Dynamic Planning Integrated to Production and Maintenance in Composites Industry: Application of MaSe Methodology.

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Abstract

In the composites industry, each change must take into account lot of parameters before being able to set it up. This requires an important amount of data sharing in a limited time. Nonetheless, only a minor part of this data is concretely used by the planners for an almost real-time analysis and optimization within production systems.

This paper proposes a multi-agent approach for dynamic planning integrated to production and maintenance. According to the supply chain operations reference model (SCOR), to focus on the process of transforming products to a finished state to meet projected or actual demand, we will work on the “make” area of supply chain.

This paper aims to present the problem of supply chain dynamic planning considering maintenance interventions and using a multi-agent system (MAS). The main objective of the system is ensuring collaboration between three different entities, planning, production and maintenance in order to take better decisions. To model the proposed system, we used the multi-agent system engineering (MaSE) methodology.

Keywords

Supply chain, Planning, maintenance, production, multi-agent system.

1. Introduction

The constant and unpredictable composites activities progress requires each time more complex techniques and technologies, the miscommunication and difficult data sharing between planning, maintenance and production services, the continuing growth of customers’ demands for new products and the considerable amount of maintenance interventions are the most important factors that impact the smooth process of the supply chain during the last years.

The supply chain complexity is reflected in the fact that it deals with 3 levels: strategic, tactical and operational. The strategic level includes prescribing facility locations, production technologies and plant capacities. The tactical level requires material flow management policies, inventory levels and size of the products’ batches. The operational level schedules operations to assure in-time delivery of final products to the customers. These levels interact in several ways.

Many studies noted that the involvement of maintenance and production plays a vital role for a successful production planning. The advantages of collaboration between these actors of the supply chain are more significant when done in a dynamic way. In fact, deciding the best quantity to produce and to maintain in the right moment will save costs and make the client satisfied. Hence, there is a need for a system allowing data sharing and cooperation between planners, producers and maintenance technicians; at the same time, this system must ensure the optimization of the production planning.

Multi-agent systems (MAS) have been developed in the context of distributed artificial intelligence and are expressed by a set of distributed cooperating agents each of which acts autonomously. This system is defined as an approach to complex problems in a distributed manner where decisions should be taken from a considerable amount of information from various sources.

The complexity of the MAS is shown in the fact that the agents have the ability to communicate with each other in order to share results or request resources. The existence of a coordinator agent is important to address this issue since it's the one which ensures the interaction and running of the system. The communication between agents can take two forms: **the negotiation**, which results from a competition between agents, or **the planning**, which indicates a cooperation between them.

In the next of this paper, we will present in details the production planning problem in the aeronautical sector. The second section will be devoted for a literature review of the integration of production and maintenance in the planning process. We will present in the third section the developed system using multi-agent system engineering (MaSE). Finally, we will conclude and give a description of future research perspectives.

2. Production planning problem

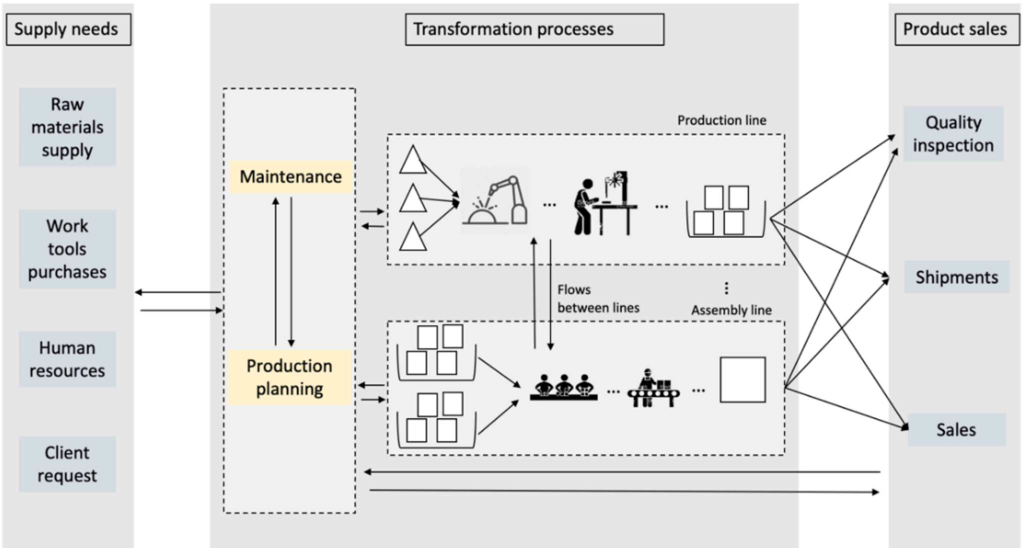

Fig 1. Supply chain network structure in the aeronautical sector

In this section, we describe the overall planning situation including planning decisions and the planning horizon. Based on this analysis, we derive and discuss the model requirements. Fig. 1 shows the supply chain structure for the aeronautical manufacturing system, which consists of three parts: needs supply, transformation processes, and product sales.

For the **supply needs**, several types of materials and tools exist originating from different sources as there are primary raw materials from carbon fibers suppliers as well as other materials from coating and surface treatments contractors, or from other metal production plants. However, supply contracts are generally carried out under a closed planning horizon where the system does not automatically modify the supply recommendations during the planning of component requirements. This is particularly useful for the MPS (Manufacturing Planning and Scheduling) but does not allow modification in the case of a lack of material or unplanned client demand. Regarding the selection of input materials, a large number of tools has to be taken into consideration as well.

Additionally, decisions must be taken for transportation modes and shipment dates, i.e., the arrival dates of materials at the plant. Herein, raw materials can be either transported via maritime, land, or via air transport. Depending on the transportation mode, different costs, delivery times, and restrictions regarding the shipment size occur. Considering these shipping durations, decisions must be taken up to 6 months before processing. In a multi-plant environment, it must also be decided, in which plant a part should be manufactured.

In the **transformation processes**, we can identify two main processes : parts production line and assembly line. In the parts production line, raw materials are processed and transformed into byproducts that will be assembled later in the process. The applied technologies per article can differ in terms of their processes, part size, lot size, resulting parts, and costs.

In this planning step, operational decisions must be taken on the production plan including process inputs and manufacturing as well as material flows for each article in each planning period. The production plan needs to be defined according to the specific technical capabilities of the production processes (including tools and human resources). In some cases, a network perspective is essential, depending on if production plants are interlinked via intercompany flows, i.e., materials and sub articles of the processes are shipped from one site to another. Based on the purchasing decisions, maintenance contributions and the production plan, inventory levels result for each material.

In this final step, which is the **product sales**, different product quality requirements including cosmetic restrictions or packing restrictions must be considered according to contractual terms. This section of the supply chain will not take part of our study.

In practice, companies encounter uncertainties in different steps of their processes, especially in material shipment arrival times, process capacities, and maintenance interventions. Uncertainties in non-quality products due to maintenance occur in the company's supply chain and are usually addressed by using safety stocks and buffer capacities. Hence, coping with these uncertainties remains a core challenge for the productors. To resolve these uncertainties, we suggest to elaborate forecasting algorithms. By so doing, industries dismiss the risk of non-delivery by having a dynamic process planning integrated to production.

In a nutshell, the planning decisions that have to be addressed in operational and tactical production planning comprise decisions on:

- The takt time needed to produce each article
- The bottlenecks that can delay product delivery
- The process inputs, production levels, and material flows for each product
- The preventive maintenance planning
- The unexpected intervention of corrective maintenance
- The inventory levels for each article in each planning period
- The customers requirement in terms of quality and delays

As the accuracy and distribution of maintenance tools becomes prominent, targeted planning and preparation of maintenance measures becomes the key enabler for efficient and effective production, that's why we will focus more in this paper on the integration of maintenance in a dynamic production planning.

3. Literature review

In most cases, production planning and maintenance planning are treated as separate problems. However, production and maintenance planning have a high impact on each other. In the following paragraphs, we will present several approaches that have been developed to support the decision-making process during the planning and the maintenance operations.

E. T. Valencia and al. demonstrate that in the last years, the uncertainty of the external environment has led to define the availability of resources and plan the production mainly in short term planning horizons. The article reveals that researchers recommend gathering data in real time through the use of cyber-physical systems when looking for reliability in production plans. The research also indicates that in order to face disruptions, production planning applications are mainly addressed to balance resource utilization using ERP that cannot always take decisions in a dynamic way.

E. H. Aghezzaf and N. M. Najid discuss production planning and preventive issues in a multi-line production system taking into consideration possible failures of production resources. The problem is presented as a nonlinear mixed-integer model when each production line implements a cyclic preventive maintenance policy. The paper also proposes and discusses a Lagrangian-based heuristic procedure as a solution for this optimization problem.

Weinstein and Chung highlighted the fact that the maintenance policy is often determined at the operational level by negotiation between production and maintenance services. The result is often not optimal for the overall objectives of the organization. To meet the need for increased consideration of the maintenance function, the paper presents a three-part model to asses an organization's maintenance policy. The first part generated the production plan using a linear programming formulation. The second part developed a MPS (Master production Schedule) to minimize the weighted deviations from the fixed objectives. In the last part, work center loading requirements are used to simulate equipment failures for maintenance policy best selection. Several factors influence the maintenance policy including the category of maintenance activity, maintenance activity frequency, failure signifcance, maintenance activity cost, and aggregate production policy.

M. Gallab presentes a methodology for modelling, analyzing and simulation of the complexity of risk analysis of maintenance activities in a supply chain. Based on a multi-agent system, the simulation of the proposed model is realized on the platform AnyLogic. The proposed methodology helps the maintenance managers to control the risk related to the equipment, and thereby improve the productivity. The paper presentes the failure scenarios that may occur during maintenance with the hazards that are associated to these failures. Then, the risks identified were listed in order to implement safety barriers to avoid such failures to improve the maintenance service particularly, and throughout the supply chain.

4. Methodology used

In order to build practical multi agent systems for our research, we have developed the Multiagent Systems Engineering (MaSE) methodology introduced by DeLoach & Wood as a full-lifecycle methodology aiming to analyze, design, and develop heterogeneous multiagent systems. We chose this methodology since it focuses on guiding the designer from an initial set of requirements through the analysis, design and implementation of a working multiagent system. It uses a considerable number of graphically based models derived from standard UML models in order to describe the different types of agents in a system and also their relations with other agents. MaSE describes as well an architecture independent detailed definition of the internal agent design.

The general operation of MaSE follows the phases and steps described below and uses the associated models.

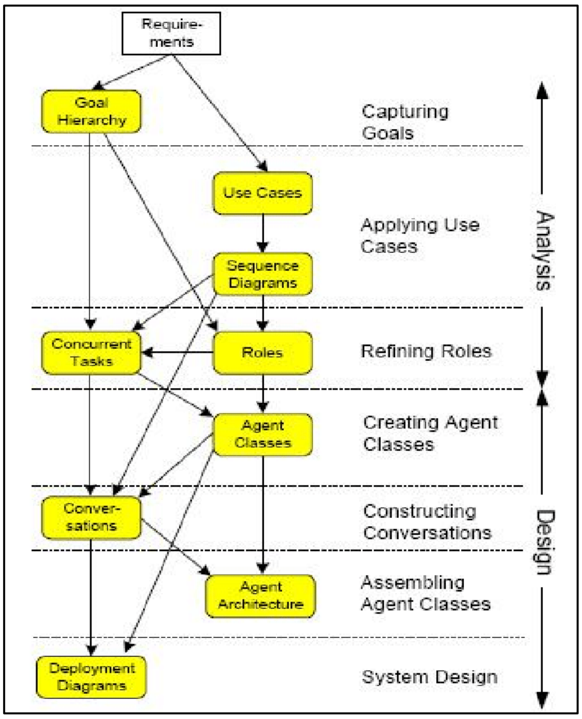

Fig 2. MaSE phases

As shown above, the methodology of Mase is based on two main phases: analysis and design. The first phase, Analysis, includes three steps: capturing goals, applying use cases, and refining roles. The first step, Capturing Goals, takes user requirements and turns them and top-level system goals. After defining system level goals, we extract system-level use cases and define Sequence Charts in the applying use cases step.

This step defines an initial set of system roles and communications paths. Using the system goals and roles identified in the use cases, we refine and extend the initial set of roles and define tasks to accomplish each goal in the refining roles step.

4.1. Capturing goals

In order to follow the MaSE methodology, the first step to complete is choosing a goal which will be defined as a system-level objective. Lower-level constructs may inherit or be responsible for goals, but goals always have a system-level context. In general, there are two main steps for capturing goals : one to identify them, and the other to structure them.

Fig. 3 represents the goal hierarchy diagram for our proposed system. The objective of the system is the integration of dynamic planning to production (goal 1). To that end, it’s important to have a control on the delivery delays (goal 1.1) and to maintain the satisfaction of the custumers requirements (goal 1.2). To make the control of the delivery delays possible, it’s necessary to define production times (goal 1.1.1), then to control the production cycles (goal 1.1.2), and to share this data with planning and production (goal 1.1.3). Furthermore, in order to achieve the client satisfaction, the means of production for each product have to be selected (goal 1.2.1) and the procedures of maintenance for each mean have to be identified (goal 1.2.2). The achievement of all these goals will make possible the instant re-planning of production at each contingency encountered.

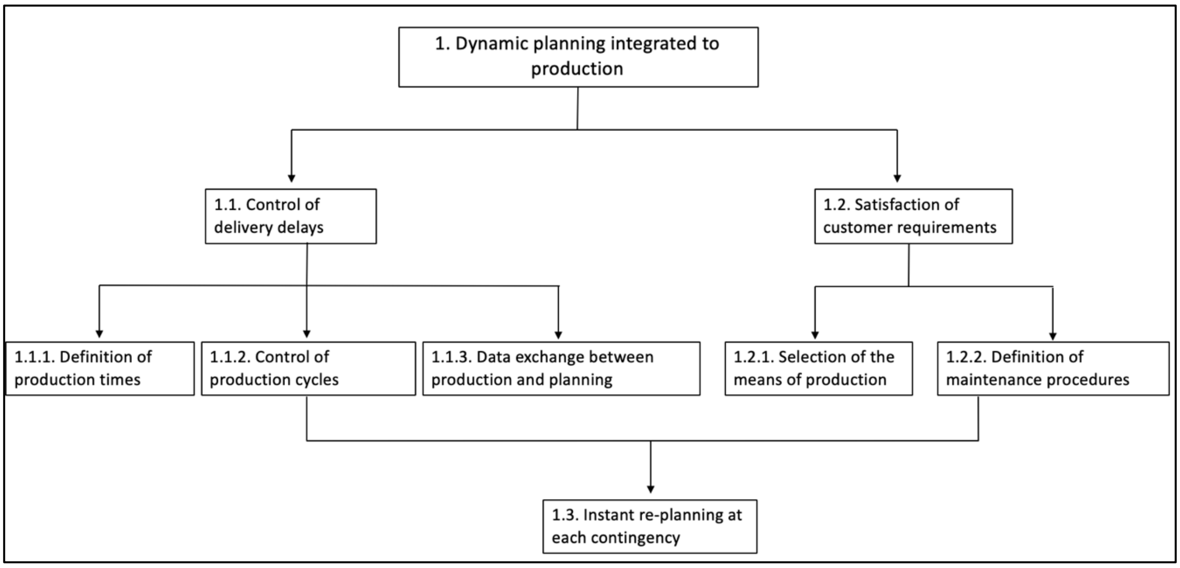

Fig 3. Goal hierarchy diagram

4.2. Applying use cases

In order to identify how the system should behave in a given case, the application of The Applying Use Cases step is important. It helps determining the required communications between agents within a multiagent system. To do so, a sequence diagram is created to define the minimum communication that has to take place between roles.

As shown in Figure 4, when a maintenance intervention takes place within a mean of production, this leads to a change of the deadline delivery. This information must be communicated to the planning notifier who will create an alert to the data checker. The data checker must verify all inputs and constraints and communicates them to the planning optimizer. In this step of the process, a new planning must be scheduled and communicated to the relevant stakeholders (i.e the production) to update their data in order to satisy the customer's requirements.

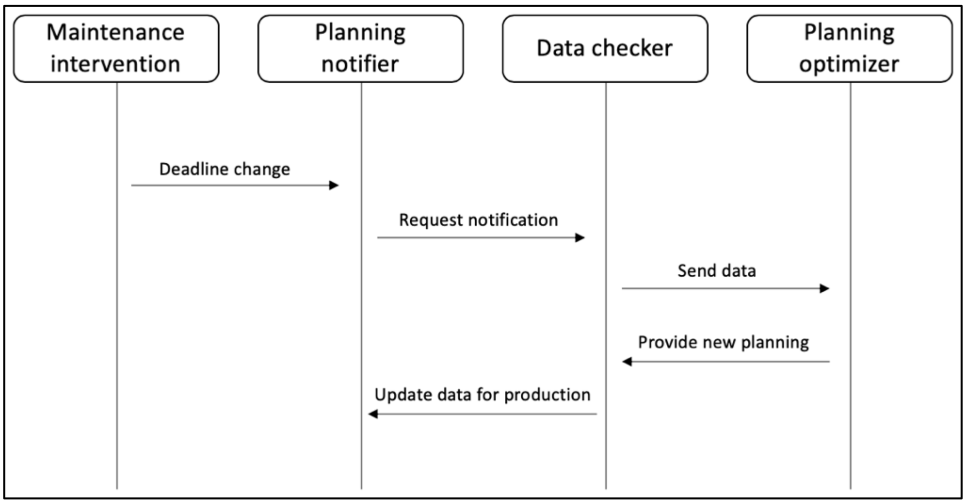

Fig 4. Sequence diagram

4.3. Refining roles

The third step in MaSE aims to ensure that all the needed roles have been identified and to define behaviors and communication between them.

In Figure 5, three roles have been defined with their various collections of concurrent tasks : Maintenance, Production planning and Planning optimization. For each role we have defined the necessary inputs that helps achieving their goals. For example, to achieve the customer's satisfaction, production planning needs to be informed about the constraints regarding customers' fixed delays and the production cycles for each product to be realized. In the other hand, maintenance should keep the production means available to ensure the process control and by doing so, it can make changes in the production plan previously established. At this step, production planning updates data and communicates it to the planning optimizer which will choose the optimal resources and plan in order to respect the customer's demand.

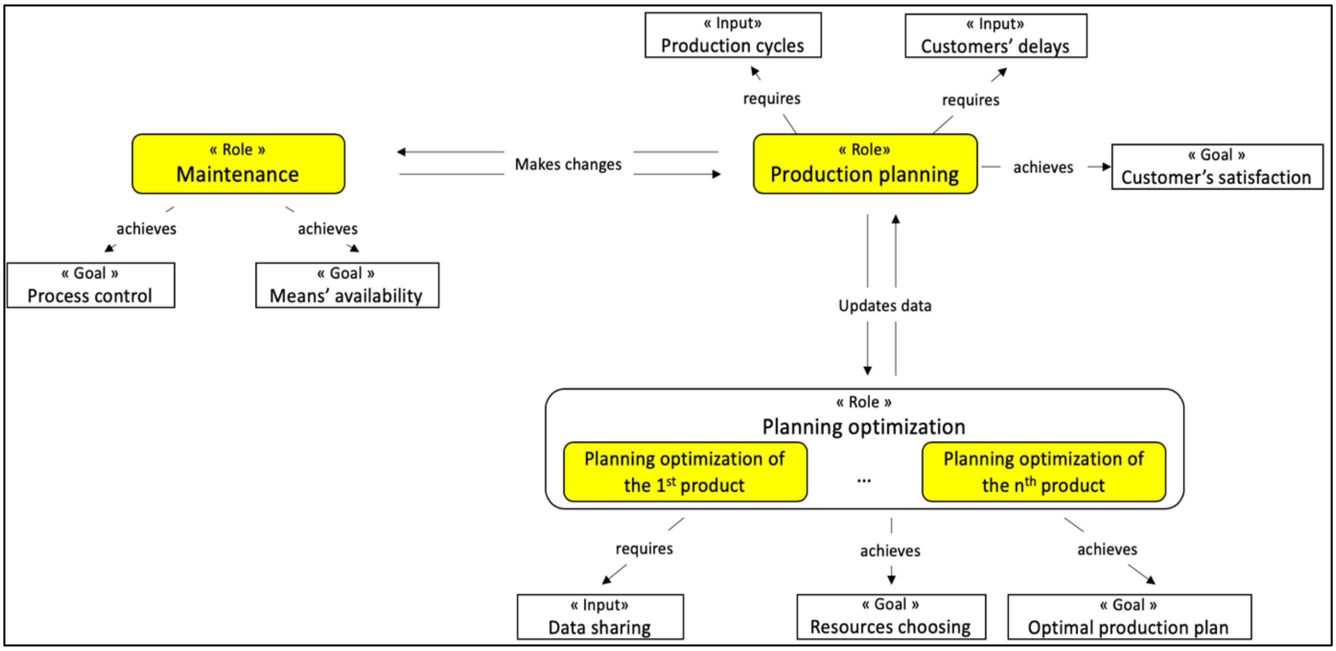

Fig 5. Role model diagram

4.4. Creating agent classes

Figure 6 shows the agent class diagram which presents different agent classes that are identified from roles and depicted as boxes and the conversations between them as lines connecting between them. To make the organization more clear and efficient, we define a one-to-one mapping between agents, and we list the roles played by each one of them.

The optimization agent, for instance, possesses data from the different membres of the supply chain and has to propose an optimal producton plan to the planning agent. It communicates as well with the maintenance agent to get information about the means to repair and the repairing time.

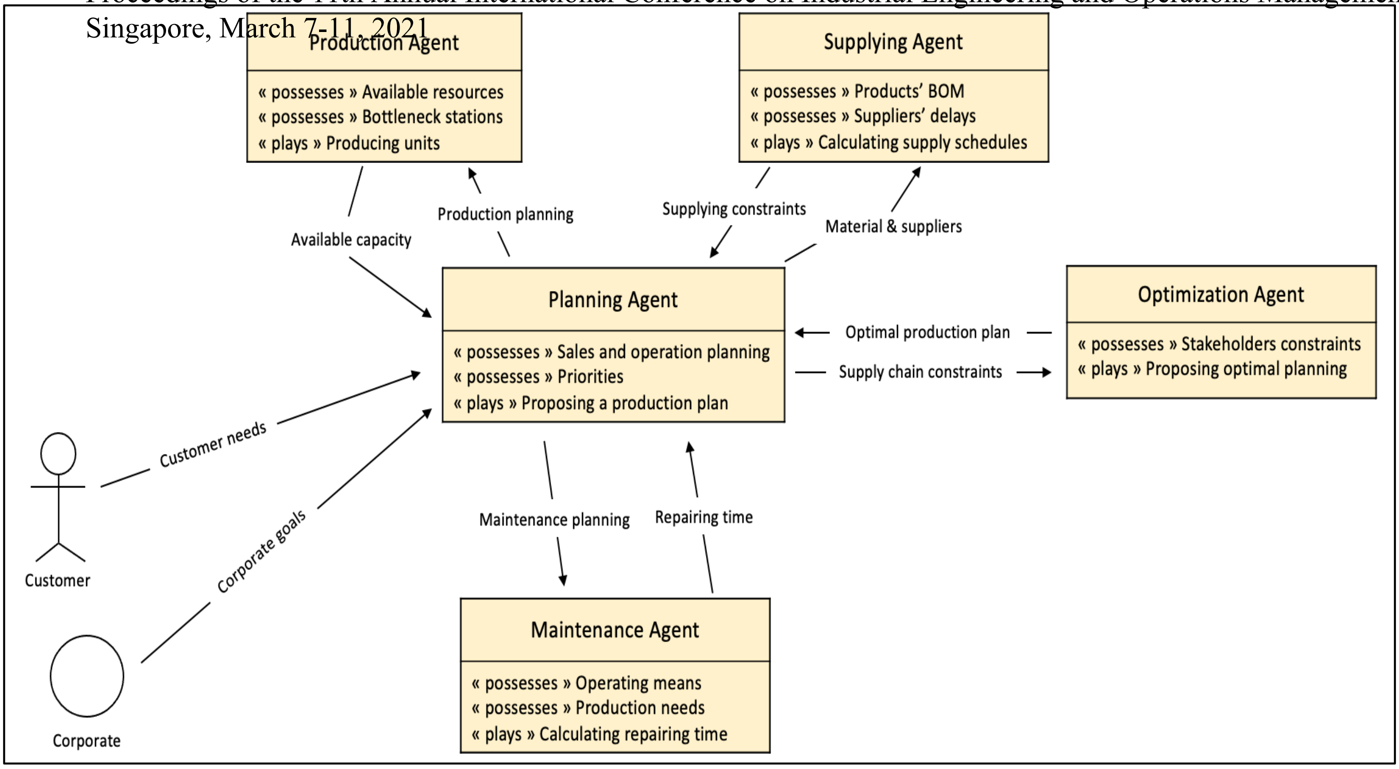

Fig 6. Agent class diagram

5. Case studies

After checking all products' bill of material (BOM) and the delays proposed by supliers to ship raw materials, the supplying agent calculates the **Supplying schedule** and communicates it to the planning agent for integration in the calculation of the final production plan.

The production agent possesses the available **resources** for each shift (manpower, machines, control gates, …). It has also information about **bottleneck stations** and time shift for each operation. This data is communicated to the planning agent to adapt the production plan with the available resources.

As for the maintenance agent, it needs information from the planning agent to inform about the production needs in terms of tools. It possesses data about the operating means and the ones that need maintenance intervention. The maintenance agent calculates the **Repairing time** for each broken tool and communicates it to the planning agent.

All the outputs mentioned above are communicated to the planning agent that proposes an initial production plan based on the customers priorities and the Sales and operation planning. However, other supply chain constraints can occur during this process and need a dynamic decision to obtain an optimal planning :

- Case study N°1 : Tool breakdown – unplanned maintenance intervention

In the case of a tool breakdown, both agents of maintenance and production will send a notification to the planning agent. The production agent will alert the lack of resources (mean of production in this case), and the maintenance agent will give information about the time needed for the tooling to be operational again.

The role of the planning agent now is to negotiate with other agents to identify the optimal planning that gathers information below:

- The repairing time needed by maintenance.
- The possibility to use another tool for the same reference.
- The time proposed by the supplier in case the maintenance needs to purchase spare parts to carry out the intervention.
- Customer priorities to see if there is a possibility of launching in production another reference.

- Case study N°2 : Lack of resources

The manpower shortage is no joke for the manufacturing industry. Once the production planning is established, it indicates for each part reference the name of the resource responsible for its production or control. If this person is absent at the beginning of the shift, an immediate modification of the planning must be carried out to not impact the deadlines imposed by the customer.

The production agent therefore notifies the planning agent of the number of available resources. The latter must negotiate the following information with the other agents and updates the production planning instantly based on this data:

- Verify if the production has another resource available and trained to carry out the same reference.
- Review customer priorities to see if there is a possibility of launching in production another reference.

- Case study N°3 : Non-conforming products

The combination of high quality products at low cost has been a critical issue for manufacturers to remain currently competitive in global markets. Once we produce all the parts given by the production plan, a variety of control methodologies are used before delivery to the client (sampling inspection, 100% inspection, re- inspection, control charts ...). At this stage, non-conformities can be detected and the delivery may not be satisfied if we do not act dynamically.

The production agent notifies the planning agent of the number of non conforming parts detected. The planning agent calculates the number to be reworked or reproduced and negotiates the following information with the other agents:

- Verify with maintenance agent the available means
- Verify with production agent the available resources for rework or production
- Verify the non conformity cost vs. the production costs
- Review customer priorities to see if there is a possibility of launching in production another reference.

6. Assembling agent classes

The final architecture of the multi agent system for simultaneous design of the product and its supply chain is given in fig.7.

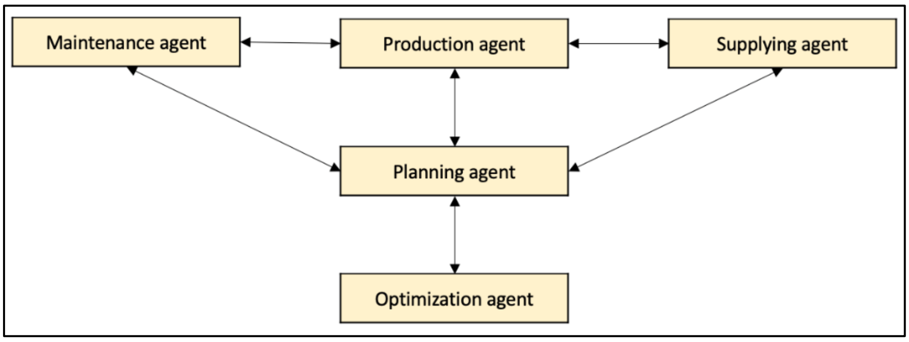

Fig 7. Final architecture

7. Working hypothesis

The assumptions adopted for the development of the model to determine the decision variables, which are the number of batches to be produced for each shift, the number of preventive maintenance actions to be performed and the perfect corrective maintenance action, are as follows :

- The production system is scheduled in the form of a jobshop.
- Integrating maintenance policy with production planning will significantly influence total cost reduction.

- Downtimes are fixed, in which the start of an interval and its duration are known in advance (lunch breaks, days off, holidays, etc.)
- The frequency of preventive maintenance activities required for minimizing total costs is influenced by the financial consequences of equipment failure.
- Each piece is produced on a unique tooling.
- In the case of a production tool failure, corrective maintenance is carried out immediately.

Constraints :

- Load capacity : $\sum_{m=1}^{N} X\text{p} \leq \text{Mmax} \quad \forall \text{p} \in \text{P}$
- Clients' demand : $\text{Sp} + \sum_{p \in P}(1\text{-NRp}) * X_p \geq D_p$
- Delay respect : $T_{rcp} \leq T_{fcp}\ \forall c \in C ; \forall p \in P$
- Non-negativity and binary constraints : $X_p \geq 0$; $Yp \geq 0$

Minimize: Total cost =
Procurement cost +
Fixed manufacturing cost +
Maintenance cost (preventive + corrective (variable)) +
Fixed facility operating cost +
Variable facility operating cost +
Transportation cost

8. Conclusion

In this paper, we presented a model of a Multi-Agent System for a dynamic planning integrated to production and maintenance in the case of composites industries. Indeed, the designed MAS allows structuration of the planning task and enables an instant decision making for an efficient chain. The system modeling was made using MaSe methodology. Our MAS allows communication and negotiation between the agents : production, maintenance, planning and supplying.

The next step in this work will be the implementation of agents and proposing optimization models as a decision making tools for production planners. And finally, some tests with real data must be done to validate this architecture.

9. References

P. M. G. and J. F. Joel E.Igba, Kazem Alemzadeh, "A framework for optimizing product performance through using field experience of in-service products to improve the design and manufacture stages of the product lifecycle," *Azevedo*, 2013.

A. Chraibi, S. Kharraja, I. H. Osman, and O. Elbeqqali, "Multi-agent system for solving Dynamic Operating Theater facility layout problem," in *IFAC-PapersOnLine*, 2015, vol. 28, no. 3, pp. 1146–1151.

Acatech, "Smart Maintenance for Smart Factories: Driving Industrie 4.0 through smart maintenance," 2015. [Online]. Available: https://www.acatech.de/wp-content/uploads/2018/03/acatech_POSITION_KF_EN_Smart_Maintenance_final.pdf. [Accessed: 15-Jan-2020].

X. Liu, P. Peng, Q. Li, and X. Ma, "Joint optimization of preventive maintenance and economic production quantity with considering demand adjustment," *IEEE Int. Conf. Ind. Eng. Eng. Manag.*, vol. 2017-Decem, pp. 1916–1919, Feb. 2018.

B. K. S.H.A. Rahmati, A. Ahmadi, "Multi-objective evolutionary simulation based optimization mechanism for a novel stochastic reliability centered maintenance problem," *Swarm Evol. Comput. BASE DATA*, 2018.

E. T. Valencia, S. Lamouri, R. Pellerin, P. Dubois, and A. Moeuf, "Production Planning in the Fourth Industrial Revolution: A Literature Review," *IFAC-PapersOnLine*, vol. 52, no. 13, pp. 2158–2163, 2019.

E. H. Aghezzaf and N. M. Najid, "Integrated production planning and preventive maintenance in deteriorating production systems," *Inf. Sci. (Ny).*, vol. 178, no. 17, pp. 3382–3392, Sep. 2008.

L. Weinstein and C. H. Chung, "Integrating maintenance and production decisions in a hierarchical production planning environment," *Comput. Oper. Res.*, vol. 26, no. 10–11, pp. 1059–1074, Sep. 1999.`

M. Gallab, H. Bouloiz, E. Garbolino, M. Tkiouat, M. A. ElKilani, and N. Bureau, "Risk analysis of maintenance activities in a LPG supply chain with a Multi-Agent approach," *J. Loss Prev. Process Ind.*, vol. 47, pp. 41–56, 2017.

S. A. DeLoach, "The MaSE Methodology," in *Methodologies and Software Engineering for Agent Systems*, Kluwer Academic Publishers, 2006, pp. 107–125.

S. A. Deloach, "Analysis and Design using MaSE and agentTool," Apr. 2001.

E. Nunes and S. Sousa, "A dynamic programming model for designing a quality control plan in a manufacturing process," in *Procedia Manufacturing*, 2019, vol. 38, pp. 581–588.

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