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Department of Mechanical & Aerospace Engineering

Master's Degree Program in Automotive Engineering

Master’s Degree Thesis

Investigation on enterprise processes according to a hierarchical model compliant with the I4.0 paradigm

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Abstract

For the manufacturing, under the tendency of Industry 4.0, everything is going to connect because of the continuous development of automatic control and advanced sensor. Also, the article points out the concept of 'Digital Factory' which uses digital technology for modeling, communications and to operate the manufacturing process. With this approach, the operator of the factory can totally monitor, control and optimize all the production variables in the manufacturing system in real-time.

In this paper, it introduces a practical automobile wheel hub production line. The thesis will simulate the wheel hub production line with a simplified edition to learn and describe the practical use of digital factory. Also, it improves the hierarchical model. The production line, however, will be built in a FLEXSIM to simulate and acquire the data we need, which is based on a 2D background to fit the real one.

Key words: Industry 4.0, production system, hierarchical model, wheel hub, digital factory, FLEXSIM.

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CONTENT

Chapter 1: Background of Industry 4.0

1.1 The 4th industrial revolution

The concept of the Industry 4.0 is point out by Germany nine years before, born under a situation that human is facing the challenge of lacking of the resource and the natural environment on earth is becoming worse, so the main topic of this revolution is 'Green', which means human kind uses the most eco-friendly technology of manufacturing without sacrificing the nature.

Just like AI, block chain, autonomous driving, which are based on the information technology revolution, changing people's life gradually. As the result of the introduction of personal computer, intelligent cell phone and Internet, these makes human's life more convenient than ever before. And people become more rely on those technology achievements. The same improvement is happening in manufacturing area. As fully automatic manufacturing and digital management of manufacturing in many companies have been already achieved. The new technology allows continuous interactions not only among humans and between human and machines, even among machines, becomes the new tendency. This provides the researcher a better manufacturing environment. Managers and researchers can totally monitor and control each single step of the whole manufacturing process, and by interconnecting, each device can communicate so to improve the efficiency.

1.2 Manufacturing in Industry 4.0 era

In a brief word, the Industry 4.0 gives the chance of the combination of Information Communication Technology (ICT) and Cyber Physics System (CPS). About manufacturing, researchers more focus on CPS, through powerful background computing and simulation, every object and event in the real is converted into digital information, which will be stored, analyzed and controlled.

Chapter 2 Production hierarchical models

With the Industry 4.0 becoming a trend, 'Digital Factory' is a concept being put forward, which uses digital technology for modeling, communications and operates the manufacturing process. This arrangement of technology allows managers to configure, model, simulate, assess and evaluate items, procedures and system before the factory is constructed. configuration, design, screen and control of a production system are been already achieved in the digital factory. An indicator of informatization for a corporation becomes true. Also, this technology is supported by the virtual simulation technology. The fastest improvement automation of the company is based on the continuous development of automatic control and advanced sensor. Therefore, the digital factory is the combination of both, that is, the digital factory is not just the realization of the virtual simulation, neither the simple application of automation for the real factory, but a new approach of factory under the support of digital technology and cyber physics system.

2.1 Relative literatures

Before the introduction of Production hierarchical models this thesis puts forward. It is necessary to find more literatures about enterprise modeling framework and management modeling about production system to summarize their definition and try to find some inspiration about the improvements of the hierarchical model right now.

2.1.1 Models and systems about enterprise or production management

2.1.1.1 ARIS

This architecture is been put forward by Professor Scheer from German. ARIS is the abbreviation of "Architecture of Integrated Information Systems", which is a system to help describe a company's structure and help to build a model to reflect the situation of the company. The benefit of built a model with the system like ARIS is:

- Enhance the adaptability of enterprises
- Reduce the cost of business process design and implementation
- Support knowledge integration
- Support workflow management and process monitoring

As in the ARIS, there are five description views and each view have three levels.

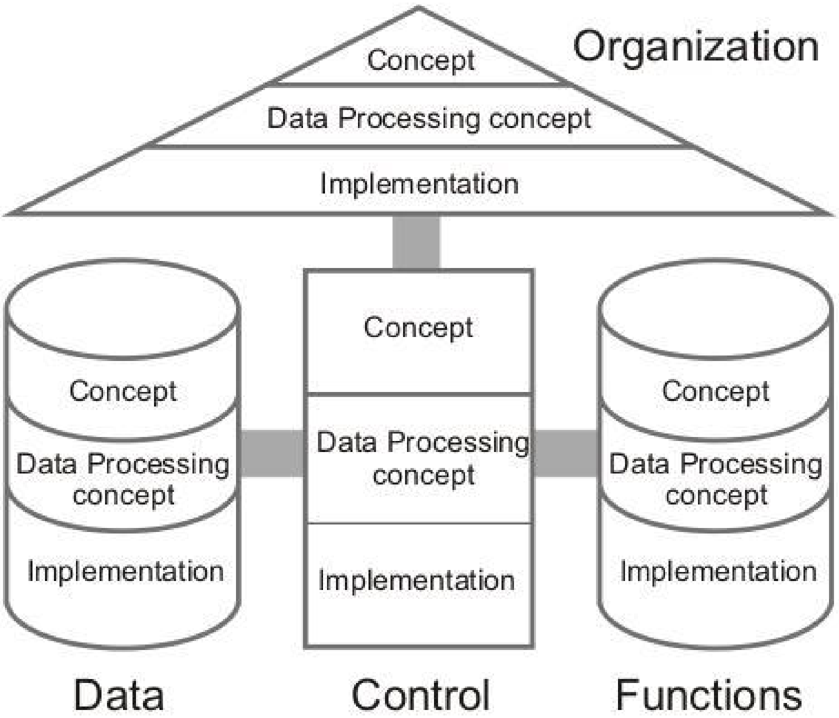

Figure 5, Model of ARIS Framework

The five description views:

- The organization view establishes a hierarchy of physical units, grouping units and devices that perform the same work goal.

- The data view includes the data processing environment and the functions triggered by the message and the functions that caused the trigger;

- The functions view transforms the flow of input to output;

- The product/service view provides an overview of the entire product/service portfolio. This includes all physical and non-physical inputs and outputs, as well as financial;

- The control (process) view records the relationship between the above four views and the entire business process. It connects all other views into a time-logical schedule.

Three levels in each view:

- Concept (requirement definition) is about the statements of demands, which is a structured representation of the business processes by means of description models that are understandable for the business side;

- Data processing concept (design specification) is the description of the model design, an implementation of the analyze and design one or more solutions that meet the needs and optimization from the Concept layer;

- Implementation (implementation description) is the clarify the technical conditions and constraints of the implementation plan.

2.1.1.2 MES & ERP

1) MES is defined as "the management information system for the workshop layer between the upper-level planning management system and the lower-level industrial control", which provides the execution/tracking of the plan and all resources (people, equipment, materials, Customer needs, etc.). The purpose is to solve the black box problem in the factory production process, and to realize the visualization and controllability of the production process.

   The MES system is the core of the digital workshop. MES through digital production process control, with the help of automation and intelligent technology, to achieve intelligent workshop manufacturing control, production process transparency, manufacturing equipment CNC and production information integration. Workshop MES mainly includes workshop management system, quality management system, resource management system and data collection and analysis system, etc., which is realized by technology platform layer, network layer and equipment layer.

2) ERP is MRP II (Enterprise Manufacturing Resource Planning) next-generation manufacturing system and resource planning software. In addition to the existing production resource planning, manufacturing,

finance, sales, procurement and other functions of MRP II, there are quality management, laboratory management, business process management, product data management, inventory, distribution and transportation management, human resource management and regular Reporting system.

2.1.1.3 CIMOSA

CIAMOSA is an abbreviation of "Computer Integrated Manufacturing Open System Architecture", which is a CIM open architecture. Its purpose is to provide an open CIM reference architecture oriented to the life cycle of the CIM system (the enterprise integration of machines, computers and people). At each stage of design, implementation, operation and maintenance, CIM system description, implementation methods and supporting tools are provided, and a set of formal systems is formed.

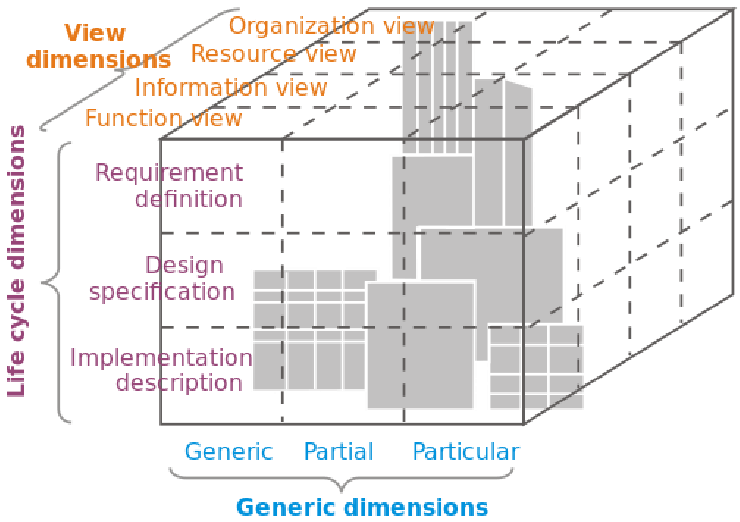

Figure 6, CIMOSA cube

The CIMOSA model framework is composed of three dimensions: ①

generic dimensions explain the gradual evolution of the enterprise model from general to special; ② life cycle dimensions indicate that the enterprise modeling process is a gradual derivation from requirements analysis, design description to implementation description The process of view; ③ The view dimensions point out that the enterprise modeling process is a process that starts from the collection of functions and gradually generates each view in an iterative manner.

The four views:

- the function view describes the functional structure required to satisfy the objectives of an enterprise and related control structures;
- the information view describes the information required by each function;
- the resource view describes the resources and their relations to functional and control structures;
- the organization view describes the responsibilities assigned to individuals for functional and control structures.

And the three levels in lifecycle dimensions is the same as ARIS.

2.1.1.4 PERA

Purdue Enterprise Reference Architecture (PERA) is widely used to describe the main interdependence and interconnection between all important components in large industrial control systems. The Purdue model is a good entry point to begin to understand the OT environment.

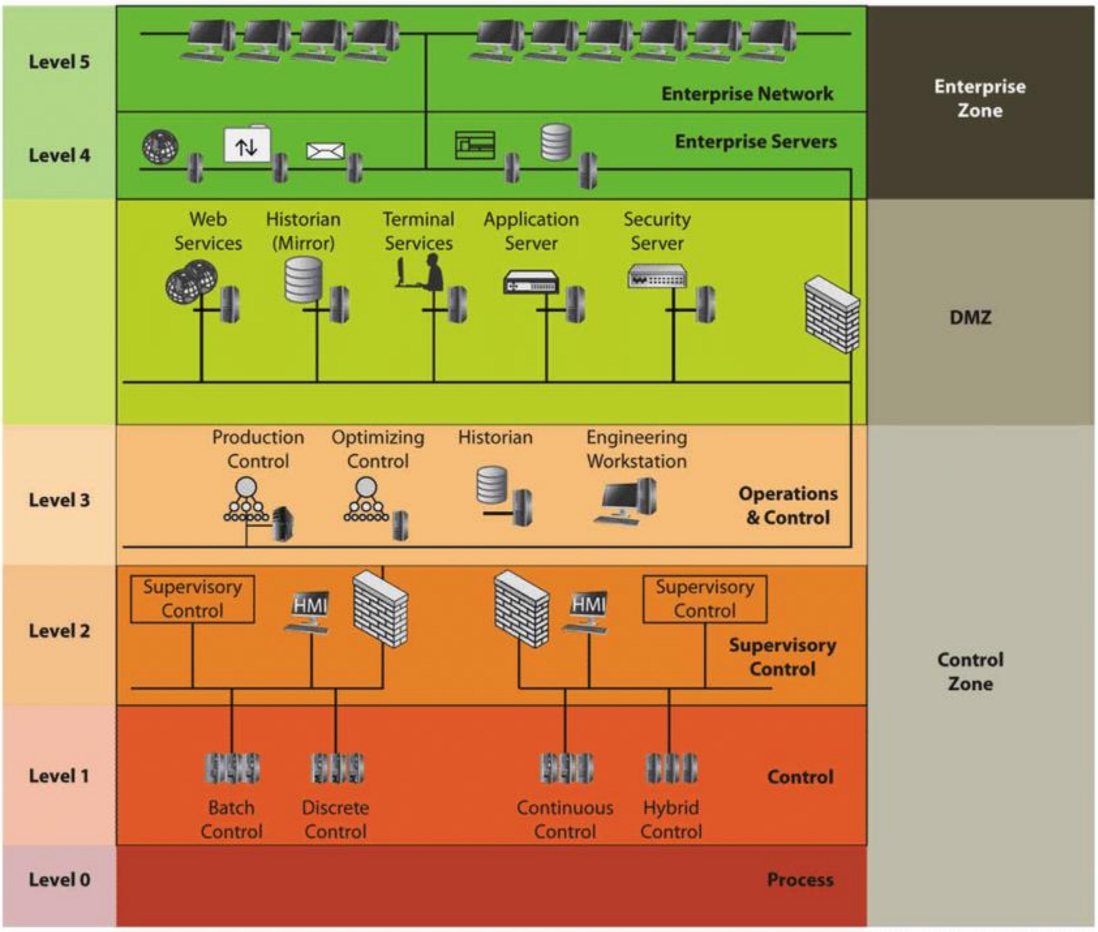

Figure 7, PERA

- Level 5 Enterprise Network

  The enterprise zone is responsible for supply chain management. ERP systems developed by companies such as SAP and JD Edwards are mainly used to understand and respond to supply and demand. These systems receive data from all subordinate systems (usually across multiple sites or an enterprise), and manage work orders by viewing the overall supply, production, and demand. This level is generally not directly connected to the industrial control system, but there is a clear need for accurate and timely information from various OT networks and industrial control system components.

- Level 4 Enterprise Servers

  Level 5 is usually deployed in the company headquarters or multi-site headquarters, and level 4 represents the IT system that controls the operation of local facilities in each site, workshop, or facility. This layer receives work orders from the 5th layer and monitors the operation status of the lower layer to understand the operation status. Its functions also include the monitoring of the production progress execution, the problem management of the local factory, and the data of the 5th layer enterprise system. To update.

- DMZ

  The ICS-DMZ of the industrial control system realizes information sharing between IT and OT. This is a more modern architecture driven by NIST's network security framework, NIST 800-82, NERC CIP, and

ISA-62443 and other industry standards. ICS-DMZ usually includes replica server, program patch management server, engineering station and configuration change management system. The role of the DMZ zone is to achieve the secure exchange of IT information without exposing the underlying key components directly to the attacker. This is a key area of safety planning.

- Level 3 Operations & Control

  Level 5 and 4 only exist on the IT side of the network, and the DMZ zone serves as a padding between level 5 and 4, just like the sandwich layer in Oreo cookies, level 3 and below The system on the OT side of the network is defined and included. The third layer usually contains the monitoring part of the SCADA system, the screen and control access of the DCS, or the control room that monitors and monitors other parts of the OT network. The third level is the main level of operator-level interaction with the system. Operators can view and monitor process events and trends, respond to alarms and events, and use functions such as work order maintenance to manage process runtime and availability to protect products quality.

- Level 2 Supervisory Control

  The second level has many of the same functions as the third level, but the second level mainly realizes the local control of a single area in the process through the function of the process unit or the production line level. The difference between this level and others is that the actual industrial control system begins to appear on this level, such as programmable logic controller (PLC) and variable frequency drive (Variable Frequency Dive, VFD). However, the main systems in level 2 also include human-machine interface (HMI). In this level, you can view the real-time process events and the local screen of operator-level process interaction through the human-machine interface panel, and realize automatic control of the process through these logic-driven components.

- Level 1 Control

  Although devices such as PLC and VFD also exist in level 2, level 1 is where these devices mainly appear. The first layer includes Basic Process Control Systems (BPCS). The BPCS system is a general term applicable to non-safety-related control systems. It mainly performs and manages the following functions:

  The BPCS system implements process control within configurable limits (set points).

The BPCS system provides real-time data for the human-machine interface to achieve operator-level interaction with the process.

The operator interacts with the setpoints and logic in this layer of BPCS system to optimize plant operations.

Manage and respond to process-level alarms and events at this level. Level 2 relies on information from level 3 and above for scheduling, monitoring alarms, and providing feedback on the implementation of the management process.

The BPCS system also includes sensors, actuators, relays, and other components for measuring process values and reporting the results to PLC, DCS, SCADA, and other components from layer 1 to layer 5.

- Level 0 Process

  This layer is also called the Equipment Under Control (EUC), which is where physical devices controlled by level 1 are placed. These devices include drives, motors, valves, and other components that make up the actual process. The integrity of level 0 is critical for safe and efficient operations, as this is where physical equipment in the process is operated in reality. If the BPCS and the controlled equipment cannot operate normally, or the information about the process status is inaccurate, then the BPCS or the operator cannot accurately respond to the process conditions.

All these levels (levels 0-5) interact with each other to ensure that the process performs its pre-designed functions. According to the revised version of the Purdue reference model referred to, you will find that the functional safety layer (safety layer) is included in the process layer (layer 0) as part of the process layer; or in a sense Logically below the process level. The functional safety layer is a layer that protects the system from dangerous failures when a hardware failure or other uncertain adverse conditions cause the entire system to be interrupted. There are several engineering protection layers (engineered layers of protection) within the functional safety layer. These protection layers include from logically coded "interlocks" to PLC instructions on how to respond to adverse events, to safety instrumented systems (SIS) and physical safety control measures, such as ensuring that such as excessive pressure during the formulation process A safety valve where the condition does not occur.

2.1.2 Social responsibility Evaluation model based on Entropy method and Random effect model

The evaluation model is built based on the business field the company or the factory is managing on. It can set several indexes, which have positive or negative impacts on company or factory's value. By using mathematical model as the Entropy method and Random effect model, after the calculation, it obtains a CSR Evaluation Index to evaluate the statement of a company or factory concerned about their social responsibility. And the model could also give the result to show how long will the company benefit from spending funds on this.

2.2 The hierarchical model of production system

After checking the literatures above, this article is going to summarize and suggest to improve the hierarchical model of production system, which includes seven layers corresponding to different aspects of the system.

There are:

- The 2D layout: devices position
- The 3D layout: occupied space
- The flow model: where material and fluid and energy arrive or depart
- The variables model: which variables are measured and controled (the

measuring system and the simulation system)

- The management model: to plan and forecast the production process
- The financial model: about costs and profits of the manufacturing system
- The social model: the impact of the manufacturing process on society and environment

To build a such model, the first thing is to analyze the requirement of the production system, like many other engineering projects, this is based on the requirement of the company, so before building the model, it is necessary to know these requirements to avoid misunderstanding during the process.

Normally, those requirements shall be summarized as three questions:

- What does the model look like?
- What need to be simulated?
- What are the indicators we need to pay attention to?

In detailed, it can be divided into several steps:

Firstly, fully understanding the technical scheme, including the producing process, devices, layout, operators;

Secondly, clear the object of the simulation. To build a model which can be adjustable to the real production, all the objects of the model for each single device, process need to be clarified. Also, it is needful to figure out the level of detail for each model according to the requirements;

Thirdly, there should be an explicit representation of the model to show the model in the method, which can clearly express the production process, devices, layout, etc.

Finally, this model must be suitable to kinds of simulation software, like FLEXSIM, which this article uses, and by simulation, the thesis can describe the model according to the restrictions of the design, like space, time, human resource, devices, etc.

Below are different layers of the hierarchical model based on the production system. And this thesis is more focus on simulation that help to describe the hierarchical model. So, about the conception of each layer, which has already existed in other literatures, there will be a brief introduction only.

2.3 2D model

The 2D model of a production system indicates the layout of the production line or an entire factory. The layout refers to the overall arrangement of the basic positions of each workshop, auxiliary sections, production service departments, facilities, equipment, warehouses, passages and so on. The layout of the workshop is designed to improve the efficiency of using the plant space. Firstly, it is convenient for operation, and avoids overcrowding of those production machines. Secondly, it helps the factory watching out the ventilation, fire prevention and explosion prevention of the plant to ensure safe production.

The goals of the layout design are:

- Reduce or eliminate waste and ensure a "lean" environment to minimize cost
- Design for preventive maintenance
- Provide for employee convenience, safety, ergonomics, and comfort
- Support inventory control and minimization
- Avoid unnecessary investments that do not add value to the plant
- Promote effective use of people and productivity

In this paper, the 2D model has been already defined, so the FLEXSIM simulation will directly work on the background of the AutoCAD DWG file, which refers a wheel hub production line.

2.4 3D model

After introducing the 2D model, here is a brief description of the 3D model. The height limitation of the workshop is considered in the 3D model, so it can show us not only the height of the production line but also give us an indicator to design other auxiliaries in the workshop like HVAC, lightning systems. By using the CAD and directly based on the 2D model. Just extend the 2D blocks with the height of each production devices respect to the practical situation, the researcher of building the model gets the 3D block model of the production line.

2.5 The flow model

The flow model, also can be called as material flow, is a description of the transportation of raw materials, pre-fabricates, parts, components, integrated objects and final products as a flow of entities. The term applies mainly to advanced modeling of supply chain management.

2.6 The variables model

Manufacturing machine is the fundamental work unit of the producing process for a factory. The performance and operating state directly affect the manufacturing level and manufacturing cost of the factory. Therefore, it is necessary to evaluate the performance of the manufacturing machine and track its operating state, dealing manufacturing problems timely in any emergencies to ensure reliability and efficiency of the manufacturing process.

This paper utilizes kinds of variables of a machine to evaluate the performance of the production line or on a specific machine.

The ISO 22400 standard "Automation systems and integration —Key Performance Indicators (KPIs) for manufacturing operations management", provides an overview of the concepts, the terminology and the methods to describe and to exchange KPIs for the purpose of managing manufacturing operations. To evaluate the performance of manufacturing operations, a total of 34 KPIs are presented in its latest update – ISO 22400-2:2014. In the standards, the KPIs are described by means of their formula, corresponding elements, unit of measure, timing and other characteristics. The ISO 22400 aims at defining the most important and generally used measures for the manufacturing industry, and therefore it has been recognized for its potential contribution on manufacturing operations management.

In order to evaluate the performance of our manufacturing machine, it is necessary to build a general variables model of a manufacturing device based on ISO 22400 standard. This model should include all the variables needed in ISO 22400, which are Time variables, Logistical variables, Quality element and Energy elements. And based on the ISO 22400, the KPIs could be divided into three different categories, which are production, quality and maintenance.

2.7 The management model

Since, during these years, the market competition is going to getting fiercer. And diversity of market demand is increasing, it is necessary for a company to cautiously schedule the production to reduce the inventory level in a limited amount and a short lead time while enough to satisfy the market demand. The management model of the production system refers to fully planning the production process, which includes order management, production scheduling, inventory management, etc.

2.7.1 Order management

Order management system (OMS) is a part of the logistics management system. Through the management and tracking of orders issued by customers, the progress and completion of orders are dynamically mastered to improve the operational efficiency in the logistics process, so to save operation time and operational cost and improve the market competitiveness of logistics. The main function of the order management system is to provide users with integrated one-stop supply chain services through unified orders. Order management system is an indispensable part of logistics management chain, through the order management and distribution, warehouse management and transportation management organic union, stable effective logistics management in each link, give full play to the role, the warehousing, transportation, order as an organic whole, meet the needs of logistics information system. Order management is to manage, query, modify, print and other functions of various orders issued by the merchant, and meanwhile feedback the information processed by the business department to the merchant.

The order management system generally includes order processing, order confirmation, order status management (including cancellation, payment, delivery and other states, as well as order delivery and order query) and so on. Below are some basic functions:

- **Order management**

The system can realize single and batch orders, order management and inventory management, and the next order when the stock warning and prompt function, order management and customer management at the same time connected, can query the history of orders and order execution.

- **Distributor management**

With emphasis on the enterprise's marketing channel construction, planning the information flow, logistics and cash flow in the supply chain system, strengthen the close cooperation between enterprises and vendors, and internal business process through a distributor specification to improve the resource management ability, at the same time to provide customers a full range of sales and service experience.

- **Order Fulfillment**

The filled-out order form is sent to the warehouse responsible for the inventory that will fulfill the purchase. In the warehouse, inventory is monitored and the continuous supply from vendors is recorded. If inventory runs out unexpectedly by a large purchase order, warehouse managers will place an order to the purchasing department to place an order to vendors. If the business manufactures the goods, the warehouse notifies production of low or depleted inventory.

2.7.2 Production scheduling

After receiving the order and transfer it into the production schedule, the production scheduling have to be put forward by us. It means that to arrange, control and optimize production work and workloads within the production system. It includes plan of production process, human resource, purchase raw materials and devices resource.

It has a significant effect on the productivity of the production system. In manufacturing, the purpose of scheduling is to minimize the production time and costs, by telling a production facility when to produce, with which operator, and on which machine. Production scheduling aims to maximize the efficiency of the operation and reduce costs.

The benefits of production scheduling include:

- Process change-over reduction
- Inventory reduction, leveling
- Reduced scheduling effort
- Increased production efficiency
- Labor load leveling

- Accurate delivery date quotes
- Real time information

2.7.3 Inventory management

The inventory cost is a nonnegligible part of the finance of the factory and company. The procurement and transportation cost of the goods, the storage cost which contains the capital interest, material handling and human resource, investment amortizations, maintenance and shrinkage are all included in it.

Therefore, it is important for us to carefully manage the inventory level to reduce the demand uncertainty for keeping a safety stock level, and to separate different operations phases, which is the approach to allow sourcing, making and delivery to work at different rates and allows the different phases to be “asynchronous” and absorbs upstream variations.

The main things should be decided are:

- Replenishment policy: the amount and the time of order

  Influences on:

  -Stock carrying costs

  -Setup/order emission costs

-Stock out / downstream service costs

Constraints:

-Production capacity and flexibility of upstream production level

-Physical space limit of warehouses.

- Control level: the detail and the frequency of

  -control of the stock level of each item

  Influences on:

  -Cost of control

  Constraints:

  -Availability of resources to perform the controls (people, computers, ...).

2.8 The financial model

While talking about the financial model of the company, the first thing should be considered is the cost.

Cost=Price – Profit

Where, the price is mainly due to the market, every company operate in a competitive market and the price competition is very significant for the competition among companies. The customer will not pay more price for the same performance of the service or product.

The profit depends on the company's marketing strategy and stage.

So, the cost is a kind of critical thins needs the company manages this more cautiously, which is controllable and directly affects the competitiveness of the company. By improving to reduce the cost, the company can maximize the profit at the same price relative to competitors or decrease the price having the same profit comparing to competitors.

As general definition, cost is the sum of monetary values of resources, goods, and services consumed by a Company to produce products sold and services rendered.

It can be classified by several criteria:

1) Volumes

- Variable cost: The cost that is directly proportional to volume of products produced

- Fixed cost: It does not change with volume variation of product produced

- Semi variable cost could be: Sum of a fixed plus a variable part or fixed within certain productive range with no correlation with production volume, but could be change with level of activity (e.g. Step correlation)

2) Attribution criteria

- Direct cost is directly attributable to the product or service and it is easily measurable as resource consumed per relative unit cost of the resource. Direct cost analysis allows the monitoring of the impact, on cost base, of resource required to produce that product.

- Indirect cost is not directly attributable to the product in objective way. Indirect costs are amounts spent or necessary to deliver the service or the product, but not exclusively related to the specific product/service. For this reason, indirect cost is associate to the product trough criteria for allocation.

3) Observation criteria

- Specific costs refer specifically and exclusively to the object observed. These costs, variable or fixed, are associated to productive factors consumed to produce a specific object (product, services, processing phase). Specific costs for a product would not be sustained if the product/service is no more produced. For example, specific cost could be, the depreciation of technical resource used by a specific department within the company. Referring to the product as object observed, can be classified as specific the cost for tools dedicated for its production (i.e. dies, check figures).

- Common costs are not associate at one object observed. These costs can be associated to the object observed only in an indirect and not univocal way using assumption, criteria and subjective base of attribution. Some examples of common costs are cost of personnel of IT, cost of managing warehouse common to all products, administrative, commercial, marketing expenditure Referring to the product as object observed, can be classified as common the cost of machine used to process the product (e.g. press, DEA)

2.8.1 Cost analysis of the production system

To analyze the cost of our production system, the hierarchical model includes a cost model. For a production system, it can divide the total cost into three categories: bill of material (BOM), bill of process (BOP) and mark-up.

2.8.1.1 Bill of material

Usually, the bill of material means the design frame of the product. It can be a single part or a complex part, assembled part or a system. It includes raw materials and purchased part (in case of manufacturing of an assembled product/system where subcomponents are bought from other manufacturers).

2.8.1.2 Bill of process

Bill of process refers to the cost during the process procedure, it includes direct labor, indirect labor and machine cost.

1) **Labor** is that all the operative human resource related to the manufacturing of the product, it can be categorized as two part: direct labor cost and indirect labor cost.

- **Direct**:

  The cost for direct labor per hour is below:

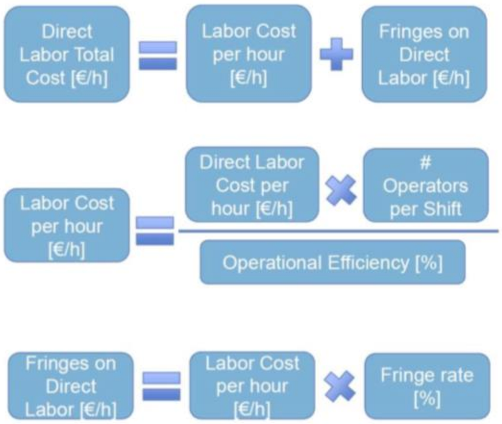

Figure 1, Direct labor cost

- **Indirect**:

The calculation of this per hour is shown below:

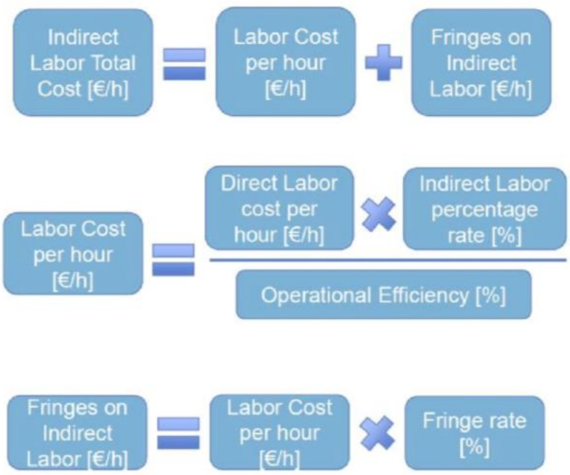

Figure 2, Indirect labor cost

2) **Machine cost**: The process of transforming a product can be split in single phases of production process. Each phase can be represented as a cost center, aggregating the resources required in terms of direct labor cost, indirect labor cost, and machine cost.

we can calculate the machine cost by summing all the terms above:

$$\begin{aligned}&Machine\ Cost\ per\ Hour\\&\quad = Capitalization\ Cost + Interest\ Cost\\&\quad + Energy\ \&Utility\ Cost + Other\ Cost\\&\quad + Machine\ Maintenance\ Cost + Floor\ Space\ Cost\\&\quad + Perishable\ Tooling\ \&\ Supplies\ Cost + Insurance\ Cost\\&\quad + Property\ Tax\ Cost\end{aligned}$$

2.8.1.3 Mark-up

The mark includes three parts: Scrap, SG&A and Profit.

- **Scraps** are when product (or services) deviate from quality requirements or specifications.

  Producing defects represent a cost for the company because resource and time has been absorbed to produce a non-complain products.

  Cost of scrap and rework due to defects should be charged on good parts produced in order to recovered cost of resource spent.

  Usually scrap and rework costs for a process are charged as a percentage on value added by the transformation.

- **SG&A**: it is the acronym for Selling, General and Administrative Expenses. It is a major non-production cost presented in an income statement. SG&A expenses consist of the combined costs of operating the company, which breaks down to:

  Selling: The sum of all direct and indirect selling expenses, which includes salaries, advertising expenses, rent, and all expenses related to selling product

  General: General operating expenses, depreciation and taxes that are directly related to the general operation of the company.

  Administration: Executive salaries and general support and all associated taxes related to the overall administration of the company.

  We can represent the SG&A as percentage:

Figure 3, SG&A Cost

- **Profit** instead is the final margin for the company operations. It should be calculated as below:

$$Profit = Price - Production\ cost - scrap\ cost - SG\&A\ cost$$

2.8.2 Diagram of the financial model

Depending on the analysis above, we can build a financial model of the production system shown in the diagram below:

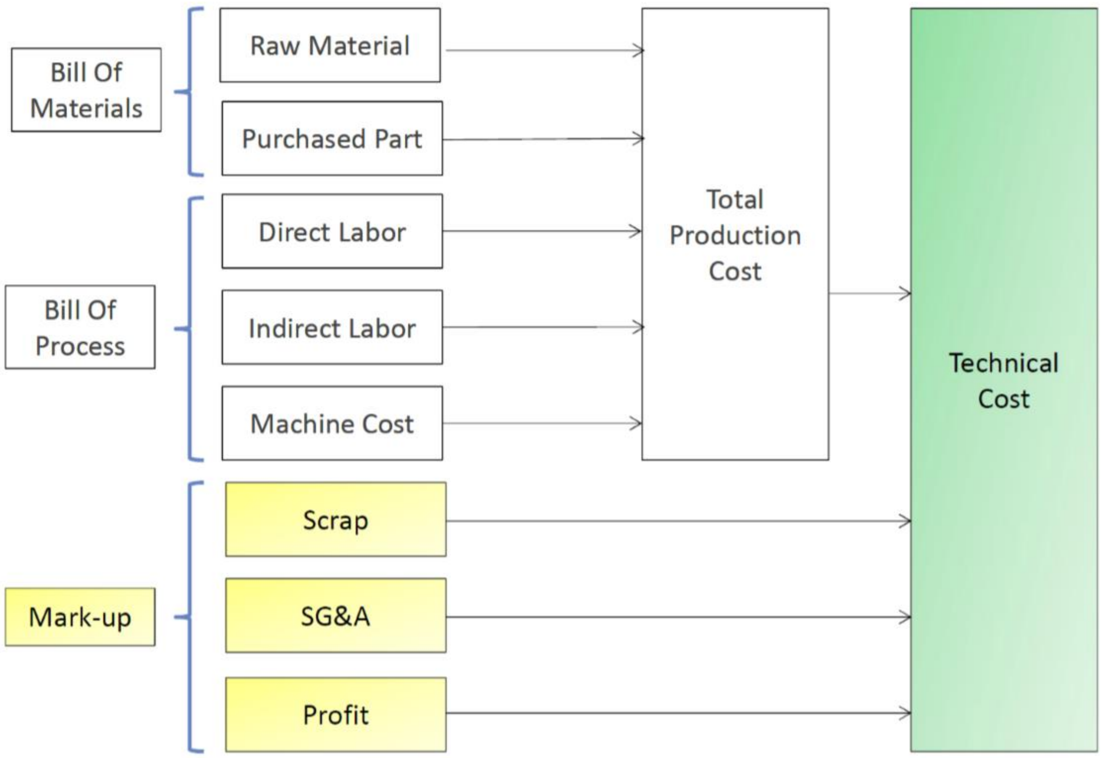

Figure 4, Financial model

2.9 The social model

The social model, before this thesis, is a more abstract description of some factors that have effects on production system. So, in this article, with the inspiration and suggestion from other literatures, the social model of the production system represents social responsibility (the environmental and social effects of the production system). This layer can be judge by table of detailed indicators, which is ASRP (Architecture for Social Responsibility of Production). It includes 5 first level and 12 second level index, which have positive or negative infect on the social responsibility.

By checking a production system according to the terms in the table below, the model can evaluate that how eco-friendly and society-responsible a production system is.

ASRP			
1st Level	2nd Level index	Definition of Index	Influence on Social Responsibility
Customer and consumer responsibilities (A_1)	Operating income /cost ratio (X_1)	Operating income /Cost ratio	positive
	Whether it was punished for product quality (X_2)	If punished X_2=1, No X_2=0	negative
	Whether passed the relevant product quality certification (X_3)	If passed the standard or certification like ISO9001:2015 Yes X_3=1. No X_3=0	positive
Supplier Responsibility (A_2)	Accounts payable turnover ratio (X_4)	Operating cost/ Average occupancy of accounts payable	positive
	Purchase rate of goods and services (X_5)	Cash for purchasing goods and receiving labor services / Operating income	positive
Employee responsibility (A_3)	Employee income and expenditure rate (X_6)	Salaries paid for employees / Operating income	positive
	Average annual income of current employees (X_7)	Salaries paid for employees / Number of employees in the current year	positive
Government responsibility (A_4)	Tax contribution rate (X_8)	(Tax payment-Tax refund) / Operating incoming	positive
	Fine rate (X_9)	(Fines paid + Tax late fees) / Operating incoming	negative
Social public and environmental responsibility (A_5)	Donation investment rate (X_{10})	Donation / Operating incoming	positive
	Employment growth rate (X_{11})	(Number of employees in the current year-Number of employees in the previous year) / Number of employees in the previous year * 100%	positive
	Whether obtained relevant environmental certification (X_{12})	Pass the certification like ISO14001:2015 Yes X_{12}=1. No X_{12}=0	positive

Table1, Architecture for Social Responsibility of Production

Chapter 3 The production line built in real case vs FLEXSIM

As the hierarchical model of production system needs be displayed by simulating. It is better to write the description in a table to compare the real one versus to the one built in the software. Because of the stage of the research right now, the FLEXSIM digital model will built both in complete line and a simplified single line. All of these two are described in the table, but the simulation will only focus on the single line FLEXSIM model.

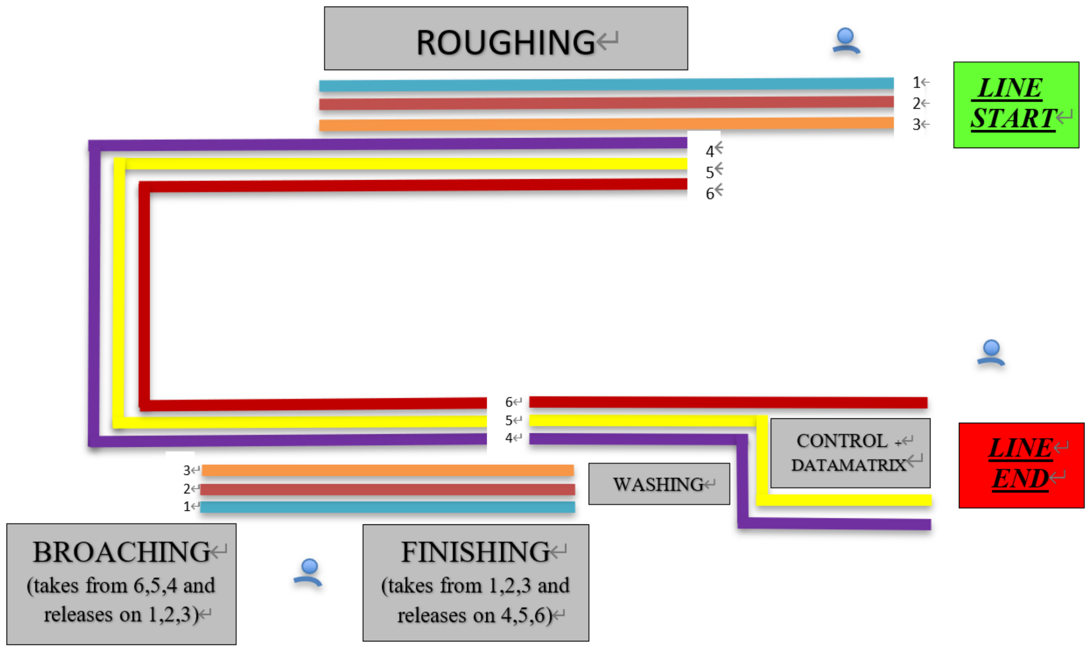

Figure 8, The concept sketch of the production line

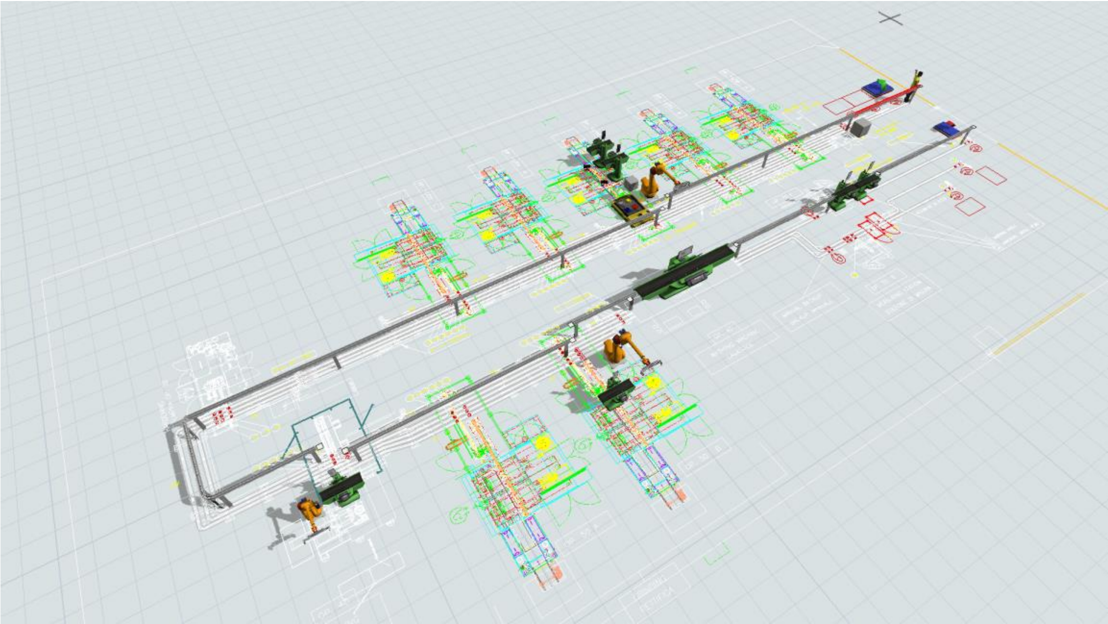

Figure 9, The FLEXSIM single line model

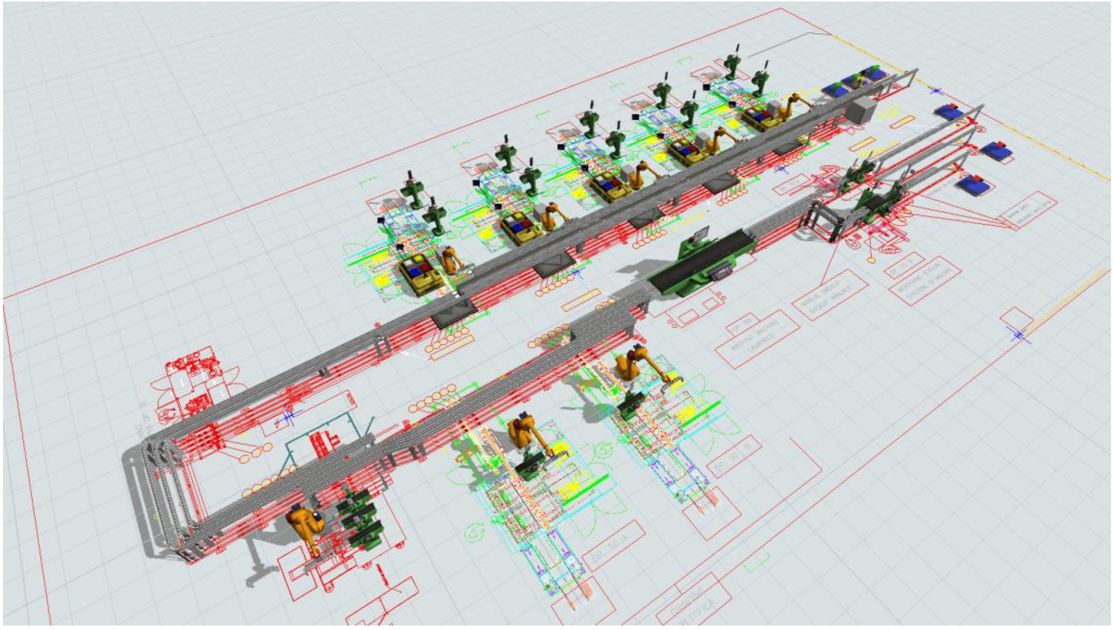

Figure 10, The FLEXSIM complete line model

REAL	FLEXSIM
1. Parts loading on conveyors Firstly, the pieces are contained in metal boxes and loaded by a forklift on one of the three tilting platforms corresponding to the three products manufactured by the line (D35, D37 and L0. Both D37 & L0's diameter is 37mm).	The three tilting platforms corresponding to the three products manufactured by the line (D35, D37 and L0. Both D37 & L0's diameter is 37mm) will be presented by four sources （Source 1, 2, 3, 4） in the Software. There will be two sources working as D35. To simulate the difference schedule of production of D35 with first four machines or with all five machines In the single line model will be set only one source.

Secondly, the pieces are picked up by the operators and positioned on the conveyors with the shaft facing upwards. These operators are fully responsible for loading procedure at the start of the production line, indeed They check for each product series (therefore for each of the 3 conveyors) that there is an adequate number of pieces waiting to enter the line (the entry is sanctioned by passing through a sensor).	There will be one operator who pick up those pieces and put them on three conveyors. All the conveyors will be built fit to the size on the DWG background to make the transportation time more similar to the practical situation. And a gate logic is set on the conveyor after the sensor to control the numbers of parts entering the line, once there are three parts waiting in the queue for processing. Other parts will be stopped before the sensor and wait on the conveyors. In the simplified edition, there will be only one conveyor (actually composed of two connection conveyors, the connection point is exactly near

	the sensor to simulate the gate). And the control logic of the number of the parts entering the line is: while the number of waiting for processing are more than three. The fourth one will be stopped by the gate before the sensor.
Then the pieces will wait in another buffer, which is positioned before each roughing machine (the available space is never used completely because it is managed by the operator at the beginning of the line so each machine has an "infinite" buffer). The destination of each conveyor is set periodically (sometimes even every hour) based on the daily production plan.	The conveyor, which the robot arm will pick the parts from it, will be set a queue nearby as a buffer. During the operation, the new parts will wait on it to be picked by robot arm if necessary. In the single line edition, the conveyor will perform as a buffer itself.

2. Pieces transported by conveyors	
There are 3 parallel conveyors (identified as the numbers 1,2,3. In the image they correspond respectively to blue, burgundy, orange) which carry the pieces from the 3 loading positions to the roughing process section.	There are 3 parallel conveyors which carry the pieces from the 3 loading positions to the roughing process section.
Parts D35 are carried by conveyor No,3; While D37 are on conveyor No,2; And L0 are transported by No,1.	The simulation model will set exactly the same transport strategy of 3 kinds of hub as in real. Based on the 2d dwg model.
In correspondence with the first work station (op10 + op20), there are 3 other conveyors (4,5,6 corresponding respectively to violet, yellow, red) which lead the pieces to the exit of the roughing	And it will work as a gate before roughing to monitor the number of pieces entering the line (as introduces before). In the single line, the robot picks the parts from the conveyor. And the control gate is working as introduced in the former parts.

line towards the hardening. D35 will be moved to conveyor 6 after Roughing. D37 are going to the next process by conveyor No,5. So as L0 (This kind of part will be picked up to line 4 after OP10+20 finished). Some pieces (D35 for petrol cars) pass directly to the broaching station, the others (D37 for diesel cars) go first to temper. The different pieces are recognized because they always travel on the same conveyor after exiting the roughing.	

3. Roughing by CNC EMAG (OP10 e OP20) The roughing work station consists of 5 parallel machines, indicated with the letters A, B, C, D and E. Actually, they are not parallel, since each machine has a HW structure and a SW control dedicated to the machining of certain pieces. Currently the first 4 machines are set to work D35, the last machine works both D35 and D37 (including L0). However, the 1st and 3rd station have always done D35 and all could be set up differently. Each machine performs two separated operations: the OP10 on	In the model, roughing work station consists of 5 parallel machines on the position in that background. Each machine contains two processor represents OP10 & OP20 Currently the first 4 machines are set to work D35, Connect to conveyor 3. the last machine works both D35 and D37 (including L0) in a sequence for each part will be operated eight hours (this can be change later with the real schedule). However, the 1st and 3rd station have always done D35 and all could be set up differently. Each machine performs two

one side of the hub and the OP20 on the opposite side. The robot arm of each machine takes the blank 1 from the conveyor and always positions it in the station α of the conveyor shuttle. The shuttle moves backward to the CNC machine until it has α under the laser beam, which with a rotation of xxx °, identifies the position of the depression of the raw hub 1. The shuttle then moves under the OP10 spindle. The spindle grasps the blank 1 and rotates it so that the depression is in the desired position. The mandrel releases in part. The blank and a positioning	separated operations by two processor model: the OP10 on one side of the hub and the OP20 on the opposite side. Each processor can only operate one hub per time. There will be install one laser, one robot mod for each machine. The shuttle in this machine will be represented by task executor (AGV). Sliding between the robot and processor. To simulate the robot moving parts between four positions on the shuttle. In FLEXSIM, the simulation model put four queues named as A, B, C, D versus to α, β, γ, δ. Each queue is set to contain only one part waiting for roughing. By setting that robot, the

device consisting of a ring that supports two pins, inserts these pins into the depression of the piece and applies a rotation sufficient to correctly position the piece. The spindle grasps the piece again and starts the OP10 processing of the blank 1. During the same time, the shuttle exits the processing chamber to bring the blank 2 back. And its position is on α station. Once the machining on OP10 is completed, blank 1 is released to the shuttle's β station. With the shuttle always inside the processing chamber, the OP10 spindle grabs the blank 2 (already scanned by the laser before entering) from the α station and	model completes the tasks of bring pieces from conveyors to queue A. The task executor then brings part1 to OP10 processor. And the robot will bring part2 on A. Then with the executor takes part1 from OP20 to B. The robot will move in a schedule motion that overturns the pieces to C. The executor, however, brings part2 in OP10 and shuttles part1 to OP20. So, A is empty, and the robot will put part3 on A. Part1 finished OP10 is brought by the executer to D. Waiting for the robot finishes the operation on A, B & C. Then the robot picks up part1 to the conveyor later.

starts the machining. At this point the shuttle, with only the piece 1 on position β, comes out of the processing chamber. The same robot arm as mentioned before takes part 1 and moves it from the β position to the γ position with overturning it. Then this mechanical arm takes the blank 3 and rests it in position α. In summary, at this moment the piece 1 is on γ, the blank 3 is on α and the piece 2 is being processed by OP10. The shuttle then re-enters (after laser scanning of the raw material 3) so that the spindle of OP10 releases the piece 2 on β and brings the blank 3 from α to OP10. While the spindle of OP20 takes	The laser beam process will be simulated by a time delay. This delay will be set every time after the robot arm put a new one on A, before the shuttle send it to op10, it will stop for 10S. In the simplified model. It will reduce to only one conveyor, one robot, one shuttle (with four queue A, B, C, D on it) and one OP10+OP20. But the logic of operation is the same.

the piece 1 from γ. Right now, OP10 and OP20 are engaged respectively with piece 3 and 1. While the shuttle exits the processing chamber with only piece 2 on position β. The raw 4 is taken and positioned in α and while the piece 2 from β is turned over and positioned in γ (so it becomes 4 in α and 2 in γ). After scanning 4, the shuttle returns inside the chamber, receives the piece 1 in position δ from OP20 and the piece 3 in position β from OP10. Successively releases the blank 4 and the piece 2 respectively to OP10 and OP20, which start the processing. The shuttle goes out of the chamber with 1 in δ and 3 in β,	

the piece 1 is qualitatively controlled by a camera and in case of a positive outcome it is released on one of the conveyors added from the roughing line (4,5,6). The arm overturns the piece 3 in γ from β and takes the stock 5 from the conveyor, positioning it in α. After the scan it returns and receives 4 in β, 2 in δ and releases the stock 5 to OP10 and the piece 3 to OP20. The shuttle exits with 4 and 2, 2 goes to the next station if the quality control passes, while 4 is overturned and placed in γ and the raw material 6 is taken and placed in α. And so on … It can never happen that the conveyors are full, except for the negligence of the operators who	

load too many pieces at the beginning of the line.	

4. Broaching (OP40) There are three broaching machines, respectively, for hub of diameter D35 and D37. The image above shows the shape of the arm (seen from above) that picks up the pieces from the conveyors and brings them into the broaching machine. This arm is composed of 6 heads that grip the different types of hubs. With the present setting, the sixth conveyor is the one that transports the D35 from roughing. The outer heads (at the top of the picture) of the arm pick up the D35s, carry them inside the broaching machine. When the operations finished, the same heads release them on the third conveyor.	There are three broaching machines, respectively, for hub of diameter D35 and D37. In the model, it sets a robot arm which can carry no more than 3 pieces per time. Separate them to BROACHING 1, 2, 3. And it will pick these parts back to conveyors after finished broaching. Since the D35 produced much more than other 2 kinds. The arm will pick only D35 while only D35 arrives at OP40. If the D37 or L0 arrives at OP40. Then the robot will pick D37 and D35 or L0 and D35 per time to operation. The single line model, however, will only have on robot arm which picks one part per time,

The central heads take the D37s from the fifth conveyor and release them on the second. While the more internal heads take the L0s and release them on the first conveyor.	and the machine working on this part. Then it will be picked up by the same robot back to the conveyor.

5. Finishing (OP50) This work station consists of two parallel machines indicated with the letters A and B. Both machines can work both D35, D37 also L0. Here is depicted the shape of the arm, which takes the semi-finished products from the conveyors and brings them inside the processing chamber. In this case, the arm has only two prehensile heads. The lower one deals with the D37s and the L0s (taking them from the first and second conveyor respectively and releasing them on the fourth and fifth). While the upper one (in the photo) deals only with D35 which	This work station consists of two parallel machines indicated with the letters A and B. Both machines can work both D35, D37 also L0. Right now, it has been set as the first working on D35, another one working on D37 & L0. In this case, each machine has their own arm. The robot arm has only available position for carrying two hubs. One deals with the D37s and the L0s (taking them from the first and second conveyor respectively and releasing them on the fourth and fifth). Another one (in the photo) deals only with D35 which they are taken from the third conveyor and released on the sixth. And the arm picks parts in the same

they are taken from the third conveyor and released on the sixth.	logic as OP40. In the simplified model. There will be one robot arm working on carrying parts from conveyor to machine. And the machine processing the parts. Then the arm put it back to conveyor.

6. WASHING (OP60) The OP60 machine performs 4 total operations: pre-washing, washing, rinsing and drying. It is important to define the process times and the use of water or solvents. In particular, a mixture of water and oil is used to prevent the pieces from rusting.	The OP60 machine performs 4 total operations: pre-washing, washing, rinsing and drying. This Process is represented by processor108 in FKEXSIM. And the hubs directly pass through the processor without robot arm. In the single line, this process will be only one processor and connects directly working on WASHING process.

7. Dimensional geometric control and Data matrix writing (OP70)	
The workstation is made up of two parallel MARPOSS machines that dynamically measure the geometric dimensions of the hub. If there is a gap, the piece is not marked and leaves laterally, an operator then takes the discarded piece (often by a few milli-meters), cleans it or takes it to the washing station, and measures it again. If the piece is rejected the second time too, it is placed in a box located at the end of the line. The hub is identified by laser writing of a data matrix that will allow to go back to the geometric information of the piece and its	Comparing to the 2D DWG background, this simulation sets three working station composed of 2 processors for each. To represent the dimensional control and datamatrix writing. And there is an operator take control of dimensional control. The hubs pass this process also without robot arm. The single line model will only have one station with 2 processors in series. Simulate the OP70.

process traceability (as far as possible). The availability of the measurements, associated with the traceability of the machined part, could be useful to trace the drifts of the machine's operation.	
8. Hub transport to the unloading station 9. Hub discharge from the line The operator removes the piece from the conveyor, performs a quick visual check and inserts it in the box in which special cardboard spacers are inserted too.	These two processes will be represented by the Sink.

Chapter 4 The simulation of the production line built in FLEXSIM

As the simplified single line FLEXSIM model has been built with the description in the above chapter. It is the next step that going to focus on setting the variables (also relative operation logic) this article needs and add several monitor points in the software model to simulate the real sensor in production line.

4.1 Variables setting and acquiring

It has mentioned in chapter 2 that the hierarchical model has the variables model layer to evaluate the performance of the manufacturing machine and track its operating state, dealing manufacturing problems timely in any emergencies to ensure reliability and efficiency of the manufacturing process. This paper more concentrates some kinds of variables of a work unit and operator to evaluate the performance of the production line based on the ISO 22400.

They are:

- Actual personnel work time (APWT), time that a worker needs for the execution of a production order.

In this model, there are four operators. One works as bring material from source to the line, second operator's duty is to bring the scrap parts from each work unit to a final sink used to collect failure parts. Both the former two people's work time will be acquired by the time difference from they start working to the finish. The third one works on rework operation. All three operators above are setting with moving speed 2m/min, load/unload time 1min, acceleration and deceleration are 1m/min^2. The fourth worker (operator 4) is a virtual person, the time of this operator's is a collection of each work unit's failure repairing time and prevent maintenance time(every day maintenance time is one hour, the whole production line works eight hours per day, this set in the timetable of each work unit).

For tacking the time, there is a dashboard to monitor operator 1, 2, 3 (the dashboard is created in the FLEXSIM in the form of state pie as Figure11, by choosing the operator 1, 2, 3, then the result of percentage of time will be show on the dashboard). And the operator 4's work time is calculated in the excel by getting the time data from simulation, which is the sum of every day's maintenance time and total repairing time. The data from simulation result table and calculation in excel will introduce later.

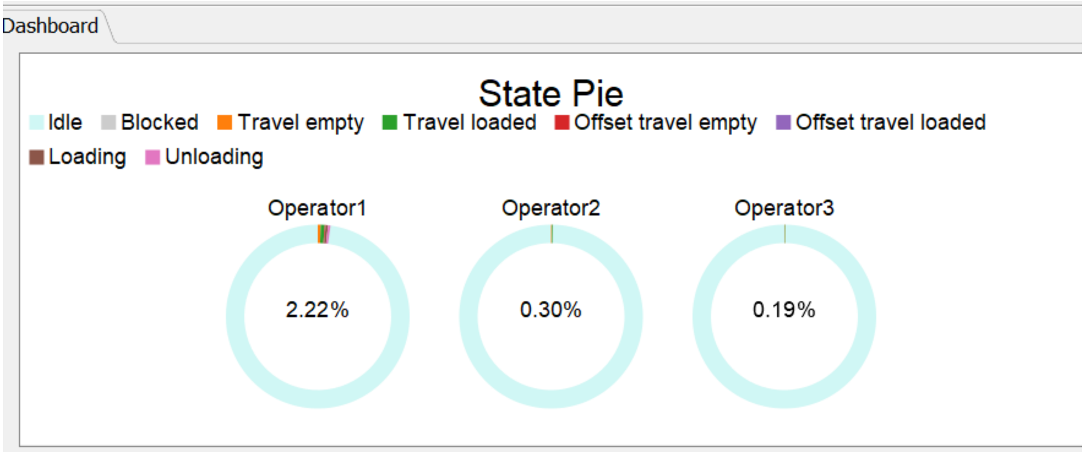

Figure 11, The dash board for checking the work time of operators

- Actual order execution time (AOET), start time - end time of a production order. It includes the AUBT, the actual transport and the AQT.

This time will be acquired by the start time of the source and the finish time on Sink. But it needs to consider every day the time that the production line gets off work, which is not included.

This value is acquired by calculation in excel, and the time data is from the table export from FLEXSIM.

	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6	Col 7	Col 8	Col 9	Col 10	Col 11	Col 12
Row 1	1	2.64	5.30	27.50	334.58	366.93	392.93	406.69	432.69	435.41	446.41	452.30
Row 2	2	14.18	16.84	70.70	407.37	439.72	465.72	479.49	505.49	508.21	519.21	525.09
Row 3	3	25.73	28.39	113.90	480.16	512.51	538.51	1444.86	1470.86	1473.58	1484.58	1490.47
Row 4	4	37.28	39.94	181.69	1455	1487.35	1513.35	1534.86	1560.86	1563.58	1574.58	1580.46
Row 5	5	48.82	51.48	309.58	1527.79	1560.14	1586.14	1599.90	1625.90	1628.62	1639.62	1645.51
Row 6	6	79.14	81.80	382.37	1630.15	1662.50	1750	1763.76	1789.76	1792.48	1803.48	1809.37
Row 7	7	122.34	125.00	455.16	1765	1797.35	1823.35	1837.11	1863.11	1865.83	1876.83	1882.71
Row 8	8	190.13	192.79	527.96	1837.79	1870.14	1896.14	1909.90	1935.90	1938.62	1949.62	1955.51
Row 9	9	318.02	320.68	1502.79	1910.58	1942.93	1968.93	2884.86	2910.86	2913.58	2924.58	2930.47
Row 10	10	390.81	393.47	1575.58	2885	2917.35	2943.35	2957.11	2983.11	2985.83	2996.83	3002.71
Row 11	11	463.60	466.26	1677.94	2947.79	2980.14	3052.64	3066.40	3092.40	3095.12	3106.12	3112.01
Row 12	12	536.39	539.05	1812.79	3020.58	3057.64	3083.64	3097.40	3185.00	3187.72	3198.72	3204.60
Row 13	13	1511.23	1513.89	1885.58	3093.37	3185	3211	3266.96	3292.96	3295.68	3306.68	3312.56
Row 14	14	1584.02	1586.68	1958.37	3226.26	3258.61	3284.61	3298.38	3324.38	3327.10	3338.10	3343.98
Row 15	15	1686.38	1689.04	2922.79	3299.05	3331.40	3357.40	3371.17	3397.17	3403.49	3414.49	3839.86
Row 16	16	1821.23	1823.89	2995.58	3371.85	3404.19	4330	4343.76	4369.76	4372.48	4383.48	4389.37
Row 17	17	1894.02	1896.68	3068.37	4345	4377.35	4403.35	4417.11	4443.11	4445.83	4456.83	4462.71
Row 18	18	1966.81	1969.47	3201.26	4417.79	4450.14	0	0	0	0	0	0
Row 19	19	2931.23	2933.89	3274.05	4490.58	4522.93	4548.93	4625.00	4651.00	4653.72	4664.72	4670.60
Row 20	20	3004.02	3006.68	3346.85	4625	4657.35	4683.35	4697.11	4723.11	4725.83	4736.83	4742.71

Figure 12, The table of time acquired from each critical point

planned order quantitty	Exit from source	Enter con1	Exit con2	AQT ROUGHING	Enter con3	APT ROUGHING	ADOT ROUGHING	Exit con7	AQT BROACHING	Enter con8	APT BROACHING	ADOT BROACHING
1	2.64	5.3	27.5	22.2	334.58	307.08	24.86	366.93	32.35	392.93	26	364.29
2	14.18	16.84	70.7	53.86	407.37	336.67	0	439.72	32.35	465.72	26	46.79
3	25.73	28.39	113.9	85.51	480.16	366.26	0	512.51	32.35	538.51	26	46.79
4	37.28	39.94	181.69	141.75	1455	1273.31	0	1487.35	32.35	1513.35	26	948.84
5	48.82	51.48	309.58	258.1	1527.79	1218.21	0	1560.14	32.35	1586.14	26	46.79
6	79.14	81.8	382.37	300.57	1630.15	1247.78	0	1662.5	32.35	1750	87.5	76.36
7	122.34	125	455.16	330.16	1765	1309.84	0	1797.35	32.35	1823.35	26	47.35
8	190.13	192.79	527.96	335.17	1837.79	1309.83	0	1870.14	32.35	1896.14	26	46.79
9	318.02	320.68	1502.79	1182.11	1910.58	407.79	0	1942.93	32.35	1968.93	26	46.79
10	390.81	393.47	1575.58	1182.11	2885	1309.42	0	2917.35	32.35	2943.35	26	948.42
11	463.6	466.26	1677.94	1211.68	2947.79	1269.85	0	2980.14	32.35	3052.64	72.5	36.79
12	536.39	539.05	1812.79	1273.74	3020.58	1207.79	0	3057.64	37.06	3083.64	26	5
13	1511.23	1513.89	1885.58	371.69	3093.37	1207.79	0	3185	91.63	3211	26	101.36
14	1584.02	1586.68	1958.37	371.69	3226.26	1267.89	0	3258.61	32.35	3284.61	26	47.61
15	1686.38	1689.04	2922.79	1233.75	3299.05	376.26	0	3331.4	32.35	3357.4	26	46.79
16	1821.23	1823.89	2995.58	1171.69	3371.85	376.27	0	3404.19	32.34	4330	925.81	46.79
17	1894.02	1896.68	3068.37	1171.69	4345	1276.63	0	4377.35	32.35	4403.35	26	47.35
18	1966.81	1969.47	3201.26	1231.79	4417.79	1216.53	0	4450.14	32.35	0	-4450.14	46.79
19	2931.23	2933.89	3274.05	340.16	4490.58	1216.53	0	4522.93	32.35	4548.93	26	4522.93
20	3004.02	3006.68	3346.85	340.17	4625	1278.15	0	4657.35	32.35	4683.35	26	108.42
21	3076.81	3079.47	3419.64	340.17	4687.79	1268.15	0	4720.14	32.35	4746.14	26	36.79
22	3209.7	3212.36	4392.79	1180.43	4760.58	367.79	0	4792.93	32.35	4818.93	26	46.79
23	3282.49	3285.15	4465.58	1180.43	4833.37	367.79	0	5765	931.63	5791	26	946.07
24	3355.28	3357.94	4538.37	1180.43	5806.26	1267.89	0	5838.61	32.35	5905.36	66.75	47.61
25	3428.07	3430.73	4662.79	1232.06	5879.05	1216.26	0	5911.4	32.35	5937.4	26	6.04
26	4401.23	4403.89	4735.58	331.69	5951.85	1216.27	0	5984.19	32.34	6070.19	86	46.79
27	4474.02	4476.68	4808.37	331.69	6085	1276.63	0	6117.35	32.35	6143.35	26	47.16
28	4546.81	4549.47	5781.26	1231.79	6157.79	376.53	0	6190.14	32.35	6216.14	26	46.79
29	4671.23	4673.89	5854.05	1180.16	6230.58	376.53	0	6298.27	67.69	7226	927.73	82.13
30	4744.02	4746.68	5926.85	1180.17	7205	1278.15	0	7237.35	32.35	7263.35	26	11.35
31	4816.81	4819.47	5999.64	1180.17	7267.79	1268.15	0	7300.14	32.35	7326.14	26	36.79
32	5789.7	5792.36	6132.79	340.43	7340.58	1207.79	0	7372.93	32.35	7398.93	26	46.79
33	5862.49	5865.15	6205.58	340.43	7413.37	1207.79	0	7505	91.63	7531	26	106.07
34	5935.28	5937.94	6278.37	340.43	7546.26	1267.89	0	7578.61	32.35	0	-7578.61	47.61
35	6008.07	6010.73	7242.79	1232.06	7619.05	376.26	0	7651.4	32.35	7677.4	26	7651.4
36	6141.23	6143.89	7315.58	1171.69	7691.85	376.27	0	7724.19	32.34	8650	925.81	46.79
37	6214.02	6216.68	7388.37	1171.69	8665	1276.63	0	8697.35	32.35	8723.35	26	47.35
38	6286.81	6289.47	7521.26	1231.79	8737.79	1216.53	0	8770.14	32.35	8796.14	26	46.79
39	7251.23	7253.89	7594.05	340.16	8810.58	1216.53	0	8842.93	32.35	8868.93	26	46.79
40	7324.02	7326.68	7666.85	340.17	8945	1278.15	0	8977.35	32.35	9003.35	26	108.42

Figure 13, The table of time acquired from each critical point transfer in excel

The columns with color are variables needs to calculate by excel

And here is a brief introduction of this table, each row is the time that a material pass through each point. Column 1 is the serial number of each wheel hub. The later columns are points to check time. The time track in each column is set in the "Triggers" like "On Entry" or "On Exit". If the time track on entry, means it get the time when a material enter the conveyor or a processor. Same as on exit. The code for achieve this function in the triggers is “settablenum("time",getlabel(item,"product"),4,time());”, which the number 4 is the column number.

Col 2	Exit from source
Col 3	Enter conveyor 1
Col 4	Exit conveyor 2
Col 5	Enter conveyor 3
Col 6	Exit conveyor 7
Col 7	Enter conveyor 8
Col 8	Exit conveyor 8
Col 9	Enter conveyor 9
Col 10	Enter Washing Processor
Col 11	Enter conveyor 10
Col 12	Exit conveyor 10
Col 13	Exit Geometric Control
Col 14	Exit Data Matric Control
Col 15	Exit conveyor 11
Col 16	Enter rework Washing
Col 17	Enter conveyor 10 after rework
Col 18	Exit conveyor 10 after rework

Table2, column respects to time point

- Actual production time (APT), actual time during which a work unit is producing. It includes only the value-adding functions.

In this model, the basic setting is on the processor, they This variable is going to monitor by the time that a wheel hub raw material entering a work unit and leaving it.

It is calculated in the excel. The final result of this variable is a mode number of the whole column. Since this paper supposes that most of the time the work unit is working normal without failure.

- Actual queuing time (AQT), actual time in which the material is either in transport or waiting for the process to begin.

In the model, it will be partially effects by the conveyors transport speed. And the speed is 1m/min. By concentrating on the time that a wheel hub staying on the conveyers which before each work unit, this article can get the variable.

AQT is acquired by calculation in Excel table. And the final result is a mode number of time actual time of each work unit.

- Actual unit down time (ADOT), when the work unit is not executing order production although it is available.

While a material leaving the work unit, and if the work unit is empty, it is start to count the time until the next part arriving.

ADOT is acquired from Excel calculation. The final result is reported as the mode number.

- Actual unit setup time (AUST), time consumed for the preparation of an order at a work unit.
  This time can only set in the FLEXSIM processor, and they are set as 1 minutes, so it is no possible to have a work unit set up time. And this simulation will not monitor on this variable.

- Time between failures (TBF), AUBT between two consecutive failures of a work unit including AUST, APT and TTR related to the orders being processed and without delay times.

This is set by MTTR/MTTF part. In the simulation, if a processor member of a work unit is breakdown, the whole work unit is breakdown also. So, it will be set as a whole work unit failure together. But different work unit has is different distribution of failure time.

TBF is obtained from the excel calculation by the time failure next time minus former time. And the final result showed later is the average value of the TBF of each work unit.

	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6
Row 1	918.23	226.96	1044.02	372.50	1845.81	255.07
Row 2	933.07	231.89	1128.75	396.85	1854.89	275.86
Row 3	1028.77	2661.17	1484.54	1608.26	2126.23	364.04
Row 4	1034.04	2690.04	1529.86	1628.50	2129.47	518.43
Row 5	1040.20	2990.72	2233.76	2052.03	4511.35	1087.61
Row 6	1049.46	3037.22	2284.51	2170.89	4521.48	1092.52
Row 7	1594.80	5845.33	2532.35	2657.42	5920.17	1130.42
Row 8	1620.15	5886.08	2575.12	2699.45	5995.52	1131.32
Row 9	2799.71	6221.18	3191.11	3392.95	6547.36	1246.49
Row 10	2823.68	6293.27	3261.96	3403.49	6575.32	1287.28

Figure 14, The table of time of failure and repairing for restart working about each work unit acquired from MTBF MTTR in FLEXSIM.

The odd number of Row is the start time of failure, the even number Row is the end of the failure by repairing, from column 1-6 means six work units from Roughing to Data matrix control). Each time in the table is acquired by set the “MTBFMTTR” function, which are in the “On Break Down” and “On Repair” custom code as:

```
int NO=getlabel(node("/Robot1",model),"MTBFMTTR");
setlabel(node("/Robot1",model),"MTBFMTTR",NO+1);
settablenum("MTBFMTTR",getlabel(node("/Robot1",model),"MTBFMTTR"),1,time
());.
```

- Time to repair (TTR), time during which a work unit is unavailable due to a failure.

  This variable is considered in a same process in setting the MTTR/MTTF.

TTR is recorded by excel, it is the time interval between each odd and even Row, for instance the Row 1 and Row 2. And the final result is an average number about each work unit.

	A	B	C	D	E	F
1	ROUGHING	TIME TO REPAIR	TIME BETWEEN FAILURE	BROACHING	TIME TO REPAIR	TIME BETWEEN FAILURE
2	918.23	14.84		226.96	4.93	
3	933.07		110.54	231.89		2434.21
4	1028.77	5.27		2661.17	28.87	
5	1034.04		11.43	2690.04		329.55
6	1040.2	9.26		2990.72	46.5	
7	1049.46		554.6	3037.22		2854.61
8	1594.8	25.35		5845.33	40.75	
9	1620.15		1204.91	5886.08		375.85
10	2799.71	23.97		6221.18	72.09	
11	2823.68		2301.37	6293.27		651.38
12	5101.08	44.95		6872.56	3.03	
13	5146.03		1974.22	6875.59		1292.55
14	7075.3	56.93		8165.11	5.47	
15	7132.23		760.04	8170.58		1595.05
16	7835.34	66.78		9760.16	120.62	
17	7902.12		2761.89	9880.78		2832.75

Figure 15, The table of time of failure and repairing for restart working about each work unit in Excel. Each two Row of time is been setting different color for easier distinguishing.

- Failure event count (FE), count over a specified time interval during which a work unit is unavailable due to a failure.

The event number is counted by the Excel, since in the table 14 it is clear that each two Row is one failure event in FLEXSIM.

- Planned order quantity (POQ), LOT SIZE or Production order quantity.

In this simulation, it works on 800 parts waiting for process. However, due to logic setting of Roughing in the model, it actually needs four more parts send from source to the line. So, in the simulation setting, it is 804. But the final result is only need to count the 800.

- Scrap quantity (SQ), produced quantity that did not meet quality requirements.

This process needs new logic added in the model, except the last work unit data matrix, there are 5 queues as the temporary collectors of the failure parts produced by each work unit. The logic of failure parts is in the exit trigger of each work unit. An operator works on collecting these parts and bring them to the sink 2 that only used for recycle of failure parts. In this simulation, the scrap quantity has a percentage as 0.5% of the total number of parts produced by each work unit.

In the model, this quantity is recorded by the dashboard "throughput" function, which chooses the Sink 2 output.

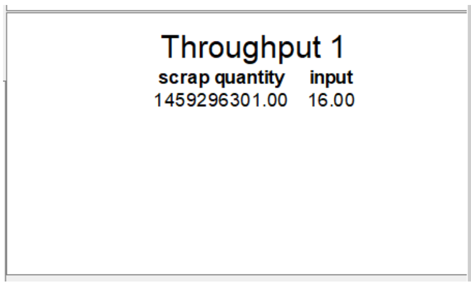

Figure 16, Scrap quantity

- Rework quantity (RQ), this is only considered as the operation between geometric control and washing process.

The wheel hubs, needs to be washed again, will be send back to washing process with the 5% of the quantity of parts that pass through the geometric control in first time by the operator 3 besides the line (the logic of percentage of the re-washing is setting on the exit of Geometric Control). What is needed to pay attention is that all the parts have been reworked are production which satisfied the quality requirement. The scrap quantity is another variable differently counted by the exit port of each work unit.

RQ is directly monitor from the dashboard of the re-washing queue output. Same as SQ, it is a throughput function.

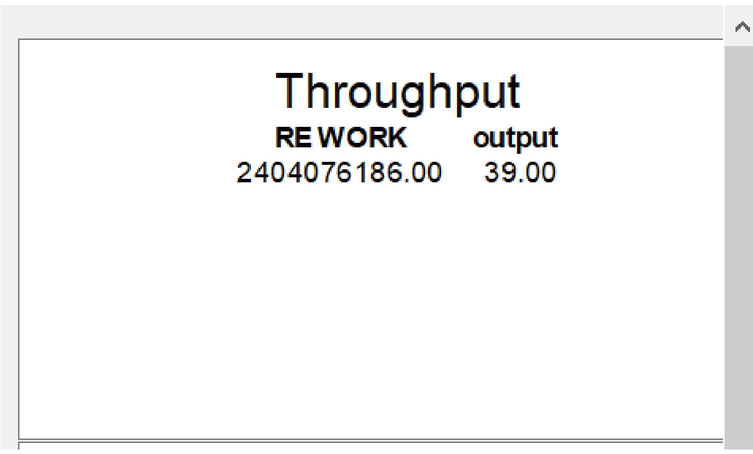

Figure 16, Rework quantity

- Actual direct energy consumption (ADEC) Measured direct energy consumption per work unit and during actual unit busy time.

This variable cannot be monitor by FLEXSIM in this paper.

There is a simplified approach, by searching on the relative processor and robot, this simulation considers the power of one processor is 15kw, the robot is 6kw, the shuttle is 1kw, the washing machine and the geometric control are 1.5kw, so as the data matrix machine. And the energy consumption will be the result of multiplied the power with the final result (a mode number) production time of each work unit, which is calculated in the excel.

4.2 Simulation result

After checking all the variables this paper concentrating on, it is time to run a simulation to see how the variables monitored.

And here is the model that sets as prepared for simulation.

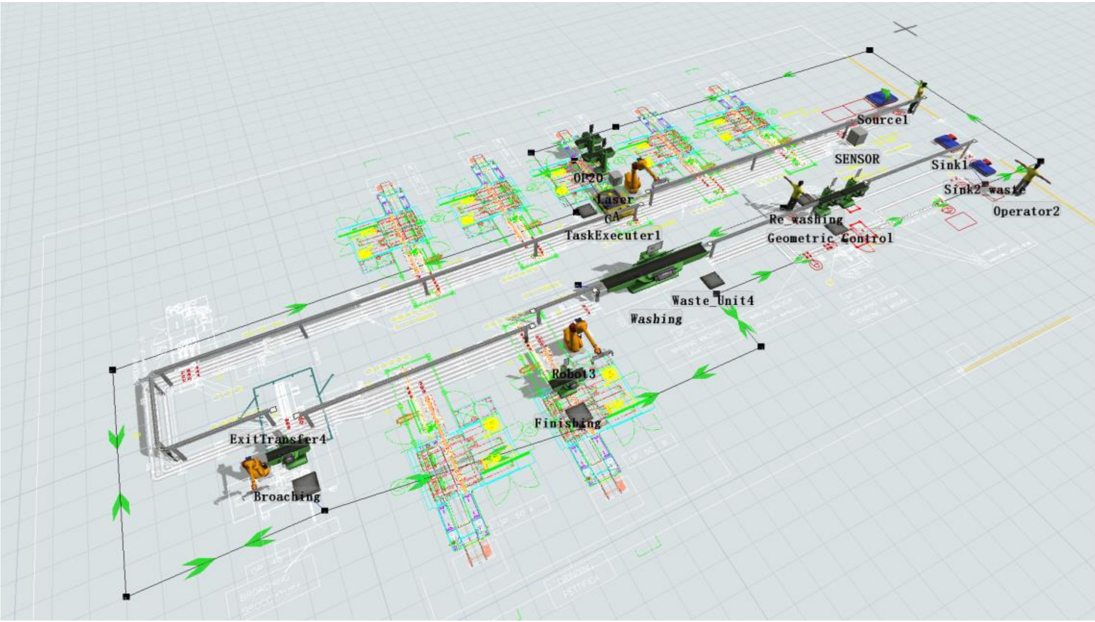

Figure 17, The FLEXSIM single line model modified for simulation

By operating the simulation, the results of each work unit can be obtained from Software dashboard, time table. And they are collected in the table below.

	Operator 1	Operator 2	Operator 3	Operator 4
Actual personnel work time **(APWT)** (min)	4264	578.56	364.28	38869.37

Table 3, APWT

Planned order quantity (POQ)	800
Scrap quantity (SQ)	16
Rework quantity (RQ)	39
Actual order execution time (min) AOET	59625.08

Table 4, POQ, SQ, RQ, AOET

Work unit / (min)	Roughing	Broaching	Finishing	Washing	Geometric control	Data matrix
Actual production time (APT)	1278.15	26	26	11	11	11
Actual queuing time (AQT)	1180.17	32.35	13.76	2.72	5.89	0
Actual unit down time (ADOT)	0	46.79	46.79	61.79	20	20
Time between failures (TBF)	1069.03	965.54	969.59	976.85	1014.49	942.63
Time to repair (TTR)	28.34	30.31	29.94	30.41	28.90	31.61
Failure event count (FE)	166	186	184	181	174	190
Actual direct energy consumption (ADEC) **(kw.h)**	788.19	9.1	9.1	0.275	0.275	0.275

Table 5, variables of each work unit

4.3 Conclusion

This paper includes three parts of tasks. These jobs have been done are: 1, Introducing the hierarchical model, searching some relative literatures and giving a suggestion of change on Social model layer; 2, Two FLEXSIM models built as closed to the real workshop as possible (one for the complete production line with three parallel unit lines, another for simplified simulation single line); 3, The simulation setting improvements and obtain the variables.

The simulation part is the field that this thesis more focuses on. And the software simulation of the production system shows several advantages in Industry 4.0, especially the “digital factory”.

Firstly, as in this paper, the simulation models are built based on description, not by checking the practical factory layout. The simulation can help the researchers or managers to analysis how the production system work, even if the factory or production line is under schedule but has not been built yet. By simulating the production line on software, those variables, which from international standard and hierarchical model, can be monitored by the virtual sensor set in the model or calculated in Excel. This can contribute to find if the production line working in a high efficiency, also low cost, low energy waste approach. And give the improvements to the schedule of production line before it starts to build in real, for example the layout or the process machine performance may need to change, which helps a lot on reducing the cost of architecture.

Secondly, not only at the stage before the production line built in real, but also during the production line working, the simulation can help the researcher analysis and try to improve the system without interrupting the daily producing plan in the factory. For instance, after analyzed the data from real production line sensors, the manager finds out there are still several variables can be improved. But it is unnecessary to trying to adjust the machine on the line several times, which influences the normal producing schedule. The manager can directly simulate the improvements in software model and give the suggestion directly in one time, and test on the production line to see the result is good or not.

Thirdly, the simulation can check if there are mistakes on collecting the data from sensors. Since the software simulation model is built also to show how the sensor working on the production line. It can help the manager and researcher to find out if the approach to obtain the data is correct as what the analyze really needs. As during building and simulation, it is already to know some planned variables. The difference between simulation result and the planned time table, also compare to the real sensor can point out if there are something wrong happened.

Finally, it is important that these advantages are based on the simulation model built as real as possible to the real production line. In this thesis, the simulation model is actually a simplified edition, there are still places need to improve. Especially the setting of the virtual sensor in the simulation line. So as another complete line, which has been built but without simulating yet.

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