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AIRCRAFT HEAVY MAINTENANCE PROCCESS SIMULATION AND PLANNING

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ABSTRACT

In aircraft maintenance packages the initial sub-package which is prerequisite of all C checks is called "C1 check". In this study a method for the improvement of C1 check planning and implementation by simulation is sampled and software package architecture is proposed. Instead of simulating and attempting to plan the complete process which is consisted of 225 of maintenance tasks with a total of 715 technician man hours, the complete "C1" maintenance package is modeled as a series of parallel and series "shift packages" which are combinations maintenance task cards of shift duration activity. Sample ARENA simulations for; sample shift packages as well as for groups of shift packages are studied in the study.

INTRODUCTION

In civil aircraft world; design, development, production, operation, personnel training, maintenance (MRO), air traffic control and all related sub-activities are regulated and controlled by international rules and organizations. The top regulating organization is International Civil Aviation Organization (ICAO) established under United Nations in 7th December 1944 with Chicago Convention. Under ICAO rules several National Civil Aviation Authorities were established such as: EASA (European Aviation Safety Agency), FAA (Federal Aviation Authority), Turkish Civil Aviation Authority (DGCA-SHGM). Turkey operates and maintains aircraft according to Turkish Civil Aviation Authority Regulations which are fully compliant with EASA and FAA regulations. Aviation Products, their Utilization and Organizations Approval (Aircrafts, Engines) Top down Regulation Hierarchy is shown in Figure 1.

Certification of Product and Parts and Appliances

1-Product
Design Organisation Approval (Subpart J)
Product Organisation Approval (Subpart G)
Aircraft (Type Certification) Certification Basis For Large Aircraft (CS25)
Engine (Type Certification) Certification Basis (CS-E)
Propeller (Type Certification) Certification Basis (CS-P)
Changes to Type Certifications:
Design Organisation Approval (Subpart j)
Production Organisation Approval (Subpart G)
STC (Suplemental Type Certification)
Major Changes/Minor Changes
2-Parts and Appliances
ETSO Parts: (European Technical Standard Orders)

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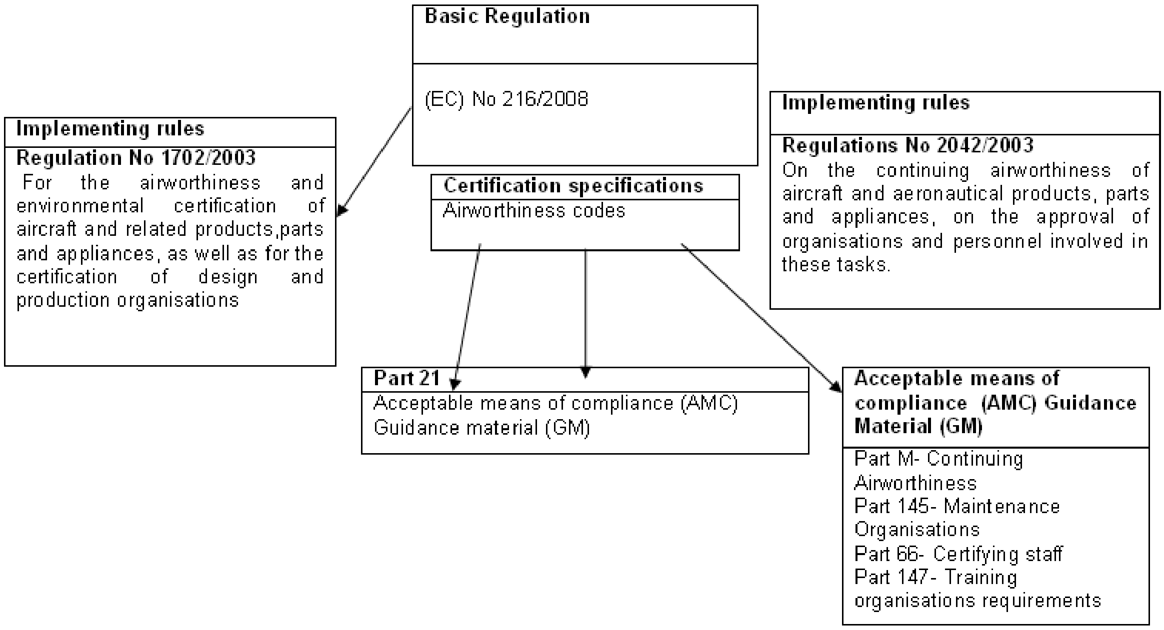

Figure 1: Top Down Hierarchy of EASA Civil Aviation Regulations Covering the Complete Product Life Cycle of an Aircraft

Reliability

Reference 3 describes the concept of Continuing Airworthiness which is closely related with Reliability of aircraft and its systems. Relatively few systems are designed to operate without maintenance of any kind. For most systems there are two types of maintenance, one or both of which may be applied. In preventive or scheduled maintenance, parts are replaced, lubricants changed, or adjustments made before failure occurs. The objective is to increase the reliability of the system over the long term by preventing the aging effects of wear, corrosion fatigue, and related phenomena. Whereas, corrective or unscheduled maintenance is performed after failure has occurred in order to return the system to service as soon as possible. Such maintenance is performed at unpredictable intervals because the time to any specific unit's failure cannot be established ahead of time.

The amount and type of maintenance that is applied depend strongly on its costs as well as the cost and safety implications of system failure. Thus, for example, in determining the maintenance for an aircraft engine the trade-off would be much different the potentially disastrous consequences of engine failure would eliminate repair maintenance as a primary consideration. Concern would be with how much preventive maintenance can be afforded and with the possibility of failures induced by the ability to maintain.

Reliability and Maintainability for the Airplane

Reliability is the performance over time. Aircraft reliability is defined as the ability of aircraft to be operated in specified standard at certain time. Reliability is built into the design of the airplane systems and components. It also influenced by the environment and type of operations. Reliability would deteriorate because of wear and tear caused by operation and environment as shown in Fig.2. Therefore, some sort of preventive maintenance should be performed to restore this deterioration in reliability.

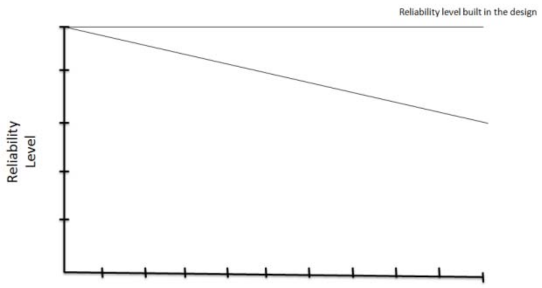

Figure 2: Reliability Variation versus Time.

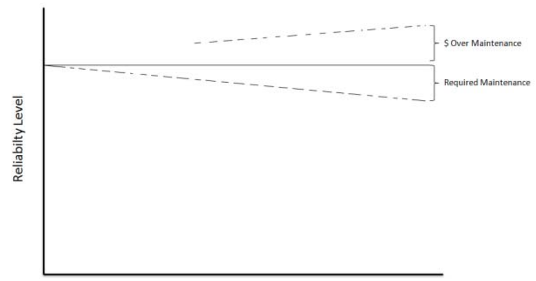

Figure 3: Over Maintenance Effect

Aircraft ground time for maintenance is very important for airlines. Less ground time means that there is more time for aircraft in services, and then there is more revenue in turn. Aircraft ground time has been dramatically reduced through optimization maintenance program, combining with airline experience.

One of the main objectives of an airline is to have an airplane ready and fit to fly when needed. This fitness-for-flight is called availability. It is also called uptime. However, the availability of an airplane depends on how often failures occur (Reliability), and how long it takes to fix it (Maintainability). Reliability and maintainability are functions of availability. Availability A_o;

$$\mathrm{Ao} = \frac{\text{Operaing Time}}{\text{Operating Time} + \text{Downtime}}$$

$$= \frac{Nf\,MTBF}{Nf\,MTBF + Nf\,MDT} = \frac{MTBF}{MTBF + MDT}$$

Where, *Nf* Number of failures, *MDT:* Mean Down Time, MTBF: Mean Time between Failures.

Since A_0 (Availability of a serviceable airplane) is the primary objective of any airline, the airlines should be interested in improving both the *reliability* and *maintainability* of the airplane, in the design stage and through the *life of the airplane.* For the airline to influence the *reliability* and *maintainability* of the airplane at the design stage, it should compile and include in their airplane specifications file, a set of design targets. These targets should be submitted to manufacturer for consideration and agreement to include in the design of the airplane.

Monitoring and analysis under service conditions will highlight those airplane systems, components and power plants which are unreliable and cause technical and cost problems. The airline must be in a position to quantify the extent of problem and the urgency with which it needs to be eliminated. Also the airline should provide in-service data to the manufacturer so that improvement on the reliability of in-service and new airplanes can be made.

Application of a maintenance program cannot provide a reliability level greater than that inherent to the design but increase cost as shown in Figure 3. Inappropriate or inadequate maintenance can, however, degrade reliability. If a reliability program provides proper analysis and recommends appropriate corrective action, the quantity and frequency of maintenance will be indicated for each system, component and structure. In order to increase the inherent reliability level, product improvement is required.

Estimation of the Improvement in Reliability with Maintenance

In order to estimate how much improvement, in reliability we derive from the preventive maintenance, we consider preventive maintenance in which the system is restored to an as-good-as-new condition each time maintenance is applied.

Maintenance

Civil Aviation Authorities mandates certain system and dispatched reliabilities for an operating aircraft, its engines and systems. For this purpose a performance tracing and recording system for aircraft down to component level is established for a measurable, sustainable, and compound reliability. By EASA regulations aircraft operation responsibility is given to airlines under Part M regulation and operators are responsible for assuring: “Continuing Airworthiness” of aircraft they operate. Aircraft generates revenue only when it is operated by the operator

The defined Reliability for the aircraft and for its systems reduces by the utilization of the aircraft its systems and certain Maintenance Operations must be performed to restore the Reliability as shown in Figure 2 and 3.

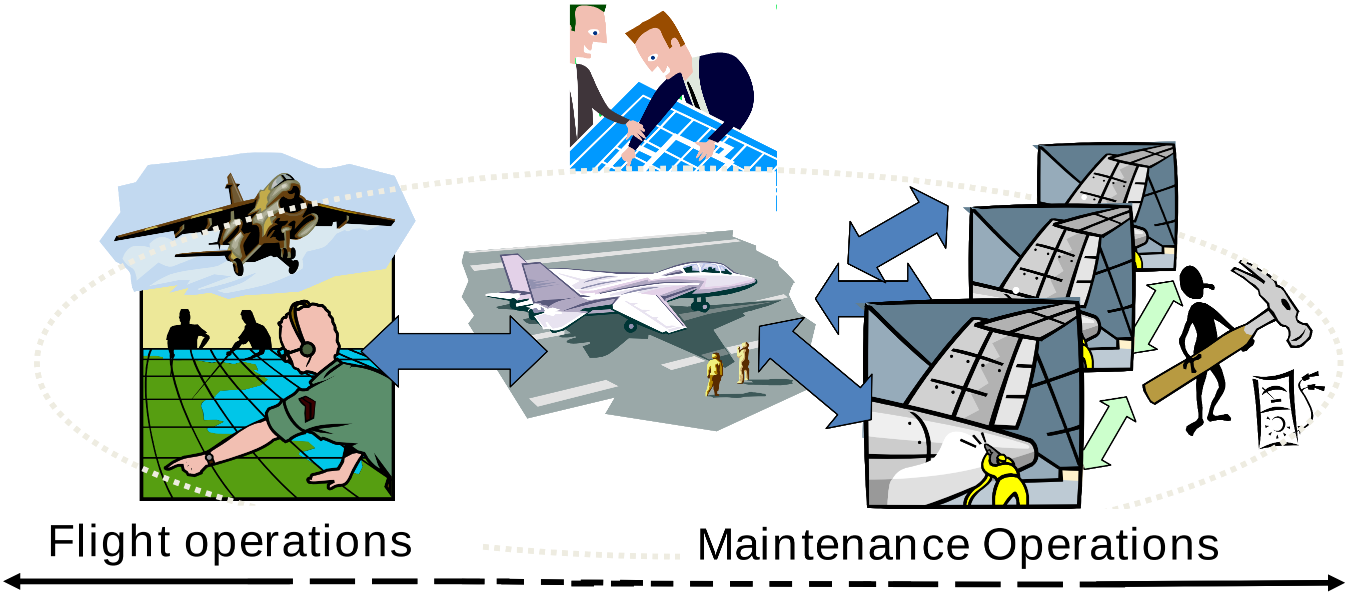

Figure 4: Aircraft Flight Operations and Maintenance Operations.

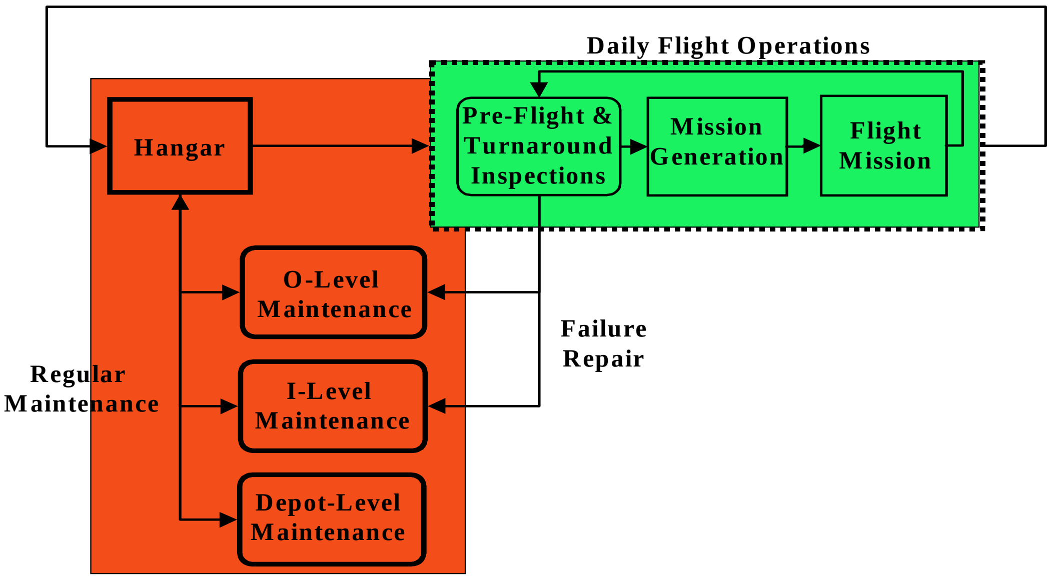

Figure 5: Flight Operations and Maintenance Types

These maintenance operations, depicted in Figures 4 and 5 are necessary for the aircraft to keep its "Continuing Airworthiness" condition. These maintenance activities are series of actions defined by the Original Equipment Manufacturer (OEM) with the "Maintenance Planning Manuel" (MPM) of the corresponding aircraft.

Table 1: Flight Operations and Maintenance Types.

	Maintenance Levels		
	LINE	BASE	
Maintenance types	Pre-flight inspections, scheduled maintenance, minor failure repair	Term maintenance, failure repair	Term maintenance, damage repair
Location	Airport	MRO center	
Duration	Minutes-hours	Hours-weeks	Weeks-months
Example tasks	Refueling, minor repairs, e.g. light bulb change	Component change/repair, e.g. hydraulic pump change	Elaborate component or structure changes/ repairs, e.g. bird crash repair

MPM is consisted of "Maintenance Task Cards" which are basically the execution of predetermined tasks such as; disassembling a component, system, part on the aircraft, performing some inspections, replacing parts on condition or without any evaluation, control, inspection changing in any case "non-conditional" then assembling the disassembled components, performing some local tests, and some inspections Each activity is conducted at a specific location; which is referred as "Zone" in the task card. These actions are defined and instructed in complete details by a paper copy of task cards, which constitutes the "Maintenance Package", prepared by Maintenance Engineering and compiled together by the Production Planning Department.

Content of each task card is prepared by the Engineering Department. Each task card must be done by a specific skilled technician who received certain series of trainings and has gained certain level of experience in order to be qualified and authorized to conduct these maintenance activities. The major process of aircraft heavy maintenance center is the execution of a series of maintenance task cards constituting several maintenance packages for different aircraft. At an instant time/day in the heavy maintenance hangar, several different types of aircraft are in this main process. Each aircraft has an execution time for its defined maintenance package and requires certain resources.
As summary each task card contains;

- Task card number,
- "Zone" is of the aircraft where specific component, system, part,
- Required number of skilled technician
- Necessary tools, jigs, fixtures and fixtures,
- Needed replacement parts.
- Necessary consumable materials; sealant, and cleaner,
- Standard time for implementing the task card content,
- Instructions to implement the required activities,
- Instructions to be conducted for on-continual activities,

For a specific aircraft estimated time for the execution of product specific Maintenance Package is set by the production planning based on the past practices. Therefore task cards are grouped in shifts level and estimated times of execution of these shift level activities and how many shifts would be needed to complete Maintenance Package is defined. Activities are visualized with MS Project based Gant Charts. In this planning required number of different skilled technicians, tools, consumables, and parts are also determined and their proper allocations and availabilities are organized.

Common problems occur during the execution of Maintenance Task Card Packages can be outlined as;

- Each aircraft may not be completed in the expected, (delays).
- Each day all the planned activities as the total number of planned task cards are not fully completed,
- Available skilled technicians are not utilized in the optimum level,
- Task cards are not completed within the proposed standard times,
- During the implementation of certain task cards some additional activities are required which were not planned originally.

These unplanned activities are called non-routines. For example when corrosion on a structure is found and certain additional inspections and repair actions would be needed. These non-routines require at least additional technician times but also may require additional engineering evaluation (sometimes damage is needed to be reported to the manufacturer of the aircraft) which means more additional time compared than in house engineering evaluation and defining the necessary action which is additional to the planned task cards.

DEFINITION OF PROBLEMS

In MRO, industry the definition of the end product is not easy to define. Customer expectations, civil aviation requirements and complexity of the aircraft and its system have conflicting objectives and constraints therefore the value of the end product cannot be represented with one parameter. Objectives of the customer- airline operator, continuing airworthiness and the MRO service provider company are depicted in Figure 6.

The customer, operator of the aircraft, has the responsibility to attain the predefined "Reliability Level" for the aircraft by implementing approved maintenance task cards and customer wants to accomplish this with lowest possible cost and shortest grounding time for the aircraft. MRO service Provider Company must complete the maintenance package as with full compliance to its Part 145 responsibility with lowest cost.

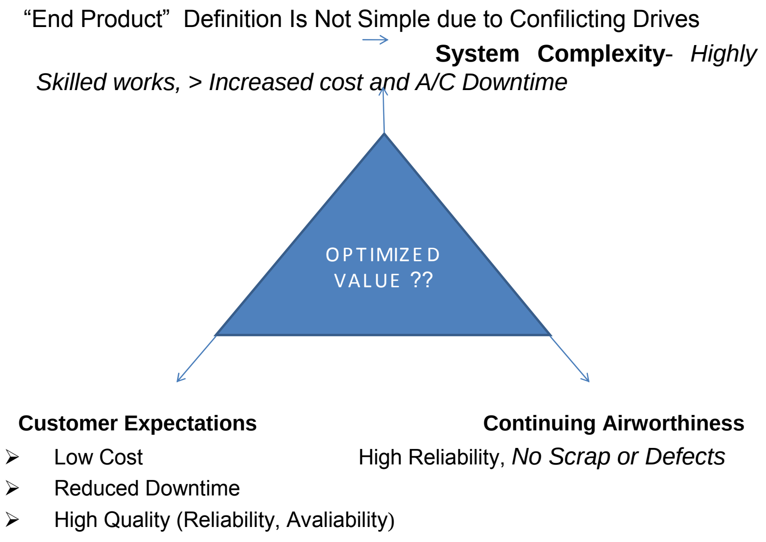

Figure 6. Conflicting Objectives of the Base Maintenance; Airline Operator, Airworthiness Requirements and MRO Company.

OBJECTIVES

The first objective of this study was to identify the portion of the Base Maintenance Main Process which can be standartized and efficiency and productivity can be improved. C1 checks are selected as the main sub-process, because "C1" checks are repeated in all C checks. Task cards of the C1 check are studied with this vision and grouped in terms of related activities, zones and skilled technician requirements. C1 check for the considered aircraft requires 715 man-hours of work for routine task cards which is equivalent to 11-shifts of work where the effective working hours per person is taken as 6.5 hours. If an average of 16 men per shift is allocated to the C1 check, routine cards can be accomplished in 7 shifts. These activities only include standard C1 task cards, without any additional non-routines and any other applications such as Service Bulletins.

It is visualized that if C1 checks can be executed with a well standardized process with better planning, improved sub-processes and with higher efficiency, it can be an important asset of Turkish Technic for the new HABOM facility at Sabiha Gökçen Airport in Istanbul. If this achievement can be accomplished this new way of conducting C1 checks is proposed to be called as “C1 FACTORY”.

As the first step; it is suggested that all task cards which do not generate significant amount of non-routine items can be executed with better efficiency if Lean Principles would be applied. In other words if execution of these type of task cards would be done within narrower distributions around their standard times, this will be the first improvement towards the C1 FACTORY concept. In view of this study C1 check routine task cards are aimed to be modeled and simulated by ARENA. Schrage *et al*, Reference 4, have studied above described problem and proposed solutions by; utilizing Lean Principles and advanced simulation tools. We called this first improvement as On Time Execution of Routine Task Cards, with the utilization of Lean and 5S applications. THY Technic has a vast experience in Lean Principles, Value Stream Mapping (VSM) and 5S applications and implemented these methods in several sub-processes of MRO activities.

PROBLEM SOLVING

Step 1 : Applying The Lean Principles

Reference 4 have well defined the application of Lean Principles in aircraft heavy maintenance; as organizations begin to accurately specify value, identify the entire value stream, make the value-creating steps for specific products flow continuously, and let customers pull value from the enterprise, several improvements would occur. There is no end to the process of reducing effort, time, space, cost, and mistakes while offering a product or service which is ever more nearly what the customer actually wants. Suddenly Perfection the fifth and final principle of lean thinking, does not seem like a crazy idea. Application of Lean principles in a main process require a Value Stream Mapping (VSM) and Turkish Technic has conducted several VSM studies for its major processes.

Why should this be? Because the four initial principles interact with each other in a virtuous circle. Getting value to flow faster always exposes hidden muda (waste) in the value stream. And the harder you pull, the more the impediments to flow are revealed so they can be removed. Dedicated product teams in direct dialogue with customers always find ways to specify value more accurately and often learn of ways to enhance flow and pull as well. Reference 4 proposed a sequence of activities to implement the fire Lean Principles in the Routine Task Cards processes and it is implemented to TT as;

1. Specify Value: A research team, in partnership with Turkish Technic(TT) can develop a Benefit to Cost Ratio (BCR) that captures the value of TT's MRO process conducted mainly for its major customer, Turkish Airlines. The combined team will use various techniques, including 'brainstorming' and a Quality Function Deployment (QFD) Planning Matrix to define the value to the customer.

2. Identity the Value Stream: This research team has collaborated with TT subject matter experts to map out process steps and activities associated with the MRO application of narrow body aircraft. While most of this task are being accomplished by the Production Planning Engineers with assistance of a research engineer, it also required some involvement of the Maintenance Engineers. This task focused to identify any obviously wasteful steps or activities in the process. The goal was to reduce the MRO process down to approximately 30 to 40 key activities. TT existing Proccess Development Department has been conducting the similar activities for nearly six years.

3. Flow: After the Value Stream have been identified the research team focused on to identify and simulate the flow process. In this study the Arena Simulation program made available to TT by Doğuş University* used for modeling and simulation during several Industrial Engineering students projects. The ARENA Flow Process template is designed specifically to model combined discrete-continuous systems such as the certain portions of the main MRO process. As a result of these task, attempts were made to redefine the work of functions so they can make a positive contribution to value creation. The flow process identifies requirements at every point along the value stream, ensuring that value is truly added by each step in the process.

4. Pull: The research team will investigate means to transform the TT MRO process from a reactive or 'push' system that provides resources to meet process needs to a 'pull' system that draws the aircraft through the value stream at the planned rate. This approach requires strong interaction with Turkish Airlines (THY), as well as other suppliers and vendors that support TT, but benefits both customers and suppliers through improved planning and resource allocation.

5. Perfection: The research team, identified ways to implement continuous improvement in TT's MRO processes. As the other lean principles are applied,there is no end to the process of reducing effort, time, space, cost, and mistakes while offering a product or service which is ever more nearly what the customer actually wants. Study group looked for ways to improve the turn around time beyond the initial goal of reduction.

Step 2: Predicting The Non-Routines, Modeling Activities as Probabilistic Process

Turkish Technic (TT) is a maintenance company provide services to THY and nearly 30 other airline operators for their Boeing 737 and Airbus 320 narrow and wide body aircraft. They perform scheduled maintenance work packages known as a "C" checks, which are a prescribed annual maintenance period of inspections and repairs. In addition to the prescribed requirements for the "C" check defined by the FAA and EASA approved maintenance plans, THY frequently adds additional inspections, repairs or modifications to the work package for a specific aircraft. The total scheduled (defined) work packages are coordinated and finalized between THY and TT approximately one month prior to the arrival of an aircraft.

As an aircraft progresses through the defined work package of "routine" tasks, the inspectors and mechanics at TT often find additional discrepancies in the aircraft that were hidden from view prior to arrival at TT. The discrepancies are written up with estimates for the labor and material required to repair them. These "non-routine" tasks are added to the work package scope after approval by THY. After all the inspections, repairs and modifications are completed, the aircraft is returned to flight status, undergoes flight tests, and is delivered back to THY.

Proposed Approach to Define the C1 FACTORY

Identifying Value and Understanding the Value Stream

In order to make recommendations that have the potential to reduce the downtime of aircraft being serviced by TT, a thorough understanding of their MRO process was needed. This understanding is obtained in reference 4 through the following means:

- Utilization of the "House of Quality" from Quality Function Deployment (QFD) to Identify the critical aspects of the process that affect Value from the customer's viewpoint.
- Analysis of a process flowchart, which represented the Value Stream and was created by the planning staff at TT for summarizing the basic steps followed during the MRO process and as a part of this study it presented all task card activities.

Modeling the Flow Process

TT has a very well established Production Planning and Control Proccesses where;

- Studying the behavior of the sub-activity of MRO processes,
- Developing understandings for the observed behaviors.

* With student version application limitation, used in courses and Graduation Projects.

- Seeking answers for several "What if" questions by experimentations,

were well executed with conjunction of Proccess Development Department.

ARENA software has been used to simulate preventive maintenances by Reference 1 and specificly for airline operation Line Maintenance by Reference 5. In view of these applications, in order to develop the ARENA model of TT's MRO process, the following sequential approach which consisted of:

- The events that take place throughout the MRO process,
- Resources and constraints that restrict the MRO process
- Data analyses to fit profitability distributions to the various process (sub)tasks,
- Modeling translation and verification.
- Attemps for validation of the ARENA shift package models,

were experimented with parameters in the ARENA model to assess the impact of changes in the distributions around the standart time.

Understanding and Picturing the C1 Check Process

C1 check is consisted of nearly 225 standart and routine task cards which consumes around a total of 715 man hour skilled work as based on standard times of task cards. All C1 check activities require 17 different skill types for different steps of C1 the check. Firstly it is determined that C1 check package is assumed to be done in fixed certain number of shifts according to best practices, experiences and by implementing Lean Principles. Shift level combinations of serial and parallel task cards, which are called as 'Shift Packages' in the study, are defined as based on Production Planning and Control Department's current application and implementation approaches. This planning are based on THY's 78 years of experience.

RESULTS

At this stage of the study a laborious activity of extracting distributions of 'Actual' versus 'Standard' execution times of the considered task cards was conducted. Authors thank to several Industrial Engineering students who involved this process through the TT maintenance data base for various aircraft for their several C checks which were accomplished in last ten years. Examples of the execution time distributions are shown in Figure 7 for selected six task cards. Distributions are developed for C1 portion of C1, C2, and C4 checks data obtained from maintenance records of a fleet of one aircraft model. Curves show improvements in the reduction of execution times between earlier C checks compared to later C checks. This clearly indicates that TT has implemented Lean Principles successfully in the MRO process and continuous improvement trends are established. It is also evaluated that it is the right time to utilized simulation tools to conduct experiments, where and how further improvements can be made in MRO Processes.

Instead of attempting to simulate and plan the complete process consisted of 225 maintenance task cards, the complete "C1" maintenance package is modeled as parallel and serial 'shift packages'. Execution of different shift packages on several aircraft in a base maintenance facility is shown schematically in Figure 9. Sample ARENA simulations for groups of "shift packages" are studied.

In this study it is proposed that complete C1 check can be standardized. In order to conduct several C checks, primarily their C1 check portion within the concept of "C1 Check" certain work descriptions for skilled technicians, supporting personnel, logistics department must be prepared. Reference 6 reviewed the possible applications of different hardware and software in planning, execution and competition post evaluation of maintenance tasks. As being the final part of the study; a software architecture is defined for; extracting and recalling several data and document from through the ERP system of TT, fast and macro level simulation of the execution of several C checks which will be conducted, generating different outputs and online control and tracking of the on-going C check processes.

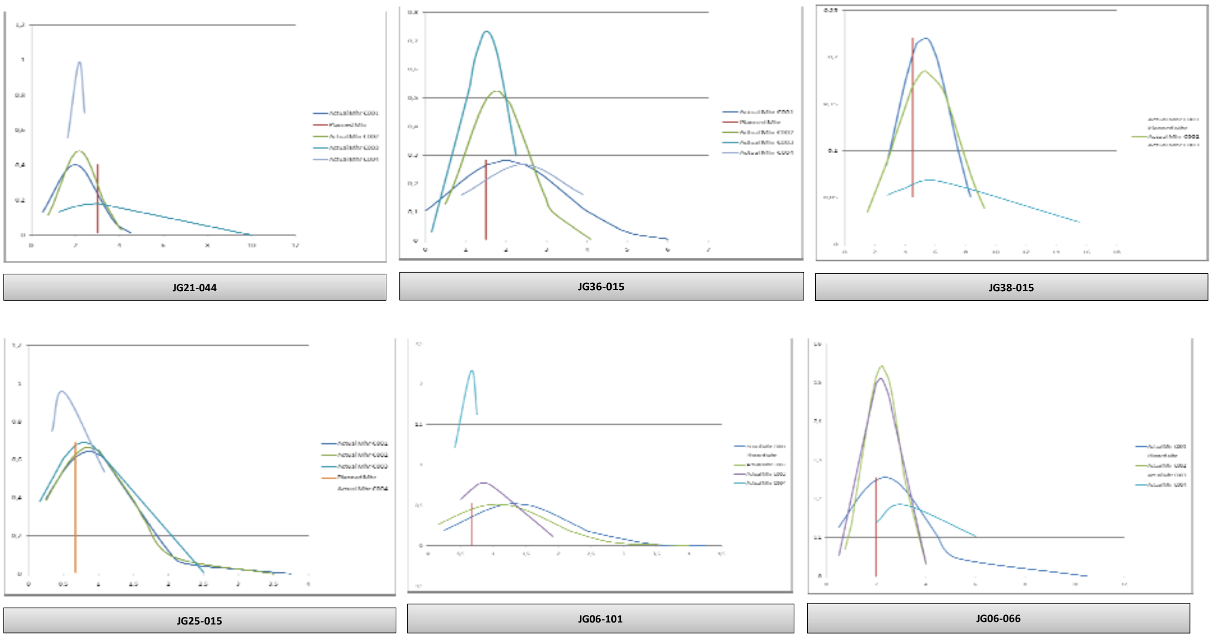

Figure 7. Actual Execution Times of Several C1 check Task Cards compared with their standart times (shown as vertical lines).

Sample of these shift packages are modeled by ARENA software with the introduction of; distributions of execution times, required resources, constrains, serial and parallel sequences of these task cards. An outline of this modeling with the use of ARENA software is given in Appendix. An example of simulation for a Shift Package is shown in Figure 7, where serial and parallel task cards of this Shift Package are executed. Experiments on the simulation of Shift Packages are also conducted such that distributions of execution times of task cards are narrowed, availability of resources constrains are manipulated and certain task cards are added or removed. In these experiments it was aimed to see whether the simulated Shift Packages could be executed within a time of 6 to 7 hours since the effective work hour of a shift is around 6.5 hours. In these experiments some non-routine (unexpected) event probabilities, which are again defined as based on the previous C1 checks data, are introduced in the models. Simulations successfully showed the impact of a possible non-routine occurrence in the Shift Package change the completion and/or total execution time distribution of the considered Shift Package. As result, simulations made by ARENA software are useful to visualize processes as well conducting virtual experiments on the task card executions.

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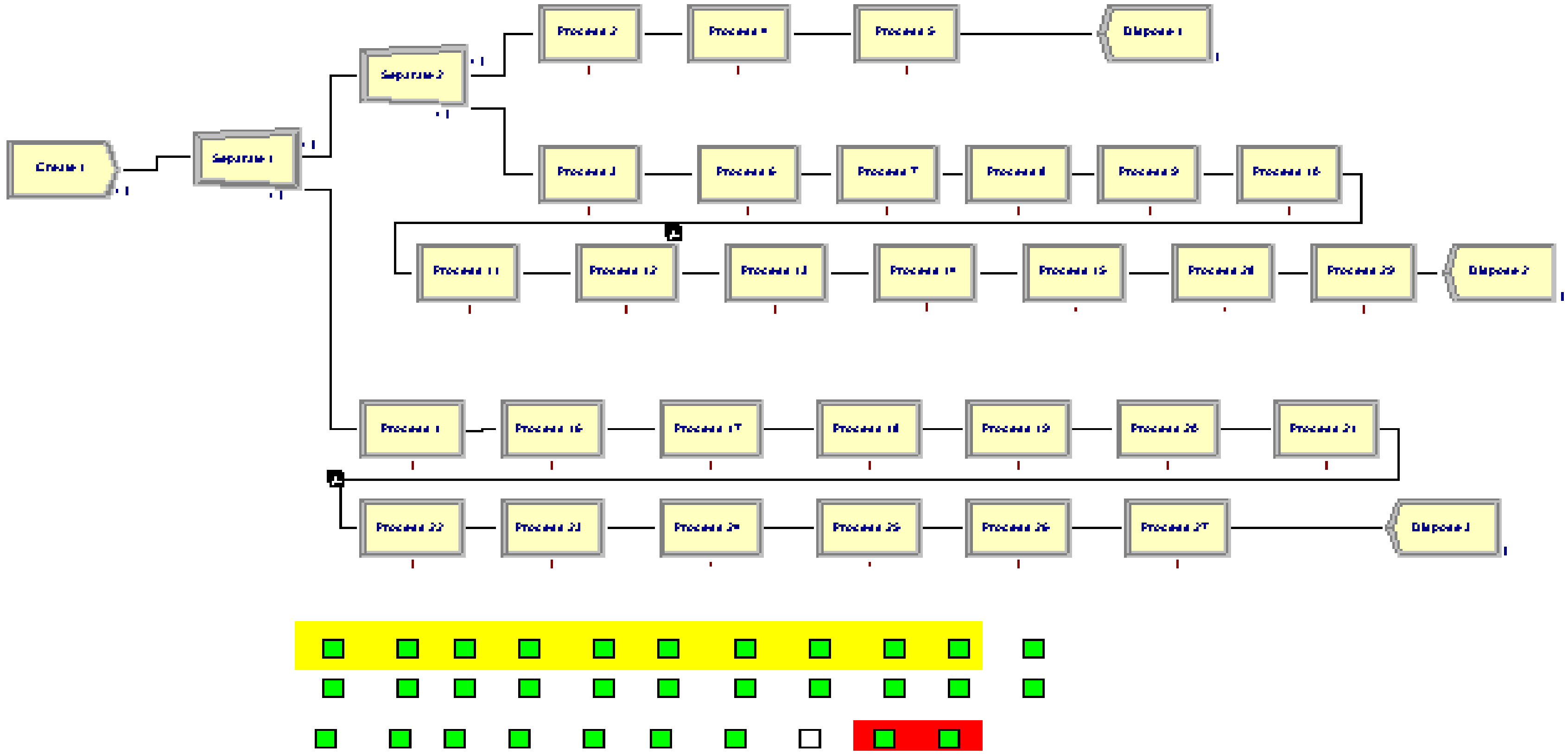

Figure 8: Simulation of A Section of C1 Check package, “Shift Package” by ARENA Simulation Software.

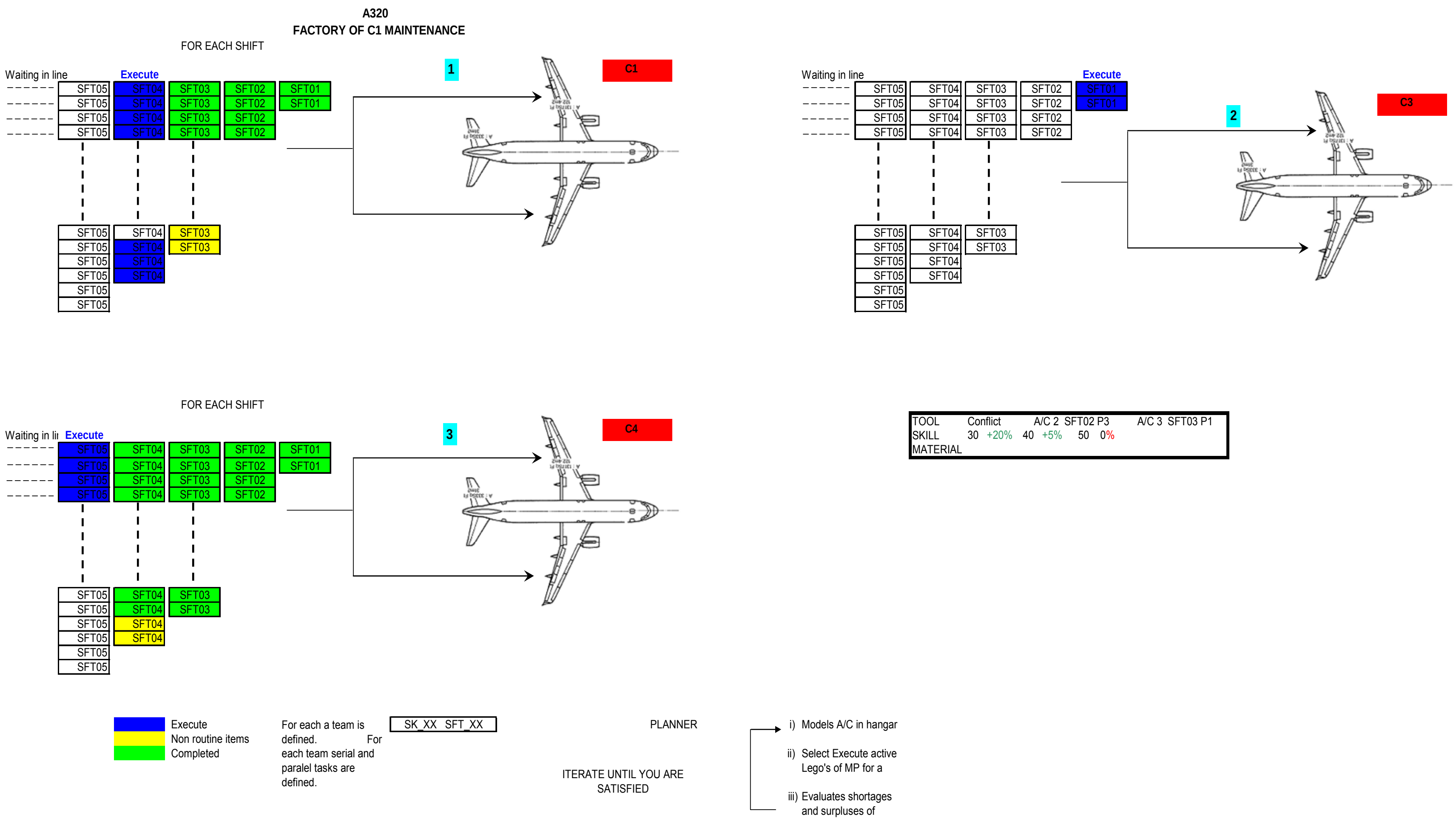

Figure 9: Execution of Several C1 Maintenance Packages in the Proposed C1 Factory Concept.

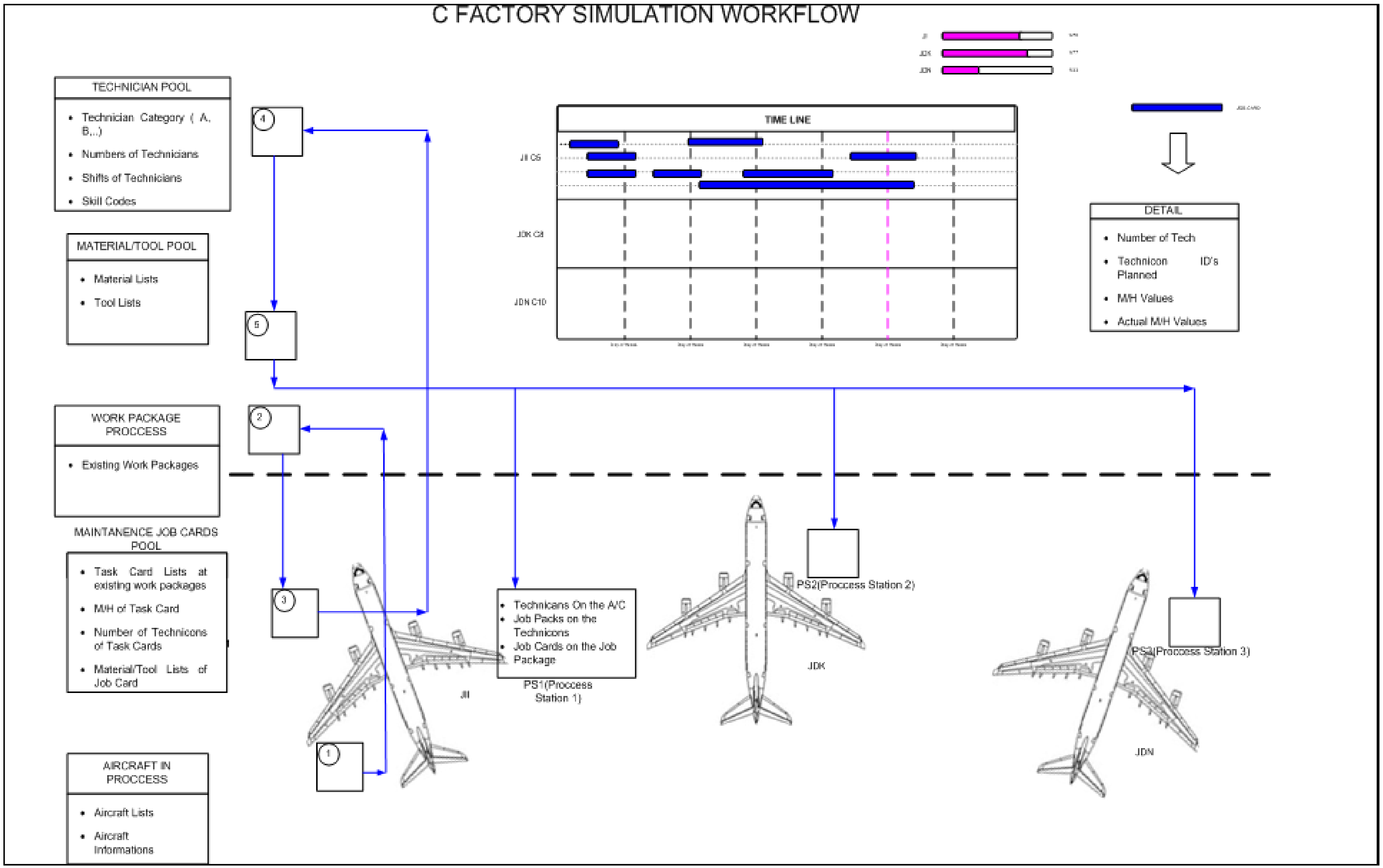

Figure 10: The Information Generation for the Proposed C1 Factory Execution Workflow.

CONCLUSION and REMARKS

This study provided a new visualization for the C check maintenance package execution process at TT. Distributions of task cards execution times are obtained from TT's previous maintenance records and different data extracting and processing methods are defined for different sources and formats. First observation made by the evaluation of execution time distributions clearly indicate that TT has ben implementing Lean Principles and Value Stream Mapping applications in several MRO processes successfully and significant improvements in task card execution times are achieved.

ARENA software is found to be a powerful and useful tool to effectively simulate C checks task card executions in the MRO process. It is not only used to picturize the existing process but also providing an experimenting application for different 'What If' questions. By changing distributions of execution times, adding and removing task cards form a defined Shift Package and manupulating resources and constraints are providing different execution cases in minutes. Results of these experiments can give a very valuable guidance for defining new targets in Lean and VSM applications.

This study has aimed to capture the potentials of process simulation and visualization by ARENA software, the importance and value of data in the existing maintenance records for the company and observing the macro level results of Lean and VSM applicaitons. Since this study only provided limited samples for the potential applications; the second stage of the study may focus on the quantification of benefits to be obtained by implementing the method for; one complete C1 check, several parallel and serial execution of C1 packages in different C checks and stocastic approaches for predicting occurances of non-routines and distribution of waiting times before the execution of the non-routines during C checks.

Acknowledgements

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Appendix

Arena Simulation Model

Create Module

This module is intended as the starting point for entities in a simulation model. Entities are created using a schedule or based on a time between arrivals. Entities then leave the module to begin processing through the system. The entity type is specified in this module.

Create module is used to generate our entity which is named as *Ucak.* Because there is only one entity in the simulation model, entities per arrival and max arrival are set to 1, whereas the time between arrivals is set to a constant.

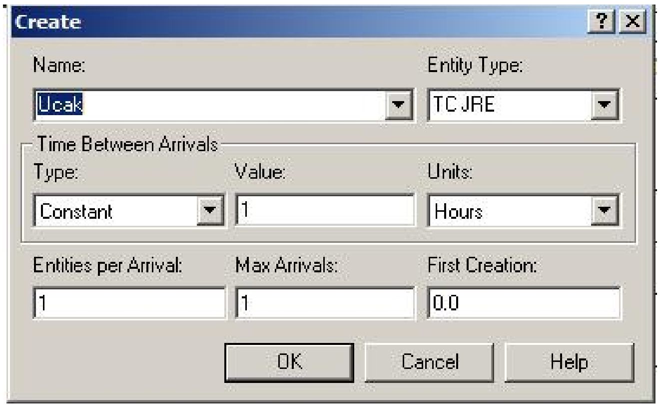

Figure A1. The airplane as the entity created at t = 0.

Process Module

This module is intended as the main processing method in the simulation. Options for seizing and releasing resource constraints are available. Additionally, there is the option to use a "submodel" and specify hierarchical user-defined logic. The process time is allocated to the entity and may be considered to be value added, non-value added, transfer, wait or other. The associated cost will be added to the appropriate category.

In Figure A2, the logic of the process and its parameters can be seen. During the simulation, the entity will first seize required amount of specific resource; then the resource will be delayed while processing and lastly resources will be released.The user of the model can define the delay type with its parameters in appropriate time units.

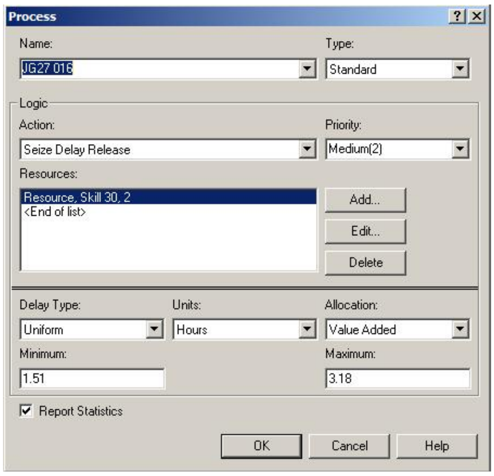

Figure A2. Process module

Separate Module

This module can be used to either copy an incoming entity into multiple entities or to split a previously batched entity. Rules for allocating costs and times to the duplicate are specified. Rules for attribute assignment to member entities are specified as well. When duplicating entities, the specified number of copies is made and sent from the module. The original incoming entity also leaves the module.

Since there is only one entity created for the whole simulation, the separate module is used to duplicate the entity with 100% occurrence probability for every process and after the completion of the all processes, they are batched to one. The reason behind this structure of the model is the algorithm of the Arena software, because as mentioned before Arena is helpful mostly in simulating continues type of production where entities are moving through processes. However, it needs to be created an immobile entity which is a plane in maintenance and parallel processed task cards which are obtained by separate nodes. The separate node details are shown in Figure A3.

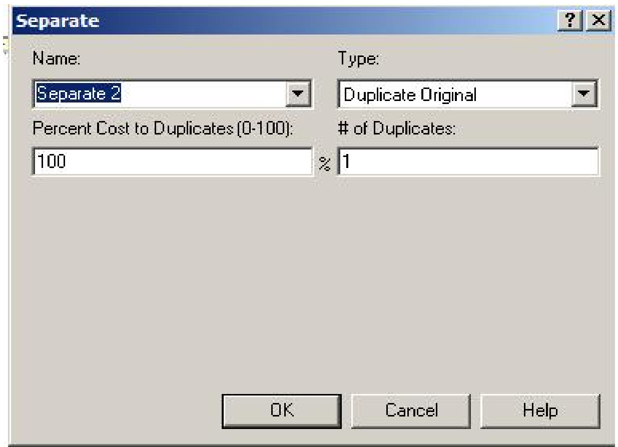

Figure A3. Separate Module

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