Bachelor thesis

Definition of optimal production and performance indicators for production control by the example of container manufacturing

carried out for the purpose of obtaining the academic degree of Bachelor programme Mechanical Engineering – Management under the direction of

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with the approval of the board of examiners.

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Vienna, June 2015

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Signature of the author
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Abstract

This thesis focuses on the study of production control, especially on one-item-production control in the case of tank production. The scope of this work is to research indicators to control production, deeply describe all of them and select the most suitable performance indicators for tank production.

This thesis is a step of a very big project whose main purpose is to establish a new generation of production and information system in this type of production. The performance indicators selected in this work will be used to design a new indicator system, and the generation of these indicators in the information system will be automate by a business intelligence system.
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1 Introduction

Production control is an essential issue for companies, since the introduction of production systems the main goal of companies is to produce in short time a lot of products of good quality with low costs to be able to work in huge markets. This goal can only be achieved controlling the production. Nowadays, being efficient and productive is getting even more important for companies due to high competition in markets. Companies are competing being more productive and efficient than others to get the trust of customers, and this fact has spurned the development of production control. Currently, a lot of new approaches and technologies have appeared to control production in an automatically and systematically way using information and knowledge about processes.

The problem that motivates this thesis is that the most part of these approaches are created to control mass production processes, standardized processes which continuously produce high quantities of the same product. Actually, that's because most of the production processes fulfil this characteristics, as this is the usual idea that everybody has about a production process. Nevertheless, some companies decide to work in smaller segments of market providing specific and customized products of high quality. In this case, standardized process are not useful, as they just produce the same product repetitively and have a very poor capacity to produce different products. Customized products are produced to order by customized processes, which are specially designed to provide to the product the characteristics that the customer requires. This idea can seem old-fashioned reminding the master craftsman creating his products in his studio, but nowadays the idea of product differentiation and also the need of specialized products just can be supplied by this kind of production known as one-item production or project production.

Thinking about this type of production many of the concepts defined to control mass production are not suitable for it. Therefore, this is the start point of this thesis and the main motivation, analyse the existing concepts defined to control mass production and find out which can also be suitable for project production. To accomplish this objective one case study will be used, the case of KRESTA industries.

KRESTA industries is a company which was founded as a contract manufacturer in 1986 by Franz Kreuzer. Nowadays, KRESTA industries is known as a complete-solutions supplier for plant engineering and construction. [1]

Currently, KRESTA industries is constituted for several branches working in different fields. In this case, the focus will be on the production of containers or tanks. KRESTA produces customized tanks to order and installs them. The main issue of this company is to produce tanks that exactly fulfil all the requirements that the customer asks for.
Within this thesis first can be found a research in literature where all the necessary concepts about production processes and production control are deeply described, this part is the theory part of the thesis. Following the theory part there is the practical, where the production process of the case study and the special requirements of it are explained. Finally, can be found the collection of indicators, where all of them are described in a record card, and then the selection of the ones that are suitable for controlling the production process of KRESTA industries and the justification of the decisions.
2 Theory part

2.1 Project definition [2, pp. 32-33, 38-39] [3, pp. 68-70] [4, p. 1] [5, pp. 5-6]

This thesis analyses how to control production in one-item production, but this type of production, as many others, is not an independent process, some related activities should be performed before it and also some activities are carried out after ending the production process. Therefore, to clearly understand what a production process is and how it works, first should be defined the whole related activities and how they are performed. The group of all these activities is a project.

There are several definitions of what is meant by “project”, for example The Project Management Institute defines a project to be “a temporary endeavour undertaken to create unique product, service or result” [6], the British Standard BS 6079-1 defines a project as “a unique set of co-ordinated activities, with definite starting and finishing points, undertaken by an individual or organization to meet specific objectives within defined schedule, cost and performance parameters” [7] or Juran defines a project as “a problem scheduled for solution”. [8]

However, independently of the considered definition there are seven primary characteristics which define a group of processes as a project and consequently are common to all projects:

- Objective: a project should have a goal, talking about product projects the goal is the product itself.
- Schedule: a project should have a defined end point in time within which the objective must be achieved.
- Complexity: every project has a complexity, it depends on the technologies needed to achieve the objective.
- Size and nature of the task: knowing the size and the nature of the task of a project is very useful to develop a plan of action to accomplish the project within the established time, cost and schedule constrains.
- Resources: to carry out the activities of any project are needed certain resources which are organized for every project.
- Organizational structure: a project should have a project manager, which takes decisions and has the responsibility of the project, and a project team, which performances the project.
- Information and control system: these both systems are needed in a project to handle problems through the typical functional lines of authority.

Once defined what a project is, it’s time to define the process groups that constitute it. A project is formed by five processes or phases, they are all connected, and this
linkage is illustrated in Figure 1. Every phase should be performed and they are organized in a specific order.

**Initiating process**: In this phase the project gets started, it is when takes place the evaluation of an idea, the preliminary analysis of risk and the first estimation of the time, cost and performance requirements. A project gets initiated through the cycle of needs emergence, recognition and articulation, followed by the definition of formal functional and technical specifications.

**Planning process**: this is the most important phase of a project, thus it is tightly related to the success of the project. This is the process by which the elements in the initiating phase are refined and the idea is converted into a detailed description. In this phase the project management plan is defined and also the selection of the best alternative for implementing the work.

**Executing process**: in this phase people and other resources co-ordinate to achieve the final form of the product. The executing process is closely related to the planning process, and the organization of the executing process is decided during the planning process.

**Monitoring and controlling process**: this phase is related to planning and executing phases, and it is taking part during the executing process. Through it the work is compared to the plan, therefore this phase measures and defines how well the executing process is performed. Thru this process potential problems are identified and corrective actions can be applied to control the execution of the project.

**Closing process**: as its name indicates, in this phases all the activities get closed, it is the end of the project. This phase includes project diagnosis,
evaluation, lessons learned, process assets update, and procurement closeout. This process should be performed in any project, even if it is not successful.

To conclude this part, and to continue this work should be clarified that this thesis deals with the control of the production, and therefore from this point it is focused on the executing process and the monitoring and controlling process.

2.2 Concept of production [9, p. 165] [10, p. 2] [11, pp. 2-4] [12, p. 89]

In a general definition, production is the group of interrelated activities which comprise the transformation of inputs, which could be materials, labour, equipment and capital, into desired outputs, which provide the needs of the customer and achieve his satisfaction. In a more comprehensible way a production system can be defined as a process which involves the use of an organization’s resource to provide something of value.

Once defined it, a classification can be made depending on the nature of the output. Bearing in mind this criterion can be identified two general types of production: service production and product or good production. Service production provides an abstract result or output to the customer, as its name indicates it provides a service, and product production provides a product with physical dimensions.

This work focuses on the production of chemical tanks and containers, thus on product production. This type of production is related to the process performed in factories, where the conversion process is carried out and the materials input is the basis, therefore it can be said that product production equals to manufacturing.

Manufacturing can be defined as all the activities which comprise the transformation of raw materials and information into a usable form of product for human needs. The major inputs in this process are capital, machines, equipment and tools, and also labour is required to operate and maintain the equipment. The conversion process consist in combine the raw materials with the other inputs by a suitable process technology and convert all the inputs into products.
2. Theory part

2.2.1 Production process types [13, p. 36] [12, p. 91] [14, p. 91]

The process choice determines the overall configuration of the operations system, thus it influence the nature of material and information flow in organisation, as well as the production planning, control systems, scheduling and the procurement practices.

There can be found several process types, but first is necessary to define the four key factors which invariably dictate the most suitable process type for an organisation, known as ‘the four V’s’: volume, variety, variation and visibility.

**Volume** [9, p. 169] [14, pp. 19-20]

The volume of produced products determines the degree of the repeatability of the tasks, i.e. the systematization of the manufacturing process, and also the investment in specialized equipment. As the volume of products increase the systematization increases and this fact reduce the product cost.

**Variety** [9, p. 169] [14, pp. 19-20]

The variety of produced products defines the grade of flexibility of the process, and also it affects the product cost. Increasing the variety of products that an organization produces, needs an increment of the flexibility of the process, and therefore it increases the product cost.

**Variation** [9, p. 169] [14, pp. 19-20]

The variation in the demand of the products determines the capacity of the process. A marked variation in the demand means that the capacity of the process must change, this fact can cause a low utilization of resources and the increase of the unit costs. Otherwise, organizations with regular demand can plan its activities well in advance, this results in a high utilization of resources and lower unit costs.

**Visibility** [9, p. 169] [14, pp. 19-20]

This factor refers to the degree of visibility that customers have of the production process. This is a more difficult dimension to visualise, it refers to the implication of the customer in the process. In processes where the customer participates, and therefore, he can ask for any type of product, there’s a high visibility or received variety. This fact makes difficult for high-visibility operations to achieve high production of resources and also tend to increase the costs.

To simplify the classification of the processes, this text focuses on the produced products’ characteristics, thus the volume and the variety. These two dimensions are the most significant to choose the process type because they are intern factors, so they are totally controlled by the organization. In an opposite way, the variation in the demand and the visibility are extern factors and they are more difficult to control.
2. Theory part

Consequently the type of process will differ in the volume of product produced and also in its customization degree. Actually, these two characteristics are usually related in an inverse relationship. As a result, high-volume processes often have a poor customization degree, and low-volume processes often have a high variety or customization degree.

According to this, can be defined four basic process types briefly explained below.

**Project process type** [9, pp. 170-174] [12, pp. 91-93] [14, pp. 91-93]

Project processes are those which produce high customized products only once, so in a very low volume. Project processes are unique, therefore usually resources needed are exclusively assembled for each project. These processes tend to be complex, large and usually take a long time to be completed. The production tasks can be ill-defined and uncertain, sometimes changing during the process.

**Job process type** [9, pp. 170-174] [12, pp. 91-93] [14, pp. 91-93]

Job processes’ products are similar to project processes’ products, they are high customized but they can be produced more than once, so they are not completely unique. There can be identical sub-processes between different products, therefore resources can be shared among them. This fact reduces the complexity of these processes compared to projects.

**Batch process type** [9, pp. 170-174] [12, pp. 91-93] [14, pp. 91-93]

Batch processes deal with moderate volume and moderate variety. As the name implies products are produced in batches, the degree of repeatability of the process depends on the volume of the batch, so high volume batches result high repetitive processes and narrow variety. Thus, when the batch has low volume, batch processes differ little from job processes. Because of this, the batch type of process can be found over a wide range of volume and variety levels.

**Mass or line process type** [9, pp. 170-174] [12, pp. 91-93] [14, pp. 91-93]

Mass processes are those which produce goods in high volume and relatively narrow variety. Mass processes are essentially repetitive and largely predictable, therefore resources can be organized around a product creating a line flow in the whole process with each step performing similar types of activities all the time. Little variability is still possible so long as it does not create disruption of the existing flow of the standard process.

**Continuous process type** [9, pp. 170-174] [12, pp. 91-93] [14, pp. 91-93]

Continuous processes produce high volume standardised products in a rigid production flow, without variety. One kind of product flows in the production line without
2. Theory part

interruptions. This type of process operate for longer periods of time, and they are usually literally continuous, thus products are inseparable, being produced in an endless flow. They are often associated with relatively inflexible, capital-intensive technologies with highly predictable flow.

2.3 Project process [9, p. 170] [14, p. 92] [15, p. 3]

This thesis is focused in the production of chemical tanks and containers. These products are usually huge and unique, therefore in this type of production processes there is a high variety of products because they are manufactured by customer’s order for a specific use. The process is carry out by personnel instead of machines, consequently the production is labour intensive and the required labour skills are high.

Reading the brief description of the production process studied in this work, it is easy to identify that this thesis deals with a project process. Project process’ goal is to provide to the customer exactly what he had ordered, and to achieve the customer’s satisfaction. The most relevant characteristic of project processes is that, even thinking in one company, every project is unique and has its singular needs. Therefore, to plan and schedule the resources and activities is a challenge caused by the absence of prior knowledge in making every particular product. Consequently the process map for project processes is certainly complex.

2.4 Project management [2, pp. 35-36] [16, p. 6] [17, pp. 84-86]

Project management can be defined as the professional activity of designing, structuring, scheduling, organizing, managing and controlling projects. Its objective is to accomplish the project on time, on cost and on scope. However, this three-fold objective is an unattainable goal, you can have any two but not all three. To try to achieve this goal it is necessary to examine the ten fundamental phases of project management which are integration, scope, time, cost, quality, human resource, communications, risk, procurement and stakeholder, and to find the best performances which will achieve the requirements of each of them.

2.4.1 Control Gates

Control gates are a very useful tool for project management, and need to occur throughout the project phases to control all three aspects: business, budget and technical.

A control gate can be defined as a management event during the project which make sure that new activities are not performed until the previously activities, on which the new ones depend, are satisfactorily completed. Therefore, the principal objectives of control gates are to confirm that all current phase activities and products are
accomplished, to check that the risk of continuing to the next phase of the project is acceptable and that the team is prepared to progress, and finally to promote a buyer/seller synergistic team approach. Control gates are essential in project management, otherwise failure in control gates along the project can result failure in subsequent phases and usually cost overruns and delays.

2.5 Production control [18, p. 2]

Production control is an activity that is included in project management, which objective is to reduce risk and achieve high delivery performance and quality at lowest cost possible in complex production systems.

This activity to be effective should operate in a systematic way, and can be defined as both proactive and reactive activities. Reactive production controls work by sensing or predicting the state of the production system, comparing the state with a desired standard, making fast corrections when a deviation occurs, and redirecting the company to capitalize on a deviation when correction is less feasible. On the other hand, proactive production controls plan against deviations and prevent abnormal but possible occurrences that might cause a deviation.

Thinking in control it is essential to consider the cost-benefit dimension. All control systems need and installation that has some cost associated, but control systems also have a probability of failure in their control function which must be taken into account. Despite the prevention and correction of the undesired state of affairs may produce some benefits, these facts might not have happened in the absence of the control.

Summarizing, the aim of production control systems is to maximise profits through processes, by transforming raw materials into products while satisfying product-quality specifications, operational constraints, safety and environmental regulations criteria.

2.5.1 Control systems [17, pp. 210-211] [19, pp. 332-339]

Control systems are the main components of production control, and they can be classified in three categories: feedback, feedforward and preventive control systems. Feedback, feedforward are examples of reactive control and preventive is an example of proactive control. Control systems are configured by different type of interconnected components depending on the nature of the control system.

Reactive control

All reactive control systems have the same primary structure, they are configured by a process which converts inputs into outputs, in case of production control it is manufacturing; a sensor which monitors the state of the process; and a controller which receives data from the sensor and standards given externally. The controller function
is to generate adjustments or decisions to influence the behaviour of the process in a desired way and cancel the effect of disturbances acting on the process. The difference between feedback and feedforward control systems lies in the internal configuration of controller.

In order to be useful and satisfying the cost-benefit constraint a reactive control system must be designed following these principles.

- Data and information received by the controller should be simple to understand. Therefore mustn’t be required a longer time to prosecute the information than the time allowed to make an adjustment.
- Data and information received by the controller should be timely.
- Each controller will have a sphere of responsibility and a scope for authority.

**Feedback control systems**

The controller in this type of control systems is configured by two components a comparator and an effector. The comparator compares the data provided by the sensor with the standard and sends an indicator of the deviation to the effector, which depending on the indicator received from the comparator creates an adjustment to the output of the controller.

Feedback control detects movements of the system from equilibrium and provides self-correcting adjustments, thus it enables a dynamic self-regulating system to function. Also it is important to bear in mind that the combination of process and controller can be left over long periods of time and will continue to produce a guaranteed output which meets standards.

![Feedback Control Diagram](image)

**Figure 2: Feedback Control [19, p. 333]**
Feedforward control systems

The main feature of these control systems is that the monitored data on the current state of the process is not used to compare this performance with a standard, otherwise is used to predict the future state of the process, which is compared with the future standard set.

To perform this procedure is necessary to add a new component in the controller, the predictor, moreover the effector and the comparator. The predictor receives current data or information about the current state of the process and uses a predictive model of the process to estimate the future state of the system, then this predictions is sent to the comparator which compares it with the future standard and send an indicator to the effector which create adjustments for the process. It’s clear that the success of feedforward control depends on the accuracy of the model and modelling information.

Preventive control systems

While reactive control systems are situated outside the process, preventive control systems are inside the process trying to prevent undesired states of the process. The basis of preventive control are:

- Documentation: an accurate design of documentation is very useful to prevent unintentional errors in recording and processing.
- Procedures manual: it is necessary a written statement of the functions to be performed by the personnel in the execution of data processing
- Separation of functions: the different functions performed in reactive control systems should be separated and carried out individually to prevent fraud. Not
only functional separation is important, also geographical separation, every function should take place in a different office.

- Personnel control: it is essential that the company relies on its personnel. Therefore to confirm that personnel is competent performing the tasks tests, interviews, the taking up of a reference and the checking of qualifications held will be very useful.

### 2.6 Performance measurement [20, pp. 2-6] [21, pp. 13-14]

Performance measurement is essential to perform production control. It is necessary to know how well complex processes are managed, it consist in monitoring and analysing a representative range of performance indicators.

The objective of performance measurement is to capture the operational state of the process. To achieve it, the most important action is the selection of a range of performance indicators which will depend on the process. These performance indicators should be effective to describe the state of the process, thus they must fulfil the requirements listed below.

- Measurable
- Simple and understandable, they have to communicate to everyone involved the desired information and must enable everyone to understand it and how they can help affect it positively.
- Meaningful, they must measures its purpose and drives the right action.
- Timely, believable and acceptable.
- A good operational definition, they should have an internal definition that enables everyone to know exactly what is include in the data.
- Cost effective, sometimes the cost of collecting a metric is not worth, it depends on the importance of the data.
- Auditable, there can’t be different interpretation of the same performance indicator.
- Repeatable, the data should not change in the same time periods.

#### 2.6.1 Performance indicators

A performance indicator or metric is a measurement, normally a process measurement taken over the time, which provides vital information about a process or activity and drive appropriate action. Performance indicators are useful to provide early warning of problems or bottle necks, to enable to manage processes, to provide basis for continuous improvement, to facilitate communications throughout the organization and to keep score on items of importance such as goals achievement.
Performance indicators can be classified into financial and non-financial performance measures, some examples of financial performance indicators are profitability, sales and unit cost. On the other hand non-financial performance indicators might include employee retention rates, customer satisfaction levels and product defect rates. Another possible classification is the quantitative-qualitative, which divides performance measures into ‘hard’ and ‘soft’. Hard performance indicators are those strictly computable quantities based on numerical measurable data, therefore they may be easy to collect from computer data logging systems. Otherwise soft performance indicators are metrics more difficult to measure, often captured by a set of linguistic variables such as “very poor”, “poor”, “satisfactory”, “good”, “excellent”, thus they may need interviews and questionnaires for collection, and may be subject to more uncertainty in quality. Some examples of hard performance indicators can be financial measures like unit cost and sales per day or non-financial quantities and technical measures like process plant downtime, product defect rates and product physical properties, whereas soft performance indicators might include non-quantitative measures like customer satisfaction variables.

2.6.2 Benefits of performance measurement [22, pp. 1-13]

Once determined performance measures’ goal and defined what a performance indicator is, should be clarified the importance of performance measures in companies and processes, therefore the next step is to describe the several benefits that performance measurement provide to companies.

- Improved control: performance indicators provide feedback which help the company to detect earlier the deviations in performance and to react and minimize the damage or make the most of the opportunity.
- Clear responsibilities and objectives: performance measures identify the responsible for obtained results or problems, thus everyone becomes accountable for only their performance and interdepartmental problems are reduced. In addition, performance indicators define what “good performance” means for every operation of the process, therefore every operation knows how well it is performing, this fact creates a self-correcting feedback loop which reduces deviations in performance.
- Strategic alignment of objectives: performance indicators enables a company to break its strategy down into lower level objectives and corresponding performance measures, this action determine what each operating unit must accomplish and assure everyone is working toward the same objectives, therefore this is the best way to communicate a company’s strategy throughout an organization. They are also useful to assess the effectiveness of a strategy.
• Understanding business processes: performance indicators enables companies to understand how process works. Knowing the inputs and the outputs of a process does not mean understanding it, differently the process needs to be measured to understand it, thus the company must know what happens through the process, which factors affect it and how varies the result depending on changes in it.

• Knowing what a process can do: the capability of a process is the limit of what it can do, knowing it is very important because by definition one process can’t exceed its capacity. Therefore, the capability of a process is essential to determinate which action needs to be taken to solve a problem, when a machine has not the capability to produce good products “repairing” it will not solve the problem because nothing is broken.

• Improved quality and productivity: performance indicators are essential to make quality improvement work, thus the following measures are needed to achieve it. First of all the size of the gap between what customers want and what they are getting, this measure determinates if there is a problem and its magnitude, then the measures that help understanding the process are important too to place the problem in the correct operation and to know how to start the corrective actions, and finally the size of the performance gap after applying the corrective actions, this measure proves if the attempts to improve quality worked.

• More efficient allocation of resource: performance indicators enables companies to identify problems and opportunities, this information helps the company to know the state of the process in any moment and which path to take. Therefore, thanks to performance measures companies focus improvement efforts on the major problems and opportunities.

• Better planning and forecasting: performance measures provide information about how various operation will be affected by changes in inputs and both external and internal factors. Is not easy to understand the process dynamics but once companies understand it will be easier to make operational plans and financial projections more reliable.

2.7 Business Intelligence systems [23, pp. 6-13]

Business Intelligence systems provide decisions makers with valuable information and knowledge. Business intelligence, also referred as BI uses internal or external data obtained from several sources to provide knowledge related to diverse aspects as understanding customer preferences, coping with competition, identifying growth opportunities and enhancing internal efficiency.

BI is started by data and information as inputs and its direct results are information and new knowledge or insight, obtained by revealing previously unknown connections or
patterns. Information provided by business intelligence is produced through appropriate analytics and then presented in a friendly fashion, such as through scorecards and dashboards. That’s because BI focuses on presenting information to individuals with little technical expertise, and not to the usual individuals who are more technically skilled or have previous knowledge about the specific technology.

Nowadays, business intelligence importance is increasing in the industry and this fact is driven by several factors which can be summarized into the following sets:

- **Exploding data volumes:** the union of technological progress and regulatory changes has result to a huge rise in data collecting which implies large data volumes accumulations about several aspects of the organizations. Although the availability of great quantity of data, this can only help to make decisions if managers can use it. Thus, BI enables managers to use more effectively these larger data volumes.

- **Increasingly complicated decisions:** competition between industries is increasing. Many organizations operate globally, in multiple industries and have competitors in one market which can be collaborators in another, and also the intricacy of internal and external processes and the availability of more information, all these factors result in an increasing complexity of decisions making. Not only information obtained from structured transactional data is needed, but also unstructured information available for example from e-mail messages or news media. Therefore, BI enables the managers to make decisions considering all the important factors and based on integration across these structured and unstructured sources of information.

- **Need for quick reflexes:** due to the acceleration in the step at which the global economy operates, changes in organizations had become faster during the past decade, for example nowadays market and environmental influences can result in overnight changes in organization and therefore the time available for organizations to respond to environmental changes has been decreased. BI enables managers to access quickly to actionable information and to make decisions and implement them during the available time.
Business intelligence differ from other information technologies which are used in current organizations, therefore it seems interesting to briefly define them and discuss these differences.

**Knowledge management** [23, p. 10]

Knowledge management main objective is to get the maximum from knowledge resources, it focuses on creating, sharing and applying knowledge. Traditionally it has emphasized explicit knowledge, the one that is recognized and is already articulated in some form, but nowadays it also includes tacit knowledge, which is difficult to articulate and formalize like insights, intuitions and hunches.

**Data warehouse** [23, p. 11]

Thru this technology organization’s data is obtained from multiple operational systems, for instance from point-of-sale system or customer relationship management system, and is stored in a single logical repository. Thus, data warehousing starts with data stored in different systems and often with inconsistencies, for instance in terminology or formats, and converts it into data stored in a single logical repository.

**Data mining** [23, p. 11]

The main objective of data mining is to discover hidden patterns from data stored in electronic form, usually in data warehouse. Therefore data mining starts with data and produces information, for instance patterns or relationships.

**Decision support systems** [23, p. 11]

Decision support systems and currently also automated decision systems focus on support or automation of decision making in organizations. These information technologies start with data, from warehouse or operational systems, and prior knowledge to create rules that guide the decisions.

Then, if business intelligence is compared with these other technologies can be noticed some differences:

Business intelligence has in common with data mining, data warehousing and decision support systems its nature, they are technical, while knowledge management involves social aspects and information technology. However, business intelligence and knowledge management have a common advantage over the other technologies, they have external inputs which can also be unstructured. This is a crucial distinction, because usually important information about competitors, customers and industry is only available in external systems, and a great part of it is found in unstructured form like e-mail messages, letters, presentations or web pages.
Nevertheless, also some differences exist between business intelligence and knowledge management. For instance, business intelligence starts with data and information, and the direct results are information and new knowledge or insight, while knowledge management has information and knowledge as inputs and results in the creation of new knowledge or the application of knowledge in making decision. Furthermore, while data is critical for business intelligence, knowledge management is not directly concerned with it, only when it focuses on discovering knowledge from data and information, which represent an overlap area between knowledge management and business techniques. Knowledge in business intelligence is just used to knowledge creation and only explicit knowledge can result from it, while knowledge management involves knowledge capture, sharing and application as well as creation, and the knowledge resulted can be tacit or explicit knowledge.

The following table summarizes all the distinctions analysed between the information technologies.

<table>
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<tr>
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<th>Business Intelligence</th>
<th>Knowledge Management</th>
<th>Data Warehousing</th>
<th>Data Mining</th>
<th>Decision Support Systems</th>
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<tbody>
<tr>
<td><strong>Inputs</strong></td>
<td>Data, information.</td>
<td>Data, information, knowledge.</td>
<td>Data (from multiple systems)</td>
<td>Data.</td>
<td>Data, information, knowledge.</td>
</tr>
<tr>
<td><strong>Nature of Inputs</strong></td>
<td>Internal or external, structured or unstructured.</td>
<td>Internal or external, structured or unstructured.</td>
<td>Internal, structured.</td>
<td>Internal, structured.</td>
<td>Internal or external, structured.</td>
</tr>
<tr>
<td><strong>Outputs</strong></td>
<td>Information and explicit knowledge</td>
<td>Tacit knowledge and explicit knowledge</td>
<td>Data (in a single logical repository)</td>
<td>Information</td>
<td>Decision recommendation (DSS). Automated decision (ADS)</td>
</tr>
<tr>
<td><strong>Components</strong></td>
<td>Information technologies</td>
<td>Information technologies, social mechanisms, structural arrangements</td>
<td>Information technologies</td>
<td>Information technologies</td>
<td>Information technologies</td>
</tr>
<tr>
<td><strong>Users</strong></td>
<td>Across the organization</td>
<td>Across the organization</td>
<td>IT personnel</td>
<td>IT personnel, others trained in IT</td>
<td>Specific, targeted users</td>
</tr>
</tbody>
</table>
3 Practical

During the practical part of this thesis the main objective would be writing an accurate list of performance indicators suitable for production control in project process, when just one product is produced once. To accomplish this goal the case study of “KRESTA industries” will be used.

3.1 Production process [24, pp. 34-38]

The tank production process is very labor intensive and is usually performed by skilled craftsmen, it can be classified as a project process which is explained in the theory part. In addition, every new product is a new project and therefore a new process, because every new tank has its requirements and consequently its material, dimensions and components. Nevertheless, can be described some operations that, with some differences between products depending on the characteristics, will be performed to produce the final tank, these operations are just a part of the complete production process.

Roll bending [25, p. 472]

During this operation the raw material as sheet-metal or plate-metal is rolled, formed into curved sections by means of rolls. The rolls configuration depends on the desired radius of curvature, therefore while the sheet passes between the rolls, they are bought towards each other to achieve the desired section. The configuration of the rolls will be designed depending on the desired section of the tank for every new tank.

Then, before moving the formed sheet-metal to a welding station it is assembled by means of tack welding. During this activity also the tank’s head can be assembled, which most of the times is a flanged head. This part of the tank is often purchased
from outside suppliers, nevertheless some fabricators will make a head using a single piece of metal and a flanger.

**Welding**

Depending on the characteristics of the tank the welding process can change as well as the method used for it. Usually, most tank interior welding is completed prior to fitting the last head on the tank. Although, current tanks usually have manways for interior access, working in confined spaces involves some danger for employees. Therefore, after the final head is assembled and tack welded the tank exterior seams are welded and the openings are cut for replacement of the fittings and other attachments.

Can be described four basic welding methods which are used in fabricating tanks:

- **SMAW (Shielded Metal Arc Welding)**: it is a manual process performed by an operator, which must stop and replace the consumed electrode approximately every 18 in. This fact converts SMAW in a slow process which result in identifiable surface irregularities on welds. Also, the type of electrode used has a significant impact on the mechanical strength created by the weld.

- **GMAW (Gas Metal Arc Welding)**: it uses a solid bare wire, which is fed through a welding gun from a spool or reel in an automatically or semiautomatically way, to create the arc between the work piece and the filler material. During the process a shielding gas protects the weld from environmental contamination. This process result in uniform welds with time and labor costs savings.

- **FCAW (Flux Core Arc Welding)**: this method is similar to GMAW, but instead of a bare wire it is using a tubulare wire containing granular flux. Also, it does not always need shielding gas, sometimes self-shielding flux is used or a combination of both for improved weld metal properties. This process result in welds of few fusion and discontinues due to the deep-penetrating arc.

- **SAW (Submerged Arc Welding)**: it is probably the most efficient welding method. It is an automatic process and uses a solid wire electrode submerged in a granular flux blanket. The welds resulted are smooth and uniform.

**Leak testing**

Once the fabrication of the tank is completed, it has to be inspected and checked for leaks. First a test preassure is performed it consists in seal tank openings and apply compressed air to the tank until the necessary test preassure is achieved. Afterwards, a soap solution is applied over the welds. If there are leaks on the welds, aire leaks through them and create bubbles which reveal where leaks are located. If found, leaks are repaired and then the welds are retested to ensure tank’s integrity.
In case of double-wall tanks, also have a vacuum applied to the interstitial space, this test is more sensitive to leaks and is most effective at proving simultaneously that both primary and secondary tanks are tight.

3.2 Special requirements [26, p. 25]

Tanks are produced to order, providing just one item in every production process, rather than to stock like mass production process, understood as a fixed production line which produces large batches of the same product in a continuous way. This type of special production has several requirements which mass production doesn’t have.

First of all, as this processes make product to order, the products provided are customized to fulfil all the requirements of the customer, this feature requires that the inventory management, production schedule, resource planning and product design and manufacturing data have to be flexible and changeable. Every new order may ask for a new product with new characteristics which may require different materials, process times or resources than the previous orders. A new project doesn’t starts before the ending of the previous one, and therefore, every new order restart the general production process which is described in the following table.

<table>
<thead>
<tr>
<th>Process</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Order taking and coordination</td>
<td>Defining the order and product specifications</td>
</tr>
<tr>
<td>Product development and design</td>
<td>Designing the product and its compliance with internal and external standards</td>
</tr>
<tr>
<td>Product validation and manufacturing engineering</td>
<td>Confirming manufacturability: routing and processing instructions</td>
</tr>
<tr>
<td>Order fulfilment management</td>
<td>Managing the order fulfilment by determining when production can start: managing the value added supply chain, scheduling, monitoring and controlling the process</td>
</tr>
<tr>
<td>Order fulfilment process</td>
<td>Coordinating external supplies needed: executing the production and delivery</td>
</tr>
<tr>
<td>Post order process</td>
<td>Installation: warranty claims and service</td>
</tr>
</tbody>
</table>

**TABLE 2: THE GENERAL PRODUCTION PROCESSES** [26, p. 20]

On the other hand, the production of customized products also requires a large variety of components. Depending on the characteristics of the desired final product the type
of needed components can vary and even some special components which can’t be provided by suppliers can be needed. Therefore, these processes require the ability of the company to produce special components which can’t be outsourced. Also, this fact can lead to excessive amounts of custom inventory as well as delays in deliveries. What’s more, the use of customized parts in products could result in problems when service requires a replacement part, due to customization, and thus, high costs and large periods of time will be related to part replacement. In addition in this case, replacing defective products during manufacturing also can cause disruption to production schedules and delivery schedules, because the replaced product might be the only product or an essential part to produce it.

Furthermore, this type of processes require to balance workloads to meet customer delivery sequences while maximizing utilization of resource. Every new order will ask for a custom process that can lead to requirements for unique skills which may not be fully utilized, as well as to excessive scrap rates due to specific customer requirements.

Another important issue about this type of production that differs from common production is the concept of constraint operation or bottleneck operations. This concept can be defined as the operation that limits the number of units produced per unit of time, therefore the operation of the process which produce products in a slowest velocity and where queues of products are created. Considering that in project production every product have a different production process with different operations, so is not possible to determine a constraint operation for all the products. However, if just the production process of one product is considered, the constraint or bottleneck operation could be defined as the operation that consume more time within the process.

Summarizing, due to the changeable process in project production, trying to find indicators which drives decisions to improve the process, as many of the indicators make for mass production processes, doesn’t make sense. In companies, where project production is performed, the attention to improve should be focused on the work team, and resources and not on the process. In this case, efficient processes can’t be created from past experience about the process but from experience of the company about the field. Therefore the most part of the suitable indicators will be indicators that assess the overall company performance and not just the process.
3.3 Performance indicators collection

3.3.1 Classification

First of all it can be interesting to classify the collected indicators considering the department that they evaluate, where they are useful, and if it is possible, the characteristic of the department on which they focus.

Production department

- Efficiency
  - Constraint productivity
  - Constraint utilization
  - Degree of unbalance
  - Manufacturing efficiency
  - Unit output per direct labor hour
  - Average equipment setup time

- Effectiveness
  - Manufacturing effectiveness
  - Productivity index
  - Operational equipment effectiveness
  - Takt time
  - Flexibility of production
  - Emergency man hours percentage
  - Equipment uptime
  - Unscheduled machine downtime percentage

- Quality
  - Constraint rework percentage
  - Acceptable product completion percentage
  - Scrap percentage
  - Warranty claims percentage

- Schedule
  - Constraint schedule attainment
  - Manufacturing critical path time (MCT)
  - Percentage of overtime
  - Production schedule accuracy

Logistics Department

- On-time delivery ratio
- Average duration of delivery
Engineering Department

- Product design
  - Bill of materials accuracy
  - Percentage of new parts used in new products
  - Time from design inception to production
  - Average number of distinct products per design platform

- Process design
  - Percentage of floor utilization
  - Labour routing accuracy

Human resources department

- Average time to hire
- Late personnel requisitions ratio
3.3.2 Description

<table>
<thead>
<tr>
<th>1.</th>
<th>Indicator: Constraint productivity [27, p. 250]</th>
</tr>
</thead>
</table>

**Description:**
This measurement is very useful for the management team to detect bottleneck operations and control their productivity. The detection of bottleneck operations is essential in production control because only increasing the volume of throughput of these operations will improve the company’s overall ability to generate a larger profit. Otherwise, if the enhanced operation is not a bottleneck operation, the bottleneck operation would still exist, and overall manufacturing output would not improve. The measurement should be tracked on a trend line in order to spot changes in the level of productivity.
If several different products requiring different processing times are being continually run through the bottleneck operations, then the measure should be separately calculated for each product so that productivity can be more precisely determined.

**Formula:**
This indicator is calculated as the division of the total number of units produced per hour by the number of hours worked at the bottleneck operation:

\[
\frac{\text{Number of units produced per hour}}{\text{Number of hours worked}}
\]

**Necessary information:**
- Number of units produced per hour
- Number of hours worked

**Cautions:**
This measurement should be used in conjunction with a review of the total gross margin being generated by the bottleneck operation. Otherwise, the operation can result in a high level of productivity, producing a lot of units, but provide a lower profit margin than the one provided by the production of fewer units which result in a lower level of productivity.

**Table 3: Constraint Productivity**
2. **Indicator:**
   Takt time [27, p. 251]

**Description:**
This measure determines the rhythm at which a manufacturing facility must operate in order to meet a certain level of customer demand. To achieve the current level of demand, a way to produce one unit no later than once every takt time period must be found. Therefore, takt time is the demand for company’s capacity and an issue for management to resolve.

**Formula:**
This indicator is calculated dividing the operation time by the daily requirement for a product:

\[
\frac{\text{Operating time}}{\text{Required quantity}}
\]

**Necessary information:**
- Operating time
- Required quantity

**Cautions:**
Also can be defined operational takt time, this indicators includes variations in operating time and requires quantity which takt time does not consider. Therefore, in most cases this alternative indicator is more useful resulting in a more realistic view of how much production time is actually required to produce a unit of output.

| TABLE 4: TAKT TIME |
### 3. **Indicator:**
Constraint rework percentage [27, p. 252]

### Description:
As known a bottleneck operation is the limitation of the productivity that can be achieved by a manufacturing facility, therefore to control production must be controlled the volume of work passing through it. This indicator identifies the amount of rework time at the bottleneck operation, which is very useful for the production manager because while the bottleneck operations must duplicate previously completed work, new work that would have created additional profits can’t be produced.

### Formula:
This indicator is calculated as the division of the total rework hours used in a constraint operation by the total number of hours available at the constraint:

\[
\frac{\text{Rework hours used in constraint operation}}{\text{Total hours of constraint}}
\]

### Necessary information:
- Rework hours used in constraint operation
- Total hours of constraint

### Cautions:
In this measure is not considered as rework the one that can be shifted to other machines than the bottleneck operation. Also, this measurement is less than a 24-hour day, since they can simply schedule some overtime work to handle excess work requirements.

---

**Table 5: Constraint rework percentage**
4. **Indicator:**  
Constraint schedule attainment [27, p. 253]

**Description:**  
This indication identifies production manager’s efficiency in producing according the production plan. A production plan determines which parts should be produced by the bottleneck operation and in which order should them be produced to achieve the highest profits. This measure is useful to control the amount of production passing through a bottleneck operation, if the wrong items or reduced number of items pass through it, then a company will not realize the maximum amount of profits from its operation.

**Formula:**  
This indicator is calculated as the division of the number of part hours actually produced by the number of part hours scheduled at the constraint operation. If a rework is needed then this should be added to the numerator in the formula. Also, the number of hours of work itemized in the production schedule is based on the standard estimate of hours required; if the work is completed with variance from the standard, then this variance should be included in the numerator in the formula.

\[
\frac{Part \ hours \ produced + Rework \ hours - Reduction \ in \ actual \ hours \ from \ standard}{Part \ hours \ scheduled}
\]

**Necessary information:**  
- Part hours produced  
- Rework hours  
- Reduction in actual hours from standard  
- Part hours scheduled

**Cautions:**  
Calculating this indicator can happen that the resulting measurement seems to indicate that the production schedule was precisely met, but can still be incorrect if production orders were completed in a different sequence from the schedule. To avoid this problem, this indicator should be measured for very short time periods so that the timing of jobs within the schedule cannot be shifted while still appearing to meet the schedule.

**Table 6: Constraint Schedule Attainment**
### 5. **Indicator:**
Constraint utilization [27, p. 254]

#### Description:
This indicators is used when there is no production schedule in place, it measures the amount of usage of the bottleneck operation, irrespective of what types of work are passed through it. This measure is less precise because it doesn’t considers if the highest-profit goods are being prioritized in the constraint operation, as would be the case if a production schedule were used.

#### Formula:
This indicator is calculated as the division of actual hours during which the constraint operation is used by the total number of constraint hours available:

\[
\frac{\text{Actual hours used in constraint operation}}{\text{Total constraint hours available}}
\]

#### Necessary information:
- Actual hours used in constraint operation
- Total constraint hours available

#### Cautions:
This measure can be useful as long as the constraint operation is constantly performing the same work. In addition, it does not relate well to the amount of profits being generated due to the exclusion of positioning highly profitable production first in the work queue. Therefore, it should be combined with a summary review of profits being generated by the operation.

**Table 7: Constraint utilization**
### Description:
This indicator determines the amount of productive capacity in a production cell that can’t be used because of the bottleneck operation. Therefore, it measures the capacity difference between the bottleneck operation and the capacity of the next most restrictive operation within a manufacturing cell. A ratio close to 100% reveals a minimum degree of unbalance. This indicator drives decisions about which bottleneck operations within cells should be improved or supplemented so that the degree of unbalance is reduced to achieve a smoother productive flow and a higher rate of output.

### Formula:
This indicator is calculated as the division of the maximum capacity of the work cell bottleneck operation by the maximum capacity of the next most restrictive work cell operation. An alternative is to determine the average capacity of all other machines in the work cell and use this amount in the denominator.

\[
\frac{\text{Maximum capacity of the work cell bottleneck operation}}{\text{Maximum capacity of the next most restrictive work cell operation}}
\]

### Necessary information:
- Maximum capacity of the work cell bottleneck operation
- Maximum capacity of the next most restrictive work cell operation

### Cautions:
Using the alternative of the average capacity of all non-bottleneck operations in a work cell as the denominator can result in a misleading measurement because the averaging technique may mask the capacity problem presented by the next most restrictive work station, which is much worse than the average. The degree of unbalance may not be a very useful number for work cells that rarely reach their maximum levels of production capacity. It is most useful in situations where production equipment is being fully utilized over all three shifts and is having difficulty achieving the level of demand.

### Table 8: Degree of Unbalance
### Indicator:
Manufacturing critical path time (MCT) [27, p. 258]

### Description:
This indicator determines the minimum amount of time required to actually create a product and deliver it. Therefore, it is the time interval from when a manufacturing order is created until the first element of that order is received by the customer, so it includes the time needed to obtain necessary parts from suppliers. This measurement is useful to control buffer inventory on hand and also as a baseline for manufacturing improvements initiatives.

### Formula:
This indicator is calculated as the subtraction of the order receipt date and time from the customer delivery date and time. In addition, it can be calculated in a more accurate way adding the total supplier lead time, all queue times, manufacturing times, inspection times, and delivery times.

\[
\text{Customer delivery date and time} - \text{order receipt date and time} = \text{Longest supplier lead time} + \text{Total queue times} + \text{Total manufacturing times} + \text{Total quality inspection times} + \text{Total delivery time}
\]

### Necessary information:
- Customer delivery date and time
- Order receipt date and time

or
- Longest supplier lead time
- Total queue times
- Total manufacturing times
- Total quality inspection times
- Total delivery time

### Cautions:
To calculate this indicator the required time to procure suppliers and manufacture products must be considered even if orders are fulfilled by deliveries from stock which hide the time required to procure suppliers and manufacture products.

---

**Table 9: Manufacturing Critical Path Time**
<table>
<thead>
<tr>
<th>8.</th>
<th><strong>Indicator:</strong> Manufacturing efficiency [27, p. 259]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description:</strong></td>
<td>This indicator determines the proportion of value-added operational time according the total amount of time required to convert raw materials into finished goods. This measurement can be used as a point of reference to drive improvements in manufacturing efficiency.</td>
</tr>
</tbody>
</table>
| **Formula:** | This indicator is calculated as the division of the current cycle time by the value-added time. The current cycle time is the time interval from the removal of materials from storage until the completed goods are stored, and the value-added time is the processing time of manufacturing operations which add value to the product.  

\[
\frac{Current \ cycle \ time}{Value \ – \ added \ time}
\]|
| **Necessary information:** | - Current cycle time  
- Value-added time |
| **Cautions:** | This indicators should only be measured in bottleneck operations which when they are improved this improvement is reflected in the overall process, otherwise if the improvement is focused in non-constrained operations the improvements won’t reflect in the process due to the limitation of constraint operations. |
9. **Indicator:**
   Manufacturing effectiveness [27, p. 262]

**Description:**
This indicator reveals the proportion of hours being used at the constraint operation that actually result in shipments to customers. The fact that an operation is working during a great amount of hours is not sufficient to declare the operation as effective, to do that is necessary to prove that the most part of this amount of hours are being translated into more shipments to customers and are not used for rework, for production that is later scrapped, or for testing or setup.

**Formula:**
This indicator is calculated as the division of the total throughput hours shipped in the reporting period by the total number of constraint hours consumed.

\[
\frac{\text{Throughput hours shipped}}{\text{Constraint hours consumed}}
\]

**Necessary information:**
- Throughput hours shipped: amount of hours used to produce shipments to customers.
- Constraint hours consumed

**Cautions:**
Compile the information needed for this indicator can result difficult if the operation is early in the production process and there is a significant time lag between the shipment of products to customers and the consumption of constraint hours. In this case the measurement of constraint hours might fall into one reporting period and the measurement of consumed constraint hours into another. One solution for this problem can be the manually measure of throughput hours consumed at the constraint operation, though this can be subjected to error.

**TABLE 11: MANUFACTURING EFFECTIVENESS**
Indicator: Productivity index [27, p. 263]

**Description:**
This indicator is used to measure the variation of an output quantity resulted by a change in some input quantity. Therefore, this indicator reflects the effect of some input into output. If only a small increase in the quantity of some input results in a great increase in the quantity of outputs, the considered input has a high productivity index in the process, and consequently it is important in the process. This indicator is very useful to detect which inputs are more important for the process and to drive time and resources investments. It can be used to compare the change in final products due to a change in some input but also can be used for instance to compare the change in scrapped units due to an additional hours spent on training machine operators.

**Formula:**
This indicator is calculated as the division of the total change in output quantities by the total change in input quantities.

\[
\text{Total change in output quantities} \quad \div \quad \text{Total change in input quantities}
\]

**Necessary information:**
- Total change in output quantities
- Total change in input quantities

**Cautions:**
To calculate this indicator the change in input should be isolated, otherwise it won’t be clear if the result is caused by the considered input change or by another not considered. Also should be borne in mind that sometimes doesn’t exist a causal relationship between an input and output, in this case this indicator has not any sense.

| TABLE 12: PRODUCTIVITY INDEX |
11. **Indicator:**
   Unit output per direct labor hour [27, p. 264]

**Description:**
This indicator represents the relation between the amount of direct labor hours and the amount of unit output. It is very useful in those processes where the primary form of value added to a product is direct labor.

**Formula:**
This indicator is calculated as the division between the addition of the total number of units completed during the production period and the total number of unit equivalents, less the total number of unit equivalents recorded at the end of the preceding reporting period and the total number of direct labor hours in the reporting period.

\[
\frac{Total \ units \ completed + Total \ unit \ equivalents - Total \ carryforward \ unit \ equivalents}{Total \ number \ of \ direct \ labor \ hours}
\]

**Necessary information:**
- Total units completed
- Total unit equivalents: a unit equivalent is the completed proportion of an incomplete unit
- Total carryforward unit equivalents: total unit equivalents considered in the previous period.
- Total number of direct labor hours

**Cautions:**
A very important issue in the calculation of this indicator is the measurement of the number of unit equivalents, a good approach is to determine the number of actual hours already spent on a product, per the job tracking system, and compare this to the standard number of hours recorded on the labor routing to determine the percentage of completion.

**Table 13: Unit Output per Direct Labor Hour**
### 12. **Indicator:**
Average equipment setup time [27, p. 265]

**Description:**
This indicator measures the period time between the end of one production run and the start of the following one, which is usually used to set up operations. Results useful to control this period of time when equipment is being run at maximum capacity and it’s critical to have the shortest downtime between production runs. It will have no sense if there are not jobs continually following each other preceding an equipment setup.

**Formula:**
This indicators is calculated as the subtraction of the stop time for the preceding production run from the start time for the next production run.

\[
\text{Start time for new production run} - \text{Stop time for last production run}
\]

**Necessary information:**
- Start time for new production run
- Stop time for last production run

**Cautions:**
This indicators can be calculated manually or by an automated machine. If it is measured manually by equipment setup teams, it will provide extra motivation to keep setups short, nevertheless, in this case the team should be spot-checked by an independent observer from time to time. On the other hand this indicator can be calculated by an automated machine usage tracking system which automatically sends information to a central location, it provides a more accurate measure but results much more expensive.

---

**TABLE 14: AVERAGE EQUIPMENT SETUP TIME**
### 13. Indicator: Unscheduled machine downtime percentage [27, p. 266]

**Description:**
This indicator calculates the relation between the unscheduled downtime of equipment, when equipment fail outside the schedule of planned maintenance, and the total time of the equipment. If this proportion is high, it can result in particular problems arising for the promised delivery dates of products that must be processed on the failed equipment. Therefore, this indicator is very useful for tracking a company’s ability to minimize this problem. If the percentage is very high in some type of equipment, it drives company’s actions to ease the reorganization of the production schedule around the capacity of the failed equipment. This indicator can be calculated as the summary for all the machines or individually for each one.

**Formula:**
This indicator is calculated as the division of the total minutes of unscheduled machine downtime by the total minutes of machine time.

\[
\frac{\text{Total minutes of unscheduled downtime}}{\text{Total minutes of machine time}}
\]

A variant of this indicator to provide a better idea of the maintenance staff’s ability to predict upcoming equipment fails, properly schedule them for repair concerning the production schedule, and don’t spend all the time repairing equipment, is to divide the total minutes of unscheduled downtime by the total minutes of scheduled downtime. The ideal value should be as close to zero as possible.

\[
\frac{\text{Total minutes of unscheduled downtime}}{\text{Total minutes of scheduled downtime}}
\]

**Necessary information:**
- Total minutes of unscheduled downtime
- Total minutes of machine time or Total minutes of scheduled downtime

**Cautions:**
The calculation of this indicator accurately needs a machine time-tracking equipment that is directly linked to the equipment to monitor ongoing processing which is expensive. The alternative is to calculate it manually but it can result inaccurate due to the lack of operator attention.

<table>
<thead>
<tr>
<th>TABLE 15: UNSCHEDULED MACHINE DOWNTIME PERCENTAGE</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th><strong>Indicator:</strong> Unscheduled machine downtime percentage [27, p. 266]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description:</strong> This indicator calculates the relation between the unscheduled downtime of equipment, when equipment fail outside the schedule of planned maintenance, and the total time of the equipment. If this proportion is high, it can result in particular problems arising for the promised delivery dates of products that must be processed on the failed equipment. Therefore, this indicator is very useful for tracking a company’s ability to minimize this problem. If the percentage is very high in some type of equipment, it drives company’s actions to ease the reorganization of the production schedule around the capacity of the failed equipment. This indicator can be calculated as the summary for all the machines or individually for each one.</td>
</tr>
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<td><strong>Formula:</strong> This indicator is calculated as the division of the total minutes of unscheduled machine downtime by the total minutes of machine time.</td>
</tr>
</tbody>
</table>
\[
\frac{\text{Total minutes of unscheduled downtime}}{\text{Total minutes of machine time}}
\]  
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\[
\frac{\text{Total minutes of unscheduled downtime}}{\text{Total minutes of scheduled downtime}}
\]  
**Necessary information:**  
- Total minutes of unscheduled downtime  
- Total minutes of machine time or Total minutes of scheduled downtime  
**Cautions:** The calculation of this indicator accurately needs a machine time-tracking equipment that is directly linked to the equipment to monitor ongoing processing which is expensive. The alternative is to calculate it manually but it can result inaccurate due to the lack of operator attention. |
14. **Indicator:** Acceptable product completion percentage [27, p. 269]

**Description:**
This indicator provides an idea about how much direct material and processing time is wasting the company due to produced products which are not acceptable to deliver and should be scrapped or reworked. It can be calculated for every production run or for a production time period, which is very useful when the production runs are extremely long involving several reporting periods and the company needs information sooner than the end of the runs.

**Formula:**
This indicator is calculated as the division of the subtraction of the number of rejected products from the number of products in production run by the number of products in production run.

\[
\frac{\text{Number of products in production run} - \text{Number of rejected products}}{\text{Number of products in production run}}
\]

**Necessary information:**
- Number of products in production run
- Number of rejected products

**Cautions:**
To calculate this indicator is necessary to accurately measure the number of rejected products, which involve the products that have gone through the entire production process and then been rejected, as well as the products which have rejected earlier in the process and the ones that have been returned by customers for refunds or warranty claims.

| TABLE 16: ACCEPTABLE PRODUCT COMPLETION PERCENTAGE |
3. Practical

<table>
<thead>
<tr>
<th>15.</th>
<th><strong>Indicator:</strong></th>
<th>Scrap percentage [27, p. 272]</th>
</tr>
</thead>
</table>

**Description:**
This indicators reflects the amount of scrap generated by a production manager, this indicator is very important for the process because it can be indicative of a lot of problems as the poor training of the direct labor work force, improper machine setup, materials handling problems or ordering of substandard raw materials. Considering this indicator, companies may detect this problems and drive actions to solve them. Nevertheless, to measure the amount of scrap that a company produces results difficult because it can be produced in many parts of a facility, and usually is not accumulated to measure it. To solve this problem the amount of scrap is related to the difference between the standard cost of the product and the actual cost, and is compared the aggregate cost of what was produced to what should have been produced.

**Formula:**
This indicator is calculated as the division of the subtraction of the standard cost of goods sold from the actual cost of goods sold by the standard cost of goods sold.

\[
\frac{\text{Actual cost of goods sold} - \text{Standard cost of goods sold}}{\text{Standard cost of goods sold}}
\]

**Necessary information:**
- Actual cost of goods sold
- Standard cost of goods sold

**Cautions:**
In the calculation of this indicator there are several problems caused by the calculation of it using the costs of goods sold. The first problem is that the standard costs may include a standard scrap cost already, so these value must be extracted from the standard in order to determine the actual amount of scrap. Another problem is that in the difference of cost may be other variances included, such as a price variance on raw materials purchased, also these variances must be calculated and removed from the actual cost of goods sold before the amount of scrap can be determined. In addition, the cost of goods sold should only include the direct labor and direct material costs associated with production and all the overhead costs should be removed.

**Table 17: Scrap Percentage**
16. **Indicator:**
   On-time delivery ratio [27, p. 279]

**Description:**
This indicator is essential in the determination of customer satisfaction. It reflects the number of deliveries on or before the due date. A less restrictive is to use the adjusted customer-requires due date, which is the typically date that the company offers to customers, given the company’s availability of materials and productive capacity.

**Formula:**
This indicator is calculated as the division of the number of orders shipped on or before the customers’ requires due date by the total number of orders shipped.

\[
\frac{\text{Number of orders shipped by due date}}{\text{Total number of orders shipped}}
\]

**Necessary information:**
- Number of orders shipped by due date
- Total number of orders shipped

**Cautions:**
This indicator is very important for companies and for employees which may receive bonuses for good results. For this reason, the information can be altered to achieve acceptable results modifying the due date of customers. To avoid this problem the access to this information must be restricted.

**TABLE 18: ON TIME DELIVERY RATIO**
## 17. Production schedule accuracy

**Indicator:**
Production schedule accuracy [27, p. 216]

**Description:**
This indicator is very useful to control the production schedule and verify if jobs listed on the production schedule are completed in an orderly manner and in the scheduled sequence and quantities. This is very important in a process, otherwise if the production schedule is not followed, it will result in material shortages, irate customers and projects being rushed through the production facility. It reflects the relation between the amount of scheduled jobs completed and the total number of jobs scheduled for completion. Sometimes the jobs are too long and cross over several measurement periods, in this case it is more accurate to calculate the relation between the amount of production tasks completed within each scheduled job and the total number of scheduled tasks for all the jobs.

**Formula:**
This indicators is calculated as the division of the number of scheduled jobs completed during the measurement period by the total number of jobs scheduled for completion.

\[
\frac{\text{Number of scheduled jobs completed}}{\text{Number of jobs scheduled for completion}}
\]

**Necessary information:**
- Number of scheduled jobs completes
- Number of jobs scheduled for completion
  Or
- Number of production tasks completed within each scheduled job
- Number of scheduled tasks for all the jobs

**Cautions:**
Sometimes this indicator is impacted by last-minute changes require by the customer which are hard to predict and can't be avoided.

---

**Table 19: Production schedule accuracy**
### 3. Practical

| 18. | **Indicator:**  
|     | Operational equipment effectiveness [27, p. 244] |

**Description:**
This indicator is essential to control production, it verifies the ability of the operation to produce on time and at the correct quality level which means reducing machine downtime, ensuring that it operates at the correct rate of production and that goods are completed without scrap on their first time through the process.

**Formula:**
This indicator is calculated as the multiplication of availability, performance efficiency and quality.

\[
\text{Operational equipment effectiveness} = \text{Availability} \times \text{Performance efficiency} \times \text{Quality}
\]

Availability is calculated as the division of the subtraction of downtime from net available time, by net available time.

\[
\text{Availability} = \frac{\text{Net available time} - \text{Downtime}}{\text{Net available time}}
\]

Performance efficiency is calculated as the division of actual run rate by ideal run rate.

\[
\text{Performance efficiency} = \frac{\text{Actual run rate}}{\text{Ideal run rate}}
\]

Quality is calculated as the division of the difference between total quantity manufactured and total quantity rejected or reworked by the total quantity manufactured.

\[
\text{Quality} = \frac{\text{Total quantity manufactured} - \text{Total quantity rejected or reworked}}{\text{Total quantity manufactured}}
\]

**Necessary information:**
- Net available time
- Downtime
- Actual run rate
- Ideal run rate
- Total quantity manufactured
- Total quantity rejected or reworked

**Cautions:**
This indicator is useful to represent a general indicator of the work area but drive corrective actions is needed to decompose it into the three indicators.

**Table 20: Operational equipment effectiveness**
### Indicator:
Bill of materials accuracy [27, p. 191]

#### Description:
The bill of materials is where are exactly specified the needed components to build a product and the quantities required for each part. Therefore, this indicator is useful to control the accuracy of the bill of materials and value needed to ensure that the needed parts are available when the manufacturing process begins and that the manufacturing process is performed with the minimum of stoppages caused by missing parts is at least 98%.

#### Formula:
Tis indicator is calculated as the division of the number of accurate parts listed in a bill of materials by the total number of parts listed in the bill.

\[
\frac{\text{Number of accurate parts listed in bill of materials}}{\text{Total number of parts listed in bill of materials}}
\]

#### Necessary information:
- Number of accurate parts listed in bill of materials: the correct part number, unit of measure and quantity.
- Total number of parts listed in bill of materials

#### Cautions:
This indicator is very important to verify that the production process runs smoothly, consequently even the minimum acceptable level of it is 98%, nothing less than 100% will completely ensure it. Furthermore, it is also important to control the timing of the release of the bill of materials to provide enough time to collect the necessary parts before the beginning of the manufacturing process.

| Table 21: Bill of materials accuracy |
Indicator: Labor routing accuracy [27, p. 193]

Description:
The labor routing is where are exactly specified all the times needed at all work stations through which a product must pass during the manufacturing process. Labor routing is essential in production planning because by multiplying it by the number of units to be produced, it reflects how much direct labor and machining time is needed to complete a production run. This indicator is useful to plan production properly and verify the accuracy of the labor routing comparing the number of correct machining times and machine codes and the total number of routing line items. The minimum acceptable level of this indicator is 95%.

Formula:
This indicator is calculated as the division of the number of correct machining times and machine codes by the total number of line items in the routing.

\[
\frac{\text{Number of correct machining times and machine codes}}{\text{Total number of routing line items}}
\]

Necessary information:
- Number of correct machining times and machine codes: to consider a routing line item correct the time and code should be correct.
- Total number of routing line items.

Cautions:
An essential issue to calculate this indicator is the measurement of correct machining times, if processing times are very short a small error can have major impact than in larger times. To avoid this problem the estimated time should be considered correct within a certain percentage of the actual time, usually the estimated routing time is correct if it is plus or minus 5% of the actual time.
| **21.** | **Indicator:**  
Percentage of new parts used in new products [27, p. 196] |
|---|---|
| **Description:**  
This indicator is used by companies to try to save costs. It controls the number of new parts that appear in the bill of materials of a product. For this reason, the calculation of this indicator provides motivation to engineers to design products that share components with existing product, reducing additional purchasing and materials-handling costs, using the existing work load of the purchasing and materials-handling staffs and avoiding an investment in inventory for new parts. |
| **Formula:**  
This indicator is calculated as the division of the number of new parts in a bill of materials by the total number of parts in a bill of materials.  
\[
\frac{\text{Number of new parts in bill of materials}}{\text{Total number of parts in bill of materials}}
\] |
| **Necessary information:**  
- Number of new parts in bill of material  
- Total number of parts in bill of material |
| **Cautions:**  
Engineers may disagree with the use of this indicator stating that it provides a disincentive for them to locate more reliable or less expensive parts which could replace existing components. Nevertheless, this problem can be avoid considering long-term declines in the cost of products or increases in the level of quality and combining this measures with it. |

**Table 23: Percentage of new parts used in new products**
### TABLE 22: Indicator

<table>
<thead>
<tr>
<th>Description:</th>
<th>Emergency man hours percentage [28, p. 60]</th>
</tr>
</thead>
<tbody>
<tr>
<td>This indicator is useful to control the allocation of resources during plan or facility breakdowns. It reflects the relation between direct labor hours spent on solving breakdowns and the total amount of direct labor hours invested in the process. Usually, the maximum acceptable level is 20%. Otherwise, a high level of resources consumption for emergency activities will result in a low level of the productivity rate for the labor resources.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Formula:</th>
<th>This indicator is calculated as the division of the man hours spent on emergency jobs by the total man hours.</th>
</tr>
</thead>
</table>
|         | \[
|         | \frac{\text{Man hours spent on emergency jobs}}{\text{Total man hours worked}} \] |

<table>
<thead>
<tr>
<th>Necessary information:</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Man hours spent on emergency jobs</td>
</tr>
<tr>
<td>- Total man hours worked</td>
</tr>
</tbody>
</table>

| Cautions: | An important issue to calculate this indicator accurately is to determine what can be considered as a breakdown or emergency which may depend on the process type. |

**TABLE 24: EMERGENCY MAN HOURS PERCENTAGE**
### 23. Indicator:
Percentage of overtime [28, p. 68]

**Description:**
This indicator is very useful to control the allocation of labor and resources, if the percentage of overtime is high can be provoked by a lack of resources, but also it can be used to control the performance of employees, which can be performing operations under their capabilities and using overtime without necessity, due to low motivation or lack of skills and knowledge. It reflects the percentage of time worked which was not scheduled.

**Formula:**
This indicator is calculated as the division of hours worked as overtime by the total hours worked.

\[
\frac{\text{Hours worked as overtime}}{\text{Total hours worked}}
\]

**Necessary information:**
- Hours worked as overtime
- Total hours worked

**Cautions:**
Considering just this indicator is not sufficient evidence to decide which of both problems, lack of resources or bad performance of employees, is the problem. To identify it can be combined some indicators as constraint utilization or unit output per direct labor hour.

---

**Table 25: Percentage of Overtime**
### Table 26: Equipment Uptime

<table>
<thead>
<tr>
<th>Indicator:</th>
<th>Equipment uptime [28, p. 66]</th>
</tr>
</thead>
</table>

**Description:**
This indicator is useful to control the availability of equipment, therefore it reflects the real period of time during which the equipment can work producing products. The desired uptime is the amount of uptime needed for the equipment to meet the production forecast. It can be very useful to control the expectation of the equipment output, if 100% of availability is expected all the time, then there’s not time for setup operation and more equipment is needed.

**Formula:**
This indicator is calculated as the division of the subtraction from desired equipment uptime of downtime by desired equipment uptime.

\[
\frac{\text{Desired equipment uptime} - \text{Scheduled downtime}}{\text{Desired equipment uptime}}
\]

**Necessary information:**
- Desired equipment uptime
- Scheduled downtime

**Cautions:**
Using this indicator to control if the expected output is realistic is necessary also to consider that unscheduled downtime can occur, and therefore if it is not considered the desired amount of output could not be achieved.
25. **Indicator:**
   Flexibility of production [29, p. 100]

**Description:**
This indicator is useful to control the ability of a company to supply special orders which differ in some parts from the usual orders. Therefore, this indicator reflects the flexibility of the production, the production process has a high flexibility level if it can execute a high proportion of the special orders received.

**Formula:**
This indicator is calculated as the division of the number of executed special orders by the total number of special orders.

\[
\text{Number of executed special orders} \div \text{Total number of special orders}
\]

**Necessary information:**
- Number of executed special orders
- Total number of special orders

**Cautions:**
An important issue in the calculation of this indicator is to identify special orders and to determine which type of special orders can be executed and which not. Special orders are those which differ from the standard process.
| 26. | **Indicator:**  
| | Warranty claims percentage [27, p. 274]  
| **Description:**  
| This indicator is essential to judge the quality of a company’s product, it also can be used to assess the performance of the engineering, logistics and production departments because warranty claims can be the result of poor product design, of the use of raw materials having inadequate specifications or of improper production. To make a good comparison and considering there may be a significant time lag between the date when a warranty claim is received and the date of production, the information to calculate this indicator should be recorded during several months.  
| **Formula:**  
| This indicator is calculated as the division of the total number of warranty claims received by the total number of products sold.  
| \[
\frac{\text{Total number warranty claims received}}{\text{Total number of products sold}}
\]  
| **Necessary information:**  
| - Total number of warranty claims received  
| - Total number of products sold  
| **Cautions:**  
| As this indicator considers problems in different departments considering it just in one department may ignore the true problem-causing department. Also, is necessary to consider that when a company sells its products through intermediaries, warranty claims can be used as an excuse to return unsold products without defects. Therefore, to solve both of the problems, incoming warranty products should be carefully reviewed to identify the cause of the problem before considering them as a warranty claim.  

**TABLE 28: WARRANTY CLAIMS PERCENTAGE**
| 27. | **Indicator:**  
|     | Average number of distinct products per design platform [27, p. 198]  

**Description:**  
This indicator controls the number of design platforms used to produce all the products of a company. Using a common base of platform design for most of the products is useful to avoid too many production lines each of which tooled to only manufacture one product, as well as the vast array of components needed to assemble the many products and to reduce the engineering design time as is easier to create new products from a design base than create them from raw material. In addition, using this indicator can increase the motivation of engineers to create new product without designing a new platform and reduce time. A big level of this indicator will mean that the company is able to produce several different products with few production lines.

**Formula:**  
This indicator is calculated as the division of total number of distinct products by total number of design platforms.

\[
\frac{\text{Total number of distinct products}}{\text{Total number of design platforms}}
\]

**Necessary information:**  
- Total number of distinct products  
- Total number of design platforms

**Cautions:**  
An important issue in this calculation is to decide how different should be a variation of a product to be considered a different product. Is important to define it, otherwise companies will classify little variances of a product as a new product to achieve a higher level in this indicator.

**TABLE 29: AVERAGE NUMBER OF DISTINCT PRODUCTS PER DESIGN PLATFORM**
### Table 30: Time from Design Inception to Production

<table>
<thead>
<tr>
<th>No.</th>
<th>Indicator:</th>
<th>Description:</th>
<th>Formula:</th>
</tr>
</thead>
<tbody>
<tr>
<td>28.</td>
<td>Time from design inception to production [27, p. 205]</td>
<td>This indicator is useful to control the design time. Usually, design teams take excessive time to design a new product performing design iterations to constantly revise the industrial design or tooling phases. It is very helpful to control large backlogs of design projects.</td>
<td>This indicator is calculated as the subtraction of the design start date from the completed design sign-off date.</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Completed design sign-off date</strong> − <strong>Design start date</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Necessary information:**
- Completed design sign-off date
- Design start date

**Cautions:**
Using this indicator should be taken into account that usually, the end of the design process is not just a decision of the design team but also of other departments.
<table>
<thead>
<tr>
<th>29.</th>
<th><strong>Indicator:</strong> Percentage of floor utilization [27, p. 206]</th>
</tr>
</thead>
</table>

**Description:**
This indicator controls the efficient use of available floor space and therefore, the success in design of the production process. If the percentage of floor utilization is low means that a company can squeeze the maximum amount of production out of its expensive existing facilities.

**Formula:**
This indicators is calculated as the division of amount of floor space used for machinery, operator and materials movement by total floor space.

\[
\frac{\text{Amount of floor space used for machinery, operator and materials movement}}{\text{Total floor space}}
\]

**Necessary information:**
- Amount of floor space used for machinery, operator and materials movement.
- Total floor space

**Cautions:**
Sometimes, a low level of this indicator may interfere with proper logistical flow lines through the facility and result in longer travel times for materials.

**TABLE 31: PERCENTAGE OF FLOOR UTILIZATION**
### 30. **Indicator:**
Average time to hire [27, p. 210]

#### Description:
This indicator reflects the average period of time used by the human resources department to contract employees for the job searches. Therefore, this indicator is used to control the ability to hire staff within a reasonable period of time.

#### Formula:
This indicator is calculated as the division of the sum for all completed job searches of the subtraction from the offer acceptance date of the job application date, by the number of completed job searches.

\[
\frac{\text{Sum for all completed job searches}}{\text{Number of completed job searches}} = \frac{\text{Job acceptance date} - \text{Job application date}}{N}
\]

#### Necessary information:
- Job acceptance date of every job search
- Job application date of every job search
- Number of completed job searches

#### Cautions:
Calculating this indicator should be considered that lower-quality employees may be hired in order to reduce the level of it, which is not a good performance of the human resources department. In addition, the duration of the hiring process may be incremented by the management department which can refuse candidates and doesn’t give a real control to human resources department. For this reason, this indicator should be combined with other to judge the performance of human resources department.

| TABLE 32: AVERAGE TIME TO HIRE |  |  |
### Indicator:
Late personnel requisitions ratio [27, p. 211]

### Description:
This indicator is very useful to control the scale of a company’s recruiting difficulties. It reflects the amount of jobs searches without success, and therefore can be an indicator to judge the performance of the human resource department.

### Formula:
This indicators is calculated as de division of the number of personnel requisitions open more than a defined number of days by the number of personnel requisitions opened during past three months.

\[
\frac{\text{Number of personnel requisitions open more than xxx days}}{\text{Number of personnel requisitions opened during past three months}}
\]

### Necessary information:
- Number of personnel requisitions open more than xxx days
- Number of personnel requisitions opened during past three months

### Cautions:
During the calculation of this indicator is not considered that some unfilled jobs could be more important for the company than others. In addition this indicator can be manipulated by cancelling a job search and creating a new one.

<table>
<thead>
<tr>
<th>31.</th>
<th><strong>Indicator:</strong> Late personnel requisitions ratio [27, p. 211]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Description:</strong></td>
<td>This indicator is very useful to control the scale of a company’s recruiting difficulties. It reflects the amount of jobs searches without success, and therefore can be an indicator to judge the performance of the human resource department.</td>
</tr>
<tr>
<td><strong>Formula:</strong></td>
<td>This indicators is calculated as de division of the number of personnel requisitions open more than a defined number of days by the number of personnel requisitions opened during past three months.</td>
</tr>
<tr>
<td><strong>Necessary information:</strong></td>
<td>Number of personnel requisitions open more than xxx days, Number of personnel requisitions opened during past three months</td>
</tr>
<tr>
<td><strong>Cautions:</strong></td>
<td>During the calculation of this indicator is not considered that some unfilled jobs could be more important for the company than others. In addition this indicator can be manipulated by cancelling a job search and creating a new one.</td>
</tr>
</tbody>
</table>
### Indicator:
Average duration of delivery [29, p. 100]

### Description:
This indicator reflects the average period of time that a company needs to deliver its products, since the order is finished until it arrives to the customer. It is useful to control due dates and set realistic due dates for products.

### Formula:
This indicator is calculated as the division of lead time of deliveries by the number of deliveries.

\[
\text{Average duration of delivery} = \frac{\text{Lead time of deliveries}}{\text{Number of deliveries}}
\]

### Necessary Information:
- Lead time of deliveries
- Number of deliveries

### Cautions:
The calculation of this indicator only makes sense if the deliveries considered are similar in distance. Considering this indicator to calculate the average duration of deliveries of international and national deliveries and predict the realistic due dates will result in delayed deliveries to international customers and early deliveries to national customers.

**Table 34: Average Duration of Delivery**
3.3.3 Filter

Once collected indicators and described them, the next step is to filter them selecting which are suitable and which not to control a one-item production process, particularly in the production of tanks. This decisions are made considering as criteria the special requirements of this type of production process previously described.

1. **Constraint productivity:** this indicator in mass production is useful for constraint operations which is not useful for project production. Nevertheless, this indicator can be adapted to provide good information in tank production measuring the information needed during larger periods, as months or quarters, and considering the productivity of the company and not only of one operation. Using this indicator KRESTA could control the number of tanks produced during a period of time, considering the existence of periods waiting for orders and subtracting them from the total of worked hours.

2. **Takt time:** in tank production every order demands a different type of tank with different characteristics and requirements. Therefore, the duration of the process will depend on the order, some orders will need long periods of time and others short periods of time. For these reasons, determining an average time to produce every order is not useful in one-item production. In addition, in this case where products are made to order and one by one, forecasting the demand can result a difficult activity.

3. **Constraint rework percentage:** as the anterior indicator, this indicator is also used to control constraint operations in mass production. However, it can be very useful in project production to assess employees’ skills and resources. In tank production, rework can be defined as the work whose objective is to fix defects found during the process, like extra time to achieve the desired requirements. Measuring the number of hours that operators invest in fixing or improving operations can reflect the ability of employees and resources to achieve objectives at once.

4. **Constraint schedule attainment:** this indicator controls the amount of production passing through the bottleneck operation. Trying to adapt this indicator in one-item production is not possible, the constraint operation is changing for every process and in every process just one product passes through all the operations. Therefore it doesn’t exist any production plan for operations.

5. **Constraint utilization:** this indicator is used in mass production to control the utilization of a constraint operation. In tank production this indicator can be used with some adoptions, due to in this type of production doesn’t make sense to control the utilization of every constraint operation in every process because the process won’t be repeated. Nevertheless, in tank production some resources, machines or equipment are reused from one process to another, this indicator could result useful to control the
utilization of this reused resources to inform which resources are the most used within the company and which are no longer necessary.

6. **Degree of unbalance**: this indicator is very useful in mass production to enhance the process improving the capacity of the bottleneck operation. In the case of tank production, this indicator is not useful because every process is just performed once, and getting information about the degree of unbalance of the process is not interesting as any improving activities can be performed.

7. **Manufacturing critical path time (MCT)**: this indicator can be used in mass production and project production almost in the same way. The difference is that in mass production this indicator can be based in previous runs of the process, so in real evidence, while in tank production it will be based in predictions which makes this indicator less accurate. Nevertheless, it can be a useful tool for KRESTA to set realistic due dates.

8. **Manufacturing efficiency**: this indicator doesn’t need any adaption to use it in tank production, for every process can be calculated the manufacturing efficiency of operators and equipment and use it to drive actions not in the process which won’t be repeated but in the working team.

9. **Manufacturing effectiveness**: this indicator can be adapted to tank production, considering as constraint hours the total hours of the process, resulting the inverse of manufacturing efficiency. The only difference will be between the concepts throughput hours shipped which are the amount of hours used to produce the shipment, without rework and downtimes, and the value-added hours which are the hours used to add-value to the final product.

10. **Productivity index**: in tank production the inputs, output and the process are defined depending on the characteristics and requirements of the order, and this combination is performed to produce the desired tank. The process is just executed once. For this reason, in tank production it is not possible to make experiments and change inputs to measure the change in outputs.

11. **Unit output per direct labor hour**: this indicator is not useful in tank production as in every process just one output is produced.

12. **Average equipment setup time**: this indicator is not useful in tank production because it doesn’t produce continuously but to order. Downtime between production processes is not critical, sometimes a production process can start just after the ending of another and sometimes can exist a large period waiting for an order.

13. **Unscheduled machine downtime percentage**: this indicator can be used in tank production considering it as the relation between the time during the machine is broke
3. **Practical**

down and the total time the machine is needed, considering all the processes performed during a specific period of time. This indicator will provide information about the performance of the resources that the company is using.

14. **Acceptable product completion percentage:** in tank production during every process just on product is produced, therefore there’s no place for rejected products, if errors during the production are detected corrective action must be taken to solve them. For this reason, this indicator can’t be calculated in tank production.

15. **Scrap percentage:** this indicator is very useful in tank production because customized products tend to create more scrap as they need more specific processes which are not as developed as the ones in mass production are. It doesn’t need any adaptation to be suitable for project production, but it’s important to consider that in case of customized products the calculation of a standard price become harder than in standardized products and that result in a less accurate indicator than in mass production.

16. **On-time delivery ratio:** this indicator doesn’t need any information about the production process, therefore it can be directly used in tank production.

17. **Production schedule accuracy:** this indicator is suitable and very useful for tank production. It can be used to assess the completion of orders considering the number of scheduled orders during a period of time and the number of orders completed, as well as to assess the completion of tasks within a process to complete an order.

18. **Operational equipment effectiveness:** this indicator is not suitable in tank operation because in this type of production doesn’t suit the concept of run rate, understood as number of units per unit of operating time, which is used to calculate the performance efficiency. In addition, the concept of quality defined in the description can’t be calculated in tank production as just one product is produced and there’s no place for rejected products.

19. **Bill of materials accuracy:** this indicator can be used in tank production directly, as it is used in mass production, to assess the overall performance of the engineering department in designing the product. In addition, it can be very useful in tank production where every product requires a new bill of materials and sometimes it can result very inaccurate.

20. **Labor routing accuracy:** this indicator can be used in tank production to assess the performance of the engineering department in planning the process. Nevertheless, as tank production is not as strict as mass production the level of this indicator can’t be compared to the same in mass production.
21. **Percentage of new parts used in new products**: this indicator can result very interesting in tank production. As explained several times before, in this kind of production a new product is designed for every order, this indicator can be a motivation to try to use existent or already designed parts to design new products and therefore save time and money.

22. **Emergency man hours percentage**: this indicator can be useful in tank production to control the amount of problems that occur within the company and that need direct labor hours to solve it. It usually doesn’t depend on the product that is being produced but on the resources, therefore it assess the performance and state of the resources.

23. **Percentage of overtime**: to use this indicator in tank production any adaption is needed. It will provide information of the performance of operators and resources and also of the scheduling. Nevertheless, more indicators will be needed to identify the contribution of each part.

24. **Equipment uptime**: this indicator is calculated using the desired uptime which consider the demand forecast, in tank production forecasting the demand is a very difficult issue so, it will result very hard to obtain the information to calculate it.

25. **Flexibility of production**: tank production is a flexible process by definition, therefore it doesn’t make any sense to use an indicator to assess its flexibility. In this type of production every order is a special order, thus the flexibility of production is always 100%.

26. **Warranty claims**: the calculation of this indicator doesn’t depend on production process, therefore it is as suitable for tank production as it is for mass production. Nevertheless, the level of it in tank production should be much lower than in mass production.

27. **Average number of distinct products per design platform**: this indicator is very useful in mass production to motivate them to become a little more flexible trying to produce different products using the same design platform and saving different production lines. In the case of tank production it can be used to motivate engineers to design tanks using the same design platform, and therefore to try to standardize some part of the process. Obviously this can only be possible when some of the requirements of the tanks are similar.

28. **Time from design inception to production**: this indicator is very useful to control time in tank production because in every order the tank has to be designed to fulfil all the customer requirements, and that can involve a large period of time. For this reason
3. Practical

this indicator is important to control this period and motivate engineers to reduce design time.

29. Percentage of floor utilization: this indicator is useful in mass customization to assess the location of the machinery, operators and materials in the process line to make an efficient use of the available space. This concept in tank production or project production doesn’t make much sense because the resources are flexible and changeable and for every process different resources can be used and located.

30. Average time to hire: this indicator doesn’t depend on the type of production, therefore it can be directly used in tank production. It is special important in project production where every order might need new requirements and therefore new specialized employees. A high level in this indicator will cause delays in the process.

31. Late personnel requisitions ratio: this indicator is useful in mass production to assess the performance of the human resources department. It doesn’t depend on the production process and therefore could be suitable for tank production, nevertheless it is not because it’s based in the concept of established processes which doesn’t have a scheduled end. In case of tank production, being more than three months without finding a person to perform the needed work will mean huge delays in orders, and what’s more, the incompletion of the order. Therefore this indicator make no sense in project production.

32. Average duration of delivery: this indicator doesn’t depend on the kind of production performed, therefore it is suitable for tank production and very useful to forecast due dates of orders.
4 Results

After analysing each indicator and justifying whether it is suitable or not, the results are presented in a table classifying the indicators as suitable or unsuitable for tank production. As can be noticed, from 32 indicator that have been collected, 21 of them are suitable to control project production and tank production. On the other hand, 11 indicators of the collection made are not suitable to control tank production, and therefore they just can be used in mass production.

It is necessary to notice that within this work just a collection of indicators have been analysed, and therefore can be found more indicators that can be useful in tank production. There are a lot of indicators to control different aspects of the production and the amount of them is still growing as the processes develop.
<table>
<thead>
<tr>
<th>Suitable indicators</th>
<th>Unsuitable indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constraint productivity</td>
<td>Takt time</td>
</tr>
<tr>
<td>Constraint rework</td>
<td>Constraint schedule attainment</td>
</tr>
<tr>
<td>Constraint utilization</td>
<td>Degree of unbalance</td>
</tr>
<tr>
<td>Manufacturing critical path time (MCT)</td>
<td>Productivity index</td>
</tr>
<tr>
<td>Manufacturing efficiency</td>
<td>Unit output per direct labor hour</td>
</tr>
<tr>
<td>Manufacturing effectiveness</td>
<td>Average equipment setup time</td>
</tr>
<tr>
<td>Unscheduled machine downtime percentage</td>
<td>Acceptable product completion percentage</td>
</tr>
<tr>
<td>Scrap percentage</td>
<td>Operational equipment effectiveness</td>
</tr>
<tr>
<td>On-time delivery ratio</td>
<td>Equipment uptime</td>
</tr>
<tr>
<td>Production schedule accuracy</td>
<td>Flexibility of production</td>
</tr>
<tr>
<td>Bill of materials accuracy</td>
<td>Percentage of floor utilization</td>
</tr>
<tr>
<td>Labor routing accuracy</td>
<td></td>
</tr>
<tr>
<td>Percentage of new parts used in new products</td>
<td></td>
</tr>
<tr>
<td>Emergency man hours percentage</td>
<td></td>
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<tr>
<td>Percentage of overtime</td>
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<tr>
<td>Warranty claims</td>
<td></td>
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<tr>
<td>Average number of distinct products per design platform</td>
<td></td>
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<tr>
<td>Time from design inception to production</td>
<td></td>
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<tr>
<td>Average time to hire</td>
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<tr>
<td>Late personnel requisitions ratio</td>
<td></td>
</tr>
<tr>
<td>Average duration of delivery</td>
<td></td>
</tr>
</tbody>
</table>

**Table 35: Results Summary**
5 Conclusions

To conclude, concerning the studied field, during the completion of this thesis a deep analysis about production processes and their control has been performed, which has result very useful to understand the differences between production processes depending on the requirements of the market, and how they affect the company direction, management and control. In addition, it has highlighted the importance of the control of processes and the amount of existent approaches related to it, as well as the importance in them of the use of indicators to get data and information about processes and create knowledge. Finally, several indicators have been studied and some of them selected as suitable to control tank production processes.

On the other hand, concerning the personal development, performing this thesis have been a spurn to enhance my research techniques and to discover all the available possibilities to get reliable information. Furthermore, the fact of doing it in a foreign language has improved my writing skills and reading comprehension.

From my point of view, nowadays project process are considered old-fashioned and not useful by common people. When people think in efficient production they always imagine lines of production with static machines where products pass through one operation to another without stopping. Nevertheless, project processes are very useful in industry because not all the requirements can be fulfilled by standard products, sometimes customized products are needed even the production of them is less efficient and more expensive than standard production. For this reason, I think that the development of this processes and the methods to control them is very necessary to achieve improvements in their efficiency.
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