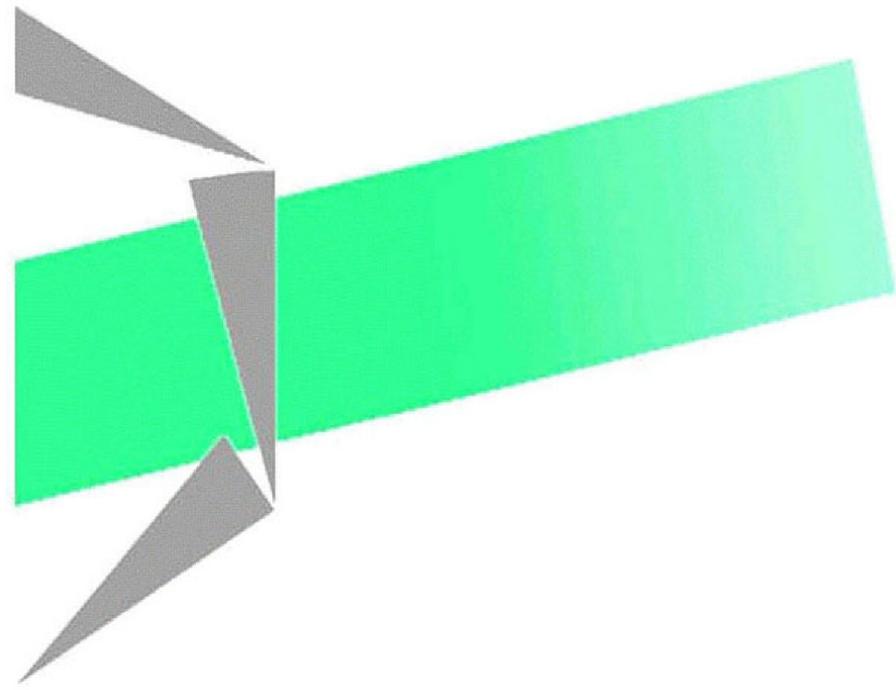


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Reconciling sales and operations management with distant suppliers in the automotive industry: a simulation approach

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Abstract

A challenge for car manufacturers is to adjust rapidly and efficiently the production capacities with a volatile market demand and despite distant suppliers. In this paper, we consider a sales and operations planning problem based on the actual situation of Renault, a French global automobile manufacturer. The issue is to find the best trade-off between sales requirements and industrial constraints while limiting inventories, emergency supplies and keeping delivery lead times reasonable for customers. A new planning method based on flexibility rates is presented. The flexibility rates are defined to limit orders of a given type of vehicles, during a certain period. A simulation model is introduced and captures the dynamics of the sales and operations management. A numerical study has been performed by using industrial data. Results highlight factors that improve system performances and several policies are compared. This research has also relevance for other industries that face long procurement lead times in an uncertain environment.

Keywords

Automotive industry ; sales and operations planning ; simulation ; flexibility ; long procurement ; uncertain demand ; customer impatience

1 Introduction

For a long time, the automotive industry has been facing a volatile and changing market demand (Elkins et al., 2004; Childerhouse et al., 2008). Forecasting becomes more and more difficult because of, amongst others, the cyclic environment and the increasing competition between car manufacturers. Moreover, customers ask for more individualized vehicles. If the product variety provides a competitive advantage for automakers (Ramdas, 2003; Aoki et al., 2013), it also complicates forecasting and supply chain management for vehicle subparts (e.g. engine types, options and equipment...). To deal with these issues, car manufacturers took up the challenge to shift from mass production to mass customization (Brabazon et al., 2010). Since the nineties, automobile manufacturers have given priority to build-to-order processes to manage their supply chain (Miemczyk and Holweg, 2004). Mass customization and build-to-order production have helped automakers to better synchronize their production with market demand (Volling and Spengler, 2011) and to master the increased exposure to demand variability (Holweg et al., 2005). Implementing build-to-order processes is challenging for many car manufacturers (Alford et al., 2000; da Silveira et al., 2001; MacCarthy et al., 2003; Howard et al., 2005) but it provides great advantages.

A new challenge appears these last years. Indeed, emerging countries and the globalization encourage carmakers to assemble vehicles and to supply parts in distant countries to reduce costs and to gain new markets. Nowadays, procurement lead times have significantly increased and may take more than two months for some vehicle components. Long procurement can also be due to the transportation mode (e.g. sea shipments are slow but cheap and contribute to reduce dioxide emissions) and new production processes (e.g. batteries for electrical vehicles).

With many distant suppliers, build-to-order supply chains begin to show several limitations, especially in the automotive industry with the increasing competition between automakers. Indeed, on one hand, sales dealers are looking for short delivery lead times with the opportunity to order any vehicle as late as possible to satisfy the customers. And on the other hand, vehicle assembly plants need to order many parts several weeks beforehand, based on unreliable forecasts, when the actual demand is unknown.

There are not many options to manage this issue. One may increase vehicle delivery lead times but it is discouraged since sales dealers are facing a very competitive environment and customers would not wait for more than a month (Elias, 2002; Holweg et al., 2005). Encouraging customers to buy from vehicle stocks is possible but has limitations, especially in markets where car buyers prefer individualized vehicles. The other possibility is to increase safety stocks to hedge against demand uncertainty but it may be very costly, especially for heavy and expensive components. Using emergency supplies (e.g. shipping parts by airplanes) may be possible but this is also very costly.

Therefore, a trade-off has to be determined between two opposite requirements: the sales department asks for more flexibility and supply planners ask for less changing demand and more visibility. Coordinating sales and supply chain remains a serious challenge because of numerous differences and conflicts in terms of objectives, responsibilities and management (Hahn et al., 2000).

The automobile manufacturer Renault has launched an exploratory project to improve its sales and operations planning process to manage plants with distant suppliers and that serves mainly build-to-order (and impatient) customers. The aim is to offer more flexibility for sales dealers while limiting logistic costs due to inventory and emergency supplies, and keeping delivery lead times reasonable. To do so, new flexibility rates and safety stock margins have been created and their specificities are described in this paper. Since processes are new, supply chain and sales departments do not know how to set up efficiently these parameters. Managers lack insights about the dynamics between these decision variables and their impact in terms of logistic costs and customer satisfaction.

The research objectives are, first, to provide a relevant quantitative model that captures the dynamics of sales and operations planning of the automobile manufacturer. Based on this model, the second objective is to compare several policies to manage flexibility and stocks, and to give practical recommendations for sales managers and supply planners. We have decided to use a simulation approach because of the complexity of the industrial situation and to obtain initial recommendations which can be easily applied and can fastly provide gains for the company.

This research is motivated by concrete and recent industrial issues: the growing importance of emerging markets for car manufacturers, the increasing number of distant suppliers and the difficulty to match sales requirements with supply chain constraints in a global, uncertain and competitive environment. This research and results we obtained have also relevance for other companies and industries that lack visibility on future demand and want to improve their sales and operations planning.

The contribution of this paper is, first, the detailed description of a new planning model for reconciling sales and operations management with long procurement lead times. We introduce a new planning method with flexibility that can help companies, especially in build-to-order environment, to better coordinate sales and operations to reduce supply chain costs while controlling the customer satisfaction

and sales requirements. Second, we present numerical results based on a simulation model that captures and understands the system dynamics. The simulation model has been used to evaluate quickly and efficiently several policies to manage stocks and inventory. Third, we provide a comparison of several policies and show their performance in terms of costs, lost sales, delayed orders and delivery times. Finally, managerial insights, practical recommendations and further research are discussed. We also present the benefits of this new planning method and how to implement it in build-to-order companies.

The paper is organized as follows. Relevant literature is presented in Section 2. The industrial problem is described in Section 3. Section 4 introduces the simulation model with the assumptions, the notations and the system dynamics. Policies used to manage stock and flexibility are presented in Section 5. Numerical results and managerial insights are detailed in Section 6. Finally, a summary of findings and further research directions are discussed in the concluding section.

2 Literature review

In this section, we present the related research to the problem described in this paper.

2.1 Supply chain globalization

A first general aspect related to our problem is the globalization that increases procurement lead times and makes the supply chain more vulnerable to demand variability. The importance of supply chain internationalization has been discussed in, among others, Levy (1995, 1997). Humphrey (2003) studies the development of automotive industry in emerging countries and highlights the complex sourcing strategies in this new environment. As stated in Tang (2006), globalization makes more vulnerable supply chains to various disruptions (uncertain demand, economic cycles etc.). The author presents several perspectives in supply chain risk management. He shows that for gaining market share and reducing costs, firms favor outsourced manufacturing and offer higher product variety. This is effective in a stable environment but in an uncertain environment, the supply chain management becomes very complex. Prater et al. (2001) argue that, in international supply chains, it is difficult to promptly react to demand because of long procurement times due to sea shipments. Ambe and Badenhorst-Weiss (2010) emphasize that changing business conditions during these last years and the global economic meltdown have increased the pressure on automotive managers to reduce cost and supply chain vulnerability.

2.2 Production planning with uncertainty

The issue of production planning with uncertainty is a rich area of research since this domain is vast and leads to various and numerous models with different assumptions and objectives. An exhaustive literature review on this research area is given in Mula et al. (2006). As the authors show, most of the analytical models address only one type of uncertainty, and assume a simple structure of the production process. For more complex situations, methods based on artificial intelligence and simulation are favored. Graves (2011) discusses how uncertainty is handled in production planning. The author details current practices and suggests possible improvements. The problem we address in this paper is directly linked to the research area of production planning with uncertainty since we consider the production plan of finished goods with uncertain demand and customer impatience. The specific characteristics of planning processes, customer impatience and demand arrivals of our industrial problem are detailed in the rest of the paper.

2.3 Sales and operations planning

The sales and operations planning is the process that links strategic plan to daily operations plans, and balances demand and supply (Grimson and Pyke, 2007). It differs from the pure production planning since it has to take into account the sales objectives and the related constraints. Typically, the planning horizon ranges from six months to over three years but this may vary by industry and product. Generally, sales and operations planning concerns product families rather than finished goods but there are few examples of situations that operate at the stock keeping unit level (de Kok et al., 2005). A large review on sales and operations planning is provided in Grimson and Pyke (2007), who note that little has been published on this topic up to now. They develop a framework for a better integration of the sales and operations planning and they provide recommendations for moving to more mature and advanced processes. More recently, Thomé et al. (2012) provide a comprehensive literature survey on the highly dispersed research about sales and operations planning. The authors highlight its considerable impact on firm performance and show that this topic has a growing interest since the last decade.

Olhager et al. (2001) discuss about the links between manufacturing strategy and sales and operations planning. The authors present two general strategies: modifying the demand or the supply. In this paper, we detail the processes used in the automobile manufacturer for modifying both demand and supply, and the related planning dynamics. We note that our planning problem can be seen midway between master production schedule and sales and operations planning because of distant sourcing.

Rexhausen et al. (2012) discuss the demand management that aims to balance efficiently customer requirements with capabilities of the supply chain. The authors analyze in depth its impact on the supply chain performance. As stated by the authors, the concept of demand management becomes increasingly popular in industry but lacks extensive analyses in academic literature. The authors argue that conflicts of interest are frequent during the sales and operations planning because of its cross-functional character. And resolving these conflicts is challenging because the involved participants are usually situated on an equal level in the corporate hierarchy. In our research, we propose new processes for the demand management that improve the compromise between customer requirements and supply chain constraints. In that sense, our research based on a quantitative planning model illustrates the general results obtained in Rexhausen et al. (2012) where the authors use a structural equation model.

Olhager (2013) presents how the operations control has shifted over the last fifty years from low level planning (shop floor level) to higher level (sales and operations planning, and more generally supply chain planning), to be able to better satisfy customers and link them to suppliers. If the operations management in automobile manufacturers has broadly followed the trend depicted in Olhager (2013)), there is now a need for more flexibility in the sales and operations planning because of the increasing lead times and the highly volatile market demand.

2.4 Supply chain flexibility and risk management

The concept of supply chain flexibility has been developed to improve firms' performance in uncertain environment. However, flexibility is an abstract word that may cover many similar concepts. Bernardes and Hanna (2009) propose a review on the overlapping terms: flexibility, agility and responsiveness. Sanchez and Perez (2005) deal with a conceptual model to link company performance with supply chain flexibility. They also provide an empirical study that shows the different dimensions of flexibility and their impact on company performance. Reichhart and Holweg (2007) propose a new holistic framework to distinguish different types of responsiveness, a key parameter in supply chain flexibility. They present four types of responsiveness: product, volume, mix and time horizons. In our research, we develop a

new concept of flexibility rates and sales constraints used in sales and operations planning to control the arrival of customer orders.

Stevenson and Spring (2009) provide a comprehensive literature review on supply chain flexibility. They show that this concept has emerged from the manufacturing flexibility but they enlarge it to include a supply chain perspective. Stevenson and Spring (2009) provide an empirical qualitative study of supply chain flexibility and how to increase it. They identify a wide range of supply chain practices and study the inter-organisational aspects. The authors discuss mainly the flexibility management between different firms while in our research, we deal with the internal flexibility by using a better collaboration between sales and supply chain functions.

Christopher and Holweg (2011) explain that the demand volatility and uncertainty are increasing and therefore the supply chain should adapt its structure for more flexibility to fight these turbulences. New supply chain structures are required because these disturbances are very likely to continue in the future. Merschmann and Thonemann (2011) analyze the relationship between environmental uncertainty, supply chain flexibility and firm performance, using structural equation modeling and a survey of German manufacturing companies. They show that highly flexible supply chains are more costly than less flexible supply chains, and companies that can match uncertain environments and high flexibility realize better overall performances.

Our research is also linked to the supply chain risk management (SCRM). Indeed, the SCRM is based on collaboration with relevant information exchanges, and establishment of joint and transverse processes with industrial partners (Lavastre et al., 2012). Tang (2006) defines the SCRM as "the management of supply chain through coordination or collaboration among the supply partners so as to ensure profitability and continuity". However, in this paper we only focus on the internal collaboration between the supply chain and sales functions of the company. We present a model that enables a better collaboration and information exchange between participants that have conflicting objectives, in order to control efficiently logistic costs and to ensure a good customer satisfaction.

Thun and Hoenig (2011) provide an empirical study of SCRM in the German automotive industry. They identify and analyze the likelihood and impact of internal and external supply chain risks. They show that supply chain complexity, product variants and globalization increase the vulnerability of the supply chain, and risk management can improve substantially the firm performances. A comprehensive review on SCRM is given in Tang and Nurmaya Musa (2011). This research area has received a growing attention during the last decade. The authors classify the different major risk issues. Our study is related to the deliver issue, due to demand volatility and the risk to do not satisfy customers. Ghadge et al. (2012) present another literature survey with a holistic approach that provides critical insights on the present and future of the SCRM.

2.5 Multiple sourcing

In our research, two supply modes are considered: a normal replenishment by sea with long lead times and an emergency supply by air which is more costly but faster. Dual sourcing and more generally multiple sourcing have been studied extensively during the last decades. Since our main issue is not about managing this dual sourcing, we do not aim to provide a broad review on multiple sourcing. We only focus on critical and relevant papers for our context. We refer readers to (Minner, 2003) and Thomas and Tyworth (2006) for more detailed literature reviews on multiple supply problems. Although this issue has been mainly treated with time-discrete models, there are few researches that use a continuous-time approach (see e.g. Jain et al., 2010; Song and Zipkin, 2009).

The situation depicted in Tagaras and Vlachos (2001) is close to our problem. The authors study a periodic review inventory system with two replenishment models. Emergency supplies can be used in case of imminent stockouts. The unsatisfied demand is backordered. The authors investigate base-stock policies for the regular replenishment contrary to our problem where a standard materials requirement system is used. They use simulations to determine optimal solutions and compare several heuristics. They show that there are significant gains by using emergency supplies compare to the situation with only regular orders. Their model is extended in Vlachos and Tagaras (2001) by considering a capacity constraint for the emergency mode.

Scheller-Wolf et al. (2007) deal with a single-stage periodic review inventory system with backorders and dual sourcing. They consider a normal replenishment and a more expensive one with a shorter lead time. They introduce a class of policies called single index and study their performance. They also demonstrate when dual sourcing outperforms single sourcing. Veeraraghavan and Scheller-Wolf (2008) propose more sophisticated policies named dual index that performs very well. These policies are then generalized in Sheopuri et al. (2010). We also show in our study the potential benefits of using dual sourcing in some situations but contrary to their models, we consider different policies and lost sales.

Bhatnagar et al. (2011) discuss an issue close to ours: the coordination of aggregate planning decision and short term scheduling in global supply chains with dual sourcing. Like in our problem, the authors consider long procurement by sea transportation based on forecasts and fast procurement by air shipments based on revised forecast closer to the demand period. They investigate the coordination between the planning model that determines sea procurement and inventory, and the scheduling model that determines the short-term schedule and air procurement. Our model is quite different because we consider the coordination between parts procurement and customer orders acceptance by using flexibility limits.

The literature on multiple sourcing mainly focuses on the choice of joint or alternative use of several supplies. Our research differs from these earlier works in the sense that it does not focus on a trade-off between the normal and emergency supplies. The work presented here is mainly on the coordination between customer orders acceptance and normal replenishment. The emergency supplies are used as a last resort to prevent parts shortages. Normal replenishments follow a common MRP process with a specific safety stocks calculation that is detailed later.

2.6 Challenges for the automotive industry

The automotive industry presents several specificities that make complex the production planning in an uncertain environment. Product variety is an important characteristic that prevents reliable forecasts and limits visibility on future demand. Global automakers may have to schedule more than two thousands components per final product, with billions of possible combinations. If product variety is a source of competitive advantage (Ramdas, 2003), it also increases operational costs (Stäblein et al., 2011) and makes forecasts more difficult, especially for very specific vehicle parts. Pil and Holweg (2004) deal with the product variety and present different order fulfillment strategies to handle it. They show how high the product variety is in the automotive industry and how complex it gets to handle. (Scavarda et al., 2010) are interested in the product variety in emerging markets.

In addition to the large variety of end-products, cars manufacturers have to satisfy car buyers, who are more and more demanding, in a highly competitive environment. To deal with this issue, they strive to satisfy customers with their desired vehicle variants in a reasonable delivery time (Aoki et al., 2013). Automakers have redesigned their supply chain with a build-to-order approach to reduce vehicle delivery time despite the product variety and the uncertain demand. Volling and Spengler (2011) present a

simulation model for build-to-order planning policies in the automobile production. They provide a new framework comprising separate interlinked models for order promising and master production scheduling. Holweg and Pil (2004) argue that supply chain must be able to respond to changing demands and the supplier responsiveness plays a key role in the automotive industry. But this may be very challenging for vehicle assembly plants with global sourcing. Holweg and Pil (2004) present a comprehensive study on dysfunctional value-chain strategies and show how car manufacturers are struggling to improve their supply chains to satisfy customer desires efficiently. A better integration of customers to improve supply chain performance is discussed in Tomino et al. (2011).

Because of the cyclic environment, the market demand in the automotive industry is highly variable. Wang et al. (2011) develop a data driven simulation methodology that provides rapid analyses and remodeling capability to respond efficiently to the fluctuation of demands. Childerhouse et al. (2008) study the impact of order volatility in the European automotive industry. The authors show that longer lead times lead to inaccurate sales forecasts and amplify the demand volatility.

The issues about joint sales and operations planning in the automotive industry have received less attention in literature. According to Meyr (2004), the literature is relatively poor in terms of global and comprehensive overviews of the short and mid-term planning of car manufacturers. The authors highlight the complex organizational issues in sales and operations coordination for production planning. As described in Hahn et al. (2000), Hyundai Motor Company has developed new mechanisms to coordinate sales and supply chain. Even if Hyundai management concedes that the process further can be improved, the customer satisfaction has increased with the better integration of sales and supply chain departments. Tomino et al. (2009) have engaged in-depth interviews of several executives from Japanese automobile manufacturers that have improved their production planning by adopting market flexible customizing system. The authors compare planning practices of Toyota, Nissan and Mitsubishi and show how they strive to adapt their production plans to customer demand.

The order fulfillment processes are also investigated to improve sales and operations planning and customer satisfaction. Brabazon and MacCarthy (2004) propose a new system design named virtual-build-to-order that is attractive to mass customizers such as those in the automotive industry. Virtual-build-to-order aims to adapt production with market demand when the manufacturing lead times exceed customers' acceptable waiting times and when holding costs are important. The idea is based on product reconfiguration and a floating decoupling point. The virtual-build-to-order method has been applied to Ford's vehicle order fulfillment process in Brabazon et al. (2007). The authors use a simulation model to evaluate alternative policies and estimate benefits of virtual-build-to-order. Our automobile manufacturer has already developed a similar method to improve its ordering processes but gains are not sufficient, especially for car models with very high variability of demand. Our study presents another system design to improve the supply chain flexibility. We note that virtual-build-to-order and our system design are completely compatibles, and it seems possible to cumulate the benefits of both.

The problem depicted in this paper is original for the following reasons. Based on a real industrial situation, we consider the coordination of sales and supply chain for production planning with long procurement lead times, demand uncertainty, progressive arrival of customer orders, possibility to delay orders with flexibility rates, stochastic customer impatience and the use of emergency supplies in case of inventory shortage. The planning dynamics has also other specificities that are detailed in the rest of the paper. Moreover, our planning problem can be seen as a hybrid situation between sales and operations planning and master production scheduling because of distant sourcing that forces the automobile manufacturer to include strategic and sales objectives into the weekly production planning. To the best of our

knowledge, there is no research to handle all aspects of the industrial problem presented in this paper. The closest study to ours is the one by Amrani-Zouggar et al. (2009, 2010) who present flexibility rates and frozen horizon but applied on a problem of supply chain contracts. Bassok and Anupindi (2008) detail another similar study with flexibility and commitments in supply chain contracts. The differences with our research are that we do not consider a buyer-supplier relation but the coordination between sales and operations. Moreover, there is no commitment from sales department on future demand and our model takes into account the specific ordering dynamics with customer impatience.

3 Problem description

The problem described in this paper is largely based on the actual industrial processes of the French global automobile manufacturer, Renault. This section describes the different stakeholders and the production planning in details. The sales and operations planning of Renault presents many similarities and some differences with other car manufacturers. In this section, we highlight the common aspects and specificities of Renault's production planning compared to other automobile firms based on the study of Tomino et al. (2009) that provides a recent and detailed comparison of production planning of Toyota, Nissan and Mitsubishi.

To gain market share in emerging countries and to reduce production cost, the automobile manufacturer has established vehicle-assembly plants in several countries in North Africa, South America and Eastern Europe. The parts suppliers may be very far from these regions (up to twelve weeks to deliver parts). Sales dealers complain for the very rigid process to order cars assembled in these plants. Indeed, for the first time, because of long procurement lead times, sales dealers are asked to send firm orders nine weeks before assembly without the possibility of making any modifications in the orders, later on. This make-to-stock configuration is problematic because of the very high costs of finished cars inventories and the impatient customers. Face to this new problem, the management decided to launch a research project to improve processes and information systems to offer more flexibility for sales dealers. The different aspects of these new processes are described below.

3.1 General aspects of the problem

Firstly, we describe the general aspects of the problem, which are relatively usual in sales and operations management. The specificities of our model are then presented in the next subsection.

3.1.1 Stakeholders

The sales and operations planning requires the involvement of two business functions: the sales function, which usually focuses on sales volume and customer satisfaction, and the supply chain function, which focuses on operations costs. More precisely in our problem, four main stakeholders are involved in the sales and operations planning. On one hand, the sales dealers and the sales department represent the sales function. On the other hand, the supply chain department and the vehicle-assembly plant represent the supply chain function.

Twice a year, the sales department provides monthly demand forecasts for the next two years. Obviously, these forecasts are not very reliable and are not a commitment for the sales function but this information helps the automobile manufacturer to estimate future investments and the demand trend. This process is similar to the so called "annual production schedule" described in Tomino et al. (2009) for Toyota, Nissan and Mitsubishi. In addition to this annual production plan, every month the sales

department provides weekly demand forecasts for the next three months at a low level of description: expected volumes for models, engines, major equipment are given but no information is provided for detailed options or other equipment (such as air conditioning, leather seats...). This process is relatively similar to the "monthly production schedule" described in Tomino et al. (2009) except that monthly forecasts are detailed here week by week, and vehicle specifications for forecasts may differ from one firm to another. It is important to note that forecasts do not bind the sales department: they are given for information only.

Based on sales forecasts, the supply chain department makes demand forecasts by using historical data for options and minor equipment to complete vehicles description. This process is relatively similar for Nissan and Mitsubishi where "manufacturers forecast the number of car sales and other specifications for a month by analyzing and aggregating orders from sales office" (Tomino et al., 2009). The method used by Renault to generate forecasts is not detailed in this paper and is not relevant for the considered problem. Weekly demand forecasts are sent to order book of the vehicle-assembly plant that is detailed in the following subsection.

Every day and in real time, the sales dealers send customer orders directly to the plants. It is interesting to note that orders are sent to the assembly plants without passing through the supply chain department. Indeed, our automobile manufacturer strove to speed up delivery time and has developed specific information systems and processes to facilitate direct connections between sales dealers and vehicle-assembly plants. In recent years, these processes have shown their limits and now, they are not sufficient to manage efficiently plants having long procurement lead times. Figure 1 gives a high-level overview of stakeholders and their main roles.

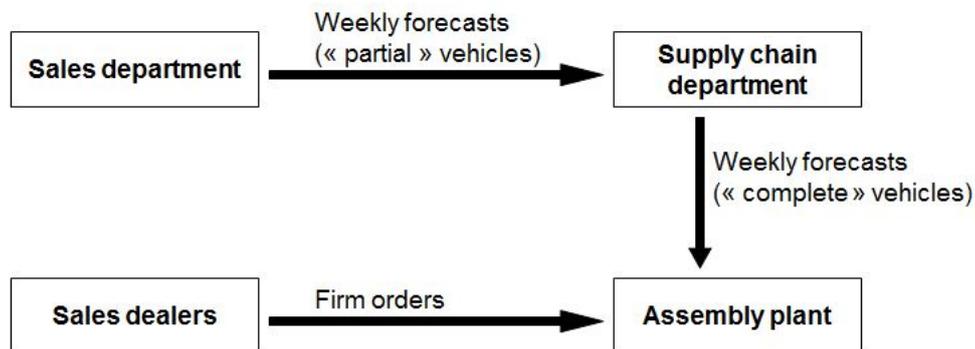


Figure 1: Overview of stakeholders

3.1.2 Order book and frozen horizon

Each vehicle-assembly plant has a six-month order book, which is composed of firm demands and forecasted orders. The order book is used by the plant to procure vehicle parts. The sum of real and expected orders equals the plant production capacity which is not necessarily constant over the time. Firm orders are sent by sales dealers and replace forecasts, according to a specific process that is described in the following subsection.

There is a commitment from sales department to keep at least the first four weeks of firm orders in the order book. As usual in literature, we name it "frozen horizon". Other automobile manufacturers

also use frozen horizon to finalize their production schedules but the length may vary depending on the manufacturer (Tomino et al., 2009). At Renault, the frozen horizon is usually seven days for most of the assembly plants but for the ones with distant sourcing, the management has decided to use a four-week frozen horizon. The frozen horizon is crucial to stabilize the production activities. During this period, the quantity of firm orders equals the total production capacity without any forecast. The frozen horizon guarantees the plant that no new order or changes will occur during the first four weeks of the production plan. If the demand is high during several periods, it may be possible to have an order book full of firm orders larger than the frozen horizon.

3.1.3 Parts procurement using the MRP framework and emergency supplies

The vehicle assembly plant uses a standard materials requirement planning system (MRP). Parts requirements are computed based on the order book. Some parts require up to ten weeks lead time. In this case, the parts supplies are mainly based on forecasted orders. Forecasts are not reliable to estimate future demand but they are the only source of information to procure parts. Because of the volatile demand, actual customer orders can differ largely from expected orders. The demand volatility and forecast accuracy largely depend on the type of the parts. Some common parts have relatively stable demand and good forecasts. But most of the parts with long procurement lead times are specific and have highly variable demands and unreliable forecasts.

Therefore, parts shortages may occur and in this case, the missing parts are shipped by airplanes and arrived in less than a week, avoiding the plant to stop the production (that would be very costly). Obviously, emergency supplies are more expensive than normal supplies. The shipment costs depend on the part's price but also on its weight for airplane transportation, and on its volume for sea transportation. Therefore, the cost differences between air and sea shipments can highly differ from one part to another.

3.2 Original aspects of the problem

In this subsection, we describe the original aspects of the problem. We also detail how these characteristics can be extended to other firms facing the issue of sales and operations coordination in an uncertain environment.

3.2.1 Sales and supply chain negotiation using flexibility rates

As usual in sales and operations planning, the main issue is to make collaborate two business functions (sales and operations) that have different objectives and constraints. In our model, the main specificity is that the negotiation is based on the so-called flexibility rates. These flexibility rates define in what extent the sales dealers can order different vehicles from the forecasted ones, and in what extent the supply chain needs to use safety stocks or emergency supplies to face changes in forecasted orders. The processes to define the flexibility rates and the related sales constraints are defined below.

Every week, the sales and the supply chain departments are negotiating the flexibility rates for each critical vehicle feature with long supply lead time. A feature can be a single option (e.g. air conditioning) or a combination of equipment (e.g. diesel engine with air conditioning) and is composed of, at least, one part with long lead time. For simplicity and a better information sharing, flexibility rates are expressed as a percentage. For instance, sales and supply chain can decide a flexibility rate of 15% for all engines.

For a given feature, the flexibility rate is used to compute the maximum quantity of vehicles having this feature that the plant can accept during a week. This maximum limit, named sales (or flexibility)

constraint, equals the flexibility rate times the expected quantity of orders for the considered week. Therefore, the sales constraints are proportional to the quantity of forecasted orders. The sales dealers can order up to these sales constraints that give them more flexibility. Indeed, before using the flexibility rates, the sales dealers complained about the rigidity of ordering processes of the plants with long procurement lead times because they could not order more than the quantity of forecasted orders.

We give the following concrete example to understand how the flexibility rates and sales constraints work. We consider diesel engines with ten weeks for procurement lead time but the sales department is not able to give a good forecast for diesel-powered cars ten weeks in advance. In week 1, the sales department expects 1500 diesel-powered cars for week 11. To ensure some flexibility for sales dealers, sales and supply chain departments agree on a flexibility rate of 10% for the feature “diesel” during the week 11. In this situation, a sales constraint of 1650 diesel-powered car is created for the week 11. Then, sales dealers can order diesel-powered cars up to this limit. If they order more than this sales constraint, then the extra orders will be postponed on the following weeks, with a risk of lost sales due to customer impatience that is detailed in the following subsection.

We may have the following intuition: a high flexibility rate allows sales dealers to order more specific cars than expected but it may require emergency supplies of parts, generating higher logistic costs. Higher inventories can also be used to cover high flexibility. On the other hand a low flexibility rate may increase order postponements, vehicle delivery times for customers and hence, the number of lost sales. Therefore, in our sales and operations planning, the trade-off between sales requirements and operations costs depends mainly on the negotiated flexibility rates for each critical feature.

Flexibility rates and their impact on the order book dynamics are an important aspect of our problem. Indeed, the sales constraints impact directly the positioning of customer orders in the order book. If forecasts underestimate real demands, then sales constraints are more likely to be saturated and some orders will be delayed and positioned on the next periods. If there is an important peak of demands, then it may be possible to have several weeks in a row with saturated constraints because of many delayed orders.

Another important characteristic of the problem is that there is no minimum commitment: sales dealers can send no order during a week even if the sales department has provided non-zero forecasts. Sales constraints represent only maximum restrictions but there is no minimum restriction for customer orders.

The flexibility rates and the related sales constraints described here are specific to Renault’s sales and operations planning but this can be applied to other firms that work in a build-to-order environment and strive to struggle against highly uncertain demand. The only requirement is to create restrictions on the order fulfillment processes to reduce the number of changes in customer demands compared to forecasts. In Tomino et al. (2009), the authors tell that, in Toyota, order changes are allowed until three days before the production but these changes must be within $\pm 10\%$ of the planned specifications. This has some similarities to our process with a 10% flexibility rate (except that at Renault, there is no minimum limit for order changes). We note that the authors do not give more details on Toyota’s system for managing this issue.

3.2.2 Demands arrival and customer impatience

Firm orders are sent by sales dealers and arrive in real time directly in the order book of the assembly plant. These customer orders replace forecasts in the order book. Replacing forecasts by real demands is not a trivial issue because the system needs to find the best association that leads to the least changes

in parts requirements. The algorithm used to match at best real demands and forecasted orders is not required for the understanding of the rest of the paper, and hence it is not detailed here. As explained before, real and expected orders have to respect the sales constraints.

If a sales constraint is saturated, the some customer orders may be delayed and positioned on the following periods. Since customers are impatient, there is a probability to lose the order depending on the delay. Therefore, contrary to the most of researches in sales and operations planning, we consider a problem with both lost sales and backlogs (for orders that are not lost but delayed). There is no penalty cost associated to delayed orders but they increase the average delivery time, which is one of the performance indicators of the sales department. All system performance indicators are detailed in the following subsection. Considering customer impatience is relevant because, in practice, it is common for car buyers to cancel an order if their waiting time is excessive. To the best of our knowledge, our research is the first quantitative model that considers customer impatience from a sales and operations planning perspective.

Furthermore, in our problem, the customer orders are not necessarily asked as early as possible. This means that sales dealers may order vehicles for a specific week in advance. In real life, this situation may happen when, for instance, there are transportation restrictions or a company asks for a large fleet of professional vehicles.

The dynamics of the order book filling with arrival of new demands and orders postponement are illustrated in the following figures. Figure 2 shows the shape of the order book of an assembly plant: as explained above, there is a frozen horizon of four weeks and the following weeks are filled by firm and forecasts. Figure 3 shows the dynamics of delayed orders and lost sales: during the week 5, the plant receives more customer orders than the sales constraint, therefore some orders will be delayed in the week after and few orders will be lost because of the customer impatience. Figure 4 gives a schematic representation of forecasts, real demands and which part of customer orders is satisfied, delayed or lost.

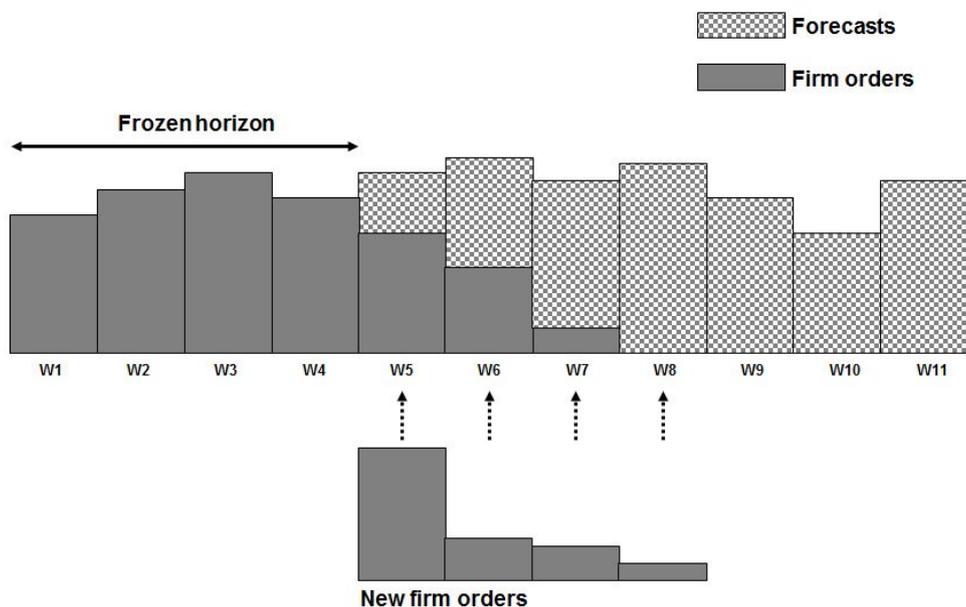


Figure 2: Arrival of new demands in the order book

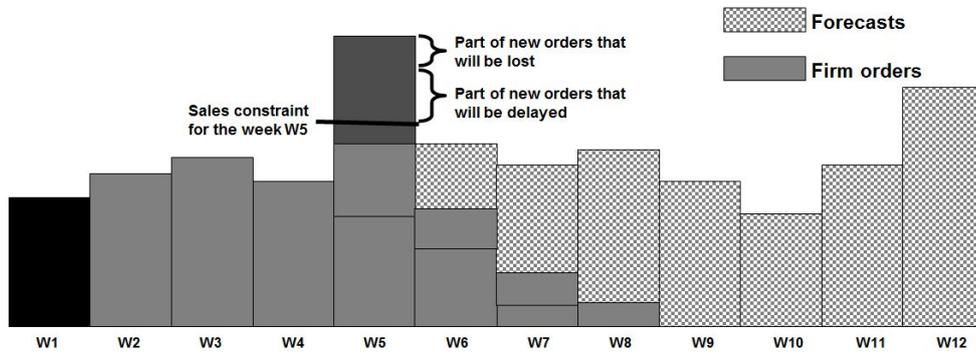


Figure 3: Lost sales and delayed orders dynamics

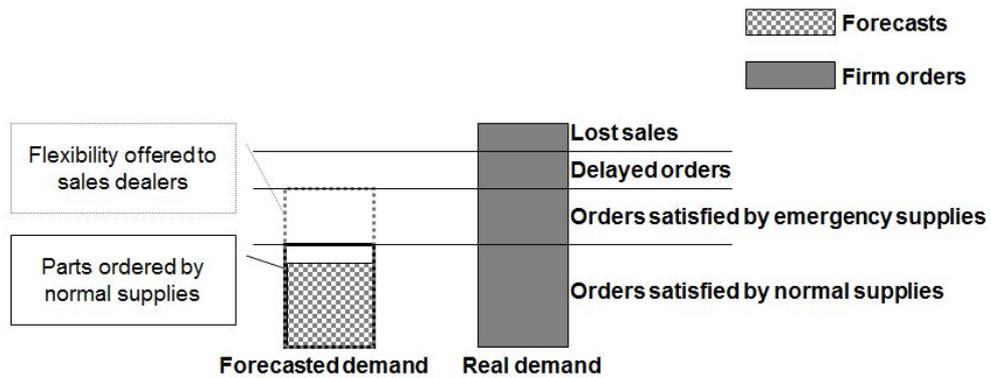


Figure 4: Schematic representation of satisfied orders, lost sales and delayed orders

3.2.3 Safety stock management

To cover the risk of having more orders than forecasts, the supply chain needs to use safety stocks. Otherwise missing parts will be shipped by emergency supplies and this may be very costly. An original aspect of our planning model concerns the safety stock management. Similarly to the sales department, the supply chain also defines safety stocks with percentages. Plants are using the so-called safety stock margins to procure an additional supply in order to cover the demand uncertainty and the flexibility given to sales dealers. For instance, with a safety stock margin of 5%, the system will order 5% more parts than expected orders. As for the sales constraints, the safety stocks are proportional to the quantity of forecasted orders.

We note that, contrary to other models that focus on dual sourcing, emergency supplies are always used to prevent shortages. In our model, a policy to control the inventory system is completely defined by the safety stock margins. And a policy to control the positioning of real demands in the order book is defined by the flexibility rates.

3.2.4 System performances

The sales and operations planning is a cross-functional process and involves stakeholders with different and often conflicting objectives. Hence it is difficult to measure objectively the overall performance of the system with only one indicator. Therefore, we consider two performance indicators measured by several variables:

- The logistics performance indicator is measured by inventory and emergency supply costs.
- The customer satisfaction indicator used by the sales department is measured by the number of delayed orders, lost sales and the average delay.

We note that considering the normal supply costs is not necessary in our problem because we already take into account inventory, emergency supplies, lost sales and all accepted orders are satisfied (in case of shortages, parts are shipped by emergency supply). Furthermore, fixed procurement costs are neglected.

Contrary to most of the studies about sales and operations planning, an original aspect of our model is that the overall performance is not only measured by cost indicators but also concrete indicators for the sales department to evaluate the customer satisfaction. This is particularly relevant in practice because firms are more and more customer-oriented and their performance is not only limited to the supply chain costs.

The objective of this study is to improve the trade-off between logistics and sales performance by using suitable safety stock margins and flexibility rates for components with long lead time. The company is willing to support more inventory and emergency supply costs if there is a significant improvement in customer satisfaction. In the following, several policies are evaluated with a simulation model, and we detail their advantages and disadvantages.

4 Simulation model

The problem is clearly not deterministic because of the demand uncertainty, the customer impatience and the risk of lost sales. Moreover, several aspects make the situation complex to analyze: the commitment to maintain a frozen horizon of at least four weeks, the mechanism of delayed orders in case of saturated constraints and the progressive arrival of firm orders week after week. Some performances variables

(number of delayed orders, average delay) are difficult to estimate with a basic analytical formulation in this context. Therefore, we decided to carry out a simulation model to investigate the dynamics of the supply chain and sales coordination. To do so, we use a discrete-time and weekly rolling-horizon model that simulates the order book dynamics and the associated parts ordering and inventory management.

The simulation approach has also other advantages. It can quickly provide results that help decision makers to improve the planning processes. Moreover, it can be easily used for thousands parts of an assembly plant. The simulation model is a first step in the analysis of this new planning model: it has already provided significant gains for the company and it makes for a better understanding of the dynamics of the flexibility rates and their impact on the sales and operations planning.

4.1 Model assumptions

We make the following assumptions, which have been validated by operational managers of the automobile manufacturer:

- Each part demand is independent from others and so, each part is managed independently. In reality, there may be correlations between some parts but for very different features (e.g. gearbox and sunroof), assuming independent demand is not unrealistic.
- Lead times are assumed constant. This assumption may not hold in real life but this has not a significant impact, especially for long procurement lead times. The variability of lead times is very low (few days) and can be neglected in our problem. Moreover, specific safety stocks are used to avoid the consequences of this variability, and therefore the impact is rather limited.
- We consider linear holding and emergency supply costs. There is no fixed cost.
- There are no restrictions on the supplier or the transportation capacities. This assumption may appear to be strong but actually this is not in conflict with reality. Indeed, supplier capacities are negotiated based on plants' capacities. Except in rare events (that may happen in reality but out-of-the scope of this study), we can always have the quantity we ask for.
- There is no inventory limitation. Even if plants may have strong physical restrictions on inventories, these limitations do not impact the coordination of sales and operations through stock and flexibility rates. Inventory restrictions are not taken into account in sales and operations planning, nor in information systems.
- Demands are generated by using uniform distribution according to historical data. Many parts have different distribution patterns (Poisson, Normal etc.) depending on several factors (lead times, suppliers, diversity...) and the simulation model can also deal with these other distributions. For the rest of the paper, we consider only uniform distributions for demand patterns. Based on industrial data, this fits with many long procurement lead time parts.
- Forecasts are generated based on the real demands and by adding an error distributed according to a uniform distribution. Based on historical data, errors appear to be very important and frequent for parts with distant suppliers. This explains why uniform distribution is preferred to Normal distribution to simulate forecasting errors. However, our simulation model can easily manage other forecast patterns.
- Customers are impatient. If the order is delayed by a week or more, then there is a probability to lose the order, depending on the delay length.

- Sales dealers send orders independent of the flexibility restrictions. This means that if a customer asks for a specific vehicle, then the sales dealer will send the associated order to the plant, even if a constraint has reached to its limit. The dealer will not try to change the customer's mind. In real life, the dealer may influence the customer but this is very difficult to track since it is not recorded and every dealer behaves differently. Moreover, it is unclear to make distinction between dealers negotiating with the customer due to flexibility constraints or other commercial reasons.
- Emergency supplies are always possible and it requires less than a week to deliver parts in emergency.
- The forecasts are never produced. If there remains some forecasted orders during the frozen horizon, they are removed from the order book. This specific assumption is due to a real process in the sales and operations planning of the automobile manufacturer.

4.2 Notations

We use the following notations for the system input parameters for a given part or vehicle feature:

H : simulation horizon

W : warm-up period length

L : procurement lead time (by sea shipments)

F : frozen horizon length, $F < L$

LC : average logistic cost (holding and emergency supplies)

c_h : holding cost per unit per week

c_e : emergency supply extra cost per unit

s_0 : initial stock level

D_t : random variable of real demand for week t

F_t : random variable of demand forecast for week t

$N_{i,j}$: new real demand for week j received during the week i , with $i < j$

m_k : demand arrival rate k weeks before real demand, with $1 \leq k \leq H$ (see A)

p_k : probability to lose the order if it is delayed by k weeks (see B)

We use the following notations for the decision variables:

π_t^s : safety stock margin for week t , with $1 \leq t \leq H$

π_t^f : flexibility rate for week t , with $1 \leq t \leq H$

For a given vehicle feature, a policy to manage the stock margin and flexibility rate is completely defined by a vector of couples (π_t^s, π_t^f) . We use the following notations for the system variables, that depend on the policy used:

s_t : net inventory level at the end of week t , $0 \leq t \leq H$

\hat{s}_t : expected inventory level at the end of week t based on parts supplies, actual and expected orders

x_t : quantity of parts ordered at week $t - L$ and that will arrive at week t by sea shipments

y_t : quantity of parts ordered at week t and that will arrive at week t by emergency supply

z_t : quantity of lost sales during week t

d_t^f : quantity of order forecasts placed in week t in the order book

d_t^r : quantity of firm orders placed in week t in the order book

d_t^{max} : maximum quantity of orders that the plant will accept for week t

4.3 System dynamics and equations

In this subsection, the system dynamics and related equations are presented.

First of all, we consider a warm-up period of W weeks during which all firm orders are perfectly known. Actually, this warm-up period exists especially for the launch of new models, new versions or options (“marketing phase”).

At the beginning of each week, new orders arrive in the order book. Real demands are known gradually and week after week. To simulate this, we define the demand arrival rates m_k ($0 \leq m_k \leq 1$). For instance, during week i the plant receives $N_{i,j} = m_{j-i}D_j$ orders for week j . Since there is a commitment for a frozen horizon of F weeks, all firm orders are known, at the latest, F weeks before assembly. Therefore we have $\sum_{k=F}^H m_k = 1$. Values of demand arrival rates are estimations based on industrial data. New real orders are placed in the order book and replace expected orders. New orders have to respect the commercial constraint d_{t+L}^{max} . Indeed, if this constraint is saturated, then next orders will be delayed with a risk to lose sales. If an order is delayed by k weeks, the probability that the customer cancels its order is equal to p_k .

Second, the plant orders parts. To do so, the expected inventory level \hat{s}_{t+L} at week $t+L$ is computed by the difference between future arrivals of parts (by sea and airplanes shipments) and the expected orders. The value of \hat{s}_{t+L} is given by equation 1.

$$\hat{s}_{t+L} = s_0 + \sum_{k=0}^{t+L} \left((x_k + y_k) - (d_k^r + d_k^f) \right), \quad t = 0, \dots, H - L \quad (1)$$

For each week t , the plant orders x_{t+L} that is equal to the quantity required to satisfy the expected demands plus the safety stock margin to cover demand fluctuation between the end of frozen horizon and parts lead time. The value of x_{t+L} is given by equation 2.

$$x_{t+L} = \max \left\{ 0; d_{t+L}^r + d_{t+L}^f + \pi_{t+L}^s \sum_{k=t+F+1}^{t+L} \left(d_k^r + d_k^f \right) - \hat{s}_{t+L-1} \right\} \quad (2)$$

Third, we define d_{t+L}^{max} as the maximum number of orders that the plant can accept during week $t+L$, based on demand forecast for week $t+L$ and on the policy parameter π_{t+L}^f . The value of d_{t+L}^{max} is given by equation 3.

$$d_{t+L}^{max} = (1 + \pi_{t+L}^f) (d_{t+L}^r + d_{t+L}^f), \quad t = 0, \dots, H - L \quad (3)$$

Fourth, in case of shortages during week t , emergency supplies are used according to equation 4.

$$y_t = \max \{0; d_t^r - (s_t + x_t)\}, \quad t = 0, \dots, H \quad (4)$$

As explained in section 3, the system performance is measured by several indicators. The average logistic cost is the sum of the average inventory and emergency supply costs, and its expression is given in equation 5. We note that the cost c_e is the extra cost due to emergency supply. The simulation model also measures the number of lost sales, the number of delayed orders that are not cancelled by the customers, and the average delay.

$$LC = \frac{1}{H} \sum_{k=0}^H (c_h s_k + c_e y_k). \quad (5)$$

4.4 Model relevance

The simulation model, assumptions and the system dynamics were developed with the active involvement of different experts, operators, supply planners and sales managers of the automobile manufacturer. The difficulty was to capture the main characteristics of the problem without taking into account all minor details of the production system and the planning processes. We also use historical demand and production data (about two years of data), and actual costs to generate relevant instances for the simulation model. Moreover, real annual inventory and emergency costs of different vehicle assembly plants have been used to validate the relevance of the simulation model.

4.5 Experimental design

For confidentiality reasons, it is not possible to provide an extensive numerical study. Consequently we have selected only one representative instance to illustrate results obtained with the simulation model. The settings used in the numerical experiments are given in table 1.

Table 1: Default simulation parameters

Parameter	Value
H	2000
W	15
L	10
F	4
c_h	1
c_e	20
s_0	0
$\min \{D_t\}$	500
$\max \{D_t\}$	2000
F_t	$D_t + U$
$\min \{U\}$	-500
$\max \{U\}$	500
m_k	see A
p_k	see B

These values are based on industrial data for one specific vehicle feature. The simulation model has been implemented in Java programming language and runs on a personal laptop (HP ProBook 6450b Intel® Celeron® 2×2 Ghz, 4 Go RAM memory). It takes less than one second to compute a simulation run of 2000 weeks.

For all the following results, we measure average performances based on batches of 50 simulation runs of 2000 weeks. We calibrate the simulation length and the number of replications to ensure that the performance measures are reliable “enough” for managers to take strategic decisions. In C, a graph illustrates the system performance as a function of the simulation length and the number of simulation runs.

5 Policies for managing stock and flexibility

In this section, we describe the different types of policies we studied and suggested for implementation at the automobile manufacturer.

We first consider the common pure build-to-order policy named Π_{BTO} that allows sales dealers to order any quantity, and without using safety stocks. With this policy, the system behaves like a classic inventory system where parts are replenished according to the MRP, without any safety stocks to handle demand uncertainty. The only restriction for sales dealers concerns the frozen horizon of four weeks. With this build-to-order policy, emergency supplies are used as there is any shortage. In real life, plants having short lead time parts and mainly build-to-order customers have implemented this Π_{BTO} policy.

Then, we consider the class of policies that uses fixed flexibility rates and stock margins for the whole horizon, independent of other parameters. The management have decided to, first, implement these intuitive policies because of operational constraints and to facilitate cooperation between the sales and the operations functions.

In the following, a policy named $\Pi_{S/x/y}$ refers to a simple static policy with $x\%$ of stock margin and $y\%$ of flexibility rate.

$$\Pi_{S/x/y} : \quad \pi_t^s = x\% \quad \text{and} \quad \pi_t^f = y\%, \quad t = 0, \dots, H. \quad (6)$$

The objective here is to observe the system behaviour under some simple static policies as a first step. An optimization procedure to find the best static policy is out of scope of this article.

In the following section, we test different simple policies by using a simulation model and show how they perform to better understand the system dynamics. Testing these policies have already and quickly provided significant gains for the industrial partner, as we detail in the section 6.

We consider the following simple static policies that are used in different assembly plants of Renault and that can also be implemented in other companies:

- Policy $\Pi_{lock} = \Pi_{S/0/0}$: no safety margin and no flexibility. This policy is currently used for plants having strong inventory restrictions and low variability in demand (car models with low diversity and large firm orders book due to high demand). It is also used in plants having mainly build-to-stock customers. This policy does not require emergency supply.
- Policy $\Pi_{S/10/10}$: 10% for both stock margin and flexibility rate. The automobile manufacturer would like to implement this simple policy in its new plant. This policy does not require emergency supply.

- Policy $\Pi_{S/5/20}$: 5% for stock margin and 20% for flexibility rate. The numerical experiments will show that this simple policy performs better (in terms of costs and also customer satisfaction) than the previous one. This policy may require emergency supply.

We note that the policy Π_{BTO} may be seen as a simple static policy with $x = 0$ and $y = +\infty$. We also note that Π_{BTO} and $\Pi_{S/5/20}$ are policies that may require emergency supply when necessary to prevent stockouts, while Π_{lock} and $\Pi_{S/10/10}$ use only normal replenishment by sea and only accept customer orders that the plant can satisfy with the classic supply.

These simple static policies are easy to implement and simple to understand. This facilitates the communication between the different stakeholders and the practical application of the new processes in the sales and operations planning. However, these simple static policies are limited because the stock margins and the flexibility rates are constant percentages of the expected demand. Therefore, the maximum limit of accepted orders and the additional procurement quantity are proportional to the magnitude of the forecasts. A low quantity of expected orders leads to only a little additional flexibility in terms of vehicles. Conversely, high quantity of expected orders leads to huge parts inventories that may be largely unused.

To avoid this inconvenient base effect, we have developed new policies, named threshold policies. For this class of policies, flexibility rates are computed based on forecast thresholds. Every week, the quantity of expected orders for a given vehicle feature is compared to the average historical demand. In case of low forecast, higher flexibility is given. Otherwise, lower flexibility is given.

In the following section, we present the results of the following example of a threshold policy Π_T . Every week the average over six weeks demand is computed. If the forecast is lower than one third of the six-weeks average, then 10% of stock margin and 50% of flexibility rate are used. If it is larger than three times the six-weeks average, then 0% of stock margin and 10% of flexibility rate are used. Otherwise, 5% of stock margin and 20% of flexibility rate are used. The following example illustrates why the threshold policy Π_T reduces the inconvenient base effect contrary to a simple policy like $\Pi_{S/10/10}$. Let's consider a component with an average weekly demand of 500 orders and a future period with only 30 expected demands due to incorrect forecasts. If the policy $\Pi_{S/10/10}$ is used, then sales dealers will be able to order up to 33 orders, beyond which the orders will be postponed. Therefore, sales dealers have only a small flexibility margin of only 3 orders, which is likely to be insufficient. However if the policy Π_T is used, then a flexibility margin of 15 orders will be offered to sales dealers (50% flexibility rate because the forecast is lower than one third of the average demand). In the opposite situation, if the forecasts overestimate the real demand, then a simple policy like $\Pi_{S/10/10}$ leads to large safety stocks that will be costly and unnecessary, contrary to the threshold policy.

6 Numerical results and practical recommendations

In this section, numerical results based on the instance of table 1 and the policies described in section 5 are presented.

6.1 System behavior

We first investigate the system behavior, and how the stock margins and the flexibility rates impact performances in terms of logistic costs (holding and emergency supplies) and customer satisfaction measured by lost sales, delayed orders and average delay.

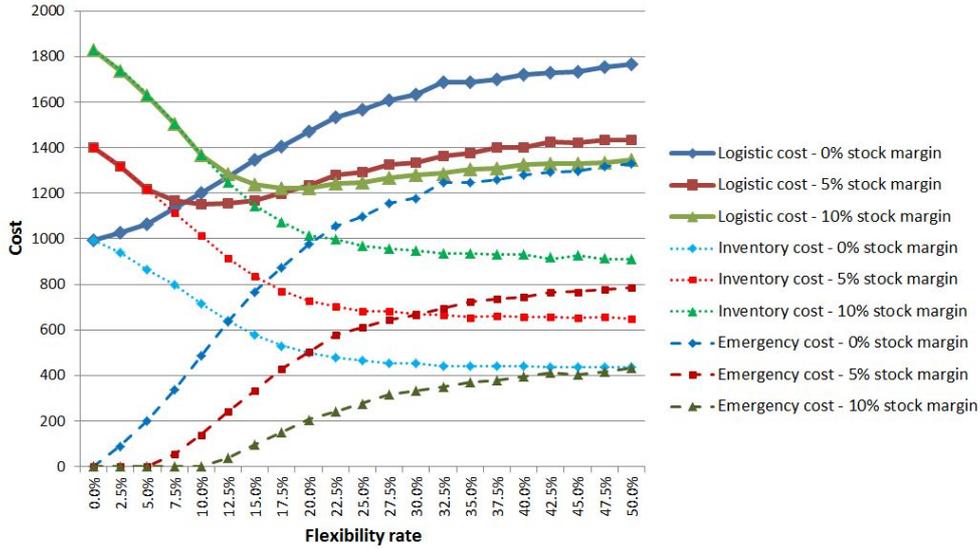


Figure 5: Logistic, inventory and emergency costs as a function of the flexibility rate

Figure 5 shows the system performance as a function of flexibility rate for different stock margins. As we could expect, without stock margin, the logistic cost is increasing as a function of flexibility rate because the plant has to use emergency supplies to satisfy demands. With a non-zero stock margin, the logistic cost begins to decrease while the flexibility rate increases because the plant accepts more orders and therefore uses its parts inventory. For example, with 10% stock margin, the average logistic cost is about 1820 euros without flexibility and about 1220 euros (33% decrease) with 20% of flexibility. Above a certain flexibility rate, the logistic cost begins to increase because emergency supplies become dominating and very expensive. Furthermore, the figure 5 shows that increasing the flexibility rate reduces the inventory cost and increases the emergency cost. This is explained by the fact that the assembly plant has to satisfy more orders. We also note that if the flexibility rate is lower than the stock margin, then no emergency supply is required (for instance: with 10% stock margin and 5% flexibility rate, the logistic cost equals the inventory cost).

In terms of customer satisfaction, figure 6 shows that increasing flexibility rate reduces significantly the number of lost sales (from 1.7% without flexibility to 0.2% with 50% of flexibility) and also the number of delayed orders (from 12.8% without flexibility to 1.6% with 50% of flexibility). The percentage of lost sales (less than 2% of the total demand) may seem low but actually, it represents an important loss for the sales department. Quantifying lost sales in cost is a very difficult task since economical consequences are uncertain and various, and some are not computable. Lost sales costs are very variable and cannot be evaluated precisely, that is why the sales department prefers to use an estimation of number of lost sales instead of cost values to negotiate with the supply chain department. However, an economical study performed by the automobile manufacturer has suggested that, for some plants, the cost of 3% of lost sales can be quite comparable to the cost of using only emergency supplies (without sea transportation). Therefore, reducing lost sales from 1.7% to 0.2% is potentially very valuable for the company.

An interesting result is that offering more flexibility to sales dealers do not reduce significantly the vehicle delivery time. As we can see in figure 6, the average delay is about 1.11 weeks without flexibility and becomes about 1.02 weeks with 50% of flexibility. We deduce the following practical recommendation: if sales dealers complain about the important number of delayed orders, then the

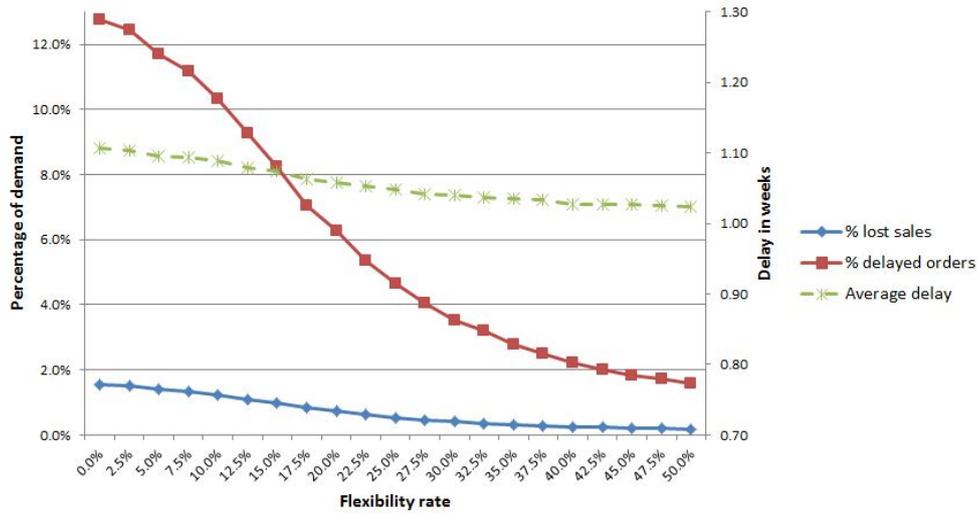


Figure 6: Customer satisfaction indicators with 5% of stock margin as a function of the flexibility rate

simulation model suggests that changing flexibility rates can be a good lever for action. On the other hand, if the main problem is rather due to long delivery times, then giving more flexibility will not be useful. In this situation, a possible solution could be to reduce the frozen horizon length that will automatically reduce the vehicle delivery time, but it will increase the uncertainty on the order book. As we can see with these results, flexibility rates are key parameters in the coordination between supply chain and sales departments.

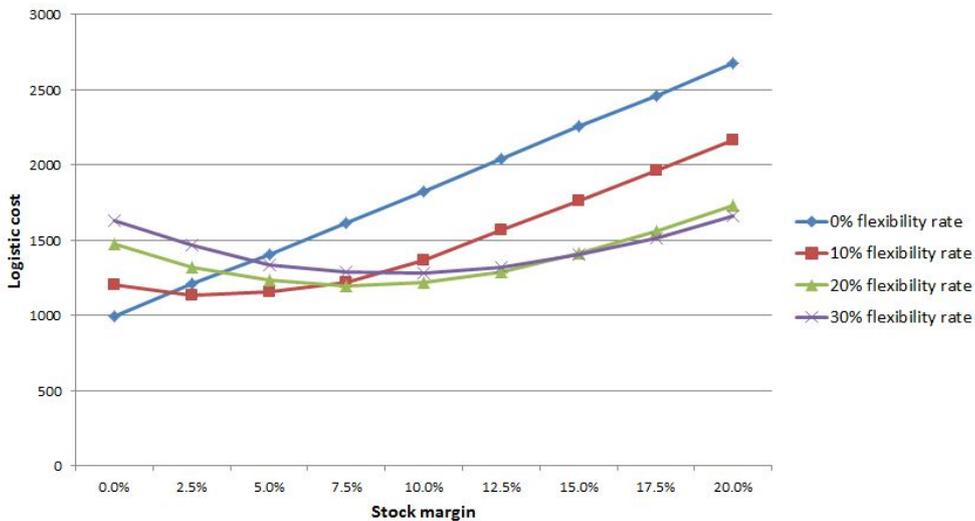


Figure 7: Logistic cost as a function of the stock margin

Figure 7 depicts the cost performance as a function of stock margin for different flexibility rates. We note that lost sales and delay performance do not depend on stock margin but only on the flexibility rates. If there is no flexibility, then it is not useful to order more parts since they are not used to satisfy demands. Otherwise, with non-zero flexibility rates, the logistic cost begins to decrease while the stock margin increases because the plant uses less emergency supplies. Above a certain stock margin, the

logistic cost increases because the extra parts inventory becomes unused to satisfy customer orders.

The simulation model has shown that the forecast quality has a strong impact on system performances. In the instance of table 1, forecast errors are uniformly distributed within the limits -500 and 500. To measure the impact of forecast quality on system performances, we vary the values of forecast errors from ± 450 to ± 50 . Obtained results are depicted in figure 8.

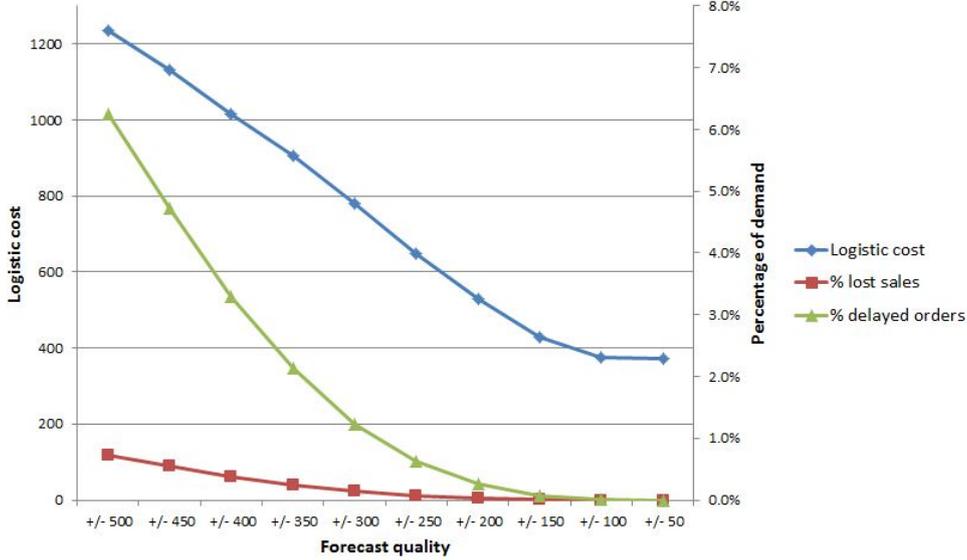


Figure 8: Performance of $\Pi_{S/5/20}$ as a function of forecast quality

Figure 8 shows that improving forecast quality is a very efficient way to reduce logistic costs and lost sales. An improvement of 10% of forecast quality leads to a reduction of about 15% of the logistic costs and 40% of the number of delayed orders. This outcome is not surprising but it is interesting to note that it might be more efficient to improve the forecasts first and then to optimize the stock-flexibility policy. In practice, several concrete actions have been deployed in the automobile manufacturer to improve forecasts both in sales and supply chain departments. However, it still remains a difficult challenge to predict future demands several months beforehand, especially in a very uncertain environment such as the automotive industry.

6.2 Comparison of policies performances

The following numerical results compare the policies described in Section 5.

Figure 9 illustrates the different policies' performances in terms of logistic costs and customer satisfaction indicators (lost sales and delayed orders). As we can expect, the policy Π_{BTO} is the best from the point of view of sales dealers since they can order any vehicle at any time (except during the frozen horizon). However this policy is very expensive (about 34% higher than $\Pi_{S/10/10}$).

Also, the policy Π_{lock} is the less expensive (about 38% lower than $\Pi_{S/10/10}$) but leads to very bad performance for sales department with 1.7% of the demand that is lost, and 12.8% that is delayed. For the policy Π_{BTO} , the plant does not use emergency shipments because flexibility constraints ensure that orders will not exceed parts supplies. The only logistic cost is due to inventories when the real demand is lower than expected.

Better compromises can be obtained by using simple static policies such as $\Pi_{S/10/10}$ and $\Pi_{S/5/20}$.

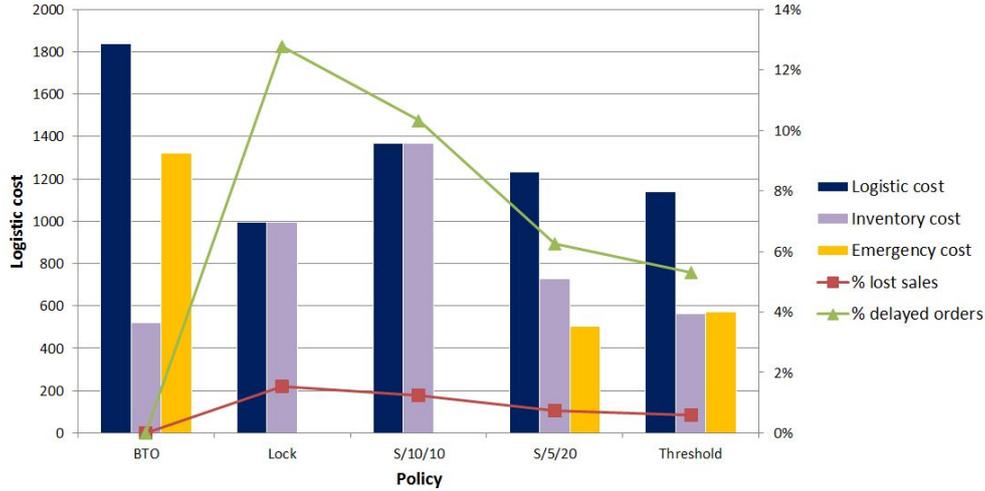


Figure 9: Comparison of policies performance

An interesting result is that the policy $\Pi_{S/5/20}$ outperforms the policy $\Pi_{S/10/10}$ in terms of both logistic costs (reduction of about 10%) and customer satisfaction (about 40% less delayed orders and lost sales). Even if the policy $\Pi_{S/5/20}$ resorts to emergency supplies when there is a shortage (contrary to the policy $\Pi_{S/10/10}$ that always procures enough parts to satisfy all demands without emergency supply), it leads to a lower average logistic costs because the inventory costs are largely reduced, and it also improves the customer satisfaction. Therefore, for this vehicle feature it is a win-win situation to switch from the policy $\Pi_{S/10/10}$ to $\Pi_{S/5/20}$.

These results show that using a basic build-to-order strategy is very costly in the situation with long lead times because of emergency supply costs. Our simulation model suggests that we can significantly reduce the logistic costs by using flexibility rates that limits the ability of sales dealers to order any type of vehicle at any time. In addition, controlling sales dealers with zero flexibility rates is very efficient to reduce logistic costs but the customer satisfaction is significantly deteriorated. We also show that some simple policies can lead to a lower average logistic costs without deteriorating the customer satisfaction.

The simulation model also shows that there is a significant gain by using the threshold policy described in Section 5 instead of the simple policy $\Pi_{S/5/20}$: about 8% of cost reduction, and about 15% less delayed orders and lost sales. This confirms our previous intuition: the use of thresholds can reduce the drawback of base effects due to static flexibility rates and stock margins defined with percentages. This result is important because it shows that using static policies are easy to implement and understand but it is not efficient when the demand variability is high and this can be significantly improved by using thresholds to define stock margin and flexibility rates. However, threshold policies are more complicated for negotiation and are less intuitive for sales and supply planners. We have suggested these new policies and the automobile manufacturer is currently considering the operational feasibility, the information systems implementation and the potential benefits.

Negotiating and deciding the best policy are not simple since both sales and supply chain departments have very different points of view and they cannot be completely satisfied. In practice, the sales department suggests several customer satisfaction indicators (e.g. maximum number of lost sales and delay) and then, the supply chain has to find the best policy to minimize its costs, while satisfying sales requirements. The simulation model we developed is a fast and easy to implement tool to test several

scenarios and to estimate supply chain costs, the number of delayed orders and the average delivery time.

7 Further research and conclusion

Coordination of sales requirements and industrial constraints in an uncertain environment is a common issue for global companies having complex supply chains structures. In this article, we propose a new planning model for managing sales requirements and industrial constraints in order to find the best compromise between customer satisfaction and logistic costs. The originality of this method is the use of flexibility and sales constraints in the sales and operations planning for partially controlling the order fulfillment process in a build-to-order framework. To the best of our knowledge, this paper is the first that investigates the dynamics of a sales and operations plan constrained by flexibility rates in a context of long procurement lead times, uncertain demand and impatient customers. This research has been conducted within the automobile manufacturer Renault. But this original planning method using flexibility and sales constraints can also be applied to other general models of sales and operations planning with uncertain demand. Our research is a first quantitative investigation on this issue and this new planning method.

The contribution of this paper is as follows: first, a simulation model based on real planning processes and industrial data is developed. Systems performances are measured in terms of logistic costs and customer satisfaction. The simulation model provides a first fast and easy to implement solution to get insights on the system dynamics and performances of different policies, although the industrial problem is complex.

Second, we provide a numerical study to detail the impact of the different parameters on the system behavior. We show that the average delivery time is not significantly impacted by the flexibility rate, contrary to the number of delays or lost sales. This study is the first analysis on the planning dynamics implied by the flexibility rates and sales constraints.

Third, we compare several policies for managing the inventory and flexibility. Both logistic costs (inventory and emergency supply) and customer satisfaction (number of delays, lost sales and delivery time) are measured. The advantages and disadvantages of different policies are discussed. We show the potential benefits of using flexibility rates instead of a classic build-to-order ordering process in a context of unreliable forecasts and long lead times.

Based on these results, managerial insights are given to help decision makers of both supply chain and sales departments for adjusting efficiently the stock margins and the flexibility rates for specific vehicle features. New processes and information systems are implemented in the automobile manufacturer and are used to significantly reduce the logistic costs while maintaining a good customer satisfaction. The simulation model and the numerical results we obtained have also been used by managers to estimate costs and benefits of different alternative scenarios for production planning.

There are still many ways to extend this research. First, a more extensive research can be conducted on different policies for managing safety stock margins and flexibility rates. Currently, we are working on a simulation-optimization approach to efficiently compute the optimal policies. The research method consists in coupling the simulation model with an optimization procedure (see, for instance, Fu et al., 2000; Fu, 2002, for such techniques) to find the best values for safety stock margins and flexibility rates. The aim is to study their structures as a function of different parameters (costs, demand variability, customer impatience). The idea is to categorize vehicle features based on some parameters, and to say for each category if inventory, emergency supply or flexibility should be favored. Since we lack

information on the objective function, different optimization techniques and heuristics can be tested.

Second, the frozen horizon length may be another decision variable. Indeed, this parameter is negotiated between sales and supply chain at the start of production of a car model and, generally, it does not change afterwards. But it can be modified if potential benefits are identified. A longer frozen horizon length gives more visibility on future demands but increases vehicle delivery time. Moreover, as we show in this article, delivery time cannot be reduced efficiently by using flexibility rates, hence the need to consider the frozen horizon as a variable. We also note that the concept of frozen horizon is relatively common in literature (Sridharan et al., 1987; Xie et al., 2003; Stadler and Kilger, 2008; Graves, 2011).

Third, in this paper, emergency supplies are used as a last resort to ship parts by planes in case of inventory shortage. Actually, there exists another option for our automobile manufacturer: it is possible to ship some parts by using trucks. This may require several weeks but it is less expensive than air shipments and faster than sea transportation. Determining policies to use efficiently truck shipments in some situations will be valuable for the automobile manufacturer. The use of multiple modes of supply in inventory management is also a rich area of research in the literature, as detailed in section 2. Finally, a more comprehensive study can be conducted to compare the safety stock management described in this paper with traditional inventory policies.

Although this research is related to the automotive industry, the model, the methodology and the results of this paper can be extended to other firms and situations where demand is uncertain, customers are impatient and parts procurement has to be done based on unreliable forecasts. Nowadays, our research work is especially relevant as globalization increases, supply chains become more international, market environment remains uncertain and customers are increasingly demanding. In these conditions, reconciling sales and supply chain is crucial to improve customer satisfaction and to reduce logistic costs.

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A Demand arrival rates

In our simulation model, we use the following values for the demand arrival rates m_k . These values are estimated based on industrial data (see Table 2).

Table 2: Default values for the demand arrival rates

k	m_k
$k < F$	0
$k = F$	0.40
$k = F + 1$	0.30
$k = F + 2$	0.15
$k = F + 3$	0.10
$k = F + 4$	0.05
$k > F + 4$	0

B Customer impatience

Customer impatience is a difficult parameter to estimate because it may vary significantly from one customer to another. We use the following default values for the probabilities to lose an order after a certain delay (Figure 10). These estimations are based on marketing studies carried out by the automobile manufacturer.



Figure 10: Customer impatience

C Simulation length and the number of replications

The following figure shows the average logistic cost as a function of the simulation length and the number of replications (Figure 11). We note that by using 2000 weeks and 50 simulation runs, the difference in logistic costs is less than 1% compared to a limit-situation of 4000 weeks and 5000 simulation runs.

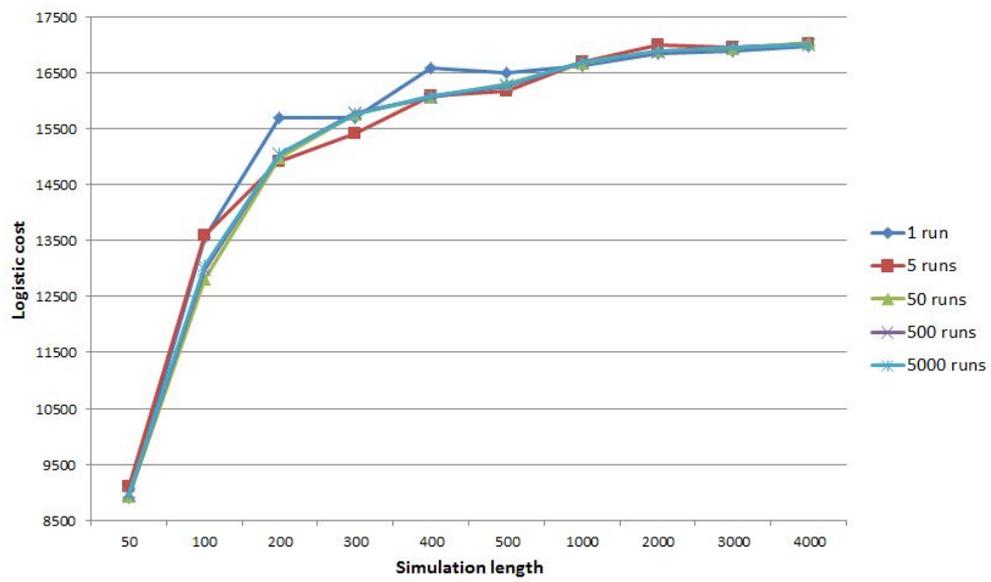


Figure 11: Average logistic cost as a function of the horizon length and the number of simulation runs

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