. Overall, our investigation increases the knowledge related with demand's uncertainty treatment in supply chain performance.

Purpose – The goal of this paper is the definition of a new indicator multi-echelon overstock, to define targets for the optimal inventory excess that is most valuable in a multi-echelon perspective, at a certain moment, considering the impact of demand volatility along the supply chain.

Methodology/approach – In order to achieve the aim of this work, we utilize the real options theory to coverage and measure the demand uncertainty impact along the supply chain, valuing the flexibility and the capacity to define targets to support the exercise of such options in a performance framework. We adapted the Black and Scholes formula to consider more than one echelon under a fixed time frame, which is valid because we limited the study for target setting purposes.

Findings – A theoretical framework has been added to previous paper, exploring multi-stage inventory systems and supply chain performance.

Practical implications – In the paper two questions are addressed: one is the discussion on how the overstock level at one stage affects the level of the overstock in another linked stage, and the other explored the quantification of the impact of demand uncertainty along different stages of a chain.

Originality/value – The paper attempts to provide an original indicator that can be used as a corrective factor to close the gap between performance evaluation and uncertainty impact, in a target setting approach. This model considers multi-echelon interactions.

Limitations – This model is designed for target setting purposes, which does not count with supply chain planning restrictions and is not based on a sequential decision process. The demand was modelled considering one stochastic process. These limitations will be solved in the next papers.

Future research –Future developments can be done considering the dynamic of supply chain nodes interaction and different supply chain designs. In the present study we assumed a static supply chain network configuration with a defined number of echelons. In real terms, the design and the dynamic link between stages can influence the uncertainty effect.

11.3. ESSAY IV: INTEGRATED INVENTORY VALUATION IN A MULTI-STAGE SUPPLY CHAIN

The pressure to reduce inventory has increased as competition expands, product variety grows and invested capital costs increase. This investigation addresses the problem of inventory quantification and distribution within a multi-stage supply chain, under market uncertainty and management flexibility. The approach is based on an optimisation model, emphasizing the demand uncertainty and the relevant dimensions of supply chain design, as number of stages, lead time, service level and processing activities cost. Overstock quantification enables the understanding of inventory level sensibility to market uncertainty. A comparison among supply chain stages revealed that higher downstream overstock levels decrease upstream stages uncertainty exposition. The contribution of the study relies on management ability to balance inventories, in each node, according to risk exposure and promoting the optimisation of the invested capital in multi-stage supply chains. Overall, the investigation increases the knowledge related with demand's uncertainty treatment in flexible and integrated supply chains.

Purpose – The goal of this paper is the discussion on a multi-stage overstock, under a sequential decision process, to support the planning interaction between different echelons. It aims the calculation of an integrated and balanced global overstock value, and allows the quantification of the marked demand uncertainty in the upstream stages of a supply chain (independently of the extension of the concept to single or multiple firms).

Methodology/approach – In order to achieve the aim of this work, we utilize the real options theory to coverage and measure the demand uncertainty risk impact along the supply chain, valuing the flexibility to exercise such sequential options. We explored the problem using a binomial tree. This technique allows the consideration of a period of time rather than a single period which endows to split a planning period, considering different lead times in each echelon. On the other hand it is a relatively simple technique compared to other models and hence can be easily developed.

Findings – A theoretical framework has been added to previous paper exploring sequential decisions valuation.

Practical implications – The paper emphasizes the impact of lead time, service level and activity costs undertaken in each echelon in the global overstock value, under conditions of market demand uncertainty. In real terms it also reinforces the impacts of a balanced multi-echelon approach.

Originality/value – The paper attempts to provide an original global inventory approach, considering the link between different echelons and the impact of non-coordinated decisions, which importance is highly recognized when the echelons are subject to different management responsibilities. Besides the impact of market uncertainty, unbalanced management purposes also intensify the effect of inventory level in the upstream stages.

Limitations –Besides the provided discussion on the integration and coordination of firms and supply chain, we did not consider any corrective factor in the model.

Future research –A future research topic can be explored regarding the interaction of the concept of firm and supply chain, mainly introducing integration factors to reflect the level of coordination. Also an interesting research point is the interaction between different planning periods.

To support the generality of the paper and the results an appendix has been developed and incorporated in this essay.

11.4 ESSAY V: PRODUCT MIX STRATEGY AND MANUFACTURING FLEXIBILITY

The manufacturing industry is facing a turbulent and constantly changing environment, with growing complexity and high levels of customisation. Any investment solution should address these problems for a dynamic market and within limited budget boundaries, so that companies try to remain competitive. The authors propose a real options model to support firms making important investment decisions, specifically decisions associated with the acquisition of new equipment aimed at allowing firms to increase their manufacturing flexibility for the production of both standard and customized products. This paper is partially based on a real operating experience related to visual finishing technology features in an industrial company that conforms to the definitions of the product mix. The authors' motivation for this work is driven by firms' desire to satisfy specific customer needs, and to respond to them quickly under uncertain demand. Our goal, using theories from finance, production management, and product offering management, is to conclude that there is a relevant difference between the evaluation of the technology that is to be chosen, and the potential value due to product mix adaptations that are able to provide the maximum return from investment. We address problems related to standard and customized production systems, and the decision to invest in a set of resources that will enable this choice.

Purpose – The goal of this paper is to discuss investments in capacity extensions considering future product mix flexibility and market demand uncertainty. We address questions related with product mix customisation impact, flexibility impact in investments evaluation and risk share between partners in a supply chain.

Methodology/approach – In order to achieve the aim of this work, we utilize the real options theory to coverage and measure the demand uncertainty impact also as to include the potential value from changes in the product mix of the company.

Findings – The potential flexibility of an investment in the way to deal with product mix complexity adds value to the decision. Companies are facing and struggle against more demanding markets, requiring a much higher diversification of products, which complicates the manufacturing processes that were decided and intended to persecute standardized activities, capitalizing on the benefits of economies of scale.

Practical implications – The paper emphasizes the impact of market demand uncertainty, product mix complexity (balancing between standard product mix and customized product mix), process sequence, and risk sharing, considering adaptation costs that result from the customized products requests in the investment features evaluation.

Originality/value – The paper attempts to support original investment decisions incorporating the product mix flexibility value.

Limitations –The division between standard and customized product mix was defined based on a parameter. The model does not consider sequential investments.

Future research –Products customisation can be originated by the need to adapt the offer to new markets, where the demand has different behaviours, by the need of differentiation in existing markets, or as the result of innovation activities that extend the portfolio of the company to reinforce actual situation against competitors or gain market share. As so, the consideration of the main reasons for the customisation can contribute to a better representation of stochastic demand, splitting standard product mix behaviour from different classes of customized products, emphasizing the causes for such product mix enlargement.

11.5. ESSAY VI: LABOUR SHIFTS PLANNING UNDER DEMAND UNCERTAINTY AND DIFFERENT SERVICE LEVEL TARGETS

Firms that experience demand uncertainty and demanding service levels face, among other things, the problem of managing the number of shifts. Decisions regarding number of shifts involve a significant capacity expansion or release in response to a change in demand. We will quantify the impact of anticipating a shift workforce expansion that is treated as an investment while considering required service level improvements. The decision to increase a shift, whether it involves the use of temporary workers or the hiring of permanent employees, is one that involves significant risk. Traditional theories consider investments as reversible and thus do not capture the idiosyncrasies of shift management, in

which costs are not fully reversible. Using real options theory, we quantify managers’ ability to consider that irreversibility and to make shift decisions under conditions of uncertainty with maximum flexibility. Our model helps managers taking decisions on shifts expansion that are more accurate under service level targets, and to defer commitment until future uncertainties can at least be partially resolved. Overall, our investigation contributes to studies on the time taken to introduce a labour shift change, while valuing service level improvements.

Purpose – The goal of this paper is to discuss workforce planning, mainly shifts increase under conditions of market uncertainty and targeting different service levels.

Methodology/approach – In order to achieve the aim of this work, we utilize the real options theory to coverage and measure the demand uncertainty impact, also as to include the influence of different service levels in workforce planning problems.

Findings – The model supports decisions regarding workforce shifts adaptation, considering the potential value from service level increase, according the market requirements, under conditions of market demand uncertainty. The study addresses several workforce strategic and planning issues, like labour link (temporary versus regular workforce), skills, or overtime.

Practical implications – The paper emphasizes the impact of market demand uncertainty, and service level requirements in workforce planning decisions.

Originality/value – The optimal timing regarding a workforce shifts expansion is an important input as the workforce training/adaptation requires a preparation period that should be anticipated. The trigger moment that supports the change can avoid future losses regarding lack of capacity to perform the required operations and to support potential sales. We provide different demand representations which contribute to the generality of the proposed model. Under these conditions we also value the changes in workforce due to efficient practices or technology upgrades. These practices can support a decrease in the required workforce size.

Limitations –Despite the discussions regarding the consequences of the inclusion of temporary workers, we did not quantify the potential consequences in the increase of quality problems, also as the lack of goals alignment which can have negative consequences on the efficiency of the work station under analysis.

Future research –For future developments it is possible to include in the model other constraints, mainly exploring the preparation period for the workforce adaptability, which affects the time frame between the decisions and the operative date.

11.6. *ESSAY VII: VERTICAL INTEGRATION TIMING STRATEGY UNDER MARKET UNCERTAINTY*

Outsourcing and integration strategy are actual topics on supply chain area. From strategic integration decision to capacity availability incurs time and costs at the preparation stage. The timing strategy takes into account a firm's effort at the preparation stage. The capacity to be installed, the related fixed costs and the production marginal costs evolution will be determinant for the timing to change. We intend to quantify the impact of anticipating a capacity expansion, treated as a risky investment in a strategic vertical integration. Traditional methods consider investments as reversible and thus, do not capture the idiosyncrasies of capacity management, in which costs are not fully reversible. Our model helps managers to more accurately decide to change from outsourcing to an integration strategy and defer commitment until future uncertainties, related with market and lack of information, can be partially solved. Finally, we provide a time framework for decision support system considering the preparation period.

Purpose – The goal of this paper is to discuss decisions regarding integration versus outsourcing under conditions of market uncertainty, addressing the trigger moment for the decision to change, including the impact of a preparation period, which can be relevant in integrating activities, as they normally require additional equipment investments and workforce preparation.

Methodology/approach – In order to achieve the aim of this work, we derive the real options theory to coverage and measure the demand uncertainty impact also as to include the influence of a preparation period in network decisions. The methodology supports flows in both directions of change, from outsource to insource or vice-versa. The main discussion is about costs irreversibility. Integrating activities require costs that are irreversible or partially reversible, on the opposite, the outsourcing decisions are also affected by irreversibility. We support this generalization based on previous studies that present cost of the change, mainly the costs of dismantling or inoperability of existing facilities (e.g Yao et al., 2010).

Findings – Our main findings follow the logical principle in financial economics supporting that no decision should be undertaken unless its net benefits at least compensate for the loss of "option to wait" (Dixit, 1989; Huchzermeier and Loch, 2001; McGrath, 1997).

Originality/value – we contribute to the current literature by increasing the application of option models to capture total values in irreversible situations, supporting the decision-making. The optimal timing regarding the change is a plus but a special attention has been drawn in the preparation moment to support the change.

Limitations –The paper did not consider the evaluation of a partial decision. To solve this limitation we add an appendix. Nevertheless another limitation remains valid, which is related to sequential decisions framework, considering different times to be applied for the sequential partial decision.

Future research – The model relies on two key assumptions. First, we assume that demand conforms to geometric Brownian motion, which implies that when the demand process hits zero, it stays at zero (e.g. the firm can goes out of business). Second, we assume an infinite horizon and stable parameter values over time. Investigating the sequential change from one strategy to another by using different trigger moments, linked with demand evolution, are worthy topics for future research.

To extend the paper presented an appendix has been developed and incorporated in this essay, addressing one of the limitations listed above, related with partial decisions. We exposed the potential value between two alternatives using the optimal moment for the decision, an optimal profit approach is then modelled, where different regimes are incorporated, considering both full and partial insourcing.

11.7. ESSAY VIII: FLEXIBLE BUSINESS PLANS IN DYNAMIC MARKETS: A STRATEGIC APPROACH

Management flexibility has become a relevant issue as the market uncertainty increases. Any plan should address this uncertainty in a dynamic market, within limited budget boundaries; therefore, the purpose of this study is the development of a predictive model to provide insights to business planning, valuing the extent a plan can endure a set of likely evolutionary changes. We assume that the main target of a business plan is to guide the market profitability using additional investments. We will focus our attention on market changes and their impact on the project budget. We derived our model from the real options methodology: the analogy, the assumptions, formulation and interpretations. Our main results and conclusions rely on the differences in the decision evaluation for each milestone, also as on the potential value from the adaptation of project budgets. The managerial problem for which we address our investigation is the fact that a business plan is going to be executed in a working environment that is dynamic. The paper enables to quantify the impact of uncertainty in business plans evaluation, complementing the traditionally management tools based on a payback analysis.

Purpose – The goal of this paper is to discuss sequential decisions process under conditions of market demand uncertainty stressing the importance of flexibility in the number of decision points.

Methodology/approach – In order to achieve the aim of this work, we derive the real options theory to coverage and measure the demand uncertainty impact, also as to include the influence of different number of milestones.

Findings – Our main findings are related with the value of sequential decisions, mainly in what concerns irreversible investments where the release of partial investments increases the value of the options.

Originality/value – We contribute to increase the solutions for general business plans analysis, considering demand uncertainty and the plan design. An emphasis is done on the number of decision points in the plan evolution.

Limitations –We consider the same volatility affecting all the possible decision points.

Future research – The model should be extended to include different levels of uncertainty during the project life.

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ESSAY II: OVERSTOCK – A REAL OPTION APPROACH

ABSTRACT

In the last decades, firms have been facing a new challenge, considering the increasing uncertainty of the markets and the pressure to achieve better levels of performance within the stake-holders expectations. Three main problems have emerged in dealing with management performance: the increasing pressure to reduce working capital, the growing variety of products and the fulfilment of a demanding service level. Most of the popular indicators have been developed based on a controlled environment. A new indicator is now proposed based on the uncertainty of the demand, the flexibility of the supply chains, the evolution of the products' life cycle and the fulfilment of a required service level. The model to support the indicator is developed using a real options approach.

Keywords: overstock, stock management, real options, supply chain

1. INTRODUCTION

Stock levels depend on the internal management capacity and flexibility, which is easier than to deal with unpredictable clients or powerful suppliers (outside partners). The focus has turned to stock levels requiring managers to think in a different way.

Several authors have stated that inventories are perceived with scepticism and as a bad management practice, due to funds allocation, disguise quality problems, uncoordinated and individual attitudes in a supply chain and the associated costs that tend to be very relevant for the firm profit and loss statement (e.g. Ballou, 1999; Katz, 2006).

Capital management is a task assigned to the financial department, which considers the stock of low rotating items as an element to slow the cash flow and the stock of movers as a very risky decision, when the demand is highly volatile. It is difficult to decide whether to have or not stock, mainly when the causes that provoke the buffer (e.g. lack of capacity, highly volatile demand, unreliable supplies, very demanding service level), in certain nodes of the supply chain, are not clearly understood.

Traditionally, managers tend to analyse stock risk using the turnover. This metric gives a general idea of the potential problems, but it makes more difficult the communication between financial and supply chain managers. Even the storage time approach, as a more recent indicator, going deeply in the analysis of stock aging, cannot solve the gap of communication between finance and logistics because this indicator focus mainly on the past and historical data.

But why companies need inventory? According to Chase, Jacobs and Aquilano (2006), the main challenges of an inventory strategy are to allow independence between operations, minimize impacts of demand variability across the supply chain, allow flexibility in the resources planning, protect from delays in sourcing and use favourable purchase conditions. Also Joseph, Larrain and Singh (2008) presented the main goals to justify the existence of inventory, like production scheduling improvement, production smoothing, stock-out costs minimization, purchase costs reduction, prices speculation or hedging and at the end to shorten the delivery days. Based on these opinions, we can justify the existence of stocks using the main reason for their existence, which is the need to guarantee a certain service level considering demand variability.

Excess stock, overcapacity and excessive lead times or even "over" planning, can be seen as internal corrective or preventive actions to avoid, or to compensate, the poor service level perceived from the exterior of the chain (Forslund and Jonsson, 2007).

Besides the traditional financial perspective about the negative impact on invested capital, stocks allow shorter lead times in a competitive market, with demand uncertainty, and manage customer strategy and service, avoiding a shortage or backorder.

Our goal is to find the optimal inventory excess that is most valuable to the firm, at a certain moment, by using different levels of demand volatility. We present an alternative model for inventory management, based on real options, considering the need of an excess in inventory value, depending on the demand uncertainty levels and addressing risk in an economically feasible way. Uncertainty creates opportunities that can affect the way inventory is managed, which are not considered by the traditional tools.

2. LITERATURE REVIEW

Many studies have pointed the inventory level as a buffer to minimize the impact of demand uncertainty, specifically in what concerns the safety stock (e.g. Antanies, 2002; Forslund and Jonsson, 2007; Jian and Ma, 2004; Lapide, 2008).

The appropriate level of safety stock is determined considering the uncertainty of demand or supply and the desired level of product availability (e.g. Ballou, 1999). As uncertainty and the required item availability increases, also the safety stock will increase (Chopra and Meindl, 2001).

The traditional models split costs considering ordering or replenishment costs, carrying costs and costs of insufficient demand (stock out costs) (Ballou, 1999; Silver, 2008; Silver, Pyke, and Peterson, 1998). Heijden (2000) notes that the service level fulfilment is usually included in traditional inventory models by using a penalty cost on shortages when minimizing inventories (also referred by Handfield, Warsing, and Wu, 2009). The safety stock minimization depends on two different costs, under an inverse relationship, the first is the cost of holding stocks, and the second is the cost of being out of stock. The concept of economic order point (EOQ) relies on the trade-off between the fixed order cost and the holding cost. The conventional approach doesn't consider any future value on inventory carried within the firm neither the potential profit coming from uncertainty. Considering this, the real options approach in inventory management will have an advantage over the traditional models (Osowski, 2004).

To solve the problem of uncertainty we can find in literature different approaches, like the calculation of a reserved stock (e.g. Tan, Güllü, and Erkip, 2009), improve information using forecast methods or decision support systems (e.g. Matuyama, Sumita, and Wakayama, 2009; Moole and Korrapati, 2004), improve order prioritisation from retailer (e.g. Bish, Liu, and Suwandechochai, 2009), share information among the players in the chain (e.g. Ryu, Tsukishima, and Onari, 2009; Sheffi, 2001), use flexibility in sourcing or adjusting the yield rate of the internal resources (e.g. Mukhopadhyay and Ma, 2009). Techniques extending linear programming model, by considering uncertainty and cash flows (e.g. Sodhi and Tang, 2009), discrete event simulation models with uncertainty impact (e.g. Walsh, Williams, and Heavey, 2007) or multi-stage stochastic optimisation (Lusa, Corominas, and Muñoz, 2008) have been used. Song, Zhang, Hou and Wang (2010) presented the reorder point and order quantity, based on optimal policy parameters to deal with demand uncertainty, but limited to one single item which, according to Hemmelmayr, Doerner, Hartl and Savelsbergh (2010), does not consider the relevant product mix uncertainty.

The basic inventory decisions show how much inventory to purchase or carry when facing uncertain demand. Conventional inventory management techniques suggest stocking an inventory level that maximizes expected profits, but cannot handle risk or the time value of money in a theoretically acceptable form (Osowski, 2004).

We can find some examples related with the applications of option pricing in the inventory problem, like Becker (1994), Chung (1990), Stowe and Gehr (1991), and Stowe and Su (1997) who described inventory as an option on future sales. Osowski (2004) improved the work of Stowe and Su (1997) using bull spread options (long and call options), to determine the optimal level of inventory held by a prototypical agribusiness firm. The use of real options is justified to value opportunities, specifically, when applied to inventory problems, real options focus is to value inventories as an option on future sales, also as giving value to uncertainty by allowing more flexibility in the decision process. Our work can be linked with Osowski (2004) in what concerns the utility in the use of contingent claims, specifically real options, when applied to inventory decisions and also with one of the conclusions referring that a higher demand uncertainty level creates higher value. Our work differs from Osowski (2004), mainly because we apply a single option to determine the optimal excess of inventory, considering product demand volatility, for each item category, by comparing the value of optimal stock (underlying asset in our model) with the existing one (exercise price), instead, the related author method is to find the optimal inventory level and only after apply an option on that value.

3. REAL OPTIONS

The origin of the term "real option" go back to 1977 and was coined by professor Stewart Myers (Moel and Tufano, 2000; Myers, 1977), later was popularised by Mauboussin (1999), who used the concept to explain the gap between "business intrinsic value", as calculated by traditional tools like the discounted cash flows, and the "stock market value" as it is perceived by investors. Gertner and Rosenfield (1999) defined real options as a method to value opportunities associated with the possibility of changing decisions in order to solve uncertainty, which differs from the traditional discounted cash flow technique. In opposition to financial options, real options require active reaction of the management team. Real options can be seen as a mechanism to support the decision process and as a way to value managers' team flexibility. The potential value is not a tangible asset neither a trade of underlying asset in liquid markets. Considering this fact, real options have no market price (there is no capacity to estimate the future unit price as there is no forward market) (Boyer, Christoffersen, Lasserre, and Pavlov, 2003).

4. OVERSTOCK AS A REAL OPTION

When a company faces a stochastic demand, in scale and mix, it is required an efficient resources management, also as the adaptation to restrictions in the capacity of the supply chain, according to the required volume and time. In this situation, the managers should choose alternatives that are able to minimize the risk of inventory and the risk of not having the item available, in face of a demand manifestation.

In the past, the process required to strive for shorter lead times, shorter invested capital and shorter costs, changed the supply chain in order to become leaner. But, from September 11th 2001, a new feeling of uncertainty rose and changed the form of managing the supply chain. Many companies faced unexpected disruptions in global supply chains, due mainly to the reaction of the Government in protecting against terrorist attacks (Sheffi, 2001; Sheffi, Rice, Fleck, and Caniato, 2003). The physical flow of materials depends on the availability of infrastructures (from the firm, the suppliers and the public global providers). Dual source strategies rise to minimize the risk associated with a disruption and companies complemented the "just in time" concept with the "just in case" concept (Sheffi, 2001), which means a revaluation of the need of safety stock, both on source and client delivery. In nearby periods, other authors defended that planning should change from a push centralized strategy to a pull market oriented strategy (e.g. Sengupta, 2004). Both ideas seem to be opposite since a pull strategy is related to make to order and minimum stocks level (just in time). In fact, we can close the gap using a Push-Pull boundary (combination of a pull and push strategy), by determining the optimal location (e.g. using a Multi-echelon Inventory optimisation tool) and the form to store inventory in a chain (components, semi-finished product, finished product at the Plant, etc.,) (Simchi-Levi, Kaminsky, and Simchi-Levi, 2004). This explains the need of changing the tools that support the stock management, from a historical data support to a future data based, within limitations of resources, but minimizing the risk.

Most of the applications of the term overstock were related with excess of stock. In 2007, new approaches were done using the concept of overstock risk (Jia-zhen, Jian-jun, and Jin, 2007). Recently, Ding and Chen (2008) considered overstock an avoidable and shared loss between supply chain players.

The use of the real options approach requires a specific discussion regarding two possible limitations, one related with the quantification of the capacity extension and with the irreversibility of the decision. For the first, we assume that there are no resources shortages or capacity constraints. However, in what concerns irreversibility, we follow Henry (1974) for whom, the irreversibility can be seen as a limitation for the application of the resources within an extended period of time. If there are no capacity constraints, there are available resources which incur in a opportunity cost, as so, the limitation of use support the irreversibility to the application of the real options methodology. We also reinforce the flexible interpretation of irreversibility in real options referring to Santaniello theorem (Santaniello, 2005) of irreversible benefits (used by Demont et al. 2004; Wesseler et al., 2007).

4.1. MODEL ASSUMPTIONS

Considering an installed capacity and restrictions in the use of an outsource option, it is possible to use an option value on the inventory, meaning the use of an option to increase stock. This option should be based on the demand uncertainty, in quantity and mix, to allow risk minimization of a negative answer to a client request. An option on inventory allows risk minimization of product shortages, for which the company assumes a lead time, and it forces the minimization of the out-of-mix stock risk for excessive inventory. For the basis of our model we consider that there is a relation between demand uncertainty and inventory (e.g. Schmitt, 2008), and between product portfolio and inventory (e.g. Stalk, 2008). The uncertainty affects the demand (as a stochastic process) but also the combination of items (as a logistic basic unit part) – this is what we can call as “the mix effect”.

In the present model, overstock is defined as the excess above maximum stock. This excess, allows the minimization of sales lost risk, due to restrictions in the available capacity of the supply chain. To apply this concept, an item classification is required, changing the traditional "ABC" perspective (e.g. Peterson and Silver, 1979), to a more complex classification (e.g. Flores and Whybark, 1986; Graham, 1987; Guvenir and Erel, 1998; Jamshidi and Jain, 2008; Saaty, 1980), regarding the actual context of uncertainty, the mix variety and diversity, products life cycle decrease and the consequent innovation process increase. Considering these arguments, products should not be treated in the same way.

4.2. ITEMS CLASSIFICATION

The criteria normally used for items inventory classification has generally been based on the items' value. The use of a stock's classification is relevant as it tends to define the importance of the item in the invested capital on stocks.

Some studies were done in order to improve inventory management using other criteria, besides the value, like the obsolescence, lead times (of the supplier or manufacturer), substitutability, reparability, criticality or commonality (e.g. Graham, 1987; Guvenir and Erel, 1998; Ramanathan, 2006; Wiersema, 2008).

We are going to use a combination between the traditional ABC's adapted classification (based on Pareto's rule), using the turnover to split the items into three categories (fast movers, movers and slow movers); the segmentation (e.g. private labels) and the product's life cycle. We refer to the importance of the product's life cycle in inventory management (Ahiska and King, 2009), mainly in three states: the introduction, the end of maturity (decline) and the terminal phase (e.g. Ballou, 1999; Wiersema, 2008).

We will assume "A's" as the terminology for those items representing more than 80% of the gross sales value. These items can follow a make to stock procedure, depending on the existing push or pull strategy and they are defined as "fast movers". "B's" for items that fulfil the gross sales value gap between 80% and 95%. They can follow an assembly to order procedure, based on available components, in a stage where standardization is possible. They can be defined as "movers". "C's" is the name for the items with a low rotation, they are used to promote sales of A's or B's items (mix attraction) and should be stored on small batch quantities. They can be identified as "slow movers". "Sp's" for those items that are assigned to one client or market segment, nevertheless the use of a specific or shared distribution channel and their stock risk tends to infinitive. We can define them as "specific products" (niche oriented). "N's" is the name for the new items identified as "new products" or “phase-in products”, with a high risk exposure. “P’s” is the designation of the items that are in the end of the maturity stage, where there should be a preparation of the tools to allow a minimum phasing-out cost. For these items, risk is a variable with high probability to occur. They are known as “products with potential risk”. O’s for the items in the “death” stage with constant risk.

4.3. OVERSTOCK EXPRESSIONS

Overstock should be calculated by item group, considering different demand quantities also as different service levels, using the previous classifications (A, B, C, Sp, N, P and O).

We are going to define the variables that will support the development of the model. The item code will be represented by “ i ”; number of weeks by “ w ”; standard lead time in weeks for each item by “ L_i ”; actual stock value (euros) for each item by “ I_i ”; historical sales value (euros) (each item) for “ w ” weeks by “ Vw_i ”; variance coefficient by “ α “ (depending on the item category); actual book of orders value (euros) (each item) for “ w ” weeks by “ δw_i ”; sales forecast value (euros) (each item) for “ w ” weeks by “ βw_i ” and item profit margin (sales unit price - unit cost) / sales unit price by “ θp_i ”.

Item classification	Overstock expression
A	$\sum_{i=1}^{n}\left[L_i\cdot\alpha_A\cdot\frac{\beta w_i}{w}\cdot(1-\theta p_i)\right]-\sum_{i=1}^{n}(I_i)\ ;\ i = A_1...A_n$
B	$\sum_{i=1}^{n}\left[L_i\cdot\alpha_B\cdot\frac{\beta w_i}{w}\cdot(1-\theta p_i)\right]-\sum_{i=1}^{n}(I_i)\ ;\ i = B_1...B_n$
C	$\sum_{i=1}^{n}\left[L_i\cdot\alpha_C\cdot\frac{\delta w_i}{w}\cdot(1-\theta p_i)\right]-\sum_{i=1}^{n}(I_i)\ ;\ i = C_1...C_n$
Sp	$\sum_{i=1}^{n}\left[L_i\cdot\alpha_{Sp}\cdot\frac{\delta w_i}{w}\cdot(1-\theta p_i)\right]-\sum_{i=1}^{n}(I_i)\ ;\ i = Sp_1...Sp_n$
N	$\sum_{i=1}^{n}\left[L_i\cdot\alpha_N\cdot\frac{\beta w_i}{w}\cdot(1-\theta p_i)\right]-\sum_{i=1}^{n}(I_i)\ ;\ i = N_1...N_n$
P	$\sum_{i=1}^{n}\left[L_i\cdot\alpha_P\cdot\frac{Vw_i}{w}\cdot(1-\theta p_i)\right]-\sum_{i=1}^{n}(I_i)\ ;\ i = P_1...P_n\ ;\ L_i = 0$
O	$\sum_{i=1}^{n}\left[L_i\cdot\alpha_O\cdot\frac{Vw_i}{w}\cdot(1-\theta p_i)\right]-\sum_{i=1}^{n}(I_i)\ ;\ i = O_1...O_n\ ;\ L_i = 0$

Table 1: Overstock expression

Table 1 presents formulas to support the calculation of the overstock value, by item group, based on demand forecasts, historical demand or book of orders, using a variance coefficient, reflecting the standard deviation. The overstock is the additional value that a company is willing to support in order to prepare future sales; in this way, the approach we present is related with value creation rather than cost minimization, which traditionally is applied to inventory analysis. It is a deterministic approach based on collected information. In the next step we will introduce real options to include stochastic demand also as different parameters in the overstock formula.

4.4. MODELLING OVERSTOCK AS A REAL OPTION

We consider the items classification previously presented as an auxiliary process, as the information of the output of this process depends only on the firm. We also assume that stocks refer only to manufactured items and the demand (quantity) is a stochastic variable (the firm does not have any influence on quantity and sales price, is a price taker).

We assume that the products can be analysed individually, according to a defined classification and lead times are fixed and known. We consider that any demand not fulfilled from inventory is lost at moment “t“, but we ignore the impact of losing market share in period “$t+1$“ due to a disruption in near time “t“.

The main question of the model is the calculation of the optimal value of the overstock in time “t“ (option value).

4.5. VALUING THE FLEXIBILITY

The decision is about the level of overstock value (stock above the previous existing level). The model will not consider the efficiency in the use of the available resources (this issue should be treated in the manufacturing flexibility) neither the restraints in the capacity, once we assume that is not relevant to the decision process. The overstock value should be calculated according to each product classification.

4.6. SOURCE OF UNCERTAINTY

The source of uncertainty is the demand (quantity) by item group, which we are going to represent by “$D(\overset{a}{i})$“. We consider that the company cannot influence the sales price with the level of overstock. The evolution of the demand is the most important input for the option valuation. We assume that the demand of each product category is stochastic and follows a geometric Brownian motion (assumption done also by Bengtsson, 2001; Pindyck, 1988; Tannous, 1996). The demand process can be presented as:

$$dD(\overset{a}{i}) \equiv \alpha D(\overset{a}{i})dt + \sigma D(\overset{a}{i})dz \tag{1}$$

Where $dz = \varepsilon(t)\sqrt{dt}$; $\varepsilon(t) \approx N(0,1)$; $\alpha =$ instantaneous drift; $\sigma =$ volatility; $dz =$ increment of a wiener process; where $\varepsilon(t)$ is a serially uncorrelated and normally distributed random variable.

From equation (1) we can state that the demand ($D(\overset{a}{i})$) is log-normally distributed with a variance that grows with the time horizon (also an assumption of the model presented by Bengtsson, 2001). The demand is modelled as a continuous process. We assume that all the production and stock policy is make-to-stock.

4.7. DECISION RULES AND PAYOFF

The modelling consists on the representation of the overstock option. The proposed model formulation is described as follows.

.Sets to support a general application for different echelons within the same or different supply chains:

- $\overset{\upsilon,Sc}{\varphi} \in \overset{Sc}{\phi}$ set of echelons in a supply chain Sc managed by a single company υ ,
- $t \in T$ set of planning period under analysis,
- $\overset{a}{i} \in \overset{a}{X}$, $\overset{a}{X} = A, B, C, S_p, N, P, O$ set the item group.

The parameters that support the model are referred to company υ , supply chain Sc and a single item group $\overset{a}{i}$: " $h(\overset{a}{i})$ " - stock aging factor; " $D(\overset{a}{i})$ " - demand in quantity for the item category; " $c_v(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})$ " - variable production cost of a single unit; " $p_v(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})$ " - unit sales price; " $1 - S(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})$ " - stock out rate for item class; " $K(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})$ " - value calculated as a function of the stock out rate (normal distribution); " $S(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})$ " - required service level for item category: % of the quantity fulfilled on the required date; " $L(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})$ " - lead time definition; " $j(\overset{\upsilon,Sc}{\varphi})$ " - Weighted average cost of capital, reported and adjusted to period t (simplification); "$\theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})$" - average stock unit cost; "$I_{t-1}(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})$" - existing inventory level in the beginning of period n; "n" - period between "$t-1$" and "t"; "$M_v(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})$"$=\left(p_v(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) - c_v(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})\right) . D(\overset{a}{i})$; "$k_s(\overset{\upsilon,Sc}{\varphi})$" - cost of holding stocks for each item for period n.

If we study one overstock option, which expires at time t, and gives us the option to adjust the stock level, if the benefits exceed the costs, respecting the maximum allowed capital, the value of the option at time "t", $\underset{\underset{\varphi}{\upsilon,Sc}}{\overset{\overset{a}{i}}{\Omega}}(t)$, can be written as:

$$D(\overset{a}{i}) \cdot \theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot L(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot K(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \left(1 - j(\overset{\upsilon,Sc}{\varphi}) - h(\overset{a}{i}) - \frac{k_s(\overset{\upsilon,Sc}{\varphi})}{\theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})} \right) - \\ - M_v(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \left(1 - S(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \right) - I_{t-1}(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \tag{2}$$

The value of the overstock option is the expected terminal value of the condition:

$$\underset{\underset{\varphi}{\upsilon,Sc}}{\overset{\overset{a}{i}}{\Omega}}(t) = \max \begin{bmatrix} D(\overset{a}{i}) \cdot \theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot L(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot K(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \left(1 - j(\overset{\upsilon,Sc}{\varphi}) - h(\overset{a}{i}) - \frac{k_s(\overset{\upsilon,Sc}{\varphi})}{\theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})} \right) - \\ - M_v(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \left(1 - S(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \right) - I_{t-1}(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}), 0 \end{bmatrix} \tag{3}$$

Where "$D(\overset{a}{i}) \cdot \theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot L(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot K(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})$" represents the stock value using the traditional approach; "$M_v(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \left(1 - S(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \right)$" represents the potential lost margin related to sales not fulfilled on time and "$j(\overset{\upsilon,Sc}{\varphi}) + h(\overset{a}{i}) + \frac{k_s(\overset{\upsilon,Sc}{\varphi})}{\theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})}$" represents the opportunity cost of the invested capital, the risk of obsolescence and the weight of the handling costs on the average stock unit cost.

s.t.

$$0 \leq \sum_{\varphi} \underset{\underset{\varphi}{\upsilon,Sc}}{\overset{\overset{a}{i}}{\Omega}}(t) \leq \underset{\upsilon}{C}^{t}, \forall \varphi \in \upsilon \tag{4}$$

$\underset{\upsilon}{C}^{t}$ = maximum invested capital value allowed in stocks for company υ , $\upsilon \in Sc$, for time t .

In this form, the overstock value can be expressed as a European call option (max{A-E,0}), where "$D(\overset{a}{i}) \cdot \theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot L(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot K(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})\left(1 - j(\overset{\upsilon,Sc}{\varphi}) - h(\overset{a}{i}) - \frac{k_s(\overset{\upsilon,Sc}{\varphi})}{\theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})} \right) - M_v(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})\left(1 - S(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \right)$" is the value of the underlying asset (A). The actual stock level $I_{t-1}(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})$ can be treated as the exercise price (E). An overstock manufacturing order should take place if $\underset{\underset{\varphi}{\upsilon,Sc}}{\overset{\overset{a}{i}}{\Omega}}(t) \geq 0$. The overstock option gives the right to increase stock level above the existing one, for each product category, and expires in time t .

Boundary conditions:

Absorbing barrier: 0; when $\underset{\underset{\varphi}{\upsilon,Sc}}{\overset{\overset{a}{i}}{\Omega}}(t) \leq 0$

Expiration optimal condition:

$$\max\begin{bmatrix} D(\overset{a}{i}) \cdot \theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot L(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot K(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})\left(1 - j(\overset{\upsilon,Sc}{\varphi}) - h(\overset{a}{i}) - \frac{k_s(\overset{\upsilon,Sc}{\varphi})}{\theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})} \right) - \\ - M_v(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})\left(1 - S(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \right) - I_{t-1}(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}), 0 \end{bmatrix} \tag{5}$$

Value matching at $\underset{\underset{\varphi}{\upsilon,Sc}}{\overset{\overset{a}{i}}{\Omega}}(t)^*$ (optimal overstock level):

$$D(\overset{a}{i}) \cdot \theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot L(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot K(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})\left(1 - j(\overset{\upsilon,Sc}{\varphi}) - h(\overset{a}{i}) - \frac{k_s(\overset{\upsilon,Sc}{\varphi})}{\theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})} \right) - \\ - M_v(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})\left(1 - S(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \right) - I_{t-1}(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \tag{6}$$

4.8. VALUING THE OPTION

The value of an overstock option, for time t, must satisfy the following differential equation:

$$\alpha.D(\overset{a}{i}).\frac{d\underset{\underset{\varphi}{\upsilon,Sc}}{\overset{\overset{a}{i}}{\Omega}}}{dD(\overset{a}{i})} + \frac{1}{2}.\sigma^2 \frac{d\underset{\underset{\varphi}{\upsilon,Sc}}{\overset{\overset{a}{i}}{\Omega}}^2}{d^2D(\overset{a}{i})} - r\underset{\underset{\varphi}{\upsilon,Sc}}{\overset{\overset{a}{i}}{\Omega}} = 0 \tag{7}$$

To solve the optimisation we will use the Black and Scholes model:

For simplification we will assume:

$$\begin{cases} A = D(\overset{a}{i}) \cdot \theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot L(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \cdot K(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})\left(1 - j(\overset{\upsilon,Sc}{\varphi}) - h(\overset{a}{i}) - \frac{k_s(\overset{\upsilon,Sc}{\varphi})}{\theta(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})} \right) - M_v(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi})\left(1 - S(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \right) \\ X = I_{t-1}(\overset{a}{i}, \overset{\upsilon,Sc}{\varphi}) \end{cases}$$

The equation to be solved:

$$\underset{\underset{\varphi}{\upsilon,Sc}}{\overset{\overset{a}{i}}{\Omega}}(t) = Ae^{-t}N(d_1) - Xe^{-t}N(d_2)$$

With,

$$\begin{cases} d_1 = \dfrac{\left[\ln\left(\dfrac{A}{X}\right) + \left(r + 0{,}5\sigma^2\right).t \right]}{\sigma\sqrt{t}} \\ d_2 = d_1 - \sigma\sqrt{t} \end{cases}$$

And $N(d)$ is the cumulative standard normal distribution function (we used the Excel function NORMSDIST to compute this value). It is the probability that a normally distributed variable with a mean of zero and a standard deviation of one would have a value less than d. "$\ln$" denotes the natural logarithm.

4.9. *VALUATION MODEL: NUMERICAL EXAMPLE*

The numerical example chosen is about the application of the concept within a flooring industrial company, considering a single stage. We are going to apply the concept to one of the categories, within the company portfolio, denoted by "CS". Considering the volatility of the demand distribution, of more than 20%, the firm needs to anticipate the stocks level to avoid disruptions. The problem is how to anticipate within a certain required level of performance. The demand is considered a stochastic variable, with a volatility assumption of 25%. In table 1 we will present the data to support the example. The notation has been simplified as we are testing the model in a product group and single stage managed by a single company.

Factor	Description	Value	Unit
D	demand quantity	262.051	m^2
I_{t-1}	stock value at the beginning of period	4.849.145	euros
h	stock aging factor	0,002	coefficient
c_v	variable production cost of a single unit	5,000	€/sku
p_v	unit sales price	15,000	€/sku
S	required service level	95,000	%
j	weighted average cost of capital	0,500	%/month
L	lead time definition	1,500	months
k_s	holding stock cost/unit for the period	0,263	€/sku
θ	average stock unit cost	7,500	€/sku

Table 2: Variables and parameters value used in the model

5. RESULTS OF THE MODEL

In this section we present and analyse the results from the application of the model to a case study.

First we applied the parameters value to the model and we calculated the overstock value (option value): $\Omega(t) = 323{,}7 \times 10^3$ euros. The obtained value means that the company should reinforce the stocks by 323,7 x 10^3 euros. Why this increase? The company potentially can sell 5.172,8 x 10^3 euros (323,7 + 4.849,1), if the company wants to use all the potential future sales, minimizing the risk of stock out, should provide additional stock.

The impact on the stock level due to the introduction of a stochastic variable will be analysed. The first approach will be the analysis of the impact of the growth of the demand on the overstock value, for different volatility parameters.

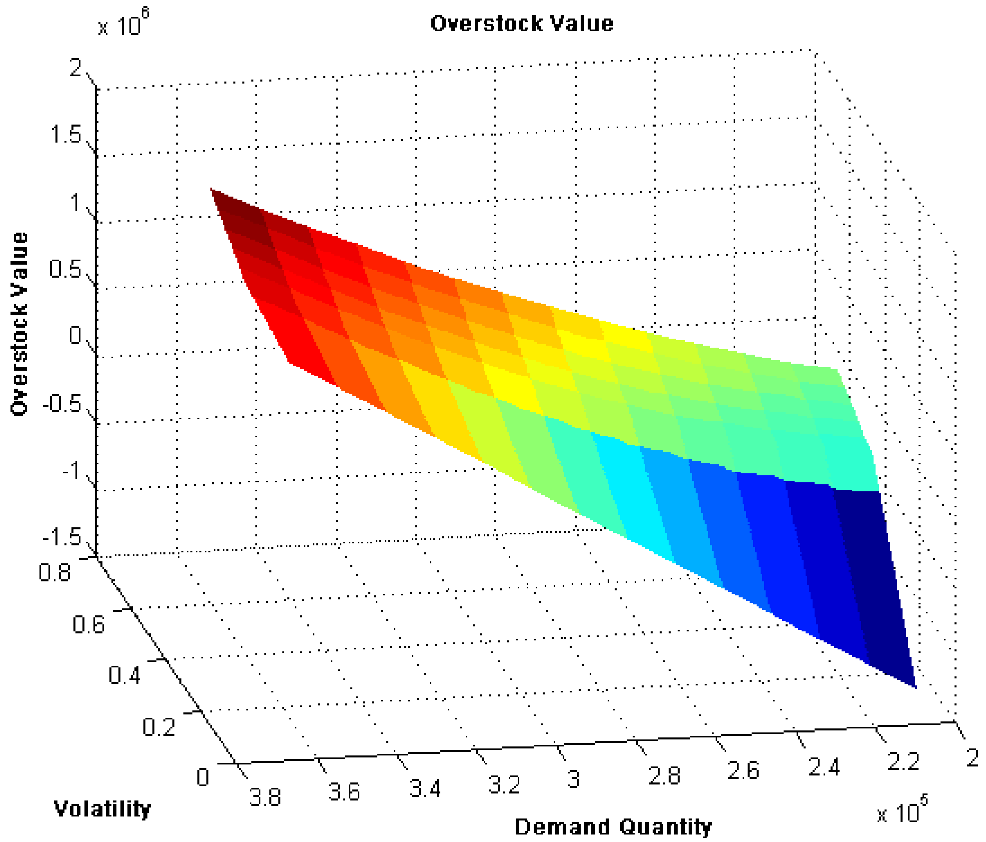
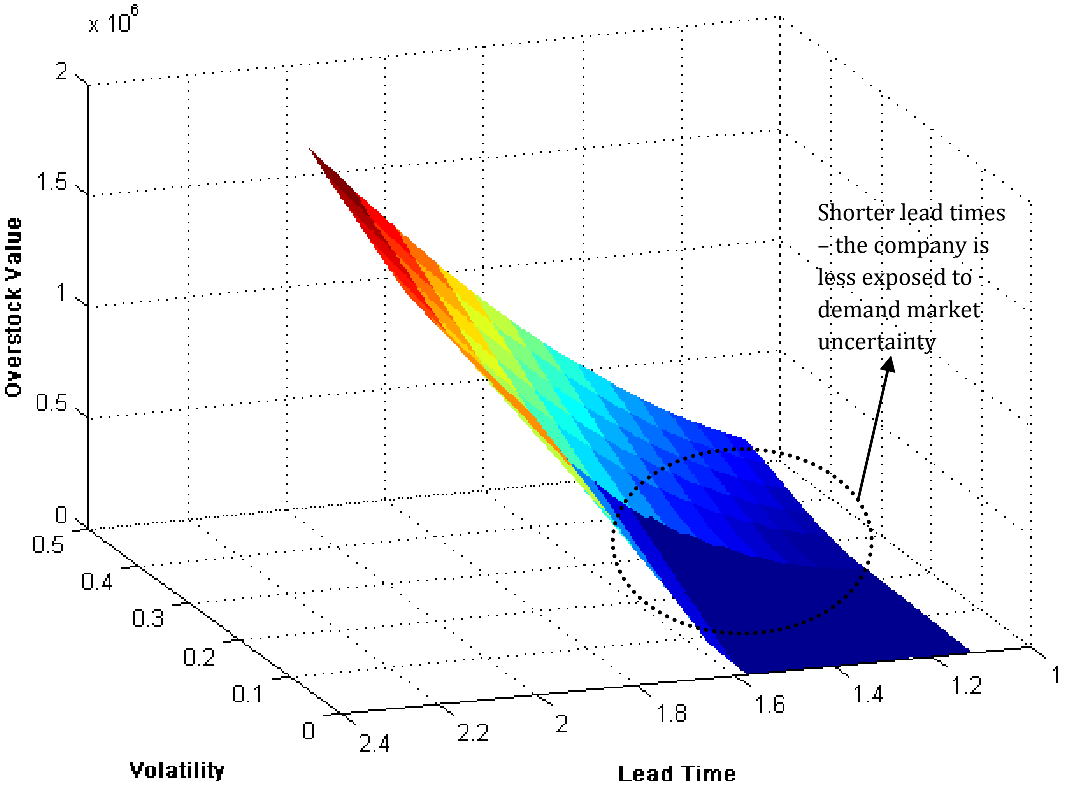


Figure 1: Demand quantity variation, demand volatility and the overstock value (euros)

In figure 1 we establish the relation between demand quantities, volatility and overstock value. The model presented does not affect the expected elasticity between overstock value and demand quantity, as stated in the graph. The results support the direct impact of demand quantity on the overstock value, which is in line with traditional techniques that suggest the calculation of the stock based on demand forecast, lead time and service level. Nevertheless, the most important results are those related with the inclusion of demand uncertainty. The overstock value refers to the excess of stock required to assure future sales, compared with an initial situation. This concept, when negative, states for an excess in the existing stock value at the moment of the decision. The calculation of the initial stock value is not the purpose of the present research. On the other hand, the value of the overstock, when positive, stands that a reinforcement of the initial stock should be done in order to hedge against demand variations, maximizing the potential future sales. In an environment with uncertainty, as the volatility increases, the required overstock value also increases. For a lower uncertainty level, the overstock tends to zero, which means that there is no need to reinforce the existing stock at the moment of the decision. It is also important to read the relation between demand quantity and demand volatility. For high demand quantities, the exposure to the market uncertainty implies the need of a higher overstock level, on the opposite, for lower demand quantities, even for extremely high volatility levels, the overstock value is less expressive.



Shorter lead times – the company is less exposed to demand market uncertainty

Figure 2: Lead time, demand volatility and the overstock value (euros)

Figure 2 support the relation between lead time, volatility and overstock value. When the lead time increases there is an additional need of time to answer for a request. This period of time, demands a high level of stock to buffer the gap between the output time of the physical flow and the orders date. The same analysis can be applied to the volatility. From the figure results that shorter lead times protect the company against the demand uncertainty, which reinforces the importance of lean companies to minimize the demand risk. Companies facing high lead times are subject to a higher impact when the demand volatility level changes. The changes in the volatility level can occur due to changes in actual markets but also can result from a growth strategic approach aiming new markets development. In particular, a few models in the literature capture the dependency between demand uncertainty and lead-times (Orcun et al., 2009; Pahl et al., 2007). There's a recursive situation as the demand variability affects production lead-times, and customer requirements introduce the need to hold additional inventory due to increase of lead time, which requires additional releases that further will increase the capacity utilization (Aouam, 2011)

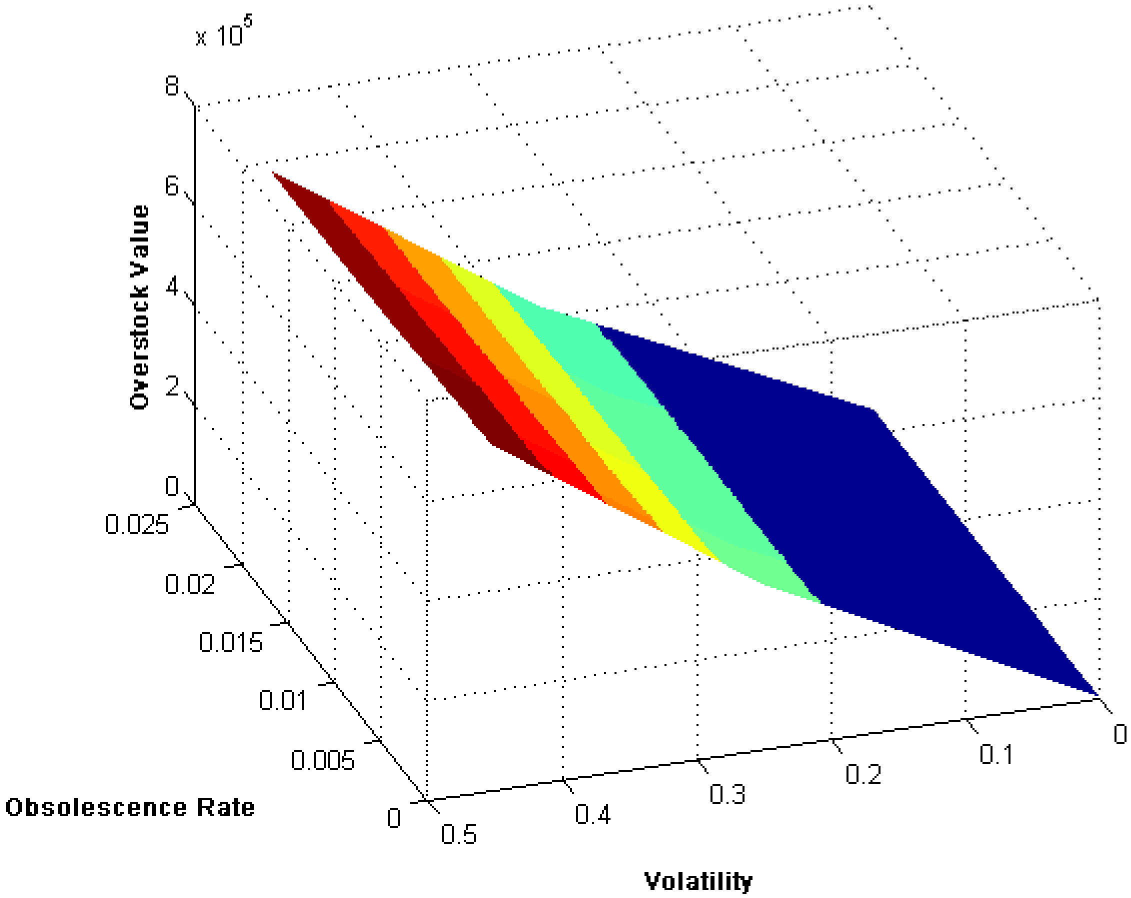


Figure 3: Obsolescence rate, demand volatility and the overstock value (euros)

The obsolescence rate states for the average stock that can go toward a "phase out" in a short period of time. There is a high risk perception and for this reason, the overstock allowed decreases as this rate increases. To avoid more risk, the firm must develop the activities to support the phase out process in a proper way. The phase out consequences are manageable in stable environments, however, in turbulent markets becomes one of the most critical activities that can affect the inventory level, perpetuating slow movers in warehouses that will increase significantly the risk that must be reflected in company balance sheet. There are four basic inventory costs: storage costs, ordering costs, obsolescence and opportunity cost. Obsolescence is especially high for technology companies, as they usually experience rapid growth in different technologies. If a new technology comes out, an old technology stopped in the warehouse can potentially lose a lot of its value.

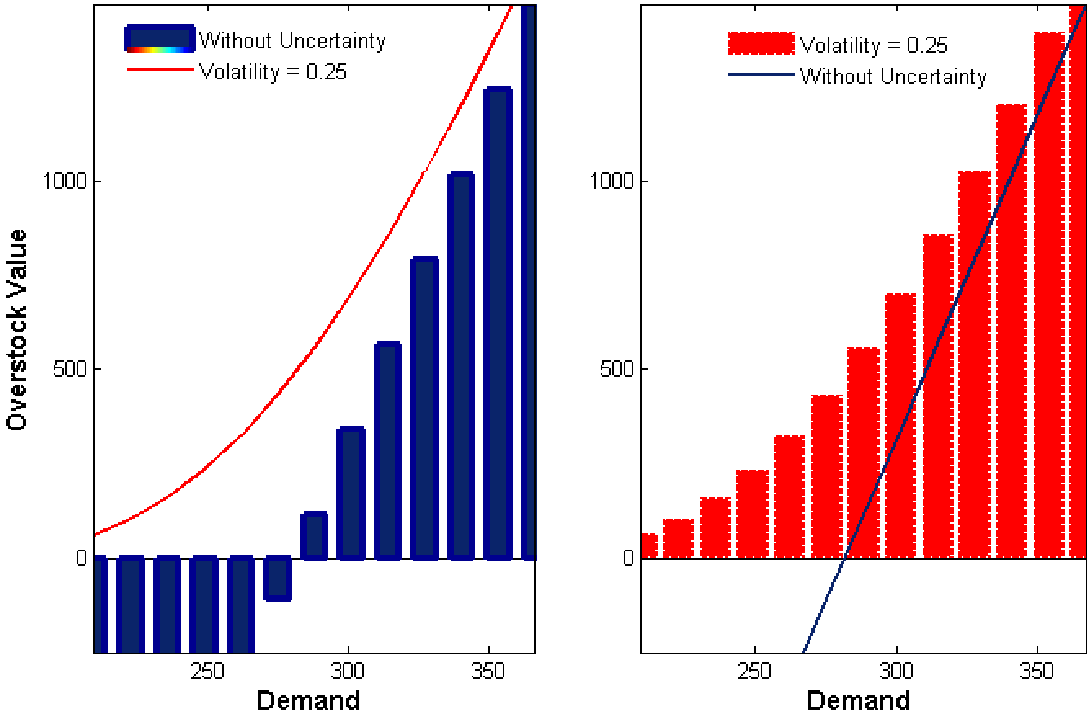


Figure 4: Overstock value (euros) with and without demand uncertainty

Overstock value in 10^3 euros and Demand in 10^3 m^2

The graphic shows the difference between considering or not the uncertainty impact on the overstock value. When considering the volatility impact, the overstock increases, which reveals the difference of the value coming from uncertainty. For low demand quantities the existence or not of uncertainty have a higher impact, instead, as demand quantities increase, the difference in the optimal overstock value tends to decrease.

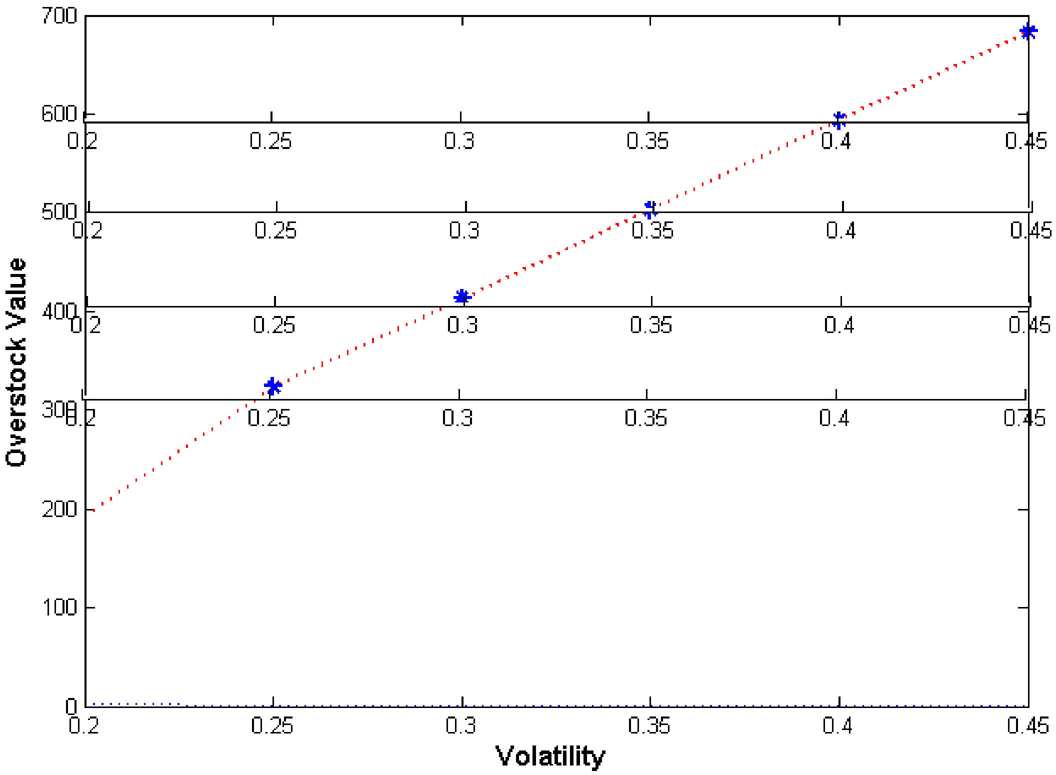


Figure 5: Optimal overstock value (10^3 euros) for different volatility levels

In the picture we identify the optimal overstock value for different volatility levels. We conclude that there is a relation between uncertainty and the optimal overstock value, for a high volatility rates the optimal overstock value increases. The impact of uncertainty is critical and is one of the major causes for stock-outs, causing protectionism and lack of trust among the players in the chain which can result in high inventory levels in the downstream stages of a supply chain. Additionally, it is possible to extend the analysis for multi products, considering different volatility rates. The model returns the optimal overstock value for each product classification.

6. DISCUSSION AND CONCLUSIONS

The goal of this study was the determination of the overstock level, in order to satisfy the service level requirements also as the adequacy of the invested capital on stocks, under uncertain environments. The common way to analyse stocks is based on historical data and treats all the items in the same way, not respecting the products life cycle evolution.

The numerical models normally used, do not adapt to changes in the demand because they tend to follow the past tendencies. In this way, overstock comes as an alternative tool for stocks management. The calculation of the adjusted overstock level can be supported on the real options approach, mainly based on two drivers: the demand - as an uncertainty variable input, and the overstock - as a flexible indicator within the supply chain. In the overstock decision process, there is a relation between the increase of the uncertainty and the need to increase the stock value. The model also states that, in the absence of uncertainty there is no need of overstock.

When applying the real options approach to the overstock calculation, we can understand the influence of the demand's volatility on the invested capital. The use of the real options (ROA) has been associated with the measurement of value due to the flexibility within uncertainty environments. The ROA is a way to support the decision process, in order to maximize the required value improvement.

The contribution of this work is the enlargement of the tools used for stocks management, respecting the actual need of future oriented based decisions, as a consequence of the increasing in the uncertainty of the markets, also as the need to account for the product life cycle evolution. We conclude that the overstock level can be calculated and used, and there is an optimal value to be fulfilled. We also stated the link between the demand quantity and volatility with the stock value, the lead time and service level definitions and the product life cycle impact, based on the use of the obsolescence factor.

The model was aimed to introduce the volatility of the demand on the stock value calculation. Nevertheless, there is also an important impact of the items classification, as it can give a better view about the study of the best process to apply for the demand's behaviour.

7. LIMITATIONS AND FUTURE RESEARCH

Some of the assumptions done will be solved in the next essays. Even so, we will discuss the most important ones, mainly pointing out potential limitations in the generalization of the results obtained. We assumed of an installed (fixed and known) output capacity, this means that the company cannot use contingent resources in short term to increase capacity output neither outsourcing, otherwise, it would be possible to minimize part of the demand increase, consequently, avoiding the need of overstock. However we assume that the installed capacity is enough to absorb additional production to fulfil the overstock. The capacity issue will be addressed in the next chapters. The efficiency in the uses of resources is also ignored which does not disturb the results, as any improvement action regarding efficiency normally extends a single planning period, and so, is normally ignored for planning purposes. We assume that the demand is uncertain and can be treated by each product classification individually using an auxiliary process. This assumption can be violated when items suffer two effects: cannibalisation effect (e.g. replacement) or combined mix effect (e.g. offer by package); this can be solved by the introduction of a correlation factor to combine the different demands, nevertheless this approach would require to treat at the same time, different stochastic demands. The demand is assumed under a geometric Brownian motion, only to simplify the calculations; the consideration of other stochastic processes is possible (e.g. demand shocks, mean reverting) and can easily be overcome using different techniques as presented in the first part of the thesis. On the other hand the assumption on manufactured items does not violate the generalization of the model as the proposed classification can be applied also for trade business. We considered that disruptions in the planning period under analysis will not influence the future market share of the company, which is not critical as we are dealing with an overstock option which aims to avoid future losses. If we were able to calculate such an impact we could incorporate it in the objective function of the model and it should be expectable that an increase in overstock will occur. Finally this paper aims at providing a solution for a independent echelons, this will be complemented in the next papers, using a multi-echelon approach.

A future application of the concept can count with a sequential approach between different echelons of the supply chain under analysis, and an additional and more elaborated level of uncertainty could be applied, based on each product category. The consideration of the impact of the capacity constraints, along the chain, can limit the exercise of the overstock option at one echelon and could a further topic to be investigated.

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ESSAY III: TARGET SETTING UNDER UNCERTAINTY

ABSTRACT

The main goal of this study is the definition of a key performance indicator, able to measure the impact of the demand uncertainty in a multi-stage supply chain inventory level. Despite the traditional bullwhip effect being normally analysed considering the particular dimension of the demand volatility in the amplification of upstream orders, an endogenous effect can be found and measured using a new indicator, able to help managers understanding the demand uncertainty penetration in the different stages of a supply chain. With this metric, managers are able to establish a more reliable target for their stock level, in each node, according to the risk exposure, promoting the optimisation of the invested capital in an aggregated supply chain analysis. The mathematical model is supported on the real options methodology. Overall, our investigation increases the knowledge related with demand's uncertainty treatment in supply chain performance.

Keywords: overstock, demand uncertainty, supply chain management, supply chain performance.

1. INTRODUCTION

The purpose of inventory can be split in three relevant parts: to support the current book of business in predictable environment; to support seasonality, opportunities and to smooth forecasting mistakes; and finally, to support the impact of environment uncertainty. Supply chains are exposed to different types of uncertainties that can affect the expected compromise assumed as a service level. The uncertainty sources can be internal linked with the capacity availability or external due to the inbound of resources or changes in the demand. This paper, specifically, focuses the determination of a key performance indicator that measures the impact of the demand uncertainty in the upstream stages of a chain; according to the last downstream stage overstock value. The methodology is based on the real options approach, mainly focusing the uncertainty and flexibility measurement. We are going to evaluate the impact, in the upstream stages, of a non-optimal overstock level in the last downstream stage, assuming different values for the decision. The existence of overstock can be seen as a hedging policy that provides flexibility in the supply chain. Other authors have also referred the importance of a hedging policy within a supply chain for planning purposes (e.g. Ritzman at al., 1979; Wijngaard and Wortman, 1985; Guerrero et al., 1986; Vollman et al., 1992; Baker, 1993). However, we did not find any previous study that used the real options approach, within supply chain performance, as a solution to measure the demand uncertainty penetration degree in the supply chain nodes.

While our results are valid for the specific supply chain and the operating environment we used in the model, we must emphasize the importance of the ability to model supply chains realistically, to obtain valid and useful results, mainly the distribution of the different stages and the interaction between them. Our model is based on a six echelon supply chain network.

Establishing the degree of uncertainty penetration, the study provides a contribution to the ambiguity in the evaluation of the managers' performance. In particular, the model intends to answer two practical questions, supported on real options approach: (1) Does the overstock level in the downstream stage, affects the demand uncertainty penetration in the supply chain? (2) And can we measure the endogenous supply chain exposure level, to the demand uncertainty, considering different downstream overstock levels, under the use of a specific indicator?

2. LITERATURE REVIEW

This paper extends the previous work of the authors on the analysis of the overstock model based on the real options approach, considering demand as a stochastic variable (Fernandes et al., 2010a, 2010b), by introducing the uncertainty impact in the different stages of a chain, allowing the definition of a management relevant key performance indicator for measuring the exposition of the upstream stages to the demand volatility.

Literature review will be split in three relevant parts: background of solutions to treat uncertainty in the supply chain management, the background of solutions using a multi-stage inventory system and past studies aiming the supply chain performance.

For the first issue related with uncertainty, we could state that most of the existing literature on inventory management, pointed the safety stocks as a way to deal with the uncertainty from the demand side (e.g. Antanies, 2002; Jian and Ma, 2004; Forslund and Jonsson, 2007; Tan, 2008). But nevertheless the improvements done on traditional safety stock, the demand is normally assumed as being deterministic. However, some studies have pointed a stochastic approach, which of the most common are: the base stock model, stochastic multi-echelon systems and strategic safety stock. The main assumptions of past approaches that make the difference from the present study, are based on the trade-off decision between assuming holding inventory costs, stock-out costs and the level of uncertainty.

For the second issue related with inventory management, we can find in the literature two different modelling approaches. The first approach is based on multi-echelon stochastic inventory theory, where the demand is faced as a stochastic variable and the decision is about the inventory level at each stage in the supply chain. Another approach is based on mathematical programming principles, where the demand is a forecast input in the model, safety stocks are known, based on an external calculation and the decision is about the allocation of stocks into the different stages of the chain (e.g.

Stadtler, 2003; Spitter et al., 2005). The studies of Forrester (1961) have been referred as the beginning of the interest in multi-stage inventory systems, but already Clark and Scarf (1960) had done a first relevant analysis of serial multi-stage inventory systems under random demand. Inderfurth and Minner (1998) associated the use of a multi-echelon scheme with safety stock by using a normally distributed demand, following previous Inderfurth study in 1991, related with the distribution of the safety stock throw multiple stages of a chain. Lawson and Porteus (2000) posted a specific attention on the need of a top down oriented decision process, transforming a multidimensional into a series of one-dimensional sub-problems stated at each node analysis. Abhyankar and Graves (2000) modelled a two-stage supply chain, subjected to non-stationary demand in the form of a two-state Markov modulated Poisson process. They concluded that the inventory hedging policy can be used as way to deal with demand uncertainty, protecting the upstream stages of a chain. The model presented was based on a two steps approach: the first is the determination of the stock level and the second is the calculation, based on an optimisation model, of the best stage to which the hedge stock must be allocated. Viswanathan and Piplani (2001) proposed a one-vendor, multi-buyer supply chain model and analysed the impact of coordinating inventories, using a common replenishment date. Most of the past literature reinforced the need of integrated decisions supported on a multi-echelon approach and on information coordination aiming the goals congruence (e.g. Banerjee et al., 2007; Chan and Chan, 2009; Mangal and Chandna, 2009; Liu et al., 2011. Recently, Li (2010) posted a specific attention on the importance of information in a multi-stage supply chain, revealing the concept of evolved ultimate demand track between different stages and Wang et al. (2011) used a coordination mechanism, based on a cost function, to support integrated performance in multi-echelon supply chain. He and Zhao (2011) proposed a contract based model to support the multi-echelon coordination.

The last point refers to the supply chain performance. The reference studies in supply chain performance measures can be found in Lee and Whang (1993), Voudouris (1996), Chen (1997), Beamon (1998, 1999), Lambert and Pohler (2001), Hausman (2003), Askariazad and Wanous (2009), Gleich et al. (2009), Pochampally et al. (2009), Wong (2009), Acar et al. (2010) and Merschmann and Thonemann (2011). Most of the found literature on supply chain performance relies on cost (the most studied), customer responsiveness/back-orders, activity time, congruence goals (Lee and Whang, 1993; Chen, 1997) and flexibility. The studied decision variables are related with inventory levels, ordering size, production scheduling and number of stages.

We can find a link between demand uncertainty and performance evaluation in Wong (2009) and Acar et. al. (2010), following the three decades old conclusion by Dewhirst (1978) that, in high volatile environments, the establishment of quantified targets is unrealistic. To minimize the gap between a realistic target and reality management practices, it is possible to use a corrective parameter carved by the dispersion of the possible values that should be considered in the performance evaluation, like stated in the “Guide to the Expression of uncertainty in measurement” (1993). The mentioned contribution is important to support this study, as the uncertainty factor (corrective parameter) can persuade managers in correcting the performance measures and it also emphasizes the importance of this approach in real management environments requiring realistic targets.

One of the relevant performance measures in supply chain is related to the flexibility in dealing with uncertainty, mainly from supply, demand, lead time (Acar et al., 2010) and technology (Thapalia et al., 2009). Merschmann and Thonemann (2011) stated the importance of suiting the supply chain model to the uncertainty exposition of the chain, realizing that companies concerned with flexibility can perform better in markets with high volatility; instead, efficiency should be the priority when companies operate in low uncertain markets. For Beamon (1998), the flexibility is a qualitative supply chain performance measure, when it measures the degree to which the supply chain can respond to random fluctuations in the demand, and is a quantitative metric when it refers to the inventory levels, mainly focusing on cost minimization (based on the amount) and the number of stages (supply chain modelling).

3. MODELLING

We will formulate our problem using the real options methodology. The objective function maximizes the option premium that we denote by overstock.

Considering an installed capacity and some restrictions in the use of an outsourcing (subcontracting) option, it’s possible to use an overstock option to increase stock above an initial position, for different stages in a chain, considering the risk minimization of product stock-out. We assume that the overstock decisions in all stages are centralized on a single supply chain authority and that all the inventory information is available for the intervening, avoiding internal behaviour impacts in the model construction. We also assume that there are no resources’ shortages in the chain for the short period under analysis (which differs from the study of Tan (2002)).

We assume that a possible items classification should be treated as an auxiliary process, we will consider only manufactured items stock and the demand (quantity) will be treated as a stochastic variable (the firm does not have any influence on quantity and sales price – is a price taker). We consider that any demand not fulfilled from stock is lost at moment t, the lead-times are fixed and known and we will not consider the impact of lost market share in period $t+1$, caused by a disruption in near time t. We assume that the supply chain has an arbitrary number of stages and inventory decision points. These stages are required before the product is ready to be delivered, under the customer specification and they are numbered in the inverse order of the material flow. We will number the downstream stage, closer to the market, with "1". The decision on the multi-stage overstock level is based on the results of a stochastic model that is solved using real options. The formulation of the problem requires a deterministic approach for most of the elements, except the demand, affecting all the stages of the chain. The model will not consider the efficiency in the use of the available resources, neither the capacity constraints.

The differences in the stages of the chain are only linked with the activities processing time and the activity costs. The starting overstock value is in the last downstream stage of the chain where the supply chain interacts with the customer (retail perspective).

The source of uncertainty is the demand (quantity), that we are going to represent by D. We consider that the company cannot influence the sales price with the level of overstock, and the evolution of the demand to be the most important input for the option valuation. We assume that the demand is stochastic and follows a geometric Brownian motion (assumption done also by Bengtsson, 2001; Pindyck, 1988; Tannous, 1996). The demand process can be presented as:

$$dD \equiv \alpha D dt + \sigma D dz \quad (1)$$

Where: $dz = \varepsilon(t)\sqrt{dt}$; $\varepsilon(t) \approx N(0,1)$; α = instantaneous drift; σ = volatility; dz = increment of a winner process and $\varepsilon(t)$ is a serially uncorrelated and normally distributed random variable.

From equation (1) we can state that the demand D is log-normally distributed with a variance that grows with the time horizon (also an assumption of the model presented by Bengtsson (2001)). The demand is modelled as a continuous process. We assume that all the production and stock policy is make-to-stock. The following notation will be used in the model.

h	Stock aging factor	k_s	Cost of holding stocks for each item for period n
D	Demand in quantity for the item category	c_λ	Unit cost for each stage
c_v	Variable production cost of a single unit	I_{t-1}	Existing inventory level in the beginning of period n
p_v	Unit sales price	n	Period between " $t-1$ " and " t "
$1-S$	Stock-out rate for item class	λ	Supply chain stage
K	Value calculated as a function of the stock-out rate (normal distribution)	ϕ	Number of stages
S	Required service level for item category: % of the quantity fulfilled on the required date	φ	Supply chain stage number
L_t	Lead time definition	ζ_λ	Operation in each stage
t_λ	Time processing for each stage	M_v	$(p_v - c_v).D$
j	Weighted average cost of capital, reported and adjusted to period t (simplification)	Ω_λ	Overstock option in each stage
θ	Average stock unit cost	Ω_φ	Overstock option for stage φ

Table 1: Notation

3.1. DECISION RULES AND PAYOFF

If we study an overstock option, $\Omega_{\varphi}(t)$, which expires at time t, and gives us the option to adjust the stock level, if the benefits exceed the costs for changing the stock level, respecting the maximum allowed capital, the value of the option at time t and stage φ, can be written as (identification):

$$D\cdot\left(\theta-\sum_{\lambda=1}^{\varphi-1}c_{\lambda}\right)\cdot\left(L_t+\sum_{\lambda=1}^{\varphi-1}\tau_{\lambda}\right)\cdot K\left(1-j-h-\frac{k_s}{\left(\theta-\sum_{\lambda=1}^{\varphi-1}c_{\lambda}\right)}\right)-M_v\left(1-S\right)-\sum_{\lambda=1}^{\varphi-1}\Omega_{\lambda}-I_{t-1} \tag{2}$$

Then we calculate: the value of the overstock option in stage φ is the expected terminal value of the condition:

$$\Omega_{\varphi}(t)=\max\left[D\cdot\left(\theta-\sum_{\lambda=1}^{\varphi-1}c_{\lambda}\right)\cdot\left(L_t+\sum_{\lambda=1}^{\varphi-1}\tau_{\lambda}\right)\cdot K\left(1-j-h-\frac{k_s}{\left(\theta-\sum_{\lambda=1}^{\varphi-1}c_{\lambda}\right)}\right)-M_v\left(1-S\right)-\sum_{\lambda=1}^{\varphi-1}\Omega_{\lambda}-I_{t-1},0\right] \tag{3}$$

Each stage φ requires a defined number of operations denoted by ζ_{λ} with a standard unit cost of c_{λ} and the time duration of τ_{λ}.

Where Ω_{φ} represents the value of the overstock at stage φ; "$D\cdot\left(\theta-\sum_{\lambda=1}^{\varphi-1}c_{\lambda}\right)\cdot\left(L_t+\sum_{\lambda=1}^{\varphi-1}\tau_{\lambda}\right)\cdot K-\sum_{\lambda=1}^{\varphi-1}\Omega_{\lambda}$" represents the stock allowed for a certain demand quantity level in stage φ; "$M_v\left(1-S\right)$" represents the loss margin related to sales not fulfilled on time; "$j+h+\frac{k_s}{\left(\theta-\sum_{\lambda=1}^{\varphi-1}c_{\lambda}\right)}$" represents the opportunity cost of the invested capital, the risk of obsolescence and the weight of the handling costs on the average stock unit cost and $\Omega_{\varphi-1}$ represents the overstock in the previous stage.

Subject to:

$$0\leq\sum_{\lambda=1}^{\phi-1}\Omega_{\lambda}(t)\leq C^t \tag{4}$$

$$(\phi - 1) > 0 \tag{5}$$

C^t = maximum invested capital value allowed in stocks for time t.

The overstock in each different level can be expressed as a European call option, where "$D \cdot \left(\theta - \sum_{\lambda=1}^{\varphi-1} c_\lambda \right) \cdot \left(L_t + \sum_{\lambda=1}^{\varphi-1} \tau_\lambda \right) \cdot K \left(1 - j - h - \frac{k_s}{\left(\theta - \sum_{\lambda=1}^{\varphi-1} c_\lambda \right)} \right) - M_v \left(1 - S \right) - \sum_{\lambda=1}^{\varphi-1} \Omega_\lambda$" is the value of the underlying asset (A) for each stage of the chain. The actual stock level "I_{t-1}" can be treated as the exercise price (E). An overstock manufacturing order should take place if $\Omega_\varphi(t) \geq 0$. The overstock option gives the right to increase stock level above the existing one and expires in time t.

The value of an overstock option, for time t and stage φ, must satisfy the following differential equation:

$$\alpha . D . \frac{d\Omega_\varphi}{dD} + \frac{1}{2} . \sigma^2 \frac{d\Omega_\varphi^{\ 2}}{d^2 D} - r\Omega_\varphi = 0 \tag{6}$$

The mathematical model developed supports the calculation of the endogenous effect of the demand uncertainty along the chain. The purpose and the practical application rely on the definition of the adequate targets for the invested capital on stocks. The process of establishing the performance target is prior to the reality and usually based on the historical data or expected forecasts. When the chain has different decision stages, in which different stocks level can be applied, it's of huge importance the balancing of all the buffers according to the demand uncertainty. Wrong decisions may involve non-optimal stocks in each stage, which can provoke and intensify the effect of the demand uncertainty, causing the risk increase in the upstream stages of the chain. We want to emphasize that the definition of invested capital targets must consider the uncertainty exposition of the chain. We also want to conclude that it is possible to get a key performance indicator ($KPI\Omega D$) that measures the endogenous demand uncertainty to be managed.

The presented indicator compares the overstock in the downstream stage with the overstock in the upstream stages of the chain. Therefore, the metric gives a percentage that reflects the impact of uncertainty penetration in the chain, which can be used as the corrective factor; a lower percentage means a less uncertainty and so, the required correction is minor. The overstock in the last downstream stage is denoted by “Demand overstock” = ΩD and the upstream stages overstock by “Endogenous overstock” for each stage $\varphi = \Omega E$. The $KPI\Omega D$ “endogenous effect of the demand uncertainty” can be presented as:

$$KPI\Omega = \frac{\sum_{\varphi=2}^{n} \Omega E_{\varphi}}{\sum_{\varphi=2}^{n} \Omega E_{\varphi} + \Omega D} x100 \qquad (7)$$

With:

$$\Omega E_{\varphi>1} = \max\left[D \cdot \left(\theta - \sum_{\lambda=1}^{\varphi-1} c_{\lambda} \right) \cdot \left(L_t + \sum_{\lambda=1}^{\varphi-1} \tau_{\lambda} \right) \cdot K\left(1 - j - h - \frac{k_s}{\left(\theta - \sum_{\lambda=1}^{\varphi-1} c_{\lambda} \right)} \right) - M_v \left(1 - S \right) - \sum_{\lambda=1}^{\varphi-1} \Omega_{\lambda} - I_{t-1} \right] \qquad (8)$$

$$\Omega D_{\varphi=1} = \max\left[D \cdot \theta \cdot L_t \cdot K\left(1 - j - h - \frac{k_s}{\theta} \right) - M_v \left(1 - S \right) - I_{t-1} \right] \qquad (9)$$

4. VALUATION MODEL

The numerical example chosen is about the application of the concept within a flooring industrial company. The company works with different product categories. We are going to apply the concept to one of the categories denoted by CS. The company analyses the performance of stocks management based on historical data. But, considering the volatility of the demand distribution, higher than 20%, the firm needs to anticipate the stocks level to avoid any disruptions. The demand is considered a stochastic variable. Demand volatility assumption = 25% and the supply chain is composed by 6 stages (plus the last downstream stage that is used only for simulation). The time processing and unit cost for the stages were assumed based on a relation with lead time and average stock unit cost. All data is referred in table 2.

Factor	Description	Value	Unit
D	demand quantity	262.051	m^2
I_{t-1}	stock value at the beginning of period	4.849.145	euros
h	stock aging factor	0,002	coefficient
c_v	variable production cost of a single unit	5,000	€/sku
p_v	unit sales price	15,000	€/sku
S	required service level	95,000	%
j	weighted average cost of capital	0,500	%/month
L	lead time definition	1,500	months
k_s	holding stock cost/unit for the period	0,263	€/sku
θ	average stock unit cost	7,500	€/sku

Table 2: Parameter values used in the model

5. RESULTS

In table 3 we can find the endogenous uncertainty impact as the answer to the proposed KPI. It must be seen as percentage of the external demand uncertainty volatility able to affect the upstream stages of the chain. The uncertainty effect decreases as the stages are more upstream in the chain; the downstream stages are those that are more exposed to the market uncertainty. Table 4 shows the effect of different downstream overstock value in the downstream stage. For higher downstream overstock values, the global overstock increases.

Demand Overstock level	1st stage	2nd stage	3rd stage	4th stage	5th stage	6th stage	Endogenous impact					
0	42,30%	26,85%	16,55%	9,10%	4,02%	1,19%	100,00%	..	..	..	..	
200.000	29,74%	20,76%	13,33%	7,42%	3,26%	0,93%	..	75,45%	..	..	..	
400.000	19,95%	15,26%	10,21%	5,76%	2,50%	0,68%	..	..	54,36%	..	..	
600.000	12,68%	10,58%	7,38%	4,21%	1,79%	0,46%	..	..	..	37,10%		
800.000	7,59%	6,87%	4,99%	2,86%	1,18%	0,28%	..	..	..	..	23,76%	
1.000.000	4,25%	4,15%	3,12%	1,78%	0,70%	0,15%						14,14%

Table 3: Simulation values (endogenous impact)

Demand Overstock level	1st stage	2nd stage	3rd stage	4th stage	5th stage	6th stage	Global overstock value
0	323.714	205.489	126.645	69.636	30.795	9.090	765.368
200.000	242.284	169.138	108.540	60.461	26.538	7.584	814.543
400.000	174.842	133.769	89.521	50.487	21.887	5.981	876.488
600.000	120.939	100.948	70.439	40.124	17.050	4.378	953.878
800.000	79.620	72.117	52.345	29.968	12.339	2.903	1.049.292
1.000.000	49.470	48.340	36.323	20.727	8.130	1.691	1.164.681

Table 4: Simulation values (global overstock value)

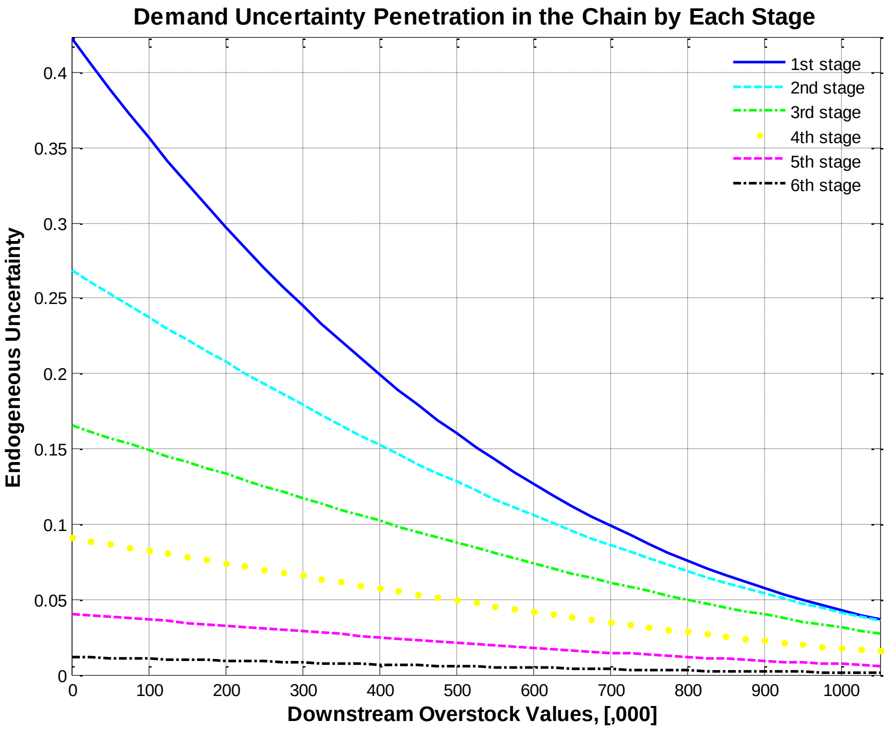

Figure 1: Demand uncertainty penetration in the chain by each stage

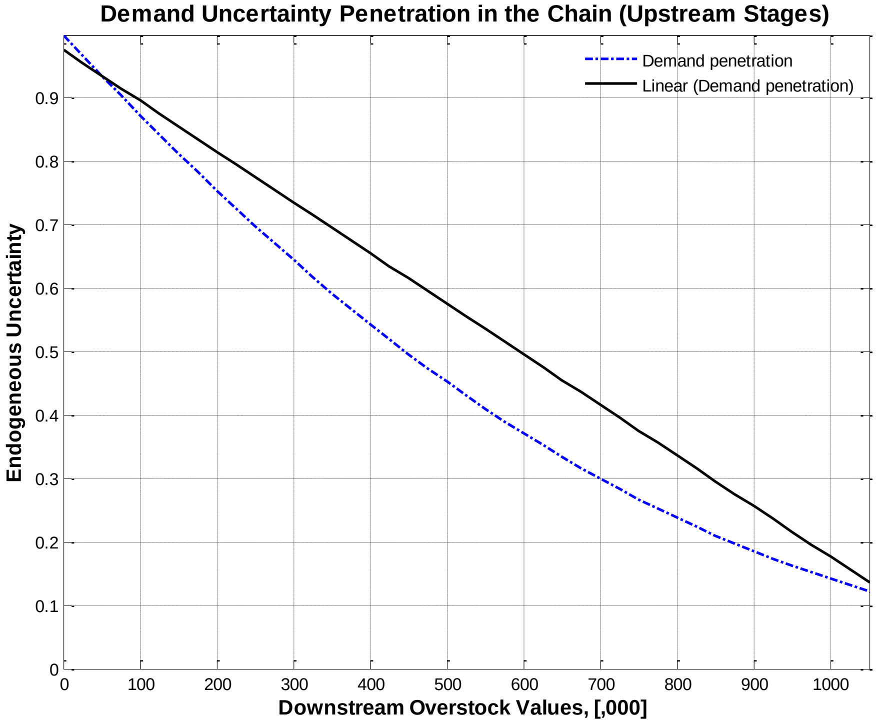

Figure 2: Demand uncertainty penetration in the chain (upstream stages), according to different demand overstock values

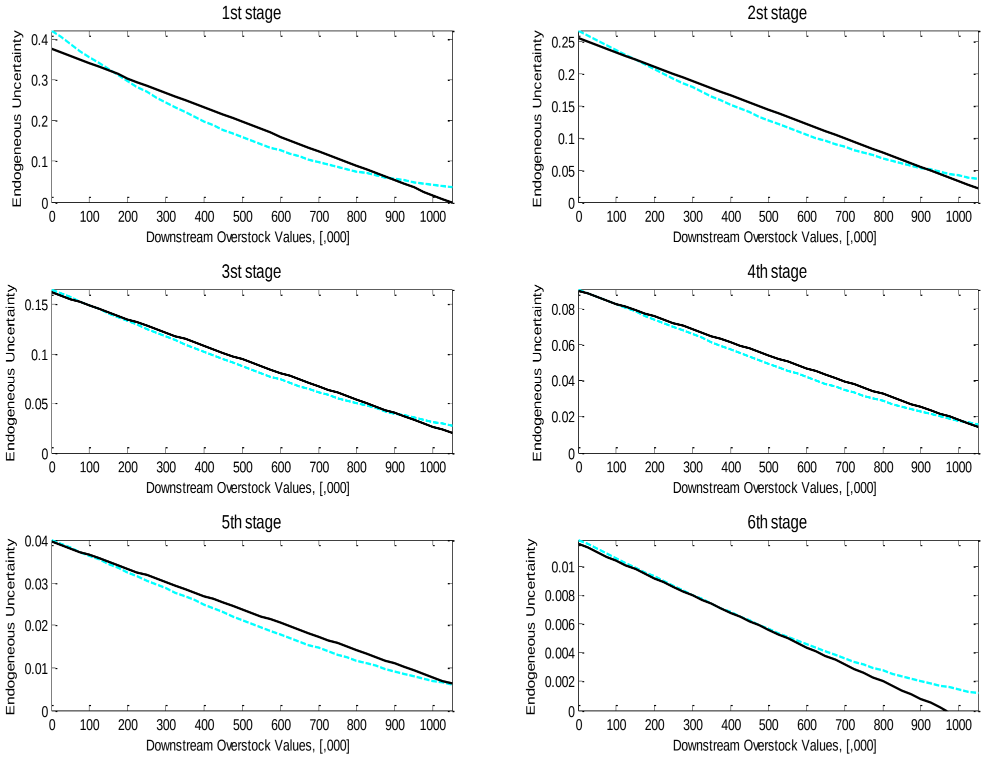

Figure 3: Endogenous uncertainties by each stage, according to different downstream overstock values

Analysing figures 1 and 3, we can infer that there is a demand uncertainty impact all over the chain, which decreases for the upstream stages of the chain and varies depending on the downstream overstock value. This is caused by the increase of downstream buffers: high overstock targets downstream of the chain will decrease the demand uncertainty penetration.

From figure 2, we realize that the existing demand uncertainty penetration is not linear along the chain. Using the results in table 4, we can conclude that the global overstock increases for a high demand overstock target – more uncertainty downstream, which reveals the required additional cost to increase flexibility value in the downstream of the chain.

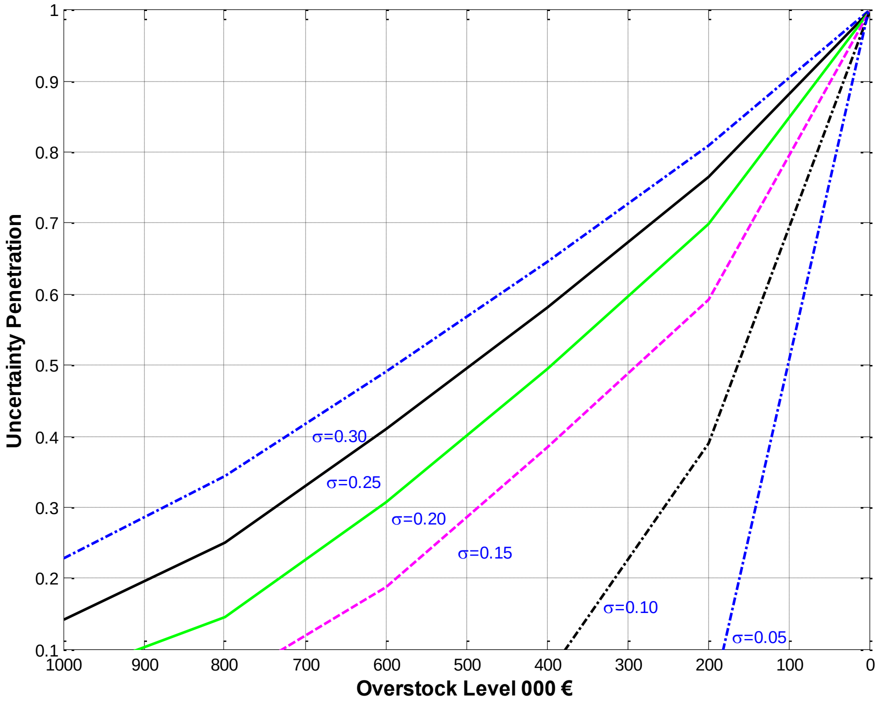

Figure 4: Relation between uncertainty penetration and demand uncertainty, for different downstream overstock values

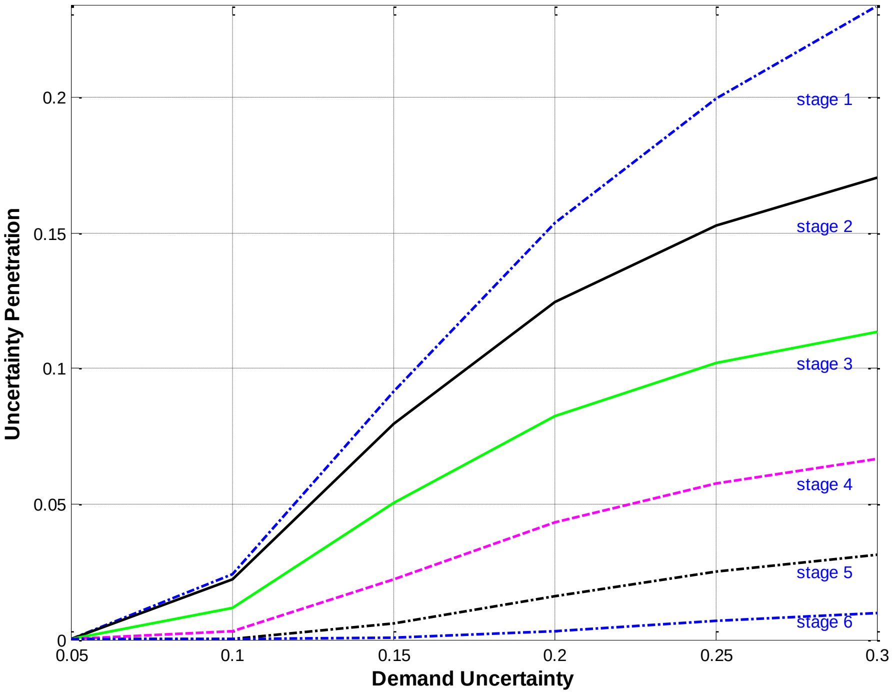

Figure 5: Relation between uncertainty penetration and demand uncertainty, by each stage of the chain

From figure 4, we can state that the demand uncertainty penetration depends on the external demand volatility but can be smoothed by the increase in the demand overstock level. Complementing the analysis with figure 5, we denote that the downstream stages are the most affected by changes in external demand volatility. The penetration in the chain tends to be less aggressive in the upstream stages.

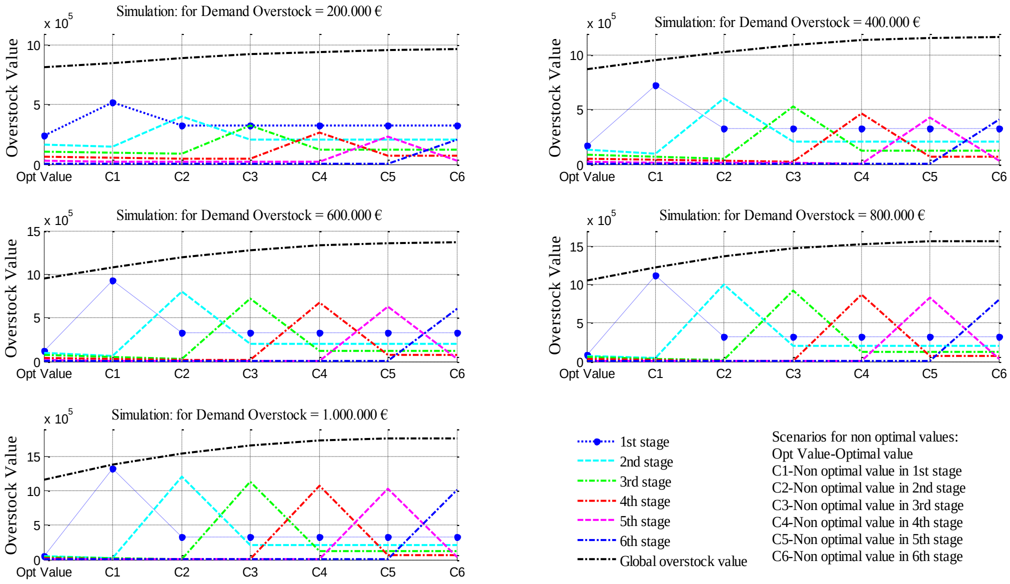

Figure 6: Simulation of the global overstock value (option value), considering different scenarios for the multi-stage overstock value, optimal and non-optimal

In figure 6, we simulate different scenarios by changing the stage where we add a non-optimal demand overstock value. We conclude that a non-optimal value provokes a higher impact, when it is exercised in the upstream stages of the chain.

In global, we can conclude that the level of invested capital on stocks, inside the chain, is affected by the uncertainties' exposure. The level of the existing flexibility in the chain and the risk management tools must be considered in the establishment of the overstock level in the last downstream stage of the chain, and that the application of real options methodology, allows the calculation of the KPI, that should be seen as a corrective factor for managing performance.

We realized that there's a relation between the interaction of the nodes and the uncertainty penetration effect, based on the processing cost and time, which is consistent with the work presented by Emerson et al. (2009).

6. CONCLUSIONS

We conclude the paper by reiterating the main results, contributions and management implications. Our motivation relied on the lack of tools to measure the demand uncertainty penetration in a supply chain also as the difficulty in adjusting targets to support the performance evaluation process. Using the real options methodology, this research confirmed that is possible to quantify the uncertainty penetration level in a multi-stage supply chain and our key results support the empirical observation about the relation between the inventory level and the uncertainty penetration. We reinforced the importance of flexible supply chains in high uncertain environments to improve firms' performance.

We based our study in the target setting process. Assigning a target implies accountability and management capacity to deliver results, which is of great importance in face of high uncertainty environments, where the managers capabilities to react have a huge impact in the performance of the company. The knowledge about the risk exposure can help in the target setting, mainly in the definition of the performance boundaries to measure the intensity of the success. Our corrective factor contributes to close the gap between managers' performance evaluation and uncertainty exposure.

Management by goals intend to focus the organization persecuting the most important actions to get the best results. Normally the target setting does not count with the uncertainty due to the dynamic of the business, as it is based on a simple time based scenarios and assumptions approach. The contribution of this work is the enlargement of tools used for target setting, in the supply chain performance management process, under high demand volatility. The calculated uncertainty penetration factor (KPI) allows the correction of targets under different external demand volatility values, minimizing the gap between realistic targets and performance evaluation.

7. LIMITATIONS AND FUTURE RESEARCH

This paper solves one limitation from the previous paper, the one referring the multi-echelon approach. Even so, we still discuss limitations not yet pointed in previous chapter. We assumed that the decisions on the overstock level are centralized in a single authority and that all the information regarding inventories is available for all the intervenient. However, the supply chain concept involves different firms and even inside a firm, different sections, with different goals, which can affect the results. Finally we linked the echelons based on processing activities time and operations cost, ignoring the effect of internal service level. Both these last points will be further explored in the next chapter. Further developments should be provided pointing the effect of restrictions in the available capacity, mainly in a multi-echelon approach.

Considering the achieved results, we think that future developments can be done considering the dynamic of supply chain nodes interaction and different supply chain designs. In the present study we assumed a static supply chain network configuration with a defined number of echelons. In real terms, the design and the dynamic link between stages can influence the uncertainty percentage penetration.

8. FINAL REMARKS

This paper suggests that target setting must be seen as a global performance driver, helping managers focusing on the main goals, even under a daily pressure. But, managers can only believe in the targets if they are fair, which means, if they reflect the actual firms and markets dynamics through the incorporation of the uncertainty. This paper also recommends a global target alignment for the different stages of a supply chain as; under uncertain demand the inventory buffers can change the impact level of the volatility in each node. The dynamic interaction between different responsibilities in the chain does not allow an unbundled target setting process.

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ESSAY IV: INTEGRATED INVENTORY VALUATION IN MULTI-ECHELON PRODUCTION/DISTRIBUTION SYSTEMS

ABSTRACT

The pressure to reduce inventory has increased as competition expands, product variety grows, and capital costs increase. This investigation addresses the problem of inventory quantification and distribution within multi-echelon supply chains under market uncertainty and management flexibility. This approach is based on an optimisation model emphasising demand uncertainty and the relevant dimensions of network design as number of echelons, lead time, service level, and cost of processing activities. Overstock quantification enables the understanding of inventory level sensitivity to market uncertainty. A comparison among production sites and storage facilities revealed that higher downstream overstock levels decrease upstream echelons of uncertainty exposition. The contribution of this study relies on management's ability to establish inventory targets for each stocking point according to risk exposure and to promote the optimisation of working capital. Overall, this investigation increases knowledge related to the treatment of demand uncertainty in flexible and integrated supply chains

Keywords: inventory; market uncertainty; supply chain management; multi-echelon supply chain.

1. INTRODUCTION

Carrying inventories becomes essential in most businesses because the different activities within a network take place at different times in different locations and at different rates. In fact, inventory is one of the largest working capital investments and is an important concern for managers in all types of businesses, mainly for companies that operate on relatively low profit margins, where poor inventory management can seriously damage the business. Additionally, given today's global financial crisis, the supply chain inventory management could be more crucial than before in the business cycles analysis as the lack of financial available resources limits the available investments value. Therefore, inventory value and location optimisation is one of the significant topics in supply chain circles today, considering the dynamic state of markets all over the world.

There are many reasons for variability and uncertainty in inventory value. The rates of withdrawal from the system may depend on customer demand which is stochastic both in time and amount. Quantities may be delivered with defects causing returns. The lead time associated with an order for replenishment depends on the capabilities of the available resources and the response of a customer to a shortage condition may be uncertain.

The uncertainty plays a role in most inventory management situations. The retailers want enough supply to satisfy customer demands, but ordering too much increases holding costs and the risk of losses through obsolescence or spoilage. In addition, a small order increases the risk of lost sales and unsatisfied customers.

The managers set a planning schedule considering the imprecise nature of forecasts of future demands and the uncertain lead time of the upstream stages network. These are normal situations, and the answers managers' get from a deterministic analysis very often are not satisfactory when high uncertainty levels are present. The decision maker faced with uncertainty does not act in the same way as the one who operates with knowledge about the future.

To optimise inventory, we need to manage the uncertainties, constraints, and complexities across a multi-stage supply chain on a continuous basis. As so, many companies adopt, at an operational level, inventory control systems, which enables them to handle many variables and continuously update in order to optimise the multi-stage supply chain network. In most of the cases decision-makers need support models to overview the supply chain inventory problems before making executive decisions or implementing operational inventory control systems.

The purpose of inventory can be split in three relevant parts: to support the business in a predictable environment; to support seasonal opportunities and smooth forecasting mistakes; and finally, to support the impact of environmental uncertainties. Supply chains are exposed to different uncertainties that can affect expected service levels. The sources of uncertainty can be linked to capacity availability, inbound resources, or changes in demand.

The understanding of inventory distribution in a supply chain has become a critical issue in business cycle analysis. We will focus our attention between production work in process and final inventory levels. One of the risks of final products inventory is related to diversification. The costs of carrying inventory have always been relevant, but in today's scenarios, there is major concern related to capital costs. The effect of interest rates on the determination of inventory levels has raised some discussions in the literature. Standard economic models consider inventory only as a buffer between sales and production, and it has been seen as an inefficient practice among manufacturing firms (e.g. just in time, lean practices).

This study is aimed at the determination of overstock in a multi-echelon supply chain considering the impact of demand uncertainty. We intend to evaluate the impact of an optimal balanced integrated overstock versus a non-optimal situation. To this end, the existence of overstock can be seen as hedging to ensure flexibility in the supply chain. Other authors have also referred the importance of hedging within a supply chain for planning purposes (e.g. Ritzman et al., 1979; Wijngaard and Wortman, 1985; Guerrero et al., 1986; Vollman et al., 1992; Baker, 1993). However, we did not find any previous study that used sequential decisions approach in a multi-echelon supply chain to balance inventories considering demand uncertainty penetration.

Our results are valid for the specific supply chain part and operating environment that we used in the model. Nevertheless, we must emphasise the generality of the model to incorporate different supply chain designs and interaction stages.

The present study reduces ambiguity about optimal overstock levels. In particular, the model intends to answer two practical questions: (1) Can we calculate an integrated and balanced overstock level for a multi-echelon supply chain? (2) What is the impact of demand uncertainty on the upstream echelons of inventory level?

This paper is structured as follows. In the next two sections, the background theory is supported and the reasoning for the used technique to solve the problem is presented. Section 4 illustrates the problem under study. Section 5 presents the mathematical formulation of the model, with generic constraints. Section 6 describes the flooring company case study. In section 7 we present and discuss the results. The paper concludes with some final remarks and a discussion of future research.

2. LITERATURE REVIEW

Literature review will be split in three relevant parts: the background solutions to treat uncertainty in supply chains, the background solutions on multi-echelon inventory and theoretical support on sequential decisions valuation.

Exploring the first issue related with uncertainty, we found that the need to consider uncertainty in the inventory decisions can essentially be traced back to the core functionality of planning models, which basically refers to the future allocation of resources based on current information and on future projections. The demand uncertainty is a subject that has been largely studied using different approaches (e.g. Guillén et al. 2006; Varma et al., 2007). The different approaches agree on the fact that demand cannot be fully explained by deterministic parameters, the markets behaviour are not justified by selling prices neither by quality or service levels, which increases the complexity associated with demand's forecasting models. Most of the existing literature pointed the safety stocks as a way to deal with the uncertainty from the demand perspective (e.g. Antanies, 2002; Jian and Ma, 2004; Forslund and Jonsson, 2007; Tan, 2008). The use of a certain amount of inventory acting as a buffer helps hedging against the demand uncertainty; however, the increase in inventory could be significantly high (Svensson, 2001). Antanies (2002) pointed out the potential hard effects of such a situation on the working capital levels required to support the business.

For Jian and Ma (2004) the coordination of the safety factors used to establish the inventory at each supply echelon can reduce the inventory level, mainly in high uncertainty markets.

Some studies have pointed a stochastic approach, which of the most common are: the base stock model, stochastic multi-echelon systems and strategic safety stock. The main assumptions of past studies are based on the trade-off decision between assuming holding inventory costs, stock-out costs and the level of uncertainty. Different mechanisms have been pointed to solve the uncertainty problem, like the modular product design (Ulrich, 1995; Baldwin and Clark, 1997), based on the use of common components at upstream echelons, concentrating the differentiation in the downstream echelons (Lin et al., 2000; Waller et al., 2000); the use of the make-to-order mechanism (Fisher, 1997; Lee, 2002), which avoids forecast mistakes that are common in make-to-stock procedures; and the probabilistic selling, recently presented by Fay and Xie (2011), using the selling influence to adjust the inventory size.

For the second issue related with the inventory management, we can find in the literature two different modelling approaches. The first approach is based on multi-echelon stochastic inventory theory, where the demand is faced as an uncertain variable and the decision is about the inventory level quantification at each stage in the supply chain. Another approach is based on mathematical programming principles, where the demand is a forecast input in the model, safety stocks are known, based on an external calculation and the decision is about the allocation of stocks into the different stages of the chain (e.g. Stadtler, 2003; Spitter et al., 2005). The studies of Forrester (1961) have been referred as the beginning of the interest in multi-echelon inventory systems, but already Clark and Scarf (1960) had done a first relevant analysis of serial multi-echelon inventory systems under random demand. Inderfurth and Minner (1998) associated the use of a multi-echelon scheme with safety stock, using a normally distributed demand, following the study of Inderfurth in 1991, related with the distribution of the safety stock throw multiple stages in a chain. Lawson and Porteus (2000) posted a specific attention on the need of a top down oriented decision process, transforming a multidimensional into a series of one-dimensional sub-problems at each node. Abhyankar and Graves (2000) modelled a two-stage supply chain, subjected to non-stationary demand. They concluded that the inventory hedging can be used to deal with demand uncertainty, protecting the upstream stages of a chain. The model presented was based on a two steps approach: the first is the calculation of the stock level and the second is the determination, based on an optimisation model, of the best stage to allocate the hedging stock. Viswanathan and Piplani (2001) proposed a one-vendor, multi-buyer supply chain model and analysed the impact of coordinating inventories, using a common replenishment date.

Most of the past literature reinforced the need of integrated decisions supported on a multi-echelon approach and on information coordination aiming the goals congruence (e.g. Banerjee et al., 2007; Chan and Chan, 2009; Mangal and Chandna, 2009; Liu et al., 2011). .

Some authors presented solutions to minimize distortions related with incentives and lack of information. Chen (1999) considered information delays in multi-echelon framework and proposed incentive schemes between echelon managers aligned with the firm, however, requiring the presence of a central planner. Forslund and Jonsson (2007), following Petersen et al. (2005), posted a special attention on the role on accurate, reliable, timely, accessible and valid information on the supply chain planning; whenever partners without reliable information use higher levels of safety stock. Tan (2008) used the imperfect advance demand information in forecasting. Chan and Chan (2009), proposed an information sharing approach in multi-echelon supply chains to convey exact inventory information to upstream stages, using a simulation approach to test the effectiveness of such methodology. Recently, Li (2010) posted a specific attention on the importance of demand information track between different stages.

Partnerships may be a way to overcome information asymmetries. Corbett and DeCroix (2001) studied an incentive conflict related to the amount of efforts that partners exert to improve supply chain efficiency. They concluded that both the manufacturer and the supplier can exert and agree in efforts with mutual advantages. However, the existence of such effort contracts does not assure supply chain coordination for all the situations. Baiman et al. (2000), by exploring the relation between information, costs and quality in a total supply chain concept, demonstrated that supply chain coordination is possible even if some of the effort levels are non-contractable; Stonebraker and Liao (2006) focused their study on strategic alignment between market and operations variables for efficiency and success of supply chain management; Banerjee et al. (2007) discussed an integrated decision process, based on a linkage inventory mechanism between different echelons, and they opened the discussion on the problematic related with inventory linkage in multi-echelon supply chains under a stochastic approach. Paulraj and Chen (2007) established links between market uncertainty, strategic supply chain management and company performance (in line with Lee (2002)). Mangal and Chandna, 2009 research focused on collaborative planning with transshipments and replenishment among different echelons as a way to improve inventory levels. In 2010, Acar et al., following the negative consequences pointed by Canbolat et al. (2007) for non-coordinated decisions among different echelons, mainly the upstream ones, defended a centralized authority for the decision process. Liu et al. (2011) explored an integrated decision mechanism with link between activities, for global co-ordination across multiple locations; Wang et al. (2011) used a coordination mechanism, based on a cost function and He and Zhao (2011) proposed a contract based model to support the multi-echelon coordination. Ramanathan et al. (2011) discussed metrics for collaborative relationship with suppliers; they conclude that incentives motivate the collaboration of supply chain members in order to improve overall performance.

For the last issue, we will refer to the importance of sequential decisions in the flexibility indicators and the associated values. Logistic decision makers can benefit from the capacity to delay commitments and being able to change the inventory levels between distinct stages. Flexibility facilitates the efficient allocation of stocks in a dynamic environment using as much new information as possible. The compound options technique has been used to solve the problem of sequential decisions in real options frame. Geske (1979) showed that risky securities with sequential payouts can be valued as compound options; nine years later, Carr analysed sequential options to exchange risky assets. In the 90's, Trigeorgis (1991) presented a numerical method, to value complex decisions with multiple interacting alternatives and Dixit and Pindyck (1994) modelled sequential investment decisions. In the next decade, Alvarez and Stenbacka (2001) developed a mathematical approach to find the value and the optimal exercise rules of compound options and one year later, Lin extended the conclusions of simple to multi-echelon compound options, presenting the closed form solution, and comparing several numerical calculating methods. In the same period Buraschi and Dumas (2001) extended a solution for the valuation of compound options when the underlying value follows a general diffusion process. In 2002, Herath and Park applied the binomial lattice framework, and in 2003, Elettra and Rossella, in the same thinking line of Geman et al. (1995), discussed the time-dependent volatility. In 2004, Gukhal derived analytical valuation formulas for a two stage compound option when the underlying value follows a diffusion process.

We follow past studies concerning the need and the importance of buffers as a mechanism to protect against the increasing market uncertainty. The literature supports our reasoning on recognizing and arguing for the need of coordination between different multi-echelons also as different impacts of demand uncertainty, depending on the stage positioning along the chain. A network inventory optimisation requires that the strategies are applied to one echelon regarding to its impact on the other echelons (Lee, 2003). Finally the literature presented listed out the advantages of sequential decisions approach, considering the flexibility to decide and manage the consequences of decisions whenever they are profitable or not. Most of the techniques used to solve the problems raised, are in line with the real options reasoning (Trigeorgis, 1996; Kogut and Kulatilaka, 2001; Smit and Trigeorgis, 2004).

Specifically, we will develop the concept of balanced multi-echelon overstock as a flexible inventory planning technique in uncertain environments. The right level of overstock in a network can be viewed as a series of decision points, where that value consists of two components: one is the value of current echelon overstock; the other is the value of downstream overstock. At each echelon the manager receives information regarding the overstock in the linked stage, and simultaneously, the manager decides whether to plan an overstock. In this model, we consider that the decision time frame is given in advance, and decisions can only be made within this period. Only when the overstock goal of the downstream stage is defined can the overstock of the previous stage be planned. However, if the upstream overstock target is not achieved, it is not possible to increase stocks in the next stage considering a capacity-balanced supply chain. A multi-echelon decision reflects that when the management team adopts an integrated strategy, they are not only interested in a single echelon, but in the integrated overstock perspective. Such multi-echelon decision problems can be modelled with embedding options.

Overall, this application contributes to the techniques used in inventory planning under uncertainty. We employed a new concept of overstocking in inventory management to hedge against demand uncertainty, supported on a sequential optimisation process, aiming integrated decisions and we generate an indicator reflecting the effects of uncertainty penetration in the upstream nodes of a chain. Furthermore, we conclude that the overstock value at one echelon depends heavily upon the availability and number of overstock options at other echelons.

3. REASONING TO CHOOSE REAL OPTIONS TO SOLVE THE PROBLEM

First we concentrate on the techniques to be used. Companies facing market uncertainties have three basic alternative solutions to solve inventory problems. First, they can simply guess for uncertain quantities and proceed with one of the deterministic models under different scenarios. Second, they can develop mathematical models to deal with uncertainty. The disadvantage of this approach is that analytical models with closed solutions can be very complex and difficult for many managers to understand. The third option to capture the market uncertainty is to develop a simulation model. The advantage of the simulation model (e.g. Monte Carlo) is that it is relatively easy to develop regardless of the complexity of the problem under analysis. In this work both situations will be theoretically explored, considering stochastic market demands.

On the other hand we have the conceptual problem. It is not appropriate to forecast demand as a normal distribution, where demand positive or negative shocks are possible and can be generated in highly uncertain markets. In addition, a traditional approach with demand distribution does not consider the information arrival that significantly affects the future demand. In highly uncertain markets, the decision-makers are not sure whether the current demand will go up or down. This situation is closely related to the financial option-pricing problem. Therefore, we adopt the framework of option pricing to model an inventory problem in an uncertain environment.

The following table refers to the analogy between financial option and overstock decision.

Financial options	**Overstock decisions**
Stock price	Demand
Exercise price	Initial inventory level
Time to maturity	Planning period
Stock volatility	Demand volatility

Table 1: Analogy between financial options and overstock decisions

4. VALUATION FRAMEWORK

Two distinct methodologies for representing uncertainty can be identified. These are the scenario-based approach and the distribution-based approach. The applicability of the scenario-based approach is limited by the fact that it requires forecasting all possible outcomes of uncertain parameters; however, by assigning a probability distribution to the continuous range of potential outcomes, the need to forecast exact scenarios is obviated. Therefore, the distribution-based approach is adopted in this work.

For simplifying the exposure, we will consider a firm as being described by a ϕ stages sequential process, meaning that there are ϕ different places where inventory can be kept. The production/inventory system operates on fixed planning periods when production/inventory decisions are applied. We assume a continuous-time demand process within the defined planning points. This makes the problem solvable. The decisions will be optimised considering an integrated and sequential approach. Furthermore, our analysis considers that the overstock value at one echelon depends heavily upon the overstock availability at other echelons.

We assume an installed capacity and restrictions in the use of an outsourcing (subcontracting) alternative. We consider that the overstock decisions in all echelons are centralized on a single authority and that all the inventory information is available for the intervenient, avoiding internal behaviour impacts in the model construction. We also assume that there are no resources' shortages in echelons and period under analysis (which differs from the study of Tan (2002)).

We base our reasoning on the correct sequence and value of inventory in multi-echelon production sites and storage facilities. At each echelon, the management team decides the overstock level and, at the same time, decides whether to exercise it. We ignore capacity constraints and output rates. The overstock value becomes an asset which, if exercised, affords the right to sell the inventory surplus. In our study intermediate inventories exist, not only because of process inefficiencies (e.g.

long lead times) but as a strategy to exploit future sales. There are four major empirical implications derived from our model. First is the impact of uncertain demand, second comprises lead times between stages, third is the impact of service level, and fourth is the impact of costs in the form of added value at each stage.

The stages are sequentially undertaken and the time framework depends on the operations flow and lead time. Echelon φ can be only undertaken after previous upstream echelons $\varphi-1$, $\varphi-2$, $\varphi-3$, $\varphi-4$ till $\varphi-5$, respectively. The overstock distribution across an integrated network allows risk minimization without committing to a major working capital. Each echelon has its own operations, time processing activities, lead time, service level and resources.

We will consider only manufactured items and the demand (quantity) will be treated as a stochastic variable. We consider that any demand not fulfilled from stock is lost at moment t, the lead-times are fixed and known and we will not consider the impact of lost market share in period $t+1$, caused by a disruption in near time t. The multi-echelon overstock level is based on the results of a stochastic model. The formulation of the problem requires a deterministic approach for most of the elements, except for the demand, affecting all the echelons in the chain.

The starting overstock value is in the last downstream echelon of the chain where the company interacts with the customer (retail perspective).The source of uncertainty is the demand (quantity), that we are going to represent by D. We consider that the company cannot influence the sales price with the level of overstock, and the evolution of the demand to be the most important input for the option valuation. We assume that the demand follows a geometric Brownian motion (assumption done also by Bengtsson, 2001; Pindyck, 1988; Tannous, 1996). The demand process can be presented as:

$$dD \equiv \alpha D dt + \sigma D dz \qquad (1)$$

Where: $dz = \varepsilon(t)\sqrt{dt}$; $\varepsilon(t) \approx N(0,1)$; α = instantaneous drift; σ = volatility; dz = increment of a wiener process and $\varepsilon(t)$ is a serially uncorrelated and normally distributed random variable.

From equation (1) we can state that the demand D is log-normally distributed with a variance that grows with the time horizon (also an assumption of the model presented by Bengtsson (2001)). The demand is modelled as a continuous process within the defined planning horizon. We assume that all the production and stock policy is make-to-stock.

We hereafter employ the notations: λ represents supply chain echelon; φ is the supply chain echelon number, ϕ accounts for the number of echelons; p_v is the unit sales price; c_v is the variable production cost of a single unit; θ is the average stock unit cost; h is the stock aging factor; j is the weighted average cost of capital, reported and adjusted to period t; k_s is the cost of holding stocks for each item for period n; c_λ is the unit cost for each echelon; n is the period between "$t-1$" and "t"; I_0 is the existing inventory level in the beginning of period n; $M_v = (p_v - c_v).D$; L_φ is the lead time for echelon φ; t_λ is the processing time for each echelon; ζ_λ represents the operations in each echelon; S_λ is required service level for each echelon: % of the quantity fulfilled on the required date; $1-S_\lambda$ is the stock out rate for each echelon; K_λ is the value calculated as a function of the stock-out rate (normal distribution) in each echelon; Ω_λ overstock value in each echelon; Ω_φ is the overstock value for echelon φ; $r = 1 + r_\eta$ is the discount factor, where r_η is the risk free interest rate.

If we study the overstock value $\Omega_\varphi(t)$, which expires at time t, and gives us the possibility to adjust the stock, if the benefits exceed the costs for changing the stock level, the value of the overstock at time t and echelon φ, can be written as:

$$D \cdot \left(\theta - \sum_{\lambda=\varphi+1}^{\phi} c_\lambda\right) . \left(L_6 + \sum_{\lambda=\varphi+1}^{\phi} \tau_\lambda\right) \cdot K_\varphi . \left(1 - j - h - \frac{k_s}{(\theta - \sum_{\lambda=\varphi+1}^{\phi} c_\lambda)}\right) - M_v . (1 - S_\varphi) - \sum_{\lambda=\varphi+1}^{\phi} \Omega_\lambda - I_0 \qquad (2)$$

Then we calculate the optimal value of the overstock in echelon φ, as being the expected terminal value of the following condition:

$$\Omega_\varphi = \max \left[\begin{array}{l} 0; D \cdot \left(\theta - \sum_{\lambda=\varphi+1}^{\phi} c_\lambda\right) . \left(L_6 + \sum_{\lambda=\varphi+1}^{\phi} \tau_\lambda\right) \cdot K_\varphi . \left(1 - j - h - \frac{k_s}{(\theta - \sum_{\lambda=\varphi+1}^{\phi} c_\lambda)}\right) - \\ - M_v . (1 - S_\varphi) - \sum_{\lambda=\varphi+1}^{\phi} \Omega_\lambda - I_0 \end{array} \right] \qquad (3)$$

Each echelon φ requires a defined number of operations denoted by ζ_λ with a standard unit cost of c_λ and the time duration of τ_λ. Where Ω_φ represents the value of the overstock at echelon φ; "$D \cdot \left(\theta - \sum_{\lambda=\varphi+1}^{\phi} c_\lambda\right) . \left(L_6 + \sum_{\lambda=\varphi+1}^{\phi} \tau_\lambda\right) \cdot K_\varphi$" represents the stock allowed for a certain demand quantity in echelon φ; "$M_v(1-S)$" represents the lost margin related to sales not fulfilled on time; "$j+h+\frac{k_s}{(\theta-\sum_{\lambda=\varphi+1}^{\phi}c_\lambda)}$" represents the opportunity cost of the invested capital, the risk of obsolescence and the weight of the handling costs on the average stock unit cost and "$\sum_{\lambda=\varphi+1}^{\phi}\Omega_\lambda$" represents the overstock in the downstream echelons.

To compute the problem we will use the binomial model, assuming that inventory follows a binomial multiplicative diffusion process. The supply chain nodes are linked using the lead time, which counts for the processing time within the stage operations. We will consider that the overstock required to maximize the fulfilment future sales at echelon φ, Ω_φ, may rise to $\Omega_{\varphi u}$ with probability q_φ or fall to $\Omega_{\varphi d}$ with probability $1-q_\varphi$, where $u_\varphi = e^{\sigma\sqrt{\Delta t_\varphi}} > 1$; $d_\varphi = \frac{1}{u_\varphi} < 1$, and $d_\varphi < r < u_\varphi$. A binomial tree (see Fig. 1) is built for the network, considering the periods of time associated with each echelon lead time: $\Delta t_\varphi = \frac{L_\varphi}{m}$; where m is the computation number. The terminal nodes represent the terminal value of the overstock at the end of each echelon. We simulate upstream echelons by setting $p_\varphi \equiv \frac{(r-d_\varphi)}{(u_\varphi - d_\varphi)}$ and using the following formula:

$$\Omega_\varphi = \left(p_\varphi \Omega_{\varphi_u} + (1-p_\varphi)\Omega_{\varphi d}\right)/r \tag{4}$$

Equation (4) supports the calculation of the discounted overstock value. In the next equations we will model the different probabilities to set the expected overstock for each echelon, using a binomial tree with three steps. This binomial tree supports the deduction of equations (5) to (8).

The first step is the creation of the binomial tree:

Binomial Tree

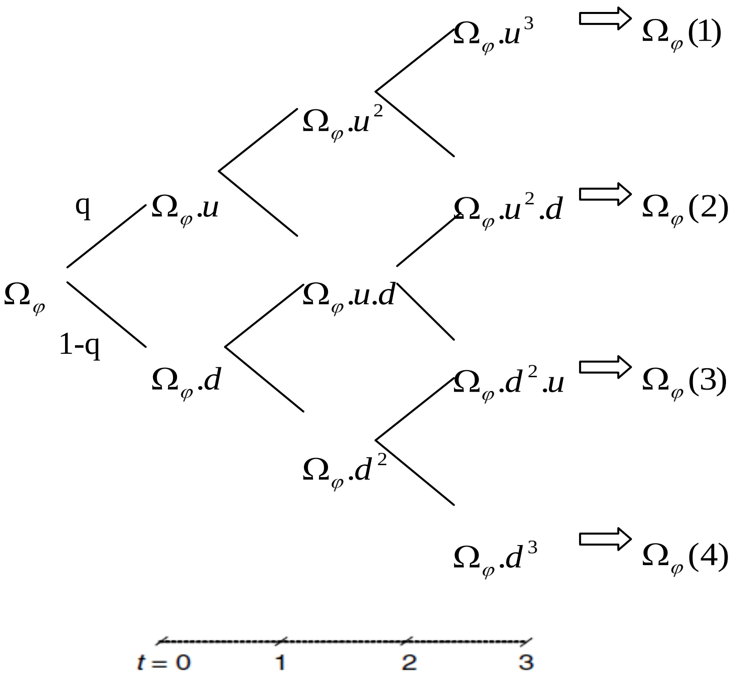


Figure 1: Binomial tree for three steps

If the demand follows a geometric Brownian motion and affects the value of overstock, the estimation of its value, at any point in time, follows a lognormal distribution. By equating the first, second and third moment of a binomial and lognormal distribution, we calculate the corresponding values of u and d , and we get the approximation for the overstock value at the end of each echelon (Cox et al. (1979) and Hull (2003)).

Second step: find the optimal value at each final node of the tree, for echelon $\varphi : \varphi \in \mathrm{N} \,|\, 0 < \varphi \leq \phi$,

$$\Omega_\varphi(1) = \max\left[\begin{array}{l} 0; D \cdot \left(\theta - \sum_{\lambda=\varphi+1}^{\phi} c_\lambda\right) . \left(L_6 + \sum_{\lambda=\varphi+1}^{\phi} \tau_\lambda\right) \cdot K_\varphi . \left(1 - j - h - \dfrac{k_s}{(\theta - \sum_{\lambda=\varphi+1}^{\phi} c_\lambda)}\right) . u^m - \\ - M_v . (1 - S_\varphi) . u^m - \sum_{\lambda=\varphi+1}^{\phi} \Omega_\lambda - I_0 \end{array}\right] \qquad (5)$$

$$\Omega_{\varphi}(2)=\max\left[\begin{array}{l}0;D\cdot\left(\theta-\sum_{\lambda=\varphi+1}^{\phi}c_{\lambda}\right)\cdot\left(L_6+\sum_{\lambda=\varphi+1}^{\phi}\tau_{\lambda}\right).K_{\varphi}.\left(1-j-h-\frac{k_s}{(\theta-\sum_{\lambda=\varphi+1}^{\phi}c_{\lambda})}\right).u^{m-1}.d-\\-M_v.(1-S_{\varphi}).u^{m-1}.d-\sum_{\lambda=\varphi+1}^{\phi}\Omega_{\lambda}-I_0\end{array}\right] \tag{6}$$

$$\Omega_{\varphi}(3)=\max\left[\begin{array}{l}0;D\cdot\left(\theta-\sum_{\lambda=\varphi+1}^{\phi}c_{\lambda}\right).\left(L_6+\sum_{\lambda=\varphi+1}^{\phi}\tau_{\lambda}\right).K_{\varphi}.\left(1-j-h-\frac{k_s}{\left(\theta-\sum_{\lambda=\varphi+1}^{\phi}c_{\lambda}\right)}\right).u.d^{m-1}-\\-M_v.(1-S_{\varphi}).u.d^{m-1}-\sum_{\lambda=\varphi+1}^{\phi}\Omega_{\lambda}-I_0\end{array}\right] \tag{7}$$

$$\Omega_{\varphi}(4)=\max\left[\begin{array}{l}0;D\cdot\left(\theta-\sum_{\lambda=\varphi+1}^{\phi}c_{\lambda}\right)\cdot\left(L_6+\sum_{\lambda=\varphi+1}^{\phi}\tau_{\lambda}\right)\cdot K_{\varphi}.\left(1-j-h-\frac{k_s}{\left(\theta-\sum_{\lambda=\varphi+1}^{\phi}c_{\lambda}\right)}\right).d^{m}-\\-M_v.(1-S_{\varphi}).d^{m}-\sum_{\lambda=\varphi+1}^{\phi}\Omega_{\lambda}-I_0\end{array}\right] \tag{8}$$

Equations (5) to (8) represent the expected overstock value at each echelon, considering the probability of the value to go up or down. After establishing the overstock value for each step we start with the sequential approach, using three computations for each node.

Third step: find the option value at earlier nodes, starting at the penultimate time step, and working back to the first node of the tree (the valuation date), where the calculated result is the value of the option. Now we use the value at the end of the echelon φ and discount by one period; this is the first computation, for echelon $\varphi:\varphi\in\mathrm{N}\mid 0<\varphi\leq\phi$,

$$\begin{cases}\Omega_{\varphi 31}=\left(p_{\varphi}.\Omega_{\varphi}(1)+(1-p_{\varphi})\Omega_{\varphi}(2)\right)/r\\ \Omega_{\varphi 32}=\left(p_{\varphi}.\Omega_{\varphi}(2)+(1-p_{\varphi})\Omega_{\varphi}(3)\right)/r\\ \Omega_{\varphi 33}=\left(p_{\varphi}.\Omega_{\varphi}(3)+(1-p_{\varphi})\Omega_{\varphi}(4)\right)/r\end{cases} \tag{9}$$

In the second computation we discount the values calculated in the first computation. Second computation, for echelon $\varphi:\varphi\in\mathrm{N}\mid 0<\varphi\leq\phi$,

$$\begin{cases} \Omega_{\varphi 21} = \left(p_\varphi.\Omega_{31} + \left(1 - p_\varphi\right)\Omega_{\varphi 32}\right)/r \\ \Omega_{\varphi 22} = \left(p_\varphi.\Omega_{\varphi 32} + \left(1 - p_\varphi\right)\Omega_{\varphi 33}\right)/r \end{cases} \quad (10)$$

In the third computation we discount the values of the second computation. Third computation, for echelon $\varphi : \varphi \in \mathrm{N} \mid 0 < \varphi \leq \phi$,

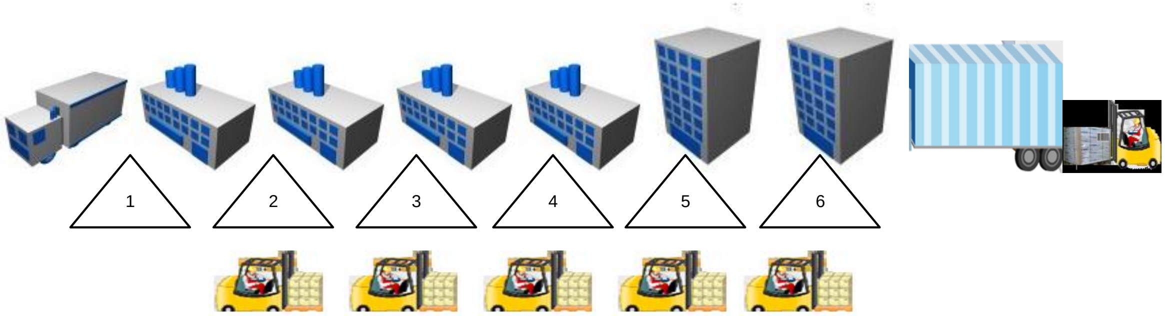
$$\Omega_\varphi = p_\varphi.\Omega_{\varphi 21} + \left(1 - p_\varphi\right)\Omega_{\varphi 22} \quad (11)$$

Finally we find the overstock value, for time t and echelon φ (Ω_φ), which must satisfy the following differential equation:

$$\alpha.D.\frac{d\Omega_\varphi}{dD} + \frac{1}{2}.\sigma^2 \frac{d\Omega_\varphi{}^2}{d^2D} - r_\eta \Omega_\varphi = 0 \quad (12)$$

5. NUMERICAL EXPERIMENTATION AND RESULTS

We used a flooring company to test our model. The company persecutes its operations using four intermediate warehouses and two final product warehouses. The example allows a better understanding of the model for manufacturing and distribution companies. The production takes place in plants, which supply customers through finished products' warehouses. The company has an initial stock of purchased components (echelon 1). The first operation to be executed refers to sanding process were the raw material thickness is adapted to the required specification; after being sanded, sheets are stored in an intermediate warehouse (echelon 2), after which they are painted to form a new semi-finished item to be stored in another intermediate warehouse (echelon 3). In a new department the varnish activities are performed, using the painted sheet from the previous echelon, after which the products are stored (4). The last operations (echelon 5) take place at the finishing department where the packing activities are executed and painted and varnished sheets are accomplished in pallets. The final products are then delivered to production end-line warehouses (echelon 5). Then the products go into a central warehouse where handling, picking and loading activities are performed (echelon 6). The goods are measured in a single unit (square meters (sqm)) in all the stocking points.



Legend: "1" refers to echelon number 1 (components' stock); "2" – echelon number 2 (intermediate warehouse stock for sanded sheets); "3" – echelon number 3 (intermediate stocks for painted sheets); "4" – echelon number 4 (intermediate stocks for varnished sheets); "5" – echelon number 5 (end-line warehouses); "6" – echelon number 6 (central warehouse).

Figure 2: Company network design

Table A1 in appendix, refers the data used in the example. Using the real data we will present and discuss the main results.

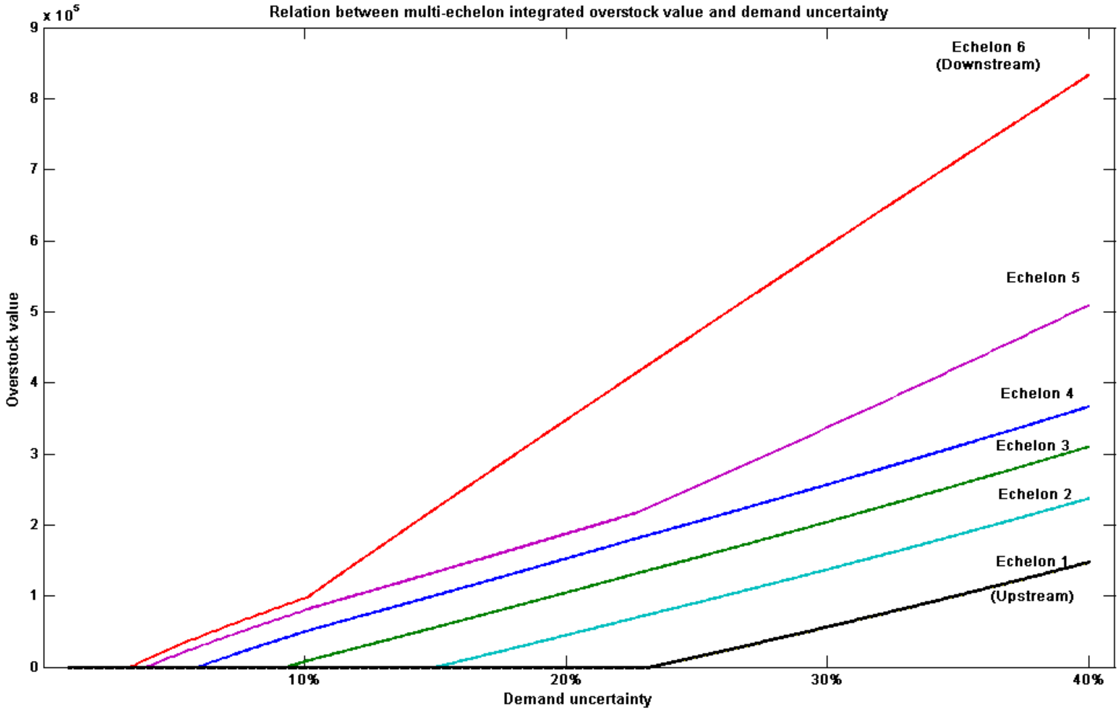


Figure 3: Relation between multi-echelon integrated overstock value and demand uncertainty

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We tested the impact of different demand uncertainty levels on the optimal overstock value required for each echelon under a sequential approach (Fig.3). Considering the design of the supply chain that we used in our numerical experimentation, the echelon number six refers to the last node in the network – central warehouse, before the items enter in the retailing area. For high uncertainty levels, the overstock increases for all the echelons. This effect is stressed in the downstream nodes and less aggressive in the upstream nodes, mainly in the plant intermediate warehouses (stages 4, 3, 2 and 1). With these results we understand the sensibility between overstock level and demand uncertainty. We must emphasize that the overstock acts as a flexible measure to minimize the impacts due to an increase in the demand risk. For demand uncertainty levels below 3,3% there is no need to overstock; from uncertainty level range between 3,4% to 3,9% it's required overstock but only for the central warehouse, above which and until 6% it's also required overstock in the end-line warehouses. For uncertainty levels above 6% the company should have overstock in the factory warehouses. For high uncertainty levels above 23,3%, the company should reinforce stocks (overstock premium) in all the echelons.

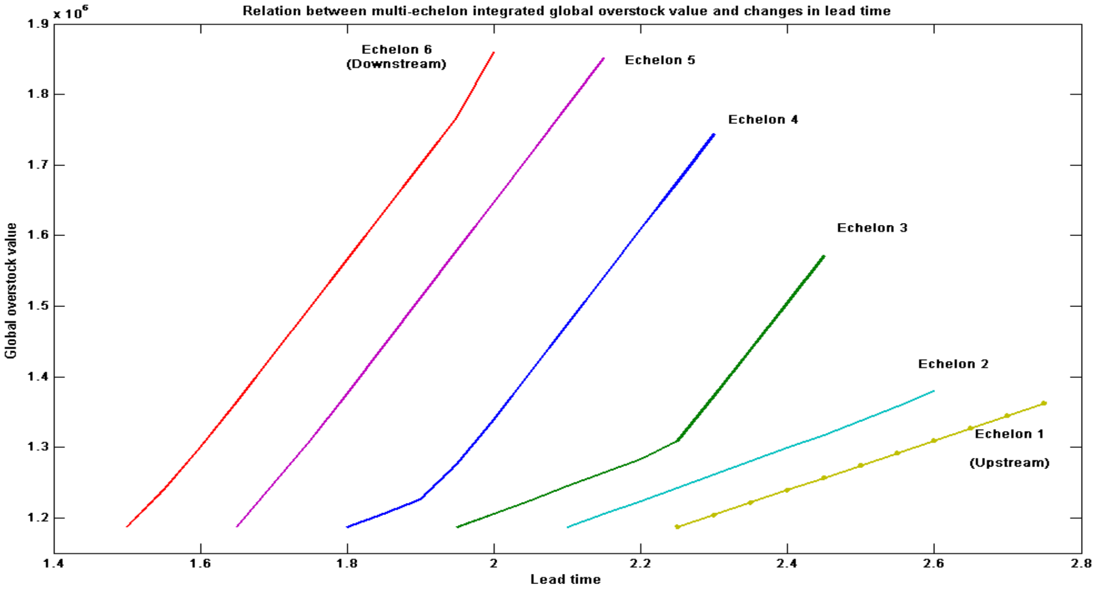

Figure 4: Relation between multi-echelon integrated global overstock value and changes in lead time

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We formulated different scenarios for changes in lead times along the nodes in the chain (Fig. 4). For different lead times we simulated the optimal global overstock level. The results show that a decrease in lead time allows for a lower overstock value for all the echelons. The managerial implication is that efficient practises or agile process designs, able to decrease lead times, can contribute to an overstock decrease. However, the impact is different considering the positioning of the stocking points in the chain. For the downstream echelons – finished products warehouses and end-production buffers there is a higher impact. A reduction in lead time in the last downstream stage of 3% accounts for a reduction in global overstock value of 4%; on the opposite, a reduction of 2% in the last upstream echelon (stage 1) only causes a reduction of 1,4% on the global overstock value. The downstream stages' overstocks are more sensible to improvements in lead time, which means that flexibility has more value in the final echelons, closer to the market.

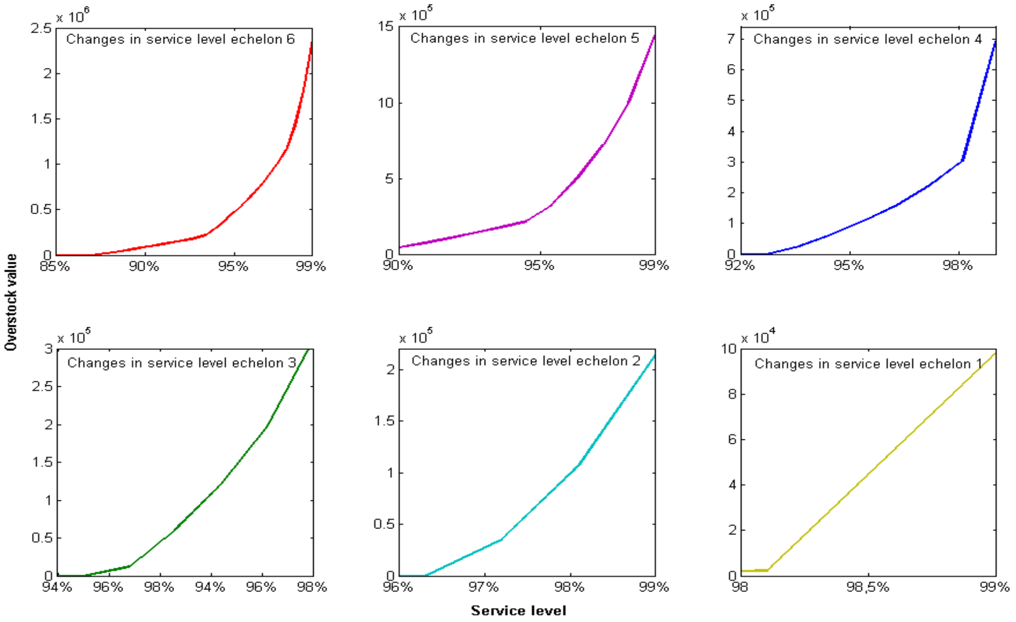

Figure 5: Relation between overstock value and changes in service level, by each echelon

In figure 5 it is shown how service level impacts on overstock value. Service level measures the percentage of the required production or sales quantity delivered within the agreed deadline and, as a consequence, the capacity to satisfy the external customer or the internal client (the downstream echelon). With this analysis (Fig. 5) we conclude that overstock is more sensible to service level changes in the downstream echelons, where changes in the service are more expressive and with higher implications. For central warehouse service level below 87,8% there is no need for overstocking in this last downstream echelon. It also stated that high service level rates tend to concentrate the overstocking efforts in the last downstream stages, for a service level of 95,8% in the final downstream stage, the upstream overstocks value represent 60% of the total overstock, nevertheless, when the service level increases to 96,6% the upstream overstocks value impact decreases to 51,2% (Table 2). Finally, when service level is closer to 100%, the overstock value tends to infinitive, in all the echelons where such a metric is applied.

Central warehouse service level (echelon 6)	Global overstock distribution (indicator)	
	Central warehouse	Upstream echelons
87,8%	0,0%	100,0%
95,8%	39,6%	60,4%
96,6%	48,8%	51,2%
99,4%	88,0%	12,0%

Table 2: Impact of different service levels on echelon 6, global and upstream overstock values

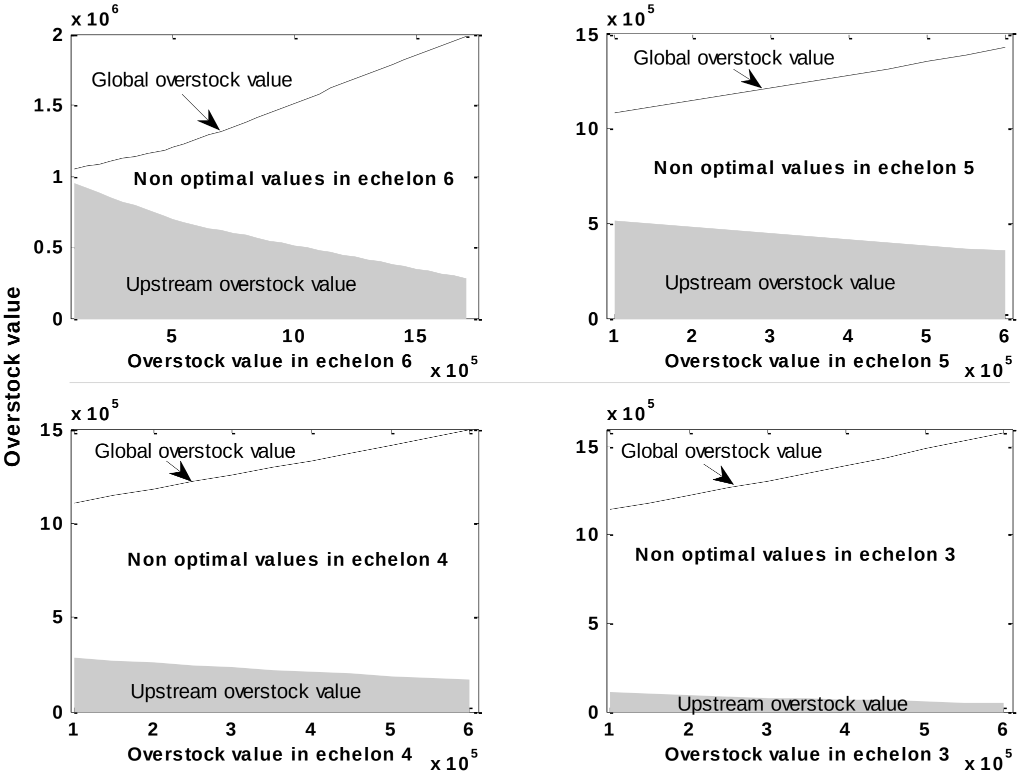

Figure 6: Impact on upstream echelons of non-optimal overstock values

Traditionally, the multi-echelon inventory literature assumed the existence of a single authority for the entire supply chain, with information flowing about demand patterns and with the capacity to define and impose a global optimal inventory policy spread all over the existing echelons. Nevertheless, some authors have recently started dropping this assumption. The existence of incentives in the supply chain, intra or inside a single firm concept, generally generate conflicting goals. The information asymmetries are also a reality because individual parts have some private information that is not shared among others parts, and echelon managers lack information about the entire supply chain. For this purpose and to support the generalization of the model, different situations considering distortions – specifically provoked by non-optimal values - have been tested. For higher non-optimal overstock values in different echelons, the global overstock value increases. We also considered the extreme situations of not allowing higher amounts of overstock at certain echelons, which can be due to lack of space or sequential processes able to reduce intermediate stocks. From empirical knowledge, the communication distortion is higher as the distance from the market is amplified; this is also stated in the figure 6. A practical consequence relies on wrong upstream decisions (internal suppliers). Based on the results, we follow the literature that defends integration and alignment in inventories decision process to protect the supply chain from the market uncertainty.

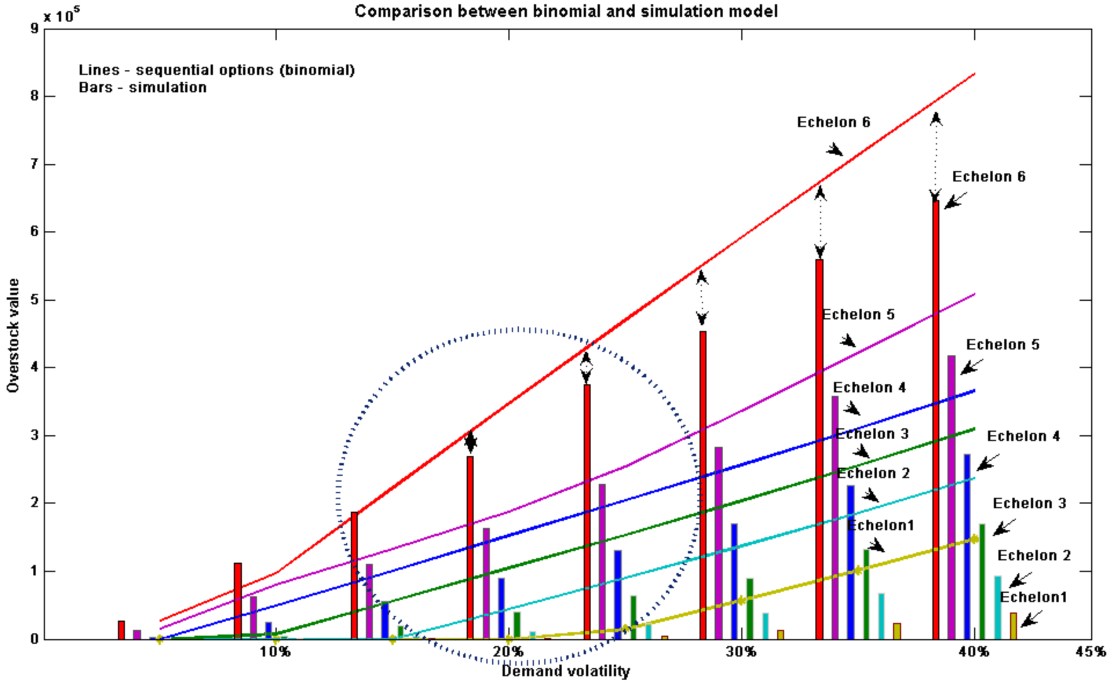

Figure 7: Comparison between binomial and simulation model

In figure 7 there are shown the results comparing the proposed sequential approach (lines) with a simulation model (bars). Our findings are supported by both algorithms, considering impacts of different demand uncertainty levels. With this test we support the adequacy of the model under study being confronted with an algorithm based on simulation. Specifically we used Monte Carlo simulation (formula in appendix). The results presented in figure 7 show the similarity of the solutions for uncertainty levels between 10% and 25%. For high uncertainty levels, both models maintain the same behaviour, concentrating the overstock on the downstream echelons which is in line with our findings.

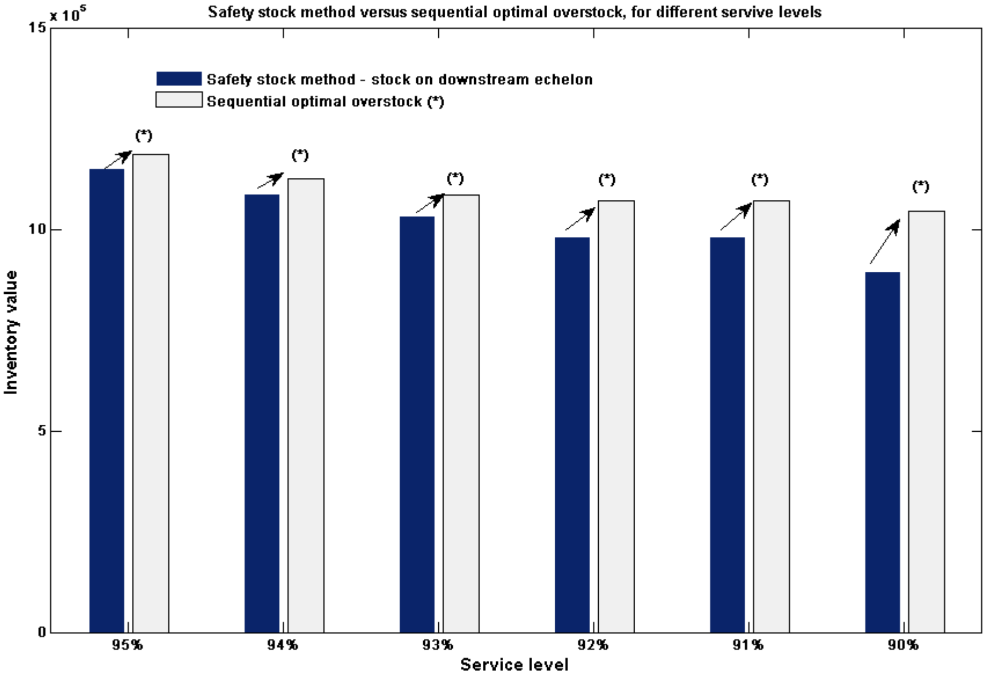

Figure 8: Safety stock method versus sequential optimal overstock, for different service levels

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Finally on figure 8 we compare the results using the proposed sequential approach with the traditional safety stock formula for the downstream stage. Our model intensifies the need of inventory mainly due to the demand uncertainty levels. The proposed model also splits the inventory by each echelon in an optimal approach. The safety stock is calculated by each echelon based on the requirements of the downstream level, being affected by the replenishment policy of that echelon that can distort the behaviour of market demand.

6. CONCLUSIONS

In this research, by employing a sequential decision frame applied to inventory management, we intend to analyse and value the overstock in a setting characterised by the dynamics of a multi-echelon network and under demand uncertainty. Furthermore, we explore the link between the echelons to approach a generalised optimal integrated inventory model. This study also emphasises the impact on the inventory level of internal lead-times, service level and activity costs. We conclude the paper by reiterating the main results, contributions, and management implications.

Our motivation relied on the lack of tools to measure demand uncertainty penetration in supply chains, and also on the difficulty of understanding the relation between performance stages regarding inventory management. The model quantifies the uncertain penetration level in a multi-echelon network with manufacturing and distribution stocking points. The results confirm the empirical observation of the positive relation between the inventory level and the uncertainty level. Non-optimal values caused by distortions in information availability or lack of global co-ordination have an impact on the inventory level.

The purpose and the practical applications of the present study rely on the definition of adequate levels of inventories to hedge against demand uncertainty. When the supply chain has multiple decision echelons at which different stock levels can be applied, it is very important to balance all the buffers depending on uncertainty of market demand and endogenous penetration. Wrong decisions may involve non-optimal stocks at each echelon, which can provoke and intensify the effect of demand uncertainty causing increased risk in the upstream echelons of the chain.

7. LIMITATIONS AND FUTURE RESEARCH

We have discussed the impacts from unbalanced overstock value in a multi-echelon approach but we did not explore the impacts of the integration level of a firm in a supply chain or the opposite. This is a potential relevant extension of the present work.

The results achieved are promising, but possibilities for improvements should be further explored. The extension of stochastic demand representation and the inclusion of normal planning issues like capacity restrictions, will allow for a general application of the concept. Considering the relevance of these improvements to support the generalization of the model, we have incorporated in appendix an additional model using additional demand processes representations, solving the potential discussions on limitations due to the assumption of geometric Brownian motion. We also included impacts from capacity restriction.

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A. APPENDIX

variable	value	variable	value
D	262.051 sqm	k_s	0,263 €/ sqm
ϕ	6 echelons	I_0	4.849.145 €
p_v	15 €/ sqm	r_η	5 (%/year)
c_v	5 €/ sqm	m	3
θ	7,5 €/ sqm	$c_\lambda, \lambda \in \mathrm{N} \mid 0 < \lambda \leq 6$	3,75; 4,5; 5,25; 6,00; 7,75; 7,5 €/sqm
h	0,002 coefficient	$\tau_\lambda, \forall \lambda \in \mathrm{N} \mid 0 < \lambda \leq 6$	0,15
j	0,5 (%/month)		
L_φ	$L_6 + \sum_{\lambda=\varphi}^{\phi-1} \tau_\lambda, \phi - 1 > 0$	σ	25%
L_6	1,5	$S_\lambda, \forall \lambda \in \mathrm{N} \mid 0 < \lambda \leq 6$	95%

Table A1 (3): Parameter values used to obtain the results

A.1. SIMULATION MODEL

The Monte Carlo simulation repeats pay-offs function to generate a number of pay-offs to calculate the expected value of the option. The general formula is presented as:

- $E\left[\overset{x}{f}(X_t)\right] = \frac{1}{\overset{s}{N}} . \sum_{i=1}^{\overset{s}{N}} \overset{x}{f}\left(\overline{X}(t, \upsilon_i)\right)$, where: $\overline{X}$ represents the approximation of x, t represents time and υ_i is the series of calculation points;
- The value is discounted to actual moment;
- At each stage we deduct the downstream overstock values.

B. APPENDIX

In this additional discussion, we follow Tan (2002) assuming restrictions in the available manufacturing and storage capacity and out-put rates equilibrium within the planning period. We ignore the use of an outsourcing (subcontracting) alternative.

A model is presented not only based on abstractions of the real world, but whose illustration case can provide guidance and insight to the inventory management within companies in the actual uncertainty environments.

The model takes into account three important characteristics of real problems, such as production/storage capacity limits, multi-product production and uncertainty in demand flows. In this work, we try to overcome these actual problems by presenting a new model which contemplates both inventory value and distribution in the context of a multi-stage network, and which allows for a multi-product environment with limited capacities and uncertainty in the demand flow. A real options formulation model is proposed and adapted to allow an easier application to real life problems, without a loss in generality. We solve the model for a flooring company case study and present the results.

Our results are valid for the specific supply chain and the operating environment we used in the model. Nevertheless, we must emphasize the generality of the model to incorporate different supply chain designs and stages interactions, considering limitations in supply chain partners cooperation and information flow.

The main objective of this study is to consider demand uncertainty in an inventory decision model. The conventional approaches, such as the newsvendor problem, of inventory stocking decisions rely on a specific distribution of demand. The second objective of this research is to establish a coordination model of a multi-stage supply chain with a real option framework (overstock). Actions taken by the multiple partners in the supply chain often result in inventories that are higher than what could be achieved if the supply chain were to coordinate its actions with a common objective of maximizing supply chain profits.

The stages are sequentially undertaken and the time framework depends on the operations sequence and lead time. Downstream stages can be only undertaken after previous stages. The overstock is split across an integrated supply chain, which allows risk minimization without committing to a major invested capital. Each stage has its own operations, time processing activities, lead time, resources, capacity constraints and output rate.

B.1. MODEL MATHEMATICAL FORMULATION

In this section we present the mathematical formulation with generic sets. The parameters and the objective function will follow. The techniques for the resolution of the model are presented in appendix.

.Sets to support a general application for different network designs:

- $\overset{A}{F} = \{1,\ldots,N_p\}$ potential factories, within supply chain A
- $\overset{A}{W} = \{1,\ldots,M_q\}$ potential warehouses, within supply chain A ,
- $Z = \{1,\ldots,X_l\}$ items' classification

.Parameters

- ($\gamma^p_{(f)-(f+1)}$) Relation between out-put units factory f and $f+1$,

$f \in \overset{A}{F}$ (equivalent finished units).

- (g^p_f) Maximum capacity of factories, $f \in \overset{A}{F}$
- (g^q_w) Maximum capacity of warehouses (or distribution centres), $w \in \overset{A}{W}$
- (c^p_f) Unit cost of factory, $f \in \overset{A}{F}$
- (c^q_w) Unit cost of warehouse (or distribution centre), $w \in \overset{A}{W}$
- (L^p_f) Lead-time of operations in factory, $f \in \overset{A}{F}$. Lead time is the amount of

time from the point at which one determines the need to order to the point at which the inventory is on hand and available for use.

- (L^q_w) Lead-time of activities in warehouse (or distribution centres), $w \in \overset{A}{W}$
- (S^p_f) Service level assumed by factory, $f \in \overset{A}{F}$.
- (S^q_w) Service level assumed by warehouse (or distribution centres), $w \in \overset{A}{W}$.

Represents the % of the quantity fulfilled on the required date

- (k^q_f) Holding cost for inventory in factory (intermediate stock), $f \in \overset{A}{F}$. This

is the cost of holding an item in inventory for some given unit of time.

- (k^q_w) Holding cost for inventory in warehouse (or distribution centre),

$w \in \overset{A}{W}$. This is the cost of holding an item in inventory for some given unit of time. It usually includes the lost investment income caused by having the asset tied up in inventory. This is not a real cash flow, but it is an important component of the cost of inventory.

- ($r = 1 + r_\eta$) The discount factor, where r_η is the risk free interest rate.

- (j) The weighted average cost of capital, reported and adjusted to the planning period.
- $(1-S_f^p)$ Stock-out rate in factory, $f \in \overset{A}{F}$. When a customer seeks the product and finds the inventory empty, the demand can either go unfulfilled or be satisfied later when the product becomes available. The former case is called a lost sale, and the latter is called a backorder. Anyhow, both situations are disturbing and count for the stock-out rate.
- (h) The stock aging factor. This parameter quantifies the items obsolescence, due to storage time.
- (τ_{f-1}^f) Cycle time. The time between operations in consecutive network stages. Is the cycle time between factory, $f \in \overset{A}{F}$.
- (I_0^f) The existing intermediate inventory level in factory, $f \in \overset{A}{F}$ in the beginning of the planning period.
- (I_0^w) The existing final products inventory level in warehouse (or distribution centres) at the beginning of the planning period, $w \in \overset{A}{W}$.
- We hereafter employ the additional notation p_v for the unit sales price and K_f^p and K_w^p for the value calculated as a function of the stock-out rate (normal distribution), for each factory $f \in \overset{A}{F}$ and warehouse $w \in \overset{A}{W}$, respectively.

.Decision variables

- Maximum overstock value allowed for each factory (Ω_f)
- Maximum overstock value allowed for each warehouse (or distribution centre) (Ω_w)

The model considers:

Max (demand, costs, time, service, obsolescence, initial stock)

Using the above definitions, the overstock model (Ω_f and Ω_w) are formulated as follows, by each item category:

$$\max\left[0; D_z.\sum_{f=1}^{N}\Phi_{zf}^{\ p} + D_z.\sum_{w=1}^{M}\Phi_{zw}^{\ q} - \sum_{f=1}^{N} I_{z0}^{\ f} - \sum_{w=1}^{M} I_{z0}^{\ w}\right],\ \forall\ z \in Z \tag{B.1}$$

With,

$$\begin{aligned}\Phi_{zf}^{\ p} &= c_{zf}^{\ p}.L_{zf}^{\ p}.K_{zf}^{\ p} - \left(p_{zv} - \sum_{i=f}^{N} c_{zi}^{\ p}\right) + S_{zf}^{\ p}.\left(p_{zv} - \sum_{i=f}^{N} c_{zi}^{\ p}\right) - \\ &- L_{zf}^{\ p}.K_{zf}^{\ p}.c_{zf}^{\ p}.j - L_{zf}^{\ p}.K_{zf}^{\ p}.c_{zf}^{\ p}.h_z - L_{zf}^{\ p}.K_{zf}^{\ p}.k_f^p\end{aligned} \tag{B.2}$$

$$\begin{aligned}\Phi_{zw}^{\ q} &= c_{zw}^{\ q}.L_{zw}^{\ q}.K_{zw}^{\ q} - \left(p_{zv} - \sum_{i=w}^{M} c_{zi}^{\ q}\right) + S_{zw}^{\ q}.\left(p_{zv} - \sum_{i=w}^{M} c_{zi}^{\ q}\right) - \\ &- L_{zw}^{\ q}.K_{zzw}^{\ q}.c_{zw}^{\ q}.j - L_{zw}^{\ q}.K_{zw}^{\ q}.c_{zw}^{\ q}.h_z - L_{zw}^{\ q}.K_{zw}^{\ q}.k_w^q\end{aligned} \tag{B.3}$$

s.t.

- $g_f^p \geq g_{f+1}^p.\gamma_{(f)-(f+1)}^p \geq \ldots \geq D,\ \forall\ z \in Z$
- $g_w^q \geq D,\ \forall\ z \in Z$
- $\sum_{f=1}^{N}\sum_{z=1}^{X} \Omega_{zf}^{\ p} \leq \sum_{f=1}^{N} R_f$, R_f is the capital restriction for factory $f \in \overset{\mathrm{A}}{F}$
- $\sum_{w=1}^{M}\sum_{z=1}^{X} \Omega_{zw}^{\ q} \leq \sum_{w=1}^{M} R_w$, R_w is the capital restriction for warehouse $w \in \overset{\mathrm{A}}{W}$

We assume that the demand is stochastic. For the generality of the model we will formulate the problem considering two stochastic processes: a geometric Brownian motion (assumption done also by Bengtsson, 2001; Pindyck, 1988; Tannous, 1996) and mean reversion. Different techniques will be used to solve the objective formula.

- When demand follows a geometric Brownian motion, the process can be presented as:

$$dD \equiv \alpha D dt + \sigma D dz \tag{B.4}$$

Where: $dz = \varepsilon(t)\sqrt{dt}$; $\varepsilon(t) \approx N(0,1)$; α = instantaneous drift; σ = volatility; dz = increment of a wiener process and $\varepsilon(t)$ is a serially uncorrelated and normally distributed random variable.

To compute the problem will use the binomial model, assuming that inventory follows a binomial multiplicative diffusion process. The supply chain nodes are linked using the lead time, which counts for the processing time within the stage operations. We will consider that the inventory required for future sales at factory f or warehouse w, Ω_f or Ω_w, may rise to Ω_{fu} or Ω_{wu} with probability q_f or q_w, or fall to Ω_{fd} or Ω_{wd} with probability $1-q_f$ or $1-q_w$, where $u_{f,w} = e^{\sigma\sqrt{\Delta t_{f,w}}} > 1$; $d_{f,w} = \frac{1}{u_{f,w}} < 1$, and $d_{f,w} < r < u_{f,w}$. A binomial tree is built for the supply chain, considering the periods of time associated with each stage (factory or warehouse) lead time; $\Delta t_{f,w} = \frac{L_{f,w}}{m}$, m is the computation number. The terminal nodes represent the terminal value of the overstock at the end of each stage. We simulate upstream stages by setting $p_{f,w} \equiv \frac{(r - d_{f,w})}{(u_{f,w} - d_{f,w})}$ and using the following formula:

$$\Omega_{f,w} = \left(p_{f,w}\Omega_{fu,wu} + (1 - p_{f,w})\Omega_{fd,wd}\right)/\,r \tag{B.5}$$

Second, considering that the demand can face sudden changes, we will assume that the demand follows a mean reversion process (MRP) with jumps. The demand is described using the following equation:

$$dD = \kappa(\overline{D} - D)dt + \sigma D dz + \overset{j}{\Phi}\, dq \tag{B.6}$$

Where: $dz = \varepsilon(t)\sqrt{dt}$; $\varepsilon(t) \approx N(0,1)$, κ is the speed of reversion, $\overline{D}$ is the long term mean, σ is the volatility of the process; $dz =$ increment of a wiener process; where $\varepsilon(t)$ is a serially uncorrelated and normally distributed random variable and $\overset{j}{\Phi}$ is the jump size, with distribution dq (Poisson), for jumps occurrence. Jump size is modelled as a random variable.

To compute the problem when demand follows a mean reversion we will use the Monte Carlo simulation technique.

B.2. CASE: FLOORING COMPANY

We used a flooring manufacturing company to test our model. The company persecutes its operations using four manufacturing departments and two distribution platforms. The example allows a better understanding of the model for manufacturing or distribution companies. The production and manufacturing take place in plants, which supply customers through finished products' warehouses. The first stage refers to agglomeration process were the raw material is transformed in plank sheets of 0,44 sqm, after being agglomerated, sheets are assembled with a vinyl décor layer to form a semi-finished item in another industrial plant (stage 2). In stage 3 the painting and varnish activities are performed with diversified items, using the vinyl composite sheet from the previous stage. The last manufacturing plant (stage 4) is the finishing stage where the cutting and packing activities are executed, briefly, vinyl painted and varnished composite sheets are cut in planks. The final planks are delivered to production end-line warehouses (stage 5) where handling and picking are done for the expedition warehouse (stage 6). The goods are measured in square meters (sqm) and we reported all the intermediate productions in finished units' equivalent measures.

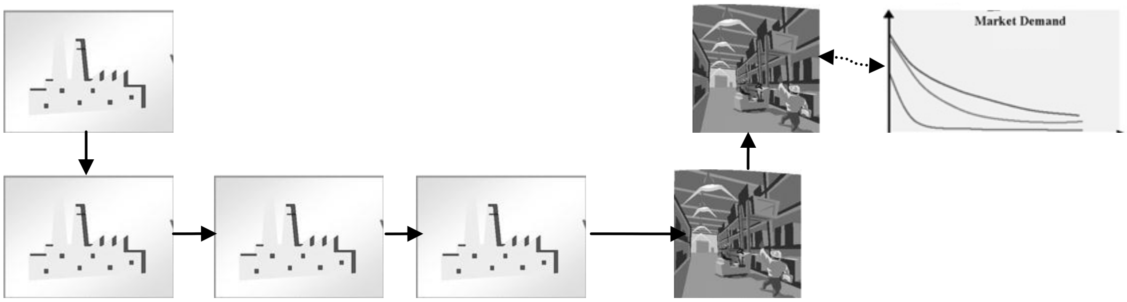


Figure B1 (9): Company network representation

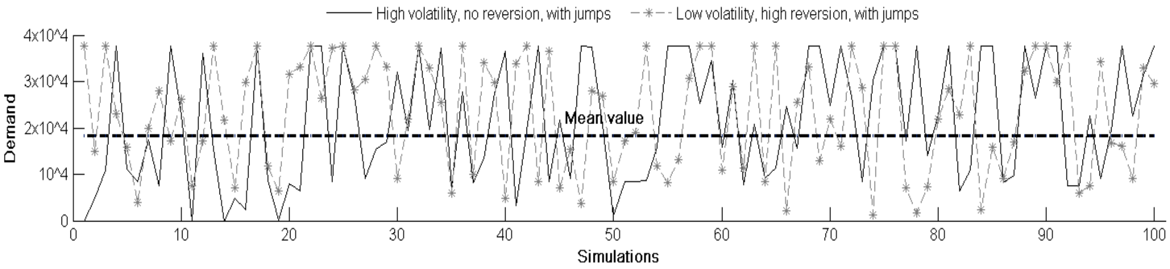


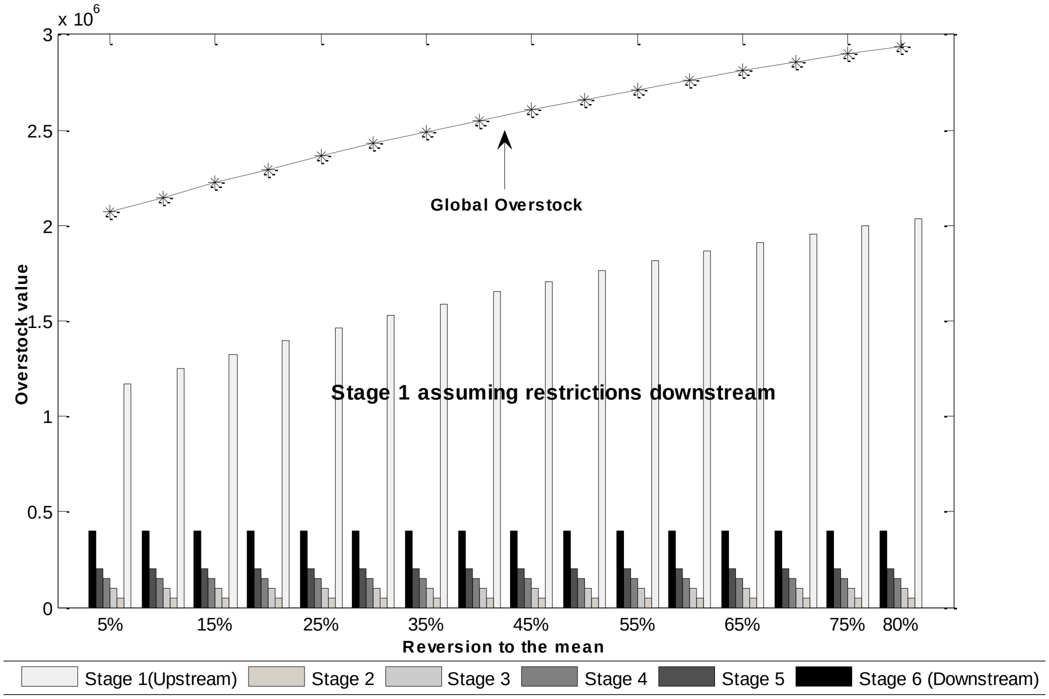
Figure B2 (10): Demand representation using mean reversion for high and low volatility, high and low reversion and with or without jumps

Figure B2 refers to historical demand behaviour. Using the analysis of historical data we conclude that mean reversion is the best demand process design to be considered.

The results comprise five major scopes: (1) the effect of demand behaviour on multi-stage overstock value; (2) the influence of lead-time changes on multi-stage overstock value; (3) the influence of service level changes on multi-stage overstock value; (4) capital restrictions on inventory value and (5) the influence of non-optimal overstock values. An additional scope is related with the influence of the network design stocking points on overstock value.

(1) Effect of demand behaviour on multi-stage overstock value.

We tested the effects of changes in reversion to the mean, considering restrictions in each stage invested capital.

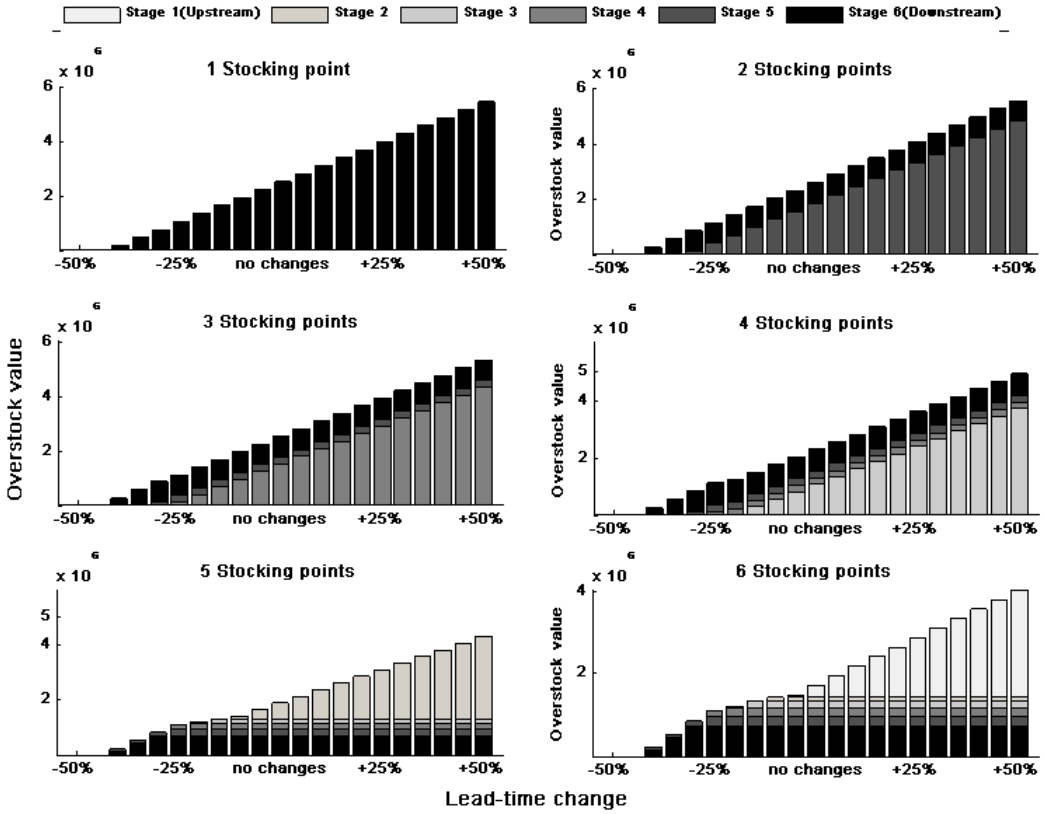


Restrictions in overstock level by each stage as follows: stage 6 – 400 000 €; stage 5 – 200 000 €; stage 4 – 150 000 €; stage 3 – 100 000 €; stage 2 – 50 000 €. Demand jumps = 54 000 sqm (positive or negative).

Figure B3 (11): Effect of changes in reversion to the mean on the overstock value

Analysing the results in Fig. B3 it can be seen that when changing the reversion to the mean, an increase on the actualised overstock is observed. This is valid for any of the stages considered but, due to restrictions in invested capital, the overstock need is more intensive in the most upstream stage; in our case, in the agglomeration plant.

(2) The influence of lead-time changes on multi-stage overstock value.

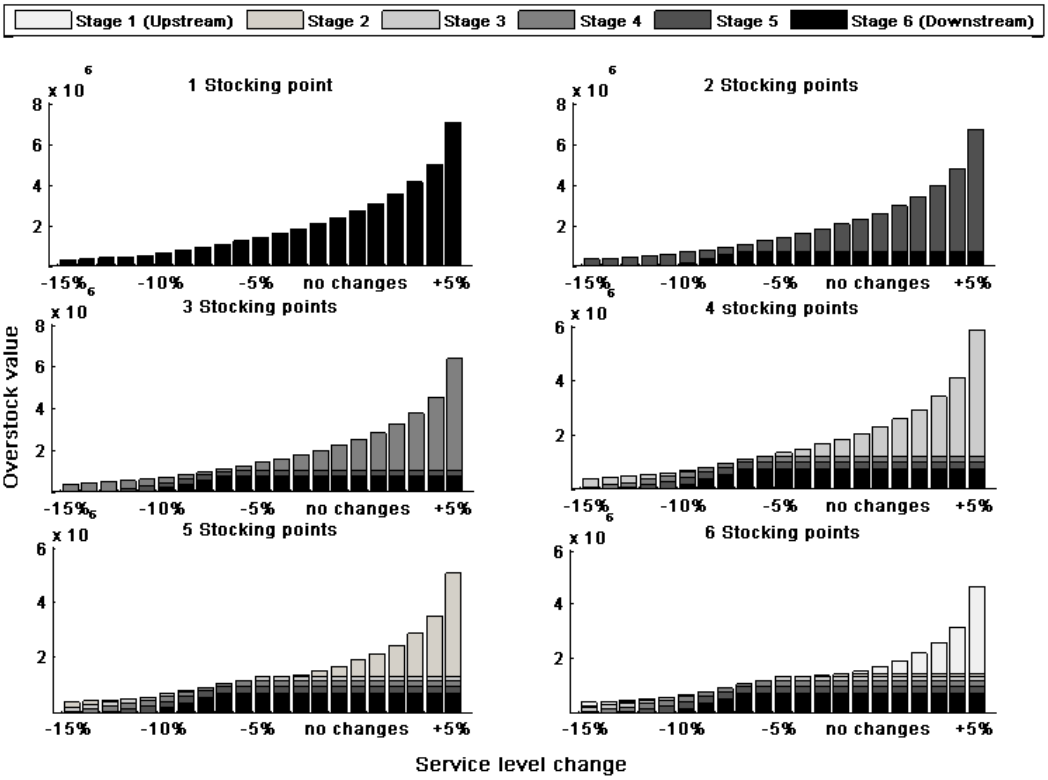


Restrictions in overstock level by each stage as follows: stage 6 – 750 000 €; stage 5 – 250 000 €; stage 4 – 200 000 €; stage 3 – 150 000 €; stage 2 – 100 000 €. Demand jumps = 54 000 sqm (positive or negative). κ *= 0,40;* σ *=0,35*

Figure B4 (12): Effect of changes in lead-time on the overstock value, considering different stocking points (stages at where inventory is possible)

As it can be observed in Fig. B4, that the lead-time reduction, caused by a probable efficiency increase, results in overstock decrease. This is partially explained by the increment of rotation in the planning time frame. Increases in lead-time originate higher overstock needs. As the network is composed by more available stocking points, the overstock tends to decrease, which is consistence with the decrease in the upstream stages' costs.

(3) The influence of service level changes on multi-stage overstock value.

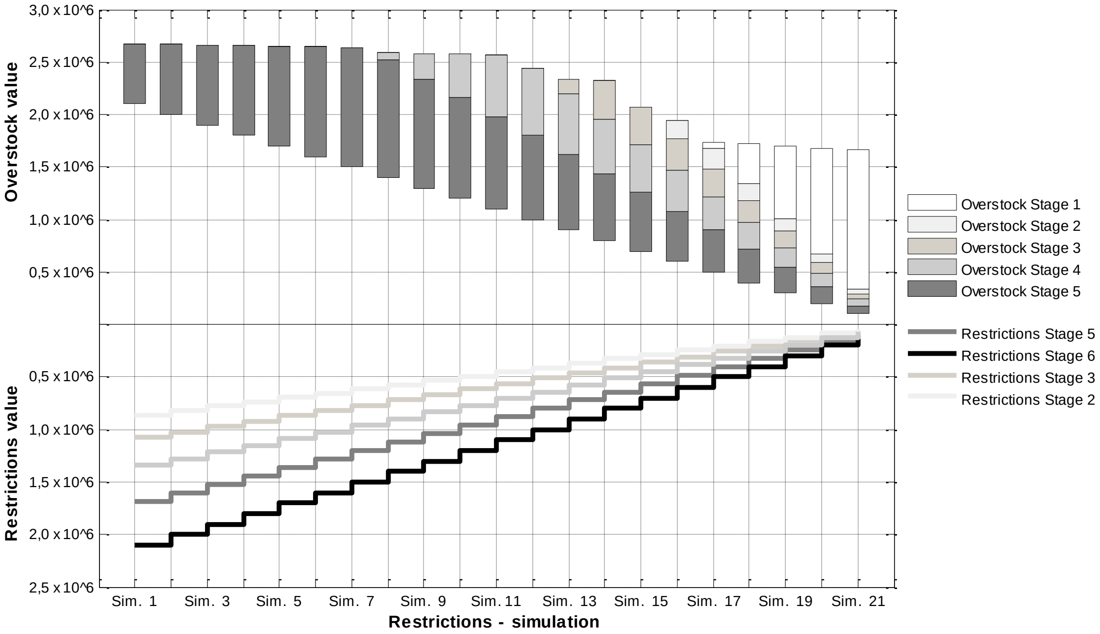


Restrictions in overstock level by each stage as follows: stage 6 – 750 000 €; stage 5 – 250 000 €; stage 4 – 200 000 €; stage 3 – 150 000 €; stage 2 – 100 000 €. Demand jumps = 54 000 sqm (positive or negative). κ = *0,40;* σ *=0,35*

Figure B5 (13): Effect of changes in service level on the overstock value, considering different stocking points (stages at where inventory is possible)

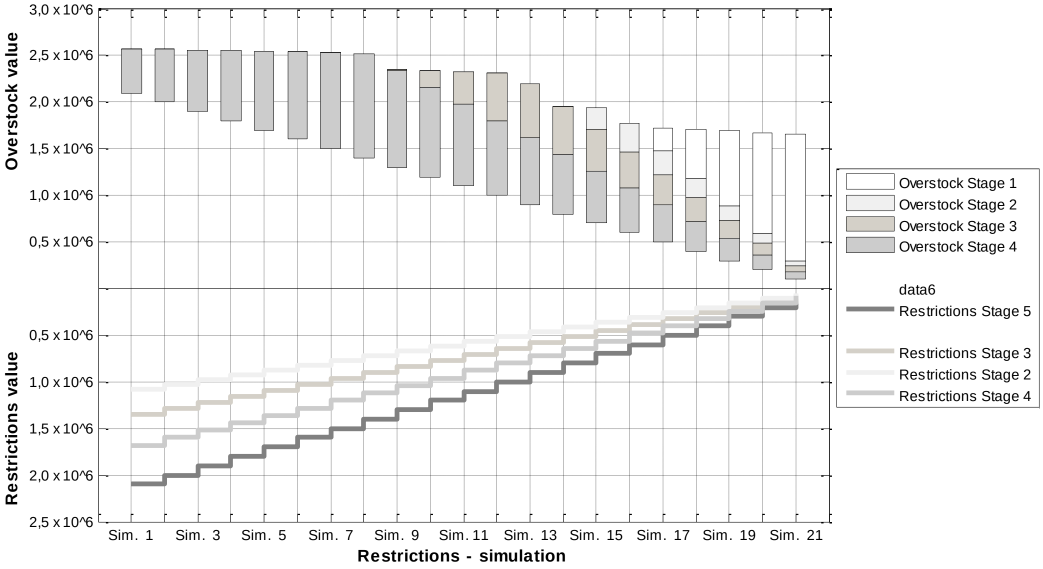
Accordingly to the results observed in the former figure, the overstock value is more sensitive to changes in service level when there is only one possible stocking point. This is essentially explained by the increase in risks. Thus, it was considered interesting to analyse the impact on the overstock value caused by changes in the service level but also in the number of stocking points, whereas they are downstream or upstream the supply chain. As simulations where done on the number of stocking points it appears to be clear the concentration of stocks in the upstream stages of the chain, where the incorporated costs are lower.

(4) Effects of capital restrictions on inventory value.



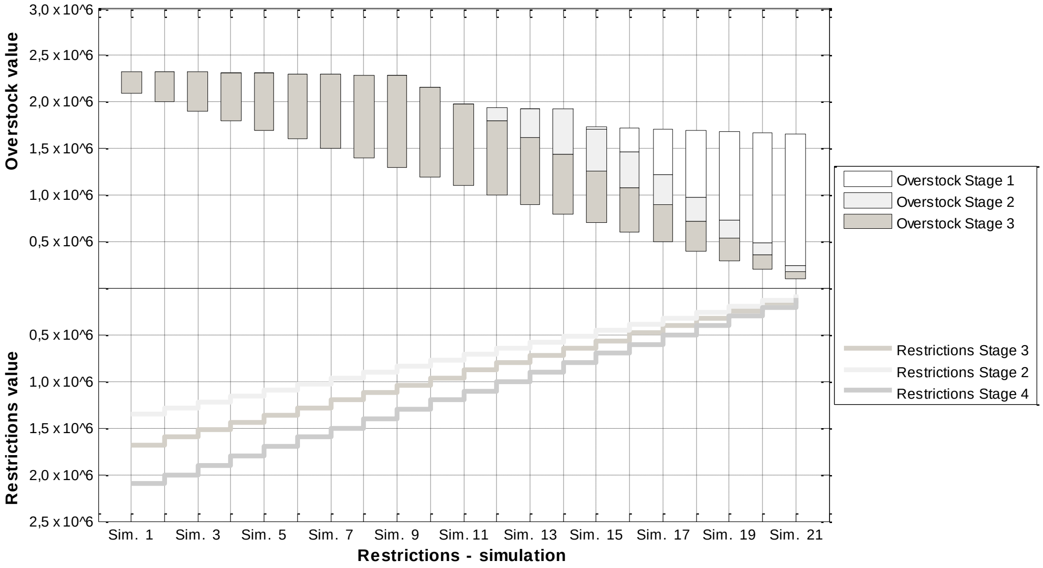
Demand jumps = 54 000 sqm (positive or negative). $\kappa = 0{,}40$; $\sigma = 0{,}35$

Figure B6 (14): Effect of restrictions in five stages



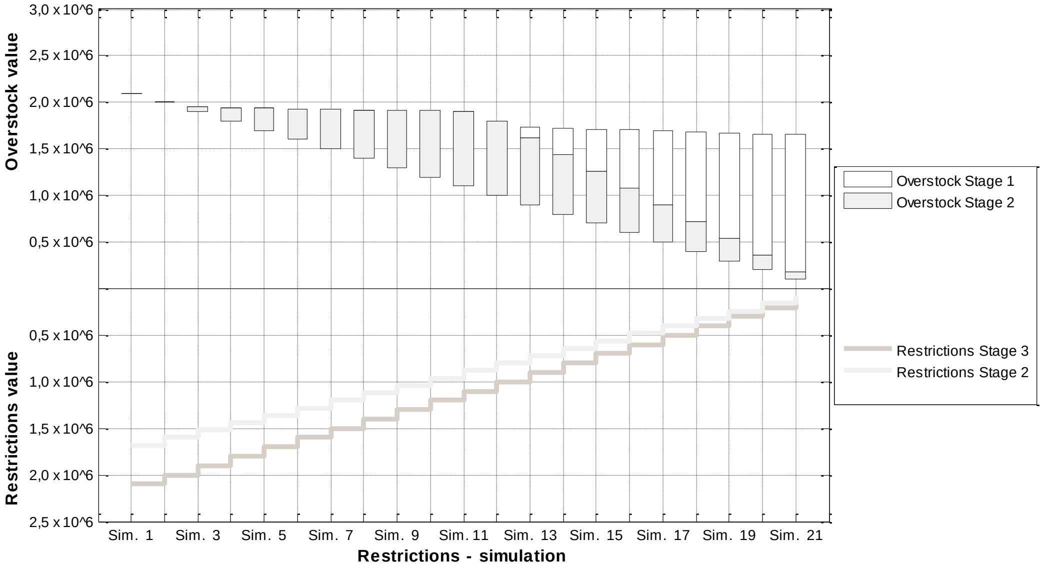
Demand jumps = 54 000 sqm (positive or negative). $\kappa = 0{,}40$; $\sigma = 0{,}35$

Figure B7 (15): Effect of restrictions in four stages (no overstock in stage 6 – expedition warehouse).



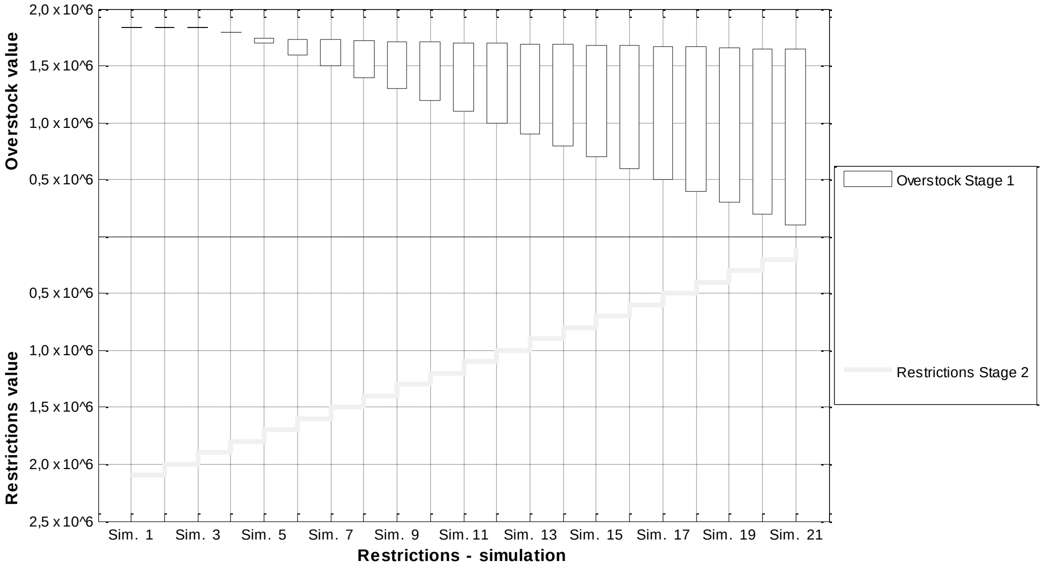
Demand jumps = 54 000 sqm (positive or negative). κ = 0,40; σ =0,35

Figure B8 (16): Effect of restrictions in three stages (no overstock in stage 5 and 6 – end-line warehouses and expedition warehouse)



Demand jumps = 54 000 sqm (positive or negative). κ = 0,40; σ =0,35

Figure B9 (17): Effect of restrictions in two stages (no overstock in stage 4, 5 and 6 – cutting and packing plant, end-line warehouses and expedition warehouse)

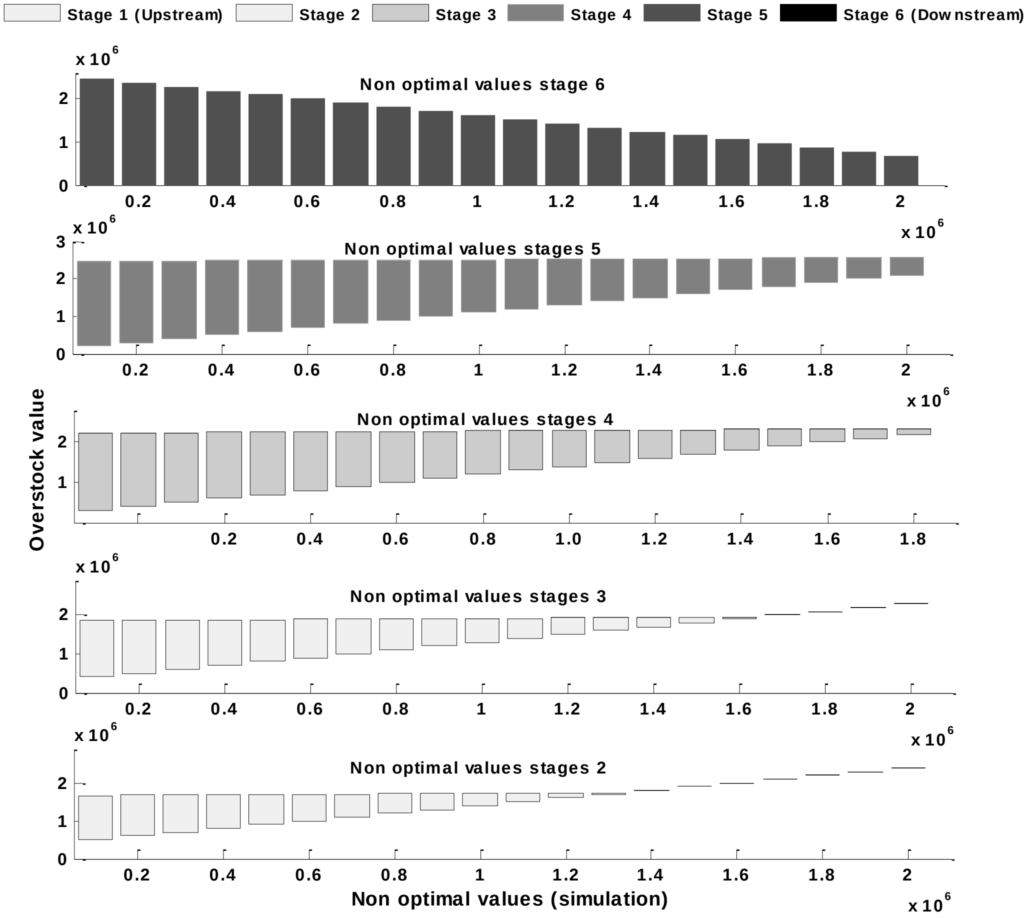


Demand jumps = 54 000 sqm (positive or negative). κ *= 0,40;* σ *=0,35*

Figure B10 (18): Effect of restrictions in one stages (the only place to put overstock is on the agglomeration plant - upstream)

As it can be notice in Fig. B6 to B10, restrictions affect the optimal overstock value. Restrictions affect the calculation of the optimal value as we impose maximum stocks, which can be different (less) than the optimal overstock according the model to that stage. It is also relevant to emphasize that the concentration of overstocks in upstream stages (intermediate stocks on the plants) tends to decrease the inventory value. The interpretation of these results can be linked with the concept of premium as it is considered in real options theory. The overstock can be considered an asset that will result in future sales; thus, the value of such asset depends on the time required to transform stocks into effective sales. In this line of thinking a higher time flow decreases the premium value, in our case, the overstock value. On the other hand we can use the cost and risk theory to justify that stocks in upstream stages are less risky and less costly (low incorporation of resources).

(5) The influence of non-optimal overstock values.



Demand jumps = 54 000 sqm (positive or negative). κ *= 0,40;* σ *=0,35*

Figure B11 (19): Effect of non-optimal values in different supply chain stages

Figure B11 presents different scenarios for non-optimal overstock values that can result from unbalanced supply chains, which is normally consequence of the absence of a single authority or to the lack of available information within the chain partners. We simulated non-optimal values for each stage that is replaced by a fixed amount of 100 000 € in the following computation in the immediately upstream stage. Non-optimal values or distortions on the supply chain have a more significant effect on the downstream stages. Figure 11 shows the effect on the upstream stage of a non-balanced value.

Despite our conceptualisation about a balanced and integrated supply chain, where decisions are done under a single authority and all the information is available, there are different realities. From empirical knowledge, the communication distortion is higher as the distance from the market is amplified. A practical consequence relies on wrong upstream decisions. Based on the results, we support integration and alignment in inventories decision process to protect the supply chain from the market uncertainty.

Traditional Approach Strategy	**Agile Supply Chain Strategy**	**Multi-stage Overstock Strategy**
1-Stock is held at multiple echelons.	1-Stock is held at the fewest echelons.	1-Stock is held at multiple echelons. The intensity in each node is related with demand volatility penetration.
2-Replenishment is driven sequentially by transfers from one stocking echelon to another.	2-Replenishment of all echelons is driven from actual sales/usage data collected at the customer interface.	2-Overstock for upstream stages are dependent of the last downstream stage overstock value.
3-Production is planned by discrete organizational units with batch feeds between discrete systems.	3-Production is planned across functional boundaries from vendor to customer, through highly integrated systems, with minimum lead times	3-Production is planned across functional boundaries from customer to vendor, through highly integrated systems, according to the downstream overstock level.
4-Majority of stock is fully finished goods, dispersed geographically, waiting to be sold.	4-Majority of stock is held as "work in progress" awaiting build instructions.	4-High upstream overstocks implies for a smaller global overstock value.

Table B1 (4): Comparison between different strategies

Considering the results and analysing table B1, there are two main opposite strategies that need to be balanced. One is to hold the stocks in the upstream stages of the chain, where the adding value to raw material is small. The main advantages supporting this idea are the minimization of invested capital value and also additional flexibility, due to the possibility of redirecting a common semi-finished item into different finished items, according to market needs. The other strategy is having a faster service by holding the inventory closer to the market, in order to improve the service level. This idea can have negative impacts on additional invested capital value and on the stock risk, due to a higher number of items.

By balancing the network inventory according to the uncertainty exposition, organizations can use the overstock to satisfy shortages due to high unpredictable demand.

ESSAY V: PRODUCT MIX STRATEGY AND MANUFACTURING FLEXIBILITY

ABSTRACT

The manufacturing industry is facing a turbulent and constantly changing environment, with growing complexity and high levels of customisation. Any investment solution should address these problems for a dynamic market and within limited budget boundaries, so that companies try to remain competitive. The authors propose a real options model to support firms making important investment decisions, specifically decisions associated with the acquisition of new equipment aimed at allowing firms to increase their manufacturing flexibility for the production of both standard and customized products. This paper is partially based on a real operating experience related to visual finishing technology features in an industrial company that conforms to the definitions of the product mix. The authors' motivation for this work is driven by firms' desire to satisfy specific customer needs, and to respond to them quickly under uncertain demand. Our goal, using theories from finance, production management, and product offering management, is to conclude that there is a relevant difference between the evaluation of the technology that is to be chosen, and the potential value due to product mix adaptations that are able to provide the maximum return from investment. We address problems related to standard and customized production systems, and the decision to invest in a set of resources that will enable this choice.

Keywords: uncertainty, manufacturing flexibility, product mix strategy, investment decisions.

1. MANAGERIAL RELEVANCE

Today's firms are constantly trying to figure out better ways of exploiting economies of scale, while also satisfying the increasing demand for highly customized products. Most of the existing equipment was designed for large-scale production, and it was evaluated using the considerations of economic order quantities. These problems result from strategic definitions of whether or not a company is focused on a low cost approach, or if the firm is prepared for small quantities and customized orders. This dilemma is timely in the industry, mainly referring to our numerical example related to flooring. The challenge is about the choice of flexible equipment features that should be balanced with reasonably customized offers.

2. INTRODUCTION

In recent years, in order to satisfy finely targeted niche markets, with an increasing number of product variants, decreasing lot sizes, accelerated lead-times, and shorter products' life cycles, companies have dramatically increased their product mix. As a result, a high degree of equipment flexibility is now required, and companies must incorporate this need into discussions of new investments.

Despite the way managers think, traditional approaches that are based on discounted cash flows techniques, and which compare future profits with the cost of investment for a certain demand's quantity, do not actually consider the value of product mix flexibility. As a consequence, volume increase or economies of scale are still the more attractive argument to use in a project payback. The problem of the traditional approach is that investing in more flexible equipment that is able to produce smaller and more customized batches, does not generate the required profitability over the expected period of time in order to cover the initial costs. Investments in flexible equipment are generally more costly than those for inflexible equipment, and the potential benefits are difficult to value with accuracy at the initial time. This is particularly true in the presence of high levels of uncertainty, when it is difficult to predict if a certain option will be exercised or not.

Any company offers a mix of standardized and customized products. The strategic problem of offering only standard products is the fact that the other suppliers could easily copy the solutions; on the other hand, the operational dilemma of the company is about the use of the equipment under analysis, and whether it can be used for standard products that are based on big orders, or for smaller, customized orders.

Investments tend to be evaluated considering a single measurement and associated yield of the particular machine under analyses; these is considered the same for all the products, despite different batch volumes. Smaller batches are seen as unpopular and customized products the exception, but normally they are at the core of the reasoning for some additional investments that argue for more flexibility and market requirements. Managers have to initially decide whether to invest in a flexible manufacturing system that has the possibility of producing customized products, or in dedicated systems, which are inflexible concerning customisation. In other words, the firm has to consider whether it is valuable and convenient to spend additional money to acquire equipment features that offer flexibility. In short, the model is more valuable if the benefits resulting from the product offer flexibility are greater than the costs of the initial investment.

The investment in flexible manufacturing equipment and the subsequent ability for customized products is generally greater than the investment in equipment that aims a standard mix based on a limited range of products.

Flexible manufacturing equipment is designed to produce a wide variety of product variants (in our work, the product property with the greatest potential is the surface design), each of which has small lot sizes, with the efficiency of mass production. For our purposes, our choice in industrial equipment is based on cost effectiveness and customisation (Gupta, 1989).

Specifically, we propose a method that uses real options for the overall economic figure of an investment in new equipment, primarily, and aiming the visual finishing at an industrial company. The firms customize their product mix to meet market needs, yet also to provide a quick response times.

The main challenges are calculations of managerial flexibility to support the decision whether or not to accept an investment that is able to provide additional customisation by adding costs. Our motivation comes from an investment problem that was encountered by an industrial company. The alternatives are either a flexible or an inflexible product line. To simplify our approach, an item group represents a number of items with similar manufacturing characteristics, which is applied to the equipment under analysis (common simplification in capacity problems).

We will investigate the differences between evaluating an investment in new equipment for an industrial company, and consider alternative scenarios for the product mix. The problem we present is formulated by two questions: (i) what is the value of product mix customisation? (ii) How much money is a firm inclined to spend in order to have a more flexible equipment? And we will consider two situations affecting the profit function: (i) in which the supplier does not let themselves be exposed to risk (charging the customers with additional costs by using a premium on selling price), and (ii) in which the supplier allows themselves to be partially exposed to risk (charging the customers only with the initial costs related to equipment adaptation, assumed as sunk costs). To answer these questions, an appropriate methodology to support investment decisions, taking into account these characteristics, needs to be used. We aim to conclude that there is a relevant difference in the evaluation of decisions about what equipment to choose, considering the potential value related to changes in the standard mix that are able to provide the maximum return from investment and fulfil the market demands.

3. LITERATURE REVIEW

Valuing manufacturing flexibility has been done for more than two decades. In this paper, however, we will focus on the flexibility related to product mix.

Traditionally, investment appraisal is based on net present value and other discounted cash flows techniques. These techniques ignore the value of flexibility related with management adaptation, or the influence of new information during the project life time (Trigeorgis, 1996). Another relevant problem is the increase of variables affecting the decision process, despite the required profitability under demand fluctuation (Beach et al., 2000), such as flexibility, cost adaptability, equipment's requirements and eventual reconfiguration (Lorenzer et al., 2007), mainly linked with the diversified customer base, product models and variants extension, smaller lot sizes, accelerated time to market and shorter life cycles (Chryssolouris, 2005; Wiendahl et al., 2008). Recent developments in technology, like flexible manufacturing systems, can provide benefits that are not properly captured by traditional approaches; we refer mainly to economies of scope (Li and Tirupati, 1995). The Real options approach, on the other hand, requires expected discounted future cash flows to be significantly above the investment costs, by addressing the limitation of traditional approaches and valuing the flexibility of management decisions along the project period (Dixit and Pindyck, 1994).

Traditional techniques admit that management makes an irrevocable decision on the basis of future market expectations, assuming that the deterministic discounted cash flows are known at the initial moment. The traditional techniques can be used and are valid in the absence of uncertainty, but their use is not correct when managers are able to react in the presence of new information from the market and, therefore, to improve the value of the project.

Manufacturing flexibility is the ability to deal with a changing environment and can be seen as a competitive priority (Correa, 1994; Fine and Hax, 1985; Sethi and Sethi, 1990), but acquiring flexibility has a cost (Pellegrino, 2010) and should be valued (Kaplan, 1986). The literature reports several methods to measure the manufacturing flexibility (see, e.g. Beskee, Kahraman and Irani, 2004; Boyer and Leong, 1996; Brill and Mandelbaum, 1989; Chang et al., 2001; Gupta, 1993; Ramasesh, Kulkarni and Jayakumar, 2001; Tsourveloudis and Phillis, 1998).

Different studies on managerial flexibility have been done for almost two decades, using real options and other techniques (see, e.g. Trigeorgis, 1996; Andreou, 1990; Bollen, 1999; Karsak and Özogul, 2005; Kumar, 1995; He and Pindyck, 1992). The bases of the developments are the decisions whether to buy flexible or non-flexible equipment and how much capacity should be acquired, with regard to the fact that investment is irreversible.

Different types of flexibility can be evaluated such as the “volume”, “process” and “product mix”, which can be, respectively, defined as the ability to operate profitably at different outputs or scales, with different designs and routes or in the presence of several products being manufactured without causing set-ups increase (e.g. Browne et al., 1984; Fontes, 2008). We refer specifically to product mix flexibility and the capacity of production equipment to handle the product mix changes, and we follow Berry and Cooper (1999) that defined product mix flexibility as the ability to manufacture a wide range of products or variants with expected low changeover costs. Gerwin (1987) focused on equipment and features related to volume and mix flexibility. Slack (1988) discussed the implications of the resources on flexibility, e.g., process technology versus volume and mix flexibility. Olhager (1993) mapped, among others, set-up time as a source of volume and/or mix flexibility. Chang et al. (2005) studied, e.g., the ratio of manufacturing technology to the mix and volume flexibility. Hutchison and Das (2007) listed the ability to produce a wide range of products and quick changeover times as capabilities to achieve mix flexibility. Finally, we can refer Wang et al. (2011), who put the attention on the relationship between mix optimisation and manufacturing complexity.

In 1996, Trigeorgis proposed a real option approach to value the managerial flexibility and Suarez and Cusumano, examined the use and implementation of manufacturing flexibility, showing that the degree of flexibility depends on what the firm is aiming to achieve concerning product-demand characteristics. In 1998, Chryssolouris, Anifantis and Karagiannis presented some flexibility measures, considering the manufacturing system ability to react to dynamic changes in inputs. Koren, Speredelozzi and Hu (2003) evaluated manufacturing systems, considering the configuration of machines and material handling. In 2004, Kurtoglu used the cost of changing a system, aiming the production of new products/variants and Wiendahl and Heger referred to the concept of changeability. Wahab (2005) studied measures for machine and product mix flexibility.

Typically, scale economies are used to support investment decisions; in contrast, scope economies are not directly incorporated in assessment techniques. However, exceptions can be found in literature, as the percentage of products that are standard or customized (Safizadeh and Ritzman, 1996), the number of complementary technologies/standards employed (Lin and Kulatilaka, 2006) and the modularity of the product (Gomes and Joglekar, 2002). Generally, allied arguments have faced flexibility as outcomes of management know how (Bohn and Jaikumar, 2005).

The research in this paper differs from previous literature regarding three aspects: (i) we quantify the investment decision under demand uncertainty; (ii) we examine the impact of different equipment features on investment flexibility value; and (iii) our model incorporates the problematic of product mix distribution between standard and customized items, making a closer approach to the reality. Although previous research has addressed one or two of the above points, nothing has been found integrating all three aspects. Thus, our research provides additional contributions to the literature.

4. GENERAL PROBLEM IDENTIFICATION

A recent trend is that commodity-producing companies try to fit the market requirements to the existing production facilities. This is because consumers have become more demanding when it comes to finding a suitable product for their needs.

The company we will use in our example has an extensive product portfolio, containing more than one thousand articles. The company divides its customers into three different segments: specialty, chains and contracts. The fact that the company has a wide variety of products, but wants to maximize batch volumes, in order to minimize the unit cost, will lead to a new reality in investments evaluation.

The problem with this strategy is that the company has to extend its product portfolio further, which leads to higher overhead costs and a need for greater flexibility in production facilities. The company faces a problem related with surface finishing variant, as the initial costs are very high. This causes small and customized orders to be expensive to produce. New techniques for surface finishing need to be evaluated. In this new design technique project is discussed whether it should be used only for development of new standard products or if it should be used as a production machine for small customised products.

Actually, the production tries to minimize the total time of set-ups. The factor that has greater impact on the total set-up time is the number of changes in production orders. Consequently the production tries to minimize the number of production orders by maximizing the batch sizes.

5. MODEL

In this section, we will derive our model focusing on the research questions outlined in the introduction. We relate our problem with the equipment acquisition function; however, we realize the importance of extending the issue to future resources argument configuration. We focus our approach on assembly systems, where the set-up time is a relevant activity, consuming resources and costs, to endure the process flexibility.

It is stated that the most important factor influencing manufacturing investment decisions is the product demand. Therefore, the uncertainty in demand (quantity) is recognized as the only source of uncertainty in our valuation framework, which will be represented by "D". Also, Cobb and Charnes (2004) or Rabbani, Vahed and Torabi (2008) and other authors used the demand as a source of uncertainty to support manufacturing investment decisions. The change in demand (stochastic variable) is modeled as a geometric-Brownian motion (assumption also used by He and Pindyck, 1992; Chung, 1990; Pindyck, 1988; Tannous, 1996).

We assume that the product demand can be based on standard or customized products, for a certain period of time, the possibility of sequential investments is not considered within the review period, and we consider the existence of a salvage value at the end of the investment period. We stress that the strategy of splitting demand between standard and customized products is influenced by the company.

We restrict our model to buying resources perspective, considering that there are no outsourcing alternatives for the specified activities, and we ignore the inventory planning influences in the equipment performance.

Considering the equipment and process analysis, we assume that features like processing times, the set of product types that the system is capable to produce and their required operations are known. Based on this information, we interpret flexibility as the ability to switch between different products, without incurring major changing costs (based on Gerwin, 1982; Gupta and Somers, 1992; Buzacott, 1982)

We will use two relevant indicators related with integration and impact of set-ups. Equipment effectiveness depends on the integration of various stations, taking into account the buffer sizes, the loading conditions and the balanced workload up and downstream of the chain. Integration aims to significantly reduce part waiting times and work-in-process inventory (Benjaafar, 1995; Calabrese, 1992). There is also an impact from different scheduling policies on the performance of each process configuration. For limited or not allowed buffers, our main performance measure is the expected throughput rate, while for systems with infinite buffers is the equipment flow time. For both systems we can use an integration flexibility factor as presented in the model. We derived the indicator considering the technical equipment features, mainly the output rate, and the up and downstream process stations capacity. We used the worst situation as the basis (minimum boundary) and then we derive to other alternatives considering the global flow output improvements, but always subject to a maximum boundary according to the investment budget. The integration costs are calculated as the inverse of flexibility factor, and are applied to the cost of lost or unused flow capacity. This means that if we choose equipment with lower output within up and downstream stations, and limited buffers, we should book an opportunity cost. An example is provided in table 6 (appendix).

On the other hand, set-up time is usually incurred each time a machine switches from one item type to another type, which affects the flexibility of the equipment (Browne, Harhen and Shivnan, 1988). The set-ups may be due to exchange of tools, designs, dimensions or programs. The frequency of set-ups is determined by the number of items being processed in the same machine and the used scheduling policy, which is being affected by lower and more frequent orders. Although it is difficult to extend the analytical models for zero set-up times, we didn´t restrict the model to capture the effect, when applicable. We derived the indicator, considering the time of change required in each task to be performed, in accordance with the technical parameters of equipment under consideration, but subject to budget constraints (upper limit). We use the worst case (minimum boundary) as the basis and derived the alternatives using a flexibility ratio, which we apply in the reverse order for the set-up cost function. An example is presented in table 5 (appendix).

For a general application of the model, we consider the possibility of dividing a complex investment in different homogeneous units, in the same way as the integrated equipment.

The demand process is written as:

$$dD = \alpha D dt + \sigma D dz \tag{7}$$

Where $dz = \varepsilon(t)\sqrt{dt}$; $\varepsilon(t) \approx N(0,1)$; α is the instantaneous drift; σ the volatility; dz is the increment of a wiener process and $\varepsilon(t)$ is a serially uncorrelated and normally distributed random variable.

From equation (7) it follows that the demand D is log-normally distributed with a variance that grows with the time horizon (also an assumption of the model presented by Bengtsson, 2001). The demand is modelled as a continuous process that can be applied realistically, considering that the manufacturer accepts any order, despite the economic lot size, and there is no relevant influence of inventory buffers between the equipment production output and the market demand. We assume that the product mix is defined by the company, which cannot influence the overall demand quantity but influences the selling price, within a set price corridor. The parameters used in the model are described in table 2.

We will model two situations, considering the flexibility and inflexibility of the equipment concerning the product mix. This can be applied for the same volume of demand, assuming different indices in the product mix. We consider that there is always a balance between the volumes and prices for each index. This is a realistic assumption, considering the existence of a higher price (premium) for customisation. We derived the model equations (8) and (19) based on the reasoning described in table 1.

Management issue	Issue interpretation	Issue measurement	Model
Investments evaluation	Based on cash flows (profit functions)	We used a marginal approach: difference between selling price and variable production costs. We compare additional revenues with net investment (we considered a salvage value)	$"Q.(pv_x - cv) - I_{i-1} + S"$
Market uncertainty	Uncertainty source related with demand	Traditional known variable sales quantity $"Q"$ transformed in unknown quantity $"D"$	$"Q" \rightarrow "D"$
Mix versatility	The ability to changeover to produce a new (set of) product(s) very economically and quickly	We used product range relation: between standard and customised products	$"x";"(1-x)"$
Equipment flexibility	Ability to changeover and adapt equipment to produce different parts (products)	We use the concept of set-ups to translate a relevant cost, in the profit function, affecting the decision process	$"\left(\frac{ks_{i-1}.\lambda s_i}{\varphi}\right)";"\left(\frac{ks_{i-1}.\lambda s_i}{\theta}\right)";"\gamma s_i"$
Equipment integration	Routing or process design and flexibility	We translated the impact of process configuration in the balance between linked equipment outputs	$"ki_{i-1}.\lambda i_i";"\gamma i_i"$
Selling price policy	Based on price positioning	Selling price premium	$"(1-y).\Delta c_f"$

Table 1: Model reasoning

Parameter/Variable	Description	Parameter/Variable	Description
$I_i = I_{i-1}.\gamma i_i.\gamma s_i ; i \geq 1$	Investment in flexible technology (equipment or homogeneous unit) index i	p_y	Selling Price premium for customized products
I_b	Maximum allowed investment budget	cv	Variable production unit cost
I_0	Investment in inflexible equipment (or homogeneous unit)	Δcf	Development costs of customized products for a single unit
S	Salvage cost (% of investment value)	y	Customer index participation in Δcf
T	Time to expiration	r	Risk-free interest rate
i	Index for technology flexibility. $i = 0$; equipment (or homogeneous unit) dedicated to standard products; $i \geq 1$; flexible technology able to produce customized items	$ks_i = ks_{i-1}.\lambda s_i ; i \geq 1$	Fixed set-up cost by order for option technology i
γs_i	Flexibility factor for additional investment value regarding set-up costs	$ki_i = ki_{i-1}.\lambda i_i ; i \geq 1$	Integration cost for option technology i
γi_i	Flexibility factor for additional investment value regarding integration costs	ks_0	Fixed set-up cost by order for inflexible technology
λs_i	Flexibility factor for set-up costs optimisation	ki_0	Integration cost for inflexible technology
λi_i	Flexibility factor for integration costs optimisation	φ	Average quantity by order for standard products
x	Offer index for standard products	θ	Average quantity by order for customized products
pv_x	Selling price standard products		

Table 2: Notation

5.1. PRODUCT MIX FLEXIBLE MODEL

When studying an investment acquisition, which expires at the end of time "T", and gives us the opportunity to buy more flexible technology, whether the benefits of the possibility of manufacturing customised products, exceed the costs for acquiring the additional equipment resources, respecting the maximum allowed investment budget; the optimal alternative (value matching), which we denote as "flexible investment acquisition", at the end of "T", can be expressed as:

$$D.\left[\begin{array}{l} x.\left(pv_x - cv \ - ki_{i-1}.\lambda i_i - \dfrac{ks_{i-1}.\lambda s_i}{\varphi} \right) + \\ + (1-x).\left(pv_x + p_y - cv \ - ki_{i-1}.\lambda i_i - (1-y).\Delta c_f - \dfrac{ks_{i-1}.\lambda s_i}{\theta} \right) \end{array}\right] - I_{i-1}.\gamma i_i.\gamma s_i + S \qquad (8)$$

Then we calculate the $FIA_i(T)$ as the expected terminal value of the condition (expiration optimal condition):

$$FIA_i(T) = \max\left\{\begin{array}{l} D.\left[\begin{array}{l} x.\left(pv_x - cv \quad - ki_{i-1}.\lambda i_i - \dfrac{ks_{i-1}.\lambda s_i}{\varphi}\right) + \\ + (1-x).\left(pv_x + p_y - cv \quad - ki_{i-1}.\lambda i_i - (1-y).\Delta c_f - \dfrac{ks_{i-1}.\lambda s_i}{\theta}\right)\end{array}\right] - \\ - I_{i-1}.\gamma i_i.\gamma s_i + S \\ \\ \\ \end{array}\right\} \tag{9}$$

Where, $FIA_i(T)$ is the additional value of flexible investment acquisition; “$D.x.\left(pv_x - cv \quad - ki_{i-1}.\lambda i_i - \dfrac{ks_{i-1}.\lambda s_i}{\varphi}\right)$” represents the profit function for standard products within a certain demand level “D” and the offer mix “x”; “$D.(1-x).\left(pv_x + p_y - cv \quad - ki_{i-1}.\lambda i_i - (1-y).\Delta c_f - \dfrac{ks_{i-1}.\lambda s_i}{\theta}\right)$“ represents the profit function for customized products within a certain level of demand “D” and the offer mix “$1-x$”; “$I_{i-1}.\gamma i_i.\gamma s_i$” represents the investment in technology for a flexible combination of products, considering integration flexibility factor “γi_i“ and production flexibility factor “γs_i“; finally, “S“ represents the salvage value.

s.t.

$$i \geq 1 \tag{10}$$

$$p_y \geq 0 \tag{11}$$

$$0 \leq x \leq 1 \tag{12}$$

$$I_i \leq I_b \tag{13}$$

$$\gamma i_i \geq 1 \tag{14}$$

$$\gamma s_i \geq 1 \tag{15}$$

$$\lambda i_i \leq 1 \tag{16}$$

$$\lambda s_i \leq 1 \tag{17}$$

Thus, the value of the alternative can be expressed as a European call option with the following differential equation:

$$\alpha.D.\frac{dFIA_i}{dD} + \frac{1}{2}.\sigma^2 \frac{dFIA_i^2}{d^2 D} - rFIA_i = 0 \tag{18}$$

5.2. PRODUCT MIX INFLEXIBLE MODEL

$$IA_0(T) = \max\left\{ D.\left(pv_x - cv \quad - ki_0 - \frac{ks_0}{\varphi} \right) - I_0 + S \right\} \tag{19}$$

Where, " $IA_0(T)$ " represents the additional value of inflexible technology, " $D.\left(pv_x - cv \quad - ki_0 - \frac{ks_0}{\varphi} \right)$ " represents the profit function for standard products within a certain level of demand " D " , " I_0 " accounts for the investment in inflexible equipment and " S " represents the salvage value.

6. MODEL APPLICATION

To generate some insights to the model we will present an example based on real data. The numbers presented on table 3 are adapted for confidentiality reasons. The most important indicators are computed on table 7 (appendix). We assume that a company has the opportunity to invest in new equipment, in a dynamic market, where customised products are available.

6.1. BRIEF DESCRIPTION OF THE MARKET AND THE COMPANY

To enhance the understanding of the example, we will make a brief description of the market and the products within the firm's scope.

For the production of innovative products, surface decoration players want faster turnaround time, shorter runs and more flexibility in the surface finishing process. Considering ultimate surface finishing technology, endless products with different patterns and colours can be created, using multiple designs simultaneously. This situation allows the development of new products and the offer of customized solutions. New trends in design are requiring more realistic patterns. The trend is random printing for unlimited number of items from existing and conceptualised surface patterns. Specifically, it is in the contract market where customers are demanding more customized products.

The company divided its customers into three different segments: specialty, mass chains and contracts. The specialty segment refers to dedicated stores and the contract market refers to construction segment. The market can also be divided into a consumer market and a contract market, where consumer market encompasses sales through retail shops, like specialty shops and home centers. On the other hand, the contract market comprises public environments. The market is highly fragmented with a large number of players and the company offers products to the large-scale home centers as well as to the small-scale specialty retailers. The company tries to offer a broader scope of products for specialty retailers that can get exclusive products. The problem with this strategy is that the company has to extend its product portfolio further, which leads to greater complexity in the innovation process, as well as in the production facilities.

The product offering consists of standard and customized products. The undertaking of the customer is either a mandatory concept, where the customer agrees to contract a certain volume such as a complete chain of stores, or a prescribed concept. Consequently the risk for the company is much higher in the latter case. When it comes to custom orders, the company’s concerns are related with volumes, with prices and technical properties, as well as how the company should deal with the customisation process, leading to internal adjustments in the manufacturing department.

The production equipment under analysis uses a layer preparation, a design printing process and a wear layer finishing. The final step is a quality check for mechanical defects. The equipment type is based on high productivity, design flexibility, set-up time and costs, economical printing of short runs, lower production costs and reduced inventory and storage space. Compared with the limitations of conventional techniques of surface finishing, this new technology offers a wide variety of image variations, reduced set-up costs (reducing the need to manufacture minimum quantities), superior quality and a dynamic range of items.

6.2. NUMERICAL ILLUSTRATION

We will evaluate five hypotheses. Mix definition impacts on investments evaluation and on the model dynamics: “H1” - specialization in standard products and “H2” - mixed offer. “H3” - flexibility technology, measured as a reduction on set-up costs, has a relevant influence on investment evaluation.

“H4” - demand uncertainty impacts the investment value and “H5” - selling price premium can also support a mix strategy aligned with more flexible equipment in uncertain environments.

We will consider that more flexible equipment has shorter time consuming set-ups, as it is less sensitive to possible production changes (also defended by Alexopoulos et al., 2005; Bateman, Stockton and Lawrence, 1999; Chryssolouris and Lee, 1992; Chryssolouris, 1996).

I_b	I_0 x1,5x 10^3 €	λi_i	$1/\gamma i_i$	y	20%
I_0	1.200 x 10^3 €	λs_i	$1/\gamma s_i$	r	6%
S	10% x I_0	x	90%	ks_0	240,57 €/un
D	250 x 10^3 Un	pv_x	cv x 1,2 €/un	ki_0	0,3 €/un
T	10	p_y	2,5 €/un	φ	1.500 un/order
γi_i	1,02 (see table 6)	cv	10 €/un	θ	150 un/order
γs_i	1,1 (see table 5)	Δcf	1 €/un	σ	20%

Table 3: Numerical parameters

7. RESULTS AND DISCUSSION

Mix definition impacts on investments evaluation and on the model dynamics: “H1” - specialization in standard products and “H2” - mixed offer.

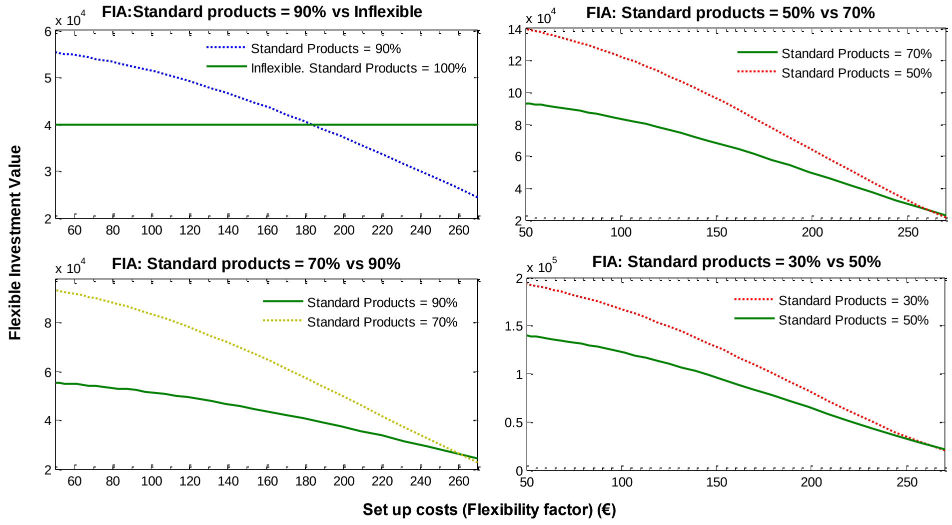


Figure 1: Inflexible investment, flexible investment acquisition value (FIA) and set-up costs, for different mix alternatives

From figure 1, we can say that the flexible investment acquisition value (FIA) increases as the index for standard products decreases. The impact is smaller when the set-ups are more time consuming and expensive, which means a low level of equipment flexibility according to our assumptions. Considering that the company aims to achieve a minimum flexible investment acquisition value of 31 x 10^3 €, the optimal mix index for standard products should be 75%; in the case the company wants to offer 90% as standard products, FIA is 29 x 10^3 €, which means less flexibility in the mix. We found the level of flexibility, using the set-up costs, so that the value of flexible investment is higher than the inflexible one. These results are important for the real operational environment used to model the problem, as well as to support the mix strategy, which is influenced by the technical solution to install.

“H3” Flexibility technology, measured as a reduction on set-up costs, has a relevant influence on investment evaluation.

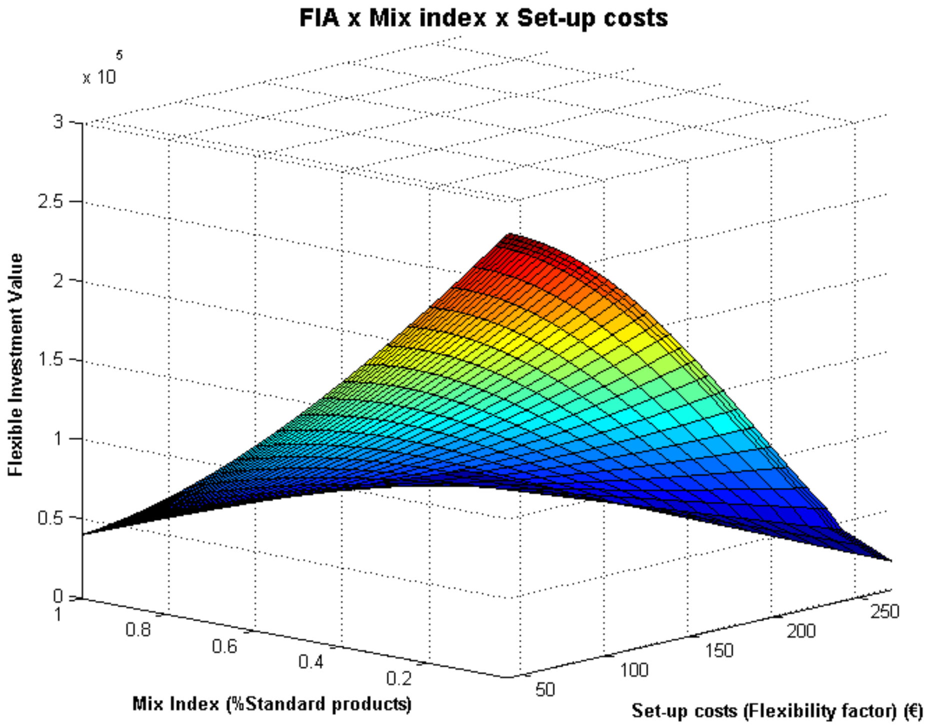


Figure 2: Flexible investment acquisition value (FIA), set-up costs and mix index

From figure 2 we can conclude that there is a relevant link between set-up costs reduction, due to less time required for changes, and the flexible investment acquisition value, considering the equipment features. Theoretically, the equipment is designed to produce specific types of outputs, with the most efficient capacity. However, when the firm expands its product range, the efficiency is reduced, i.e. increasing the cost and time to produce the same amount of output, or decreasing the level of output with the same amount of cost and time. Therefore, the changeover cost due to product range variety can decrease the flexibility. In practice, if equipment additional features can reduce the cost and time of the changeover, the product offer management will be more flexible; so, the range of customized products can be expanded. On the other hand, if the product range can be expanded by reducing disabilities when switching from one item to another, the equipment is more flexible.

Equipment specification (set-ups)			**Mix Index (% standard products) / FIA**					
	Flexibility factor (set-ups)							
Equipment type	**Additional investment**	**Costs optimisation**	**95%**	**80%**	**50%**	**25%**	**Additional investment**	**Maximum value**
Flexible								
M1	1,0	1,0	28,5	30,9	36,0	40,6	1.200,0	1.800,0
M2	1,1	0,9	31,7	37,6	51,0	63,7	1.320,0	1.800,0
M3	1,6	0,6	39,8	55,3	94,0	132,9	1.920,0	1.800,0
M4	2,2	0,5	43,6	64,2	116,5	169,6	2.604,0	1.800,0

Table 4: Relationship between set-up costs reduction and the flexible investment acquisition

Complementing the analysis of figure 2 with table 4, we can make a real calculation approach: if the value of the inflexible investment is 1.200 x 10^3 euros and if 80% of the mix are related with standard products, the buyer is not willing to pay more that 1.357,6 x 10^3 euros (1.320 x 10^3 euros, with a premium of 37,6 x 10^3 euros) to acquire equipment technology "M3", considering a budget limitation of 1.200 x 10^3 euros x 1,5.

"H4" - demand uncertainty impacts the investment value.

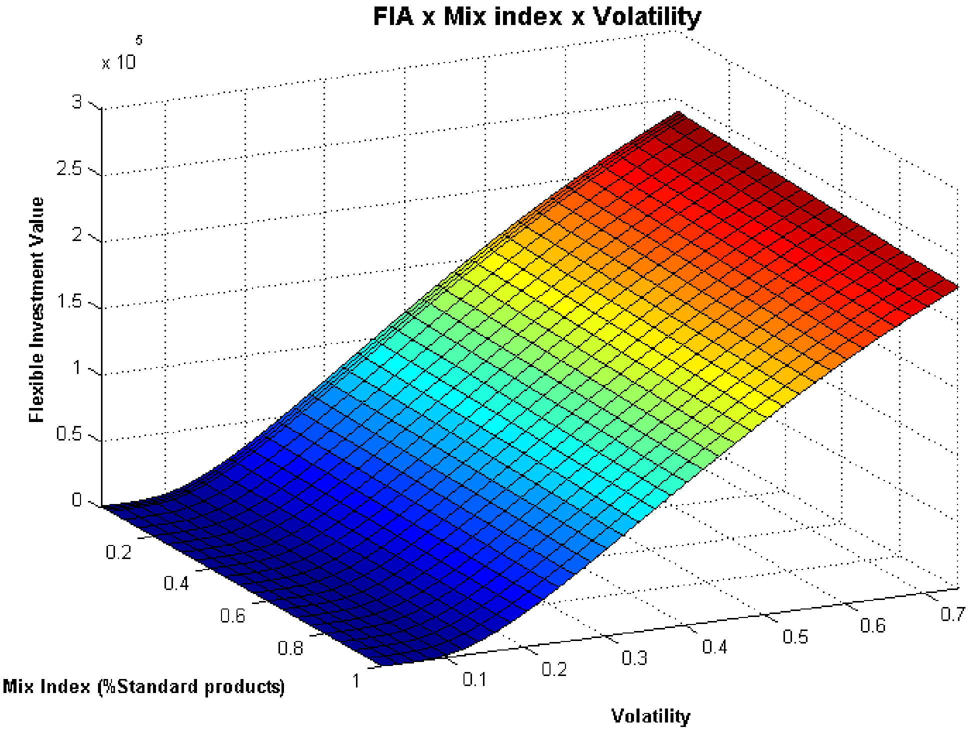


Figure 3: Flexible investment acquisition (FIA) value, demand volatility and mix index

The figure 3 shows that the flexible investment value is higher for markets facing increasing uncertainty levels. These results are in line with the literature on the evaluation of investments using real options (e.g. Dixit and Pindyck, 1994; Duoxing, 2008; Trigeorgis, 2000), where is stated that, for environments with higher uncertainty, there are more opportunities to be valued along the project life time. The difference in the mix, between standard and customized products, is more significant for environments under high uncertainty levels. This confirms that the high flexible investment value is not driven only by the general and often used argument to "invest later" but strengthened by the high percentage of products' customisation.

"H5" - selling price premium can also support a mix strategy aligned with more flexible equipment in uncertain environments.

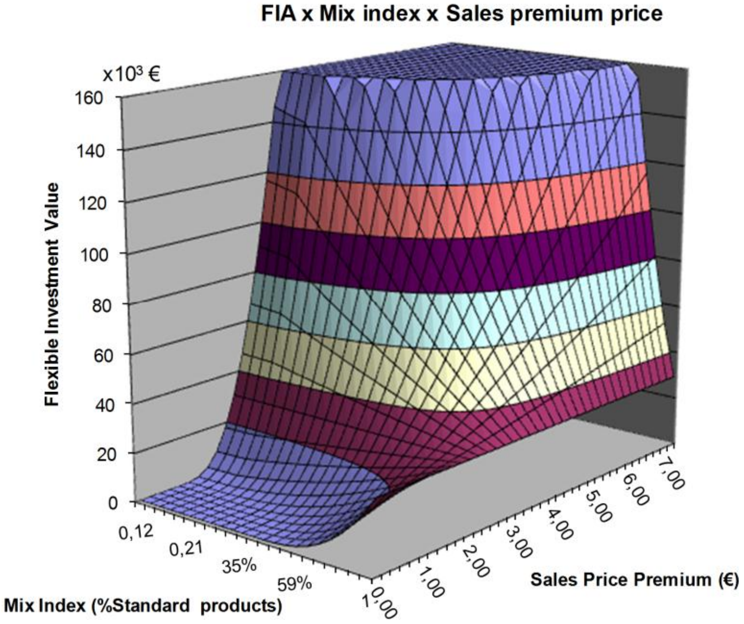


Figure 4: Flexible investment acquisition value (FIA), mix index and selling price premium

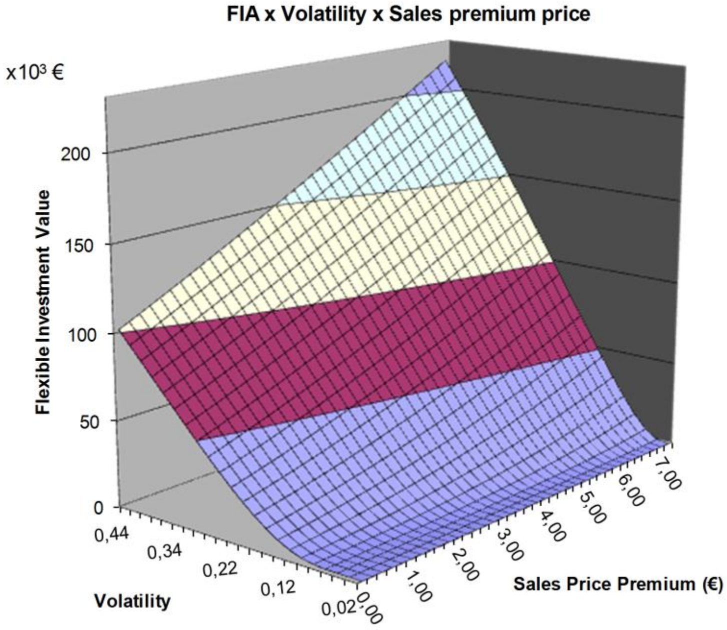


Figure 5: Flexible investment acquisition value (FIA), demand volatility and selling price premium

The existence of a selling price premium can support the mix strategy between standard and customized products. A company that wants to endow the mix with more customized products should request a selling price premium, able to compensate the factory complexity. We investigated different profit function scenarios: the supplier doesn't expose to risk (charging the customers with additional costs, using a selling price premium), supplier exposes partially to risk (charging the customers only with the initial costs related with equipment adaptation, assumed as sunk costs). The results from figures 4 and 5 show that a higher selling price premium has more impact as the standard products percentage decreases (more customized products). In the presence of a lower selling price premium, the additional value is related only with set-up costs reduction (flexibility).

8. CONCLUSIONS

The aim of this work was to be an investigation of the decisions and evaluations about the equipment to be chosen, considering the mix index impact. In general terms, our conclusions are in line with past studies in terms of what affects the use of real options in investments evaluations, considering the impact of demand volatility. The novelty refers to additional equipment flexibility that is dependent on the technology flexibility factor and on the impact of mix index and demand volatility, which is in line with actual concerns as markets become more competitive and unpredictable. We also simulate the results for both situations, considering and not considering the existence of a selling price premium applied to customised products.

The numerical example shows that the opportunity for additional equipment flexibility can be quantified, and that there is a relevant link between investment choice, product mix strategy, and selling price positioning.

9. LIMITATIONS AND FUTURE RESEARCH

We considered only a buying resources perspective, ignoring outsourcing alternatives. This argument does not limit the extension of the model. In our reasoning a decision regarding integration or outsourcing can be treated as two options, considering the maximization of both premiums. Nevertheless we intend to approach high sophisticated equipment that normally is not available in outsourcing. As so, we think this will not disturb neither the interpretation of the results or the generalization of the model. We ignored the influence of inventories, considering that inventories exist only to cover inefficiencies (process flow, lack of capacity or abnormal downtime), as such, they should not be considered.

We point two possible directions for future research. One for different investment arguments configuration like availability - measures the loss of productivity for unplanned stops; performance - measuring the loss of productivity of small breakdowns and failures of speed; and quality - measures the productivity loss of material that do not comply with requirements; but also environmental argumentations in the concept of “green” supply chains (e.g. energy consumption, gases released to the atmosphere). The other direction considers sequential investments that could increase the flexibility value considering the possibility of partial installations. We minimize the impact of this last point, considering that investments can be split in different homogeneous units, to be evaluated also separately.

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A. APPENDIX

Equipment type	**Surface preparation**		**Textile design ink**		**Ceramic design ink**		**Wood design ink**		**Printing presses cleaning**	**Colour and design tuning**	**Surface finishing**		**Worst case**		**Flexibility factor (set-ups)**	
	Same pattern	*Different pattern*	*Standard format*	*Specific format*	*Standard format*	*Specific format*	*Standard format*	*Specific format*			*Standard finishing*	*Specific finishing*	*Standard finishing*	*Specific finishing*	Additional investment	Costs optimisation
<u>Inflexible</u>																
M0	0’’	na	5’’	na	5’’	na	8’’	na	2’	3’	0’’	na	5'	na	1,0	1,0
<u>Flexible</u>																
M1	0’’	15’	10’’	10’	9’’	10’	20’’	15’	8’	5’	0’’	20’	13'	63'	1,0	1,0
M2	0’’	14’	8’’	6’	6’’	8’	15’’	14'	6’	5’	0’’	18'	11'	57'	1,1	0,9
M3	0’’	10’	6’’	4’	6’’	6’	10’’	8’	4’	5’	0’’	12’	9'	39'	1,6	0,6
M4	0’’	8’	5’’	2’	5’’	2’	8’’	6’	2’	3’	0’’	10’	5'	29'	2,2	0,5

Table 5: Surface finishing equipment specification regarding set-ups time

Equipment type	**Glue & pressing station**	**Surface finishing**	**Cutting & profiling station**	**Flexibility factor (integration)**	
	Available Output	**Available Output**	**Available Output**	**Additional investment**	**Costs optimisation**
M0=M1	140 pcs/minute	120 pcs/minute	150 pcs/minute	1,00	1,00
M2		122 pcs/minute		1,02	0,98
M3		128 pcs/minute		1,07	0,94
M4		135 pcs/minute		1,13	0,89

Table 6: Internal process framework for a single shift

Period	D_t (x10^3)	$R_t=\ln(D_t / D_{t-1})$	$R_m=(R_t)^2$	$(R_t-R_m)^2$	% Standard Mix	Nº Orders (standard mix items)	Nº Orders (customized items)
1	261,59			0,00	79%	133	223
2	296,36	0,12	0,02	0,01	84%	192	178
3	261,95	-0,12	0,02	0,02	89%	185	120
4	372,73	0,35	0,12	0,12	93%	128	150
5	305,45	-0,20	0,04	0,04	98%	132	210
6	325,00	0,06	0,00	0,00	95%	194	267
7	272,32	-0,18	0,03	0,03	86%	165	298
8	314,18	0,14	0,02	0,02	98%	209	123
9	445,45	0,35	0,12	0,12	82%	187	235
10	319,18	-0,33	0,11	0,12	83%	165	220
11	309,09	-0,03	0,00	0,00	89%	134	256
12	317,68	0,03	0,00	0,00	94%	191	150
13	449,55	0,35	0,12	0,12	92%	155	265
14	316,27	-0,35	0,12	0,13	86%	215	140
15	262,50	-0,19	0,03	0,04	85%	138	254
16	358,64	0,31	0,10	0,09	92%	165	292
17	332,23	-0,08	0,01	0,01	84%	201	263
18	367,27	0,10	0,01	0,01	98%	212	146
19	284,77	-0,25	0,06	0,07	88%	272	300
20	301,23	0,06	0,00	0,00	87%	197	165
21	352,64	0,16	0,02	0,02	94%	203	180
22	362,73	0,03	0,00	0,00	98%	216	204
23	356,68	-0,02	0,00	0,00	91%	210	290
24	338,64	-0,05	0,00	0,00	96%	437	265
25	313,18	-0,08	0,01	0,01	88%	279	289
	R_m	0,01					
		Sum	0,98	0,98			
	8.197,32	VH	19,80%	20,19%	90%	4.914	5.483
VH=historical uncertainty							
D_t=demand for period t			Average quantity by order			1.500	150
		Volatility		20%			
			Offer index for standard products		90%		

Table 7: Computation of some relevant parameters and indicators used in the example

ESSAY VI: A REAL OPTIONS APPROACH TO LABOUR SHIFTS PLANNING UNDER DIFFERENT SERVICE LEVEL TARGETS

ABSTRACT

Firms that experience demand uncertainty and demanding service levels face, among other things, the problem of managing the number of shifts. Decisions regarding number of shifts involve a significant capacity expansion or release in response to a change in demand. We will quantify the impact of anticipating a shift workforce expansion that is treated as an investment while considering required service level improvements. The decision to increase a shift, whether it involves the use of temporary workers or the hiring of permanent employees, is one that involves significant risk. Traditional theories consider investments as reversible and thus do not capture the idiosyncrasies of shift management, in which costs are not fully reversible. Using real options theory, we quantify managers' ability to consider that irreversibility and to make shift decisions under conditions of uncertainty with maximum flexibility. Our model helps managers take decisions on shifts expansion that are more accurate under service level targets, and to defer commitment until future uncertainties can at least be partially resolved. Overall, our investigation contributes to studies on the time taken to introduce a labour shift change, while valuing service level improvements.

Keywords: Labour shifts; Workforce planning; Timing options; Investment decisions.

1. INTRODUCTION

In the current economic and industrial conditions, with constant fluctuations in demand, shift management is not an easy task. Moreover, due to legal and cost constraints, it is not always possible to engage and dismiss employees in response to demand volatility (Sillekens et al., 2011).

In this paper, we define a model for its intended application in make-to-order manufacturing environments "no inventory businesses" where short lead times are desirable. Nevertheless, given its generality, the model can also be used by service firms in estimating shift work volumes in accordance with the expected service level. We exclude the use of inventory, long lead times, or outsourcing to buffer the negative impact of variability in demand and focus instead on the shifts mechanism to increase capacity. We focus on the decisions that firms take in expanding labour shifts to improve the service level.

For generality, we will employ the following terminology: (i) 'service level improvement value', to quantify the impact of increasing sales order fulfilment by changing the number of labour shifts; and (ii) 'service level improvement deferred value', to quantify the impact of delay in labour shift change under pressure to improve service levels.

The role played by the number of labour shifts in uncertain environments continues to evolve such that greater emphasis is necessary on the timing of the change. Manufacturing jobs tend to be more skilled due to use of increasingly sophisticated equipment. Therefore, production workers require extensive training that is conducted in advance and which counts as an irreversible cost. One way to deal with this trend is to anticipate when labour shifts should change, for which a 'trigger moment', or decision point is needed.

Companies are actually working at much higher levels of uncertainty, with a range of possible future outcomes or unbounded possible outcomes. In highly uncertain environments, the traditional methods of workforce shift planning are of little use, and new approaches are required.

In this study, we focus on two important questions: (1) How do we value a decision regarding shifts increase or shifts expansion delay while considering service level requirements? (2) What is the decision point or trigger moment for applying this shift increase?

2. LITERATURE REVIEW

Labour shifts planning refer to the availability, allocation and transition of the workforce. Specifically, our model uses the real options theory to value the advantages of workforce shifts increase mechanism to hedge against demand volatility. To frame our research, we will explore the background theory on workforce planning, contingent approaches and real options methodology.

Holt et al. (1960) started the research in workforce planning and flexibility by analysing the difference between keeping surplus permanent workforce levels and frequent capacity adjustments. We can find in literature references considering the problem of workforce planning in uncertain demand environments (e.g. Chattopadhyay and Gupta, 2007; Lusa and Pastor, 2011; Milner and Pinker, 2001). Charnes et al. (1974) sketched a chance-constrained model applied on budget and on the workforce size under certain requirements. Aside from chance-constrained models, El Agizy (1971) have already included uncertainty in the objective function. Martel and Price (1977) considered a multi-period stochastic goal programming model, where workforce surpluses and shortages are compensated using other recourse variables. Günther (1989) presented a hierarchical planning model for workforce flexibility, considering the cost function. On a similar line, Cette and Taddei (1994) and Everaere (1997) described different kinds of workforce contracts, also Erol and Dupont (2000) proposed a hierarchical planning model including linear constraints, and Kane et al. (2000) presented a human resource costs optimisation model based on Markov chains. Barnes-Schuster et al. (2002), Cachon (2003) and Pac et al. (2009) modelled the problem under a particular contract type named as "option contract". In 2003, Pinker and Larson argued that the sizes of regular and temporary labour are planning decision variables that can be adjusted by setting the number of workforce shifts. One year later, Dellaert and Kok (2004) reinforced the importance of the workforce link with the company, whether it is permanent or temporary and Azmat and Widmer (2004) proposed a three-step algorithm to determine the minimal workforce assignation in the work distribution. It's a heuristic method that generates a timetable, respecting a given set of constraints including legal ones. Mundschenk and Drexl (2007) investigated workforce planning optimisation under deterministic conditions. Zhu and Sherali (2009), following past concepts and solutions approaches for stochastic programs (e.g. Birge and Louveaux, 1997; Kall and Wallace, 1994), presented a model using a stochastic recourse matrix and a two-stage stochastic program, to address a multi-category workforce planning problem with recruitment capacity constraints and demand uncertainty. Sillekens et al. (2011) presented a complex aggregated workforce planning model with multiple parameters and decision variables related with workforce composition and working time. The novelty of the study is the aggregation of planning factors like technical features as well as workforce limitations to support the production flexibility evaluation. Lusa and Pastor (2011) proposed a multistage scenario-based optimisation approach for dealing with uncertain required capacity, using a linear programming model and working time. Overall, the workforce planning models decide the workforce supply for the future (Chien et al., 2008).

Searching past literature we can identify two types of planning models (Price et al., 1980; Purkiss, 1981): descriptive or exploratory, and normative models. Descriptive models (e.g. Edwards and Morgan, 1982; Ugwuowo and McClean, 2000) are analytical tools that simulate the response of the workforce system within certain conditions (Markov (cross-sectional) models (e.g. McClean, 1991; Morgan, 1979), renewal models (e.g. Bartholomew, 1982), and semi-Markov models (e.g. Yadavalli and Natarajan, 2002)). Normative models are optimisation tools to support the ideal workforce system under a given criteria. The main techniques used in the optimisation models are linear programming, integer programming, goal programming (used when there are multiple targets, such as workforce size, personnel flow and costs (e.g. Corominas et al., 2005; Price and Piskor, 1972)), stochastic programming, and dynamic programming (e.g. Caia et al., 2010; Yan et al., 2008).

Some discussions on real options will follow. Mainly, we address the problem of capacity expansion and decisions irreversibility. For this we will start by describing the main assumptions to support the application of real options approach on general capacity expansion problems. After which we will discuss the applicability of real options on workforce capacity problems. At the end we will debate the advantages of a contingent approach in workforce planning.

Real options have been used in stochastic market environment to the evaluation of manufacturing capacity problems, either on a strategic or on an operational level. A large number of studies have been conducted on capacity expansion problems (Bean et al.; 1992; Higle and Corrado, 1992; Lieberman, 1989; Li and Tirupati, 1994; Souza, 1996). McDonald and Siegel (1985) studied an abandon option to shut down a plant aiming the capacity reduction, however, no analytical formulae was provided; Pindyck (1988) explored capacity expansions as options based on the irreversibility of capital investment and the uncertainty of the outputs. One year later, Majd and Pindyck (1989) quantified the value of flexible options in production firms' capacity operating in dynamic environment. In the 1990's, Abel et al. (1996) discussed options in capacity expansion, claiming that parallel to a call option, there is also a put option of investing in the present and selling in the future as uncertainty intensifies. For them the investment is completely expandable and reversible within the first period, whereas expandability and reversibility can be restricted within the second period (somehow extends the standard timing model which investigated incremental investment (e.g. Dixit, 1995; Pindyck, 1988). Dangl (1999) also concentrated on the optimal timing of capacity investments. In 2000, Birge applied real options theory to production planning problems, stressing the benefits of adjustable resources; Billington and Johnson (2003) remarked that the real options approach is appropriate for the optimal timing and capacity adjustments under uncertainty, following Benavides et al. (1999) who have studied the optimisation of capacity timing and scale expansion using sequential decisions; Wu et al. (2005) supported the use of real options for planning capacity at a strategic level in highly volatile environment. Capacity choice is typically one of the decisions related closely to investment decisions and, complementary, real options theory is similar to the resource-based view in claiming that present resources and capabilities arise out of past investments. However, the real options framework offers an economic logic for incremental investments (Bowman and Hurry, 1993), and specifically addresses the issue of finding a mechanism of resource dimensioning (McGrath et al. 2004), which the resource-based view lacks.

But why are real options particularly relevant to workforce planning? The determination of time when expansions occur started to be of interest for planning purposes, mainly on uncertain markets, where it is difficult to anticipate the workforce needs. Workforce capacity decisions traditionally are based on the valuation of discounted cash flows (Brigham and Ehrhardt, 2007). The idea behind real options was able to limit the exposure to losses, and capitalize on opportunities for higher profits. Consequently, an enterprise can be more flexible in adapting to changes due to internal or external requirements or conditions, like the service level and market uncertainty. Real options logic makes a fundamental contribution to the structuring of risk (Block and MacMillan, 1993; McGrath and

Mac-Millan, 2000). Dixit and Pindyck (1994) refer that real options theory offers managers the ability to value flexible workforce investment decisions under uncertain environments. Nembhard et al. (2005) proposed a real options model to value workforce flexibility considering work heterogeneities. Jacobs, 2007 discussed the application of options to solve problems of uncertain human resource demand. Qin and Nembhard (2010) studied the intensity of labour per unit of production. They stressed the importance of using real options in high uncertain environments, considering the workforce planning as a series of investments in capacity during the products' life cycle. Chou (2011) applied options to intellectual assets such as human resource. The consensus in the literature is that real options application requires two main conditions: first, the underlying feature under analysis is modelled by a stochastic process, such as a geometric Brownian motion process, Poisson jump process, or mean-reverting process (Hull, 2008); second, there is managerial flexibility which value depends on the underlying stochastic process. In particular, if the workforce capacity is adjustable, then the workforce dimensioning is an option. In this reasoning, companies with more flexible resources, including workforce level, are more capable of maximizing potential results under uncertainty market conditions or different service level requirements. Two main differences can be established between traditional techniques and real options: first, the workforce planning techniques require optimisation in order to orient decisions for long-term profit; second, traditional planning tools do not take a long-term view in workforce planning as does using real options. Extending real options thinking to workforce planning relies on the assumption that human capital has value, considering future opportunities, and that the value changes over time. Another advantage of the real options approach is the visibility of the initiatives since the initial stage investments are more explicit, also as added investments that can follow. The notion of real options is in the broader context of sequential decision making, which means that the link between different planning periods can be supported on sequential options, making a useful approach to workforce planning problems. As so, the present study opens a new challenge to the use of real options in workforce planning and points for future directions on the possibility of extending the approach for multi-planning periods.

But how can we value human capital? Several researchers have discussed human capital as a valuable strategic asset for the firm (Snell et al., 1996; Wright et al., 1994). The investment in workforce capital includes costs from selecting, hiring, training, and the compromised dismissing costs. Since demand can change substantially in a stochastic environment and the companies can establish different targets for their service levels, different efficiency yields or output rates, the manufacturing capacity, including workforce planning, has to be dynamic (Dorroh et al., 1994; Mody, 1989). A concern with the combined effect of irreversibility and uncertainty led Weisbrod (1964) to introduce the concept of option value. He argued that if a decision has irreversible consequences, then the flexibility of the option to choose the timing of that decision should be included in a cost-benefit analysis. The expansion of workforce may also be considered as timing options in relation to acquisition of workforce number and skills for which uncertainties of future demand exist. We can defend irreversibility of decisions related to workforce expansion cost when there are high fluctuations in firm results, due to demand volatility, because the expenses associated with regular employees are relatively fixed and there are sunk costs associated with changes in the workforce quantitative or qualitative composition.

Bengtsson (2001) discussed the value of having the option to hire personnel on short contracts when demand is uncertain. He considered the irreversibility for an extended period of time and to increase the importance of the decision, he also suggested the inclusion of future production options (options on options) able to justify a change in the workforce. This type of option gives the opportunity, but not the obligation, to hire personnel and if demand is sufficiently high they will utilize this opportunity, otherwise not (McDonald and Siegel, 1985). Normally, the consideration of future options increases the present value of a decision (Trigeorgis, 1993). In this study we focus our attention in anticipating decisions, considering the trigger moment. Other studies have explored the significance of contingent, or temporary workers including Cardon (2003), Foote and Folta (2002), Mayer and Nickerson (2005), or Marler et al. (2002). Purcell (1998) discussed how the use of contingent labor is increasingly becoming associated with the firm performance. Foote and Folta (2002) and Pinker and Larson (2003) analyzed how temporary workers create options for the firm. For Foote and Folta (2002) there may be an optimal productivity point in the balance between temporary and regular employees. They used a dual option workforce approach to quantify the flexibility of temporary workforce, in the context of valuing human investment decisions. One advantage of using temporary workers is that they can be dismissed, with a small cost impact, if demand does not increase as expected (Wessel, 2001). Based on this, the decision to hire temporary workers is almost completely reversible. Our model differs on that, assuming a dual strategy, considering both temporary and regular workers in non-qualified production tasks. We also use a dual option but applied to workforce shift expansion to buffer against market uncertainty and workforce expansion delay. Cardon (2003) recommended a mix between temporary and regular employees to maximize benefits such as cost savings or flexibility, while minimizing the risks of diminished trust and reduced productivity from regular employees, which is also reiterated by Dube (2003), for whom the reason why many corporations have shifted to contingent employment is related with the high costs of regular workers. Mayer and Nickerson (2005) identified performance outcomes as the rationale for the choice between regular workers and temporary workers, since these last ones have lower or any performance goals. Competition is forcing firms to seek for flexibility in the area of workforce management (Lepak and Snell, 1998) and contingent workers may provide such flexibility to adjust workforce levels in response to changes in demand (e.g., Mangum et al., 1985; Matusik and Hill, 1998). The contingent approach may reduce or even eliminate the cost of hiring and dismissing regular workers in face of market uncertainty (Way, 1992). Matusik and Hill, (1998) noted that the use of contingent workers in the short run, may result in higher costs. However, these costs are incurred to provide the necessary flexibility, which may offset the costs in the long run. Such costs can be considered the option premium. In terms of option expiration, the use of contingent worker may continue if uncertainty of volume persists, and the option to alter scale does not expire. These studies provide a rationale for why firms should incorporate contingency into the workforce. A criticism against the application of real options theory may be the lower commitment towards employees through contingent labour link, reallocation of employees or variable pay. Nevertheless, we have to disagree because the creation of options can be done and should be adopted according to strategic, economic and legal scenarios within which a company operates.

A novel aspect of the model we present is that it describes the influence of a volatile market and service level targets definition on the measure of workforce level, mainly shifts dimensioning. Facing a sudden increase in demand or in the service level, a manufacturer may want to adjust the production volume to meet customer requirements and maximize the opportunity of increasing profits; however, the manufacturer may not have prepared sufficient workforce shifts for this unexpected change. On the other hand, the maintenance of an overcapacity in workforce is an opportunity cost. Following the exposure of Sethi and Sethi (1990) about different types of flexibility, we value a particular kind of flexibility related with the volume and expansion. While previous studies have recognized the ‘‘flexibility’’ value associated with temporary workers, they have not explored the mixed regular and temporary workforce shifts expansion decision. Companies can use temporary workers to increase flexibility with respect to market fluctuations (e.g. Foote and Folta, 2002) but, in our model we also stress the attention on the regular workforce shifts expansion, considering the increase in available capacity. Past studies such as Zhu and Sherali (2009), stated the importance of considering service or production level targets in integrated workforce planning. Callahan and Stuebs (2010) defined labour flexibility as the capacity to modify the workforce size, composition and link with a company.

3. MODEL FORMULATION

We base our reasoning on the fact that a company wants to fulfil a promised service level (fulfilment of sales orders in the desired quantity and timeframe). The service level is subject to the downstream work centre output, which depends on the available number of shifts. A fixed number of workers are required for each shift. Firms are experiencing the effects of postponed deliveries and a reduction in service level due to the lack of capacity, which in turn, adversely affects the profits. A decision to change the number of shifts that is taken at a non-optimal moment can destroy value. In this reasoning, the determination of the trigger moment to invest with an eventual change can support the deferrable option value. We intend to calculate the right moment for the creation of a new shift, using the demand critical level that can support this decision. In this case, there will be irreversible costs: the labour costs during the minimum time contract, costs of initial training, and explicit costs of future dismissals. We will ignore the various possible social costs, since we cannot assess their value (Osterman, 1988; Worrell et al., 1991). Ignoring these costs will not bias our conclusions.

Due to the required training period and specific capabilities, we will assume a dual strategy to adjust the actual situation with the targeted service level (better than the actual one): shifts expansion using regular, full-time workers within a period of time, or shifts expansion using a mix of regular and temporary workers. For this study, we will ignore the temporary use of cross-trained regular workers from other work stations because we assume that the upstream work stations are balanced and that there is no available workforce. The intensity of workforce training can be extended to new stations of the company; in this way, the marginal revenue of each trained employee can be raised, leading to a possible partial payback of the irreversible training costs (Mundschenk and Drexl, 2007). Using demand uncertainty and the available fixed output of each shift, we will determine the optimal moment to change a shift, assuming the existence of irreversible costs within a certain planning period $\left[0,T\right]$. We assume that hiring/subcontracting additional workers does not have any use besides the specific situation that we are considering. Investing in a new shift to improve service levels, under stochastic demand, should be analysed considering that the results from the investment, deducted from the value of the option to defer, should be equal or above the actual profit.

Demand is the main uncertainty source that affects the number of shifts. The model will be applied to a single work centre with a defined number of workers per shift (also in Mundschenk and Drexl, 2007), as so, the capacity expansion size will refer to the additional shifts. We will differentiate the workers who work directly on the flowshop production line from those performing common tasks (the importance of this assumption is related to the required skills to execute the tasks (Ahn et al., 2005); Bard et al., 2003; Thompson and Goodale, 2006). We assume that the firm follows a make-to-order policy, is oriented by a pull strategy, and is subject to stochastic demand.

The demand, for each moment, is a stochastic variable, denoted by D_t. We will consider two different models to represent the demand (for possible models see table 1 in appendix).

First we will assume that the demand follows a geometric Brownian motion (GBM) (similar assumptions for example in Whitt, 1981; Bengtsson, 1999; Nembhard et al., 2005, and Fernandes et al., 2010). However, the product types should be a concern while modelling the demand uncertainty, since these assumptions may vary. We will represent demand using the following equation:

$$dD_t = \mu_{D_t} D_t dt + \sigma_{D_t} D_t dw_D \tag{1}$$

Where: $dw = \varepsilon(t)\sqrt{dt}$; $\varepsilon(t) \approx N(0,1)$; μ = instantaneous drift; σ = volatility; $dw =$ increment of a wiener process; where $\varepsilon(t)$ is a serially uncorrelated and normally distributed random variable.

Second, considering that the demand can face sudden changes, we will assume that the demand follows a mean reversion process (MRP) with jumps (assumption also done by Khajuria (2008) considering a study on Timber market). The demand is described using the following equation:

$$dD_t = \kappa\left(\overline{D} - D_t\right)dt + \sigma_{D_t} D_t dw_D + \Phi_t dq \tag{2}$$

Where: $dw = \varepsilon(t)\sqrt{dt}$; $\varepsilon(t) \approx N(0,1)$, κ is the speed of reversion, $\overline{D}$ is the long term mean, σ is the volatility of the process; $dw =$ increment of a wiener process; where $\varepsilon(t)$ is a serially uncorrelated and normally distributed random variable and Φ is the jump size, with distribution dq (Poisson), for jumps occurrence. Jump size is modelled as a random variable.

It's expectable that in a certain moment there will be a demand level that supports the shift expansion decision, considering the outcome results. To model our problem we will assume a different profit function, prior and after the decision, for the two different strategies, which we will denote as $\pi_0(D_t)$, $\pi_1(D_t)$ or $\pi_2(D_t)$, respectively.

We will assume that the shifts change will occur within a single period and there will be instant production availability. For our purpose we will define a planning period as the period in which we make a decision on labour shifts expansion. We will ignore the time for the adaptation period, mainly related with training but we will consider the training costs within the required investment value. We use the service level performance to leverage the decision process about shifts increase.

The following notation will be used: m_v representing the unit margin, the difference between sales price and variable costs, S_A the contractual agreed service level (sales quantity percentage to be delivered within the agreed deadline, contractually supported with customers), S_0 the service level before decision (percentage of the required sales quantity delivered within the agreed deadline and normal working time), S_1 the service level before decision (percentage of the required sales quantity delivered within the agreed deadline including overtime), S_2 the targeted service level after decision (percentage of the required sales quantity to be delivered within target), p_v is the unit selling price, c_v is the unit variable cost, $m_v = p_v - c_v$, α_0 non-fulfilment penalization unit cost according contractual required service level, K represents the number of shifts, n_f is the fixed number of flowshop line workers (affected by an historical additional percentage to cover absenteeism) , n_c is the fixed number of common tasks workers (affected by an historical additional percentage to cover absenteeism), w_a is the available working time by shift and planning period, w_o is the maximum overtime hours percentage by shift and planning period, β is the number of units produced by hour, φ_i additional shift fixed operating cost, φ_f cost of each regular flowshop line worker, by hour on the planning period basis, φ_c cost of each regular common worker, by hour on the planning period basis, ω_1 overtime percentage premium cost by worker, ω_2 represents the cost by each temporary worker by working hour, γ_f and γ_c represent the actual investment value, per flowshop line worker and common worker, respectively (permanent workforce costs: hiring, training and committed costs due to the contractual relation), ρ discount rate, $\frac{w_a.(n_f.\varphi_f + n_c.\varphi_c) + \varphi_i}{D_t}$ and $\frac{\rho.(n_f.\gamma_f + n_c.\gamma_c)}{D_t}$ represent, respectively, the additional produced unit operating fixed cost and the investment cost by each unit.

Analytically the unit profit functions before and after investment will be defined according the following equations.

$$\pi_0(D_t) = m_v S_0 - \alpha_0 (S_A - S_0) \tag{3}$$

Equation (3) represents the unit profit function prior to any shift increase.

$$\pi_1(D_t) = m_v S_2 - \alpha_0 (S_A - S_2) - \left(\frac{S_1 - S_0}{\beta} \right) . (1 + \omega_1) . K . \left(n_f . \varphi_f + n_c . \varphi_c \right) - \\ - \frac{w_a . \left(n_f . \varphi_f + n_c . \varphi_c \right) + \varphi_i}{D_t} - \frac{\rho . \left(\gamma_f . n_f + \gamma_c . n_c \right)}{D_t} \tag{4}$$

Equation (4) represents the unit profit function after a shift increase for strategy one (pure regime: regular “full-time” workforce). In this strategy the shifts’ increase is done using regular workers for all the tasks.

$$\pi_2(D_t) = m_v S_2 - \alpha_0 (S_A - S_2) - \left(\frac{S_1 - S_0}{\beta} \right) . K . \left[(1 + \omega_1) . n_f . \varphi_f + n_c . \omega_2 \right] - \\ - \left(\frac{S_2 - S_1}{\beta} \right) . n_c . \omega_2 - \frac{w_a . n_f . \varphi_f + \varphi_i}{D_t} - \frac{\rho . \gamma_f . n_f}{D_t} \tag{5}$$

Equation (5) represents the profit function after a shift increase for strategy two (mixed regime: regular workforce plus temporary workers, on-call workers or comp-time arrangements for common tasks). There are tasks requiring a high level of qualification and there are tasks that can be handled with a low qualification. Since higher-qualified jobs have higher costs for the company, the cost and the number of qualified workers are relevant parameters. In this strategy the shifts’ increase is done using regular line workers and temporary workers for the common tasks. Nevertheless, and based on Sillekens et al. (2011), we reinforced the need, for practical terms, to limit the proportion of temporary workers, considering the line specificity.

Subject to,

$$S_0 = \frac{\beta . w_a . K}{D_t} \tag{6}$$

$$S_1 = \frac{\beta . w_a . K . (1 + w_o)}{D_t} \tag{7}$$

$$0 < S_0 \le S_1 \le S_2 \le S_A \le 1 \tag{8}$$

The goal is the calculation of the demand critical point D_t^*, above which the investment in an additional shift, considering the fulfilment of a required service level target, should be done. Specifically we want to maximize the two profit functions, considering a trigger moment for the change, based on the demand quantity. Analytically we will use the following objective function, for each strategic approach. There will be a moment $\tau \in [0, T]$ where we should increase the number of shifts (exercise an option) to maximize the value for the company (difference between expected value and costs which we denote as premium).

For strategy one:

$$\begin{cases} \sup\limits_{D_t^*} E_{D_t}\left(\int_0^{\tau} D_t \pi_0(D_t) e^{-\rho t} dt + \int_{\tau}^{\infty} D_t \pi_1(D_t) e^{-\rho t} dt \right) \Leftrightarrow \\ \Leftrightarrow \sup\limits_{D_t^*} E_{D_t}\left(\int_{\tau}^{\infty} D_t \pi_1(D_t) e^{-\rho t} dt - \int_{t}^{\infty} D_t \pi_0(D_t) e^{-\rho t} dt \right) \Leftrightarrow \\ \Leftrightarrow \sup\limits_{D_t^*} E_{D_t}\left(\int_{\tau}^{\infty} \left[D_t \pi_1(D_t) - D_t \pi_0(D_t) \right] e^{-\rho t} dt \right) \Leftrightarrow \\ \Leftrightarrow \sup\limits_{D_t^*} E_{D_t}\left(\int_{\tau}^{\infty} \left[D_t \pi_1(D_t) - D_t \pi_0(D_t) \right] e^{-\rho t} dt \right) \end{cases} \tag{9}$$

Using Oksendal (2003) theorem (also used by Pimentel, 2009), derived from Markoviana property, equation (9) results in calculating the maximum service level improvement value (SLI) that satisfies the condition:

$$SLI\left(D_t^*\right) = \int_0^{\infty} \left[E\left(D_t^*\right) . \pi_1(D_t) - E\left(D_t^*\right) . \pi_0(D_t) \right] e^{-\rho t} dt \tag{10}$$

For strategy two:

$$\begin{cases} \sup\limits_{D_t^*} E_{D_t}\left(\int_0^{\tau} D_t \pi_0(D_t) e^{-\rho t} dt + \int_{\tau}^{\infty} D_t \pi_2(D_t) e^{-\rho t} dt \right) \Leftrightarrow \\ \Leftrightarrow \sup\limits_{D_t^*} E_{D_t}\left(\int_{\tau}^{\infty} D_t \pi_2(D_t) e^{-\rho t} dt - \int_{t}^{\infty} D_t \pi_0(D_t) e^{-\rho t} dt \right) \Leftrightarrow \\ \Leftrightarrow \sup\limits_{D_t^*} E_{D_t}\left(\int_{\tau}^{\infty} \left[D_t \pi_2(D_t) - D_t \pi_0(D_t) \right] e^{-\rho t} dt \right) \Leftrightarrow \\ \Leftrightarrow \sup\limits_{D_t^*} E_{D_t}\left(\int_{\tau}^{\infty} \left[D_t \pi_2(D_t) - D_t \pi_0(D_t) \right] e^{-\rho t} dt \right) \end{cases} \tag{11}$$

In the same line, by using Oksendal (2003) theorem, equation (11) results in calculating the maximum service level improvement value (SLI) that satisfies the condition:

$$SLI\left(D_t^*\right) = \int_0^{\infty} \left[E\left(D_t^*\right) . \pi_2(D_t) - E\left(D_t^*\right) . \pi_0(D_t) \right] e^{-\rho t} dt \tag{12}$$

Both situations are subject to conditions presented in (6)-(3).

With: τ = first optimal time to invest, is the stopping time when the demand reaches the critical point $D_t = D_t^*$; $E(..)$ denotes the expected value; specifically $E(D_t^*)$ denotes the expected value of critical demand quantity in moment t which is obtained by: $E(D_t^*) = D(0)e^{\mu_D \tau}$, for geometric Brownian motion model; and $E(D_t^*) = D(0)e^{-kt} + \overline{D}.(1 - e^{-kt})$, for mean reversion model; $\pi_0(D_t)$ = unit profit function before investment (equation (3)); $\pi_1(D_t)$ = strategy one unit profit function after investment (equation (4)); $\pi_2(D_t)$ = strategy two unit profit function after investment (equation (5)); D_t = demand during time $t \in [0, \infty]$ (equation (1) for GBM and equation (2) for MRP). We should note that, for finite planning periods: $\infty \Rightarrow T$, where T represents the maturity date of the planning period (midterm planning horizon is typically from 12 to 24 month (Sillekens et al., 2011).

The first flexibility source of interest is the option to exercise. In this case, management can execute an option to buy an additional workforce shift. The second flexibility source is the option to defer; managers can wait to see whether demand justifies reinforcing the existing shifts.

We simulated the demand behaviour for each stochastic process, using formulas A. (C.14)-A. (C.17). The most commonly used simulation model is the well-known Monte Carlo method, which we will apply to solve the optimisation problem presented. One of the strong points of the simulation model is that it enables us to deal with "path dependent" real options. In general, the Monte Carlo simulation method would give the same result as the rigorous economics-based option valuation models such as the Black and Scholes equation and the binominal option valuation model, if it is based on the risk-neutral dynamics. Using Monte Carlo technique we simulated repeated pay-offs for the function to calculate the expected value of the option. The general formula for the service level improvement expected value is presented as:

$$E[SLI(D_t)] = \frac{1}{\overset{s}{N}} . \sum_{i=1}^{\overset{s}{N}} MAX \overset{SLI(D_t)}{f} \left(\overline{X}(t, \upsilon_i) \right) \qquad (13)$$

where: $\overline{X}$ represents the approximation of $SLI(D_t)$, t represents time, υ_i is the series of calculation points and $\overset{s}{N}$ represents the number of simulations (≥ 2000).

Using Monte Carlo simulation, we derive the optimal service level improvement $SLI(D_t^*)$, which we recall is the value that maximizes the expected discounted benefit of the change, as stated in equations (10) and (12).

4. ILLUSTRATIVE EXAMPLE

We tested our model in a flooring industrial company. All the data were adjusted for the required confidentiality. We focus our study on a single activity, described as ‘painting’. The work centre operates with one machine and one shift, with six people per shift: four line workers and six common task workers. The core business of the company experiences a stochastic demand. The painting process requires a workforce with specific design capabilities. Temporary work can only be applied for ordinary or common tasks, like filing, packing or doing errands. The minimum investment period of a labour agreement is one year, which helps anticipating, not only salary costs, but also other costs pertaining to employee contract termination. There are also fixed costs related with initial training. We will assume that the annual salaries and the initial training costs represent the investment cost. Some additional fixed costs will be incurred to support activities arising from a new shift (auxiliary services like compressed air and dust extraction). The company targets the fulfilment of a certain service level, considering the actual capacity, use of overtime, and temporary workers for common tasks. Internal workers are not available. The company should reinforce the ‘painting’ activity with a new shift, but there must be a decision point to support the change that is based on the expected fulfilment of the improved service level. Agreements with customers, mainly in the mass chains segment, imply a penalty cost due to lack or delays in deliveries. We exclude the inventory alternative, since the company provides customized products and follows a make-to-order production policy, which is oriented by a pull strategy. Table 1 lists the data used in the example. The parameters were based on historical data (appendix C).

Variable	Value	Unit	Variable	Value	unit
D_t	165 (x10^3)	m^2/year	ω_2	18	Euros/hour
$\overline{D}_t$	200 (x10^3)	m^2/year	S_2	80	%
p_v	20	Euros/ m^2	S_A	85	%
c_v	10	Euros/ m^2	ρ	6	%
ω_1	25	%	μ_D	3	%
φ_i	45 (x10^3)	Euros/year	α_0	25	$\% p_v$
φ_f	7,5	Euros/hour	m_v	$p_v - c_v$	Euros/ m^2
φ_c	6,25	Euros/hour	n_f	4	nº of workers
β	165	m^2/hour	n_c	6	nº of workers
σ_D	20	%	K	1	Shift
γ_c	28 (x10^3)	Euros	w_a	1.500	Hours
γ_f	35 (x10^3)	Euros	w_o	5	%
S_0	70	%	κ	15	%
S_1	75	%			

Table 1: Data

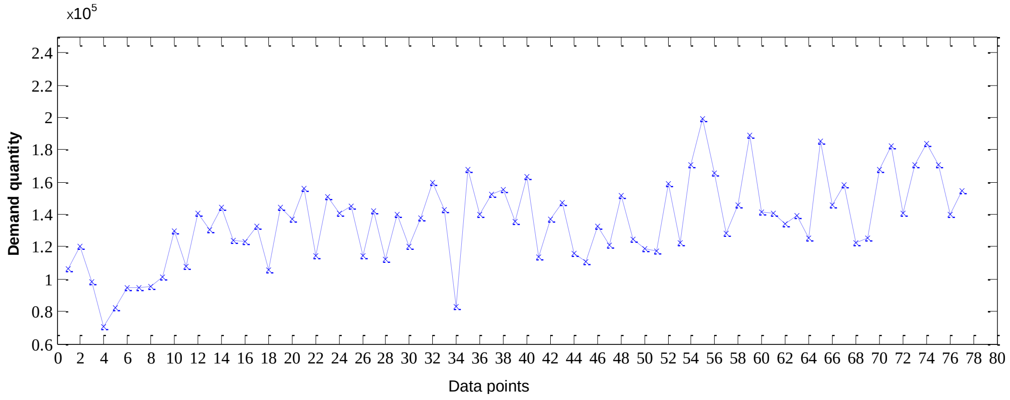

Figure 1: The historical data of demand

The demand in the example we are using is uncertain and subject to jumps. We collected data for more than 6 years to understand the pattern and allocate the most appropriate forecasting process.

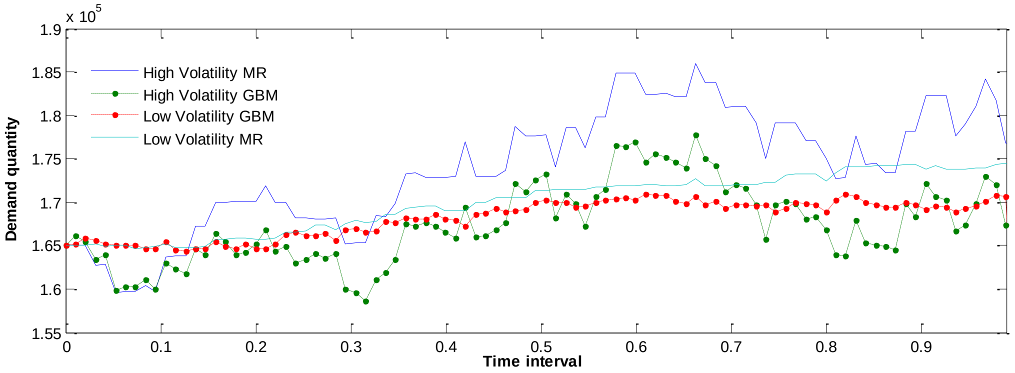

Figure 2: Demand representation using MRP and GBM, for low and high uncertain environments

Table 2 and 3 present the results of the evaluation concerning the increase of an additional shift, for strategy one and two, respectively, considering that the demand follows a mean reversion process with jumps.

Critical Demand level	174.554	m^2
Service level improvement-investing value	92.638	euros
Discounted cash flows	64.780	euros
Service level improvement-deferred value	27.857	euros

Table 2: Results for strategy one

Critical Demand level	172.074	m^2
Service level improvement-investing value	146.493	euros
Discounted cash flows	123.133	euros
Service level improvement-deferred value	23.260	euros

Table 3: Results for strategy two

Considering the results for strategy one, the company should increase the number of shifts only when the demand reaches 174.554 m^2. The project should not be implemented at that moment if the discounted cash flows are negative, which is not the case. The alternative to stand up the decision is valued at 27.857 euros. The value of maintain the option opened is valued at 92.638 euros.

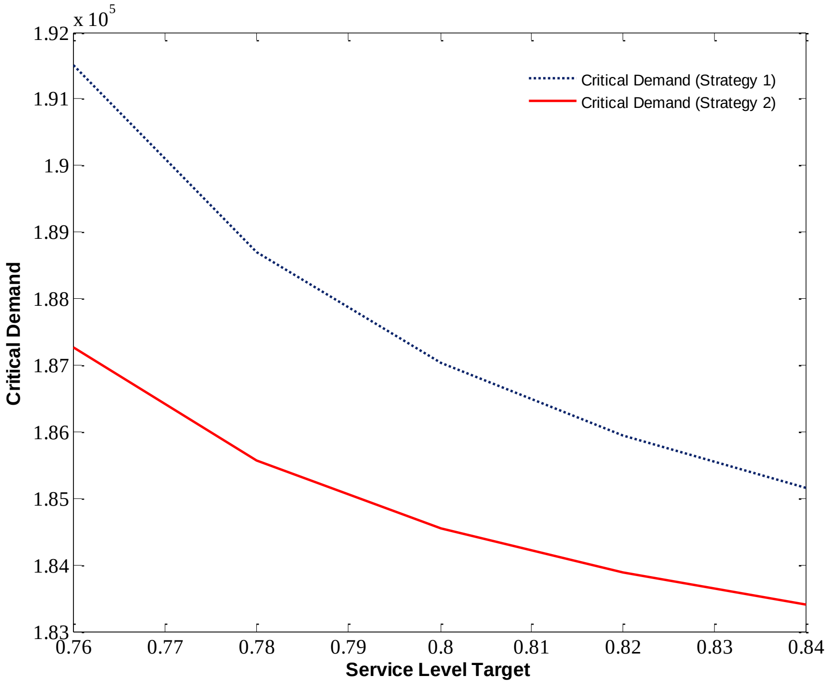

Figure 3: Relation between service level target and critical demand for alternative strategies

From figure 3 we explore the relation between service level target and critical demand. When the gap between actual situation and the new service level is high, there is an opportunity for the company that should be quantified. We denote that situation by realizing that the critical demand level, to justify the increase in the number of shifts, decreases. Strategy one refers to the use of regular work and strategy two considers the use of temporary work to cover the need of common tasks. The critical demand that supports the decision is lower in the strategy two allowing the anticipation of the decision.

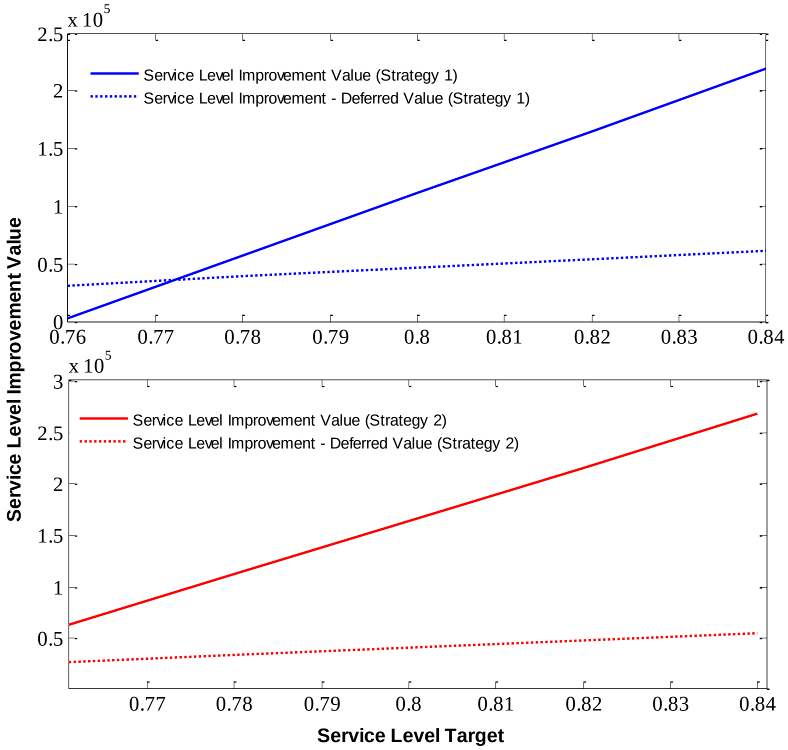

Figure 4: Relation between service level target, service level improvement value and service level deferred value for alternative strategies

Figure 4 shows the relationship between service level target and service level improvement value, complementing the results of figure 3. For high service level targets, the service level improvement value increases, this is consistent with an anticipation in the decision moment to increase the number of shifts. Strategy two is more flexible, meaning that the use of temporary work for common tasks adds value under uncertain environments. There is an interesting relation between “go” or “wait” decisions, which we show as service level improvement value (go) and deferred value (wait). When the improvement value is higher than the deferred one, the firm should decide to invest in a new shift. There is a neutral moment when the improvement value equals the deferred value after which, the opportunity to invest becomes interesting.

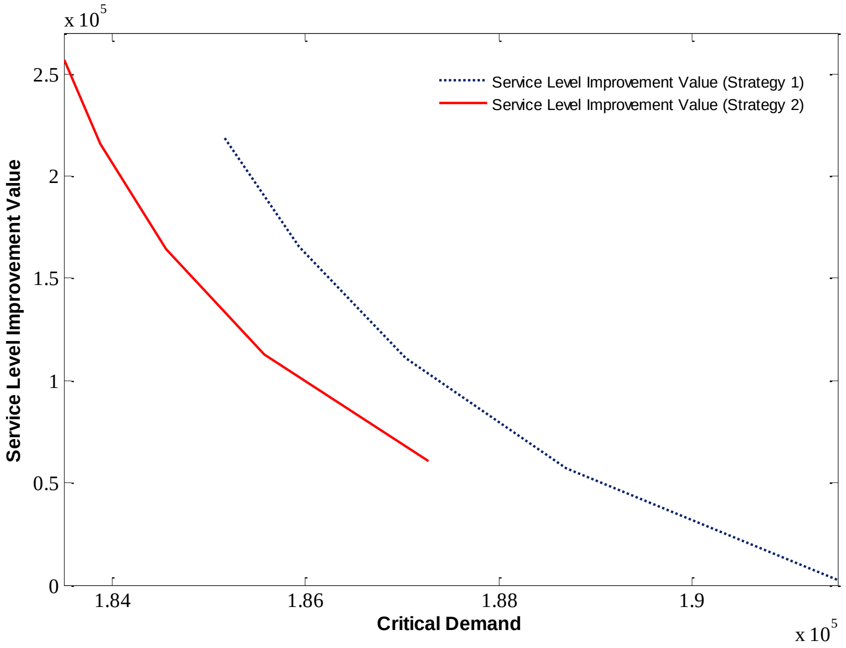

Figure 5: Relation between critical demand and service level improvement value, for alternative strategies

The relationship between critical demand and service level improvement value is illustrated in figure 5. The firms that use temporary work (strategy two) are more flexible in the decision process and so, they can anticipate decisions. This is denoted by the lower level of critical demand for the trigger moment that supports the shifts increase. Under more flexible workforce, the service level improvement value increases for both strategies but the intensity is higher for the most flexible one – the strategy two.

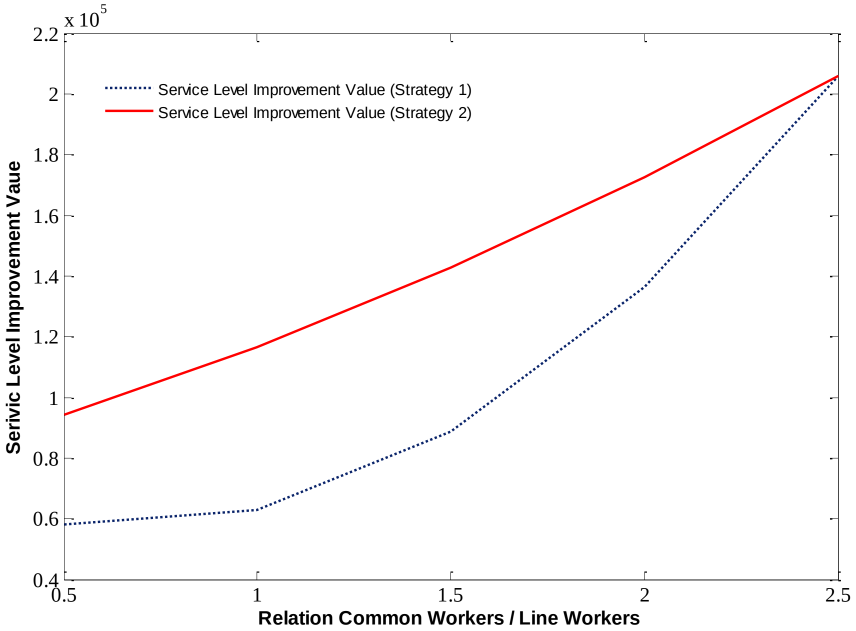

Figure 6: Relation between common and line workers and service level improvement value, for alternative strategies

In figure 6 we introduced the relationship between workforce composition and service level improvement value, for different strategies. A higher weight of common workers increases the value. The impact is more expressive in strategy two, where common workers have a temporary contract with the firm. Using these results, we can also conclude that simple equipment requiring less qualified workers allow faster changes in the number of shifts. The number of workers and the relation between qualifications is also relevant to support equipment investments in new technology. From table 4, we denote the influence of the number of required workers, for each shift, in the service level improvement value. These results can be used to support an equipment investment able to optimise the number of employees. It might pay to have a few specialists, handling uncommon hard tasks when they occur however, adjusting the qualifications of the workforce according the requirements, broken down into a disaggregated level within a work flow, can reduce the overall costs of the workforce and improve its performance.

n_f	n_c	Service level improvement value (euros)	
		Strategy 1	Strategy 2
2	2	168.296	186.175
2	3	139.221	157.285
2	4	116.930	135.100
3	3	102.005	129.555
3	4	81.941	109.614
4	4	77.076	113.838

Table 4: Service level improvement value, considering different number and composition of workers and different workforce strategies

S_0	S_2	Service level improvement value (euros)	
		Strategy 1	Strategy 2
60%	70%	54.625	113.726
60%	80%	210.654	262.073
60%	90%	524.704	563.541
70%	70%	0	0
70%	80%	101.297	154.851
70%	90%	457.854	496.270
80%	80%	0	0
80%	90%	55.924	107.370

Table 5: Service level improvement value, considering different service levels and different workforce strategies

The results presented in table 5 show that the gap between actual and targeted service level will influence the value of the decision. For relevant service level gaps the improvement value increases, but is limited by the agreed service level, above which, the opportunity value will decrease. We tested these results as a theoretical situation when the target equals the actual service level. In this situation, the company should not invest in an additional shift using the service level argument.

5. CONCLUSIONS

The purpose of this study is to identify the optimal moment for changes in the number of labour shifts to enhance performance through the service level. We used the service level improvement value concept as a flexibility measure to quantify the changes. Our model provides a relevant perspective on the very complex and difficult problem of determining the right moment to increase workforce shifts, subject to hiring permanent employees, due to process requirements and legal conditions under uncertain demand. We believe firms can benefit through an improved understanding of the conditions under which they should increase capacity using additional shifts, after considering the right time to do so, including hiring and training periods.

We incorporated in the model many parameters used for planning purposes, in an operational approach, such as overtime, but also with strategic concerns regarding the workforce composition, between common and qualified workers. Specifically, our model, using real options theory, is able to identify the trigger moment and quantify the value for shift decisions under conditions of uncertainty and management flexibility, while considering service level requirements.

6. LIMITATIONS AND FUTURE RESEARCH

We used some assumptions that should be discussed to support the generalization of the model. First we considered that the service level depends on the availability of workforce shifts. This assumption means that a work station can only produce with the full composition of a shift, otherwise it's not possible to perform the activities and as consequence, the service level will be affected. This assumption does not limit the changes in the number of workers per shift, meaning that the model can incorporate changes in workers per shift due to efficient practices or technological upgrades. We assume that demand not fulfilled will be postponed to future planning periods, as so, affecting the service level in the current planning period. The irreversibility of the costs is discussed and supported in the paper. The application is not limited to legal constraints as the model considers different possible costs for training and dismissal. We ignored social costs, because they are difficult to quantify, but we realise that in some countries could represent a relevant part of the investment costs, mainly under adverse conditions of unemployment. The assumption regarding non available internal workforce does not limit the results, because an opportunity utility cost should also be considered and so, it becomes closer to a temporary worker solution that is treated by the model. The same applies for the potential use of the existing shift in other work stations, which can be considered as an internal profit. We did not consider the impact of inventories, assuming a make-to-order approach. For this reason we defend that the only purpose to the use of inventories is to compensate inefficiencies. Nevertheless the policy, the model is affected by market demand that could smoothed by the use of buffers in the downstream echelons.

We posted a special attention on the generality of the model, by adapting Monte Carlo optimisation mechanism for different demand forecast models and different parameters. This allows for future applications in other industries with different demand patterns. We considered that production is immediately available after the decision on workforce shift increase this opens a relevant future research topic for the inclusion of other time constraints, like the recruitment and training period, affecting the timeframe between decision and the operative date.

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A. APPENDIX

List of Figures:

B. APPENDIX AUXILIARY TABLES

Model	References	Application
Geometric Brownian Motion	Paddock, Siegel and Smith (80's)	Imprevisible model
Mean reversion	Schwartz (1997)	Previsible model
Mean reversion with jumps	Dias and Rocha (1998)	Realistic model

Table 6: Stochastic models framework

C. APPENDIX FORECASTING FORMULAS USED IN THE MODEL

1 - for Geometric Brownian motion (GBM)

$$D_t = D_{t-1}.e^{\left(\alpha - \frac{1}{2}.\sigma^2\right).\Delta t + \sigma.N(0,1).\sqrt{\Delta t}} \tag{C.14}$$

2 - for GBM with jumps

$$D_t = D_{t-1}.e^{\left(\alpha - \frac{1}{2}.\sigma^2\right).\Delta t + \sigma.N(0,1).\sqrt{\Delta t}} + jumpsize \tag{C.15}$$

3 - for Mean reversion process (MRP)

$$D_t = D_{t-1}.e^{-\kappa.\Delta t} + \overline{D}_t.\left(1 - e^{-\kappa\Delta t}\right) + \sigma.\sqrt{\frac{1 - e^{-2\kappa.\Delta t}}{2\kappa}}.N(0,1) \tag{C.16}$$

4 - for MRP with jumps

$$D_t = D_{t-1}.e^{-\kappa.\Delta t} + \overline{D}_t.\left(1 - e^{-\kappa\Delta t}\right) + \sigma.\sqrt{\frac{1 - e^{-2\kappa.\Delta t}}{2\kappa}}.N(0,1) + jumpsize \tag{C.17}$$

With, $N(0,1)$ = standard normal distribution

D. APPENDIX PARAMETERS ESTIMATION

Demand modelling processes require the determination of critical parameters. The demand historical data collected from the period between 2005 and 2011 is used to estimate the following parameters: demand volatility, demand drift, long run equilibrium demand and demand reversion rate. In the company, the historical data is normally used for economic evaluations also as for planning purposes.

Demand volatility estimation:

We calculated volatility as the standard deviation of demand logarithms for the period under analysis.

$$\sigma_D = \text{Standard deviation } \left[\ln(D_t) - \ln(D_{t-1})\right], \forall t \in [0,T] \Rightarrow \sigma_D \approx 20\%$$

Demands drift estimation:

For geometric Brownian motion application, the drift is the trend or the linear growth rate of the diffusion process.

$$\begin{cases} \left(\mu_D - \frac{1}{2}\sigma^2\right) = \frac{1}{N}\sum_{t=1}^{N}\left[\ln(D_t) - \ln(D_{t-1})\right], \forall t \in [0,T] \\ \mu_D = \left(\mu_D - \frac{1}{2}\sigma^2\right) + \left(\frac{1}{2}\sigma^2\right) \end{cases} \Rightarrow \mu_D \approx 3\%$$

The long equilibrium demand is the mean quantity that demands tend to revert over time. Reversion rate is the speed at which quantities revert to the long-run mean demand. The two parameters are estimated using the first-order autoregressive process, in discrete time, as suggested by Dixit and Pindyck (1994). In the case of least-square regression, we can take the mean reversion forecast formula and simply turn it into a least-square regression ($y = a + bx + \varepsilon$).

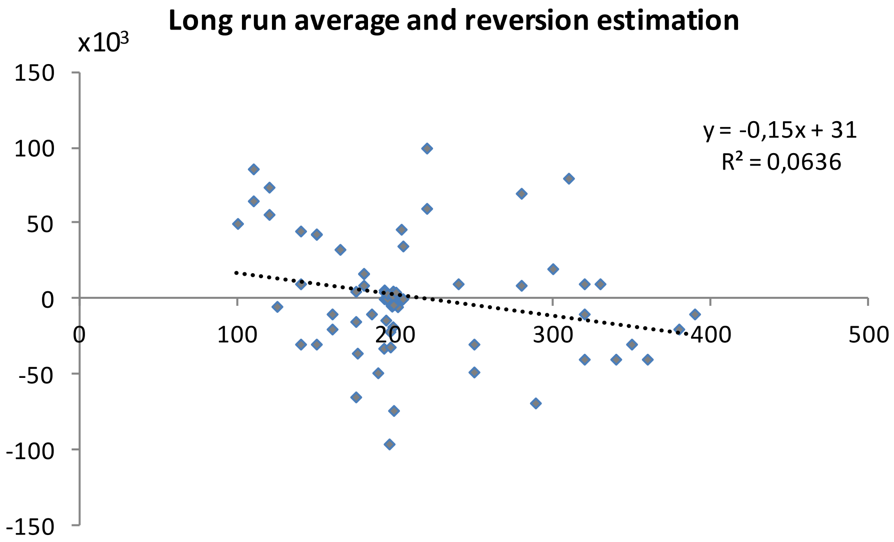

Figure 7: Long run average and reversion estimation

a	31
b	-0,15

Table C1 (7): Regression parameters

Using the results from regression (figure 7) we could define the values for long run mean demand and reversion speed, as follows:

$$\overline{D} = -\frac{a}{b} \approx 200.000\text{m}^2$$

$$\kappa = -\ln\left(1+b\right) \approx 15\%$$

Jumps probability and size are independent of historical data as they depend on abnormal information arrival. As a result, it is critical to estimate these parameters, and so it is better to choose reasonable parameters that to calculate non-reasonable ones from historical data. We assumed the size considering spot promotions impact, which may vary according to the market conditions.

We use table C2 to exemplify how to compute historical data and to estimate the parameters used in the model.

Data points		D_t (x10^3)	$\ln(D_t)$	$\ln(D_{t-1})$	$\ln(D_t) - \ln(D_{t-1})$	D_{t-1} (x10^3)	$D_t - D_{t-1}$ (x10^3)
2005	1	199					
2005	2	180	5,19	5,29	-0,10	199	-18,50
2005	3	189	5,24	5,19	0,05	180	9,00
2005	4	140	4,94	5,24	-0,30	189	-49,00
2005	5	185	5,22	4,94	0,28	140	45,00
2005	6	175	5,16	5,22	-0,06	185	-10,00
2005	7	160	5,08	5,16	-0,09	175	-15,00
2005	8	150	5,01	5,08	-0,06	160	-10,00
2005	9	120	4,79	5,01	-0,22	150	-30,00
2005	10	176	5,17	4,79	0,38	120	56,00
2005	11	140	4,94	5,17	-0,23	176	-36,00
2005	12	110	4,70	4,94	-0,24	140	-30,00
2006	1	175	5,16	4,70	0,46	110	65,00
2006	2	110	4,70	5,16	-0,46	175	-65,00

2006	3	196	5,28	4,70	0,58	110	86,19
2006	4	100	4,61	5,28	-0,67	196	-96,19
2006	5	150	5,01	4,61	0,41	100	50,00
2006	6	193	5,26	5,01	0,25	150	42,76
2006	7	160	5,08	5,26	-0,19	193	-32,76
2006	8	140	4,94	5,08	-0,13	160	-20,00
2006	9	150	5,01	4,94	0,07	140	10,00
2006	10	193	5,26	5,01	0,25	150	43,07
2006	11	199	5,29	5,26	0,03	193	5,93
2006	12	125	4,83	5,29	-0,46	199	-74,00
2007	1	120	4,79	4,83	-0,04	125	-5,00
2007	2	194	5,27	4,79	0,48	120	74,07
2007	3	180	5,19	5,27	-0,08	194	-14,07
2007	4	197	5,28	5,19	0,09	180	16,69
2007	5	175	5,16	5,28	-0,12	197	-21,69
2007	6	180	5,19	5,16	0,03	175	5,00
2007	7	197	5,28	5,19	0,09	180	16,91
2007	8	165	5,11	5,28	-0,18	197	-31,91
2007	9	198	5,29	5,11	0,18	165	32,82
2007	10	198	5,29	5,29	0,00	198	0,07
2007	11	193	5,26	5,29	-0,02	198	-4,84
2007	12	193	5,26	5,26	0,00	193	0,08
2008	1	198	5,29	5,26	0,02	193	4,52
2008	2	198	5,29	5,29	0,00	198	0,07
2008	3	199	5,30	5,29	0,01	198	1,62
2008	4	202	5,31	5,30	0,01	199	2,38
2008	5	201	5,30	5,31	0,00	202	-0,58
2008	6	197	5,28	5,30	-0,02	201	-3,79
2008	7	197	5,29	5,28	0,00	197	0,07
2008	8	193	5,26	5,29	-0,02	197	-4,29
2008	9	198	5,29	5,26	0,02	193	4,60
2008	10	194	5,27	5,29	-0,02	198	-3,69
2008	11	194	5,27	5,27	0,00	194	0,08
2008	12	195	5,27	5,27	0,01	194	1,18
2009	1	195	5,27	5,27	0,00	195	0,07
2009	2	199	5,29	5,27	0,02	195	3,16

2009	3	199	5,29	5,29	0,00	199	0,07
2009	4	204	5,32	5,29	0,03	199	5,17
2009	5	204	5,32	5,32	0,00	204	0,06
2009	6	250	5,52	5,32	0,20	204	46,17
2009	7	202	5,31	5,52	-0,22	250	-48,47
2009	8	196	5,28	5,31	-0,03	202	-5,20
2009	9	199	5,29	5,28	0,01	196	2,56
2009	10	195	5,27	5,29	-0,02	199	-3,95
2009	11	195	5,27	5,27	0,00	195	0,07
2009	12	198	5,29	5,27	0,02	195	3,32
2010	1	200	5,30	5,29	0,01	198	2,05
2010	2	205	5,32	5,30	0,02	200	4,43
2010	3	205	5,32	5,32	0,00	205	0,06
2010	4	205	5,32	5,32	0,00	205	0,06
2010	5	240	5,48	5,32	0,16	205	35,07
2010	6	250	5,52	5,48	0,04	240	10,00
2010	7	220	5,39	5,52	-0,13	250	-30,00
2010	8	280	5,63	5,39	0,24	220	60,00
2010	9	289	5,67	5,63	0,03	280	9,00
2010	10	220	5,39	5,67	-0,27	289	-69,00
2010	11	320	5,77	5,39	0,37	220	100,00
2010	12	310	5,74	5,77	-0,03	320	-10,00
2011	1	390	5,97	5,74	0,23	310	80,00
2011	2	380	5,94	5,97	-0,03	390	-10,00
2011	3	360	5,89	5,94	-0,05	380	-20,00
2011	4	320	5,77	5,89	-0,12	360	-40,00
2011	5	280	5,63	5,77	-0,13	320	-40,00
2011	6	350	5,86	5,63	0,22	280	70,00
2011	7	320	5,77	5,86	-0,09	350	-30,00
2011	8	330	5,80	5,77	0,03	320	10,00
2011	9	340	5,83	5,80	0,03	330	10,00
2011	10	300	5,70	5,83	-0,13	340	-40,00
2011	11	320	5,77	5,70	0,06	300	20,00

Table C2 (8): Demand historical data and parameters estimation

Note: data simulated due to confidential reasons.

ESSAY VII: VERTICAL INTEGRATION TIMING STRATEGY UNDER MARKET UNCERTAINTY

ABSTRACT

Outsourcing and integration strategy are actual topics on supply chain area. From strategic integration decision to capacity availability incurs time and costs at the preparation stage. The timing strategy takes into account a firm's effort at the preparation stage. The capacity to be installed, the related fixed costs and the production marginal costs evolution will be determinant for the timing to change. We intend to quantify the impact of anticipating a capacity expansion, treated as a risky investment in a strategic vertical integration. Traditional methods consider investments as reversible and thus, do not capture the idiosyncrasies of capacity management, in which costs are not fully reversible. Our model helps managers to more accurately decide to change from outsourcing to an integration strategy and defer commitment until future uncertainties, related with market and lack of information, can be partially solved. Finally, we provide a time framework for decision support system considering the preparation period.

Keywords: vertical integration, outsourcing, decision process, market uncertainty

1. INTRODUCTION

In the current economic and industrial conditions, with demand ever fluctuating, capacity management is not an easy task. As an answer to demand uncertainty, stressed by shocks, we focus on the operations' integration mechanism, based on own capacity expansion. We target the decision on how firms should endow their operations as an alternative to outsourcing. For generality, we will employ the term "integration value" to quantify the impact on profit function considering own capacity.

The role of outsourcing and integration, in uncertain environments, continue to evolve in a way that requires a greater emphasis in the timing for the change. The switch strategy is time-consuming, due to the increased equipment's sophistication and the production workers required training time and, as a consequence, the decisions should be done in advance. One way to deal with this trend is to anticipate integration, considering the preparation stage, for which a trigger moment is key.

In this study we emphasize three useful questions: (i) How can we value a decision on integration? (ii) How can we find the trigger moment to apply for capacity increase decision? (iii) What is the impact of the preparation stage on investment timing decision and integration value?

2. LITERATURE REVIEW

Outsourcing versus vertical integration can be explained as a function of the capital intensity (e.g. Antràs, 2003) and product cycles (e.g. Antràs, 2005).

Many arguments have been used both for and against outsourcing as an alternative to achieve competitive advantages (see Gilley and Rasheed, 2000), but only few authors investigate the impact of such an alternative on the firm's economic performance (e.g. Fixler and Siegel, 1999; Jiang, Frazier and Edmund, 2006; Kurz, 2004; Mol, Tulder and Beije, 2005; Ten and Wolff, 2001). The outsourcing decision can impact on the firm's performance in a "U" shape, meaning that a firm should know the optimal degree of outsourcing versus the level of integration (Kotabe, Mol and Murray, 2007). Of the few stated studies, we can find some management impacts structured in different classes, for instance, Quinn and Hilmer (1994) made an overview on strategic implications; in 1997, Lever posted a special attention on financial and human resources implications. In 1999, Rabinovich et al. and later on, in 2002, Andersson and Norrman, concentrated on logistic functions. Momme (2002) studied the impact in the control dimension by focusing on the core activities. In 2010, Reitzig and Wagner concluded that a firm increase performance in conducting downstream activities and, in 2011, Sharda and Chatterjee defended that there are similarities and differences between outsourcing firms and their performance, due to combinations of work designs, strategy and market relations.

Other studies have been focusing on benefits and risks of an outsourcing decision (e.g. Jiang, Belohlav and Young, 2007; Schniederjans and Zuckweiler, 2004). Briefly we can identify three different approaches: the focus on strategic core competences (e.g. Quinn and Hilmer, 1994; Prahalad and Hamel, 1990; Sanders et al., 2007), cost impacts (e.g. Holcomb and Hitt, 2007) and resource management approach (e.g. McIvor, 2009). Despite these past considerations, we are also interested in the papers that study outsourcing from the operational planning level whereas, based on scale economies reasoning, some companies outsource even with no cost advantage (e.g. Cachon and Harker (2002) using a queuing capacity model). Specifically, we will concentrate our study on outsourcing decisions when a company faces a potential capacity expansion, which is the decision whether to build or expand own production capacity. Mathematical models have been developed to evaluate the benefits of expanding capacity and outsourcing (e.g. Mieghem, 1999; Tsai and Lai, 2007).

Some studies have made explicit under which conditions to outsource part of the production volumes (e.g. Kok, 2000; Yang, Qi and Xia, 2005). Kouvelis and Milner (2002) show that greater market demand uncertainty increases the reliance on outsourcing, on the other hand, greater supply uncertainty increases the need for vertical integration. The option of outsourcing in production planning models results in production smoothing (Kamien and Li, 1990) and in different amounts of safety stocks needed in a supply chain (Malek, Kullpattaranirum and Nanthavanij, 2005). The effect of outsourcing on company productivity is dependent on the nature of the outsourced inputs (services or materials) (Gorg and Hanley, 2005).

One prominent perspective to explain vertical integration is transaction cost economics. It has its focus on market failure and captures ways to reduce risks by integrating economic activities under a coordinated management. According to transaction cost economics, the question whether an activity should be integrated or not depends on the specificity of the investment, the frequency and the costs of interaction between firm and the supplier, the amount of uncertainty and an eventual opportunity to the supplier (Williamson, 2008), due, for instance, to economies of scale (Argyres, 1996). One major problem with the transaction theory is that it focuses on one transaction, lacking for a systemic approach (Puranam, Gulati and Bhattacharya, 2008; Reitzig and Wagner, 2010). The outsourcing and integration reflect the “make or buy” decisions, which are at the bases of the transaction costs theories (Beverelli and Mahlstein, 2011; Williamson, 1985). Recently Ciliberto and Panzar (2011) analysed the relation between downstream activities outsourcing decisions and the fixed costs at the upstream stages of a supply chain.

Another perspective is the resource-based view of the firm focusing on internal capabilities as the main criteria for outsourcing decisions (e.g. Conner and Prahalad, 1996; Zander and Kogut, 1995). In the resource-based view of the firm, management team devote specific attention to the development of the organization’s internal resources and capabilities as a key competitive advantage (Teece, Pisano and Shuen, 1997). In 2011, Olausson and Magnusson relied on specific attention to human resources requirements and coordination; Zirpoli and Becker (2011) addressed the problem of outsourcing product development tasks; Timlon (2011) argued for a socio-economic approach in strategic outsourcing decisions; Narayanan et al. (2010) studied task complexity and end customer orientation of outsourcing decisions.

Some authors defended the use of both perspectives (cost and resources) (e.g. Broedner, Kinkel and Lay, 2009; Jacobides and Winter, 2005) advocating that transaction cost perspective identify different modes for organizing transactions and the capability or competence perspective relies on basic assumptions of the resource-based view of the firm (e.g. Kogut and Zander, 1996; Penrose, 1995; Prahalad and Hamel, 1990).

The literature summarizes a number of advantages and disadvantages of outsourcing, while empirical data are still rare (Beaumont and Sohal, 2004; Bengtsson and Haartman, 2005; Gilley and Rasheed, 2000). Among the disclosed advantages of outsourcing, manufacturing cost reductions, reduced investment and consequently less fixed capital costs, are the most prominent, as they improve short term profitability (this is also used to justify general planning optimisation (e.g. Yao, 2011)) .

The modern theory of the firm has made considerable progress in explaining the determinants of vertical integration, assuming that the level of vertical integration results from independent transactional choices (Macher and Richman, 2008; Masten and Saussier, 2002; Novak and Stern, 2009; Whinston, 2003). Some approaches were done considering uncertainty effect in an outsourcing option, based on production cost and degree of product differentiation (e.g. Hamada, 2010), market uncertainty and the optimal proportion of outsourcing (Alvarez and Stenbacka, 2007; Li and Wang, 2010), competition and foreign exchange uncertainty (Liu and Nagurney, 2011), and demand uncertainty from the outsourcing side (Boulaksil, Grunow and Fransoo, 2011).

Recently, we found a study regarding outsourcing timing using real options methodology (Moon, 2010). Basically our model focuses on an investment option, mainly on the integration trigger moment, instead of an outsourcing decision. In this way, we defend the application of the model to justify irreversible costs due to own capacity investments, contrasting the author attention on the preparation step for an outsourcing decision by drawing his model on irreversible hidden costs.

The research in this paper differs from previous literature mainly in five aspects: (i) we quantify the integration decision under demand uncertainty; (ii) our model determines critical demand quantities as the trigger moment for a capacity investment; (iii) we examine the impact, on the trigger moment, of the uncertainties in demand for products; (iv) our model incorporates positive shocks impacts in products' demand; and (v) we use an investment preparation stage period, making a closer approach to the reality. Although previous research might have addressed one or two of the above points, none has been found which integrates all five aspects at once. Thus, our research provides additional contributions to the existing literature.

For generality, we address an actual and important topic in the area of supply chain management, under a strategic approach, related with partnerships in the chain (Childe, 2011)

3. INTEGRATION TIMING MODEL WITH INVESTMENT PREPARATION STAGE

In this section we will begin with a description of the model. Then we will provide the regime change optimal timing, considering a preparation stage.

The main uncertainty source affecting the integration decision is the demand. We assume that the demand is a stochastic variable, denoted by D and follows a geometric Brownian motion (similar assumption in Bengtsson (2001) and Fernandes, Gouveia and Pinho (2010a, 2010b)), subject to a Poisson process, such that:

$$dD_{t+n} = \mu_D D_{t+n} dt + \sigma_D D_{t+n} dz_D + D_{t+n} dq \tag{1}$$

Where: $dz = \varepsilon(t)\sqrt{dt}$; $\varepsilon(t) \approx N(0,1)$, μ =instantaneous drift, σ = volatility, dz = increment of a wiener process, where $\varepsilon(t)$ is a serially uncorrelated and normally distributed random variable; $dq = (1+u)$ with probability λ_u and jumps intensity represented by u . The time required to perform integration investment will be denoted as "preparation stage" and is represented with n . This time considers the construction time plus training period.

It's expectable that in a certain moment there will be a demand level that supports the integration decision, considering the preparation period and the outcome results. To model our problem, we will assume a different profit function prior (pure outsourcing) and after the decision (pure integration) that we will denote as π_0 and π_1 , respectively.

We consider that the integration will occur within a single period and instant production will not be available immediately to face demand changes.

We also assume that the decision to outsource is affected only by profit advantage, and not by competitive advantages through proper market positioning, such as the degree of product differentiation (also defended by Hamada, 2010). In the present approach, we will not consider partial insourcing possibility (Roberts, 2004).

The following notation will be used: p_v representing the unit selling price, c_{v1} is the unit outsourcing cost, c_{v2} the unit integration variable cost, φ counts for own fixed operating costs, γ is the investment value, ρ discount rate, $\frac{\varphi}{D_{t+n}}$ and $\frac{\rho\gamma}{D_{t+n}}$ representing, respectively, the unit operating fixed cost and the investment cost by unit; n represents the time frame according investment implementation time and training period.

Analytically the unit profit functions before and after investment will be defined in the following equations, considering pure outsourcing and pure integration:

$$\pi_0(D_{t+n}) = p_v - c_{v1} \tag{2}$$

$$\pi_1(D_{t+n}) = p_v - c_{v2} - \frac{\varphi}{D_{t+n}} - \frac{\rho\gamma e^{\rho n}}{D_{t+n}} \tag{3}$$

The goal is the calculation of the demand critical point D^*, above which justifies the investment in full integration.

Analytically we will use the following objective function:

$$\sup_{D^*} E_D \left(\begin{array}{l} \int_0^{\tau-n} D_{t+n} e^{-\rho n} \pi_0 \left(D_{t+n} \right) e^{-\rho t} dt + \int_{\tau-n}^{\tau} D_{t+n} e^{-\rho n} \pi_0 \left(D_{t+n} \right) e^{-\rho t} dt + \\ + \int_{\tau}^{\infty} D_{t+n} e^{-\rho n} \pi_1 \left(D_{t+n} \right) e^{-\rho t} dt \end{array} \right) \tag{4}$$

With:

τ = first optimal time to invest;

$\pi_0 \left(D_{t+n} \right)$= unit profit function before investment decision, equation (A.27);

$\pi_1 \left(D_{t+n} \right)$= unit profit function after investment implementation and with pure integration (3);

D_{t+n} = demand during time t, equation (1)

For the pure integration regime, we will replace equations (A.27) and (3) on equation (A.29):

$$\sup_{D^*} E_D \left(\begin{array}{l} \int_0^{\tau-n} e^{-\rho t} \left[p_v D_{t+n} e^{-\rho n} - c_{v1} D_{t+n} e^{-\rho n} \right] dt + \\ + \int_{\tau-n}^{\tau} e^{-\rho t} \left[p_v D_{t+n} e^{-\rho n} - c_{v1} D_{t+n} e^{-\rho n} \right] dt + \\ + \int_{\tau}^{\infty} e^{-\rho t} \left[p_v D_{t+n} e^{-\rho n} - c_{v2} D_{t+n} e^{-\rho n} - \varphi e^{-\rho n} - \rho \gamma \right] dt \end{array} \right) \tag{5}$$

We can rewrite equation (A.30) by decomposing the first member, then we obtain,

$$\sup_{D^*} E_D \left(\begin{array}{l} \int_0^{\infty} e^{-\rho t} \left[p_v D_{t+n} e^{-\rho n} - c_{v1} D_{t+n} e^{-\rho n} \right] dt - \int_{t-n}^{\infty} e^{-\rho t} \left[p_v D_{t+n} e^{-\rho n} - c_{v1} D_{t+n} e^{-\rho n} \right] dt \\ + \int_{t-n}^{\infty} e^{-\rho t} \left[p_v D_{t+n} e^{-\rho n} - c_{v1} D_{t+n} e^{-\rho n} \right] dt - \int_{t}^{\infty} e^{-\rho t} \left[p_v D_{t+n} e^{-\rho n} - c_{v1} D_{t+n} e^{-\rho n} \right] dt + \\ + \int_{\tau}^{\infty} e^{-\rho t} \left[p_v D_{t+n} e^{-\rho n} - c_{v2} D_{t+n} e^{-\rho n} - \varphi e^{-\rho n} - \rho \gamma \right] dt \end{array} \right) \tag{6}$$

The members do not depend on τ nor on D^* are ignored so, we can rewrite equation (6) as,

$$\sup_{D^*} E_D \left(\int_t^{\infty} e^{-\rho t} \left[c_{v1} D_{t+n} e^{-\rho n} - c_{v2} D_{t+n} e^{-\rho n} - \varphi e^{-\rho n} - \rho \gamma \right] dt \right) \tag{7}$$

This equation maximizes profits from changing outsourcing to integration, under uncertain demand, considering the preparation stage and respecting the other deterministic parameters.

We will assume that the integration value in the critical demand point $v(D^*)$ can be represented by:

$$v(D^*) = E_D \left(\int_t^{\infty} e^{-\rho t} \left[c_{v1} D_{t+n} e^{-\rho n} - c_{v2} D_{t+n} e^{-\rho n} - \varphi e^{-\rho n} - \rho \gamma \right] dt \right) \tag{8}$$

Using Oksendal (2003) theorem (also used by Pimentel, 2009), derived from Markoviana property, we can write equation (8) as:

$$v(D^*) = E_{D^*}\left(\int_0^\infty e^{-\rho t}\left[c_{v1}D_{t+n}e^{-\rho n} - c_{v2}D_{t+n}e^{-\rho n} - \varphi e^{-\rho n} - \rho\gamma\right]dt\right) \tag{9}$$

Using the simplified convergence theorem,

$$v(D^*) = \left(\int_0^\infty e^{-\rho t}\left[c_{v1}E_{D^*}(D_{t+n})e^{-\rho n} - cv_2 E_{D^*}(D_{t+n})e^{-\rho n} - \varphi e^{-\rho n} - \rho\gamma\right]dt\right) \tag{10}$$

Because we assume that D_{t+n} follows a geometric Brownian motion subject to a Poisson process (see equation (1)), the expected value at time t comes as:

$$v(D^*) = \frac{c_{v1}(D^*)e^{(\mu_D+\lambda_u u-\rho)n}}{\rho-\mu-u\lambda_u} - \frac{cv_2(D^*)e^{(\mu_D+\lambda_u u-\rho)n}}{\rho-\mu-u\lambda_u} - \frac{\varphi e^{-\rho n}}{\rho} - \gamma \tag{11}$$

We are going to define a simple notation for each part of equation (11),

$$-\frac{cv_2 e^{(\mu_D+\lambda_u u-\rho)n}}{\rho-\mu-u\lambda_u} = B \tag{12}$$

$$\frac{c_{v1}e^{(\mu_D+\lambda_u u-\rho)n}}{\rho-\mu-u\lambda_u} = A \tag{13}$$

$$-\frac{\varphi e^{-\rho n}}{\rho} = C \tag{14}$$

$$-\gamma = E \tag{15}$$

We note that Equations (12)-(15) come from the simple manipulation of the integrals from previous equations.

Equation (11) can be written as,

$$v(D^*) = A(D^*) + B(D^*) + C + E \tag{16}$$

We can obtain the integration value v, in actual moment, by the expression (7) determined by maximizing equation (16), which satisfies the following differential equation:

$$\frac{1}{2}\sigma_D^2 D^2\frac{\partial^2 v}{\partial D^2} + \mu_D D\frac{\partial v}{\partial D} - (\rho v + \lambda_u)v(D) + \lambda_u v[(1+u)D] = 0; D \neq D^* \tag{17}$$

With:

Initial condition,

$$v(0) = 0 \tag{18}$$

Value matching condition:

$$v(D) = A.D + B.D + C + E \tag{19}$$

with $D = D^*$

Smooth condition:

$$\frac{\partial v}{\partial D} = A + B \tag{20}$$

with $D = D^*$

If we consider (17) a second order Cauchy-Euler function (Ross, 1996), the solution can be written as:

$$v(D) = a_1 D_0^{r_1} \tag{21}$$

where r_1 is the result of the following non-linear equation:

$$\frac{1}{2}\sigma_D^2 r_1 (r_1 - 1) + \mu_D r_1 - (\rho + \lambda_u) + \lambda_u (1 + u)^{r_1} = 0 \tag{22}$$

To be solved numerically.

The solution of equation (17) is,

$$v(D) = e^{-\rho t}\left[A.D^{*1-r_1} + B.D^{*1-r_1} + C.D^{-r_1} + E.D^{*-r_1}\right]D^{r_1} \tag{23}$$

For a given value of D and for $t = 0$, the value D^* that maximizes $v(D)$ is given by the solution of the following equation:

$$A.D^{*(1-r_1)}(1 - r_1) + B.D^{*(1-r_1)}(1 - r_1) - C.D^{*-r_1} r_1 - E.D^{*-r_1} r_1 = 0 \tag{24}$$

And finally, we can calculate D^* finding the closed solution,

$$D^* = \frac{-r_1(C+E)}{(A+B)(r_1-1)} \tag{25}$$

The flexibility source is the option to exercise. In this case, management can execute an integrating option.

4. ANALYSIS AND NUMERICAL STUDY

To test our model we used data from an industrial company, adjusted considering the required confidentiality. The displays activity aims business marketing support, is intensive and depends hardly on the demand behaviour, which stresses the decision of using outsourcing or integrated activities, mainly due to retailing market uncertainty. The displays operations require cutting machines and human tasks. The process does not demand specific workforce. The company can get that competences using outsourcing. Table 1 will refer to the data used in the example.

Variable	Value	Unit	Variable	Value	unit
D_t	20 (x10^3)	m^2/year	λ_u	10	%
p_v	20	Euros/ m^2	u	10	%
c_{v1}	12	Euros/ m^2	ρ	6	%/year
c_{v2}	8	Euros/ m^2	μ_D	3	%/year
φ	30 (x10^3)	Euros	σ_D	20	%
γ	1 (x10^6)	Euros	n	1,5	year

Table 1: Data

Introducing in the model the data referred in table 1, we found the following results:

Demand critical level not considering preparation stage	32.489	m^2
Demand critical level considering preparation stage	32.518	m^2
Integration option not considering preparation stage	439.646	euros
Integration option considering preparation stage	426.538	euros

Table 2: Results of the evaluation

Considering the results (table 2), the company should integrate activities when the demand reaches 32.489 m2 when there is no preparation period and 32.518, when there is a preparation period of 1,5 years. The alternative to stand up the decision, considering preparation stage, is valued at 426.538 euros.

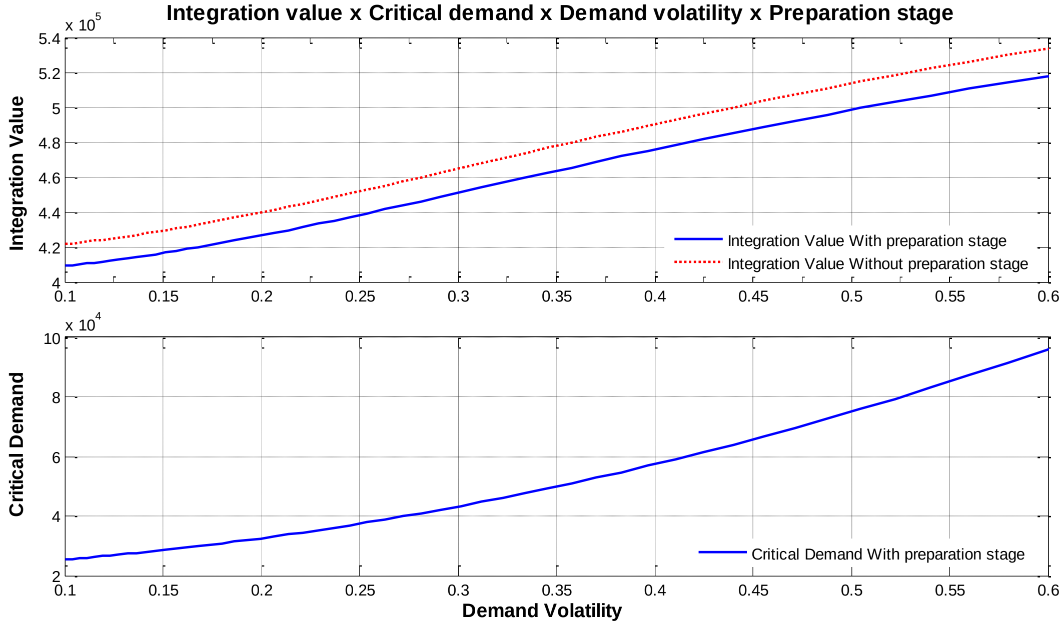

Figure 1: Integration value (000 €), critical demand, considering different demand volatility level and preparation stage

Figure 1 explains how a firm’s integration timing strategy changes when market volatility changes. The full line represents a firm’s integration value when there is a preparation stage. On the other hand, the dotted line represents a firm's integration value when the capacity is immediately available to produce. The optimal threshold for integration value increases when market volatility increases. As shown in the figure, the firm's integration value, when a market is stable, is less than the value under more uncertainty. Besides, when the market becomes more uncertain, the increased threshold implies that the firm needs to wait until the critical demand point is guaranteed.

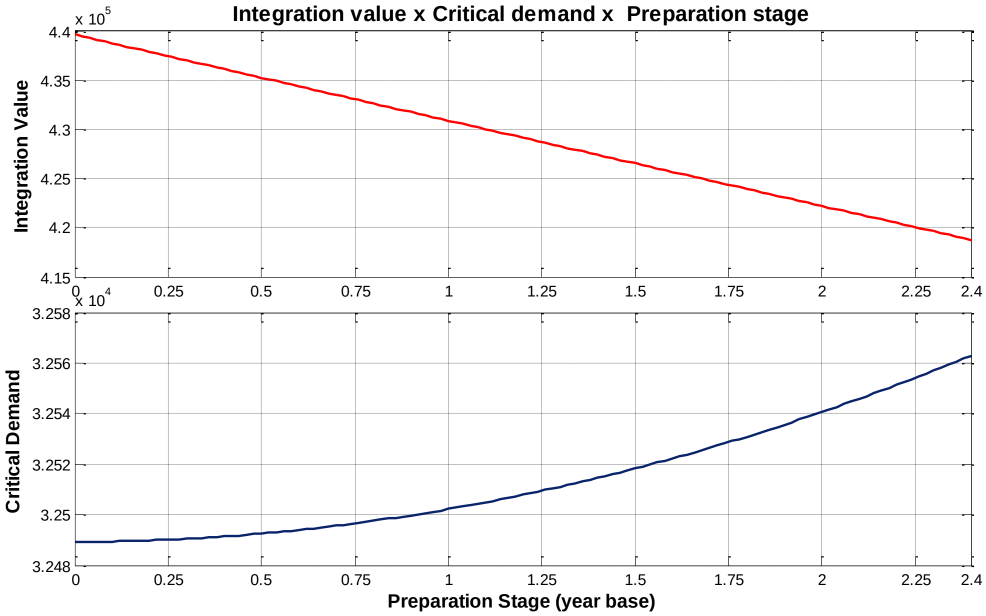

Figure 2: Integration value (000 €) and critical demand, considering different preparation stage

The example in figure 2 shows that for low preparation stages time, the flexibility becomes higher and a benefit obtained from integration increases. At the same time, figure 2 illustrates that, if an investment requires lengthy preparation, the critical demand under which the integration should be done is higher; the firm needs to wait longer. As discussed, the managers should have recognized that an optimal integration time can change depending on the preparation period.

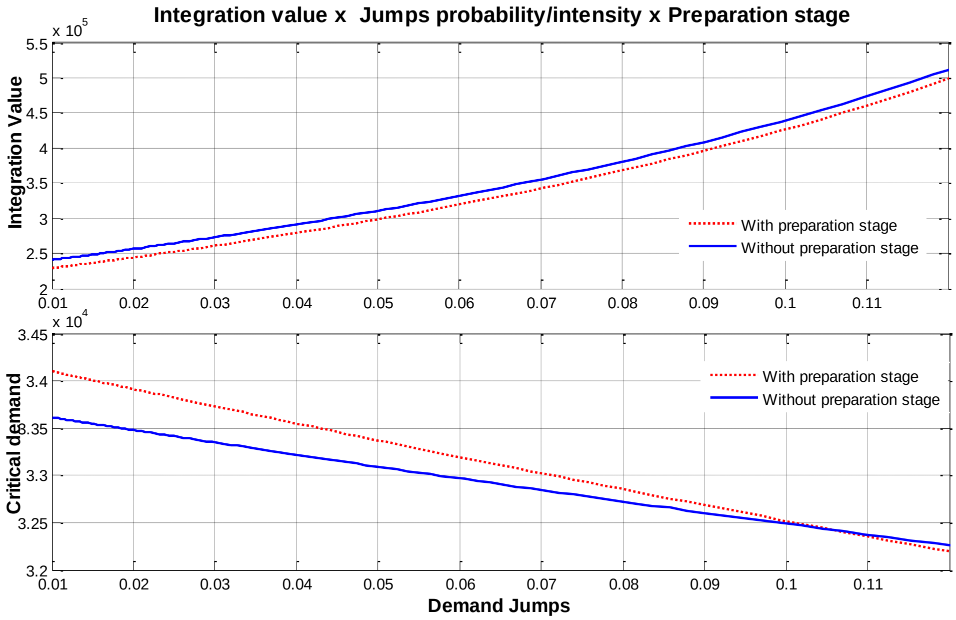

Figure 3: Integration value (000 €) and critical demand, considering preparation stage and different demand jumps

n	σ = 0%	σ = 5%	σ = 10%	σ = 20%
	$u = \lambda_u$ =0%			
0	195,9	197,4	204,2	226,2
0,5	192,0	194,1	200,4	222,3
1,0	188,2	190,2	196,6	218,4
1,5	184,3	186,4	192,9	214,6
2,0	180,6	182,7	189,2	210,8
	$u = \lambda_u$ =10%			
0	416,1	417,3	421,6	439,6
0,5	411,9	413,1	417,4	435,3
1,0	407,7	408,9	413,2	430,9
1,5	403,6	404,8	408,9	426,5
2,0	399,4	400,7	404,8	422,2

Table 3: Integration value (000 €) for different preparation stages under different demand volatilities, with and without jumps

The existence of higher unexpected positive shocks in the model brings an increase in the integration value, as the potential lost cash flows have a major relevance. The demand's critical level decreases with the increase in the intensity or probability of a shock in the demand and, in opposition, the integration opportunity values rises. In fact, the existence of a positive shock results in an aggressive increase in demand, allowing a faster contribution to the fixed costs, associated with the required investment to support the integration and anticipating the optimal moment for the decision. The integration value increases for investments without or with faster preparation stages.

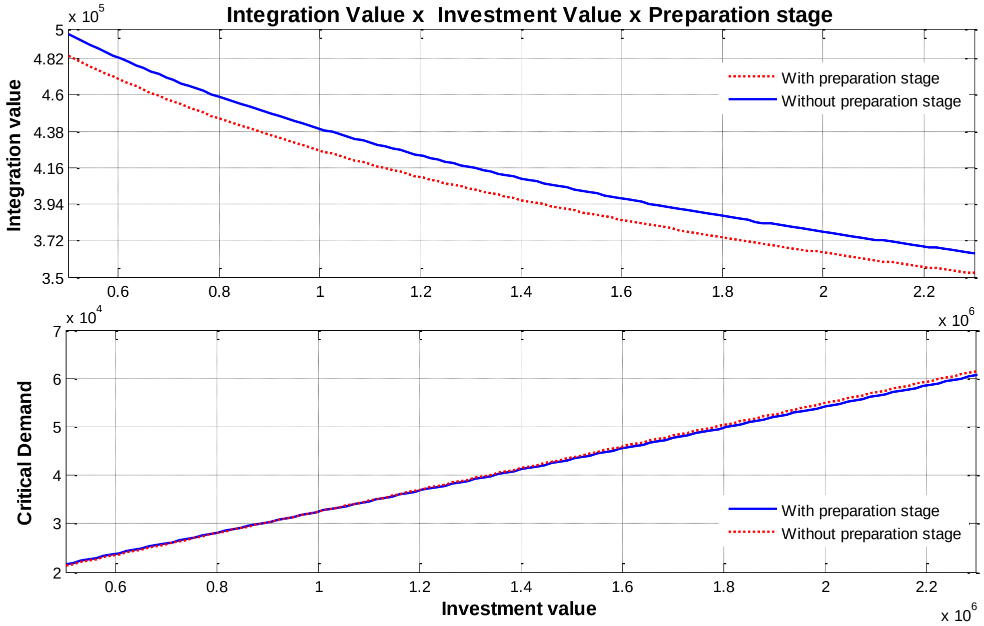

Figure 4: Integration value (000 €) and critical demand, considering different preparation stages and different investment value

Furthermore, let us discuss how the investment value can impact on the integration value, considering both situations: with and without preparation stage. Experiments show that higher investments reduce integration value and increase the time to wait (higher critical demand). The existence of a preparation stage decreases the value, as there is a gap between the moment of the decision and the availability of the capacity to endow the operations, impacting on the profit flow.

5. FINAL REMARKS

This paper examines the alternative between outsourcing and integration strategy under demand uncertainty, addressing three concerns: integration decision value, trigger moment and investment preparation stage.

Investment in own capacity within an integration strategy, requires a numerical analysis in the presence of an alternative like outsourcing. Our model adapted the real option methodology to the valuation of an integration decision. The raised problem is critical as investments to integrate became more expensive with a demanding preparation period, compared with an outsourcing alternative. We exposed the potential value between two alternatives using the optimal moment for the decision.

The development of the trigger moment, based on the critical demand value, to promote the integration of existing outsourced activities, offers a relevant tool for management purposes. Higher investments preparation stage delays the trigger moment and decreases the integration value.

The results show that in an integration decision process, the demand uncertainty is critical. Furthermore, the results support the relevance of the preparation activities in the decision time frame. Shorter preparation periods stem additional integration value. In the absence of uncertainty and management flexibility, the results are similar to those that can be achieved using traditional tools. The results of the numerical example realize the consistence of the model and the importance of the defined parameters.

6. LIMITATIONS AND FUTURE RESEARCH

In the model we did not consider the possibility of partial integration in different periods but, because we realize the importance of such flexibility in the decision process, we included in appendix further model formulation and results to support the generalization of the model. However a future research point is open to explore a time sequential approach for the partial decisions. In the model we ignored other advantages from outsourcing besides the profit one. This adequacy has been used in similar studies mainly to support the outsourcing option, not the opposite (e.g. Hamada, 2010). In fact it is difficult to quantify the value related to competitive advantages, market positioning, etc. in any alternative regarding outsourcing.

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A. APPENDIX

A.1. ALTERNATIVE MODEL FORMULATION

In this section we will complement the model presented in the paper, by developing, incorporating and analysing the results of strategy regarding partial integration. In this extent we ignore preparation period as it has already been explored.

The main uncertainty source has been presented in chapter 3 and we will only present the main changes in the model formulation.

The demand will be represented by the following equation, where the preparation period n has been ignored.

$$dD_\tau = \mu_D D_\tau dt + \sigma_D D_\tau dz_D + D_\tau dq \qquad \text{(A.26)}$$

The profit functions, by unit, before and after investment will be defined in the following equations, considering full integration:

$$\begin{cases} \pi_0(D_t) = p_v - c_{v1}, t < t^* \\ \pi_1(D_t) = p_v - c_{v2} - \varphi - \rho\gamma, t \geq t^* \end{cases} \tag{A.27}$$

With p_v representing the unit selling price, c_{v1} is the unit outsourcing cost, c_{v2} the unit integration variable cost, φ counts for own fixed operating costs, γ is the investment value, ρ discount rate, t^* is the moment when the change should occur.

The goal is the calculation of the demand critical point D^*, in moment t^* $(t^* \geq 0)$, above which the investment in integrating activities is a more profitable alternative.

Analytically we will use the following objective function:

- For full integration regime:

$$\sup_{D^*} E_D\left(\int_0^t D_t \pi_0(D_t) e^{-\rho t} dt + \int_{t^*}^{\infty} D_t \pi_1(D_\tau) e^{-\rho t} dt\right) \tag{A.28}$$

- For partial integration regime ($\overset{i}{X}$ represents the percentage of demand quantity to be produced using internal capacity):

$$\sup_{D^*} E_D\left(\int_0^t D_t \pi_0(D_\tau) e^{-\rho t} dt + \int_t^{\infty} \left(1 - \overset{i}{X}\right) . D_t \pi_0(D_\tau) e^{-\rho t} + \overset{i}{X} . D_t \pi_1(D_\tau) e^{-\rho t} dt\right) \tag{A.29}$$

With:

- t^* = first optimal time to invest;
- $\pi_0(D_t)$ = unit profit function before investment, equation;
- $\pi_1(D_t)$ = unit profit function after investment;
- D_t = demand during time t.

For the full integration regime, we will replace equations (A.27) on equation (A.29):

$$\sup_{D^*} E_D\left(\int_0^t e^{-\rho t} . D_t \left[pv - cv_1\right] dt + \int_t^{\infty} e^{-\rho t} \left[\left(1 - \overset{i}{X}\right) D_t \left(pv - cv_1\right) + \overset{i}{X} D_t \left(pv - cv_2 - \varphi / D_t - \rho\gamma / D_t\right)\right] . dt\right) \tag{A.30}$$

Simplifying equation (A.30), the objective function can be written as,

$$\sup_{D^*} E_D \left(\begin{array}{l} \int_0^{\infty} e^{-\rho t}.D_t\left[pv - cv_1\right]dt - \\ -\int_t^{\infty} e^{-\rho t}\left[D_t\left[pv - cv_1\right] - \left(1 - \overset{i}{X}\right)D_t\left(pv - cv_1\right) - \overset{i}{X}.D_t\left(pv - cv_2 - \varphi / D_t - \rho\gamma / D_t\right)\right].dt \end{array} \right) \tag{A.31}$$

The first members do not depend on t, so we can rewrite equation (A.31) as,

$$\sup_{D^*} E_D\left(\int_t^{\infty} e^{-\rho t}\left[-\left(\overset{i}{X}\right)D_t\left(pv - cv_1\right) + \overset{i}{X}.D_t\left(pv - cv_2 - \varphi / D_t - \rho\gamma / D_t\right)\right].dt \right) \tag{A.32}$$

This equation maximizes profits from changing outsourcing to integration, under uncertain demand.

Using Oksendal (2003) theorem (also used by Pimentel, 2009), derived from Markoviana property, and simplified convergence theorem, we can write equation (A.32) as:

$$v\left(D^*\right) = \left(\int_0^{\infty} e^{-\rho t}\left[\overset{i}{X}\, E_{D^*}(D_t)cv_1 + \overset{i}{X}\, E_{D^*}(D_t)cv_2 - \varphi - \rho\gamma \right].dt \right) \tag{A.33}$$

Because we assume that D_t follows a geometric Brownian motion subject to jumps modelled using Poisson process, the expected value at time t comes as:

$$v(D^*) = \frac{\overset{i}{X}\, cv_1(D^*)}{\rho - \mu - u\lambda_u} - \frac{\overset{i}{X}\, cv_2(D^*)}{\rho - \mu - u\lambda_u} - \frac{\varphi}{\rho} - \gamma \tag{A.34}$$

We are going to define a simple notation for each part of equation (A.34),

$$\frac{\overset{i}{X}\, cv_1}{\rho - \mu - u\lambda_u} = A$$

$$-\frac{\overset{i}{X}\, cv_2}{\rho - \mu - u\lambda_u} = B$$

$$-\frac{\varphi}{\rho} = C$$

$$-\gamma = E$$

A.2. ADDITIONAL RESULTS

To test our model we used data from the sample example as the one presented. Introducing in the model the data referred in table 1, we found the following results after solving the proposed model:

Demand critical level	32.489	m^2
Integration option	439.646	euros

Table A1 (4): Results of the evaluation

These results are the same as the one already presented, we are know ignoring the effect of the preparation stage.

First the results will be analysed considering economic features between outsourcing and integration, specifically, the outsourcing costs and integration investment value.

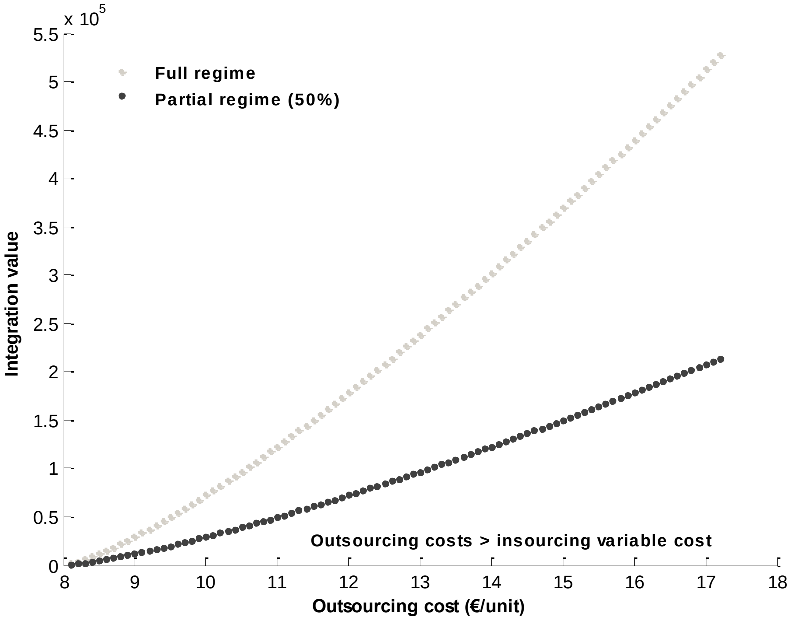

Figure A1 (5): Integration value in pure and partial regime, considering different outsourcing costs

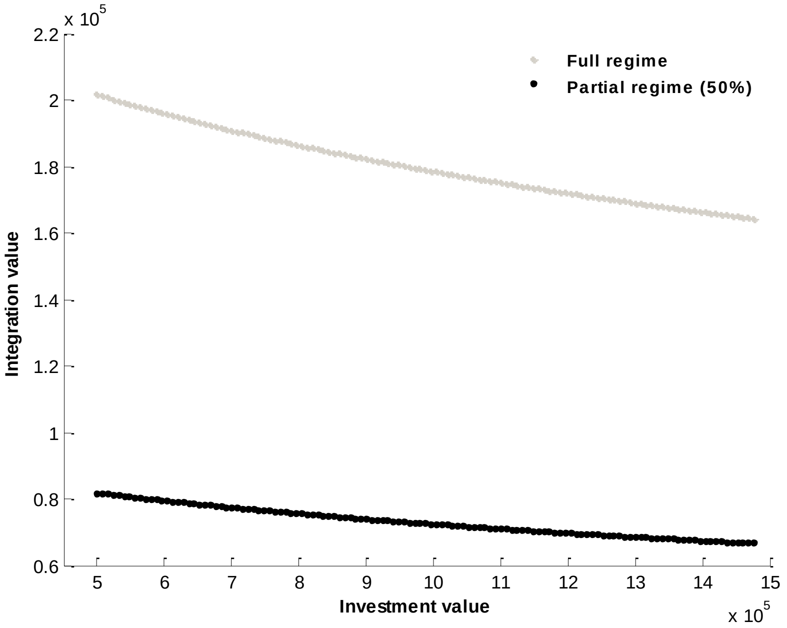

Figure A2 (6): Integration value in pure and partial regime, considering different investment values

Figure A1 considers the costs associated with outsourcing; we find that higher outsourcing costs increase the value associated with integration, whenever internal variable costs are below the outsourcing alternative costs. In regime of full integration the value of the opportunity is higher than in partial alternative, which is consistent with and increase in the output of the internalised activities under a full integration. Figure A2 shows the impact of changes in investment value in both regimes. The results point to an inverse relation between integration value and investment value. The investment value is a fixed cost that is smoothed with higher internalised activities outputs, which justifies a higher integration value for full regime when compared with partial regime.

Second the results will be analysed considering the intensity of partial integration regime.

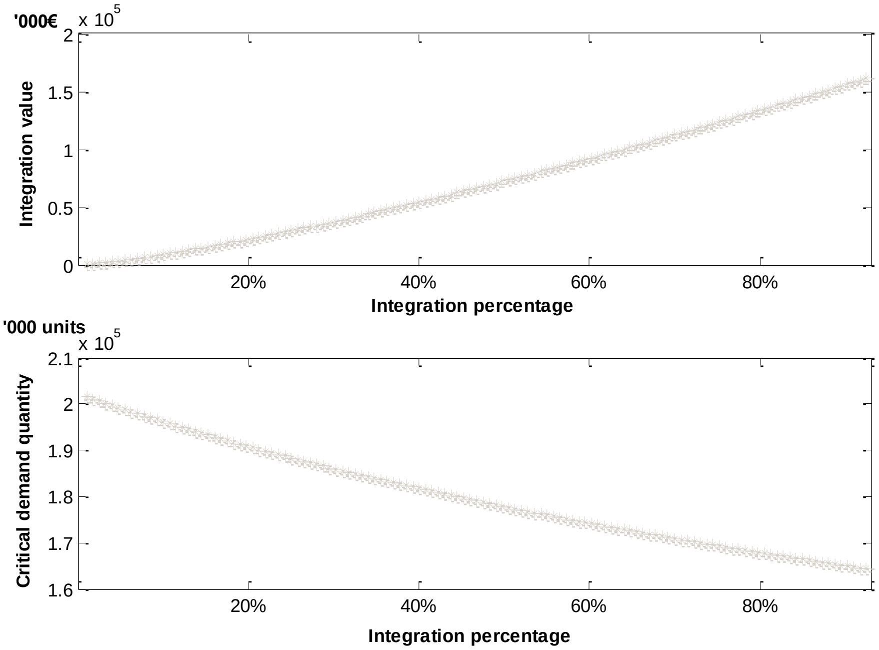

Figure A3 (7): Integration value and critical demand quantity in partial regime, considering different integration percentages.

In figure A3 we compare the evolution of integration value and the correspondent critical demand quantity. We can read that there is an inverse relation between both values. Considering only the partial regime, we simulated different scenarios for the integration percentage. As the integration percentage increases the value for the alternative between outsourcing and insourcing increases under an inverse critical demand level evolution.

Third the results will be analysed considering the market demand behaviour under shocks and volatility.

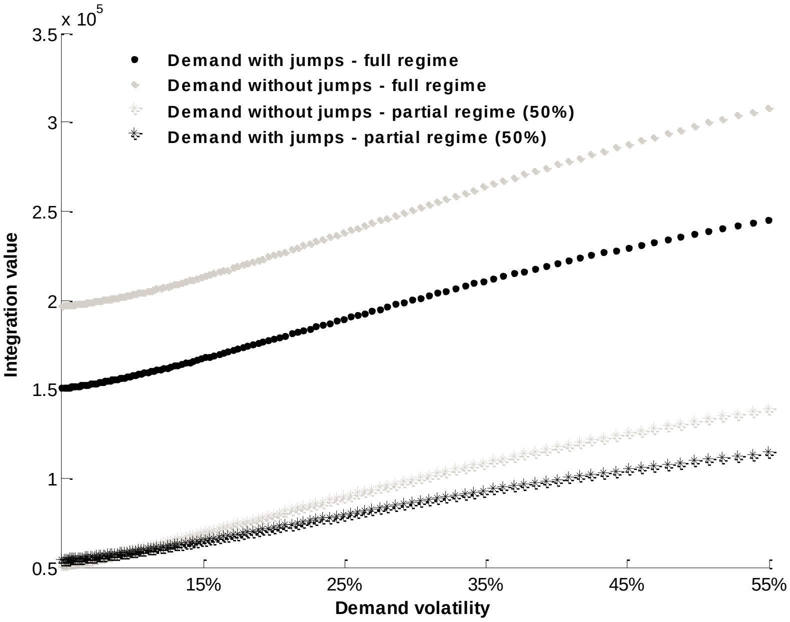

Figure A4 (8): Integration value and demand volatility, with and without shocks – full and partial integration regime.

The results from figure A4 should be analysed in three parts: the impact of demand volatility, the impact of demand shocks, and that impact considering different regimes for the integration decision. For the first, we conclude that in high uncertain environments there is higher potential value for integration. We can conclude that insourcing can be a flexible measure to minimize the impacts of demand uncertainty in a certain moment and under a defined critical demand level. When we consider the impact of demand shocks we conclude that the existence of shocks intensify the demand evolution (we have assumed that demand follows a geometric Brownian motion) and the critical demand to support the change is anticipated, which results in lower integration value. The full integration results in higher integration value because it is possible to use more available internal capacity. Partial integration does not allow such a fast recovery on the investment value to support the capacity investments.

A.3. ADDITIONAL REMARKS

An optimal profit approach has been modelled, where different regimes were incorporated, considering both full and partial insourcing. We exposed the potential value between two alternatives using the optimal moment for the decision. Our model relies on two key assumptions. First, we assume that demand conforms to geometric Brownian motion, which implies that when the demand process hits zero, it stays at zero (e.g. the firm can goes out of business). Second, we assume an infinite horizon and stable parameter values over time. Investigating the sequential change from one strategy to another by using different trigger moments, linked with demand evolution, are worthy topics for future research.

ESSAY VIII: FLEXIBLE BUSINESS PLANS IN DYNAMIC MARKETS: A STRATEGIC APPROACH

ABSTRACT

Management flexibility has become a relevant issue as the market uncertainty increases. Any plan should address this uncertainty in a dynamic market, within limited budget boundaries; therefore, the purpose of this study is the development of a predictive model to provide insights to business planning, valuing the extent a plan can endure a set of likely evolutionary changes. We assume that the main target of a business plan is to guide the market profitability using additional investments. We will focus our attention on market changes and their impact on the project budget. We derived our model from the real options methodology: the analogy, the assumptions, formulation and interpretations. Our main results and conclusions rely on the differences in the decision evaluation for each milestone, also as on the potential value from the adaptation of project budgets. The managerial problem for which we address our investigation is the fact that a business plan is going to be executed in a working environment that is dynamic. The paper enables to quantify the impact of uncertainty in business plans evaluation, complementing the traditionally management tools based on a payback analysis.

Keywords: business plan, uncertainty, flexibility, milestones.

1. INTRODUCTION

Business plan evolution is a process that aims changes in the market and additional value to a company. The value comes from the flexibility of the business plan in leading with the market change, for example, upon changes in marketing investments. Flexibility into the business plan will make it more adaptable than the original fixed version. The more flexibility in responding to future market changes, the more successful the business plan evolution is likely to be. The added value is attributed to the flexibility and the alternatives created over the evolutionary milestones of the plan. The flexibility takes the form of adaptive project budget through enduring rapid changes in marketing features, to improve the competitive position of the company.

Specifically, flexibility adds value to business plan in the form of alternatives that give the right, but not the obligation, to evolve project costs and enhance the opportunities for strategic growth. In a business plan, market behaviour changes are a major source of uncertainty that confronts the plan during its lifetime (duration between the first approach and the final milestone). We contribute to a predictive approach in business plans evaluation. We examine critical likely changes in the market and value the extent to which the business plan is flexible in enduring these changes, by adapting the project budget. We look at investment in a business plan as an initial investment plus future investments in marketing effort. For a likely change in marketing investments, the model values the flexibility of the business plan to accommodate the change.

Briefly, the approach considers the business plan as a way to think about strategic investment decisions, guided by the evolution of the market and potential opportunities. The model intends to answer the following key question: how much worth is buying flexibility to support the business plan potential growth, by managing project budget?

The managerial problem, for which we address our investigation, relies on the fact that a business plan is going to be executed in a dynamic and stochastic working environment. Specifically, for the application of the concept, we will present an example about marketing investments management.

2. LITERATURE REVIEW

According to Miles and Snow (1978), the link between the environment uncertainty (see also Dess and Beard, 1984), at each moment, and the business strategy can influence performance (e.g. Robinson, 1982; Robinson, Logan and Salem, 1986; Rue and Ibrahim, 1998; Sexton and Van Auken, 1985). Under uncertainty pressure, companies tend to react and adapt themselves by using risk management tools (e.g. Gardner et al., 2000; Paine and Anderson, 1977; Simerly and Li, 2000) or by sense-making activities (e.g. Ashmos and Nathan, 2002).

It is important to note that traditional plans can be actively misleading, as they are based on past environments (Loasby, 2000) and in assumptions. Firms must react by anticipating actions when fixed models are no longer a relevant guide to the required decisions (Davenport, 2009).

As competitive markets are more turbulent with increasing changes, managers should embrace a more dynamic learning process to adapt their plans in each moment (e.g. Clark and Gottfredson, 2009). We will consider these moments as the business plan milestones. The strategy to wait can be a barrier to evolution, for example, by not adjusting marketing costs in markets with a growth dynamics. In actual context, instead of planning their strategies in advance (Friedel and Liedtka, 2007), managers should be able to evaluate and react to new situations, by adapting the business plans. Environmental understanding is a necessary prelude to any strategy formulation, in order to enable the firm to know the unpredicted factors that can influence changes (Yasemin, Mahoney and Watson, 2008; Wilson, 1999), to assure or improve the established goals. Various definitions of environmental scanning have been proposed, for example by Morgan and Hunt (2002).

For minimizing uncertainty, firms tend to use the scenarios' planning, based on the awareness of possible results (Morgan and Hunt, 2002). Other studies (e.g. Godet and Roubelat, 1996; Schwartz, 1991; Beck, 1982; McNulty, 1977) contributed with several definitions of scenarios' planning. For example, Schoemaker (1993) suggests that scenarios provide a conceptual framework to understand the external environment. This notion is also supported by Verity (2003) for whom the benefit of scenarios' planning is the understanding of the variables states that may influence the possible uncertainties within the external environment. For Wright and Goodwin (1999), past events based scenarios can anticipate how the future will unfold. The results from past events can be seen as new information that impacts in the decision process, which in turn can lead to early contingency action facing an unfavourable future, or grasping any potential business opportunity. Despite the exposed works, Becker and Doorn (1987) presented some doubts on scenarios' planning, suggesting that is difficult to communicate the results because of the complexity of the assumptions and the required techniques to evaluate their effectiveness, also defended by Verity (2003), suggesting that scenario planning is not widely used because the methodologies are difficult to understand. For Ralston and Sampaio (2007), scenarios' planning treats the major uncertainties as a set of assumptions based on past trends, which, according to Goodwin and Wright (2001), in an uncertain environment, are unlikely to produce reliable plans. Scenarios techniques have been available as a strategic tool for thirty years, but have failed to become widely used by business managers. The technique is very flexible and this enhances the confusion about the methodology, the purpose it serves and the addressed business questions. We will refer to one of the most important part of a business plan, the capacity to revise it, using milestones.

Milestones in a business plan can be seen as decision points about the continuity of a project, eliminating ambiguities and information gaps (e.g. Bell, 2000; Sahlmann, 1994). Scenarios' planning allow speculation rather than a single plan (Hamel and Prahalad, 1994). For Fikes, Hart and Nilsson (1972), managers must be able to adapt their plans during execution, meaning the capacity of developing flexible plans. For Ambros-Igerson and Steel (1988) and Olawsky and Gini (1990), a relevant part of any plan is the execution, meaning the capacity to act and take decisions as the plan is running and new information arrives (see also Weiss, 2000). As new information is available, managers should be able to adjust the alternatives (e.g. Lovejoy, 1991). For Courtney (2003), the uncertainty can have different levels of influence in a scenarios' planning, for the worst case, a range of possible situations cannot be identified and so, flexibility in managing plans is of prior importance.

Our work differs from previous ones as we introduce the demand uncertainty effect and we value different alternatives of following a business plan, considering its milestones.

3. METHODOLOGIES

A call option gives the right to acquire an asset of uncertain future value for the exercise price. Accommodating a change in a plan is analogous to buying a business plan potential (an option on an asset) with uncertain future value, paying for that an exercise price. The exercise price corresponds to the additional investment costs. The value of the call option, is a measure of the business plan flexibility in unlocking potential future opportunities, enhancing the value of the business plan, by promoting positive alternatives or avoiding losses (in case of a disruptive changes).

We assume that the first goal of a business plan is to guide the investments. The changes could be considered as a major source of uncertainty that derive the investments. The uncertainty might be due to changes in customers' preferences, expectations or new market demands. The differences between our model, financial options and real options on projects are presented in table 1.

For a simple exposition, we will refer to marketing plans. We assume that the business plan potential for a given market is V . As the market evolves, a change in future marketing requirements i is assumed to buy x_i of the business plan potential, with a follow-up investment cost of C_i , where C_i corresponds to an estimate of the likely cost in marketing to answer the change in requirements and C_0 is the initial marketing costs. This is similar to a call option to buy x_i of the base project, paying C_i as exercise price. In this form, the investment opportunity in the market can be viewed as an upfront investment, denoted by V , plus options on future opportunities, where a future opportunity is the investment to accommodate future marketing requirement(s).

The payoff of the constructed options gives an indication of how valuable the flexibility of a business plan is to endure likely changes in marketing requirements. We assume that the interest rate is equal to zero for the simplicity of exposition. The value of a business plan (BP), which accounts for V , considering δ milestones and both the expected value and exercise cost of accommodating likely changes in marketing requirements $i's$, for $i \le n$, can be written as:

$$BP = E\left[\max\left(V - C_0, 0\right)\right] + \left(\sum_{i=1}^{n} E\left[\max\left(x_i.V - C_i, 0\right)\right]\right) \qquad (1)$$

Where, $x_i.V$ corresponds to the value of the business plan potential in accommodating changes. In this context, we consider the business plan as a portfolio of alternatives. More specifically, we view the business plan as a portfolio of marketing requirements. We argue that the value of the business plan corresponds to the value of the marketing requirements it supports, or tend to support, during its milestones development. The nature of the marketing change determines the dimension of the business plan potential; C_i is the exercise price and corresponds to the marketing investment in realizing the mentioned change, and σ is the volatility, which corresponds to the fluctuation of the business plan potential value.

For a likely change in milestone δ, if $x_i.V : E[\max(x_i.V - C_i, 0)] \geq 0$, then the flexibility of the business plan relative to the marketing change is likely to payoff, if the change is exercised. This means that the business plan is said to be potentially growing with respect to change i. In real situations, the shareholder is interested in selecting a business plan that maximizes the yield in options relative to some likely marketing changes. An option selection could be done when the value approaches the maximum, indicating an optimal payoff in investment flexibility. The opposite, if $x_i.V$: $E[\max(x_i.V - C_i, 0)] < 0$, then the business plan flexibility in response to marketing changes is not likely to add value, which can happen when the business plan is flexible but managers don't use it, or the business plan is inflexible relative to the change. In this case, the cost of accommodating the change is much more than the cumulative expected value of the business plan.

Having set the flexibility of the business plan, in responding to likely changes in marketing requirements, as an optimisation problem, the challenge is how to value such flexibility. We build a simple and intuitive analogy with Black and Scholes model to value the business plan flexibility. We formulate the business plan dynamic model. The application of Black and Scholes offers a closed and easy form to compute solution, for it we assume that $x_i.V$ is lognormaly distributed.

$$CALL = E[\max(x_i V - C_i)] \tag{2}$$

The expected value of a European call option is given by $E[\max(x_i V - C_i)]$, where E Denotes the expected value of a European call option, $x_i V$ denotes the stock price at maturity and C_i is the exercise price. In a risk-neutral world, $\ln(x_i V)$ has the following probability distribution given by,

$$\ln(x_i V) \sim \varphi\left[\ln(x_i V) + \left(r - \frac{\sigma^2}{2}\right).(T - t), \sigma\sqrt{(T - t)}\right] \tag{3}$$

Where σ stands for the volatility, r is the risk free rate, $T-t$ accounts for the number of milestones in the business plan period (time to maturity), and $\varphi[m,s]$ denotes a normal distribution with mean m, and standard deviation s. The Black and Scholes valuation of a European call option is represented by:

$$N.d_1.x_iV - N.d_2.C_ie^{-r.(T-t)} \tag{4}$$

Where,

$$\begin{cases} d_1 = \dfrac{\ln\left(\dfrac{x_iV}{C_i}\right) + \left(r + \dfrac{\sigma^2}{2}\right).(T-t)}{\sigma\sqrt{(T-t)}} \\ d_2 = d_1 - \sigma\sqrt{(T-t)} \end{cases}$$

and $N(.)$ is the cumulative distribution function of the standard normal distribution.

4. PROBLEM IDENTIFICATION

The company uses a rolling plan philosophy to follow-up the business. The rolling perspective is detailed on table 2. According the management policy, revisions are done three times a year in an adding basis. For each revision (milestone) there is a market follow-up, considering previous targets, and a profit and loss control, including the marketing costs. This philosophy has started in the 90's, but in 2009 under the pressure of the economic crisis and the need to deploy a strict costs control, company decided to suspend the concept and return to a single annual budget period. After one year, the management team faced the need to increase the annual plan review for two periods. Facing different perspectives, one question raised: why the change in the concept and in the review periods?

5. NUMERICAL ILLUSTRATION

To support our analysis and the main conclusions, we will use a numerical illustration based on an existing industrial company. The company we use has significantly experience in working with business plans for strategic decisions, concerning market and product penetration. The input values are referred in auxiliary table 3.

6. RESULTS

Milestones	σ = 5%	σ = 10%	σ = 20%	σ = 30%	σ = 40%
	Inflexible Plan				
No changes	142	178	235	278	310
	Flexible Plan (single changes)				
Milestone 1	182	218	276	319	350
Milestone 2	171	207	265	308	339
Milestone 3	158	194	252	295	326
	Flexible Plan (multi-changes)				
Milestones 1,2	212	248	306	348	380
Milestones 2,3	188	224	281	324	356
Milestones 1,2,3	229	265	322	365	396

Table 1: Scenarios for marketing costs changes and business plan values (10^2 euros), for different uncertainty levels

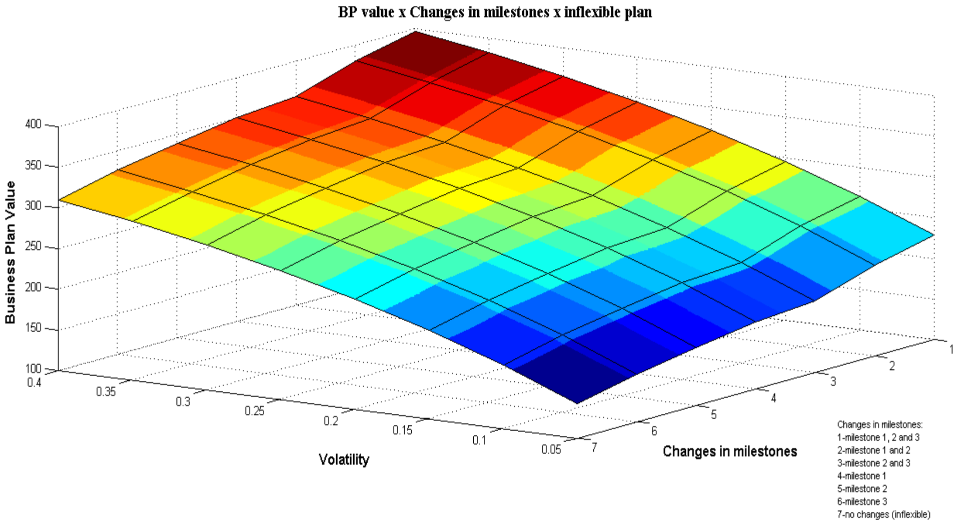

Figure 1: Business plan value, considering different changes in milestones – a global overview

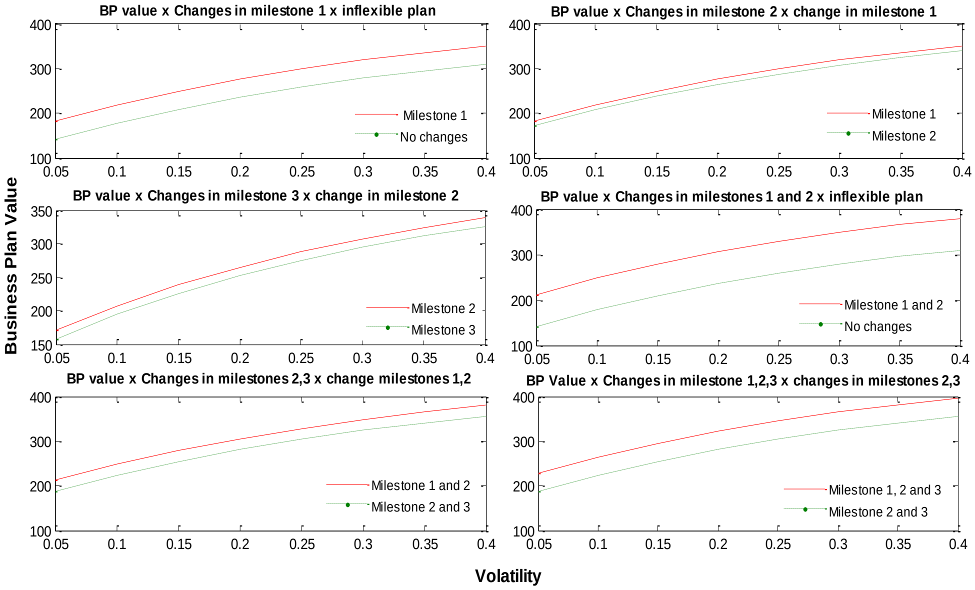

Figure 2: Business plan value, considering different changes in milestones

We simulated results considering different scenarios for changes and one with no changes (inflexible business plan). Table 1, figure 1 and figure 2, show that the early revisions can improve the potential value of a business plan: revision in milestone 1 is better than in milestone 2 and 3: as the time for the implementation is higher The number of milestones and the time between them can also improve the business plan value, considering the possible changes in consequence of marketing requirements. We can also conclude that more changes in different milestones account for a higher business plan value. We can illustrate that the business plan potential value increases under high uncertainty levels.

7. CONCLUSIONS

The results show how the uncertainty, attributed to the likelihood of the change, makes real options' theory superior to other valuation techniques, which fall short in dealing with the value of business plan flexibility under uncertainty.

The major idea of this work is that the flexibility of a business plan, to endure changes in considering the market environment has a value. More specifically, flexibility adds value to the business plan in the form of alternatives, which give the right but not the obligation to evolve the business plan and enhance the opportunities for growth, by making additional investments in marketing costs. As flexibility has value under uncertainty, the value of these options lies in the enhanced flexibility to cope with uncertainty (the evolutionary changes). We support our reasoning by comparing our approach with financial and real options assumptions.

The concept provides managers with the reasoning about the potential value of a business plan, considering different milestones, where alternative decisions can be taken, implying changes in the marketing costs allocation. The results of the model may contribute to strategic analyses, informing about the value of designing a flexible business plan.

8. LIMITATIONS AND FUTURE RESEARCH

The main assumption behind the model is that the business plan is used only to guide investments, delimiting the resources release according to market evolutions. This could raise the question about the evaluation of risk when the larger investments effort needs to be done in the earlier stages of the project evaluation. This question does not limit the applicability of the model, unless we consider an extreme situation where all the investment is done immediately in the first stage; according to our model if such a situation happens, there is no plan flexibility and the problem is limited to an investment evaluation in a single moment, for which several solutions in the literature are available. Another assumption is that business plan is considered a portfolio of requirements (applied to the problem under analysis: marketing, logistic, production, etc), those expected changes support the potential value of the plan. This opens a new research perspective to explore the impacts when the requirements are dependent on a variable evolution or parameters constraints; like transportation costs, selling price evolution or changes in the availability of resources between milestones.

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APPENDIX

Financial	Real options	Business plan dynamic
Stock Price	Value of the expected cash flows	Value of the likely change
Exercise Price	Investment cost	Estimate of the likely cost to accommodate the change
Time-to-expiration	Time until opportunity disappears	Time-to-release the investments, depending on the number of milestones
Volatility	Uncertainty of the project value	"Fluctuation" in the business plan potential value over a specified period of time
Risk-free interest rate	Risk-free interest rate	Interest rate relative to budget

Auxiliary table 1: Comparison between financial, real options and business plan dynamic

Business plan period (year bases)	September – December (year n)	January-April (year n+1)	May-August (year n+1)	September-December (year n+1)
Presentation	x			
Revision 1		x		
Revision 2			x	
Revision 3				x
Revision 1, 2	x	x	x	
Revision 2,3	x		x	x
Revision 1,2,3	x	x	x	x

Auxiliary table 2: Business plan framework

Variables	Input values
V	400x10^2 €
δ	Moment 0 ($\delta = 0$), milestone 1($\delta = 1$), milestone 2($\delta = 2$) and milestone 3($\delta = 3$)
C	C_0 = 300x10^2 €; C_1 = 100x10^2 €; C_2 = 80x10^2 €; C_3 = 50x10^2 €
x	x_1 = 133.(3)x10^2 €; x_2 = 106.(6)x10^2 €; x_3 = 66.(6)x10^2 €
i	No change ($i = 0$), change in milestone 3 ($i = 1$), change in milestone 2 ($i = 2$), change in milestones 2 and 3 ($i = 3$), change in milestone 1 ($i = 4$), change in milestone 1 and 3 ($i = 5$), change in milestone 1 and 2 ($i = 6$), change in milestone 1, 2 and 3 ($i = 7$), change in initial value ($i = 8$).
r	3%
σ	30%
$T - t$	3 milestones; T = 3; t = 0

Auxiliary table 3: Input data

Options	**Description**	$t = 0$	$\delta = 1$	$\delta = 2$	$\delta = 3$
$i = 0$	No changes	S0	S0	S0	S0
$i = 1$	Revision in the 3rd milestone	S0	S0	S0	S3
$i = 2$	Revision in the 2nd milestone	S0	S0	S2	S2
$i = 3$	Revisions in the 2nd and 3rd milestones	S0	S0	S2	S3
$i = 4$	Revision in the 1st milestone	S0	S1	S1	S1
$i = 5$	Revisions in the 1st and 3rd milestones	S0	S1	S1	S3
$i = 6$	Revisions in the 1st and 2nd milestones	S0	S1	S2	S2
$i = 7$	Revisions in the 1st, 2nd and 3rd milestones	S0	S1	S2	S3
$i = 8$	Revision in the initial moment	S4	S4	S4	S4

Auxiliary table 4: Options Framework

GENERAL CONCLUSIONS, FINDINGS, CONTRIBUTIONS, LIMITATIONS AND FUTURE RESEARCH

1. GENERAL CONCLUSIONS

Exploring supply chains flexibility under uncertainty environments in order to enhance performance was the starting idea of this thesis; hereafter we have addressed different problems in the context of the main issue, pointing methodologies, models, and supporting the main findings on numerical applications. The actual markets' dynamic have brought challenges but also opportunities that should be valued. We have acknowledged supply chain flexibility considering demand volume uncertainty, lead-time, service level, capital and labour costs irreversibility, items diversity and customisation, products life cycle, technology feasibilities, capacity increase, decisions timeframe and release of resources in dynamic plans, which were addressed through a set of reported essays.

This thesis has provided an evaluation framework of decisions affecting supply chain flexibility in dynamic business environments. It has shown that we can use real options to hedge supply chains from risk exposure, like overstocking in a single or in multi-echelons; capacity investment options, considering demand uncertainty and future potential value from flexibility in dealing with product mix diversity; workforce decisions under demand uncertainty; insourcing and outsourcing possible options, considering profits maximization. Furthermore, it has shown that using plans flexibility – that is, the use of milestones where options can be exercised, affecting the course of actions – can be advantageous. All these findings are shown to be valid when the market demand is dynamic and companies persecute high levels of performance.

Supply chains should have one or more performance measures on the three dimensions: service, assets, and speed. Concerning metrics, new indicators have been proposed: the overstock level, the uncertainty penetration (endogenous effect), the multi-echelon overstock value, the investment acquisition value, the service level improvement investing and deferred value, the integration value and the business plan flexibility. These distinct metrics enable to value flexibility and hedge the supply chain against uncertainty demand. Overall, such principles can be applied for different supply chain configurations.

The contribution of this thesis is to enlarge the framework of supply chain flexibility measures in uncertainty environments, enhancing the use of real options reasoning. Our focus was on researches that could be used by managers in real businesses environments, and for that we opted to develop essays to explore, define, model and analyse problems from general business applications. The environment of extreme volatility in which companies operate leads to solutions that enhance future options, promoting the managers capacity to decide under different alternatives. Besides the progress we have given in the application of the real options methodology, promoting essays on supply chain flexibility measurement in uncertainty environments, the disclosure of these methodologies, models and results, leveraged its acceptance for scientific publications and use in the current business management practises.

The purposes, methods and results, for each of the essays presented in this thesis will be summarized in the following section and in table 1.

2. SUMMARY OF THE ESSAYS

In essay II we introduced two novelties regarding flexible inventory management. First was the introduction of new items' classifications, covering the items' sales performance and their life cycle evolution; second was the introduction of the overstock concept, as an optimal stock excess, applied in this first approach to a single supply chain inventory stage. Our main results support that the stock value is related with demand volatility, also as the lead time, service level definitions and the product life cycle, based on the consideration of the obsolescence factor. This new indicator can help managers promoting and valuing flexible answers to the customer requirements and uncertain demand. From this essay arose an open research question from the intended supply chain integration, prompting new developments on the links between different echelons? Bearing in mind the static, single stage approach and the consideration of available capacity, the study has some limitations that the following essays will minimize.

The contribution of essay III addresses the previous open research questions in two ways, firstly, by extending the single echelon model to a multi-echelon approach; secondly, by introducing a new dynamic indicator as a target corrective factor, minimizing the gap between realistic targets and performance evaluation. In real terms, overstock can be used in the performance evaluation, helping the target setting process. We tested the inclusion of non-optimal targets in different stages and we found that a non-optimal value provokes a higher impact when exercised in the upstream stages of the chain. We also simulated the impact of the stages position in the chain and we found that the downstream stages are the most affected by the uncertainty impact. This essay recommends a global target alignment for the different stages of a supply chain, stating that the dynamic interaction between different responsibilities in the chain does not allow an unbundled target setting process.

Considering essay II and the results of essay III, we have an additional limitation regarding the dynamic of supply chain nodes interaction and different supply chain designs. In the essay IV, we adapted the model to incorporate dynamic in the multi-echelon approach. In real terms, the design and the dynamic link between echelons can influence the uncertainty influence all over the chain. The results indicate the relevant parameters that a company can influence in order to minimize the effects of demand uncertainty, such as the internal lead time and service level or the cost function regarding the use of resources. Multi-echelon overstock approach is not only useful to understand and minimize the external market uncertainty penetration but also to minimize internal risk exposure, considering the critical lead-times and service levels, also as the actual problem regarding the increase in products customisation, which implies an adjustment in the inventory distribution along the chain.

The assumption of available capacity that supported the first models was a simplification and an appendix has been added to support the generalization of the findings. In fact, companies cannot fulfil the required overstock in the presence of limited resources that could disturb the performance of echelons regarding service level and output yield.

In essay V and VI we account for an additional supply chain topic regarding flexible capacity. The available capacity has two components, the equipment and the workforce, and is influenced by the availability of the resources, the demand volume, the size and periodicity of the customer requests, but also by the complexity of the product mix. In fact, a large product mix can be a very relevant competitive advantage for a company. We want to stress that a company with a flexible product mix has more value to those customers that ask for customisations. Nevertheless the consensus on the reasoning is that investment evaluations are still stuck to the traditional discounted cash flow technique, with the normal parameters of investment cost, the output equipment capacity and the consequent expected returns.

In the essay V we developed an indicator - flexible investment acquisition value - for investments evaluation, persecuting flexibility under uncertainty demand and limited budgets. For this purpose, flexibility is the ability to produce economically, different ranges of products under unpredictable demand volumes. The results point to an important link between product mix strategies (standard versus customized mix), the features of the equipment under analysis, considering quick and easy (economic) set-ups, and the expenditure ceiling that the buyer defines. Thus, companies can reinforce their presence and flexibility in the market by acquiring additional capacity aligned with a product mix strategy.

The other topic related with capacity is the workforce management. Why this issue? If we are developing a stochastic approach for demand behaviour, this idea makes no big improvement considering a normal investment analysis, but there is a major differentiation in the essay we present. The flexibility is not only to support demand variations but mainly to endure service level improvements, as the companies persecute high levels of performance.

In essay VI we conducted an analysis on the reinforcement of work shifts. We addressed the major parameters that influence the labour, like workforce skills, overtime, temporary work, training costs, labour costs and legal constraints regarding dismissing penalties. The decision is about the moment for a shift expansion under a different service level performance (decision to increase the service level target), for which an investment (decision to hire additional workers) will be required. To put our model to reality, we considered two possible decisions regarding workforce composition: regular and temporary workers. We refer to a single shift composition within actual conditions of efficiency, process and technology. For a long term approach, we could additionally count with improvements in the number of workers or required skills per shift, due to labour efficiency (options), process integration (options) and technology upgrades (options). Free labour capacity could endure cross training among other workstations. This simulation is referred in the results of the experiment. We used a realistic model applied to the situation under analysis, considering mean reverting with jumps. Nevertheless we support the application of the model for different businesses. Commodities (mainly mass retail in our example) are generally better modelled by a stochastic reversion process to a long-term average rather than a geometric Brownian motion, although the latter is most often used in evaluating real options due to the facility of use. However, modelling a geometric Brownian motion may result in excessively high values when this is not the most realistic approximation of certain diffusion processes. The study resulted in an additional flexibility measure, which is the service level improvement value. The results support the flexibility value improvement with the reduction in the gap between actual service level and the customer requested service level. Moreover, the results about the use of temporary work show an increase in flexibility, the same holds true for any improvement in the number of workers or required skills. A final note must be done about the importance of the labour legal constraints that can affect the flexibility value: less protective laws reduce the adjustment costs. We did not include in this essay other constraints, affecting the timeframe between decision and the operative date, like the required time for preparing the change, which may be relevant to skilled labour.

Still in the theme of capacity, with the concern of the open questions, we have presented essay VII. In this essay we exploited the difference between a traditional flexibility option, which is the outsourcing, and the integration of operations. The integration requires investments to provide own capacity. The research problem is related with the value of an integration decision compared with an outsourcing alternative and the critical moment to proceed, subject to a preparation stage. We present the integration option indicator. The results show the importance of the preparation period in the flexibility value. A shorter preparation step implies faster changes, which means more flexibility. The examples we presented are based on unique investments, we didn't explore the influence of sequential investments in the flexibility value. This concern justifies the final essay that raises the question about partial release of investment costs.

We present the problematic using a real option application on the evaluation of business plans. The methodology we present can be extended to other areas and in particular, within the supply chain concept. In the last essay the results show that a large number of decision points – milestones – will increase the flexibility value. This conclusion reiterates the importance of enhancing flexibility, leveraging the arrival of new information while investment follows.

Management issue	**Flexibility metrics proposed**	**Scope**	**Main findings**	**Open research questions**	**Essay**
Flexible inventory management	Overstock	Static, single supply chain stage	stock value is related with demand volatility. The lead time, service level definitions and the product life cycle influence the stock level.	Explore different supply chain stages.	II
Integrated, multi-stage, flexible inventory management	Endogenous effect of the demand uncertainty	Target setting	Non-optimal targets have a bigger impact when defined in upstream stages. The uncertainty penetration effect is influenced by the downstream overstock targets. Downstream stages are the most affected by the uncertainty penetration.	Explore the dynamic between different supply chain stages. Explore the overstock sequence.	III
	Multi-Stage overstock	Integrated inventory management	Internal lead-time and service level can influence the overstock value. The overstock must be defined from downstream to upstream stages in a sequential approach.	Explore the problem of limited capacity to replenish the overstock	IV
Flexible investments, considering product offer strategy	Flexible investment acquisition value	Investments decisions, considering the product offer.	The product offer design can influence the equipment choice.	Preparation period and sequential investments.	V
Workforce capacity	Service level improvement-investing value Service level improvement-deferred value	Timeframe for Shifts reiforcement, considering service level target	The gap between actual and required service level influences the shifts decision. Legal constrains on workforce influences the decision. The use of temporary work increases the flexibility value. The work station required number of employees and skils inf	Preparation period.	VI
Integration versus outsourcing decisions	Integration option	Timeframe for strategy change from outsourcing to integration.	A shorter preparation step means more flexibility. Integrating activities can be an alternative to outsourcing.	Sequential investments	VII
Flexible business plans	Business plan value	Milestones decomposition of a plan	The number of milestones affect the business plan value	Extend the concept to other applications	VIII

Table 1: Supply chain flexibility framework

3. MAIN FINDINGS AND CONTRIBUTIONS

Our findings can be summarized as follows. The use of different products' classifications allow a better understanding about the risk of the stocks; the use of product life evolution and sales performance, are important inputs for a new classification that appears to be both logic, useful and as far as we explored the literature we didn't find such any approach. The overstock concept, which represents an excess of stock value to hedge against future uncertainties in demand, and it is dependent on the uncertainty level evolution. The results showed that sales uncertainty has a positive impact on overstock (inventory) indicating that firms facing high demand uncertainty build up overstocks to avoid stock-outs. However, we also noted that the overstock build-up declines as firms are more flexible regarding lead time, service level or capacity. The sequential approach to overstock decisions allow to have a better understanding, also as to value the influence of the demand uncertainty in the supply chain echelons, mainly in the upstream ones, where the uncertainty tends to have an intensified effect. On top of the uncertainty effect there can be also an information distortion among the decision makers (similar to a bullwhip effect). Also the lack of coordination causing the existence of non-optimal overstock values influences the global overstock value. Investments in capacity increase, due to volume or mix (innovation or customisation) are influenced by future expected profits that depend on demand uncertainty evolution also on the product mix strategy aiming the customers' evolution. We found a relevant link between manufacturing flexibility and uncertainty but also with the product mix strategy. We explored the influence of partnerships between manufactures and their clients when they agree to share the risk of customisation using a premium selling price. Workforce adjustments have been explored in the relation with market demand evolution or at a strategic level in relation to capacity expansions or automation projects. The findings support the influence of demand uncertainty on the decision regarding shifts expansion. However, we introduced a new approach to allow the inclusion of the service level impact; we value not the historical service level, but the improvement on the current service level by setting challenging targets. We also found that integrating activities, despite the fixed visible costs due to the potential required capacity extensions, can also embed flexibility value, in opposition to an outsourcing current situation. This approach can be extended to support non quantified decisions that, because of strategic and market concerns withdraw any outsourcing alternative. Finally we found that companies using rolling approaches in their plans are more flexible than the ones with fixed and limited milestones. The extreme situation goes to the companies that guide their activities using a fixed annual budgeting period. Our findings are in line with management reasoning that tends to split the resources allocation to minimize the potential risk.

Generally, the findings imply that firms that are not constrained to adapt their stock, to adjust their capacity or change their network, tend to respond faster to demand shocks. The reason is that a less constrained firm has the means to purchase an extra unit of flexibility: overstock, equipment flexibility, hire labour quickly or outsource production over the business cycle. The business cycle monitoring can also contribute to the value of a company. Companies less constrained in the number of revisions of their plans or projects are more flexible to adapt to changes regarding the available options.

4. A BRIEF ON LIMITATIONS AND FUTURE DEVELOPMENTS

In relation to what has been proposed in this thesis, some aspects could be studied in further detail or even expanded. The results underlie that in addition to firm level flexibility factors, integration and common assets are significantly associated with the valuation of the supply chain flexibility. We offer methods for capturing and valuing the flexibility on a company or supply chain perspective by the inclusion of multi-stages. However, we recognise the importance of improve the supply chain flexibility framework with the links between different companies that are part of the same supply chain, mainly reinforcing the importance of integration and coordination mechanisms. This theme was discussed in detail; nevertheless, it should be explored as an additional performance indicator to enhance supply chain flexibility value. As so, we propose a future research topic on supply chain performance about measuring the flexibility value of all the firms which combine to make the chain, considering an integration factor. On the opposite it would also be of interest to examine the significance of the supply chain position on the firm flexibility value (e.g. supply chain partnerships, information flow), for example, is it more valuable to be a producer or a distributor in a particular supply network? Future research in this area could also include multi-planning period problems. The extension of this concept to allow more than one planning period is likely to be both practical and challenging. In practice, information about actual and potential demand is updated every planning period. New information arriving about demand is often relevant to justify the addition of other planning periods to the model in a time-frame approach. The demand representation has been expanded considering different processes, but it can be highly explored on the basis of the novel products' classification that has been proposed, using correlation factors between products' groups, convening different business realities.

The mechanisms analysed could thus be applied to many other settings regarding supply chain flexibility, for instance, considering uncertainty in the resources that are provided, and many other situations to cover the increasing number of uncertainty sources that are affecting the supply chains and the requirements for plans and projects evaluation. The decision methodology we propose have also a relevant impact from a strategic point of view, mainly because of knowledge and integrated management practices, but also to build a timeframe to support sequential decisions in a dynamic market, considering preparation periods that, in most of the cases, dictate the success of the strategic or operational business initiatives.