Optimisation of an aeronautic production line through the management of tools and the shortage of items
Optimering av en aeronautisk produktion linje genom att hantera av verktyg och bristen på artiklar

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***Abstract*— This thesis work is part of a process to ensure the production ramp-up of the A320neo aircraft pylons at Airbus Saint-Eloi factory (Toulouse). The aim of the project was to optimise the production management in order to sustain the transition to a serial production of the assembly lines. The objective of the thesis work was to develop a model to prevent the downtime of the production lines caused by the shortage of the assembly lines or the unavailability of tools on workstations.**

Firstly, the work investigates the existing models in order to understand the causes of stocks variability. Performance of tools was determined with the Markov chain model. Then, the work provides a method to forecast production needs in terms of items and tools. An algorithm was developed to collect and process the data on the existing resources in order to compare it to the forecasted needs. Solutions were designed to identify the causes of the shortages on the production lines. In addition, by analysing the trends of the shortage of stocks and the availability of tools on workstation, a forecast of long term constraints for production is possible. The method showed promising results to identify and manage the missing items and tooling on the workstations.

Denna avhandlingsarbetet en del av en process för att säkerställa produktion ramp-up av A320neo-flygplanets pyloner på Airbus Saint-Eloi-fabriken (Toulouse). Syftet med projektet var att optimera produktionshanteringen för att upprätthålla övergången till en serieproduktion av monteringslinjerna. Målet med avhandlingsarbetet var att utveckla en modell för att förhindra driftstopp av produktionslinjerna som orsakats av bristen på artiklar eller om verktyg på arbetsstationerna.

För det första undersöker arbetet de befintliga modellerna för att förstå orsakerna till lagerförändringar. Utförandet av verktyg bestämdes med Markovchain-modellen. Sedan ger arbetet en metod för att förutse produktionsbehov i termer av artiklar och verktyg. En algoritm utvecklades för att samla och bearbeta data på befintliga resurser för att jämföra den med de prognostiserade behoven. Lösningar utformades för att identifiera brist till bristerna på produktionslinjerna. Genom att analysera trenderna om brist på lager och tillgången till verktyg på arbetsstationen är det dessutom möjligt att prognostisera långsiktiga produktionsbegränsningar. Metoden visade lovande resultat att identifiera och hantera de saknade artiklarna och verktygen på arbetsstationerna.

I. INTRODUCTION

A. Context

1) The A320neo ramp-up

The A320neo (New Engine Option) is a twin-engine jet airliner manufactured by Airbus and is currently the most fuel-efficient single-aisle airplane. Due to an increase of its orders, Airbus had to change its manufacturing management to enable a production of 63 airplanes per month in its four final assembly lines [1]. These factories are highly dependant upon the delivery of the sub-parts such as the engine pylons.

Figure 1. Photo of an A320neo [2]

2) Purpose and manufacturing of the engine pylon

The purpose of the engine pylon are to sustain the engine, transmit the forces generated by the reactor to the wings and to carry the hydraulic, electric, air and fuel system connections.

Two types of pylon exist on the A320neo, one for the CFM International engine and the other for the Pratt & Whitney engine. Both are assembled at the Airbus Saint-Eloi Factory in Toulouse through a 3-steps process : assembly of the structure, integration of equipment and geometrical and functional testings of the pylon. The assembly process is explained on Figure 3.

Figure 2. Photo of an assembled engine pylon [3]

The ramp-up of the A320neo pylon assembly required to change the static assembly lines to 3 parallel ≪ pulse ≫ lines. With this type of manufacturing process, the pylon moves every ≪ takt time ≫ to the next position or is isolated, in case of unfinished work. The last process cost time, money and space and can be triggered by the shortage of assembly items or the lack of tools.
The ≪ takt time ≫ corresponds to the amount of time the pylon stays at a workstation.

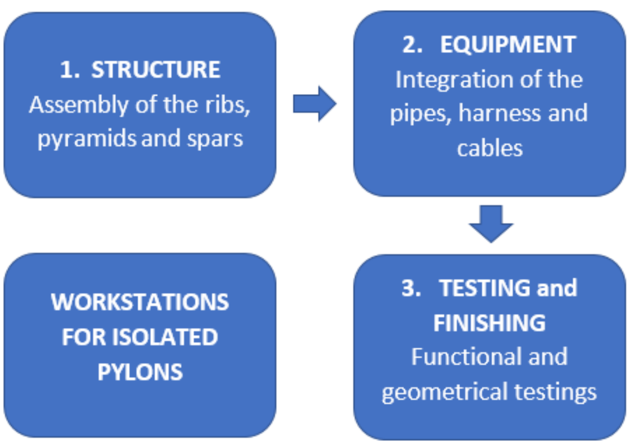

Figure 3. The stages for assembling an engine pylon

3) Variety of tools and components needed to assemble a pylon
On the production lines, one can find several types of tools. To simplify their management, tools were divided into 2 different categories :

— *specific tools* specially designed for the assembly or the transport of the pylons
— *standard tools* that can be ordered on catalogs.

Workers use the tools to assemble the various elements of the pylons together, such as, ribs, pipes, cables, and screws among others, to produce the pylon.

The numerous components are supposed to be delivered in accordance to the Material Resource Planning (MRP) that orders the list of components listed in the Bill of Material to produce a pylon. The different actors of the supply chain follow the MRP to optimize the material flow, and to ensure the production have the necessary material to produce with the minimum stocks in the warehouses.

4) The Methods and Scheduling departments
a) The Methods department
The Methods department is the interface between the Production and the Engineering departments, and aims to industrialise the products. The Methods department must furnish the necessary tools, enhance the global productivity of the assembly lines, and the optimum working conditions.
This department is composed of 19 people and is divided into 2 types of actors for the 3 parts of the assembly lines :

— The support technicians are responsible to follow the reparation, the control, and the creation of new tools.
— The manufacturing technicians create and improve the assembly instructions from the technical documents given by the engineering department. Moreover, they are in charge of drafting the instructions to repair a defective pylon.

b) The Scheduling department
The Scheduling department is responsible of the production planning by creating the Manufacturing Planning and Scheduling with the various actors of the production, in accordance to the Enterprise Functional Planning and to the assembly lines constrains. Moreover, the schedulers are in charge of ensuring that there are enough parts to complete a job assembly. The scheduling department is the interface between the stock managers and the production and thus notifies the anomalies of the supply chain to the stock managers.

B. Problem statements

The previous production process allowed more time to tackle production issues. Oppositely, the pulse lines method requires a risk control, on the failures of tools and the shortage of assembly items. The lack of these items can lead to the production shutdown with financial and organisational consequences.

The first main issue concerns the management of the tools and their availability at the assembly stations. Tooling availability depends on many actors which includes the engineering and design, the production, the quality, the maintenance, and the methods department.

In addition, the decentralisation of the large amount of information and the lack of communication between the actors created a disorganisation in the management of the tools.
The challenge is to manage the flow of information and to predict the availability of the tools in accordance to the instantaneous needs of the production.

The second main issue deals with the management of assembly items and their deliveries to the production lines. Parts are automatically ordered in accordance to the Material Resources Planning from the Enterprise Resource Planning software. This theoretical planning does not perfectly meet the needs of the production. Moreover, many disruptions occur in the material flows due to the high number of actors in the supply chain, the lack of information exchanges between them, and the short time demand changes of the production. These impediments can lead to the shortages of components on the assembly lines and the schedulers are mostly aware of the shortages when its occurs on the production lines.
The key issue is to forecast the shortages of stocks to give more time to the schedulers for finding an alternative solutions.

C. Thesis aim and Delimitation

The overall project is about preventing and curtailing the lack of resource on the production lines. Specifically, it is about creating a process to manage the large number of tools, to optimize their quantity and identify the inefficient tooling thanks to historical data. In addition, the project aims to prevent and control the shortage of items provided by the supply chains in accordance to the production demand.

The methods project focuses on the specific tools designed for the pylon assembly.
All the specific tools are reparable. The logistic project will concern all resources delivered by the supply chain which includes the Kanban resources and the parts of the pylons.

Ultimately, the goal is to develop a solution to forecast the shortage of articles provided by the supply chain, to manage the tools, and to identify the inefficient ones to reduce the production downtime.

II. Background

A. Theory of Constraints

The fundamental principle of the theory of constraints is that work flow generated in companies are constrained by *bottlenecks* and the only way to increase the productivity of the system is to enhance the performance at the *bottlenecks*. The management based on this theory focuses on the identification and the management of the *bottlenecks* in companies [4]. The main author of this theory, Eliyahu M.Godratt, proposed a process to manage these constraints [5] :

1. Identify the system's constraints.
2. Decide how to exploit the system's constraints.
3. Subordinate everything else to the above decision.
4. Elevate the system's constraints.
5. If in the previous steps a constraint has been broken, go back to step one, but do not allow inertia to cause a system constraint.

B. Supply chain theory

1) Overview of the supply chain network

The supply chain is the set of entities responsible of the financial, product, service, and information flows to ensure the customer has its demanded products on time and at a minimal cost. Thus, the overall aims of the supply-chain management are to optimize the flows to reduce the risk of shortage and to optimize the cost of the products [6].
In the case where a factory is the customer, the actors of the supply chain are the suppliers, the manufacturers, the distribution systems and the warehouses [7, 8] (Figure 4).

2) The dynamic effects of the supply chain described with the bullwhip effects [8-11]

a) Description of the bullwhip effect

The *bullwhip effect* can be consider as the phenomenon where a small perturbation in downstream demand creates considerable swings in upstream product flows.
The concept of the *bullwhip effect* was invented by a group of MIT professors during a beer distribution game to explain the dynamic effects of a multi-echelon supply chain. The negative feedbacks of the upstream actors based on their feelings create oscillations in the orders and stocks. For the customers, the *bullwhip effect* is characterized by an alternation of surplus and shortages of stocks.
Controlling this phenomenon is a key issue for providing stability to the supply chain and to avoid shortages of items.

b) Causes of the fluctuations in the supply chain

According to Lee & al. [11] the main causes of the *bullwhip effect* are the errors done on the demand forecasting, the order batching, the price fluctuation and the rationing and shortage gaming.
Indeed, every actors does its own forecasting based on the orders of their direct customers creating a cycle of orders from customers to correct the forecasting errors. Moreover, most customers do order batching to ease the products transportation and ordering. In addition, the fluctuation in price makes the buyers order excessive

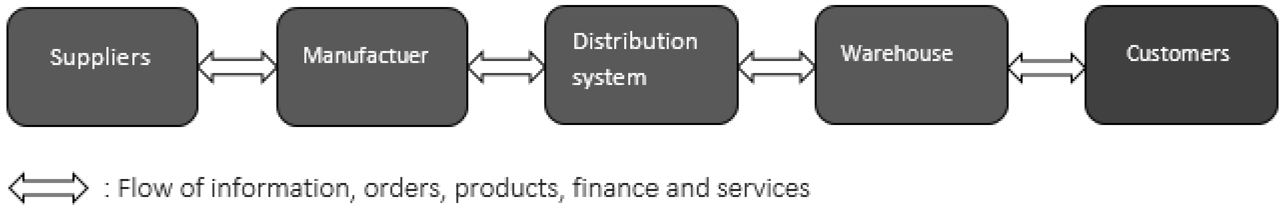

Figure 4. Actors and flows in the supply chain network

stocks when the prices are lower and reduce the orders at times of higher prices which increases the stock fluctuations. Finally, manufactures stock products to prevent shortages and this intensifies the variability of stocks.

c) Solutions
To curtail the *bullwhip effect*, Lee & al. proposed 3 solutions [11].
The first one is to share the information between the various actors of the supply chain from the orders and production forecasting to the inventory levels.
Moreover, another solution is to establish the Vendor Managed Inventory to create orders as a function of the consumption of the customers. With this type of process, the retailers have access to the stocks and can order new products if the stocks are below a defined limit.
The last strategy is to develop a Collaborative Planning, Forecasting, and Replenishment system among the actors of the supply chains to provide an overall vision of the flows and reducing the unnecessary orders causing the *bullwhip effect*.

C. Maintenance theory

The maintenance of a system can be defined as the combination of actions during the life cycle of a system to ensure that it will achieve its intended goals with its special requirements. The maintenance management is based on 2 main policies : the corrective and the preventive maintenance. The corrective maintenance is linked to the different actions to repair, restore or replace a defecting equipment. The preventive maintenance aims to minimize the risk of equipment failures through various processes such as schedule replacement of components, and detection of the incipient failures with a planned maintenance or testing. The maintenance can prioritize and structure its actions in accordance to indicators such as reliability, maintainability or availability [12-14].

1) Reliability, Availability, Maintainability (RAM) Studies
The RAM studies provide data on the system efficiency, helps to identify the bottleneck parts in the production and guide the actors on the causes of the inefficiency of the tools. The RAM studies help the actors in the decision-making of maintenance and system design changes [15, 16].

a) Reliability
The definition of the Reliability according to the AFNOR standard FD X 60-000 [17] is : ≪ Probability (or ability characterized by this probability) for a device to perform a required function under specified conditions for a specified duration. ≫ It gives an indication on the frequency of the system failures over time. The mathematical expression is [18] :

$$R(t) = P(T > t) = \int_t^{\infty} f(x)\,\mathrm{d}x \tag{1}$$

For manufactures, the most common reliability indicators are the Mean Time Between Failure (MTBF) and the failure rate (λ). Both are defined by the following expression (2) :

$$MTBF = \lambda^{-1} = \frac{\sum Operating\ time}{Number\ of\ failures} \tag{2}$$

The reliability of a system during its functioning life can be described through the Bathtub Curve model. It is divided into 3 parts [19] :

— Firstly, the number of failures decreases overtime, it is the ≪ infant mortality failure ≫. The supplier of the tooling changes the components presenting intrinsic failures.

— Secondly, the failure rate is constant and the tooling does not present signs of fatigue or wear. The tooling manager must ensure the failure rate is not too high and does not penalize the production.

— Thirdly, the failure rate increases due to the wear-out of the system and to the normal wear of the tooling components.

During the second part of the Bathtub Curve, one can use an exponential distribution to describe the reliability with a constant failure rate over time and from this hypothesis, the reliability is given by the following formula (3) :

$$R(t) = exp(-\lambda t) \quad (3)$$

b) Maintainability

The definition of Maintainability according to the AFNOR standard FD X 60-000 [17] is : ≪ For a device, under given conditions of use, probability (or aptitude characterized by this probability) so that a given maintenance operation can be performed over a time interval (0, t), when maintenance is provided under given conditions, with the use of prescribed procedures and means. ≫

In simplified words, the Maintainability is the capacity of a system to be easily maintain. One can define mathematically the maintainability using the maintainability function M(t), which is the probability to finish the maintenance for a time T inferior to t [18, 20].

$$M(t) = P(T < t) = \int_0^t g(x)\,\mathrm{d}x \quad (4)$$

The repair rate μ and the Mean Time to Repair (MTTR) are the main parameters used to characterize the maintainability of a system :

$$MTTR = \mu^{-1} = \frac{Total\, downtime}{Number\, of\, failures} \quad (5)$$

One can assume, the repair time to be exponentially distributed, then the maintainability M(t) is given by :

$$M(t) = \int_0^t \mu exp(-\mu t)\,\mathrm{d}x = 1 - exp(-\mu t) \quad (6)$$

c) Availability

The definition of availability according to the AFNOR Standard FD X 60-000 [17] is : ≪ Ability of a device to perform a function required under given conditions, at a given time during a given time interval, if provision of external means is ensured ≫

The Availability of a system/equipment is its capacity to perform its intended functions during its life time. It is a key notion to understand production shutdowns due to equipment failures. The instant availability A(t) is defined as the probability the system is available and working at time t [18]. Let Y(t) be :

$$\begin{cases} Y(t) = 1 & if\, the\, system\, is\, functioning\, at\, time\, t \\ Y(t) = 0 & if\, the\, system\, is\, not\, functioning\, at\, time\, t \end{cases}$$

$$A(t) = P(Y(t) = 1) = E(x(t)). \quad (7)$$

The availability can be obtained via the MTBF and the MTTR for reparable systems :

$$A(t) = \frac{MTBF}{MTBF + MTTR} \quad (8)$$

D. Markov Analysis [16, 18, 20, 21]

1) Markov chains

a) Definition

The Markov chain is a stochastic process fulfilling the Markov properties : the future events depend only on the present situation and not on the past states. For a continuous-time Markov chain, the mathematical expression is given by :

$$P(x_n, t_n | x_{n-1}, t_{n-1}; ...; x_0, t_0) = P(x_n, t_n | x_{n-1}, x_{n-1}) \quad (9)$$

With t_y the instant y and $t_n > t_{n-1} > ... > t_0$ and $x_n, x_{n-1}, ..., x_0$ a series of random variables.

b) Birth-death process

Markov chains can be characterized using a birth-death process :

- The birth process is when the system advances from state i to state i+1 at an arrival rate λ_i
- The death process is at the opposite when the system decreases from state i+1 to state i at a service rate μ_{i+1}

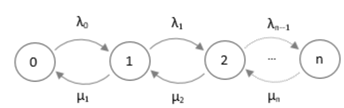

Figure 5. Markov chains

2) Steady state

The steady state is a long term perspective and implies the process will remain unchanged in time. The result is a conservation of the flows between the different states : the flow into a state is equal to the flow out of a state. Let P_i be the probability of being in state i, the conservation of the flows gives the following equation (10) :

$$P_i \lambda_i = P_{i+1} \lambda_{i+1} \; \forall n \in [0; n-1] \quad (10)$$

One can rearrange the previous equation to give the following expression (11) :

$$P_i = \frac{\prod_{k=0}^{i-1} \lambda_k}{\prod_{k=1}^{i} \mu_k} P_0 \; \forall n \in [1; n] \quad (11)$$

The law of total probabilities gives :

$$\sum_{i=0}^{n} P_i = 1 \quad (12)$$

The combination of the Equations 11 and 12 gives :

$$\begin{aligned} \sum_{i=0}^{n} P_i = \sum_{i=0}^{n} \frac{\prod_{k=0}^{i-1} \lambda_k}{\prod_{k=1}^{i} \mu_k} P_0 = 1 \\ => P_0 = (\sum_{i=0}^{n} \frac{\prod_{k=0}^{i-1} \lambda_k}{\prod_{k=1}^{i} \mu_k})^{-1} \end{aligned} \quad (13)$$

Equations 11 and 13 are be used in the methods section

III. Methods

The methods used in the project are based on the theory of constraints : optimization of the production flows by increasing the performance of the ≪ bottlenecks ≫. Indeed, in this project, the bottlenecks are the missing assembly items, or the unavailable tooling and the aims are to identify and prevent them, to give time to the schedulers and the technicians to limit their impacts [7]. The methods proposed to identify and curtail the bottlenecks follow four steps [4, 5, 22] :

- Collect the data from the ERP
- Analyses of the data
- Study of the results by the users
- Decision in accordance to the results.

A. Preventing the shortage of items on the assembly lines

The schedulers of the A320neo assembly lines must manage a total of 737 pieces and 1466 Kanban items. The management of the high number of references was simplified by dividing the schedulers into the 3 parts of the assembly lines : assembly of the pylon structure, equipment integration and end-of-line and pylon reparations. Nevertheless, the actors of the supply chain in the manufacturing process are still overwhelmed by the various hazards than can occur in the deliveries of items. This part of the project presents the method developed on the A320 pylon assembly lines to prevent the shortage of assembly components through 3 steps : forecasting the production demand for parts, extracting the warehouse stocks and developing a process to prevent the shortage as a function of the level of stocks. The assembly items depend on 2 different management methods and are divided into 2 types :

- the Kanban items, mostly small components
- the pieces items, more technical and bigger parts

The final aim is to provide a tool that forecasts the demand of the production and that compares it to the warehouse stocks. From the results, one must control and reduce the shortage in accordance to the Collaborative Planning, Forecasting and Replenishment principles.

1) The demand for small components

Kanban cards are usually used for small components such as screws, seals, bolts and nuts to signal the need to move the components from the main warehouses to the factorys warehouse. It is a logistical organisation based on the ≪ Just in Time ≫ concept for a lean manufacturing where the production is rather pulled by the demand than the offer [22, 23].

On the production lines of the A320neo pylons, one can find 2 buckets for one type of small components. The first bucket represents 3 days of consumption and the second bucket is a security stock and represents also 3 days of production. The *Milk-runner* does a round of the assembly lines and picks up the empty buckets on the line side storage. When he arrives at the *Marketplace*, corresponding to the factory warehouse, he fills the buckets with the small components. The warehouseman is in charge to ensure the replenishment of the *Marketplace* stocks. As a matter of fact, if the stocks are lower than a certain quantity, the warehouseman changes the Kanban cards of the reference from green to red on the ERP. This action automatically triggers a request to the Airlog warehouse (the outdoor warehouse) for providing stocks to the *Marketplace* (the factory warehouse). The previous description, shown schematically in Figure 6, describes how the consumption of Kanban items drives the demand of small components. Moreover, one must control the flows between the *Marketplace* warehouse and the Airlog warehouse to avoid shortage of stocks for extended period of time.

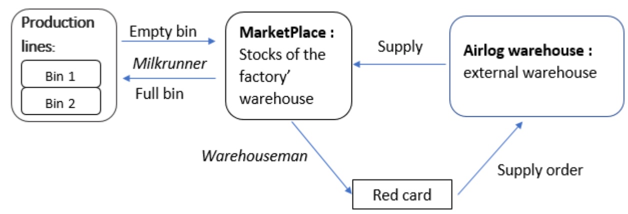

Figure 6. Supply of Kanban items

2) Demand for pieces

a) The MRP orders

The elements such as the harness, pipes, mattresses, and ribs are ordered via the Material Resource Planning. The MRP conveys orders to the Airlog Warehouse for delivering pieces to the *Marketplace* in accordance to the Enterprise Functional Planning and to the Bill of Material. The Enterprise Functional Planning is the theoretical production plan and the Bill of Material gives the components needed to assemble a pylon [24]. This Bill of Material is available on the ERP and is different for a CFM International Pylon and a Pratt & Whitney pylon and for right pylon and left pylon. To determine the real needs of the production in pieces, the following procedure was performed for each item

- First step : Determine the quantity of items used for the right and left pylons of a type of motorisation from the Bill of Material. In normal condition, the right and left pylons of an aircraft are produced on the same week. Let's call Q_{CFM} and Q_{PW} the total quantity of the item needed for the right and left pylons for the CFM motorization respectively.

— Second step : Estimate the average ratio of CFM international pylons produced the following week and a half by using the Schedule Production Planning. Let's call it R_{CFM}. The ratio of PW pylons produced the following week and a half is thus equal to 1-R_{CFM}.

— Third step : The following formula gives the minimum threshold $T_{1.5\,weeks}$ to produce correctly for one week and a half :

$$T_{1.5\,weeks} = Q_{CFM} \times R_{CFM} + Q_{PW} \times (1 - R_{CFM}) \quad (14)$$

b) Overall management of the supply of items

The MRP and Kanban cards are the processes used in the supply chain to plan and deliver the parts in accordance to the production demand. However, some hazards can appear in the supply chain flows, amongst others, the physical loss of stocks, the delays of the deliveries or inappropriate orders in the MRP compare to the production demand. The role of the schedulers is to provide an imminent solution to avoid the shortage on the production lines and to communicate the issues to the stock managers. The stock managers are in charge of ensuring the delivery of a batch of pieces on time and to follow the flows between the suppliers and the various warehouses [24].

3) Fetching the data on stocks

The flow of products and orders are virtually informed on the ERP to facilitate the management between the different actors and to enable the Vendor Managed Inventory concept. Moreover, this tracking allows the customers / the schedulers to follow the deliveries of the products in the different warehouses, to know whether the deliveries are in transit or a hazard appeared in the supply chain. Thus, one can get the warehouses and the production line side storage stocks from the ERP [25].

4) Preventing the shortage of assembly parts

a) Overview of the flow analysis

The flow analysis aims at preventing the shortages of items provided by the supply chain, or at least at emphasizing the future ones. Indeed, the process described in the next sections helps to control the stocks shortages on the production lines and gives more time to the schedulers to find a solution to avoid the production shutdown. As for the management of tools, a software on Visual Basic was developed to gather the information on stocks. On this software, the users input the weekly production rate and ratio of CFM International then trigger the extractions of stocks from the ERP and an algorithm analyses the stocks and the Kanban cards in comparison to the production demand. From this analysis, a status is given for each reference in accordance to the production needs and helps the schedulers to tackle the risky items. After the analysis proposed by the software is completed, the schedulers follow a procedure to understand the cause(s) of the shortage and estimate its gravity. Finally, solutions were designed with respect to the magnitude of the hazard.

b) Algorithm for processing the warehouse stocks

The algorithm for processing warehouse stocks is shown graphically in Figure 7. As shown in Figure 7, in the yellow box, if the piece stock at the Airlog warehouse is superior to the threshold limit (Equation 14), then the algorithm assigns the Status ≪ OK ≫ to the reference on the Excel sheet. In the opposite case, the algorithm first analyses if pieces are still available on the line side storage, if a minimum of 10 pieces are available at the Airlog Warehouses, and if the sum of the stocks of the line side storage plus the warehouses stocks responds to the production needs. It was estimated that the information on the stocks of line side storage were reliable up to 80 %. The status ≪ OK ≫ means the stocks can provide pieces for one week and a half of production. ≪ To analyse ≫ means the scheduler must investigate the lack of stocks at the warehouse.

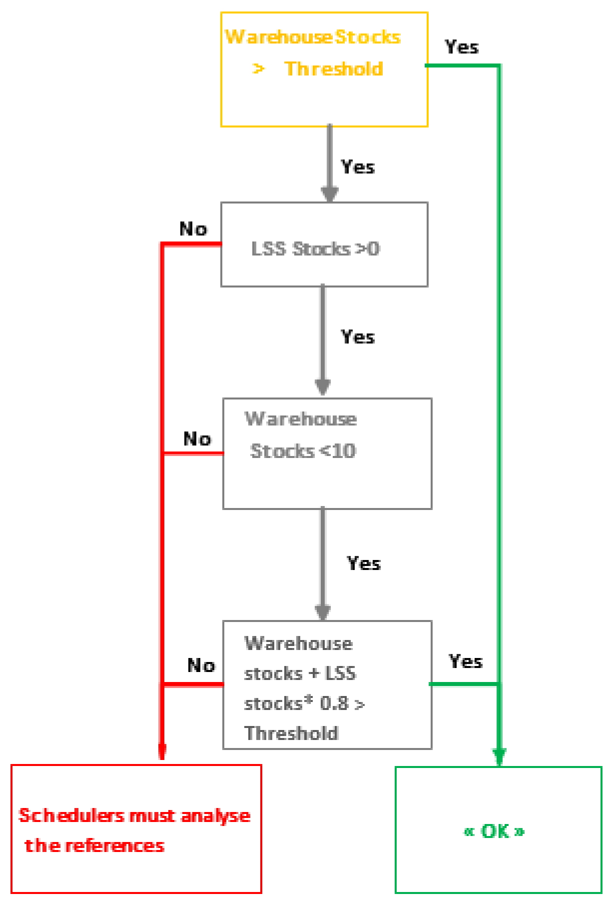

Figure 7. Processing of the stocks by the algorithm

c) Analyses of the Kanban cards

The idea is to extract the status of the Kanban cards from the ERP and if it is red for more than 3 days, the algorithm assigns the status ≪ To Analyse ≫ to the reference. Otherwise, the algorithm assigns the status ≪ OK ≫ . The algorithm also updates the stocks of the Airlog warehouse and the size of the Kanban cards to help the schedulers analyse the risky items.

d) Handling of the risky references by the schedulers

The process described in this section and represented graphically in Figure 18 in the appendix aims to integrate the Collaborative Planning, Forecasting, and Replenishment concept. The schedulers analyse the flows of stocks according to the following principles :

— Firstly, if the Airlogs stocks of an item cover at least one week of production and the next delivery date is known, then the scheduler assigns the status ≪ controlled ≫ to the reference and follows the evolution of the next delivery. Conversely, if the next delivery date is unknown but the stocks cover at least one week of production, or the delivery date is less than 3 days before the production line needs, the scheduler must assign the status ≪ Risky ≫ to the reference. The stock manager and the scheduler are responsible to find a solution to avoid the shortage.

— Secondly, if the stocks of the reference cannot cover a week of production and the next delivery date is unknown or does not respond to the production needs, the scheduler assign the status ≪ Future Shortage ≫ .

— Finally, if the assembly lines are already lacking the items, the scheduler assigns the status ≪ Shortage ≫ . The scheduler and the stock manager are responsible for solving the issue.

The statuses assigned to the references are collected over the weeks to determine the references that are regularly problematic. Moreover, thanks to historical data, the scheduler can easily understand the causes of the shortages and ask to change the size or the frequency of the orders to the stock manager.

e) Training of the schedulers to use the software

The final step was to train schedulers to use the software and to encourage them to use it. For that, several meetings were held to show how to do the stocks extractions, to trigger the analysis by the macro and to assign a status to a risky reference. Feedback was provided to enhance the software and simplify its daily use.

B. Preventing and curtailing tools unavailability

This part presents the steps used to manage the tools for production. First, it deals with the identification of the tools and actors. Then, it develops a method to forecast the tool requirement planning, in order to compare this forecast to the available tools. Finally, this parts describes the Markovian model used to compute the steady availability of the tools with the aim of identifying the inefficient tooling.

1) Value Stream Mapping of the tooling management

This part first uses the value stream mapping methods to get a vision on the tooling management and to obtain a list of the tooling used on the assembly lines. The Value Stream Mapping or ≪ material and information-flow mapping ≫ is a lean manufacturing method that aims to map all the actions and flows, in fact what is called the streams, to carry a product from the initial state to its final state. The idea is to emphasise the areas of the company that give the value to the product by having a global vision of the process [22, 23].

a) Determination of the actors and the flows of information on tools

The Value Stream Mapping was used to understand the various flows of the tools during their life cycle. Indeed, the structure of the tools management in a factory can be complex due to diverse competences necessary to ensure the proper functioning of equipment. The jigs & tools are designed and conceived by the engineering department, they are qualified as compliant to produce by the quality department, they are repaired by the maintenance department and the methods are responsible to furnish the necessary tools to the workers. The methods have a prominent role since they are the interface between the tool actors and the production lines. The repairs or modifications done on the tools are informed through transactions on SAP, the ERP of the company as shown in Figure 8. The ERP has the huge benefit to homogenize the information in a single database and thus to avoid the dissemination and/or loss of data. The software allows to follow the life cycle of the tooling by recording the actions performed on it by the various actors.

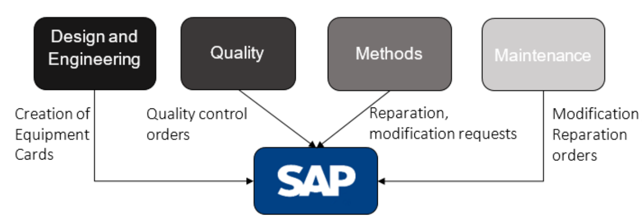

Figure 8. Roles of the departments and flows of information on tools

b) Mapping of the tooling used on the assembly lines

To manage the tools of the A320neo pylons assembly lines, they were first identified on the ERP, and those required to carry out the work on a A320neo Pylon were extracted based on their denomination :

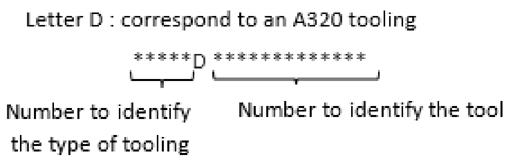

Figure 9. Numbering rules for tools

The extraction gave a list of roughly 3900 items. Since, the project was on the assembly lines of the A320neo, the next step was to remove the tooling used to produce the elementary and the structure pieces of the A320neo pylons thanks to the knowledge of technicians. Finally, tools that were no more used on the lines were removed and the final list was composed of 1420 items.

In addition, a significant part of the study was to identify the position where the tools were used. Indeed, the first step was to determine for every tooling whether it belongs to the structure, the equipment, or the end-of-lines positions. Then, the tooling can be used at 9 different positions at the assembly of the structure of the pylons, at three different positions for the equipment integration, and at 3 positions for the end-of-line positions. Finally, a tooling can also be used at the recovery position to repair or finish the work on an isolated pylon.

The information obtained through the Mapping of the tooling park were gathered and updated in the Equipment Cards on the ERP, which are used to gather the relevant information concerning a specific tool.

2) Synthesising the tooling data

a) Extraction and analysis of the data into a flexible software

Though the ERP is a reliable and robust software, it is not suitable for analysing data with special requirements. Hence, the analyses had to be carried out on a different software developed through Visual Basic. The software automatically extracts the tool updates into Excel sheets and formats the information to enable the analysis [26, 27]. Excel is a user-friendly interface and it is commonly used within the company ; it is the reason why Excel was chosen as the analysis interface. The developed interface gathers the various information on tools, gives an instant vision of the tooling park and provides an analysis of the historical data of the tools. The Excel language permits to compute simple formula and for more complex computations or to automatize different tasks on Excel sheets, the Visual Basics language was used. On the excel sheets, the users are only able to input the necessary data and trigger the analysis. The idea is to automatize the updates and the analysis to avoid the waste of time and the possible mistakes done when inputting data in the spreadsheets [28]. As a result, several functions were developed to extract on the ERP the list of actions undertaken by each department. A first function extracts the list of tools created by the design & engineering department. A second function extracts the orders of the maintenance and selects the ones assigned to the A320 pylons assembly lines tooling. A third function updates the upcoming preventive maintenance dates.

b) Overview of the process established to manage the tooling park [29, 30]

The process established to manage the tooling park is a cycle that requires to collect the data on the modification, reparation or control performed on the tools of the A320 pylon assembly lines, by the various actors in a unique database : the ERP. Then, the updates on the tools are extracted in the data-analysis software to give an overall vision of the park and to provide an analysis to help in the decision-making of the tooling actors. The concept is illustrated on Figure 10.

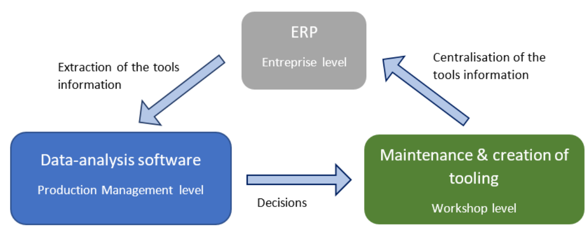

Figure 10. The process established to manage the tooling park

3) Forecasting the tool requirement planning [30]

The tooling needed to produce a pylon are normally listed on the Bill of Material. However, since the manufacturing program, and thus the Bill of Material were still in development, a process was created to redefine the needed quantity of tools on the production lines in accordance to the production rate. This process begins by categorizing each tooling according to a list of criteria. Then one can translate the criterion into mathematical expressions to compute an estimation of production needs [29].

a) List of criteria [30]

<u>Type :</u> Firstly, the study started by referencing the different types of tools.

- A Noria equipment is following the pylon through different positions.

- A stationary equipment is a tool that remains at a workstation

- A transport device can be a trolley or a conveyor

<u>Localization :</u> For each tooling, one must determine the number of positions where it is used. This includes the workstations for stationary and Noria equipment

plus the drilling centres, the buffers (including the conveyor positions), and the isolated positions for the Noria equipment.

Type of motorization : Moreover, one must specify whether the tool is used for a specific motorization (CFM International or Pratt & Whitney) or both motorization.

b) Estimation of the quantity of tooling needed in accordance with the production planning

In the interface, the user inputs the maximal number of pylons isolated $NP_{iso.}$, in the buffers $NP_{buf.}$, in the drilling centers NP_{DC}, and the ratio of CFM motorization for the week R_{CFM}. The following formulas are applied to determine the quantity needed for CFM motorisation tooling Q_{CFM} and for a PW motorisation tooling Q_{PW} needed to ensure that the production has enough tooling. Let $T_{w.}$ be the quantity of a type of a tooling needed to carry out the work at a workstation and $N_{workst.}$ be the number of workstations where the tooling is used.

For Stationary tools :

$$Q_{CFM} = T_w N_w . R_{CFM} \quad (15)$$

$$Q_{PW} = T_w N_w . (1 - R_{CFM}) \quad (16)$$

For Noria tools :

$$Q_{CFM} = T_{w.}(N_{w.} + N_{buf.} + N_{iso.} + N_{DC}) R_{CFM} \quad (17)$$

$$Q_{PW} = T_{w.}(N_{w.} + N_{b.} + N_{i.} + N_{DC})(1 - R_{CFM}) \quad (18)$$

4) Comparison of the needs to the available tools

a) Instant vision

By subtracting the number of unavailable tools to the total of tools in the factory, one can determine the number of available tools. Indeed, items can be in reparation (column F of Figure 20), or in periodic control (column G of Figure 20), or used on a workstation (column E of Figure 20), and this finally gives the number of available spares or lacking tooling on workstations (column H of Figure 20). Finally, the Equations 15, 16, 17, 18 give an estimation of the quantity needed for a type of tooling and by comparing to the number of available tools, one can determine the instant situation of the tooling park during a work week. Moreover, one can prevent the lack of tools on the workstations for the following week by forecasting the demand, comparing to the current tools availability and future possible tools unavailability. First, one must determine the tools subjected to a periodic control the following week. Then one must consider a possible failure of an equipment during the following week. Finally, the count must consider the tools supposed to return from the maintenance department. This approach can prevent the risk of shortage.

b) Follow-up of the requests of the methods

Moreover, the repair requests of the methods were extracted from the ERP and fitted in the data-software analysis to ease the follow-up of the demands and orders for the reparation, periodic controls, and manufacturing of tools. The use of Key Performance Indicators (KPI) enables the technicians to estimate their efficiency in their work and helps them in the decision-making. An example of the KPI used is given in Figure 11.

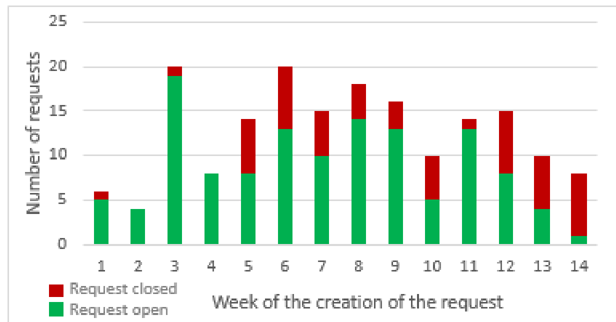

Figure 11. Evolution of the requests over the weeks

5) Estimate the steady availability of a type of tooling

a) Input data

The Mean Time to Repair is given by the ratio of the sum of the maintenance orders duration divided by the number of maintenance orders. The Mean Time Between Failure is given by the number functioning days on the ERP (by counting the number of working days between the creation of the tooling on the ERP and the current day) divided by the number of maintenance orders.

b) Assumptions and Markov Graphs

Assumptions :

— Let's assume the factory has *n* items of an equipment. In this case, the state *i* is supposed to be the state where *i* items of the equipment are in reparation and *n-i* items of the equipment are available on the production lines.
— Moreover, let's suppose the number of repair workers is equal to the number of unavailable tools.
— Let's assumed The Mean Time Between Failure (and Mean Time to Repair) was used to compute the Birth Rate (Death rate respectively).
— Let's consider all the tools have a constant birth and death rate over time. It means, the tools are on the second part of the Bathtub Curve.
— Let's supposed, the assembly lines need k items of a tooling to produce at the demanded rate.

Consequences : From these assumptions, at the state i

— the Birth Rate is given by :

$$\lambda_i = \begin{cases} \lambda k & if \quad i < n-k \\ (n-i)k & if \quad i >= n-k \end{cases} \tag{19}$$

— the Death Rate is equal to

$$\mu_i = \mu i \tag{20}$$

The resulting Markov graphs is shown in Figure 12 :

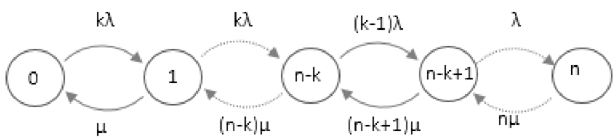

Figure 12. Markov graph to compute the tooling availability

c) Availability of the tooling on the line

If there are less tools available than the needed quantity to produce at the demanded rate, the production is defaulting. Thus, one can consider the steady availability for a type of equipment A_∞ is the steady probability that there are enough of this type of equipment to ensure the nominal production. Thus, if P_i is the probability of being in state i [20] :

$$A_\infty = \sum_{i=0}^{k} P_i \tag{21}$$

With P_i given by the equation 11 and 13.

6) Understanding the causes of the tools unavailability

The previous paragraph explains how to compute the availability of a type of equipment on the production line. Thus, one can deduce the inefficient tools by identifying the equipment having a low availability. A reasonable availability is considered to be superior than 0.96, otherwise a study on the causes of the unavailability must be done. A process to study the hazards on a type of equipment was set up to help the technicians understand the causes of the unavailability, as shown in Figure 13. The idea was to determine whether the tooling is unreliable, hard to maintain, or both, to help the technicians find the adequate solution to solve the tool unavailability on the line.

A list of solutions was proposed to help the technicians to solve the tool unavailability issue. The technician of the maintenance department can propose to change the design of the tools, to create a new tooling, to train the workers on how to use the unreliable tooling, to carry out periodic controls, or to implement spares [31].

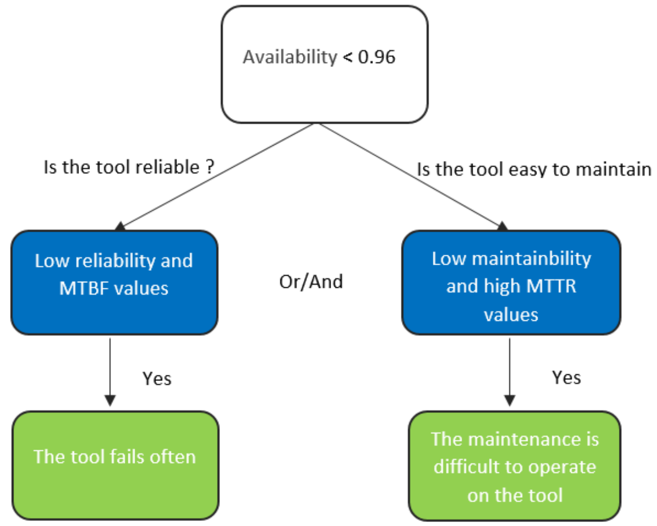

Figure 13. Analysis of the tooling unavailability

7) Integration of the technicians experiences

First of all, several meetings with the technicians were held to collect their needs and their feedback on the software. These meetings were also used to explain how to use the software and the several processes to manage the tooling park, and a note was created to resume the explanations. Moreover, the methods presented in the previous sections are based on the data collected on tools and do not integrate the experiences of the technicians. The idea is to use the technicians view to identify the criticality of a tooling on the workstation based on several criteria [17, 32, 33] :

— the time the tooling is used during the ≪ takt time ≫ at a position.
— the tooling is movable and can be shared between different workstations during a ≪ takt time ≫
— the technicians noticed the tooling fails often, or can be easily lost
— the tooling is expensive

From this criterion, the technicians assign the letter A, B or C to the tooling.

— The letter A means the tooling is critical because it fails often, or it is a crucial tooling to carry out the work at the position.
— The letter B corresponds to the need to add a spare tooling for the 3 assembly lines.
— The letter C means the tooling is very expensive, reliable or is not a crucial tooling for the assembly lines.

The integration of technicians' experiences aims to help in the decision-making of adding spare tools.

IV. Results & Discussions

A. Vision of the A320neo stocks

1) Evolution of the number of shortage of components

At the beginning, the schedulers were reluctant to use the analysis software and to make the analysis to determine the cause of the shortages. Then, the software started to prove its efficiency, notably for the piece items and they used it to follow the risky references on the assembly lines.

The OTIF (On Time in Full) is a performance indicator that aims to quantify the results of the supply chain : delivering the desired product on time, with the expected quality and quantity, at the right place.
From the OTIF, one can determine if the rules of the supply-chains are respected [34]. The OTIF is defined by :

$$OTIF = \frac{Number\ of\ delivery\ OTIF}{Number\ of\ deliveries\ ordered} \tag{22}$$

The OTIF curve increases over time through the weeks. Moreover, the number of references being in shortage decreases from an average of 3 per weeks to roughly 0 at the end of the study as shown on Figure 14. The trends is less significant for the Kanban references but still shows an increase in the OTIF ratio as shown on Figure 15.

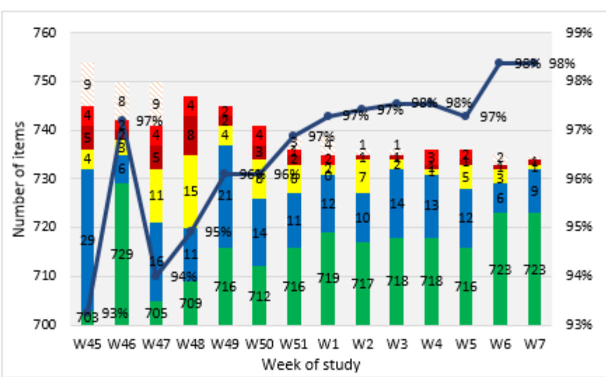

Figure 14. Evolution of the risky references for the pieces over the weeks of study

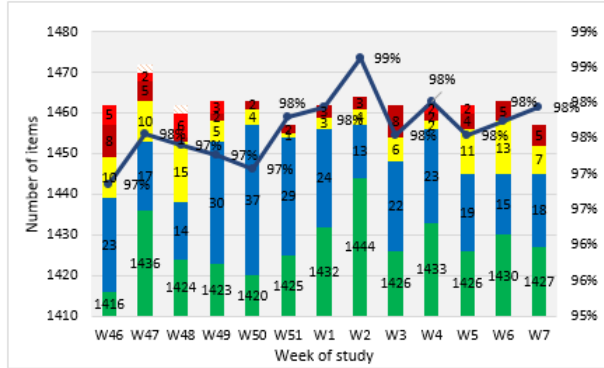

Figure 15. Evolution of the risky references for the kanban items over the weeks of study

Figure 16. Legend for figures 14 & 15

2) Comparison of the missing pieces reported with the andon system and forecasted with the software

a) Explanation of the andon system

The andon is a visual indicator triggered by the workers to notify the supervisors that the production process is facing a problem. The worker classifies the cause of the problem when declaring the andon and a software sends a message directly to the appropriate person for solving the issue.

b) Comparison of the results with the Andons

One can use the historic of the andons to compare the predicted shortage references and the reality. Figure 17 shows a comparison between the number of missing items predicted by the developed algorithm and the number of missing items reported with the andons. The trends are the same for the 2 curves, however the values are mostly superior for the andon curve. Indeed, some hazards can occur between the warehouses and the assembly lines.

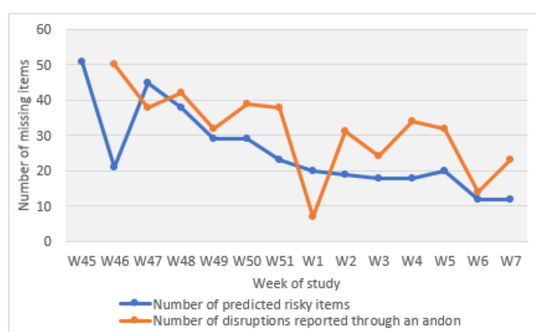

Figure 17. Comparison of the shortages of pieces predicted by the software analysis and reported with andons

c) Analysis of the historical information
Figure 21 in the appendix is a screenshot of the list counting the risky status for each piece items, for the thirteen weeks of study. It is sorted in ascending order and it appears many references often have the status ≪ Controlled ≫ . It means the supply of this items are managed according to the ≪ Just in time ≫ concept : the stocks manager minimizes the stocks but provides the right number of piecequatioes in accordance to the production needs. Besides, other references often have a ≪ Risky ≫ , ≪ Future Shortage ≫ or ≪ Shortage ≫ status such as the D000.31050.000.00 and the ABS127R88DF460 references. The schedulers must escalate the issue to the stock managers to change the batch size of the part deliveries or the frequency of their deliveries.

B. Tooling project

1) Identification of the inefficient tools
A macro was developed through Visual Basic to treat the data collected over 3 years on the ERP using Equations 11, 13 & 21 to give the unavailability of the tooling. It corresponds to the percentage of time the tooling is missing on at least one workstation. One can observe on Figure 22 in the appendix, that 15 out of 234 tools have an unavailability above 4 % and thus require a thorough study. The level of criticality permits to prioritize the tooling requiring a study.

2) Analysis of the reliability and maintainability
Let's analyse the reliability over one year of functioning, which corresponds to 260 working days. By using Equation 3, the reliability is given by :

$$R(260\ days) = exp(\frac{-260}{MTBF}) \tag{23}$$

It means, we want to study the probability that the tooling will not fail for one year. The maintenance department is supposed to repair a tooling in less than 20 days ; hence, with Equation 6, the maintainability is given by :

$$M(20\ days) = 1 - exp(\frac{-20}{MTTR}) \tag{24}$$

The reliability and maintainability are given in Figure 23 in the appendix for the tooling having the lowest unavailability rate.

Reliability and Maintainability are 2 notions that must be studied together to understand the causes of the tooling unavailability. The tools with very low reliability such as *Outillage de basculement PAF A320NEOP65* or *Palonnier mat complet* failed often. However, the tool *Palonnier mat complet* presents a high Maintainability equal to 0.92 which means it is easy to repair. This explains why it has a higher availability on the workstation than tools having a much higher reliability. The design of the tool called *Outillage de basculement PAF A320NEOP65* was changed in order to reduce its number of failures.

3) The adding of spare tools
The unavailability of the tooling on at least one workstation was computed with the implantation of an additional spare. The adding of spare tools reduces the long-term unavailability of the tooling by at least 4 times. Figure 24 in the appendix, shows the unavailability of tooling when adding a spare.

It is one of the solutions proposed to reduce the value of the unavailability, but it requires to order a new tooling that can be very expensive. One can determine if the investment will be profitable by comparing the cost of the unavailability in the initial case $C_{Unavailability}$ to the cost of the unavailability in case of adding spare tooling plus the cost of the spare tooling. For that, one must first compute the unavailability cost for one year by doing the product of the steady unavailability of the tooling, the number of working hours per day, the average working day per year, and the cost of one hour of downtime on the production line [35]. The computation gives an estimation of the cost due to the unavailability of the tooling for one year. Let's call $C_{initial}$ and C_{spare} the cost of the unavailability of the tooling on the production line without and with the adding of spare tools respectively for one year. One can compute the ≪ Break-even point ≫(BEP), which is defined as the number of years necessary to profit from the adding spare tools [32] :

$$BEP = \frac{Cost\ of\ the\ spare}{C_{initial} - C_{spare}} \tag{25}$$

Detailed results cannot be presented due to confidential issues.

V. Conclusion and Future Work

1) Conclusions
The goal of the thesis works was to prevent and control the downtime caused by the shortage of items or the unavailability of tools on the assembly lines. The general concept was to compare the future needs of items and tools to the existing resources and to identify which supply flows and tools are inefficient thanks to an analysis on the historical performances.

The project on the supply of items to the assembly lines aimed to prevent, control and reduce the number of missing items on the A320 pylons assembly lines. The resulting software provides a picture for one week and a half of the possible stock shortage at the warehouses and thus helps the schedulers to find a solution to furnish the missing items. During the weeks of studies the process showed its efficiency, which resulted in the development of the same software for the assembly lines of the A350 pylons.

What is more, managing the tooling park required to draw up the Value Stream Mapping of the tools in order to identify the type of tooling used, their quantity needed on the A320 pylon assembly lines and the actors in the life cycle of the tooling. Moreover, it helped to understand the structure of the management of the Jigs & Tools and thus the flows of information on the tooling. Thanks to this mapping, one could get an instant vision of the tooling park in accordance to the production needs. Finally, by collecting the history of the actions carried out on tools and using a Markovian model, it was possible to determine which tools were inefficient because of their unavailability on the assembly lines, and estimate the benefit of the implementation of spares.

2) Future work

First, the algorithm developed to prevent the shortage of pieces could be enhanced a step further by analysing the fabrication orders of pieces rather than the warehouses stocks. The idea is to identify if the orders will provide enough resources to support the forecasted needs according to the Manufacturing Planning and Scheduling. Thus, it would forecast the shortage longer before the algorithm developed in the project. What is more, one could update the Bill of Material and the quantity of needed tools would be provided by the MRP.

One could also enhance the tracking of tooling by implementing RFID tags on the tools and relay terminals in the factory. The solution would automate the collection of the tooling information and flows and it would reduce the time necessary to find a tooling in the factory for the workers and the maintenance department. Moreover, it would curtail the loss of items and the need to buy a new expensive tooling [25, 36, 37].

The analyses proposed for both projects could be implemented into a Manufacturing Enterprise System to steer the production in real time with the predicted constrains of piece shortages and tooling unavailability. This would be a first step toward the smart factory [25, 37].

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APPENDIX

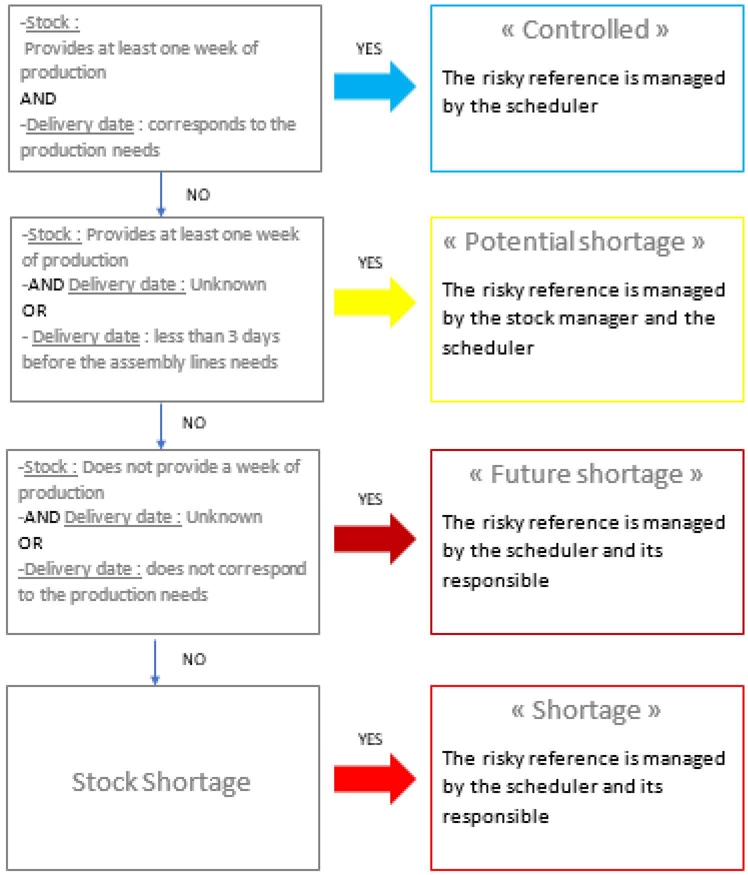

Figure 18. Note given to the schedulers to manage the risky references

B	L	M	N	O	P	Q	R	S	T	U	V	W
Reference	Stock in reception	Available Stock	Stock isolated for quality inspection	Global stock at the warehouse	Stock LSS	Status W-1	Monday 01/04/2019	Tuesday 02/04/2019	Wednesday 03/04/2019	Thursday	Friday	Status of the week
D5491587300000	0	105	0	105		OK	OK	OK	OK			OK
D5491587100000	0	106	0	106		OK	OK	OK	OK			OK
D5491587000000	0	89	0	89		OK	OK	OK	OK			OK
D5491586900000	0	87	0	87		OK	OK	OK	OK			OK
D5491586800000	0	74	0	74		OK	OK	OK	OK			OK
D5491586700000	20	107	0	127		OK	OK	OK	OK			OK
D5491586600000	0	105	0	105		OK	OK	OK	OK			OK
D5491585020000	0	99	0	99		OK	OK	OK	OK			OK
D5491584900000	20	99	0	119	17	OK	OK	OK	OK			OK
D5491581900000	0	18	0	18	24	OK	OK	OK	OK			OK
D5491581100000	0	8	0	8	26	OK	Controlled	Controlled	Controlled			Controlled
D5491540300000	0	76	0	76		OK	OK	OK	OK			OK
D5491536600000	0	102	0	102	46	OK	OK	OK	OK			OK
D5491536500000	0	99	0	99	16	OK	OK	OK	OK			OK
D5491536300000	0	456	0	456	162	OK	OK	OK	OK			OK

Figure 19. Screenshot of the interface where the algorithm provides the results of the stock process and the schedulers input the status of the risky references

Tooling number	Quantity	Quantity needed for the production	Quantity in reparation	Quantity in periodic control	Number of tooling in spare / lacking
14600D29020801000	10	10	0	0	0
14602D29020801000	11	11	0	0	0
31501D54515005000	1	1	1	0	-1
48202D54515000000	2	0	0	0	2
48202D54520000000	2	0	0	0	2
48204D54515000000	2	0	0	0	2
48204D54520000000	2	0	0	0	2
48206D54515000000	4	3	0	1	0
48206D54520000000	4	3	0	1	0
48208D54515000000	4	3	0	1	0
48208D54520000000	4	3	0	1	0
48210D54515000000	4	3	0	0	1
48210D54520000000	4	3	0	0	1
48212D54515000000	4	3	0	1	0
48212D54520000000	4	3	0	0	1
48214D54515000000	4	3	0	0	1
48214D54520000000	4	3	0	0	1
48216D54515000000	4	3	0	1	0
48216D54520000000	4	3	0	0	1

Figure 20. Screenshot of the interface giving an instant vision of the tooling park

	Reference	Controll	Risky	Future shortage	Shortag	Sum	Ratio
Equipement	D3611584100300	10	1	0	0	11	0,84615385
Equipement	D3611511020000	10	0	0	0	10	0,76923077
Equipement	D5491521000000	9	0	0	0	9	0,69230769
Equipement	D5491529900000	9	0	0	0	9	0,69230769
Structure	D5451541200000	5	0	0	3	8	0,61538462
Equipement	D000.31050.000.00	1	2	4	1	8	0,61538462
Equipement	D2902083700200	5	1	2	0	8	0,61538462

Figure 21. Summary of the riskiest references and of their status for the twelve weeks of study

TOOL	Level of criticality	Unavailability of the tooling on at least 1 workstation
Poutre d'alésage	B	35%
POSITIONNEUR BANDEAU APF PW NEO	C	23%
PALONNIER SERIE/CAMION NEO	C	21%
Banc et barre de préréglage	B	21%
Bâti mobile Station 64	C	20%
Sealing & Buffer 3 - ST64 - A320NEO	C	20%
Station de moulage 72-1 A320NEO	C	16%
S/ENS GRILLE DROITE PW	A	15%
Outillage de basculement PAF A320 NEOP65	C	13%
POSITIONNEUR BANDEAU APF CFM NEO	C	8%
CHARIOT PAF	C	6%
OUTILLAGE POSITIONNEMENT COUDE ASPI CFM	B	6%
TABLE DE ROUTAGE RAMPE OHDS PW	B	6%
Deburring -ST72 - A320NEO	C	5%
OUT Contre appui percage upa LGR/Tetard	B	2%
OUT Calage N1/LGR INF	B	1%
Frame CFM	B	1%
NEO CFM POSITIONNEUR X & Y N5/SPIGOT	A	1%
REGLAGE ENS.TUYAUTERIE FUEL	B	1%
Deburring bench RIB / Pyramid	C	1%
NEO CFM POSITIONNEUR X & Y N5/SPIGOT	A	1%
Frame PW	B	0%
Palonnier mât complet	C	0%

Figure 22. Summary of the tooling having the higher steady unavailability

C	J	K	L	M
TOOL	MTBF Mean Time Between Failure (in days)	Reliability	MTTR Mean Time To Repair (in days)	Maintainability
Poutre d'alésage	181	24%	27,9	51%
POSITIONNEUR BANDEAU APF PW NEO	789	72%	43	37%
PALONNIER SERIE/CAMION NEO	3523,333333	93%	86	21%
Banc et barre de préréglage	644,5	67%	78,5	22%
Bâti mobile Station 64	972,5714286	77%	37,57142857	41%
Sealing & Buffer 3 - ST64 - A320NEO	525	61%	12	81%
Station de moulage 72-1 A320NEO	216,9285714	30%	13,14285714	78%
S/ENS GRILLE DROITE PW	964	76%	41	39%
Outillage de basculement PAF A320 NEOP65	56,6	1%	40	39%
POSITIONNEUR BANDEAU APF CFM NEO	439	55%	37	42%
CHARIOT PAF	15345	98%	23	58%
OUTILLAGE POSITIONNEMENT COUDE ASPI CFM	1080	79%	23	58%
TABLE DE ROUTAGE RAMPE OHDS PW	730	70%	45	36%
Deburring -ST72 - A320NEO	768,5	71%	14	76%
OUT Contre appui percage upa LGR/Tetard	1793	87%	11	84%
OUT Calage N1/LGR INF	1836	87%	9	89%
Frame CFM	1072,98	78%	21,6	60%
NEO CFM POSITIONNEUR X & Y N5/SPIGOT	1711	86%	8	92%
REGLAGE ENS. TUYAUTERIE FUEL	1821,25	87%	46	35%
Deburring bench RIB / Pyramid	2751	91%	9	89%
NEO CFM POSITIONNEUR X & Y N5/SPIGOT	1340	82%	8	92%
Frame PW	2705,45	91%	31	48%
Palonnier mât complet	93	6%	8	92%

Figure 23. Reliability and Maintainability of the tooling having the higher steady unavailability

TOOL	If adding a spare
Poutre d'alésage	7%
POSITIONNEUR BANDEAU APF PW NEO	3%
PALONNIER SERIE/CAMION NEO	3%
Banc et barre de préréglage	2%
Bâti mobile Station 64	2%
Sealing & Buffer 3 - ST64 - A320NEO	2%
Station de moulage 72-1 A320NEO	1%
S/ENS GRILLE DROITE PW	1%
Outillage de basculement PAF A320 NEOP65	3%
POSITIONNEUR BANDEAU APF CFM NEO	0%
CHARIOT PAF	0%
OUTILLAGE POSITIONNEMENT COUDE ASPI CFM	0%
TABLE DE ROUTAGE RAMPE OHDS PW	0%
Deburring -ST72 - A320NEO	0%
OUT Contre appui percage upa LGR/Tetard	0%
OUT Calage N1/LGR INF	0%
Frame CFM	0%
NEO CFM POSITIONNEUR X & Y N5/SPIGOT	0%
REGLAGE ENS. TUYAUTERIE FUEL	0%
Deburring bench RIB / Pyramid	0%
NEO CFM POSITIONNEUR X & Y N5/SPIGOT	0%
Frame PW	0%
Palonnier mât complet	0%

Figure 24. Summary of the unavailability of tooling when adding a spare