Decision-Making System and Operational Risk Framework for Hierarchical Production Planning

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Abstract: Business processes are designed to perform in an ideal environment where incidents that disturb regular working processes do not exist. However, this environment is fairly idealist, since business processes are affected by many different events, forcing changes in plans or solutions that allow for business continuity. In the context of hierarchical production planning, unexpected events, such as the lack of availability of materials, rush orders and faulty machines; have to be managed efficiently because they represent a risk for business continuity, depending on their impact and duration. In this sense, operational risk management, supported by decision support systems, allow enterprises to have contingency plans that show the decision maker different ways to manage the specific event through rules that check the event's impact and analyse provenance data stored in data warehouse. In the on-going research of inter-enterprise architecture, it has been labelled its main elements: framework, methodology and modelling languages. This paper proposes a decision-making and operational risk framework, looking for solutions that facilitate the decision-making process under the arrival of unexpected events that affect hierarchical production planning.

Keywords: inter-enterprise architecture, decision-making, decision support systems, operational risk management, hierarchical production planning.

1. INTRODUCTION

Inter-enterprise architecture (IEA) facilitates the integration of collaborative business processes of many enterprises in line with their information systems / information technology (IS/IT), in order to support joint processes, reduce risks and redundancies, increase customer service and responsiveness, reduce technology costs and allow for alignment on multiple levels (Vargas et al., 2013). An inter-enterprise architecture is made up of: framework, modelling language and methodology. Due to the fact that this is a wide field of study, we want to focus on a specific context of hierarchical production planning (HPP) supported by decision support systems (DSS), when unexpected events happen that threatening business continuity.

Collaborative planning can be seen in the different hierarchical levels of organizations and should start from a strategic communicating decision across organizations at the highest level that will modify processes of both tactical and operational levels. Specifically, decisions and processes affect different activities in terms of production planning, purchase planning, distribution planning, logistics planning, among others. All these decisions involve a complex selection among a large number of alternatives. Therefore, formulate the general problem, as a single model is extremely complex. In this sense, hierarchical production planning systems facilitate decision-making decomposing the problem into sub-problems, in the context of an organizational hierarchy where decisions of the higher levels impose restrictions to the lower levels (Alemany, 2003).

The use of support systems for decision-making in the field of hierarchical production planning has increased the potential of these systems providing better information management and the use of computer tools to solve mathematical models aiding decision-making (Boza et al., 2010). Additionally, production-planning systems face decisions that force non-programmed decision-making causing, for instance: re-delivery planning, change in the amounts committed or modifications master production plan (Acevedo and Mejia, 2006; Alvarez, 2007). However, the difficulties and costs, which imply the recreation of these plans, often prevent those plans from taking effect. Thus, potential benefits are lost because organizations do not know how to respond appropriately to unexpected events, or even worse, those unexpected events endanger the business continuity if their duration is prolonged.

In this paper, keeping with the on-going research, we propose a decision-making framework and the foundations of a system to support operational risk management when unexpected events affect the hierarchical production planning. Our contribution will help enterprises to facilitate the decision-making process under the arrival of different kind of unexpected events that affect the production planning and enabling the operational risk management. In the current literature, there are some works that attempt to solve one or two kinds of unexpected events through mathematical models, proposals that have taken into account multiple events that can affected the production planning do not exist. Our approach for solving this problem is the use of inter-enterprise architecture to define and integrate the main elements of collaborative enterprises, such as business processes, human resources, technology and so on. We propose an abstract framework, in which, instead of handling one individual event, we model business processes, their interactions, and event impacts. With these, given an event, this abstract framework would compute the far reaching (i.e., both direct and indirect) impacts and provide all possible alternatives to perform and continue with the current task. This framework will enable the design of systems by allowing enterprises to have contingency plans showing to the decision maker ways to manage specific events through rules that check the event's impact and analyse provenance data stored in data warehouse.

The paper is structured as follows: Section 2 describes the related work in the fields of: Hierarchical Production Planning and Decision Support Systems. Section 3 presents our proposal of decision-making and operational risk framework, our methodology and the design foundations of a system to support operational risk management when unexpected event happen affecting the hierarchical production planning. Finally Section 4 presents the main conclusions and future steps in this research.

2. RELATED WORK

The focus of our research to this point has been about inter-enterprise architecture (Vargas et al., 2011b; Vargas et al., 2013; Vargas et al., 2013b). The foundations of this research have been the files of collaborative networks (CN) (Camarinha-Matos and Afsamanesh, 2008) and enterprise architecture (EA) (Ortiz et al., 1999; Cuenca et al., 2010). According to (Camarinha-Matos and Afsarmanesh, 2005) "CN is a network consisting of a variety of entities (e.g. organizations, people, machines) that are largely autonomous, geographically distributed, and heterogeneous in terms of their operating environment, culture, social capital and goals, but that collaborate to better achieve common or compatible goals, thus jointly generating value, and whose interactions are supported by computer networks". Enterprise Architecture (EA) is defined by (Cuenca et al., 2010), as a field that provides concepts, models and tools that enable organizations to meet the challenges of the integration of strategic areas and business processes with IT areas, achieving greater value for the companies, improving their performance, communication and degree of integration, which ultimately give rise to the creation of competitive advantage through the effective support of IT to compliance strategies and objectives. Although the use of the EA is implemented and studied in depth in the individual firm, these concepts can be extended to CN, raising the concept of inter-enterprise Architecture.

The main elements of enterprise architecture are: framework, methodology and modelling language (Vargas, et al., 2014), see Fig 1 for its graphical representation. The goal of an inter-enterprise architecture is to search for applications of the tools and methodologies of enterprise architecture, which have been developed for the individual enterprise, but adapting them in a collaborative environment between several enterprises that make up collaborative networks (Vargas et al., 2013)

Inter-enterprise architecture can be approached from different perspectives, since the interest in their study is growing exponentially given the current global market conditions that force associated companies to become more competitive. In this paper, we want to focus on a specific problematic context of hierarchical production planning and the support of decision support systems when unexpected events happen that affect the hierarchical production planning, helping to perform an efficient operational risk management, through the proposal of a decision-making framework that integrates the main elements in this context.

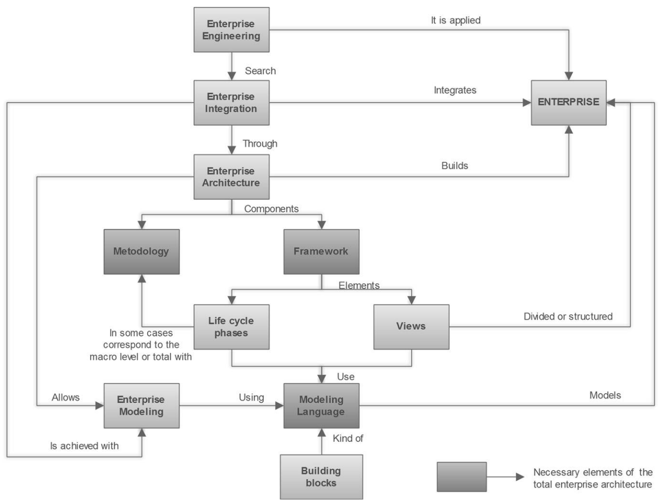

Fig. 1. Main elements of enterprise architecture (Vargas et al., 2014).

2.1 *Future manufacturing paradigms*

In the following section the authors discuss several concepts and influences of emerging manufacturing related paradigms. Some of the identified concepts are further addressed in Hierarchical Production Planning paradigm section.

Three important industrial revolutions have influenced manufacturing: first, coal, steam and mechanization, second, electricity motors and machines and third Computers, Information Technologies and Internet. The fourth major industrial revolution (Dumitrache, 2010) is currently emerging and is enabled by Future Internet paradigms such as Internet of Things and Internet of Services. Thus, the integration of these emerging technologies in industrial environment is enabled by the Cyber Physical Systems paradigm (Dumitrache, 2013; Dumitrache, 2011).

The emerging vision for manufacturing systems is encapsulated in (See Fig. 2):

- Industrie 4.0 concept developed with the aid of the German government, with the aim of implementing Smart Factories (Kagermann et al., 2013);
- Smart Manufacturing developed in USA by "Smart Manufacturing Leadership Coalition";
- Industrial Internet (of Things) introduced by General Electric and supported by "The Industrial Internet Consortium" (Evans et al., 2012; Evans and Annunziata, 2012);

Industrie 4.0 vision integrates (Blanchet et al., 2014; Kagermann et al., 2013):

- Cyber-Physical Systems including sensor and actuator networks, intelligent network control systems and human in the loop principles (See Fig. 3) (Avram and Dumitrache, 2014; Dumitrache, 2013);
- Intelligent Robots and Machines including human-robot interaction, adaptive control, context awareness (Dumitrache , 2010);
- Big Data including data agility and processing platforms;
- Network Quality Of Service;
- Energy Efficiency And Decentralization (Dumitrache and Caramihai, 2015);
- Virtual Industrialization in regard to the concept of "virtual plants and products" enabled in order to simulate the production process and further the Product Lifecycle;
- Value Networks aiming at achieving digital integration along the supply chain and along different manufacturing processes and engineering models and methods.

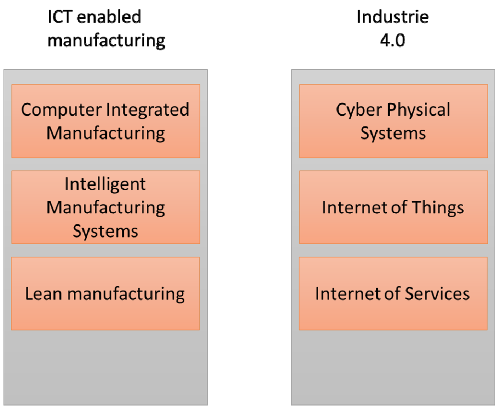

Fig. 2. Paradigms for ICT enabled manufacturing and Industry 4.0 vision.

Expected results envisioned along with Industrie 4.0 paradigm include:

- Product Lifecycle Management – Customization, Living lab;
- Flexible production, cluster dynamics;
- Business models: value chain;
- Knowledge, skills worker;
- Glocal (global - local) concept for manufacturing.

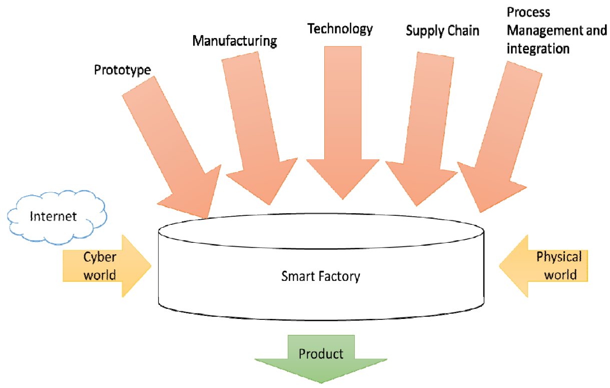

Fig. 3. Smart Factory as a Cyber Physical System.

2.2 Hierarchical Production Planning (HPP)

Collaborative and productive activities, especially the planning and control, should follow a hierarchical approach that allows coordination between the objectives, plans and activities of the strategic, tactical and operational levels, in order to reduce the complexity of the (Jüngen and Kowalczyk, 1995). This means that each level will pursue their own goals, but taking into account the higher level, on which they depend, and the lower level, which is restricted (Boza, 2006; Boza et al., 2009). In hierarchical production planning systems, the decisions are split into sub-problems. Each sub-problem is referred to a decision-making level in the organizational structure and a mathematical model is constructed for solving each sub-problem, which has different planning horizons, aggregating and disaggregating information across hierarchical levels (Vicens et al., 2001).

Operational risk is associated with the execution of companies' business functions. Risk management is the process devoted to protecting the organizations and augmenting its capability to achieve its stated strategic objectives (Borghesi and Gaudenzi, 2013). In the context of production planning the risk is associated with the arrival of unexpected events that affect the normal performance planning. Effectively preparing for unexpected events, such as the lack of available material, rush orders, faulty machines, etc., is vital to guaranteeing business continuity. Therefore, being able to cope with these changes and help decision makers react in the best way, are important issues that must be taken into account in the systems and planning processes. In this regard, there are several studies on trying to handle unexpected events through flexible proposals and robust manufacturing systems (Darmoul et al., 2013). However, most of the work in these areas only consider certain types of unexpected events, or provide limited assistance to the way people react. There is no research evidence to take into account in its proposal the management of different types of unexpected events in an integral way.

The ideal iteration of a production planning system is to be able to detect abnormal behaviour in the system, determining the type of disruption and continuously proposing alternatives depending on the type of event that occurred. Determining the type of unexpected event is important because the system will be affected differently depending on the type of the unexpected event and requires different decisions by the manager. Production systems that are able to react to various unexpected events, have a goal to achieve a coordinated adaptive behaviour during execution of production activities, responding dynamically to changes that occur while the customer demand is satisfied in a cost-effective way (Váncza et al., 2011). In this type of systems, it is also important that the system must acquire data and evidence to learn from past events (Monostori et al., 1998).

Some research carried out a typology of the different kinds of unexpected event that can happen in a manufacturing system and therefore affect production planning. According to the literature, the most complete research is presented by (Darmoul et al., 2013), in which the authors refer to the unexpected events as failures. We have classified different research works that have suggested the need to take into account in the planning process different types of unexpected event, Table 1 condenses the information provided by different authors (Grabot et al., 1996; Xu and Roland, 1997; Fox et al., 2001; Vicens et al., 2001; Álvarez and Zubillaga, 2004; Kádár et al., 2004; Mula et al., 2006; Palacios et al., 2006; Shen et al., 2006; Van Wezel et al., 2006; Alvarez 2007; Katragjini et al., 2009; Monostori et al., 2010; Zhang and Van Luttervelt; 2011; Bearzotti et al., 2012), this table categorizes the most important unexpected events that have been proposed in the literature.

Table 1. Types of unexpected event affecting production planning.

YEAR	AUTHORS	ORIGIN/SOURCE											
		SUPPLY		RESOURCES			PRODUCTION				COSTUMER		
		Delays	Quality problems	Machine breakdowns	Tools breakage	Labour problems	Scraps management	Quality problems	Production times	Product rejection	Rush orders	Order modification	Order cancelation
1996	Grabot, B. et al.			x		y							
1997	Xu, X., Roland, K.	y							x		y		
1998	Ozdamar, L. et al.			x								x	
2000	Fox, M. et al.	x		y		y						x	x
2001	Vicens, E. et al.			x					x				
2004	Alvarez, E., Zubillaga, F	y		x		y					x	x	x
2004	Kádár, B. et al.			x		y			x				
2006	Mula, J. et al.	y		y				y					
2006	Palacios, M. et al.			y					x		y		
2006	Shen, W. et al.	x		y							y	x	x
2006	Van Wezel. Et al.		y							x	x	y	x
2007	Alvarez, E			x	y				x			x	
2009	Katragjini, K. et al.	x		x					x		x	y	
2010	Monostori, L. et al.	y							x		y		
2011	Zhang, W., Luttervelt, C.	y		y									
2012	Bearzotti, L. et al.	y		y	y	y							
2013	Darmoul, S. et al	x	x	x	x	x	x	x			x	x	x
	TOTAL	10	2	14	3	6	1	2	7	1	8	8	5

x	According to Darmoul, S et al. classification (With the same or similar name)
y	It can be deducted for its context #
x (shaded)	New kind of event no having into account for Darmoul, S. et al. [14]

Two types of unexpected events have been added to the classification by (Darmoul et al., 2013): 1) Production times; a type of event relating to the variation of production times and has been cited by various authors. It has been included in the type of Production. 2) Product reject cited by (Van Wezel et al., 2006); dealing with a customer returned product because it has not met the deadlines, because the product does not have the quality requirements and should be reprocessed, or because the client does not have enough space for storage to be delivered prior to the committed delivery date. This type of event has been categorized into the category of unexpected event in the production source.

For each type of event it is necessary to consider different factors for its management such as, duration of the disturbance and criticality of the resources involved, in order to manage this kind of unexpected event in an integral way. Being able to provide to the decision maker with tools that allow her/ his analyse the information about different unexpected events and how they were handled in the past is vital. Thus, operational risk management using decision support systems represents multiples advantages (Grabot et al., 1996).

2.3 Decision Support Systems (DSS)

Information systems, which support the necessary information for managers to make their decision, have become key elements in the decision-making process. In this sense, decision support systems are indispensable tools not only to obtain an ideal solution, but also especially to obtain a broad and deep view of the problem.

A decision support systems can be defined as: An interactive information system used by decision-makers, flexible and adaptable based on information technology, models and data with the purpose of support decision-making processes, providing useful information to decision-makers at all levels of an organization, allowing to achieve the objectives set by the organization (Shim et al., 2002; Dengiz et al., 2006; Boza, 2006; Power and Sharda, 2009; Turban et al., 2005).

According to (Power and Sharda, 2009; Turban et al., 2005), the three main components of decision support systems are: Database Management Systems (DBMS), Model Base Management Systems (MBMS) and the user interface systems (UIS). The implementation of these components depends on each decision context, in this case, decision-making in hierarchical production planning.

Information systems within organizations are becoming more important to support inter-company transactions, and also to facilitate decision-making through increasingly complete systems that guide decision makers in processes where it is necessary to have enough information in a short period of time to ensure efficient decision-making.

The ideal of a hierarchical production planning system is to be able to detect abnormal behaviour in the system, determining the type of disruption and continuity proposing alternatives depending on the type of event that occurred. Determining the type of unexpected event is important because the process will be affected differently depending on the type of the unexpected event and requires different decisions by the manager. In this context, the way the decision maker sees the information can accelerate his/her perception, provide insight and control, and harness this flood of valuable data to gain a competitive advantage in making business decisions (Al-Kassab et al., 2014).

Collaborative networks see the need to adapt their processes, products and services in a competitive market, adapting to new organizational forms, and by pursuing greater flexibility.

Therefore, collaborative networks are required to define more agile processes for assertive decision-making. In order to face current dynamics, it is necessary to provide hierarchical production planning systems of sufficient flexibility. In this sense, some works have proposed different contributions in this field (Hax and Meal, 1973; Weinstein and Chung, 1999; Yan et al., 2002; Hurtubise et al., 2004; Boza, 2006). These contributions demonstrate how the data model has to be integrated with the hierarchical planning system. According to (Boza et al., 2009) the logical building blocks that play an interactive role into the information system and decision technologies for hierarchical production planning are:

- Data Modelling (DaM): Represents the internal structure and the external presentation of the data (Neagu, 1992). Related to the DSS components of (Turban et al., 2005), this building block should correspond with Database Management Systems (DBMS);
- Decision Modelling (DeM): Collect the development of the models. These models are used to evaluate possible decisions in a problem domain. Related to the DSS components of (Turban et al., 2005), this building block should correspond with Model Base Management Systems (MBMS);
- Model analysis and research (MAR): This is the instantiation of decision model with data, model evaluation and results. Related to the DSS components of (Turban et al., 2005), this building block correspond with the user interface systems (UIS).

Control systems in production planning put the focus on analysing whether or not production activity is being carried out as originally planned. In this sense, there is a baseline scenario that uses the planning process for creating the plan. Control systems checked this respect to production process activity. However, in this paper we will put the focus on the events that significantly alter the baseline scenario. The information available at the time the plan may be significantly different after an unexpected event and it would be better to rethink the plan that was made. In this case, it may be that the control system is telling us that productive activity is going as planned and yet we are losing some kind of opportunity or be close to a threat, since the initial circumstances for decision making related to the plan are different. So far, there is little evidence of research whose approach is the use of decision support systems for hierarchical production planning under unexpected event that helps the operational risk management, apart of control systems, thus we have found a gap in our research where we want to continue working.

3. PROPOSED CONCEPTUAL OPERATIONAL RISK FRAMEWORK AND DECISION MAKING SYSTEM

In order to support the decision-making process under the arrival of different kind of unexpected events that affect the production planning and enabling the operational risk management, we propose a decision-making and operational risk framework to handle unexpected events that affect hierarchical production planning. Following the foundations of our previous works (Vargas et al., 2013; Vargas et al., 2014), where we have identified the main elements for modelling collaborative networks through the use of inter-enterprise architecture: framework, methodology and modelling language. In this paper, we want to show a more practical approach in a specific problem of hierarchical production planning when unexpected events happen affecting the plans made and threatening business continuity, through the proposed conceptual framework and its validation in a case study.

It is evident that, in the real world, business processes are dynamic and need to be adapted rapidly when unexpected events affect their normal performance. However, most business processes are designed without taking into account different kind of events or disruptions, because their modelling is easier this way. In the context of hierarchical production planning, a high level workflow is shown in Figure 2. The decision support system provides the necessary data to both levels supporting decision makers in the making-decision process. The inputs in the system are capacity, stocks, production rates, costs and demand. The outputs are different for each level; in the planning level the outputs are the quantities to produce each family of product per period (generally months); and in the operational level their outputs are quantities to produce product per period (generally weeks). The reality is that this ideal environment does not exist and business processes are affected for several kinds of events that force to change plans or to search for solutions that are inefficient.

When an unexpected event occurs at the operational level the complexity of this reality is overwhelming. In order to cope with these complex situations, we propose a decision-making and operational risk framework for hierarchical production planning under the arrival of unexpected events, in which, instead of handling one individual event the system is capable to analyse different events and their duration and impact. This abstract framework would compute the far reaching (i.e., both direct and indirect) impacts and provides possible alternatives to perform and continue with the process. This framework will enable the design of systems allowing enterprises to have contingency plans showing to the decision maker ways to manage specific events through rules that check the event's impact and analyse historical data stored in data warehouse.

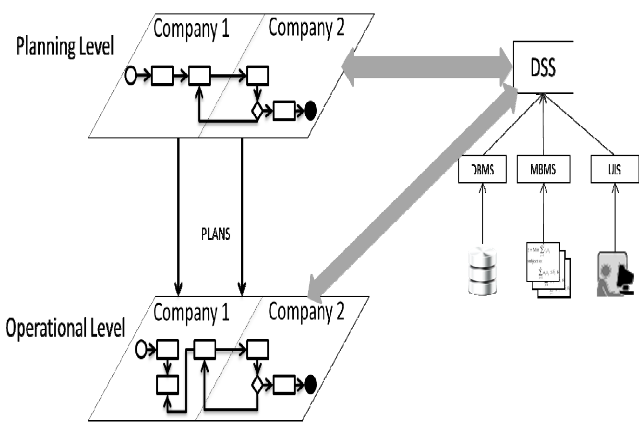

Fig. 4. Workflow of HPP in ideal conditions (no unexpected event).

Figure 3 shows the proposed framework. 1) The upper level is the planning level that sends to the operational level aggregated plans. 2) The operational level is where the risk events happen. 3) The event causes a distortion in operational schedules that the decision makers have to report to an operational decision support system (ODSS). 4) This operational decision support system must provide an alternative solution based on specific rules or models, the operational decision support system has to be flexible and provide fast and feasible solutions in the operational level. 5) At the same time, the ODSS at the lower level will report to the upper level only those disturbances that are beyond its capacity to solve them within the given autonomy, in other words only those unexpected events that were not possible to be solved by dispatching rules due to their significant impact. Due to the fact, that the solution may change the inputs to decisions made on the planning level. 6) The planning decision support system (PDSS) will be updated only for reported unexpected events and propose new plans for subsequent periods. This new plans are sending to the operational level that already have taken into account the impact of the event.

In summary, this framework represents a big picture of the choreography and integration between different decision levels and how unexpected events should be treated to ensure business continuity.

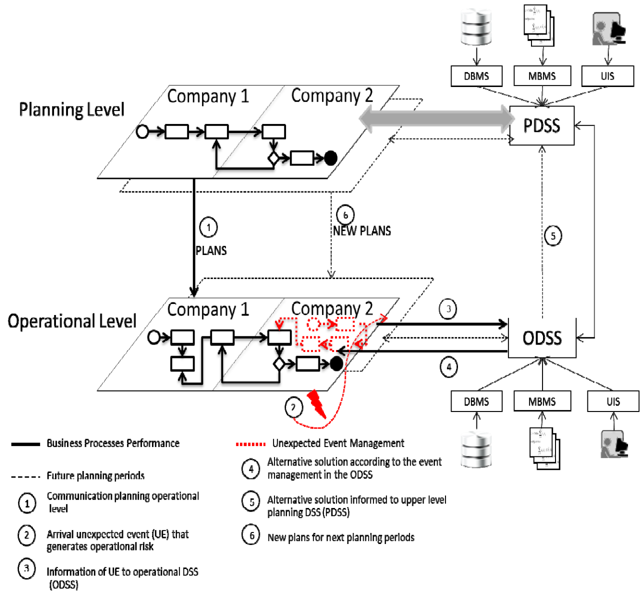

Fig. 5. Decision-making and operational risk Framework for HPP.

In this paper, we want to lay the foundations for the operational decision support system that will help to guarantee the hierarchical production planning continuity at an operational level. The system must provide to the decision maker with feasible alternative solutions based on specific rules for each kind of event, so that the decision maker will be able to have some alternative plans that allow for business continuity without affecting the plans made in the planning level in the current period, but will modify planning for future periods. The use of provenance data in this operational decision support system is vital because it gives the system robustness through the storage of historical data of alternative solutions that decision makers have made and their performance. In this way, enterprises that make up collaborative network and share knowledge allow them to be more competitive. The operational decision support system also has to be flexible if the decision maker decides to implement a different alternative that is no given; in this case it is necessary collect the new alternative into the operational decision support system and its output and performance that will be transformed in provenance data for future events.

As previously indicated, the management of each event is different according to their duration, impact, and the moment it occurs. The latest is related to the current situation against the planned one. For this, it is necessary to capture information about the planning situation, and also capture information about the unexpected events identified in Table 1. This characterization must be adapted to the issues and the context of each hierarchical production planning, but from a general perspective. Table 2 shows for each specific event the necessary inputs: elements involved in the event (Supplier-S, Product-P, Raw material-R, Worker-W, Customer-C, Tool-T and Machine-M), duration, impact and the number that identifies the specific situation. The highlighted cells represent new events that have not been considered in the literature, but that in industrial environment are also common, according to the data that is being collected in the collaborative network of the tile sector in Spain.

Table 2. Necessary input elements for a decision-making system in HPP for unexpected event management.

Event Type	Event sub-type	Specific Event	Input								#
			Elements involved in the event		Duration			Impact			
			Element 1	Element 2	0-1 days	1-5 days	More than 5 days	Low	Medium	High	
Supplier	Delays in raw materials	Delays in raw materials	S	R	x			x			1
						x			x		2
							x			x	3
	Quality problems	Difference in the quantities requested	S	R	x			x			4
						x			x		5
							x			x	6
		Raw material quality problems	S	R	x			x			7
						x			x		8
							x			x	9
Resources	Machine breakdowns	Machine breakdowns	M	P	x			x			10
						x			x		11
							x			x	12
	Tool breakage	Tool breakage	T	P	x			x			13
						x			x		14
							x			x	15
	Labour problems	Workers disease	W	P	x			x			16
						x			x		17
							x			x	18
		Under-performance workers	W	P	x			x			19
						x			x		20
							x			x	21
		High performance workers	W	P	x			x			22
						x		x			23
							x	x			24
		Strike	W	P	x			x			25
						x			x		26
							x			x	27
Production	Waste management	Low utilization of raw materials	R	P	x			x			28
						x			x		29
							x			x	30
		High utilization of raw materials	R	P	x			x			31
						x		x			32
							x	x			33
	Quality problems	Quality problems	M / W	P / R	x			x			34
						x			x		35
							x			x	36
	Production time	Poor performance in production	M / W	P / R	x			x			37
						x			x		38
							x			x	39
		High	M	P	x			x			40

		performance in production	/	/		x			x		41
			W	R			x			x	42
		Return for low quality	M	P	x			x			43
			/	/		x			x		44
			W	R			x			x	45
		Return for late delivery	P	W	x			x			46
	Product returns	Return for early delivery	P	W	x			x			47
Customer	Rush orders	Rush orders	C	P	x			x			48
						x			x		49
							x			x	50
	Modification of orders	Modification orders	C	P	x			x			51
	Cancelling orders	Cancelling orders	C	P	x			x			52
						x			x		53
							x			x	54

The operational decision support system should also be able to manage these inputs to propose a plan of action against the event, using model-based procedures to process data and facilitate new action plan process. These may be based on mathematical models, data mining, artificial intelligence or expert systems. One of these alternatives is to use a system based on rules that must be adapted to the context of each hierarchical production planning system. Based on event duration and impact, we have proposed basic rules that the system should provide to the decision maker, which are detailed in Table 3. These rules can be used as bases of each casuistry identification in the context of hierarchical production planning. Additionally the decision maker should provide to the system with information about elements involved in the solution taken that will be stored in the system for futures queries. As is shown in Table 3, there are some events that do not have elements involved in the solution, because the rule itself resolves the problem without the necessity of any element, or because the rule redirects the given event to another kind of event and its own rule.

Table 3. Rules and elements for each event for a decision-making system in HPP

Event Type	Event sub-type	Specific Event	#	Rule and elements: Rule	Element 1	Element 2
Supplier	Delays in raw materials	Delays in raw materials	1	Wait for the raw material and use the safety stock for production		
			2	Use the safety stock and order the same quantity of the delayed order to supplier 2 as a rush order, cancel order to supplier who has the delay	S	
			3	Use the safety stock and order the same quantity of the delayed order to suppliers 2 and 3 as a rush orders, cancel order to supplier who has the delay	S	S
	Quality problems	Difference in the quantities requested	4	If the difference is more units, return the rest to the supplier if the difference is less units wait missing units and start using safety stock if necessary		
			5	If the difference is more units, return the rest to the supplier if the difference is less units, order the missing quantities to supplier 2 and cancel the rest of the order to supplier who has the missing quantities	S	
			6	If the difference is more units, return the rest to the supplier if the difference is less units, order the missing quantities to suppliers 2 and 3, and cancel the rest of the order to supplier who has the missing quantities	S	S
		Raw material quality problems	7	Wait for the raw materials to be reprocessed and use the safety stock for production		
			8	Wait for the raw materials to be reprocessed and use the safety stock for production, partial deliveries are admitted while the production is not stopped		
			9	Use the safety stock and order the same quantity of the low quality materials to suppliers 2 and 3 as a rush orders, cancel order to supplier who has the event of no quality	S	S
Resources	Machine breakdowns	Machine breakdowns	10	Wait for the maintained team to fix the machine and start preparing the raw materials for the process		
			11	If possible use another machine to make the product, if not outsource the product with the faster Supplier	M	S
			12		M	S
	Tool breakage	Tool breakage	13	Wait for the maintained team to fix the tool and start preparing the raw materials for the process		
			14	If possible use another tool to process the product, if not outsource the product with the faster Supplier	T	S
			15		T	S
	Labour problems	Workers disease	16	If possible other workers work extra hours to make the product that sick worker had assigned	W	W
			17		W	W
			18	Outsource the product with the faster Supplier	S	
		Under-performance workers	19	Exchange workers between tasks	W	
			20		W	
			21	Outsource the product with the faster Supplier	S	
		High performance workers	22	Exchange workers between tasks	W	
			23			
			24			
		Strike	25	Outsource the product with the faster Supplier	S	
			26			
			27			
Production	Waste management	Low utilization of raw materials	28	If there is a problem with the raw material or the worker is doing something wrong, return raw material to supplier and use safety stock to process products or change worker of job	W	
			29	If there is a problem with the raw material, return raw material to supplier and use safety stock to process products, wait for reprocessed raw material, partial deliveries are admitted while the production is not stopped		
			30	Outsource the product with the faster Supplier and return raw material to supplier who provided the raw material	S	
		High utilization of raw materials	31	Keep working as normal		
			32	Keep working as normal, find out the origin of this high utilization and collect it in the system		
			33			
	Quality problems	Quality problems	34	If the origin of the problem is raw material, returns row material to the supplier and use the safety stock to keep working, waiting for reprocessed raw material. If the origin is a machine malfunction, informs to maintained team of problem and wait to be fix it.		
			35	If the origin of the problem is raw material, returns row material to the supplier and use the safety stock to keep working, waiting for reprocessed raw material. If the origin is a machine malfunction, informs to maintained team of problem and outsource the product with the faster Supplier		
			36		S	
	Production time	Poor performance in production	37	Depending of the origin of this event: low utilization of material; machine malfunction or labour problems, treat this event in one of the above categories		
			38			
			39			
		High performance in production	40	Keep working as normal		
			41	Keep working as normal, find out the origin of this high utilization and collect it in the app		
			42			
	Product returns	Return for low quality	43	Work extra hours to reprocess the product.		
			44			
			45	If the customer can wait for products to be reprocessed work extra hours to reprocess product, if not cancel order to customer explaining the reasons for the low quality.	C	
		Return for late delivery	46	Talk with the customer if is possible they receive the product, if not store the product and have it into account for next planning	C	
		Return for early delivery	47	Talk with the customer if is possible they receive the product, if not store the product and deliver in the right moment	C	
Customer	Rush orders	Rush orders	48	Work extra hours to make the products of rush orders	W	
			49		W	
			50	Outsource the product with the faster Supplier	S	
	Modification of orders	Modification orders	51	If the modification is for more units treated as a rush order if is for less treat the rest as a Cancelling order		
	Cancelling orders	Cancelling orders	52	If the product has a high rotation keep working as normal, if not don't produce the product		
			53			
			54			

4. OPERATIONAL RISK FRAMEWORK VALIDATION METHODOLOGY

In order to measure the impact of the Decision-Making and Operational Risk Framework (D-MORF) within the manufacturing process, a set of metrics, adapted from previous research conducted in (Stegaru et al., 2015; Moisescu and Sacala, 2014).

A D-MORF impact vector can be defined as D(i,j,k) = [Pl(s), Ve(j), Ev(k)] with the following three dimensions of the proposed model:

- Pl(i) represents the Product Lifecycle dimension, and is represented by the its business value Pbv(i)
- Ve(j) represents the Virtual Enterprise operational dimension described by the virtualization factor Vf(j) and the Glocal factor Gf(j).

- Ev(k) represents the Engineering Value Chain and encompasses the system of systems vision in terms of engineering models and methods used.

Product Lifecycle factor represents the benefits from the introduction of Industrie 4.0 oriented methods: collaborative design, rapid prototyping and iterative product development. Each element can be interpreted as an attribute. The following values can determine the level of adoption of the presented methods: 0 – none, 1 – very low, 2 – low, 3 – medium, 4 – high, 5 - very high.

Product Lifecycle factor can be determined using the following formula:

$$P_l(t) = \frac{\sum_{i=1}^{3} A_i(s)}{3}$$

The *Inter - Enterprise* operational dimension can be described in terms of complexity introduced by multiple locations in relation to organization specific virtualization factor Vf(j) and Glocal factor Gf(j). Similar factors have been used in correlation with virtual organizations and virtual enterprise, and the utility proven in a case study (Stegaru et al., 2015; Moisescu and Sacala, 2014).

The virtualization factor can be interpreted in relation to the virtualization components such as: environment, machines, workers as well as in relation to th sensing components (Sensing Objects or Sensor Networks) involved (Moisescu and Sacala, 2014).

Considering the simulation principal components $s_1, s_2, \ldots, s_n$ we evaluate the relation between a pair of components (si, sj), where i,j ϵ {1,2, .., n} by calculating the number of elements si that are in a relation with elements of sj. The matrix expressing the relation between a set of n components is defined as:

$$M = \begin{bmatrix} m_{1,1} & \cdots & m_{1,n} \\ \vdots & \ddots & \vdots \\ m_{n,1} & \cdots & m_{n,n} \end{bmatrix},$$

$$m_{i,j} = \begin{cases} 1, \text{if } s_i \text{ in a relation with } s_j \\ 0, \text{otherwise} \end{cases}$$

The Glocal factor can be interpreted as a measure of process change due to the impact of global manufacturing. Processes need to be designed in regard to flexibility and adaptability in order to operate in changing environments. The following formula can be used to calculate the Glocal factor G(j):

$$\text{Response time to change (RTC)} = t_{execution} - t_{detection}$$

$$\text{Execution time of change (ETC)} = t_{end\ execution} - t_{start\ execution}$$

$$G(j) = \frac{RTC}{ETC} * R(j)$$

Where R(j) represents the number of external (global) entities that are involved in the manufacturing process.

Engineering Value Chain refers to system of systems vision in terms of engineering models and methods used. The Black Box method can be used in order to determine the relation between value chain inputs and outputs of a system within the manufacturing supply chain. The factor can be calculated as:

$$E_v = \frac{\text{number of measurable outputs}}{\text{number of determined inputs}}$$

5. CONCLUSIONS

In this paper, we proposed a decision-making and operational risk framework and the foundations of a system to support operational risk management under the arrival of unexpected events affecting hierarchical production planning. This contribution will help enterprises to facilitate the decision-making process under the arrival of unexpected events in the hierarchical production planning ensuring in this way the business continuity.

The proposed conceptual decision-making and operational risk framework will enable to design systems by allowing enterprises to have contingency plans showing the decision maker different alternatives to manage specific events through rules that check the event's impact and duration or vital information based on historical data.

The proposal helps to manage the impacts and provide alternatives to perform and continue with the different tasks. The early identification and mitigation of unexpected events have impact in reducing cost of control implementation and vulnerability mitigation. It allows reducing the gap identified in operational risk management in production planning by identifying different types of unexpected events in an integral way.

The system queries historical data and provides feasible alternatives to the decision maker that allow continue with the processes that are running. The foundations for the operational decision support system consist on the proposal of generic inputs and rules for the system that will help enterprises to manage efficiently the arrival of unexpected events that affect hierarchical production planning.

In a collaborative context these benefits become more important because companies that make up collaborative networks start a learning process by sharing knowledge of how they handle events and the information became vital in the decision-making process allow them to retrieve the information collected in past experiences and based on this the decisions makers can handle decisions smoothly and efficiently.

Our next step in this research is to validate the functionality of our proposal in a Spanish collaborative network in the ceramic sector. In order to achieve this goal, the necessary data and information are being collected and analysed. In parallel, we are designing the operational decision support system that will support our validation in the collaborative network environment.

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