POLITECNICO DI TORINO

Department of Mechanical & Aerospace Engineering

Master's Degree Program in Automotive Engineering

Master’s Degree Thesis

Hierarchical Modelling And Application On Industrial System

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Abstract

With the rapid advancements in industry, technology and application. many concepts or production models have emerged in manufacturing. It is generally known that the concept Industry 4.0 was published to highlight a new industry revolution. Many manufacturing organizations and companies are researching and digging on this topic. The connection between traditional manufacturing machine and intelligent communications have created such models which improve the working efficiency massively.

In this thesis, I would introduce and develop a hierarchical production system model which contains seven main layers. Then based on the hierarchical model, a practical case of processing of steel hub would be acted. The raw materials which are the steel would be processed and then are transferred to industrial hub through the whole production system. Finally, I would build a virtual working line to simulate my hierarchical system and production case.

Key words: Industry 4.0, hierarchical model, steel hub, hierarchical production system, virtual working line.

Contents

Chapter 1: Background

The Industry 4.0 research project was jointly funded by the German Federal Ministry of Education and Research and the Federal Ministry of Economics and Technology. It was formed and promoted by the German Academy of Engineering, Bonhoeffer Society, Siemens and other German academic and industrial circles. Industry 4.0 which is based on the network entity system and IOT refers to the use of the Caber-Physical System (CPS) to digitize, intelligence, and ultimately supply, supply, and sell information in production, and finally achieve fast, efficient, and personalized product supply.

1.1 The development of industry revolution

Industry 1.0 was the era of mechanical manufacturing, the era of mechanical equipment introduced in the 18th century. Its typical industrial feature is the mechanization of the factories through hydraulic and steam engines. The result of this industrial revolution is that mechanical production has replaced manual labor, and the economic society has shifted from agriculture and handicrafts to a new model of industrial development driven by industry and machinery. However, Inefficiency and limited functionality are challenges that must be considered.

Industry 2.0 began in the 1970s with the main symbol of the invention of generators and telecommunications. The main components are electric technology, transportation technology, and telecommunications technology. Compared with the steam engine in the first technological revolution, electric energy can be concernedly produced, dispersed, used for transmission and distribution, and easily converted into various forms such as light energy, mechanical energy, and chemical energy.

The third scientific and technological revolution is another major leap in the field of science and technology in the history of human civilization following the steam technology revolution and the power technology revolution. The third scientific and technological revolution is characterized by the invention and application of atomic energy, electronic computers, space technology and bioengineering. It involves a field in information technology, new energy technology, new materials technology, biotechnology, space technology and marine technology.

Industrial production 4.0 include industrial Internet of Things, cloud computing technology, industrial big data, industrial robots, 3D printing, automation technology in professional knowledge, industrial production network information security, virtual reality technology and artificial intelligence technology. In the intelligent production phase, Intelligent Interconnect System Industrial Production 4.0 will closely integrate machinery and equipment, production lines, processing plants, distributors, enterprise products and customers.

1.2 The new communication technology

The 5th-Generation of mobile communication technology is the latest generation of cellular mobile communication technology, which is an extension of 4G (LTE-A, WiMax), 3G (UMTS, LTE) and 2G (GSM) systems. 4G performance goals are high data rates, reduced latency, energy savings, reduced costs, increased system capacity and large-scale device connectivity.

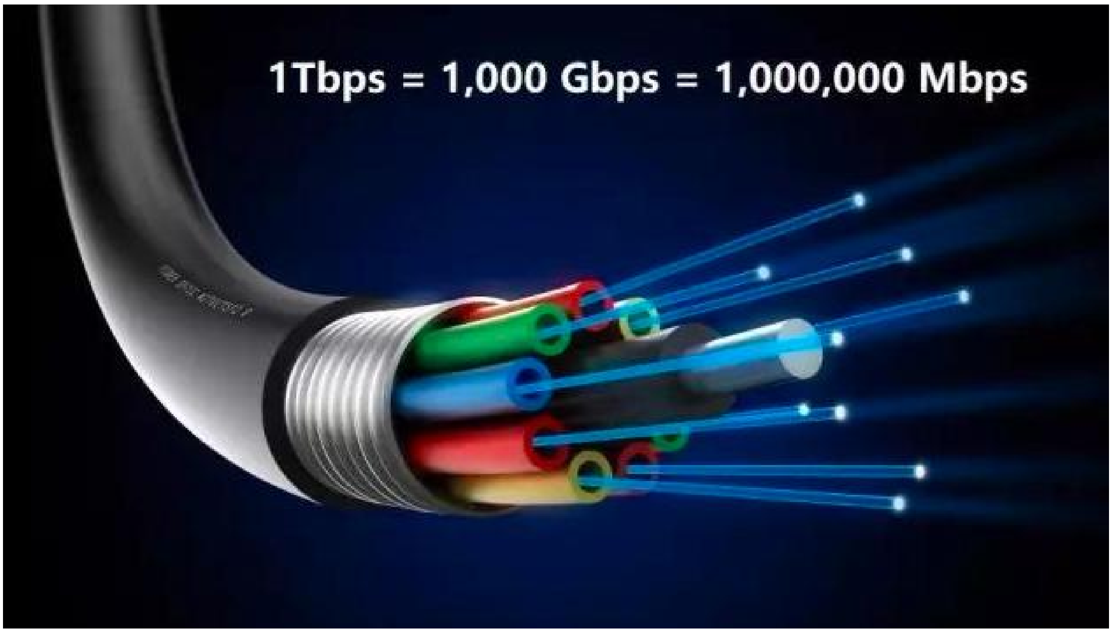


Figure 1. 4th-Generation

The main advantage of 4G networks is that the data transmission rate is much higher than the previous cellular network, up to 10Gbit/s, which is faster than the current wired Internet and 100 times faster than the previous 4G LTE cellular network. Another advantage is lower network latency (faster response time), less than 1 millisecond, and 4G is 30-70 milliseconds. Due to faster data transmission, 4G networks will not only serve mobile phones, but will also become a general home and office network provider, competing with cable network providers. Previous cellular networks provided low data rate Internet access for mobile phones, but a cell phone tower could not economically provide enough bandwidth as a general Internet provider for home computers.

1.3 Industry 4.0 and the 4th-Generation communication

1.3.1 The meaning of 4G for Industry 4.0

Real-time and secure data transmission is an important guarantee for "Industry 4.0", and 4G has the characteristics of large transmission data, high security and short delay time. The high-performance wireless network connects the massive sensors, robots and information systems in the factory, and the massive data and high-quality data generated by the connection continuously "feed" artificial intelligence, and feedback analysis and decision-making to the factory. At the same time, the 4G wide coverage network could cover the globe, connect widely distributed or cross-regional goods, customers and suppliers, and maintain a full connection to the entire product life cycle, enabling vertical, horizontal integration and end-to-end integration within and outside the plant. Future plants are a combination of digital virtual and physical reality. ICT technology is integrated with modern manufacturing to increase the flexibility, trace ability, versatility and productivity of industrial production, opening up new business models for manufacturing. The boundaries between the interior and exterior of the factory are becoming increasingly blurred. The factory is no longer an independent closed entity, but a part of a huge value chain and ecosystem. This is called a "virtual factory".

1.3.2 The driving force of 4G

Mobile Robots: Mobile robots belong to the category of flexible factories. The so-called flexible factories refer to freely movable machine equipment and free reloading production tools to ensure that factories can quickly and cost-effectively switch production between different types of product lines. To implement a flexible factory, a wireless connection is required to replace the existing wired connection in the factory. Only by getting rid of the constraints of the cable can the freely design, operate and upgrade the connected machines and robots. A stable and reliable 4G can act a wonderful role.

Factory Automation: In the automation plant, in order to improve the efficiency of the production line, real-time monitoring of each sub-component is required, real-time measurement of the quality of the produced product, and real-time optimization of the production line, which requires ultra-low latency and ultra-reliable wireless connection. At the same time, applications such as visual control robotic arms, 3D model transmission, and remote digital factories require highly reliable high-bandwidth communications.

New Human Machine Interface (NHMI): Future human-machine interface applications will undergo subversive changes. With the integration of industrial intelligence and big data, wearable industrial devices and augmented reality (AR) play an important role in human-machine integration, such as letting workers wear robots. Exoskeleton equipment, using "wearable industrial equipment plus AR technology", integrate information with real-world scenes, capture information at any time, receive cloud commands and operational assistance, etc.

Logistics: In terms of logistics, from intelligent warehouse management to logistics and distribution, we need wide coverage, deep coverage, low power consumption, large connections, and low-cost 4G IOT connectivity. In addition, the end-to-end integration of virtual factories spans the entire life-cycle of a product, connecting a wide range of sold merchandise, as well as low-power, low-cost and wide-coverage。

4G Internet of Things.

Chapter 2: Production System

Production system consists of a traction member, a load bearing member, a driving device, a tension device, a redirecting device and a supporting member. The assembly line has high capability, and can design the conveying volume, conveying speed, assembly station and auxiliary components according to requirements. The assembly line is an effective combination of people and machines, which fully reflects the flexibility of the equipment. It combines the conveying system, accompanying fixtures, on-line special machines, and testing equipment to meet the transportation requirements of various products. The transmission mode of the transmission line is synchronous transmission (mandatory) or asynchronous transmission (flexible). According to the choice of configuration, the requirements of assembly and transportation can be realized. Production system is indispensable in the company's mass production.

2.1 The 5 main production process

There are 5 main steps for the production process:

- **Rough processing**: The main purpose of roughing is to cut a wide range of raw materials. The initial processing is to transport the raw metal blocks to the CNC cutting machine through a conveyor belt. The roughing machine will rough the part according to the cutting program designed by the operator. The purpose of this step is to get the roughest possible outline and prepare for follow-up.
- **Broaching processing**: According to the processing needs, drilling needs to be performed according to the size requirements of the part. At this time, the deep drawing operation is to prepare for punching. Take parts from the corresponding product production line and enter the corresponding broaching machine to complete the drilling operation.
- **Finishing processing**: The surface of the part that has been roughed and stamped can be finished. Because the requirements of industrial production parts can meet

the product accuracy to the maximum limit within the tolerance range. Therefore, the finishing machine also needs the operator to design the cutting program according to the size requirements of the part, but it should be noted that the size of the part must be within the tolerance tolerance after finishing..

- **Washing and drying:** After the main operation steps are completed, since error correction is required at the end, the parts must be kept clean. The washing and drying operations performed by the washing machine can reduce the rework rate and ensure product accuracy.
- **Dimensional control**: In this step, an optical error check is performed with the help of a special error sensor. Within routine tolerances, the product is considered acceptable. For unqualified products, rework is required before error checking. As for the second-defective products, they are regarded as defective products.

Here I just make a rough introduction based on the original planned processing requirements. It is thought that the main purpose of this paper is to analyze the entire production and processing system based on the hierarchical model theory. Therefore, the five main processing steps and their specific evaluation indexes will be reflected in the hierarchical model operation and analysis in the next part. At that time, I will use the material flow analysis method to specifically correspond to each processing step. Here is only a rough overview of the basic process for easy understanding.

2.2 Production machines

2.2.1 Roughing machine

Most of the machining allowances on each surface are cut off so that the shape and size of the blank are close to the finished product. This stage is characterized by the use of high-power machine tools, the use of large cutting amounts and as much as possible to increase productivity and reduce tool wear.

After the first processing, semi-roughing stage would come, during the second roughing process, what we need it to to meet certain accuracy requirements, and ensure that a certain amount of machining allowance is left, to prepare for the finishing work of the main surface, while finishing some secondary surface processing.

Figure 2.Roughing machine

Here are the technical data :

Length	Width	Height	Power	Cycle Time	Weight
1800mm	1800mm	2450mm	28kw	35s	5000kg

Table 1. CNC technical data

2.2.2 Broaching machine

The broach is used as a tool for machining through-holes, flat surfaces and forming surfaces of work pieces. Broaching can obtain high dimensional accuracy and small surface roughness, high productivity, and is suitable for mass production in batches. Most broaching machines only have the main motion of straight broaching, but no feed motion and as a consequence, robotic arms are used to catch the products and transport them into the broaching machine. It is common that we can choose a vertical internal broaching machine to reduce the footprint to a greater extent and improve the efficiency of hole processing.

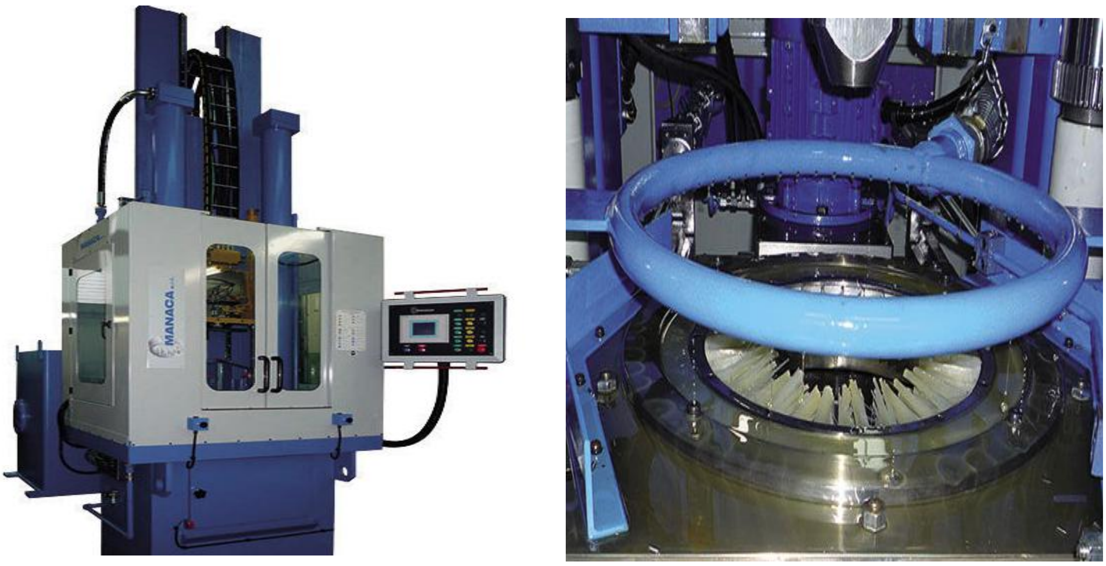


Figure 3. Broaching machine

Here are some technical parameters of the broach:

Machine	Overall height	Length	Width	Power	Force
H.V	3.2m	2.1m	2.4m	22kw	20ton

Table 2. P.C. layout data

After the processing of the broaching machine, the robotic arm will transport the processed parts to the corresponding channel and prepare for the next processing.

2.2.3 Finishing machine

Requires high precision and rigidity of the machine tool. The grinding process uses a finely-trimmed grinding wheel to produce multiple micro-cutting edges of the same height on each abrasive grain, with a small grinding depth and proper grinding. Under pressure, very fine chips are cut from the surface of the work piece, together with the friction when the micro-cutting edge is in a micro-chirped state, squeezing, smoothing, and friction polishing in the multiple non-feeding light grinding stage, so as to obtain a very high High-gloss surface with good processing accuracy and good physical and mechanical properties.

Figure 4. Finishing machine

Here are the technical date:

Length	2000 mm
Width	2255 mm
Height	3800 mm
Mass	2.96 t
Water volume	4.5L/min
Power	16kw
Cycle time	4min

Table 3. Finishing machine technical data

2.2.4 Washing machine

After rough machining, broaching, and fine surface finishing, the part has completed the basic procedures. The washing machine can wash the metal powder adsorbed on the surface of the part. If the metal powder has strong adhesion, you can consider using a solvent to carry out rinse. The purpose of this step is to prepare for subsequent dimension inspections.

Figure 5. Washing machine

Here are the technical data:

Hydraulic pressure	2.2 a.t.m
Dimensions	L=2m , W=1.5m , H=1.5m
Rated power	12 Kw
Delivery water flow	42 L/h

Table 4. Washing machine technical data

2.2.5 Dimensional Detector

Error benchmark detection. After the part passes through the laser area, the blank period waveform will be displayed on the oscilloscope in unit time. According to the wavelength and frequency, you can get whether the part radius meets the standard.

2.2.6 Transporting and handing equipment

The main transportation equipment in the production workshop mainly includes conveyor belts, robotic arms, and forklifts. Raw materials are transported to the input end by a forklift. The main role of the robot arm is to complete the scheduling between production units and channel transfer of parts. After the processing is completed, it is transported out of the warehouse by a forklift.

Figure 6. Robotic arms

Forklift are used to transport the materials and the final product:

Figure 7. Forklift

Capacity	0.9 m^2
Fuel consumption	8L/hour

Chapter 3: Hierarchical Models

Industry 4.0 emphasizes building a suitable smart factory. Throughout the entire project, from the production line manufacturing system to the management system, a very important task is to establish the interaction of information and resources. Considering the reality and ability of the implementation of the plan, we first need to simulate an ideal plant design plan, that is, consider a variety of variables, and measure the construction benefit scale through the virtual factory. Therefore, we introduce a new concept in this section called the hierarchical model. Relying on hierarchical models and variables, analyze the efficiency and significance of production and processing.

Below I will introduce the basic components of the hierarchical mode：

- The 2D layout layer: mainly related machines positions
- The 3D layout layer: 3-dimension machine design
- The flow layer: mainly consisted processing of raw materials and using of energy
- The variables layer: variables or parameters used to measure and control the system and key points to simulate the system
- The management layer: measure and forecast the production process
- The financial layer: mainly focused on profits and costs of the system
- The social layer: the influence of the product on society and environment

After introducing the concepts in a short answer, I will introduce the information contained in each layer in detail layer by layer, including: the definition of the unit layer, the input and output of each unit and its function expression, and the reference variables and standards of each layer. Then, by establishing the layer-to-layer connection, a complete system framework is formed so that we can simulate and analyze our actual case in a virtual environment.

3.1 2D model layer

2D model layer is used to describe the layout of the system. this model represent the XY dimensional description of the production devices and work shop layout, which indicates the overall arrangement of the exact position of workshop, production equipment, warehouse, conveyors and so on.

The basic step for the design of a 2D model layer is from the whole system to the specific processing device according to the content of production, geometry and function of the production process.

- Familiar with and master the relevant drawings and materials. Before carrying out the equipment layout, familiarize with the characteristics of the process, the type and quantity of the equipment, the process characteristics and main features of the equipment through relevant drawings and documents (such as process flow diagrams, plant building drawings, equipment lists, etc.). Dimensions for easy design.
- Determine the overall layout of the plant, such as the choice of centralized or separated, and determine the outline, span,column spacing of the plant according to the shape, size and number of equipment.
- Carefully consider the layout principle, and arrange within the outline according to the outline of the plant. It will be necessary to use the equipment to move around within the feasible area with a rough outline and arrange it repeatedly. Multiple alternatives can be designed and the ideal arrangement can be selected by comparison.
- After the initial layout of the equipment is completed, it can be modified according to the following factors: the arrangement of the main pipe is as short and smooth as possible; check the basic size of the equipment and the possibility of equipment maintenance; the static safety distance of the equipment; and the position of the platform that is matched with the equipment And size.

The base unit for designing is sub-functional area, XY dimensions of each device, such as length and weigh, of the device of the processing line can determine the exact

position in the sub-functional area. The sub-functional area can determine the 2D dimension of each functional area. The 2D dimension of all the function areas and processing line determine the entire production system.
Within the dimensional data of processing device from the company and design principles, the 2D model can be developed by Auto-CAD indirectly and then, the 2D layout of the workshop could be built.

However, just considering the XY dimension of the equipment and interface between workshop and environment is not sufficient. It is necessary to make the design more user-friendly based on ergonomics, high efficiency and trade-off in balance.

- High-efficiency: reasonable layout and maximum use of production equipment, which means that the production line should be at a suitable length so as to ensure that the production equipment can process more raw materials in a certain period of time and as a consequence to save more energy. Then, consider vertical development which can also ensure that production efficiency is improved under the inherent space conditions.

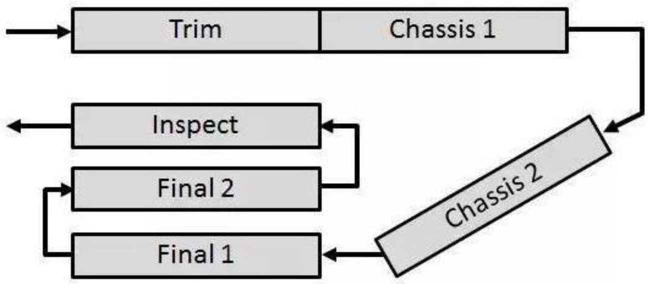


Figure 8. Line layout

- User-friendly based on ergonomics : for workers, there must be a certain space to perform operations or the replacement and replacement of machine parts.Workers should have less time to access to noise and dust or safety issues. Another very important thing is each worker have the right to stop the production line he is in, but if something happens that he can resolve within a cycle time. However, on a long production line, this means inconvenience to many other workers since when workers stop the production line, there will be a feeling of guilt for interrupting the work of others, which will cause hesitation.We can divide each production line into several sub-units and let each worker perform his or her own duties. In addition, workers can temporarily increase the speed, build a small buffer inventory in advance, and then use the obtained time to conduct a 5-minute meeting to discuss the current problems.

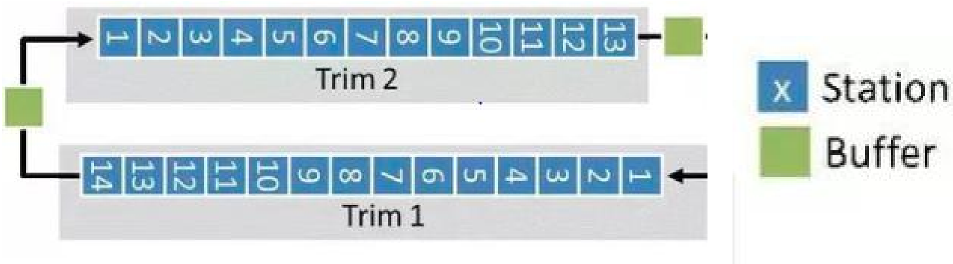


Figure 9. Station and buffer

- Trade-off: in general, the production line needs to maintain the balance of the production line, and in accordance with a specific approach when processing products, the workload, completion time and output of each workstation can be matched on a technical level. Improving efficiency is to minimize the idle time from the side, pay attention to cycle time, and minimize it on the basis of ensuring quality. So after understanding the processing sequence, estimating the processing time and calculating the cycle time, the minimum number of workstations can be calculated.

$$N_{\min} = \frac{D \cdot \sum t}{OT} = \frac{\sum t}{CT}$$

Where $N_{\min}$ is the min number workshops, D is production line expected daily output, t is total working time, CT is the cycle time, OT is the daily working time.

3.2 3D model layer

3D model, which is based on last 2D model layer, indicates the space occupancy of the system. Basing on the XY dimension from 2D model, adding information about the workshop height to depict the spatial layout.

The focus of the 3D model needs to consider the design of the system in the stereo direction. Similar to the 2D floor which the contour and span of the factory building need to be considered, the 3D floor needs to consider the number of floor of factory buildings. For equipment, when installing them, keep a certain safety distance when lifting.

The 3D layer is not only to increase the height dimension to indicated the space occupancy based on the two-dimensional model, but also to consider the auxiliaries interfaces and dynamic interfaces during machine operation:

- Auxiliaries interfaces: The 3D layer is a solid layer that inherits the 2D plane layer. We have already defined the matters needing attention in 2D modeling. In order to establish a complete and easy production workshop, while considering the actual production line, we must also consider some additional auxiliary systems, such as HVAC, lighting systems, monitoring systems, etc. It must be ensured that when these auxiliaries fail and need to be repaired and replaced, they will not interfere with the operation of the production line, so there must be a certain amount of space in the direction of the three-dimensional space.
- Dynamic interfaces: Another important piece of information that the 3D layer can provide is the dynamic interference, especially considering the era of intelligent industrialization, the widespread application of intelligent robotic arms and other institutions. When we consider the motion trajectory of the robotic arm in a three-dimensional space, the stability margin between adjacent robotic arms must be kept within the allowable range to prevent object interference. Except that, the moving of the human and interfaces on the devices and it can be analyzed in 3D dimension.

3.3 The flow model layer

Basing on the 3D model layer, flow model layer shows all the possible material transport in the plant, in a workshop, among the different work centers and between or inside devices. It is about the **material flow chart** of the production system.

In order to analyze the material flow, material flow analysis is an important method to study the benefits of production and processing. The basic idea of material flow analysis is that the impact of production activities depends to a large extent on the quantity and quality of natural resources and materials entering the entire production system. Also the quality and quantity of waste discharged from economic systems into natural systems. By studying the physical changes of the material in the input-storage-processing-output process, the flow characteristics and transformation efficiency of the material in the production and processing process are revealed.

The material flow analysis follows the law of conservation of mass, and uses the mass of the physical object as a unit to measure the degree of development, utilization, and waste of natural resources and different substances in the course of production economic activities. Because it adds the influencing factors of different types of materials, on the one hand, it avoids the problem of subjective price differences that would occur when traditional GDP measures external costs. On the other hand, it also measures substances that do not directly enter the production economy but have an impact on the environment, which are often ignored because they have no monetary value.

On this layer, using 3D plant layout and the manner in which all these material interact and flow in the plant/workshop/elements as an input and simulate it in Flexsim software so as to get empirical data. For output, plant / workshop / line / device production efficiency and materials consumed can be got and they are useful for next layers.

3.3.1 Material flow analysis

In this method, the material is a general concept and it mainly consists of three parts which are raw materials, mid product in progress, final product and energy.

- Raw materials: It represents the starting point of the production and what the firms buy from suppliers and stocks in warehouse. Raw materials firstly would be introduced into the starting point for conveying. We need to define several variables to describe them: total number at a certain period, working time and input number per time. We can get the input of raw material flow is :

$$q = \frac{Q}{t}$$

Where q is input number per time, Q is the total number, t is working time.

- Product in progress: They consist of all the parts present on the line that have undergo the whole process which are necessary for work piece manufacturing. The transfer of the work piece can track the movement trajectory of the object, from the beginning of the production line processing, which steps to the final product molding. Only when the processing order of the objects can be clarified, can the processing information of each sub-production line be collected to prepare for subsequent model layer analysis.

$$\varsigma_i = \frac{q_i}{q}$$

Where ς_i is each device efficiency, q_i is each device processing number.

- Final products: All the materials stocked and are ready to be sold or delivered and we need to make it clearly the whole efficiency of production depends on the final products, or to say, the ratio between final products and raw materials.

$$\varsigma = \frac{q_f}{q}$$

where q_f is the final products number at a certain period, which is the function of several data. ς is the final production efficiency.

- Energy consumption: In the process of production and processing, energy is a necessary condition to drive the normal operation of the entire production line. In our case, in a broad sense we need to use two main types of energy, one is diesel and the other is electricity. Specifically, the transport vehicle needs to transport raw materials to the starting point of production and processing and transport the final product out of the workshop. Diesel is the energy required by the transport vehicle. The production and processing equipment needs power consumption to maintain normal operation. For each forklift, supposing its capacity is q_{fl} and fuel consumption is ζ , we can calculate the number of scrapers what we need which has a relationship with the mass flow of input q .

$$n = \frac{q \cdot T}{q_{fl}}$$

where T is the time for finishing one loading and unloading operation, n is the number of forklifts needed which we need to notice the real number should be $[n]^*$.

We can calculate the diesel mass flow what we need:

$$M_{diesel} = [n]^* \cdot \zeta$$

where the mass flow could be united as liter per hour which is same as fuel consumption's unit.

In addition to diesel calculations, there are calculations of electrical energy. Considering that each devices in the line would use electricity. Combined with the nameplate parameters of other processing equipment, the total electrical energy E_{total} can be calculated.

$$E_{total} = \sum_{i}^{n} E_i$$

Where E_{total} is all the energy consumed, E_i is the rated power for each device.

3.4 The variables model layer

Based on the material flow layer, using the technology of sensors to measure the information which are needed to acquire the value of different variables at this layer, and with the information of production efficiency from the last scheme, it can be used to calculate the relative KPIS.

Variables and KPIS once got would be transferred to central-processor to monitor the whole system at any time. All these information could guide operators to optimize the entire system and take corrective actions.

At this layer, production efficiency and variables data from sensors would be the input and within the help of central-processor which contain KPIS calculation formulas, different kinds of KPIS are got and regard as the output information.

Manufacturing device as the fundamental unit of the manufacturing process for a manufacturing company can directly affect the the manufacturing level. It is necessary to use some kinds of variables of a device to evaluate the performance of the device and whole system, ISO 22400 could offer related information.

The ISO 22400 standard “Automation systems and integration —Key Performance Indicators for manufacturing operations management”, provides an overview of the concepts. Based on the standard ISO 22400, we use several senors to collect information and calculate the different values of variables and with the information of production efficiency from the last scheme, we can calculate the relative Key Performance Indicators.

According to the ISO 22400 standard, we will choose 4 different aspects to set indicators to analyze our production system, which are: time variable, logistical variable, quality variable, and energy variable.

3.4.1 Variables in ISO standard

The first variable we need to discuss is **Time variable**. The time parameters are used to measure most time-related variables, from the transportation of raw materials to the finished product through each processing machine, machine stop or maintenance, etc., these need to consider time parameters.

- Actual unit setup time (AUST): the actual time consumed for the preparation of an order at a device.
- Actual unit processing time (AUPT): the time spent by equipment in effective operations which contains actual working time and setup time.
- Actual unit busy time (AUBT): the time the equipment is occupied, that is, the time in the processing cycle.
- Actual order execution time (AOET): the time from the start of the order until the time of the completion of the order. It is the total processing time, and the time it takes up includes the entire processing process.
- Actual personnel attendance time (APAT): the time for a single device to be performed by the operator, but the legal labor time should be measured according to labor time.
- Actual personal work time (APWT): the actual personnel work time shall be the time that a worker needs for the execution of a production order.
- Actual production time (APT): the actual time from a qualified finished product to the completion of the product . It includes only the value-adding functions.
- Actual queuing time (AQT): the actual queuing time shall be the actual time in which the material is either in transport or progressing through a manufacturing process, i.e. the material is waiting for the process to begin.
- Actual unit down time (ADOT): the time spent during regular machine overhauls or machining when the work unit is not processing although it is available.
- Actual unit delay time (ADET): the time for malfunction-caused interruptions, minor stoppages, and other unplanned time intervals that lead to unwanted extension of the order processing time.

- Planned run time per item (PRI): the planned estimated time between actual production is a time indicator that can be dynamically adjusted based on subsequent evaluations.
- Actual transport time (ATT): time required for transport between work units.
- Planned order execution time (POET): estimated time based on order quantity .
- Planned operation time (POT): scheduled time in which a work unit can be used.
- Planned unit setup time (PUST): the planned time for the setup of a work unit for an order.
- Planned busy time (PBT): the planned busy time shall be the planned operation time minus the planned downtime.
- Time to repair (TTR): the actual time during which a device is unavailable due to a failure.
- Time to failure (TTF): the time between failures minus the time to repair.
- Time between failures (TBF): the actual unit busy time (AUBT) between two consecutive failures of a work unit including setup time, production time and repair time related to the orders being processed and without delay times.
- Corrective maintenance time (CMT): the part of the maintenance time during which corrective maintenance is performed on a device, including technical delays and logistic delays inherent in corrective maintenance.
- Preventive maintenance time (PMT): the preventive maintenance time is the part of the maintenance time during which preventive maintenance is performed on a device, including technical delays and logistic delays inherent in preventive maintenance.
- Failure event count (FE): count over a specified time interval during which a work unit is unavailable due to a failure.

Logistic variables in the production process are used to measure raw material procurement, material handling in the production process, in-plant logistics, and logistics or sales logistics in the distribution process.

- Planned order quantity (POQ): the planned order quantity is the planned quantity of products for a production order.

- Scrap quantity (SQ): the scrap quantity is the produced quantity that did not meet requirements and either to be scrapped of recycled.
- Planned scrap quantity (PSQ): The planned scrap quantity shall be the amount of process-related scrap that is expected when manufacturing the product.
- Good quantity (GQ): the good quantity is the produced quantity that meets quality requirement.
- Integrated good quantity (IGQ): the integrated good quantity is the summed product count or quantity resulting from a multi-product process used in KPI calculations instead of GQ.
- Rework quantity (RQ): the rework quantity is the quantity that fails to meet the quality requirement, but these requirements can be met by subsequent work.
- Produced quantity (PQ): the produced quantity is that a device has produced in relation to a production order.
- Raw materials (RM): the raw materials are that are changed into finished goods through the production.
- Raw materials inventory (RMI): the raw materials inventory is the inventory of materials that are changed into intermediates or finished goods through production.
- Finished goods inventory (FGI): the finished goods inventory is the amount of acceptable quantity which can be delivered.
- Production loss (PL): the production loss shall be the quantity lost during production, calculated as output minus input.
- Consumable inventory (CI): the consumable inventory is the material which is transformed in quantity or quality during the production process and which is no longer available for use in production operations.
- Consumed material (CM): the consumed material shall be the summed quantity of materials consumed by a process.
- Storage and transportation loss (STL): the storage and transportation loss are the quantity lost during storage and transportation.

- Equipment production capacity (EPC): equipment production capacity is the maximum production quantity of production equipment.
- Other loss (OL):quantity lost due to extraordinary incidents, e.g. natural disasters.

Quality variable is using statistical means to analyze or sample to check whether the processing level of the production line meets the standard. In general, we introduce a normal distribution model to measure the qualification rate of the entire production process.

- Arithmetic average (x_{ave}): in the whole series of several measurements about the processed product, it is clearly that the group number of quality $x_1, x_2 \ldots x_n$ is independent based on repetition conditions. The average value of these measures is the arithmetic average value.
- Estimated deviation ($\hat{\sigma}$): it is calculated by the average value of the standard deviation from a sequence of samples with constant random inspection size, multiplied by a confidence factor depending on the random inspection size of the standard deviations.
- Average of average values ($x_{ave,ave}$): it is calculated from the average of single sample average values x_{ave} .
- Standard deviation (σ): standard deviation is defined as the square root of the arithmetic mean of the squared deviation of the standard value of each unit from its mean. It reflects the degree of dispersion among individuals within the group.

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(x_i - r)^2}$$

- Variance (σ^2): the variance is a measure which describes how strongly a measured variable strews. It is calculated as the distances of the measured values from the average value are squared, summed up and divided by the number of measured values.

- Good part (GP): a good part is the count of individual identifiable parts, e.g. serialization, which meets the quality requirements.
- Inspected part (IP): an inspected part is the count of individual identifiable parts, e.g. by serialization, which was tested against the quality requirements.
- Upper specification limit (USL): an upper specification limit is a value below which performance of a product or process is acceptable. It represents the maximum acceptable value of a variable.
- Lower specification limit (LSL): a lower specification limit is a value above which performance of a product or process is acceptable. It represents the minimum acceptable value of variable.

The **energy variable**, as another factor in the measurement of material flow models, will also be used as a direct factor to analyze and measure the entire production system.

- Actual direct energy consumption (ADEC): the actual direct energy consumption is the measured direct energy consumption per device and during actual unit busy time.
- Planned direct energy consumption per item (PDEI): the planned direct energy consumption is the planned energy consumption in average for producing one product item.
- Time period (TP): the time period is the time during which device is in a specific state which means each new starting of a new time period.

3.4.2 Key performance indicators

Key performance indicator (KPI) is an objective quantitative management indicator that measures the performance of a process by setting, sampling, calculating, and analyzing key parameters of the input and output ends of an organization's internal processes. A tool that decomposes strategic goals into actionable work goals is the foundation of enterprise performance management. Establishing a clear and feasible KPI system is the key to good performance management.

The main goal of using key performance indicators is the integration of the organizational structure of the enterprise, with the focus on improving the efficiency of the enterprise, streamlining unnecessary institutions, unnecessary processes, and unnecessary systems.

Key performance indicators establish key performance indicators, not goals. Therefore, the setting of key performance indicators are not as good as possible, but it is necessary to grasp the fundamentals of performance characteristics and set KPI assessment indicators scientifically.

Key performance indicators emphasize indicators that play a key role in corporate performance, rather than all indicators related to business management. It actually provides a management idea: as performance management, we should seize key performance indicators for performance management, and use key performance indicators to direct employee behavior to the organization's goal direction.

It is known that production process of an enterprise is a process in which laborers use labor tools to change the object of labor. Among the three basic elements of enterprise production (labor force, labor information, labor object), labor force is the most important factor. Correct statistics, analysis, and prediction of labor productivity indicators will help enterprises organize production in an orderly manner, fully develop, and make reasonable use of it. Human resources are important. The advantage of this method is that the standards are clear and easy to evaluate. Its disadvantages are that it is difficult to set standards for simple work; it lacks a certain amount of quantification; performance indicators are only some key indicators. For other contents, there is a lack of evaluation and proper attention should be paid.

There is an important SMART principle for determining key performance indicators. **SMART** is an acronym for 5 English words:

- **S** stands for Specific, which means that the performance appraisal should focus on specific work indicators, and cannot be general.
- **M** stands for Measurable, which means that performance indicators are quantitative or behavioral, and data or information to verify that these performance indicators are available.
- **A** stands for Attainable, which means that performance indicators can be achieved with effort, and avoid setting too high or too low goals.
- **R** stands for Relevant, which means that the setting of annual business goals must be closely related to the responsibilities of the budget responsible unit. It is the result of repeated analysis, research, and negotiation by the budget management department, budget execution department, and company management. With their mutual recognition and commitment.
- **T** stands for Time-based, focusing on the specific deadline for completing performance indicators.

Based on the ISO 22400, we can clarify the key performance indicators into three different groups, which are production, quality and maintenance.

Production KPI can be defined which are based on production line and production equipment:

- Availability (A): is a ratio that shows the relation between the actual production time (APT) and the planned busy time (PBT) for a work unit.

$$A = \frac{APT}{PBT} \cdot 100\%$$

- Effectiveness (E): the relationship between the planned target cycle and the actual cycle expressed as the planned run time per item (PRI) multiplied by the produced quantity (PQ) divided by the actual production time (APT)

$$E = \frac{PRI * PQ}{APT}$$

- Overall equipment effectiveness index (OEE): availability (A) of a work unit, the effectiveness (E) of the work unit, and the quality ratio (QR) KPIS integrated in a single indicator.

$$OEE = A * E * QR$$

- Net equipment effectiveness index (NEE): index combines the ratio between actual unit processing time (AUPT) and planned busy time (PBT), the effectiveness KPI and the quality ratio KPI into a single indicator.

$$NEE = \frac{AUPT \cdot E \cdot QR}{PBT}$$

- Allocation Efficiency (AE): the ratio between the actual allocation time of a work unit expressed as the actual unit busy time (AUBT) and the planned time for allocating the work unit expressed as the planned unit busy time (PBT).

$$AE = \frac{AUBT}{PBT} \cdot 100\%$$

- Worker efficiency (WE): it considers the relationship between the actual personnel work time (APWT) related to production orders and the actual personnel attendance time (APAT) of the employee.

$$WE = \frac{APWT}{APAT} \cdot 100\%$$

- Allocation ratio (AR): the relationship of the complete actual busy time over all work units (AUBT) involved in a production order to the actual order execution time of a production order (AOET).

$$AR = \frac{AUBT}{AOET} \cdot 100\%$$

- Critical machine capability index (CMCI): it is the relationship between the dispersion of a process and the upper or lower specification limit (USL, LSL) and the average value (x_{ave}):

$$CMCI = Min\left[(USL - x_{ave})/(3\sigma), (x_{ave} - LSL)/(3\sigma)\right]$$

- Critical process capability index (CPCI): the relationship between the dispersion of a process and the upper or lower specification limit (USL, LSL) and its average of averages . The method compares the range between the upper or lower specification limit and its averages and the 3σ process dispersion.

$$CPCI = Min\left[(USL - x_{ave,ave})/(3\sigma),(x_{ave,ave} - LSL)/(3\sigma)\right]$$

- Equipment load ratio (ELR): the equipment loss ratio considers the produced quantity (PQ) in relation to the equipment production capacity (EPC).

$$ELR = \frac{PQ}{EPC}$$

- Machine capability index (MCI): the relationship between the dispersion of a process and the specification limits. The method compares the range between the specification limits (USL, LSL) and the 6σ dispersion of a series of measurements for a specific characteristic.

$$MCI = \frac{(USL - LSL)}{6\sigma}$$

- Process capability index (PCI): the relationship between the dispersion of a process and the specification limits. The method compares the range between the specification limits (USL, LSL) and the $6\hat{\sigma}$ process dispersion for a specific characteristic.

$$PCI = \frac{(USL - LSL)}{6\hat{\sigma}}$$

- Production process ratio (PRR): the relationship between the actual production time (APT) over all work units and work centers involved in a production order and the whole throughput time of a production order which is the actual order execution time (AOET).

$$PRR = \frac{\sum APT}{AOET} * 100\%$$

Sum of APT of all work units and work centers involved in a production order.

- Setup ratio (SR): the ratio of actual unit setup time (AUST) to actual unit processing time (AUPT). It specifies the percentage time used for setup compared to the actual time used for processing.

$$SR = \frac{AUST}{AUPT} * 100\%$$

- Technical efficiency (TE): the relationship between the actual production time

(APT) and the sum of the actual production time (APT) and the actual unit delay time (ADET) which includes the delays and malfunction-caused interruptions.

$$TE = \frac{APT}{(APT + ADET)} * 100\%$$

- Throughput rate (TR): it in terms of produced quantity of an order (PQ) and the actual execution time of an order (AOET).

$$TR = \frac{PQ}{AOET} * 100\%$$

- Utilization efficiency (UE): the productivity of a machine, measured by the ratio between the AUPT, AUST and the AUBT, this indicator is inversely related to the setting duration and the delay duration:

$$UE = \frac{(AUPT - AUST)}{AUBT} * 100\%$$

Introducing the **Quality KPI** after introducing the Production KPI, which is a series of index parameters used to measure the quality of the product or processing system.

- Actual to planned scrap ratio (APSR): it calculated as the scrap quantity (SQ) divided by the planned scrap quantity (PSQ) indicated how much scrap was actually produced compared with the expected (planned) value.

$$APSR = \frac{SQ}{PSQ} * 100\%$$

- Finished product ratio (FPR): it indicates the percentage of good product to the initial material:

$$FPR = \frac{GQ}{CM} * 100\%$$

- First pass yield (FPY): it designates the percentage of products, which full fill the quality requirements in the first process run without reworks (good parts). It is expressed as the ratio between good parts (GP) and inspected parts (IP).

$$FPY = \frac{GP}{IP} * 100\%$$

- Inventory turns (IT): it is specified as the ratio of the throughput (TH) to average inventory. It is commonly used to measure the efficiency of inventory, and represents the average number of times the inventory stock is replenished or turned over

$$IT = \frac{TH}{Aveage, inventory} * 100\%$$

- Integrated goods ratio (IGR): the relationship of the produced quantity of integrated goods (IGQ) to the consumed material (CM).

$$IGR = \frac{IGQ}{CM} * 100\%$$

- Production loss ratio (PLR): the relationship of quantity lost during production (PL) to the consumed material (QM).

$$PLR = \frac{PL}{CM} * 100\%$$

- Quality ratio (QR): the relationship between the good quantity (GQ) and the produced quantity (PQ).

$$QR = \frac{GQ}{PQ} * 100\%$$

- Rework ratio (RR): the relationship between rework quantity (RQ) and produced quantity (PQ)

$$RR = \frac{RQ}{PQ} * 100\%$$

- Scrap ratio (SRA): the relationship between scrap quantity (SQ) and produced quantity (PQ).

$$SRA = \frac{SQ}{PQ} * 100\%$$

- Storage and transport loss ratio (STLR): it indicates the percentage of the loss quantity during the storage and transport period (STL) respect the consumed materials(CM):

$$STLR = \frac{STL}{CM} * 100\%$$

- Quality purchased ratio (QPR): after the rework period the good quality products percentage of the whole product quantity:

$$QBR = \frac{(GQ + RQ)}{PQ} * 100\%$$

- Other loss ratio (OLR): the relationship of the quantity of loss not related to production, storage or transportation (OL) to the consumed material (CM).

$$OLR = \frac{OL}{CM} * 100\%$$

Last we introduce the concept of **Maintenance KPI** , which can be used to show the repair and process of the production system.

- Corrective maintenance ratio (CMR): it considers the corrective maintenance time (CMT) in relation to the total maintenance expressed as the sum of corrective maintenance time (CMT) and planned maintenance time (PMT):

$$CMR = \frac{CMT}{(CMT + PMT)} * 100\%$$

- Direct energy consumption effectiveness (DECE): it represents the relation of the planned direct energy consumption per item (PDEI) multiplied by the produced quantity (PQ) to the actual direct energy consumption (ADEC).

$$DECE = \frac{PDEI * PQ}{ADEC} * 100\%$$

- Direct net energy consumption effectiveness (DNECE): it represents the relation of the planned direct energy consumption per item (PDEI) multiplied by the good quantity (GQ) to the actual direct energy consumption (ADEC).Only the produced good quantity of an order during the measurement period is considered.

$$DNECE = \frac{PDEI * GQ}{ADEC} * 100\%$$

- Direct energy efficiency (DEE): it represents the direct energy consumption (ADEC) per product item of the produced quantity (PQ). Using this KPI the produced quantity during the measurement period is considered.

$$DEE = \frac{ADEC}{PQ} * 100\%$$

- Direct net energy efficiency (DNEE): it shows the measured direct energy consumption (ADEC) per product item of the good quantity (GQ). With this KPI only the good quantity of an order during the measurement period is considered. This KPI is used in applications where energy is used for production.

$$DNEE = \frac{ADEC}{GQ} * 100\%$$

- Mean operating time between failures(MTBF): the mean operation time between failures is calculated as the mean of all time between failure measures (TBF) for a work unit for all failure instances (FE).

$$MTTF = \frac{\sum_{i=1}^{FE} TBF_i}{FE + 1}$$

- Mean time to failure (MTTF): it is calculated as the mean of all time to failure measures (TTF) for a work unit for all failure instances (FE).

$$MTTF = \frac{\sum_{i=1}^{FE} TTF_i}{FE + 1}$$

- Mean time to repair (MTTR): it is the average time that an item required to restore a failed component in a work unit. The mean time to repair is calculated as the mean of all time to repair measures (TTR) for a work unit for all failure events (FE).

$$MTTR = \frac{\sum_{i=1}^{FE} TTR_i}{FE + 1}$$

Using these information, we can have a more detailed understanding of the production line. As a tool for quantitative analysis, this information will play a great role in guiding the related management of the management in the role of input information.
Once we get all the information, we can also consider how to use this information to better analyze and optimize our system. In fact, we need to pay attention to a balance when evaluating a system. For example, we may sacrifice processing efficiency to improve the quality index, of course, it may be the opposite. Maybe at some stage of

processing, we will focus on different planes according to different tasks. Therefore, in order to better evaluate the entire system, we can assign weights to each indicator, so that we can better change our operations based on current requirements in production engineering.

$$K = \sum_{i=1}^{n} \alpha_i \cdot K_i$$

Basing on this equation, if we want to improve the production quality, we need to focus more on the KPIS related quality, then according the KPI formulas, we can find the variables related with such KPI and take corrective and predictive actions followed the new plans.

3.5 The management model layer

The management layer is mainly used to describe the production scheduling process.

A complete management system can be determined by production line KPIS, production requirements and inventory levels, dynamic management which includes suppliers management and markets management. Therefore, from the upstream supply of production and market order management, to the intermediate steps of production processing management and inventory management, and then to the final market feedback management. These sub-sections can be comprehensively analyzed to obtain the ideal management plan.

3.5.1 The main parts of management

Order management: Order management is a common management issue and is included in the company's customer order processing process. Due to the variety of ways customers place orders, the ever-changing order execution path, the constant changes in products and services, and the difficulty in coordinating invoices, these conditions make order management very complex. Order management can be used to identify potential customers and potential business opportunities for existing customers. Orders depend on demand, order management is processing orders. Order management can be said to be the core content of channel management, and it is the most obvious part of the information flow in supply chain management. The impact of the bullwhip effect is closely related to the ability of order management. The order information obtained by the company will be gradually enlarged, and then the bullwhip effect will be formed. The negative effect is that a large number of products will be accumulated in the circulation channel, causing greater risks.

Lean production visual management: How well the visual management of lean production is implemented largely reflects the level of lean production site management of an enterprise. Whether on-site or in the office, visual management of lean production is of great use. On the basis of understanding its main points and standards, the extensive use of lean production visual management will bring great benefits to the internal management of the enterprise. Therefore, in enterprise management, it emphasizes that various management states and management methods are clear and clear, reaching 'at a glance', so that it is easy to understand and easy to follow, so that employees can fully understand, accept, and execute various tasks autonomously, which will give lean production Management brings great benefits.

In the following, we will analyze the management method in accordance with the order of production and processing, from the procurement of raw materials to storage, to the production and processing, and finally the completion of product sales.

Purchasing management: Purchasing management refers to the management process of organizing, implementing and controlling the procurement business process. Business flowchart of the procurement subsystem. The business flowchart of the procurement subsystem uses the functions of purchase application, purchase order, purchase inspection, receipt and storage, purchase return, purchase invoice processing, and supplier management to comprehensively control the entire process of procurement logistics and capital flow Follow up and achieve the company's complete material supply management information. The system is combined with inventory management, payable management, general ledger management, and cash management, and can provide comprehensive sales information management for enterprises. It contains three functions:

- Guaranteed supply: The most important function of procurement management is to realize the supply of materials to the entire enterprise and ensure the normal production and life of the enterprise. Enterprise production requires raw materials, spare parts, machinery and equipment and tools. As soon as the production line starts, these things must be in place. Without any of them, the production line cannot start.
- Strategic Sourcing-Supply Chain Management: On the one hand, only by organizing suppliers and establishing a supply chain system can we form a friendly coordination and cooperation environment to ensure efficient and smooth procurement and supply work; on the other hand, only the procurement management department has the most opportunities for dealing with suppliers.

Only they are most likely to establish a friendly and coordinated supplier relationship through communication, coordination and procurement of supply operations with their suppliers through their patient and meticulous work. Supply chain operations and management.

- Information management: Only the procurement management department deals with the resource market every day. In addition to being a material input window for the enterprise and the resource market, it is also an information interface for the enterprise and the resource market. Therefore, in addition to ensuring the supply of materials and establishing friendly supplier relationships, procurement management must also grasp the resource market information at any time and feed it back to the management of the enterprise to provide timely and powerful support for the company's operating decisions.

Inventory management: It is an effective control on the activities of receiving, sending, and storing warehouse goods. The purpose is to ensure the integrity of the warehouse goods, ensure the normal operation of production and operation activities, and classify and record the activities of various goods on the basis of this comprehensive management. Inventory management asks to reduce the demand uncertainty to keep a safety stock level, and to separate different operations phases, which is the way to allow sourcing, making and delivery to work at different rates and allows the different phases to be asynchronous and absorbs upstream variations.

Customer relationship management: Customer relationship management system refers to the use of software, hardware, and network technologies to establish an information system for customers to collect, manage, analyze, and utilize customer information. With the management of customer data as the core, it records various interactions between the company and customers during marketing and sales processes, as well as the status of various related activities, provides various data models, and provides support for later analysis and decision-making. The customer relationship management system is based on advanced management ideas and uses advanced information technology to help enterprises ultimately achieve customer-oriented strategies.

3.5.2 Production scheduling and benefits

After receiving all the information, we need to do simulate in ERP system to decide the production scheduling. 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**.** Here are two general schemes about the whole production scheduling.

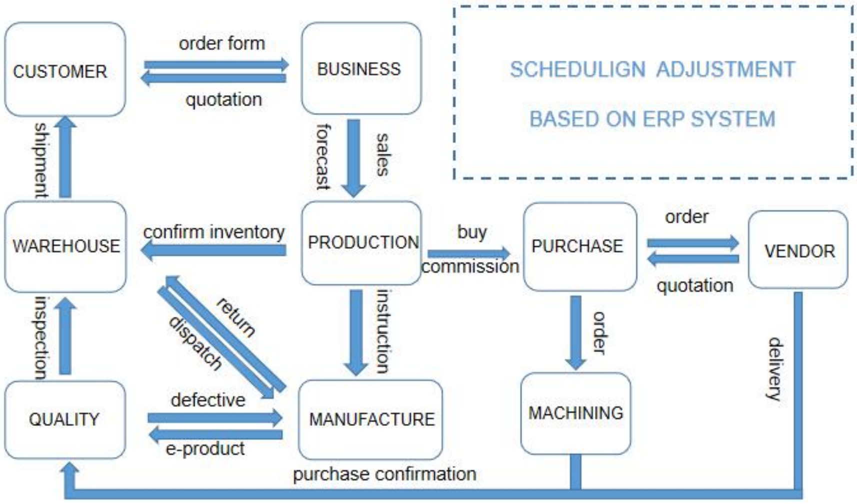


Figure 10 . Scheduling method

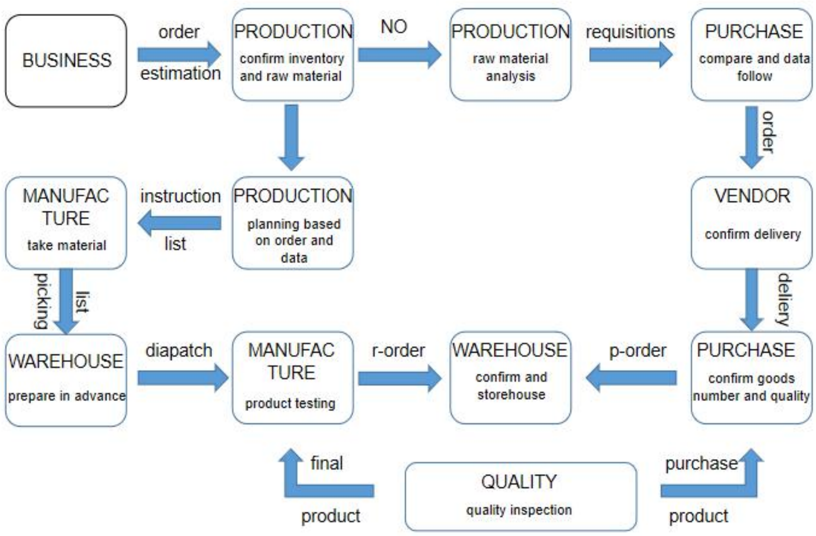


Figure 11 . Internal ERP scheme

The functions and benefits:

- Good scheduling adjustment makes reasonable use of production resources and capabilities, realizes the maximum use of production lines, equipment and people, arranges production schedules, formulates processing plans for each production line process, shortens production cycles, reduces work-in-process inventory, and guarantees timely delivery , Improve the contract performance rate, can help the manufacturing industry to schedule production intelligently, and greatly improve the efficiency of workshop scheduling.
- For the supply and demand requirements of raw materials, scheduling adjustment can calculate the shortage of materials in real time and accurately guide procurement, production and other activities. Accurate calculation of material analysis reduces the inventory backlog, improves the inventory turnover rate, avoids capital occupation and reasonable procurement to ensure that procurement can Protect the interests of the enterprise.
- Good scheduling adjustment can guide to add the material replacement function to the material management function. Material replacement can greatly reduce the risk of material shortage and achieve smooth production. It supports the selection of optimal materials, improves product quality, meets the needs of more customers, and reduces procurement costs. Promote corporate profits, maintain material replacement relationships once and apply multiple times, promote supplier competition, improve supplier service quality, and improve delivery accuracy.
- Significantly reduce the risk of processing procedures, better guarantee the smooth completion of products, timely respond to process changes caused by process changes, timely adjust processes with insufficient production capacity, request support from other departments or external factories, support the selection of new processes with lower costs, reduce The cost of the product, meeting the needs of customers with different quality requirements, and flexible selection of different processing technologies, have provided great help to production enterprises.

3.6 The financial model layer

This layer is used to describe the financial cost of the good product.

After describing the basic information, we will discuss the detailed cost components based on cost analysis.

3.6.1 Cost analysis

When we discussing the financial activity or to say making more profits, the most important thing we need to focus on is the **Cost**.

$$C = P_r - P_f$$

Where C stands for cost, P_r means price, P_f means profit.

In enterprise development strategy, cost control is extremely important. The main factor in competition is price, and the main factor in determining the price of a product is cost, because it is only possible to reduce the price of a product if the cost is reduced. The goal of cost management control must first be the entire process control, not only the production cost of the product, but the entire content of the product life cycle cost. Practice has proved that only when the product life cycle cost is effectively controlled, the cost Will be significantly reduced; and from the perspective of the whole society, only in this way can we truly achieve the goal of saving social resources.

The content of cost control is very extensive, but this does not mean that the power is used equally without any detail. Cost control should be planned and differentiated. Different industries and industries have different control priorities. Control content can generally be considered from the perspective of cost formation process and cost classification.

3.6.1.1 Cost analysis based on process

- Pre-production control: The content mainly includes: product design cost, processing technology cost, material procurement cost, production organization method, material quota and labor quota level, etc. This control is a per-control method. The actual cost has not yet occurred when the control activities are implemented, but it determines how the cost will occur. It basically determines the cost level of the product.

- Control during manufacturing: The manufacturing process is the main stage of actual cost formation. Most of the costs and expenses are incurred here, including the consumption of raw materials, labor, energy and power, various auxiliary materials, materials transportation costs between processes, workshops and other management departments.
- Control in circulation: Including product packaging, off-site transportation, advertising promotions, sales agency expenses and after-sales service costs. When the current emphasis is placed on strengthening the market management function of an enterprise, it is easy to take various promotional measures regardless of cost, and instead offset the increase in profits, so a quantitative analysis is also required.

3.6.1.2 Cost analysis based on cost

- Raw material cost control: In the manufacturing industry, the cost of raw materials accounts for a large proportion of the total cost and is the main object of cost control. The factors that affect the cost of raw materials are procurement, inventory costs, production consumption, recycling, etc., so control activities can be started from the three links of procurement, inventory management and consumption.
- Salary expense control: Wages account for a certain proportion of costs, and increasing wages is considered irreversible. Controlling the simultaneous growth of wages and benefits and reducing the proportion of wages in unit products is of great significance for reducing costs. The key to controlling wage costs is to improve labor productivity, which is related to factors such as labor quota, working hours consumption, working hours utilization rate, work efficiency, and worker attendance.

- Manufacturing cost control: There are many manufacturing expenses, including depreciation expenses, repair expenses, auxiliary production expenses, wages of workshop management staff, etc. Although it does not account for a large proportion of the cost, because it is not noticeable, waste is very common and cannot be ignored.
- Enterprise management fee control: Enterprise management fee refers to the various expenses incurred for the management and organization of production. There are many expenditure items, and it is also a content that cannot be ignored in cost control. All of the above are absolute control, that is, under the assumption of a fixed output, various costs can be controlled. In the actual system, the goal of controlling the cost of the unit finished product must be achieved.

3.6.2 Cost measure parameters analysis

Based on the above model, several kinds of cost are contributed to the final good product cost. Generally speaking, using cost calculation formulas and some related costs such as, capitalization cost, interest cost, energy / utility cost, machine maintenance cost, perishable tooling / supplies cost, insurance cost, property tax cost, indirect labor cost, energy consumption cost, raw material cost, final good production cost could be get.

Next we analyze some influencing factors and evaluation indicators based on several important components of cost.

3.6.2.1 Cost based on process

The first parameter is **Machine cost**, which refers to all costs incurred during the processing of the product other than the cost of raw materials. Including: wages of production workers, withdrawn employee welfare funds, fuel and power costs, workshop funds, business management fees, etc. Losses of waste, damage to raw materials, or overuse during processing are also part of the nature of processing costs.

- Machine hourly cost (MHC): energy consumed by the production line along the material circulation and processing path during the unit processing time.
- Net annual operating hours (NAOH): represent the time available per year to run the productions. It is derived from the gross hours per years adjusted for the inefficiencies of the process due to many factors such as machine downtime and resting time.

$$NAOH = T_G \cdot E_{oper}$$

Where T_G is gross annual operating hours, E_{oper} is operation efficiency.

- Gross Annual operating hours per year (GAOHY): it is function of hours per shift, shifts per day, production days per year.

  Hours per shift: It represents the transformation of the direct labor required to complete the required process. Conversion time is an independent variable, it only depends on the completion of labor.

  Shifts per day: Considering the complexity of the workload, the impact of the time and number of shifts on the work during the shift process will change this indicator.

  Production days per year: The value represents the total number of scheduled productions workdays per year and may vary significantly by country or region and it need to noticed holidays and resting days are also included.
- Operational efficiency (OE): refers to the ratio between the actual output and the maximum output of the process under a fixed input. It can reflect the degree to which the maximum output, the predetermined goal or the best operating service is achieved.
- Capitalization cost (CC): costs that are recorded as assets and then gradually converted to expenses in installments. Recognized as expenses in accordance with the "rational and systematic distribution principle". There is no causal relationship between long-term asset costs and income for the current period. They can benefit several accounting periods. Therefore, the beneficial relationship between it and income should be reasonably assumed, and then

systematically allocated to each accounting period according to certain rules and procedures.

$$CC = \frac{MIC - MRV}{T_G \cdot MUL \cdot E_{oper}}$$

Where MIC stands for machine and installation cost, MRV stands for machine residual value, MUL means machine useful life.

Machine and installation cost: it mainly includes the cost of purchasing new machines and a series of installation and use costs during use. The value is used in the calculation of all machine hourly capitalization rate and interest cost.

Machine residual value: is estimated cash recovery expected upon disposal of equipment at the end of its useful life stated as a percentage of the machine acquisition and installation cost. This value is subtracted from the machine acquisition and installation cost to determine the net machine investment cost.

Machine useful life: It can be estimated as the useful life. The capitalized cost is a gradually converted amount, so the length of the effective life determines the capitalized cost at the end.

- Interest cost (IC): if the fixed costs and installation costs of the production line are not paid with full funds, during the production line's operating cycle, based on the unpaid amount, production activities still need to be paid at a certain interest rate as delivery costs, which incurred interest costs. Once the validity period is over or the payment has been completed without payment, it does not need to be counted again.

$$IC = \frac{IC_{total}}{T_G \cdot MUL \cdot E_{oper}}$$

Where IC_{total} stands for total interest cost, which is the interest costs incurred in the total production cycle.

- Energy / Utility cost: according to the analysis in the foregoing, the production line must use energy from diesel and electrical energy and compressed air from transportation to operation. According to the working power on the machine nameplate, the energy consumption per unit time can be calculated. This cost is not divided by the use for time rate as it is assumed that these costs are variable.

$$EUC = W_e \cdot U_e$$

Where W_e stands for units of energy consumed per hour, U_e means the utility energy cost per hour.

Energy / Utility clarification: it is known during the process development, air gas, water loss, compressed air, electricity, auxiliary safety gas are the normal needed, all of that depends on technical data.

Since the carrier of energy use is processing equipment, energy use is, in a sense, a direct cost calculation. However, in the cost control stage, it is still necessary to pay attention that even if the processing equipment designed by different manufacturers has the same function, the use parameters may be different. Therefore, selecting a more efficient equipment is also an indirect cost control.

- Machine maintenance cost rate (MMCR): equipment maintenance costs refer to the costs incurred during a series of activities such as repair, overhaul, and maintenance during the effective life cycle of the machine.

$$MMCR = \frac{MMC_{total}}{T_G \cdot E_{oper}}$$

$$MMC_{total} = M_{p/h} \cdot N_{days}$$

Where $M_{p/h}$ means machine maintenance cost per year, this parameter times the working days N_{days} is equal to the final maintenance cost.

- Annual maintenance cost (AMC): this cost is mainly due to machine maintenance supplies, repair materials, etc. This allocation also includes the cost for maintenance labor, fringe and other costs related to the maintenance of the direct production machine and includes any special cleaning and handling that is above the norm.
- Floor space cost rate (FSCR): the total building area divided by the building area is the cost per square meter of building area, and the cost per square meter is the

ratio of the total cost of the building during the construction process to the building area. It should be noted that the building area here refers to the sum of the horizontal area of each floor of the building, not the planar area.

$$FSCR = \frac{FSC_{total} \cdot \kappa}{T_G \cdot E_{oper}}$$

Where $FSCR$ is the floor space cost rate, which is the function of floor space cost considered in gross year time. FSC_{total} means total machine footprint. κ is the factor of floor space,which is an estimated number of several parameters.

- Perishable tooling & supplies cost rate (PTSCR): the cost per hour for non-capital expense tooling, forming, machine supply items consumed in the direct production of the manufactured component and for other plant costs.

$$PTSCR = \frac{PTSC_{total}}{T_G \cdot E_{oper}}$$

- Insurance cost (INC): the objective existence of danger and random occurrence of danger in production and processing activities, on the other hand, are human factors, that is, moral hazard, which includes both professional ethics and social morality

$$INC = \frac{\mathrm{K} \cdot MIC}{T_G \cdot MUL \cdot E_{oper}}$$

Where K is the insurance cost factor.

- Property tax cost (PTC): property tax, also known as property tax, is mainly for real estate such as land and houses. It requires its tenants or owners to pay a certain amount of tax each year. The tax payable will increase as the market value of real estate increases. The total cost of insurance is based the location tax assessment factor and cost basis valuation of the machine and equipment.

$$PTC = \frac{\mathrm{X} \cdot MIC}{T_G \cdot E_{oper}}$$

Where X is the property tax cost factor.

Now we just end analyzing a series of cost components generated by the factory's real estate. Add these analysis indicators to get the machining cost. It should be noted that our units are all Euros / hour.

Second, according to the above definition of cost classification, we can know that **labor** and employee salary are also the main components of cost. Human labor, as an indispensable factor in industrial production activities, has an important proportion in the process of cost estimation. Below we divide labor into **direct labor** and **indirect labo**r for analysis and explanation.

- Direct labor: It refers to the expenses that can be directly included in a cost calculation object when the production expenses occur. Whether an expense is directly included in costs depends on whether the expense can be directly related to a cost calculation object and whether it is convenient to be directly included in the cost calculation object. Raw materials, spare parts and accessories, semi-finished products purchased, and piece-rate wages of production workers are usually direct costs.

$$DLTC = LCR + FDL$$

$$LCR = \frac{DLCR \cdot \Phi}{E_{oper}}$$

$$FDL = LCR \cdot \gamma$$

  Where $DLTC$ means direct labor total cost, which is measured by euro per hour. LCR is labor cost rate, which is measured by euro per hour. $DLCR$ is direct labor cost. Φ is a factor which means operations for shifting. FDL is fringes direct cost, which is measured by euro per hour. γ is fringe rate.

- Indirect labor: Indirect costs are a symmetry of direct costs. Production costs that cannot be easily targeted. The cost is related to a variety of products or services. Indirect costs need to be aggregated first, and then indirectly objectified according to certain standards. The salaries of personnel, depreciation of workshop buildings and machinery and equipment, rental costs, repair costs, consumption of machinery and materials, utilities, office expenses, are generally included as indirect costs. Loss of downtime is also generally included as indirect cost.

$$ILTC = LCR + FIL$$

$$LCR = \frac{DLCR \cdot \theta}{E_{oper}}$$

$$FIL = LCR \cdot \gamma$$

Where $ILTC$ is indirect labor total cost, which is measured by euro per hour. FIL is fringes on indirect labor, which is measured by euro per hour. θ is the factor that the indirect labor percentage rate.

3.6.2.2 Cost based on material

The cost based on material means the total fee of the buying materials. It can be single part or a complex part, assembled part or a system. It includes raw materials and purchased part. It should be noticed that, the cost of raw material is not just the price of the material itself, but include many aspects: base cost, transportation cost, material cost related to insurance, mark-ups of raw materials suppliers.

One thing needs to be emphasized is that material storage, inventory carrying costs and in-plant transportation are not included in raw material cost. These costs are charged on final product cost.

3.6.2.3 Cost based on Mark-up

Lastly, the analysis we need is some soft costs. In the later stage of the business chain, we need to consider a series of cost costs such as sales, operations, administration, and management. These soft costs and the two parts of our analysis above constitute the entire industrial production activity cost.This part consists of mainly two aspects, which are SG&A and scraps.

- SG&A: It is an initial concept used in accounting to refer to selling, general and administrative expenses, which is a major non-production costs presented in the income statement. Including a company's direct and indirect selling expenses, all general and administrative expenses. SG&A include direct and indirect parts, direct selling expenses include expenses related to direct sales, such as sales staff salaries, advertising expenses, related financial expenses. Indirect selling expenses It has nothing to do with direct sales, but there are certain indirect related costs, such as phone bills, interest and other communication costs, while general and administrative costs include management costs, non-sale staff salaries, rent, and utilities.

SG&A expenses consist of the combined costs of operating the company, which breaks down to:

- Selling: Cost of sales, which includes salaries, advertising expenses, cost of manufacturing, rent, and all expenses and taxes directly related to producing and selling product.
- General: General operating expenses and taxes that are directly related to the general operation of the company, but don't relate to the other two categories.
- Administration: Executive salaries and general support and all associated taxes related to the overall administration of the company.

Except SG&A, another cost needed to analyse is scraps:

- Scraps: It is part of the product or the material left over from the production of the product and has no economic value. Waste can be divided into waste related to a specific batch and waste related to all batches. For the waste related to a specific batch, its cost is traced to the WIP inventory account that generated the waste batch, and the waste cost related to all batches is included in the factory overhead. Both methods increase the cost of the accounts they affect. The cost of scrap is not recorded separately, but when the scrap is sold, the accountant will credit (deduct) the WIP inventory or indirect costs based on the sales revenue of the scrap.

Now, we have finished analyzing the parameters influencing the cost, or more precisely speaking, the profit. In general, we draw the final diagram and conclude the last relationships between cost and profit.

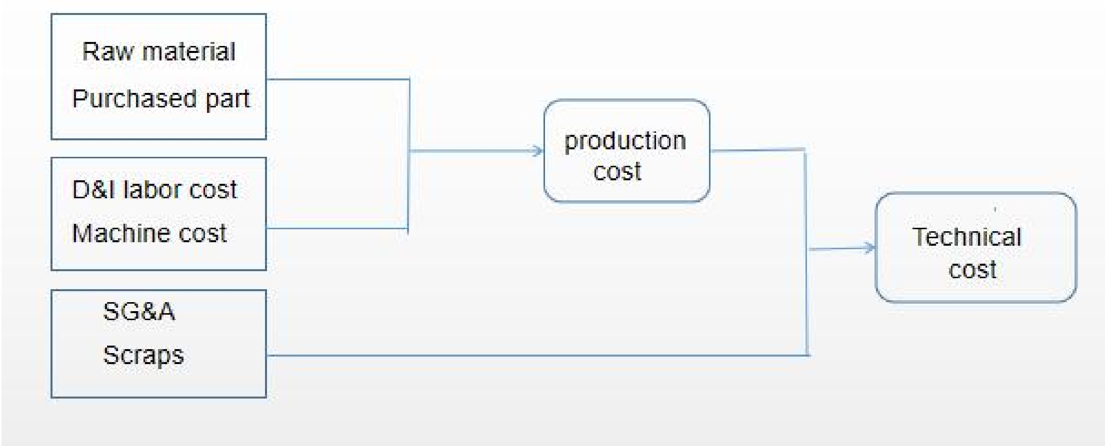


Figure 12. Financial&cost model

The final total profit could be calculated as the following equations:

$$T_p = P - P_{pc} - P_{sc} - P_{SG\&A}$$

Where: T_p means the total profit.

P means the price.

P_{pc} means the production cost, mainly related labor and machine cost.

P_{sc} means the scrap cost.

$P_{SG\&A}$ means the SG&A cost.

3.7 The social model layer

This layer is to evaluate the social effect of the production system.

Through gathering the required information from the previous schemes, such as energy consumption, contaminant emission, external influences of the production, then with a social effect evaluation formula, converts these inputs into the social effect index of the production system.

Now, we start with the most basic industrial contaminant and analyze the impact on the environment:

- Industrial waste water: Production waste water and cooling water refer to waste water and waste liquid produced in the industrial production process, which contains industrial production materials, intermediate products, by-products and pollutants generated during the production process that are lost with the water. Therefore, as a countermeasure, when processing and discharging industrial water, we must go through special precipitation and heavy ion filtration to ensure that the pollution of water resources is minimized. Here are some maximum concentration of element allow to contain in water[mg/L].

Hg	Alkylmercury	cadmium	chromium	arsenic	lead	nickel	beryllium
0.05	Null	0.1	1.5	0.5	1.0	1.0	0.005

silver	Benzo Pyrex	copper	zinc	manganese	formaldehyde
0.05	0.00003	0.5	2.0	2.0	1.0

Table 5. Waste water index

- Industrial waste air: Industrial waste gas refers to the general term for various pollutant-containing gases that are discharged into the air during the combustion of fuel and production processes in the factory area of the enterprise. Some substances enter the human body through the respiratory tract through different channels. There is also an accumulation effect, which will seriously endanger human health. Here are some index of industrial air upper level which allows to emission.[$\mu g / m^3$,one day]

PM10	PM 2.5	HCL	SO_2	NO_x
50	35	50	80	200

Table 6. Waste air index

- Energy audit: Energy auditing is an important way to improve economic and social benefits. Achieving economic, social, and environmental unity and improving the market competitiveness of energy-using units are the fundamental requirements and end-results of energy-using unit development. Energy audits are conducive to strengthening energy management and transforming energy-saving management to standardized and scientific. Energy audit is beneficial to promote the information of energy management and reduce the workload of energy management. We can analysis it depends on this equation:

$$E = \sum_{i=1}^{n} (E_i \cdot P_i)$$

Where E is comprehensive energy consumption of the enterprise.

n is the types of energy consumed by companies.

E_i is physical quantity of the i energy consumed by the enterprise.

P_i is standard i coal coefficient.

Energy management is an important and complex task that requires a lot o human, material and financial resources. The energy audit can accurately reflect the energy measurement statistics of the energy consuming unit, ensure that the energy consuming unit takes purposeful measures, use the computer to develop an energy management system suitable for the enterprise, reduce manual management workload, and reduce management costs.

Social value, also called "market value", is a presentation of external influence of the production. Social value is the average value of the goods produced by a sector, and it is determined by the weighted average of the individual values of goods produced by various producers within the sector. In general, social value can be approximated as the individual value of the kind of goods produced under the average production conditions of a sector that constitute the vast majority of the sector's products. Therefore, whether the final products beneficial to society can be obtained through improved methods and clean,efficient manufacturing is the core of environmentally friendly processing and production.

So, if we want to improve the social effect, one efficient way is to use renewable energy like wind, solar and geothermal is also a way of reducing carbon footprint for a company. For companies, they can consider using clean natural energy such as solar and wind instead of burning coal. The transportation equipment such as forklifts can be considered to use electricity or hydrogen as fuel. For local government, they can add extra tax for those companies which are not meeting emission standard.

Chapter 4. Application and simulation to the real case

In the Chapter 3, we introduced the theoretical basis of the hierarchical model in detail. In this section, we will apply the hierarchical model to the production line of Marelli Company, and introduce in detail how to use the theory of the hierarchical model to analyze, arrange, and evaluate the efficiency of a production line.

4.1 2D model layer

From the information we get, the company need to produce 3 different A-pillar parts at the same time: part-A, part-B, part-C. They have different sizes, of which part-A is 35mm, part-B and part-C are 37mm. So we need to choose two kind of machines for processing and three isolated lines.

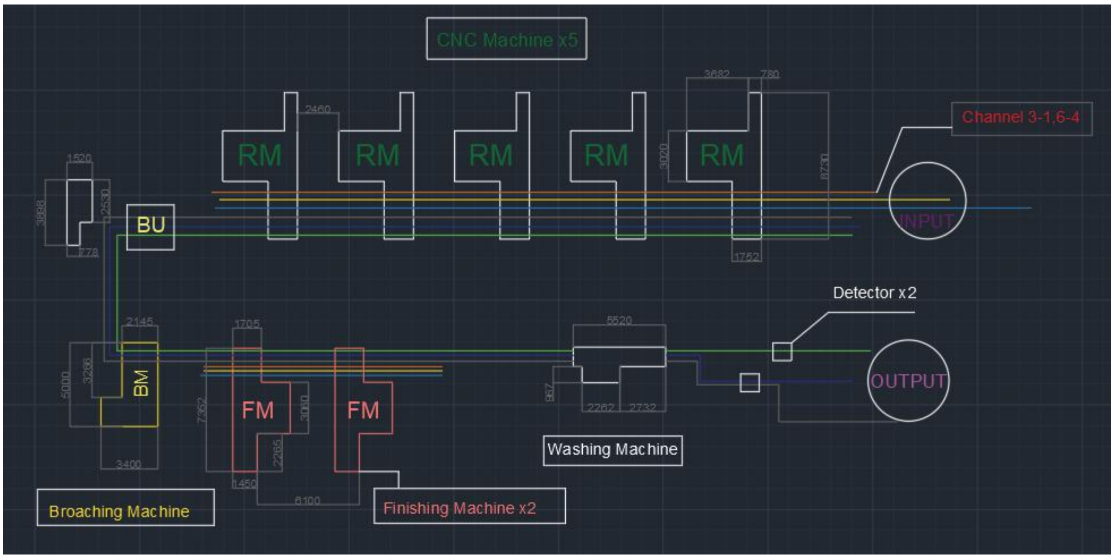


Figure 13. 2D model scheme

There are two design requirements:

- Deciding the lines depends on the processing procedures, which basically include roughing, broaching, fine grinding, washing, and size calibration. Therefore, in order to save the operating space and improve the operating efficiency as much as possible, we chose a U-series production line. We need to set the corresponding number of production lines in each processing unit according to the type of parts to be processed.

- Calculating the actual number and kinds of machining equipment. According to the data obtained and the type of mechanical processing equipment required, the production line is arranged under the dual constraints of the size of the factory floor and the size of the production line layout.

According to these two principles:

$$N_{\min} = \frac{D \cdot \sum t}{OT} = \frac{\sum t}{CT}$$

$$N_{real} = \frac{CT_{idl}}{CT \cdot \chi_{ct}}$$

Where CT_{idl} is the cycle idle time, χ_{ct} is the idle time percentage, N_{real} is the real number of workshops.

Basing on the processing requirements and the proportion of the types of parts to be processed, 5 roughing stations can be selected, of which 4 are used to process part-A and another is used for part-B and part-C.

According to the working mode of the workstation (Sliding shuttle), the tail end of the roughing work can be arranged in parallel with the starting of the broaching. The purpose of doing so is to save space and improve processing efficiency. Similarly, the broaching and surface finishing units are arranged in parallel. After the surface is washing, rinse and check directly.

4.2 3D model layer

According to the 3D model structure, we need to add height constraints on the basis of the 2D plane model. The height constraint must not only satisfy that there is no interference with the plant boundary, but also that there is sufficient space between adjacent equipment to facilitate workers' operation and equipment maintenance.

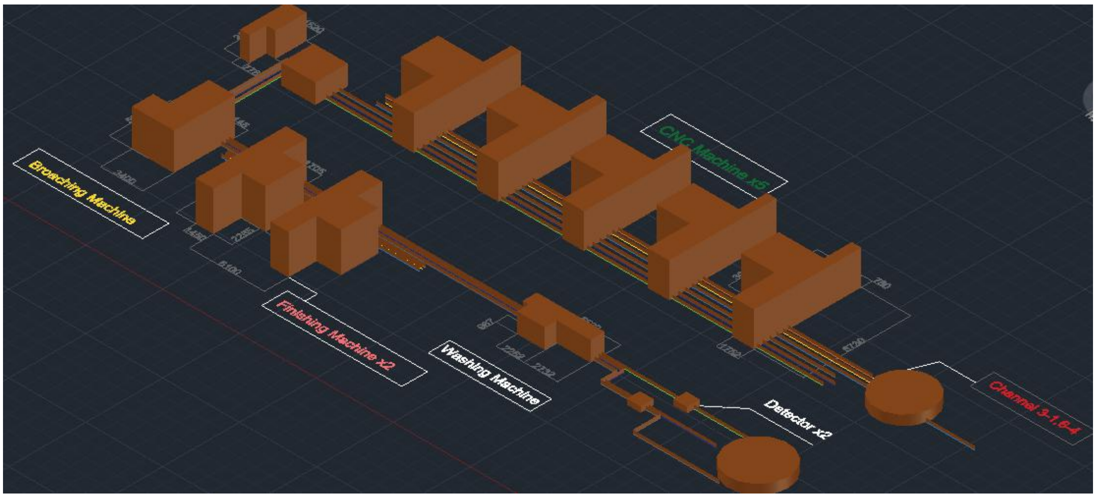


Figure 14. 3D model scheme

The above constraints can be called static constraints, but in the actual production process, some equipment operations are accompanied by dynamic constraints, such as robotic arms. This requires us to consider their operating margins in the three-dimensional layout process, so to avoid interference.

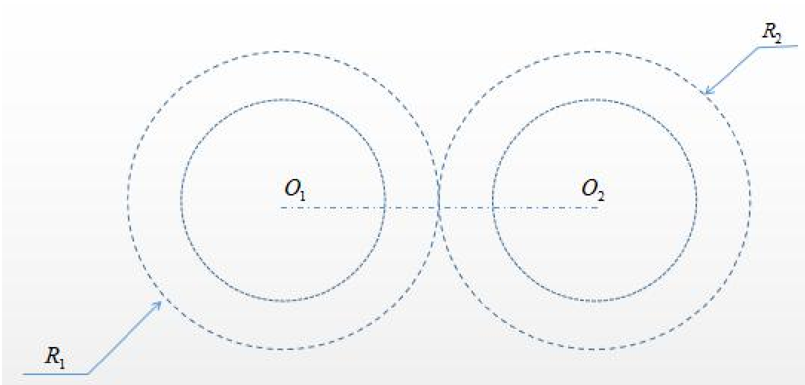


Figure 15. Dynamic dimension

We need to confirm $O_1O_2 \geq R_1 + R_2$ so as to avoid interference.

4.3 The flow model layer

First of all, our raw materials will be transported by the forklift to the beginning. At the beginning, there will be operators to converge and sort. They will put different types of raw materials on the corresponding conveyor belt. Now we take one of the production lines for analysis, such as the production line for part-A.

- Roughing machining: Each work station has 2 processing steps, OP1 and OP2. When the first part is counted into the initial station α , the processing equipment receives the input signal after the laser scanning, and the operating arm processes the work piece at the preparatory station and fills in the new one at the same time. Prepare the work piece for processing. When the first work piece finishes the first rough machining, it will be released on β and transfer to γ to enter the OP2 preparation area and be scanned by the laser. After the OP2 equipment receives the signal, the OP2 operation arm will grab the work piece at the preparation station γ for processing, and at the first preparatory station of OP1, there will be a third new work piece replenishment. Similarly, it will be scanned by laser and then processed. After the first work piece finish the OP_2 operation, it would be sent to the δ position and waiting for exit and at the same time, the work piece at γ position will start processing. Next, the work piece which is at β position would be sent to the γ position and another new work piece would enter the sliding shuttle and at α position. In conclusion, at each channel, after roughing,they would transfer to the match channel to the next process, For example, *partA* would be from channel 3 to channel 6. Here are the processing sequence with time.

T	α	OP_1	β	γ	OP_2	δ
1	$\alpha 1$					

2	$\alpha 2$	$OP_1 1$				
3		$OP_1 2$	$\beta 1$			
4	$\alpha 3$	$OP_1 2$		$\gamma 1$		
5		$OP_1 3$	$\beta 2$		$OP_2 1$	
6	$\alpha 4$	$OP_1 3$		$\gamma 2$	$OP_2 1$	
7		$OP_1 4$	$\beta 3$		$OP_2 2$	$\delta 1$
8	$\alpha 5$	$OP_1 4$		$\gamma 3$	$OP_2 2$	
9		$OP_1 5$	$\beta 4$		$OP_2 3$	$\delta 2$

Figure16.Processing sequence

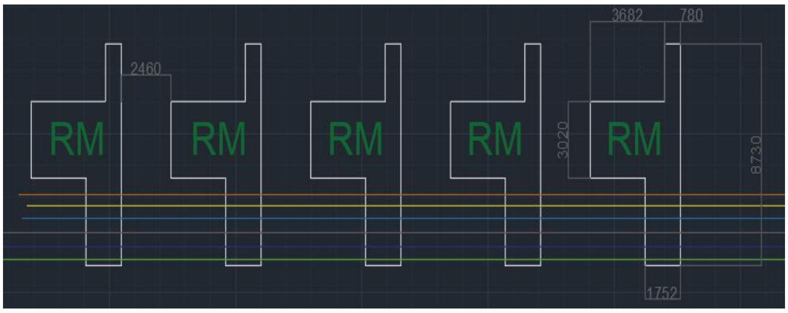


Figure17. Roughing progress

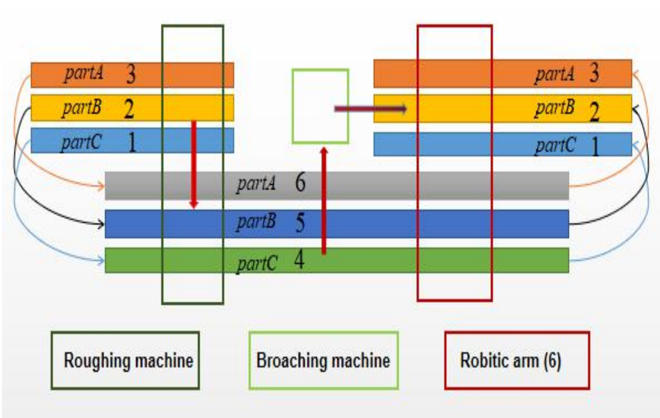
Notice: each parameter such as $\alpha 3$ means the third work piece is at the station α at the certain time.

In the course of rough machining, the machining efficiency will be calculated by the volume of the work piece material removed per minute, which is expressed by the metal removal rate per unit time. It is proportional to the cutting speed, feed amount and cutting depth. The above parameters are all in The parameters that can be set on the CNC machine according to different processing needs during processing. Metal cutting rate can be expressed as:

$$\eta = \frac{V_f \cdot a_r \cdot a_F}{1000 \cdot t}$$

Where V_f means cutting speed (mm/min), a_r means radial feed amount (mm), a_F means cutting depth (mm).

- Broaching: In this process, three different broaching machines and robotic arms will be used to complete the grasping and releasing of the parts. Each group of robotic arms will only grab the parts belonging to its production line. After processing in the broaching machine, it will be released back to the original processing channel by another corresponding mechanical arm. For example, $partB$ will transfer from channel 5 to channel 2 and the two other same.



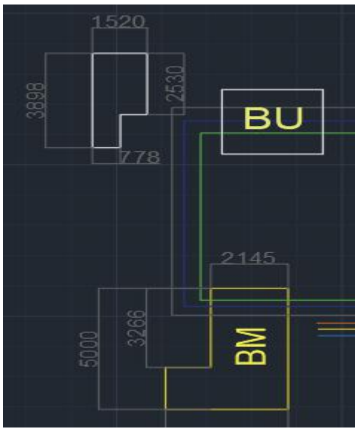
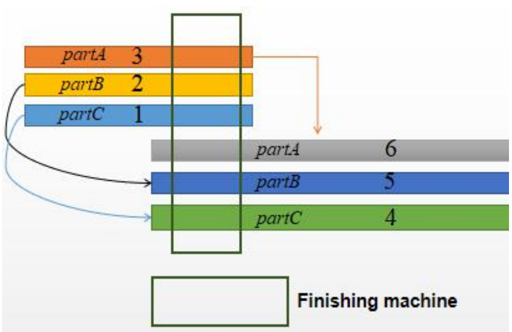


Figure18. Roughing and broaching

Notice: in our case, we need to have 3 broaching machines and 6 robotic arms for processing since each kind of work piece need to be broached isolated.

- Finishing : After the broaching, the part enters the next process, finishing. In this process, we set up two machines and two robotic arms. Considering the different processing sizes of the parts, part-A will use a separate robot arm for efficient operation.



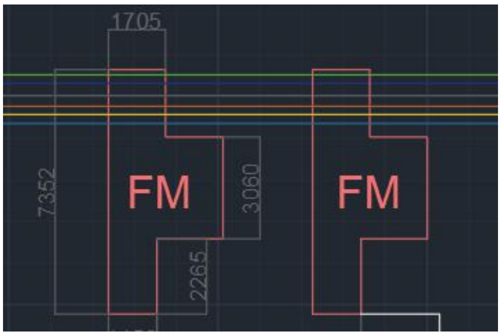


Figure 19. Finishing progress

Two finishing machines work at the same time, transporting the finished parts back to channel 4, channel 5, channel 6.

Notice: above the picture, the finishing machine is just a representative picture, it real contains the real finishing machine and conveyors which transport in and out the processing work piece.

When doing surface finishing, the processing efficiency is usually expressed as the size of the processing area per minute. Generally speaking, compared with rough machining, conventional machining is used because it has a higher metal removal rate, and finishing machining uses high-speed machining. It can achieve a high cutting speed and can cut more surface area to obtain a more ideal size.

- Washing: One workstation completes all washing-related processes, including pre-wash, washing, rinsing, dying.

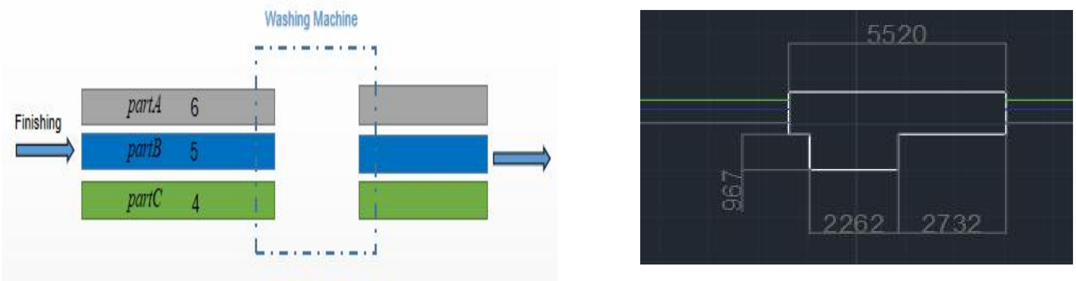


Figure 20. Washing process

- Dimensional geometric control and data recording

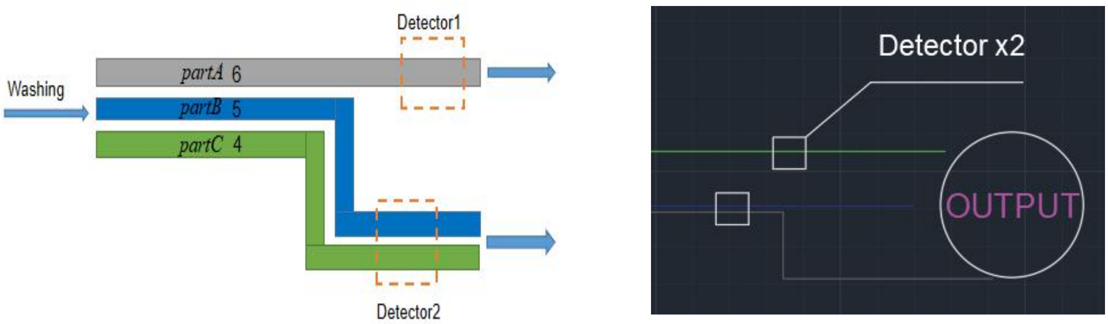


Figure 21. Dimensional control

It should be noted here that the washed parts will be tested for the size and accuracy of the tester. We thought that the parts we processed had two independent sizes, D35 and D37. Therefore, the detectors on different channels need to set different detection targets. If a defect is found, the operator can rework it for a second inspection, and if it still does not meet the standard, it is treated as defective.

- Loading and discharging: Once parts are considered good and they are packed at the end of the line and shipped out of the warehouse.

Except the material transportation, The normal operation of the production line will certainly help with the consumption and utilization of energy. Energy consumption is not only an important indicator to measure the efficiency of production, but also an important part of cost calculation. According to the following formula:

$$E_T = E_e + E_w + Q_d$$

From the equation, E_T is the total energy consumed, which contains electricity for all machines, water for washing machine, diesel for forklift. Depending on the nameplate on those machine, we can estimate and calculate the total consumption.

We introduced in detail how raw materials can be processed step by step from the input end to obtain the final product. The purpose of introducing these steps is to make better use of the theoretical knowledge of the hierarchical model to obtain the information we need, such as the amount of raw materials used, production efficiency, qualification rate, energy consumption, and operating time.

Here is the example, if we already know the amount of raw materials given to the production line in a specific time period, we can obtain the production efficiency of each processing unit according to the sensor, and finally get the processing efficiency of the entire production line. Through the final production efficiency, we can clearly know whether the production has achieved our expectations. By analyzing the processing efficiency or qualification rate of each sub-production line (roughing, broaching, finishing), we can clearly and directly find the place where the problem occurs when processing problems occur.

In the material flow layer, we will collect important information from the sensors to provide the basis for the input of the next layer.

4.4 The variables model layer

According to the definition of the variables layer, we need to collect and analyze some technical data according to the material flow layer. Based on these data, calculate the KPI under the ISO-22400 standard.

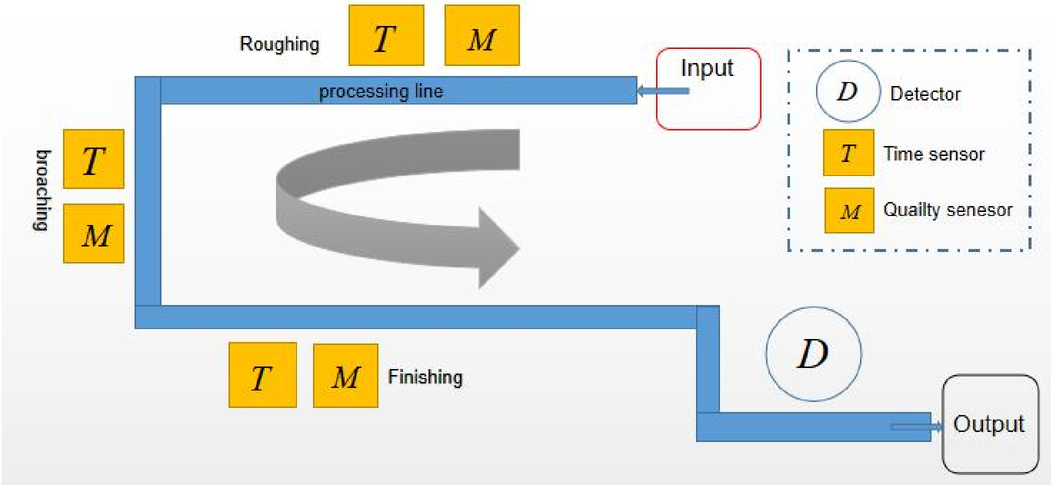


Figure 22. General processing scheme

From the beginning of the process, different types of sensors will read specific relevant information according to the settings when the material flows through each process. There are four types of important indicators for evaluating production systems, namely time variables, logical variables, quality variables and energy variables. After collecting these actual evaluation indicators and sent them to the simulation software, the entire production process is finally quantitatively evaluated by calculating the corresponding KPI.

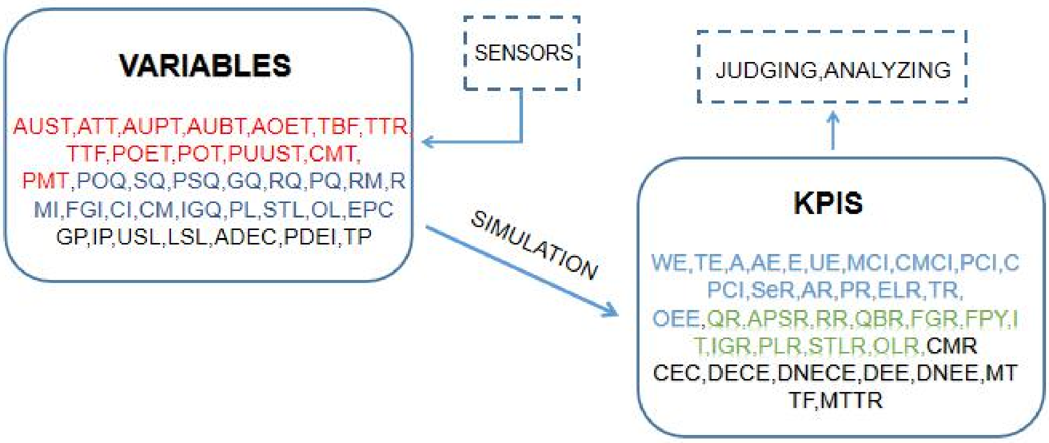


Figure 23. Variables and KPIS

When we do simulations on software, we can get the final KPIS value as soon as we input the related VARIABLES. There is a simple example for simulation:

If we want to know how much products could pass for the first time, we use the **first pass yield**, which is a key parameter to judge process accuracy, based on the knowledge of Chapter 3, we know the formula:

$$FPY = \frac{GP}{IP} \cdot 100\%$$

That formula represents percentage of products, which full fill the quality requirements in the first process run without reworks, It is expressed as the ratio between good parts (GP) and inspected parts (IP).

$$FPY \in [0,1]$$

It is clear that the higher the value of FPY, the higher the level of production and processing.

4.5 The management model layer

The above levels can be said to focus on the definition of a single production unit in a sense. However, the workshop and even the factory work in a composite environment, so if we want to maximize the message, we need to use the ERP system to do the overall analysis.

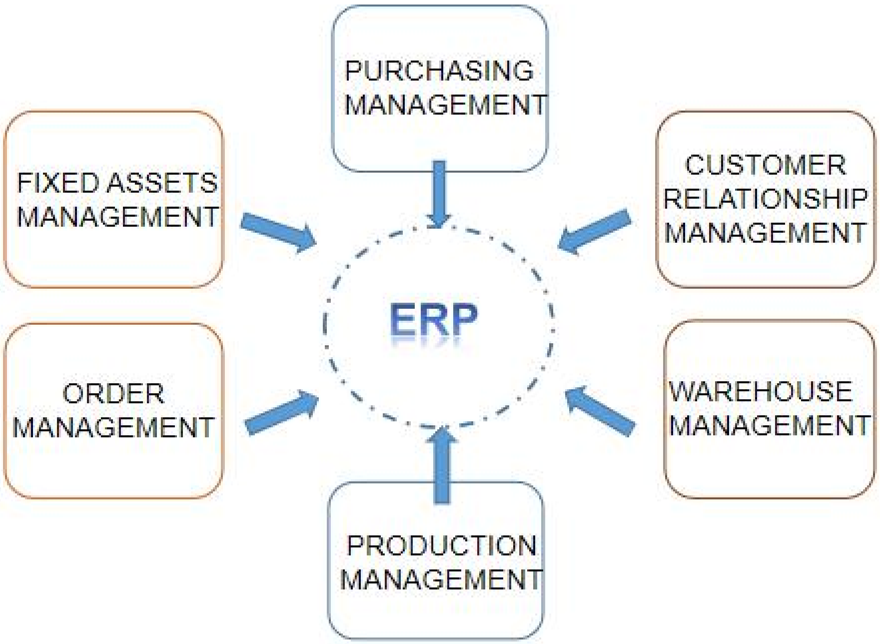


Figure 24. Management scheme

In our cases, we can analyse the management based on ERP system:

- It is necessary need to know the order quantity, and according to the order request time, we can flexibly adjust the production efficiency to meet the needs.
- Inventory management needs to be combined with market research in order to be able to respond to market changes, but it should be noted that the amount of inventory is also part of the cost, which will affect the turnover of funds.
- Purchasing management is a comprehensive judgment based on order volume, market demand estimation, etc. Blind purchasing will affect the flexibility of funds, and insufficient purchasing volume will lose market efficiency, so purchasing management is very important.
- Fixed asset management considers that if the production capacity is excessive, the production equipment can be sold or canceled, so that the production capacity and costs can be reasonably controlled.

4.6 The financial model layer

Based on the theoretical knowledge in Chapter 3, we can roughly divide the cost estimate into the following parts: Machine cost, which mainly contains maintenance cost, capitalization cost, energy cost, interest cost, perishable/supplies cost, insurance cost, property tax cost, Indirect&Direct labor cost, Raw materials cost, Scraps and SG&A cost.

In our cases, we will use cost calculation formulas to calculate the production cost:

- Net annual operating hours (T_{net}): This represents the effective working time in one year and it is measured by $hours\,(h)$.
- Machine maintenance cost (C_m): Any machine equipment needs maintenance during operation and it is measured by $euro/year$.
- Capitalization cost (C_c): As an asset, it is expected to bring future benefits to the business. It is measured by $euro/year$.
- Energy cost (C_e): This part is mainly electricity, taxes and fuel costs. Can be obtained from electricity meters, water meters, oil and gas bills. It is measured by $euro/year$.
- Interest cost (C_i): If it is borrowed, this part of the cost is based on the prevailing interest rate. It is measured by $euro/year$.
- Indirect labor cost (C_{in}): This part mainly includes the gross wages of workers, which is measured by $euro/month$.
- Raw material cost (C_r): It is measured by $euro/piece$.
- Production rate (η): It is measured by $piece/hour$.
- Scrap and SG&A cost (C_s): It is measured by $euro/year$.

Based on those data, we can calculate the production cost within the formula:

$$C_p = \frac{1}{\eta}\left[\frac{C_c + C_e + C_i + C_s + C_m}{T_{net}} + \frac{C_{in}}{154}\right] + C_r$$

Notice: “154” in the above formula means the total hours that work during one mouth, it is calculated by each day working 7 hours and 22 days within one month.

According to the data, we can find the final product cost, it is measured by $euro / piece$ .Based on the obtained cost, we can do market analysis and through analysis, we can improve some factors that have an adverse effect on cost, so as to optimize the cost structure and make the product more competitive in the market.

4.7 The social model layer

The social problem is rooted in its root cause, and it is still necessary to implement issues such as waste water, waste gas, and waste residue. In our case, we just give some advice to improve social effect:

- Industrial waste water: Use again without treatment or only after necessary treatment. Sometimes it is reused in this process, sometimes it is used by other processes. Use activated carbon to make necessary treatment in the plant to meet the city's requirements for water quality and then discharge it into urban sewage pipes or merged pipes. Dispose in the factory to make the water quality meet the requirements of draining water bodies or connecting to urban rainwater pipes or irrigated farmland.
- Industrial waste air: The exhaust gas treatment tower adopts a five-layer exhaust gas adsorption filtering and purification system. Adopt science and technology, such as the combination of low temperature plasma technology and UV photon purification, the combination of rotor concentration and high temperature plasma incineration technology.
- Industrial waste residue: In our production and processing, industrial waste is mostly in solid form. It is useful to increase particle size through chemical conditioning, heat treatment, freezing, irradiation or excoriation first to facilitate sludge filtration or compression; then concentrate the sludge to reduce volume, gravity concentration, air flotation concentration, centrifugal concentration, etc; Dehydration by vacuum filtration, pressure filtration, centrifuge, natural drying and other methods to obtain a mixture similar to waste residue and after comprehensive utilization, it can be used as agricultural compost, building materials, fermentation gas production, etc.

Of course, these processing are necessary at the later stage of the processing task. In the early stage of processing, we can also choose clean energy, new materials, and popularization of electrification to improve the social effect from the source.

Bibliography

- Ford, Henry and Crowther, Samuel. Production Life and Work. Kessinger Press, ISBN 0-7661-2771-4, (2003).
- Hirano, Hiroyuki and Furuya , Makuto. " JIT Is Flow : Practice and Principles of Lean Manufacturing". PCS, Inc, ISBN 0-9712436-1-1, (2006).
- ZHANG Y F, JIANG P Y, HUANG G. RFID-based smart kanbans for Just-In-Time manufacturing[J]. International Journal of Materials and Product Technology, 2008,33 (1-2): 170-184.
- Wagner T, Herrmann C, Thiede S. Industry 4.0 Impacts on Lean Production System [J]. Procedia Cirp, 2017, 63:125-131.
- A. M. Bonvik, C.E. Couch, S.B. Gershwin. A comparison of production-line control mechanisms [J]. International Journal of Production Research, 1997, 35(3):789-804.
- HUNGLIN WANG, HSU-PIN (BEN) WANG. Determining the number of kanbans: a step toward non-stock-production[J]. International Journal of Production Research, 1990, 28(11):2101-2115.
- CHE J G. Research on the improvement of production system with multiple varieties and small batches[D]. The University of TIAN JIN.2006-101(2):10-201.
- ZHOU L, ZHANG Z K, YANG D Q. Optimization Model for Assembly Line Balance[D]. Assembly Automation, 2015, 35(1): 137-142.
- Moodie C.L and Young H.H. Sequencing mixed assembly lines with genetic algorithms[J]. Computers and Industry Engineering, 2015, 30(4):1027-1036.
- YANG B Q, TONG M S. Mathematical Modeling of Equilibrium Scheduling of Automotive Assembly Equipment Operations. Electric drive automation, 2004,26(1):60-62.
- Ellis G. Production Product Development[M]. Project Management in Product Development.2016.
- LIU Y Y. FU. Production Management Science Based on Value Stream. The University of SU ZHOU. 2008,13(1):122-126.

- ISO 22400-1, 22400-2， Automation system and integration key performance indicators (KPIS) for manufacturing operations management.
- S.J. WANG, WANG H. LI Q. Optimal Models for a Multistage Supply Chain System Controlled under Just-in-time Philosophy[J]. European Journal of Operational Research, 2007-7.172(1):179-200.
- CHA L, XUE X J, YU J J, SONG L B. Solving U-shaped Assembly Line Equilibrium Problems Using Petri Nets[J]. Industrial Engineering, 2010,13(2):110-115.
- SONG M H, CAI Z F, ZHU L. Market Cost Analysis and Cost Balance Marketing[D]. Market and industrial production modernization, 2003,22(3):19-2.
- J.Driscoll, D.Thilakawardana. The definition of assembly line difficulty and evaluation of balance solution quality[J]. Robotics&balancing Computer Integrated Manufacturing. 2001,17:81-86.
- WANG M L, Simaria, Vilarinhom, Pedro. How to Effectively Implement Lean Logistics in Manufacturing. Industry Engineering, 2012-10(1):39-42.
- ZHAO W, Alex Teoh, Nils Boysen, SHI L M. Scheduling problem of mixed-flow assembly line in just-in-time production[J]. Journal of Management Science, 2008,3(4):23-28.
- P. Shahabudeen, G.D. Sivakumar. Algorithm for Design of the Single Stage Adaptive Kanban System[J]. Computer & Science engineering, 2008,5,54(4):800.