

## **SIMULATION-BASED ANALYSIS OF THE NERVOUSNESS WITHIN SEMICONDUCTORS SUPPLY CHAIN PLANNING: INSIGHT FROM A CASE STUDY**

Behrouz Alizadeh Mousavi  
Radhia Azzouz  
Cathal Heavey

Hans Ehm

Enterprise Research Centre  
University of Limerick  
Limerick, V94 T9PX, IRELAND

Corporate Supply Chain Engineering Innovations  
Infineon Technologies AG  
Am Campeon 1-15, Neubiberg, 85579, GERMANY

### **ABSTRACT**

In the growing globalization of production systems, the complexity of supply chains as socio-technical systems is escalating which, consequently, increases the importance of strong planning systems. Plans are developed to structure production in end-to-end supply chains that can experience nervousness due to uncertainties that results in unsatisfied customers. Although the external causes of nervousness and instabilities in supply chain planning systems were previously considered in the literature, internal nervousness of planning these complex networks can result from how the sub-components of the planning system interact. To study internal nervousness, a supply chain system of a semiconductor manufacturer is investigated as a case study. We examine internal nervousness of demand fulfillment by proposing a multi-paradigm simulation approach that combines discrete event and agent-based simulation. The results provide insight into the importance of visibility on the internal interactions of supply chain networks to reduce instability.

### **1 INTRODUCTION**

Supply Chain visibility needs to be functional to avoid instabilities and improve operation performance within complex and dynamic global Supply Chain (SC) systems (Swift et al. 2019). Instability or nervousness in planing systems can be defined through different contexts. Steele (1975) defines a nervous Material Requirements Planning (MRP) system as one that generates changes in requirements with little change in the master schedule. Moreover, for better planning and integration between SC elements, Enterprise Resource Planning (ERP) and consequently Advanced Planning System (APS) have evolved. Hierarchical Planning System (HPS) was also attached to these paradigms to better structure the production planning when the products move through different steps of manufacturing or logistics specially in complex and global SCs like semiconductor manufacturing SC (Stadtler et al. 2015).

Production complexity with thousands of product types, long production lead time, fast changing technologies, global SC with complex dynamic network, and fluctuating demand are the major reasons that drive semiconductor SCs to benefit from APS in a hierarchical structure. In fact, one of the major reasons of adopting this structure for designing complex SC systems is to provide reliable promises to the customer orders and forecasts. For the sake of this goal, Demand Fulfillment (DF) modules are used to provide promises to the customers in yearly planning horizon, whether the order is a real one or a forecast of predicted needs. To provide these promises, DF needs to know how many products are in production plans, in different production steps, in transport, or in stocks. This future availability of products is called Available-To-Promise (ATP) that is used by DF to create reliable promises (Stadtler et al. 2015). In a rolling horizon, the ATP for a specific time in the future might change. This is called ATP instability or

nervousness. With the presence of nervousness and disruption within ATP, companies are exposed to DF risks that lead to unexpected costs and unsatisfied customers (Levy 1995). In this paper, we investigate the instability of DF caused by internal interactions and lack of compatibility between the Supply Chain Planning (SCP) modules and the real production/logistic network. To illustrate, a SCP system of a semiconductor manufacturer is studied. For this objective, we used a multi-paradigm simulation modeling approach where we combined Agent Based Simulation (ABS) with Discrete Event Simulation (DES).

The remaining part of this paper is organized as follows. In Section 2, we present the literature review of the related research streams. In Section 3, first, we introduce the SCP system of our case study. Then, we describe the conceptual model behind the developed simulation model that is used to evaluate the internal nervousness of the studied SCP system.

Section 4 is devoted to describe the designed experiments of the simulation model and to analyze the obtained results. Findings and conclusions as well as future avenues are discussed in Section 5.

## **2 LITERATURE REVIEW**

Planning systems are designed to address prerequisites of manufacturing, production and supply chains where uncertainties can lead to instability (Stadtler et al. 2015). Planning instability, APS and simulation modeling are among the main research streams that are studied in this paper. Thus, to narrow down the literature to the scope of this study, the related works were organized as follows: (1) instability in planning systems, (2) ATP paradigm in APS, (3) the role of simulation in SCP studies, and (4) summary of literature in relation to the current research topic.

### **2.1 Instability in Planning Systems**

The concept of planning instability or nervousness was first introduced by Steele (1975) to damp deviations in MRP. Through the decades, planning instability has been studied in different contexts. Based on the related works, planning instabilities could be studied from different points of views:

1. Nervousness in planning systems can be caused in production planning (De Sampaio et al. 2017); or master planning (Herrera and Thomas 2009; Herrera et al. 2016); or in SCP (Pujawan and Smart 2012; Demirel et al. 2019).
2. The sources of instabilities can be classed as intrinsic (internal operations and incompatibilities) (Pujawan and Smart 2012) or extrinsic (supply and demand uncertainties) (Hasachoo and Masuchun 2016).
3. Damping strategies (Ho 2005) that could be either reactive like inventory control and buffer stocks maintenance that will attempt to find a stationary state of the system while the nervousness still exist; or proactive which is about finding the roots of nervousness to solve the causes or dampen it before it happens as studied by Sivadasan et al. (2013).
4. The structure of the planning system where the instability is evaluated. It could be for example in MRP system (Carlson et al. 1979; Heisig 2012; Li and Disney 2017); in a HPS (Moscoso et al. 2010; Meistering and Stadtler 2019); a Rolling Horizon Planning (RHP) system (Meistering and Stadtler 2019); or in APS which is shortly discussed in (Geier 2014).

Regarding the first item, studying nervousness manifestation mostly involved two parts of planning systems which are production planning (Gelders and Van Wassenhove 1982) and master planning (Sridharan et al. 1988; Herrera and Thomas 2009; Herrera et al. 2016). However, a small amount of research was done on SCP (Demirel et al. 2019), and nervousness in the whole planning system caused by system integration (Ho 2005). Demirel et al. (2019) modeled and evaluated the instability of supply networks by using generalized modelling, a methodology emanating from ecology, where they focused on the interaction between material flows network with external instabilities in planning. The analysis of nervousness in Master Schedule Planning (MSP) has been studied using different approaches. Herrera and Thomas (2009)

minimized MSP nervousness by the means of optimization and simulation. Other researchers studied nervousness in MSP by considering stochastic programming (Koca et al. 2018); and Mixed Integer Programming (MIP) formulation (Herrera et al. 2016) to re-plan the master scheduling when instability emerges while considering the cost of rescheduling.

The sources of instability or nervousness could be internal or external as stated above. In previous works, researchers mostly focused on external ones. A managerial study by Pujawan and Smart (2012) showed that internal factors have lower impact in production planning nervousness. In this paper, internal nervousness is researched arising from: (1) the information flow and timing of planning revision (Sivadasan et al. 2013), and (2) the structure of the SC network and module interactions (Demirel et al. 2019). The external factors are generally related to the bullwhip effect (Li and Disney 2017), demand fluctuation by customers (Tiacchi and Saetta 2012), and supplier side instabilities (Gruchmann and Gollmann 2017).

Damping strategies regarding the planning instability are categorized into two types: reactive and proactive strategies (Pujawan and Smart 2012). The reactive strategies have been studied more than proactive ones, since external factors are mostly out of control and prediction are not easy to forecast. Methods like stochastic optimization to address production planning instabilities are an example of reactive strategies (Koca et al. 2018). In Herrera and Thomas (2009), an MIP model is used to reduce the nervousness of MPS. Another reactive decision making method was developed in Herrera et al. (2016) to deal with production planning instabilities. This method re-actively tries to find the optimal trade-off between nervousness and cost of rescheduling. On the other side, there are a number of researchers who investigated the use of proactive strategies for planning nervousness. Sivadasan et al. (2013) lessened the nervousness by omitting the complexity-adding information flow within the supply chain. The trade-off between planning revision time periods, quality of information, suppliers cooperation and forecasting accuracy are some instances of proactive strategies.

The type of the planning system can also cause instability as mentioned in the last item. In fact, different planning systems were developed and progressed to deal with the complexity of production systems, to increase the efficiency of production and make the plans more stable. The analysis of nervousness that resulted from an MRP system started with the work by Steele (1975). Later on, Carlson et al. (1979) considered nervousness as the inconsistency of schedule set-ups and applied analysis using a dynamic lot-sizing algorithm to reduce nervousness within MRP systems. Li and Disney (2017) developed a measurement method to calculate nervousness to evaluate forecasts and orders-call-offs methods. They re-evaluated nervousness caused by forecasting errors in MRP systems. They mainly considered the problem jointly with the bullwhip effect. HPS was developed to address the challenge of short and medium planning requirements of production planning (Fleischmann et al. 2015). The integration between the planning system levels and its consequences on production plan's instabilities were studied in Gelders and Van Wassenhove (1982). Moscoso et al. (2010) addressed the problems triggered by the HPS that lead to instability and re-planning. In this empirical study, they evaluated the causes related to lead time and bullwhip effects. Meistering and Stadtler (2019) also considered HPS and designed the stabilized-cycle strategy and compared it with period-based and order-based strategies. In their problem, capacitated, multi-item and short-medium production planning were considered.

To deal with nervousness, new integrated planning systems (e.g., MPS, ERP and APS) have emerged. APS is the most recent planning system which is designed to satisfy the needs of complex production planning and SCP systems like in semiconductor manufacturing (Hegde et al. 2004; Mönch et al. 2018a). Nervousness in ERP and APS has been rarely studied.

In fact, APS consists of several integrated modules (Stadtler et al. 2015) developed based on heuristic algorithms to manage the planning processes. Planning sequences and events are patented by companies (Hegde et al. 2004; Chen et al. 2005) and studied by several researchers (Stadtler et al. 2015; Mönch et al. 2018b). To give an overview of APS nervousness and how the internal modules interact, the following subsection is presented.

## **2.2 Advanced Planning System and ATP**

Since we are analysing nervousness within APS caused by internal modules interaction, understating the literature of APS will shed light on this rarely studied area.

APS was developed based on the concept of hierarchical planning (Stadtler 2005). Around two decades ago, to solve the incompatibility of ERP systems in term of weak integrated planning power, and not to be just a transactional function; APS, by support of information technology was developed (Fleischmann and Meyr 2003). APS consists of separate software modules for planning a SCP network. These software modules are designed by software vendors, but are integrated and cooperate based on the common architecture of hierarchical planning (Stadtler et al. 2015). As defined by Stadtler (2005), "Supply Chain Management (SCM) is the task of integrating organizational units along a SC and coordinating materials, information and financial flows in order to fulfill (ultimate) customer demands with the aim of improving competitiveness of the SC as a whole." Thus, in the operational level of APS, to breakdown the objectives of SCM into detailed but generalized elements, the following processes were introduced: Demand Fulfillment, Demand Planning, Inventory Management, Capacity Planning, Material Requirements Planning, Master Planning, and Production Planning (Mönch et al. 2018a).

DF modules are responsible for computing the promise date and quantity that will be delivered to customers. In modern APS, this promising process is bounded by the planning capabilities of APS (Stadtler et al. 2015). DF needs information about the possible dates and quantities of products in different states of the planning system (production in plan, in manufacturing, in transit, or in stocks) within the planning horizon. This is realized by support of master planning. Master planning, based on the information from the whole SC (internal and external), calculates the supply chain plan (Stadtler et al. 2015). In order to improve the order promising and customer satisfaction, the master planning iteratively develops a plan for future possible supplies. This supply plan is called ATP (Stadtler et al. 2015).

ATP is used by DF to provide a promise and confirmation that indicates if the desired delivery date and quantity of customer's orders will be met or not. For ATP calculations, current and future orders, forecasts, demand plan from the tactical level, available capacity, and production schedule need to be considered. In other words, ATP is a deviation of a production plan derived from other constraints and requests. Therefore, the nervousness in ATP could have different internal and external causes as the nervousness by adjustment in demand planning mentioned by Stadtler (2005). Most of the research on ATP is modeled using mathematical programming. Jung (2010) modeled ATP by considering customer priorities and penalty costs. A more practical work regarding the ATP calculation and updating time and structure was done by Plattner et al. (2013). They evaluated ATP creation based on the aggregation of data in a SC. Their work addressed the complexity of information sharing within the SC to improve the quality of ATP. They introduced the lack of an availability check as a drawback of several current ATP calculation systems, which leads to the loss of extremely important information for planning purposes.

In conclusion, although APS and ATP were designed to stabilize the production plan and they are also successive in improving stability (Moscoso et al. 2010), nervousness in ATP has been recorded during industry practices which affects the order promising procedures. Therefore, the study of ATP nervousness as an important paradigm in stability of SCP and order management is the gap that this research work is looking on.

## **2.3 Simulation-based Decision-Making in Semiconductor SC**

SC as a set of linked value chains (information, cash, materials, decisions) plays a central role in generating competitive advantages for production systems. In this complex, integrated, and interactive relationship system, decision making is a crucial and challenging process. Modeling and simulation can assist decision makers to design, develop, analyze, and revise the SC system (Oliveira et al. 2016; Kleijnen 2005). The three main topics where SC simulation has proven to be advantageous (more than 60 percent of publications)

are: (1) understanding and diagnosing problems within SCs, (2) SC's performance improvement, and (3) experimenting new scenarios, models or projects (Oliveira et al. 2016).

The importance and complexity of SC issues in semiconductor manufacturing is increasingly important. Mönch et al. (2018a) discussed the importance of obtaining the advantages of simulation modeling for addressing the challenges in understanding, improving, and testing of the management of semiconductor SC systems. The use of simulation for evaluating SCP in semiconductor manufacturing has been used by several researchers (Mönch et al. 2018a).

Beyond the importance of simulation in SC management and semiconductor SCP, the evolution of computation power and the ability of combined simulation modeling (i.e., multi-paradigm simulation of Discrete Event, System Dynamic, and Agent Based paradigms), has make it more feasible for researchers to analyse SCP systems using more complex simulation models (Mönch et al. 2018a).

To the best of our knowledge, evaluating the nervousness of SCP by the means of simulation modeling is an area that has not yet been studied.

## **2.4 Literature Review Summary**

A conclusion from the above literature review, we can state that most of research in planning instabilities and nervousness focused on external sources of instability caused in production planning and MRP systems. Moreover, the methods to dampen instabilities are mostly reactive. Although works like Demirel et al. (2019) proactively looked at the instability of SC network caused by external reasons, there are still several open avenues with respect to the instability of SCP systems.

In this paper, we are trying to fill the gap in the literature with regards to investigating the nervousness in complex and interactive SCP systems caused by internal sources, based on a proactive damping strategy. Our focus is specifically on APS nervousness and when it is emanated in ATP. For this purpose, we used a multi-paradigm simulation modeling approach of DES and agents, a method that has not yet been exploited in this context. This study sheds light on the interactions between planning modules and production such as, information flows, planned revisions and update methods that may cause internal nervousness of ATP.

## **3 CASE STUDY AND SIMULATION MODEL**

In this study, we investigate the reasons of nervousness within the SCP system by examining the nervousness in ATP and DF caused by the lack of internal processes compatibility. In this section, we introduce the SCP system of our case study and the sources of ATP nervousness inside it. As well, we describe the conceptual model of the developed multi-paradigm simulation model.

### **3.1 SC Management and Planning**

SC as a complex system with stochastic and dynamic parts, has several elements where its total performance depends on their individual performance behaviours and interactions within the designed network (Pundoor and Herrmann 2006). A standard descriptive SC Management (SCM) model, called SC Operation Reference (SCOR) model, was developed by the SC Council to model, describe, communicate, control, and evaluate SC configurations (Huan et al. 2004). The SCM framework in semiconductor manufacturing in general and in our case study specifically follows the SCOR model and its elements of Plan, Make, Source (supply), and Deliver (see Figure 1).

Based on the SCOR model, the SCM of the case study could be divided into material flow and information flow. The material flow concerns Source (i.e., supply), Make (i.e., global production that consists of front-end, back-end, logistics and decoupling points as stocks), and Deliver (i.e., customers) parts. On the other hand, the information flow is mainly related to the plan part which is constituted of five sub-processes. Capacity planning is the process of identify, assess, prioritize, and aggregate capacities while demand planning concerns forecasting, aggregating, prioritizing and calculating demands. The divisional model planning is responsible for matching the planned demand with planned capacity and creating the

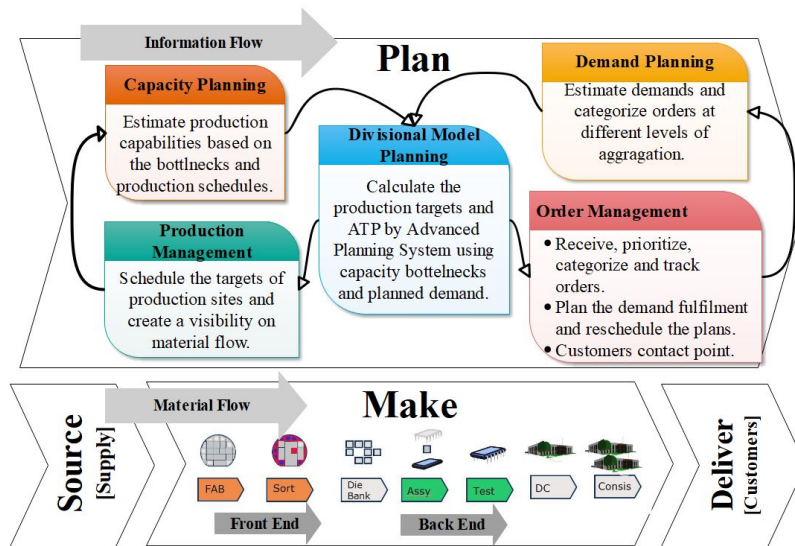


Figure 1: Supply chain reference model in semiconductor SCM case study.

production plan and ATP. In production management, production is scheduled in different parts where a visibility to the flow of materials in global production processes is ensured. Finally, order management is the process of receiving orders, ensuring contact with customers, and providing promises based on the ATP.

SCP has an iterative and hierarchical nature. Products are divided into different granularity levels based on the step of their production or the decoupling points. The time horizon of a plan describes the planning level: long term (strategical), mid-term (tactical), and short-term (operational). The higher the planning level is, the more aggregated the data is. SCP, as the main part of the SCM, is made of connected network of software modules, human interventions and decisions, and rules and regulations that all provide a complex interactive system. The head of this complex system is called APS which runs automated algorithms under a module of the Divisional Model Planning. This computation core, by the means of software modules, takes as inputs the forecasts, orders, planned demand, and stocks from demand planning as well as the capacity bottlenecks from capacity planning. These inputs are transferred into production targets to be used in production scheduling of each fab and ATP to be used by the order management system.

### 3.2 Demand Fulfillment and ATP Nervousness

DF processes provide promises for requested orders. ATP as a picture of current, ongoing, and future supplies helps DF's software modules and planners generate fast and reliable promises. The first date and quantity promised to the customer by consumption of ATP, create a baseline for orders on delivery time. Therefore, the ATP nervousness, by moving through the rolling horizon planning, leads to unconfirmed orders and customer dissatisfaction; which is always avoided by customers relationship strategy of our case study.

In this study, we experiment with the sources of ATP nervousness caused by the interactions between the Physical Paradigm (PP) (i.e., the material flow in internal SC and global production system) and the Virtual Paradigm (VP) (i.e., the information flow in the SCP system). Timing of information updates in different product granularity levels, frequency of these updates, event triggers and sequences, and SC elements dependencies and relations are examples of these complex interactions. In the case study, for the sake of advance understanding of the shift between dates and quantities promised to customers and real existence of final products, rescheduling happen regularly in DF software modules. In fact, the rescheduling checks that current dynamic ATP can still satisfy promised orders or not.

If the result of reschedule is not the same as promised, an alarm system, called Early Warning (EW), is triggered to announce the shifts for planners to be involved for adjustment or finding the reasons. EW can be positive if the new promised date is earlier than the previously confirmed date; or negative if not.

The cause and effects of EWs could not be revealed by data analysis while this nervousness effects the efficiency of the system. Thus, in this study, by modeling and simulating the whole effective SCP (as a VP) and the global production system (as PP) in a simplified model of the system, we are looking to evaluate and experiment with the causes and effects of EWs and ATP nervousness.

### 3.3 Simulation Model

As semiconductor's SCM is a complex system, planning nervousness might have internal sources that come from lack of compatibility and interaction harmony between different system elements. For example, a planning software updates the ATP based on a repetitive schedule or a user command, while the inputs of the software are not updated because of the stochastic nature of production or logistic parts (an interaction between VP and PP). To analyze the sources of ATP nervousness caused by interactions between PP and VP, we used a multi-paradigm simulation modeling approach where we combined Agent Based Simulation (ABS) with Discrete Event Simulation (DES). To better understand our approach and the complexity and challenges of the studied system, the conceptual model of the SCM system of our semiconductor case study is presented in Figure 2. The conceptual model tries to depict the internal SCM system.

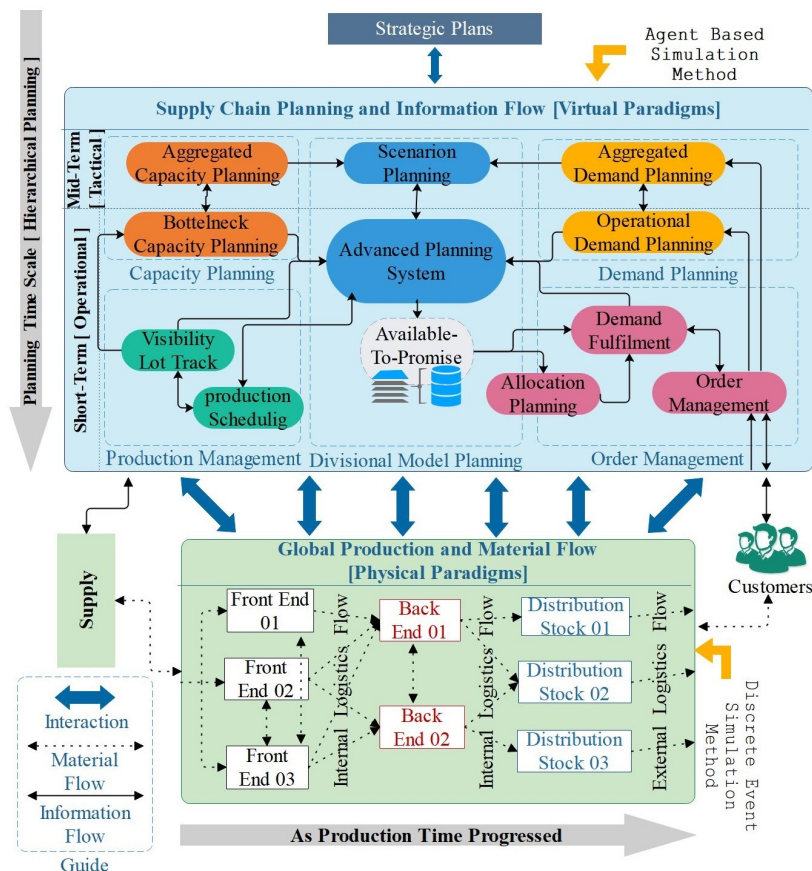


Figure 2: Conceptual model for analyzing nervousness.

As presented in Figure 2, to simulate the SCM internal system we used two different paradigms, ABS and DES. Global production and material flow, referred to as PP, are simulated by DES while SCP and

information flow, referred to as VP, are simulated by ABS. We used these two different simulation methods due to the heterogeneity of these two interactive systems. In fact, the PP is a connection of different global manufacturing and logistic processes that are responsible for transferring supply into finished products. Front-end and Back-end productions are the most important stages of semiconductor manufacturing, in addition to the decoupling points (i.e., stocks) and the internal logistics (i.e., the regular transport of materials inside the global production system). The benefits of using DES for simulating production lines and material flow, have been previously proven as reviewed by Mönch et al. (2018a). The DES focuses on the holistic manufacturing processes of front-end, back-end and internal logistic. In other words, within the DES part of our simulation model, we represent statistical behavior of production lines without going into details of the facilities. In fact, three production lines in front end, and nine production lines in back end are considered for experimentation.

The VP is simulated by the mean of ABS. In fact, the use of ABS in socio-technical systems like SC has been recently taken into consideration (Macal 2016; Clausen et al. 2019). In this work, we model and simulate the complex SCP system by the mean of ABS because of the following reasons. First, ABS and its computation core is similarly close to the paradigm of object-oriented programming that software modules of SCP are based on. Second, in ABS, the behaviour of agents affect each other which is quiet similar to the interactions between SC's elements, human decisions, and software modules. Moreover, each software module, human planner, and other element of SCP system could be modeled in a separate and bottom-up approach. This bottom-up feature of ABS gives the possibility to the modeler to construct the planning system block by block, starting from distinguishable and understandable elementary components until more complex parts are modeled.

In the VP (see Figure 2), the flow of information is as follows. Firstly, customers enter their orders which come to the order management agent. Based on the business logic, orders are then categorized and sent to the demand planning (DP) part. DP consists of two hierarchical parts which are: (1) the aggregated demand planning, that runs in mid-term (i.e., tactical) and calculates the upcoming demand based on the forecasts, orders, and business strategies; and (2) the operational demand planning which calculates and forecasts the demands within the operational planning horizon to be used by APS. On the top left side of the VP, the aggregated capacity and bottlenecks are calculated in mid-term and short-term respectively based on the data that comes from production management. In mid-term, the aggregated capacity plan and the aggregated demand plan are matched and a production scenario is developed for the production targets and stock goals. In short-term, bottleneck capacities, the operational demand plans, lot track updates, production schedules, and demand fulfillment plans in a rolling horizon all are used as inputs for the Advanced Planning System (APS). APS calculates the production targets for the DES model and updates its plan relatively to the production step. In addition, based on the number of finished products, products in process and planned production, APS calculates the future supply picture called ATP. This ATP is stored in the database and consumed by new orders and forecasts coming from customers. Automated DF and manual allocation planning are the modules that consume the ATP based on the customer orders. In DF, there is an algorithm that reschedules all the undelivered orders every day, and if any promised date is changed because of ATP nervousness when the rolling horizon plans moves, the system creates an EW.

In this multi-paradigm simulation model, we simulate simplified VP, PP, and their interactions to experiment the ATP nervousness and EW generation function, in addition to the effects of internal interactions, information update frequency and shared data quality on ATP nervousness.

## **4 EXPERIMENTS**

### **4.1 Experiments Design**

ATP plan is calculated based on the rolling horizon. Thus, it shows the amount of products in different levels of production (front-end, back-end, stock and in transit) from now to the end of the planning horizon. To create the ATP, APS should interact with the PP and get the number of products and detailed plans



in different steps of material flow (e.g., the number of products sent from back-end to final stocks with internal logistic). In the VP, the expected transit time that the APS uses to calculate the planned ATP in final stocks is a constant parameter called Planned Transit Time (PTT). PTT defines the expectation of delivery time period from back-end to stock. PTT is calculated based on the average transit time between back-end and stock. In the PP, although the material transit time is predictable, it is not fixed but varies. The real amount of time spent by the product to be delivered from back-end to the stock is called Real Transit Time (RTT). It is worth noting that, the planning system provides promises based on the PTT.

Three different scenarios could occur based on the values of PTT and RTT: (1) PTT is equal to RTT which means that the expectation is equal to reality, (2) PTT is bigger than RTT which means that what is expected, happens sooner, and (3) PTT is less than RTT which means that what is planned does not happen on time. We experimented using the developed simulation model based on these different scenarios to evaluate the effect of above mentioned relationships between RTT and PTT on the ATP nervousness. The obtained results are presented in the next subsection.

## **4.2 Results**

To examine the hypothesis of deviation between RTT and PTT as a cause of nervousness in ATP, we design three scenarios to experiment with, which are presented in Table 1. Each scenario is replicated 10 times and the average results are plotted in Figure 3. The simulation model time units is hours and it runs for the period of 25 weeks. The first 7 weeks are designed to allow the model to reach steady-state and the next 20 weeks approximates steady-state. Figure 3 shows the percentage of nervousness in ATP for the final 10 weeks before the unit is delivered, with weeks depicted in the x-axis from week 10 to 2 and from week 2 to the delivery date, the unit changes to days.

When the internal transit time between back-end and final distribution stocks can not meet the planned time, ATP nervousness in ATP is expected, mainly when it is very close to shipping the promised orders. As presented in Figure 3, the simulation model clearly verifies this hypothesis and properly shows planned and real transit time mismatch as a source of ATP nervousness. The average of deviations generated by the simulation model is validated by comparing the values to EW frequency, extracted from real data, which varies from 18 to 34 percent.

In scenario 1, we considered different PTT for each product type while the statistical distributions of RTT were the same (i.e., a triangular distribution with the maximum value of 5 days, minimum value of 3 days and a mode of 4 days). In Figure 3 the results of scenario 1 shows that, as far as the PTT increases (from 3 to 5 days), the nervousness in ATP decreases. This could be explained by the fact that a larger PTT makes the system less sensitive to possible delays in transit. However, this setting may result in a higher level of stocks that should be kept in inventory until the shipping date arrives.

In scenario 2, we considered the same PTT for all product types while we used different settings for RTT values. The results show that, when RTT is bigger than PTT, there is a big shortage in the expected products arrival date (around 70 percent). At the same time, even when the RTT is less than PTT, there is still a shortage that could be explained by nervousness in previous production steps and mostly the back-end.

In the last scenario, PTT was also considered the same for all product types and we set RTT to follow different triangular distributions with a mode less or equal to PTT. In this scenario, we recorded the lowest average of total ATP nervousness and EW frequency. We can conclude that adjusting the PTT of each products type to its RTT has direct impact on the performance of the SC system.

As a conclusion, based on the experimented scenarios, we can state that the evaluated hypothesis of the effect of PTT and RTT mismatch on ATP nervousness is proved but other sources exist. Since the simulation model can capture different interactive networks within the SC system, it could be easily expanded to evaluate other hypothesis regarding their internal compatibility and its consequences on the overall operational performance of SC.

Table 1: Experimented scenarios.

	Scenario 1		Scenario 2		Scenario 3	
Product Type	PTT	RTT	PTT	RTT	PTT	RTT
1	3 days	Triangular (3, 5, 4)	4 days	2 days	4 days	Triangular (2,3,5,3)
2	4 days	Triangular (3, 5, 4)	4 days	4 days	4 days	Triangular (3, 5, 4)
3	5 days	Triangular (3, 5, 4)	4 days	6 days	4 days	Triangular (2, 6, 3)

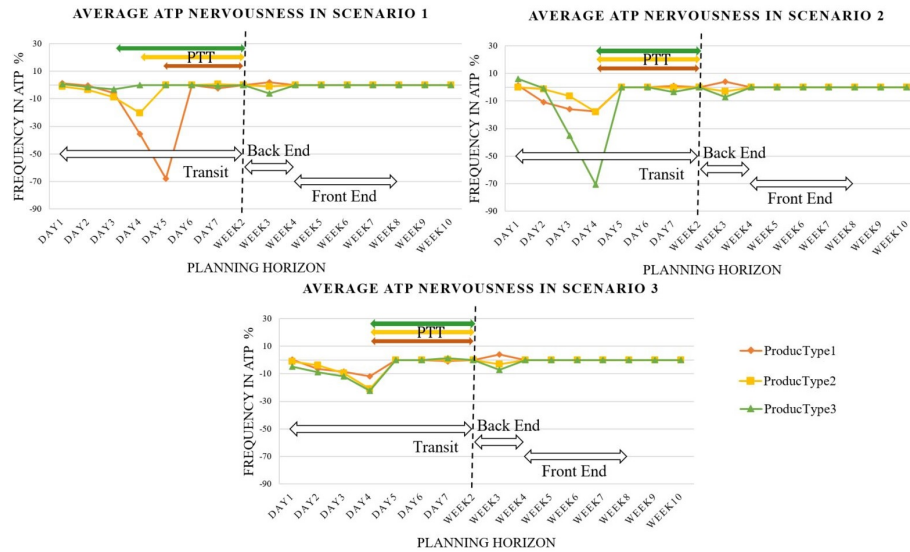


Figure 3: Frequency in ATP based on different PTT and RTT settings.

## 5 CONCLUSIONS

In this work, we researched the internal nervousness of a SC using simulation. This approach let us simulate all elements of the SC with a reasonable level of simplification. It goes beyond material flow network analysis by incorporating a complex planning system and the way it interacts with the physical system. We applied this approach to a case study of a semiconductor manufacturer SC. As it is relatively parsimonious in terms of required inputs, it could be applied in any similar context. In addition, we examined the sources of internal nervousness that affects ATP in the demand fulfillment module of a hierarchical APS. The results provide insight into the importance of visibility on the internal interactions of SC networks to reduce instability. We demonstrated the effects of deviation between PTT and RTT on ATP nervousness and EWs. Further studies could be conducted on how to adjust planning to proactively reduce nervousness. In addition, regarding the sources of nervousness or instabilities in SC, different assumptions could be raised like bottlenecks in PP. To experiment other hypotheses, the conceptual model of interactive PP and VP is easily extendable for future research and validation of conceptual model.

## ACKNOWLEDGMENTS

This project named Productive 4.0 has received funding from the Electronic Component Systems for European Leadership Joint Undertaking under grant agreement No 737459. This Joint Undertaking receives support from the European Union's Horizon 2020 research and innovation program and Germany, Austria, France, Czech Republic, Netherlands, Belgium, Spain, Greece, Sweden, Italy, Ireland, Poland, Hungary, Portugal, Denmark, Finland, Luxembourg, Norway, Turkey.

This publication has emanated from research conducted with the financial support of Science Foundation Ireland (SFI) under Grant Number SFI 16/RC/3918, co-funded by the European Regional Development Fund.

## REFERENCES

- Carlson, R. C., J. V. Jucker, and D. H. Kropp. 1979. "Less Nervous MRP Systems: A Dynamic Economic Lot-sizing Approach". *Management Science* 25(8):754–761.
- Chen, C., N. Srinivasan, and N. Syed. 2005. "Method for Updating the Supply Plan used by an Available-To-Promise System". US Patent App. 10/612,257.
- Clausen, U., M. Brueggenolte, and M. Kirberg. 2019. "Agent-Based Simulation in Logistics and Supply Chain Research: Literature Review and Analysis". In *Advances in Production, Logistics and Traffic: Proceedings of the 4th Interdisciplinary Conference on Production Logistics and Traffic*, edited by U. Clausen, S. Langkau, and F. Kreuz, 45–59. Cham, Switzerland: Springer.
- De Sampaio, R. J., R. R. Wollmann, and P. F. Vieira. 2017. "A Flexible Production Planning For Rolling-Horizons". *International Journal of Production Economics* 190:31–36.
- Demirel, G., B. L. MacCarthy, D. Ritterskamp, A. R. Champneys, and T. Gross. 2019. "Identifying Dynamical Instabilities In Supply Networks Using Generalized Modeling". *Journal of Operations Management* 65:136–159.
- Fleischmann, B., and H. Meyr. 2003. "Planning Hierarchy, Modeling And Advanced Planning Systems". *Handbooks in Operations Research and Management Science* 11:455–523.
- Fleischmann, B., H. Meyr, and M. Wagner. 2015. "Advanced Planning". In *Supply Chain Management and Advanced Planning*, edited by H. Stadler, C. Kilger, and H. Meyr, 71–95. Berlin Heidelberg: Springer-Verlag.
- Geier, S. 2014. *Demand Fulfillment bei Assemble-to-Order-Fertigung: Analyse, Optimierung und Anwendung in der Computerindustrie*. Wiesbaden: Springer Gabler.
- Gelders, L. F., and L. N. Van Wassenhove. 1982. "Hierarchical Integration in Production Planning: Theory and Practice". *Journal of Operations Management* 3(1):27–35.
- Gruchmann, T., and T. Gollmann. 2017. "Simulation-based Modeling And Analysis of Schedule Instability in Automotive Supply Networks". In *Operations Research Proceedings 2015*, edited by K. F. Dörner, I. Ljubic, G. Pflug, and G. Tragler, Volume Operations Research Proceedings (GOR (Gesellschaft für Operations Research e.V.)), 453–458. Cham, Switzerland: Springer.
- Hasachoo, N., and R. Masuchun. 2016. "Reducing Schedule Nervousness in Production and Operations under Non-stationary Stochastic Demand: The Case of an Airline Catering Company". In *2016 IEEE International Conference on Industrial Engineering and Engineering Management (IEEM)*, 941–945. Bali, Indonesia: Institute of Electrical and Electronics Engineers (IEEE).
- Hegde, S. R., R. J. Milne, R. A. Orzell, M. C. Pati, and S. P. Patil. 2004. "Decomposition System and Method for Solving a Large-scale Semiconductor Production Planning Problem". US Patent 6,701,201.
- Heisig, G. 2012. *Planning Stability in Material Requirements Planning Systems*. Berlin Heidelberg: Springer Science & Business Media.
- Herrera, C., S. Belmokhtar-Berraf, A. Thomas, and V. Parada. 2016. "A Reactive Decision-Making Approach to Reduce Instability in a Master Production Schedule". *International Journal of Production Research* 54:2394–2404.
- Herrera, C., and A. Thomas. 2009. "Simulation of Less Master Production Schedule Nervousness Model". *IFAC Proceedings Volumes* 42:1585–1590.
- Ho, C.-J. 2005. "Examining Dampening Effects for Alternative Dampening Procedures to Cope with System Nervousness". *International Journal of Production Research* 43:4009–4033.
- Huan, S. H., S. K. Sheoran, and G. Wang. 2004. "A Review and Analysis of Supply Chain Operations Reference (SCOR) Model". *Supply Chain Management: An International Journal* 9:23–29.
- Jung, H. 2010. "An Available-To-Promise Model Considering Customer Priority and Variance of Penalty Costs". *The International Journal of Advanced Manufacturing Technology* 49:369–377.
- Kleijnen, J. P. 2005. "Supply Chain Simulation Tools and Techniques: A Survey". *International Journal of Simulation and Process Modelling* 1:82–89.
- Koca, E., H. Yaman, and M. S. Aktürk. 2018. "Stochastic Lot Sizing Problem With Nervousness Considerations". *Computers & Operations Research* 94:23–37.
- Levy, D. L. 1995. "International Sourcing and Supply Chain Stability". *Journal of International Business Studies* 26:343–360.
- Li, Q., and S. M. Disney. 2017. "Revisiting Rescheduling: MRP Nervousness and The Bullwhip Effect". *International Journal of Production Research* 55:1992–2012.
- Macal, C. M. 2016. "Everything You Need to Know About Agent-Based Modelling and Simulation". *Journal of Simulation* 10:144–156.

- Meistering, M., and H. Stadler. 2019. "Stabilized-cycle Strategy for a Multi-Item, Capacitated, Hierarchical Production Planning Problem in Rolling Schedules". *Business Research* 12:1–36.
- Mönch, L., R. Uzsoy, and J. W. Fowler. 2018a. "A Survey of Semiconductor Supply Chain Models Part I: Semiconductor Supply Chains, Strategic Network Design, and Supply Chain Simulation". *International Journal of Production Research* 56:4524–4545.
- Mönch, L., R. Uzsoy, and J. W. Fowler. 2018b. "A Survey of Semiconductor Supply Chain Models Part III: Master Planning, Production Planning, and Demand Fulfilment". *International Journal of Production Research* 56:4565–4584.
- Moscato, P. G., J. C. Fransoo, and D. Fischer. 2010. "An Empirical Study on Reducing Planning Instability in Hierarchical Planning Systems". *Production Planning and Control* 21:413–426.
- Oliveira, J. B., R. S. Lima, and J. A. B. Montevechi. 2016. "Perspectives and Relationships in Supply Chain Simulation: A Systematic Literature Review". *Simulation Modelling Practice and Theory* 62:166–191.
- Plattner, H., A. Zeier, C. Tinnefeld, S. H. Mueller, and S. Hillig. 2013. "Available-To-Promise on an In-Memory Column Store". US Patent 8,601,038.
- Pujawan, I. N., and A. U. Smart. 2012. "Factors Affecting Schedule Instability in Manufacturing Companies". *International Journal of Production Research* 50:2252–2266.
- Pundoor, G., and J. W. Herrmann. 2006. "A Hierarchical Approach to Supply Chain Simulation Modelling Using the Supply Chain Operations Reference model". *International Journal of Simulation and Process Modelling* 2:124–132.
- Sivadasan, S., J. Smart, L. H. Huatuco, and A. Calinescu. 2013. "Reducing Schedule Instability by Identifying and Omitting Complexity-Adding Information Flows at the Supplier–Customer Interface". *International Journal of Production Economics* 145:253–262.
- Sridharan, S. V., W. L. Berry, and V. Udayabhanu. 1988. "Measuring Master Production Schedule Stability under Rolling Planning Horizons". *Decision Sciences* 19:147–166.
- Stadler, H. 2005. "Supply Chain Management and Advanced Planning—Basics, Overview and Challenges". *European Journal of Operational Research* 163:575–588.
- Stadler, H., C. Kilger, and H. Meyr. 2015. *Supply Chain Management and Advanced Planning: Concepts, Models, Software, and Case Studies*. 5th ed. Berlin Heidelberg: Springer-Verlag.
- Steele, D. C. 1975. "The Nervous MRP System: How to Do Battle". *Production and Inventory Management* 16:83–89.
- Swift, C., V. D. R. Guide Jr, and S. Muthulingam. 2019. "Does Supply Chain Visibility Affect Operating Performance? Evidence from Conflict Minerals Disclosures". *Journal of Operations Management* 65(5):406–429.
- Tiacci, L., and S. Saetta. 2012. "Demand Forecasting, Lot Sizing and Scheduling on a Rolling Horizon Basis". *International Journal of Production Economics* 140:803–814.

## AUTHOR BIOGRAPHIES

**BEHROUZ ALIZADEH MOUSAVI** is PhD Researcher in the Enterprise Research Center at the University of Limerick. He works under WP4 and WP5 of H2020 project Productive4.0. He holds a M.Sc. in Industrial Engineering specialized in project management from the University of Tehran. His research interests include supply chain system analysis and design, complex systems, demand fulfilment and order management systems, business process modelling, multi-paradigm simulation modeling, mathematical optimization, data analysis, and project management. His email address is [Behrouz.Mousavi@ul.ie](mailto:Behrouz.Mousavi@ul.ie).

**RADHIA AZZOUZ** has been working as Post-doctoral Researcher in the Enterprise Research Centre at the University of Limerick, Ireland since February 2018. She holds a PhD in computer science from the University of Tunis, Tunisia. Her research interests include multi-objective optimisation; dynamic optimisation; evolutionary algorithms and simulation modeling. She also worked as Software Developer for more than 7 years at Tunisie TradeNet, Tunisia. Her email address is [Radhia.Azzouz@ul.ie](mailto:Radhia.Azzouz@ul.ie).

**CATHAL HEAVEY** is an Associate Professor in the School of Engineering at the University of Limerick. He is an Industrial Engineering graduate of the National University of Ireland (University College Galway) and holds an M. Eng.Sc. and Ph.D. from the same University. His research interests include simulation modeling of discrete-event systems; modeling and analysis of supply chains and manufacturing systems; and decision support systems. His email address is [Cathal.Heavey@ul.ie](mailto:Cathal.Heavey@ul.ie).

**HANS EHM** is Principal of Logistics Systems of Infineon Technologies AG. He holds degrees in Physics from Germany and a M.S./OSU. In over 20 years in the Semiconductor industry he was granted managing and consulting Positions at Wafer Fabrication, at Assembly & Test and nowadays for the global Supply Chains. He is Board member of camLine Holding AG, an IT company for supply- and quality chains. He led many projects on national and international level in the context of IT, Semiconductor Manufacturing and Supply Chains. He leads the WP7 Exploitation and Dissemination of the co-funded H2020/Excel project Productive 4.0. His email address is [Hans.Ehm@infineon.com](mailto:Hans.Ehm@infineon.com).