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FACULTY OF BUSINESS ECONOMICS
Master of Management: Management Information Systems

Masterproef
How can business process analytics support lean manufacturing?

Promotor :
Prof. dr. Benoit DEPAIRE

Feras Alqudah
Master Thesis nominated to obtain the degree of Master of Management , specialization Management Information Systems

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How can Business Process Analytics support Lean Manufacturing?

Feras Ali AlQudah

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Supervised by: Prof. Dr. Benoit Depaire

Preface

I would like to thank God for giving me the strength, patience, and guidance to go through this research. I wish also to thank the University of Hasselt for giving me the opportunity to purse my degree.

I wish to express my genuine appreciation to my advisor Prof. dr. Benoit Depaire for his unlimited support, direction, advice, and patience with me during the preparation for this study.

I would like to thank my parents for the moral support; without them I would not be where I am. I wish to thank my sisters and brothers for encouraging me through this research.

I also would like to thank my friends for the support and for being helpful through this research.

Summary

This study addresses the application of Process analytics techniques. The goal of this research is to investigate how process analytics tools and techniques can support the goals, concepts and tools of lean manufacturing. There is an overlapping between these two subjects, but each has its characteristics. This study attempts to state the area of intersection between the different techniques, tools and goals for each subject. This master thesis contains five chapters in try to achieve the goal of the master thesis which is identifying different process analytics techniques that aid Lean manufacturing at the different stages of waste reduction.

In the first chapter, the problem definition is stated. According to this, the research question is formulated with sub questions are stated that try to give an answer on the research question. This chapter also contains the research methodology that was used to perform this master thesis.

In the second chapter contains introduction of lean manufacturing methodology presented. This chapter can be described into three sections, the first section discussed the history of lean manufacturing, how it first invented, then the changes happened to lean when adopted Lean manufacturing then definition of lean is discussed and the main goal of this managerial approach and what is it really. In the second section of the second chapter the main concepts of lean mentioned and some of them discussed to address what is main focus of Lean and what formulate Lean's philosophy. In the third and the last subsection the study addressed the different tools of Lean that leads to achieve the goals and the concepts of Lean such as Kaizen, Kanaban, 5s, cellular manufacturing, setup time reduction.

In the third chapter introduction of process analytics presented. In the first subsection different types of process analytics discussed, what the characteristics of each of them are. In the second subsection different tools are presented such as simulation, dashboards, and data mining, in the thirds subsection business process mining is discussed, what are types of business process mining, process mining techniques, and business process modeling languages, at the last subsection statistical process control presented, such as Pareto analysis, scatter diagrams, cause and effect analysis, and Stratification.

In the fourth chapter the linkage between process analytics techniques and lean manufacturing presented.

The fifth and final chapter contains the conclusions and recommendations. In the conclusions, an answer to the research questions and the sub question is given. Finally, additional recommendations are formulated for possible future research.

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CHAPTER 1: Introduction

1.1. Background

In the last few decades, the industrial sector witnessed a very huge jump in managerial concepts and strategies which affect production, organization, delivery strategies and procedures, to improve each phase and level of the production system, aiming to reduce production time, lower product cost, more quality and added value in the final finished product of the production process (Helen E 2012). This forces organizations to find, adopt and develop new managerial philosophies and approaches. Competition is not the only motivation of developing creative methodologies, the increasing awareness of the clients, demand from customers to achieve high quality valuable products, the need to lower production cost which enables organizations to compete at pricing level; all together with other business aspects were the motivators behind it (Antony 2006).

The lean manufacturing system or Toyota production system which was founded by Toyota in Japan in the 1960s was one of those approaches to help Toyota to compete in the market with American firms. Lean production made a lot of interest around its philosophy from different community's organizations, academics, and industries (Helen Cpress 2012). Lean production is adopted by a wide range of industries and organizations all around the world (Smeds, 1994).

Mainly, lean production came to replace the old mass production approach. It focuses on changes in different levels to have competitive advantages, and to add value to the product, reduce the lead time, reduce the cost through the reduction of inventories, errors, and rework, (which is defined as waste in lean production philosophy). Waste in lean philosophy must be eliminated because it's not affecting the value of the final product (Womack 1990). Lean production look at the whole process life cycle of production from raw material and production process to customer service (de Treville&antonkis 2006).

This system was lately accepted and applied in other firms where it shows good results in not just the supply chain, inventory management, improving the flow of the production process, but it also shows positive results in increasing customer satisfaction (Helen E. 2012). Lean production got an interest by professionals and researchers. There are a huge number of researches, articles written about lean production philosophy and its concept and tools (Helen E. 2012).

Lean production it's about improvements to gain maximum advantages and is known as the manufacturing practice for the twenty first century (Farris, Van Aken, Doolen, & Worley, 2009), "organizations need to find a way to enable its success, thereby achieving benefits that include reducing waste, improving cost, and enabling competitiveness" (Helen E. 2012).

Figure 1.1 Lean Production Principles

On the parallel side, business process analytics hold very potential abilities in the field of process discovery, modeling, controlling and simulation. At the same time there is similarity in its way of working, purposes and final results with different Lean tools and techniques. These abilities and similarity open the door to extensive studies around success expectation of linking different process analytics techniques within different Lean manufacturing tools and principles. The similarity in purpose can be noticed since one of process analytics purposes processes improvement by providing more understanding about the process behavior, performance, and how different processes interact with each other and with the elements within the environment.

Business Process analytics can provide process analysts, participants, decision makers and related stakeholders with deep perception of the efficiency and effectiveness of processes (zur Muehlen, M.; Shapiro, R, 2010). From a performance perspective, the purpose of process analytics is to reduce the time needed for decision makers to make their decision, which in turn will affect process performance (zur Muehlen, M.; Shapiro, R, 2010).

Linking Business process analytic to the lean production process increases an organization's chances to gain competitive advantage from applying lean production by understanding internal processes and representing the behavior of processes when a defect appears and analyzes the effect of the processes, and in case of elimination of the waste what is the results on overall process. All of that came in convenience with lean production approach.
Business Process analysis as a concept first appeared in the mid 90's and was conducted first by Agrawal, Gumopulos, and Leymann (1998) in the context of workflow management.Business process management systems (BPMS) can be considered as main source of documented events and execution of the processes within the system. BPMS is a collection of process analysis techniques that applies on event logs to assists and help to understand the situation prior to taking action in decision making (zur Muehlen, M.; Shapiro, R, 2010).
Process analysis is considered as a major technique in business process reengineering during the 1990s (Hammer; 1993). Process analysis allows stakeholders and decision makers to view business processes and system graphically to help in eliminating of the waste in these processes (Sherry Xiaoyun Sun 2007).

1.2. Thesis Objective

1.2.1. Research question

How can business process analytics support lean manufacturing?

The main objective of this thesis is to show how process analysis techniques can aid in improving lean production through the different stages of waste reduction, and to show how we can gain improvement through using process analysis techniques.
This study will come after many studies around lean production, and its improvement, or combine with other theories.

Because the perfection is non-ended process this study aims to show how can we improve lean production theory by introducing process analytic techniques through each stage of lean production due to the similarity between the purpose of the techniques and lean production philosophy, then identify the result and figure out the limitations of using the techniques when applying lean production philosophy.

The importance of the current study coming from the importance of lean production theory itself, being widely used around the world by organizations, these organization also looking for more perfection in applying lean production.

1.2.2. Sub questions

To answer the research question, it's very useful to start making question in function of the research question. Lean manufacturing can be linked to process analytics. Therefore it can be useful to investigate Lean manufacturing and its concept.

The first sub question is:

What are Lean manufacturing and the concept, and principles behind?

As stated in the problem definition, Lean manufacturing is a great managerial approach, this study will discuss lean manufacturing and the concept behind it.

The Second sub question:

What are the different tools of Lean manufacturing?

Lean manufacturing come with several tools that aims to serve the principles of lean manufacturing and the main idea behind the philosophy of lean manufacturing. This study will try to discuss these tools and to show the characteristics of each tool.

The third sub question:

What are the characteristic of process analytics?

As stated in the problem definition, a wide range of techniques for process analytics, this study will try to discuss the characteristics of each one of them and try to show how can processes improved within process metrics, what are the different tools within process analytics and what is the purpose of each one.

In order to find how business process analytics can support lean manufacturing, it's important to understand what business process analytics is, what the purpose of business process analytics is, and what are the different types and approaches of business process analytics.

With studying the characteristics of business process analytics techniques we can have a clear view about the areas that can each techniques serve, and aid lean tools in achieving the goals of each, if it can be applicable within that tool according to the characteristics of each lean and process analysis techniques and tools.

The fourth sub question:

What can lean manufacturing gain from business process analytics?

This study intended to discuss and show what can Lean manufacturing benefits from different business process analytics techniques according to the similar characteristics between them. This study will try to show the role of each tool and technique in different lean manufacturing tools that serves the goals of lean manufacturing.

1.3. Research methodology

To meet the thesis objective and to fulfill it, the methodology based on using the existing information and knowledge of both lean production will be combined together to fulfill thesis objective.

The articles and other theses were founded by using different sources, scientific databases and Google Scholar. Hasselt University provides a long list of scientific databases in which the University is a member, when visit these online sources, like Emerald Insight, ProQuest, ebscohost, etc.

To find the topics related to the two subjects certain key words were used through the scientific databases, Google Scholar, and library: “lean production, Process controlling, lean manufacturer, process analytic techniques, Business Process Management, process mining, lean framework, process discovery, six sigma, and data control”. A very important source about lean frame production were two books: “The machine that changed the world” (Womak et al.; 1990) which gives the basic information about lean production and how it’s originally founded, and “lean thinking” (Womak et al. 1996).The later book was very useful to get to know the practical aspects of lean production in organizations. About process mining I found a very good book written by van der Aalst 2011

1.4. Structure of the thesis

This Chapter provides an introduction to the thesis, by reading this chapter reader will find the importance of the study, what this thesis is all about, the purpose of the study and an introduction to the subject.

Chapter two will include a literature review on lean production theory, what is Lean Production, where does it come from, what are the main concept and principles, different tools and their purpose usage, and phases of lean thinking.

Chapter three will include literature review on business process analytics, what is business process analytics, what are different types of process analytics and the purpose of each one. It will also include literature review about statistical process control and its different analytical tools.

Chapter Four will include the linkage between lean manufacturing and process analytics, by showing possible tools that can be used to achieve Lean's goals and how can these techniques support different Lean's tools.

Chapter five and the final chapter contain the conclusions and recommendations. In the conclusions, an answer to the research questions and the sub question is given. Finally, additional recommendations are formulated for possible future research.

CHAPTER 2: Literature review: Lean Production

2.1. History of Lean Production:

Firms realized the importance of innovative methodologies in production, its effect in giving competitive advantages over the competitors, reducing cost, reducing lean time, also reducing material spaces in inventories. There is a various number of methodologies appears to provide the competitive advantage, with consideration of firm's characteristics, nature of industry involved, and the environmental conditions. Currently three of the most popular methodologies are Six Sigma, lean production, and theory of constraints. (Utts et. Al., 2005).

Lately, industrial organizations adopted a variety of management methodology to grant competitive advantages in the market over other firms, to improve production process to result improved final product to compete attract customers and improve their brands, marketing name, after adopting one of the methodologies and their tools or the way of thinking it will help the organizations to avoid most of their problems. (Dave Nave, 2002)

Mass production was one of the first methodologies raised to satisfy industrial needs at that time. In 1908 ford come up with Mass production methodology, mass production "*is the complete and consistent interchangeability of parts and the simplicity of attaching them to each other"* (Womak et. Al.; 1990).

Main idea of mass production is that to reduce cost by using gauging system and this would be achieved by using assembly lines, these assembly lines. By providing interchangeability, simplicity, and ease of attachment, these assembly lines give the competitive advantage over the competitors. In other words, a worker has a single or a few tasks during lead time, using the same tools all the time, so he will become more experienced in his work. Mass production also means minimizing the movement of the worker. On the other hand, mass production also cares about cost; its philosophy says that the cost of producing a thousand products is less than producing ten especially when the products are identical. (Hounshell, David A., 1984; James P., Danial Jones, Danial Rose, 1990).

The term *Lean* was first introduced by James Womack et al in the story of the Japanese car industry in "*The Machine That Changed the World"* book. The book mentions and describes the Toyota production system, and how Toyota was able to minimize waste, add value to products, and meets customer's needs (Womack et. Al., 1990). According to George (2002) Henry Ford was the first one who introduced the lean idea to the industry by trying to decrease lead time through reducing slowness in supply materials process. From here the concept of Just-in-Time (JIT) manufacturing later founded. On the other hand, Ford failed to create the value that satisfies customer's needs.

Toyota realized what Henry Ford wants to do in inventory management and based their manufacturing model on Ford's model to gain better improvements for the production process (Marianne Engum, 2009).
When Ford applied his strategy and after achieving high productivity and low inventories; Toyota adopted Lean manufacturing. It has been developed to suit the Japanese market and culture characteristics, whereas Japanese market is known with rare of raw materials which results in higher cost of production (Sugimori, Kusunoki, Cho, & Uchikawa, 1977). Toyota founded Just-in-Time which considered as a key element of lean production which is opposite the US production system to produce in high volumes, large numbers, and long non-value added queue. Lean management adopted small batch sizes, and not to add anything unless it's needed by the customers and this was due the lack of raw materials in Japan (Gideon Francois Jacobs, 2010).

2.2. <u>What is Lean Manufacturing?</u>

Lean manufacturing is a manufacturing philosophy which focuses on delivering high quality products at the lowest price and at proper time. Lean manufacturing focuses on eliminating waste or non-value added activities (Womack and Jones; 1996).
According to Devane (2004), the value of Lean was noticed in principles for improving workflow, decreasing setup time, and eliminating waste.

“Lean thinking is *Lean* because it provides a way to do more and more with less and less – less human effort, less equipment, less time, and less space – while coming closer and closer to providing customers with exactly what they want” (Womack and Jones; 1996).

Lean manufacturing methodology leads to more satisfying work by providing immediate feedback on work and effort to convert muda into value, also to reengineer the way of working and reform the work process instead of destroying jobs (Womack and Jones, lean thinking, 1996).
Where Muda according to Womack and Jones (1996) means waste “specifically any human activity which absorbs resources but creates no value”.

The main goal of Lean production is eliminating of waste, for that every activity or event done through the value stream creates value is called perfection. This perfection can be achieved through performing kaizen approach- **Kaizen** is a Japanese term meaning “to change and make good” (Womack and Jones, lean thinking, 1996) Kaizen will be discussed later in this study-, or kaikaku - **Kaikaku:** the term kaikaku in Japanese is generally reserved for the initial rethinking of a process (Womack and Jones, lean thinking, 1996) - were both aimed to reduce waste. But perfection and completely elimination or in other words reduction of waste in non-ended process, so these events and activities should be performed reactively to improve the elimination process (Womack and Jones, 1996).
Another aspect in Lean production is reduction of variability which includes demand, manufacturing (quality and existence), and supplier variability. Adopting lean production will significantly reduce lead time that will allow practicing make-to-order production with on time delivery of production, although when make-to-stock approach is in applied. One of the most benefits of reducing lead time is helping in lowering inventories through the supply chain (TQM Magazine, 2005). **Make-to-order** is a production approach where products are built only when order received for making (Holweg M. and Pil F., 2001), **Make-to-Stock “**is a build-ahead production approach in which production plans may be based upon sales forecasts and/or historical demand” (parry, Glenn, Andrew, 2008).
There are three types of waste defined in lean production muda, m*uri*, and m*ura.* Muri is too difficult, beyond one's power (Emiliani, Bob; Stec, David; Grasso, Lawrence; Stodder, James, 2007)

including bad work conditions. Mura means irregularity; lack of uniformity; non-uniformity (Kenkyusha's New Japanese-English Dictionary, 2003),

Since the goal of Lean is to eliminate of waste “*Muda”* what is considered as waste, according to Womack, James P.; Daniel T. Jones in their book lean thinking:

- Transport: (moving products that are not actually required to perform the processing)
- Inventory: the waste in inventory appears when the final product is not shipped on time, or any of the materials waits too long before using during production process.
- Motion: it’s the movement of any of the production elements human or tools , the waste appears when there is an unneeded movement, this movement does not add any value or the elimination of it affect the production process.
- Waiting: waiting can be seen when one of the lines waiting for another part from another line, or supplier which result increasing lead time.
- Overproduction: over production can be seen when there is sequence of production which needs to assemble different parts together, where in certain step one production line depends on another so it’s important to not product more than the next line need this will lead to over production.
- Over processing: this waste results from poor tool or skill which leads to do the process more than needed to assure that the output fits the standards.
- Defects: it’s the effort done for fixing the errors which appear in the products.

2.3. <u>The Principles of Lean Manufacturing</u>

Lean in general focuses on these aspects:

1. Elimination of Waste.
2. Value: “a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer” (Womack and jones 1996). Firms must rethink about what is value because value will differ from firm’s perspective than customer perspective, as it will even differ between firms itself, but the main idea is firms have to listen to customers, involve customers when identifying value to

the product, and this can be direct or indirect through feedback, survey ... etc. (Huskins, 2008).

3. Zero defects.
4. Pull of materials: A pull system is one of the elements in a JIT system, where the downstream process only pulls the materials that they need from the producer (Cooper, Keith, & Macro, 2007).pull “is a system of cascading production and delivery instructions from downstream to upstream activities in which nothing is produced by the upstream supplier until the downstream customer signals a need” (Womack & Jones, 1996).
5. Multifunction teams.
6. Decentralization.
7. Integration of functions.
8. Vertical information.
9. Continuous improvement: when the previous steps are done the reduction of waste increased, so the next step is perfection of the whole procedures and the activities (Stevenson, 2007).
10. Flow: Once value has been specified, it is essential to establish a smooth continuous flow of information, with as few non-value-added processes as possible. The flow should make finished products with the shortest timeline possible, with the best quality, and at the lowest cost (Womack & Jones, 2003).

2.4. Tools in Lean production

The main lean production tools include 5S and visual management, kanban, kaizen, just-in-time (JIT), total quality management (TQM). Each tool mainly applied to serve in achieving one of the aspects in the organization that applying lean production as management methodology.

2.4.1. <u>5S:</u>

5S is a method of sustaining a workplace using disciplines, such as Sort, Straighten, Shine, Standardize, and Sustain. 5S is a good starting point, and the key to waste elimination (DeHamer, 2008). It was translated into English by the authors of *The Machine that Changed the World* (Marianne Engum, 2009). The idea behind 5S is to find waste then try to eliminate it by providing simple visual signals that help in understanding .the situation (Fawaz Abdullah 2003).

In the following the description of each concept in 5S:

Sort: in this step unneeded waste and elements will be declared preparing to be removed (Rizzo, 2008). According to Kenneth Rizzo from GATF, 80% of the items in the area of work will not go back to the process after finishing the Sort stage (Marianne Engum, 2009).

Straighten: the purpose of this step is to remove overcrowded activities and order every element in the production environment starting from the most used and accessed activity. The most accessed activity should be shown, available, and accessible all the time, while less used activities should not slow the process it can be organized in storage (Fawaz Abdullah 2003).in other words, to put every item in order of usage(Cooper, Keith, & Macro, 2007; Rizzo, 2008).

Sustain: in this stage keeping the working environment clean is the purpose after removing of unnecessary activities (elements) (Marianne Engum, 2009). Cleaning also includes physical cleaning like cleaning machines and tools (Fawaz Abdullah 2003).

Systematize: the purpose of this step is to continue working on previous steps to improve the work and assure that activities are working on clean compatible procedures, in other words, continuity of improving (Fawaz Abdullah 2003).

Standardized: in this step tasks and their implementation should be done on standardized procedures to ensure that every task is performed in best practice (Marianne Engum, 2009).

2.4.2. Visual systems

A visual system helps in monitoring elements (machines) involved within production process, which gives us an early alert of coming mistakes that would stop or affect the production. This is also called waste (Fawaz Abdullah 2003).

2.4.3. Kanban Pull System

Kanaban is the Japanese name of Just-in-Time (JIT). Kanban pull system is considered in inventory and its focus of reducing inventory time by signaling upstream that material is needed for the production process. This eliminates the need to stock materials in huge amounts until being used in the process. This will reduce the cost of the inventory (Rizzo, 2008; Cooper, Keith, & Macro, 2007). Kanaban is a tool that receives its trigger for material or product replenishment through customer demand (Young, 1992). There is consideration of a pull system; it is the direct opposite of a push system that moves product or material through the manufacturing process without consideration of a requirement or need.

Kanaban's philosophy is simple: the storage of unused inventory is a waste of resources. Organizations must follow new methods to manage the change. The ideas of working come from many different disciplines including statistics, industrial engineering, production management, and behavioral science (Schonberger, Richard J., 1982).In other words having "the right material, at the right time, at the right place, and in the exact amount" (Schonberger, Richard J., 1982).

To clarify this concept let's take an example. Suppose factory produces a product from one material called X, at the initial point of production there is on bin of X at the floor, one bin of X at the inventory, and one bin of X at the supplier's business. Every bin of X has card holding information about the material, this card is called Kanaban card. When the factory starts working and the floor is empty, a flag of demand is raised (trigger), the empty bin returned to the inventory with its card, the empty bin replaced with the one in inventory so the inventory is out of this material, then the inventory calls the supplier and returns the empty bin with the card. The supplier provides the inventory with the desired material with the exact description on the card. Again this process will be repeated with the exact amount needed each time to reduce the inventory cost.

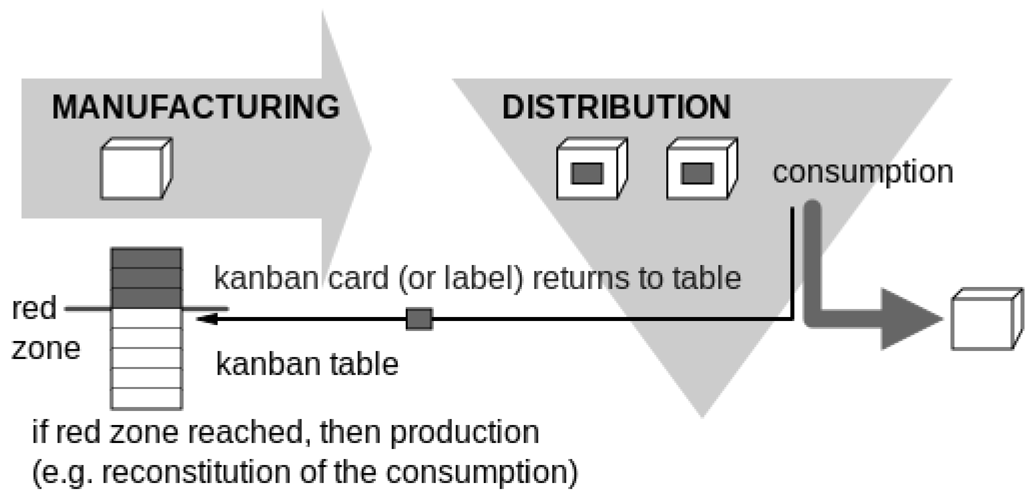

Figure 2.1 Kanaban's principle (Waldner Jean-Baptiste; 1992)

2.4.4. <u>Kaizen:</u>

Kaizen is the Japanese name of Total Quality Management (TQM) the definition of TQM according to Cua et al.: "TQM is a manufacturing program aimed at continuously improving and sustaining quality products and processes by capitalizing on the involvement of management, workforce, suppliers, and customers, in order to meet or exceed customer expectations" (Cua et al., 2001). Kaizen means continuous improvement. The kaizen event is powered by a mixed team of management and workers. According to Berger (1997), there are three principles of kaizen process orientation, improving and maintaining standards, and people orientation. In simple words, Kaizen is improving environment through process improvement that is accomplished by standards and people involvement. According to (Berger, 1997) there are three areas of improvement that kaizen principles can be implemented in these areas will be shown in Table 2.1.

Core Principles	Management improvement concepts	Practical outcomes
Process orientation	Process control through process support and evaluation	Training the workforce in simple methods and use existing skills and experience Effort are emphasized and encouraged while results are rewarded
Small step improvement	Extensive use of standards (SOPs) as the base for improvement Separate the task of improving and the tasks of maintaining standards	Discipline required to maintain standards Focus on improving own work standards using common problem-solving format- PDCA
People orientation	Active management support and involvement “mandatory volunteerism” , i.e. management policy to join but contributions based on volunteerism	Board participation using permanent or temporary groups for problem solving in parallel structures (QCCs and teams) Individual suggestion systems for training and motivation

Table 2.1: Kaizen Principles (Berger, 1997)

2.4.5. Cellular Manufacturing:

“Cellular Manufacturing: is the division of tools and machines into production cells” (Drolet et al., 1996). The concept is to portioning operations into separate production cells that consist of similar processes. The purpose of division these machines and activities into working cell were every cell is a copy of other cells, having the same tasks to finish all of the work in same amount of time required by single cell. Advantages of cellular manufacturing appear through reductions in material handling, set-up time, tooling, WIP, and cycle time (Drolet et al., 1996).

2.4.6. Setup Time Reduction

Setup time reduction is the process of reducing required time for switchover of tools and production elements from production situation into another (Aricr, 2004). Single Minute Exchange of Die (SMED) was created by Shigeo Shingo and understood that machine switchover should be considered as waste and must be eliminated to improve production process (Hopp, Spearman, 2001). Shinge mentioned four conceptual phases through the process of reducing setup time on a machine:

- Internal and External setups are not distinguished
- Separate internal and external setups
- Convert internal setups to external setups
- Streamline the changeover process

The first conceptual phase is just to express that reduction of setup time has not been taken place to improve switchover. The second conceptual phase identifies what is internal setup and what is external setup for certain machine during switchover. The third conceptual phase is to convert internal switchover to external machine switchover. External machine switchover is faster than internal machine switchover. The fourth conceptual phase is to streamline the complete changeover process to eliminate the setup time on machine switchovers. According to Arcir (2004) “Reduced machine setup times allow the production of small batch sizes whereas large setup times require organizations to run large batches of products to compensate for the time lost during setup of the machines”.

CHAPTER 3: Literate Review: Business Process Analytic

3.1. Introduction

Lately, organizations are realizing that business processes analysis and redefinition are significant factors to achieve success in their business. A good design and definition of processes result in more efficiency and better production output (zur Muehlen, M.; Shapiro, R, 2010). Business process analytics are considered as provider for process analysts, participants, decision makers, and related stakeholders with deep perception of the efficiency and effectiveness of processes (zur Muehlen, M.; Shapiro, R, 2010). Form a performance perspective, the purpose of process analytics is to reduce the time needed to have decision made by decision makers; which will affect process performance (zur Muehlen, M.; Shapiro, R, 2010). From a compliance perspective, the purpose of process analytics is to establish the commitment of process execution without encroachment rules and regulations, and to ensure that contractual obligations and quality of service agreements are met (zur Muehlen, M.; Shapiro, R, 2010).

Why business process analytics? The need of business process analytics appears in three different levels. Firstly to evaluate the events and activities that already finished; to have a clear understanding of happened so we could know what will happen now or later.
Secondly, level main concentration in real-time is monitoring of current running events, processes, and activities, so we can realize what is happening on our processes at the performance level or error reports level. Third level main concern and area of interest is forecasting and predict future acting of the processes within its environment, certain factors weather variable factors or static variables, and this results knowing and realize different scenarios and simulations (zur Muehlen, M.; Shapiro, R, 2010).

3.2. Sources for Process Analytics Data

Process analyses are mainly based on the aggregation, correlation, and evaluation of events that occur during a process execution. The events represent changes in the situation of objects within the environment of a business process. These objects could be activities, actors, data elements, information systems, or entire processes, among others. Events are the main interest for analysis process considering that events represent an activity. In other words, a narrowly scoped process analysis might focus on a single activity so measuring and examining those events which created from one activity, its performance, and the resources that are input and output of the activity. In contrast, a more widely scoped process analysis might include events from multiple processes; involve data sources outside the organization and involving events from non-process-centric information systems (zur Muehlen, M.; Shapiro, R, 2010).

Stages of process analytics are represented by figure 3.1 which shows the mixed non-standardized regular IT infrastructure: a BPMS, an electronic content management system, an enterprise resource planning (ERP) platform, and other integrated information systems through enterprise application integration (EAI) solution. Each system between them holds certain abilities and features to perform or represent processes. Each element in the IT infrastructure could be considered as a source of events. The events generated by devoted workflow systems or BPMS represent the most natural source of information for analysis. On the other hand, systems like Electronic Content Management record events those events which are used to discover business events before initialization of a BPMS process, and transactional systems ERP, for example, also manipulation of data taken with process transactions could be recorded by legacy applications. Another source of events that may be produced is EAI platforms. The register- events related to data movement between legacy systems, customized components that are built perform events if they detect changes in systems that are not designed to communicate these changes. Sources of events that are of interest in a process analytics application may also be certain external systems (zur Muehlen, M.; Shapiro, R, 2010).

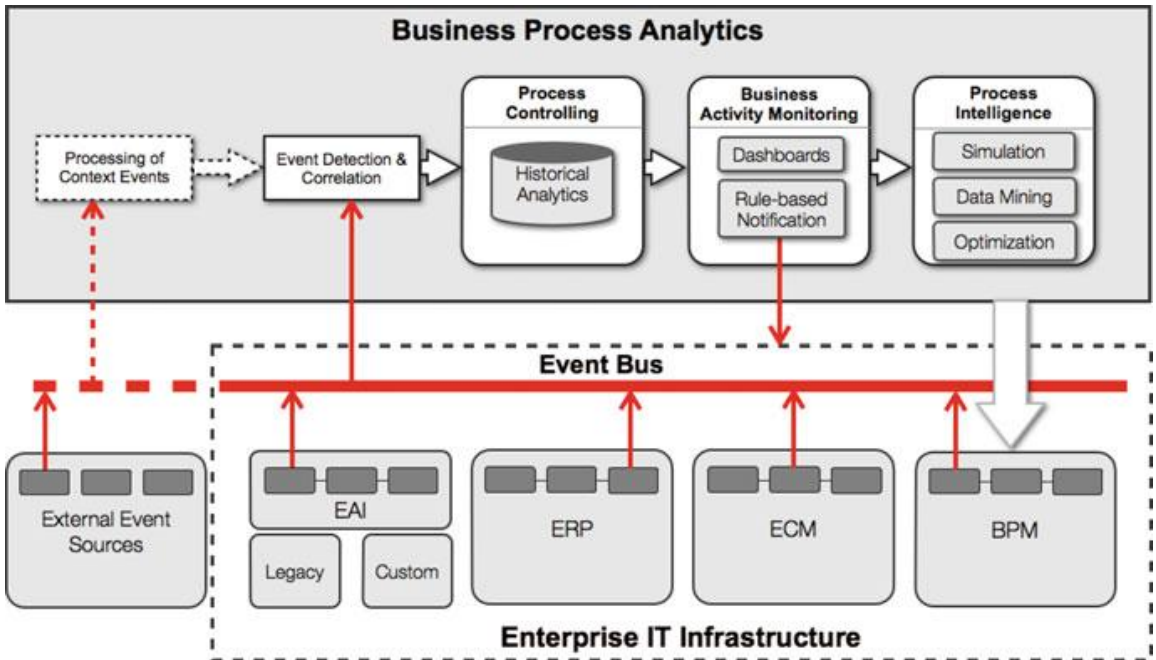

Figure 3.1 Business process analytics in context (zur Muehlen, M.; Shapiro, R, 2010)

Process events are processed in an event detection and correlation stage. Event detection is used to show the changes in operational systems that may not be published by default. Correlation is used to link events that were generated by separate sources to a common process. The resulting information can be used for historical analysis, real-time control, or predictive intelligence (zur Muehlen, M.; Shapiro, R, 2010).

3.3. A Source Format for Process Events

"In order to allow the generic design of a process analytics system, an event format is required that is not specific to the semantics of the underlying process model. Since most BPMS are general-purpose applications in the sense that they are agnostic of the business semantics they support, an event format can be based on the general states a process activity and/or business process traverses through. While each process execution environment may implement a slightly different state machine, a consensus for a standardized state model for audit event purposes has emerged in the BPM software vendor community, as depicted in Figure 3.2. The state machine described here is aligned with the state machines described in the related standard specifications Wf-XML (WfMC 2004) and BPEL4People/WS-Human- Task "(zur Muehlen, M.; Shapiro, R, 2010).

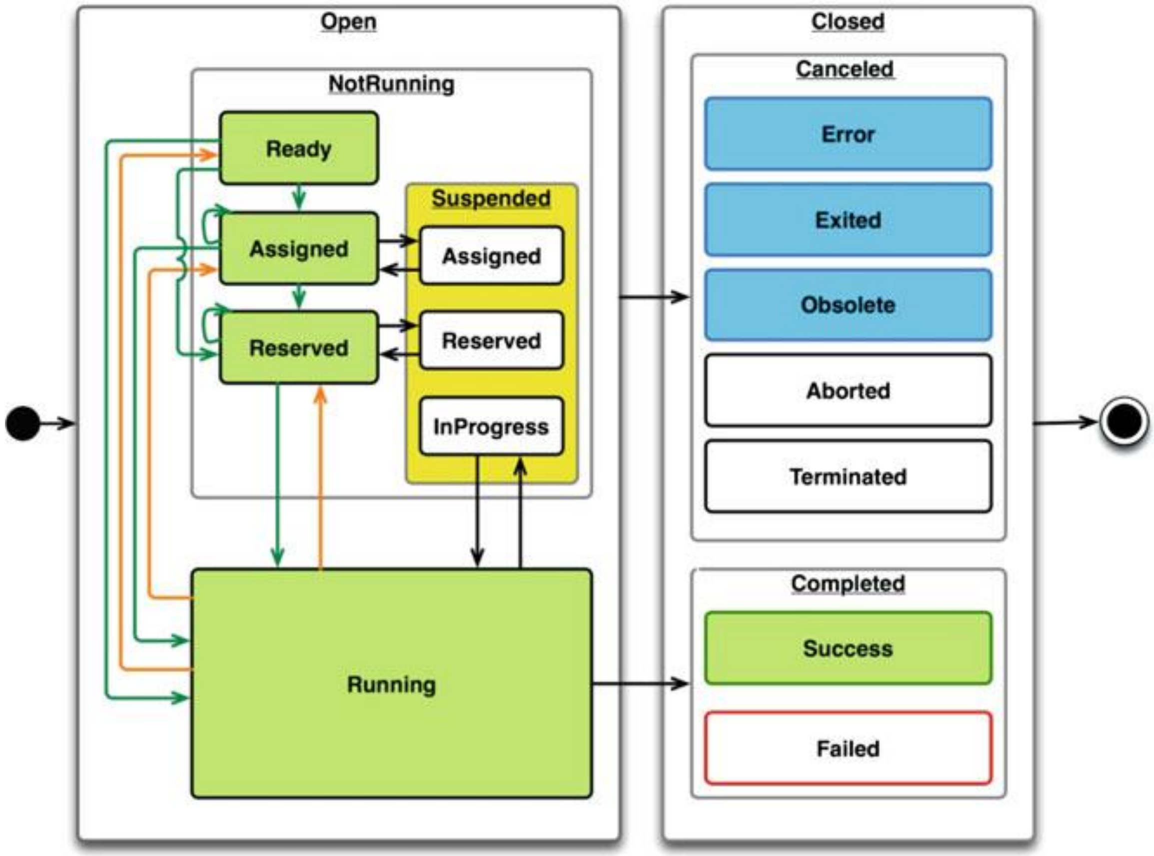

Figure 3.2 Process execution state model (zur Muehlen, M.; Shapiro, R, 2010)

According to previous literature reviews, events produced by a BPMS have exactly a proprietary format, despite that there have been many efforts at standardizing event formats. Figure 3.3 shows the structure of a process analytics event following the XML business process analytics format (BPAF) standard published by the Workflow Management Coalition. An event includes at the minimum a unique identifier, the identifiers of the process definition and instance that it created from, a time stamp, and information about the condition of the process at the time of the event (zur Muehlen, M.; Shapiro, R, 2010).

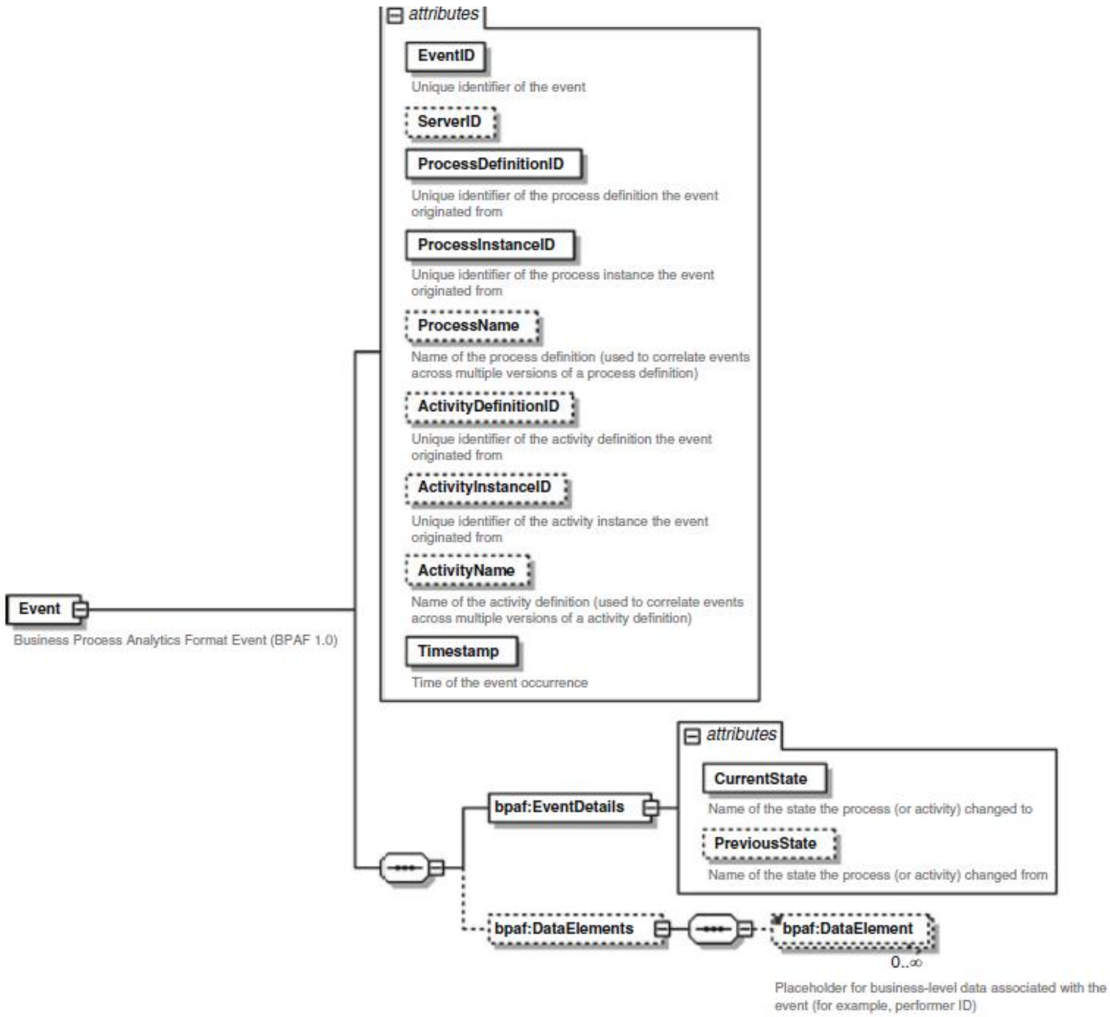

Figure 3.3 BPAF event format (zur Muehlen, M.; Shapiro, R, 2010)

Regarding to this information and the state model that discussed above, there is an ability for the process analytics system to deliver basic frequently and timing information to decision makers, such as (wait times, the cycle times of process and counts of completed versus pending process instances).A number of extra and optional data items can be contained in the event format in order to deliver greater detailed information. An event may contain information about the server that created and generated the event, which is crucial in the distributed execution environment if an analyst is trying to isolate or remove a location specific problem. Moreover, an event may contain the identifier of the activity it relates to, both for the activity definition and the activity instance, to allow for more fine-grained analysis. It may also contain the names of processes or activities to help the total number of events across multiple versions of the same process or activity (since different versions of the same process will typically have different identifiers) (zur Muehlen, M.; Shapiro, R, 2010).

Arbitrary data elements may be surrounded in an event in order to maintain specific business-relevant data that was present at the time of event occurrence. To relate events to individual corporation units, performers or machines; a common use of this field would be in the involvement of the performer ID. Last but not least, an event may include a description of the activity/process state before to its occurrence in order to identify the specific state transition that is already described by the event. This can be effective in situations where a state can be attained from multiple other states. On the other hand, through the use of timestamps this information can typically be regenerated by stepping backward in time through the recorded events (zur Muehlen, M.; Shapiro, R, 2010).

3.4. Process Metrics

Process performance range can be more understandable using analytic figures form absolute measurements, like wait times and cycle times to qualitative measurements, such as customer comments on process, and variance measurements such as service level variability. The most primary process metrics are acquired through analyzing the timestamps of several events that belong to the same process instance. Basic insight into processes behavior can be obtained by noticing and measuring these differences between timestamps. In general, process management systems give us a general perception of the information to be delivered to decision makers. Figure 3.4 shows the traversal of the state model described in Figure 3.3 over the life cycle of a process instance that involves a human performer. Business Process Management system helps in scheduling the process instance to be executed after achieving all of the conditions in Figure3.5 the activity instances placed on work list of a role that may be shared by multiple performers (state Open.Assigned). One of these performers selects the work item (state change to Open.Reserved) and starts working on the activity instance (state change to Open.Running.InProgress) (zur Muehlen, M.; Shapiro, R, 2010).

Upon selection of the work item some Business process management system will move the activity instance into this state automatically, and so will not record the Open.Reserved state. Later on, when user decides to take a break, this result in suspending resumes work on this process instance (state changes to and from Open.Running.Suspended). When continue performing instance, the business process management system changes the state of the instance to Closed.Completed.Success. Every change in the process life cycle will be recorded by business process management system with the current time, the instance ID, and additional data elements, such as the identity of the user performing the process instance, or relevant data that were available at the start of the process instance (zur Muehlen, M.; Shapiro, R, 2010). Based on these events the wait time for each process instance and type can be determined by an analyst. This will provide a general insight into what tasks that user prefers to perform or averse. Differences between tasks selectivity and starter task of the instance show the change over time needed to prepare the activity chain and other event related to this activity (zur Muehlen, M.; Shapiro, R, 2010).

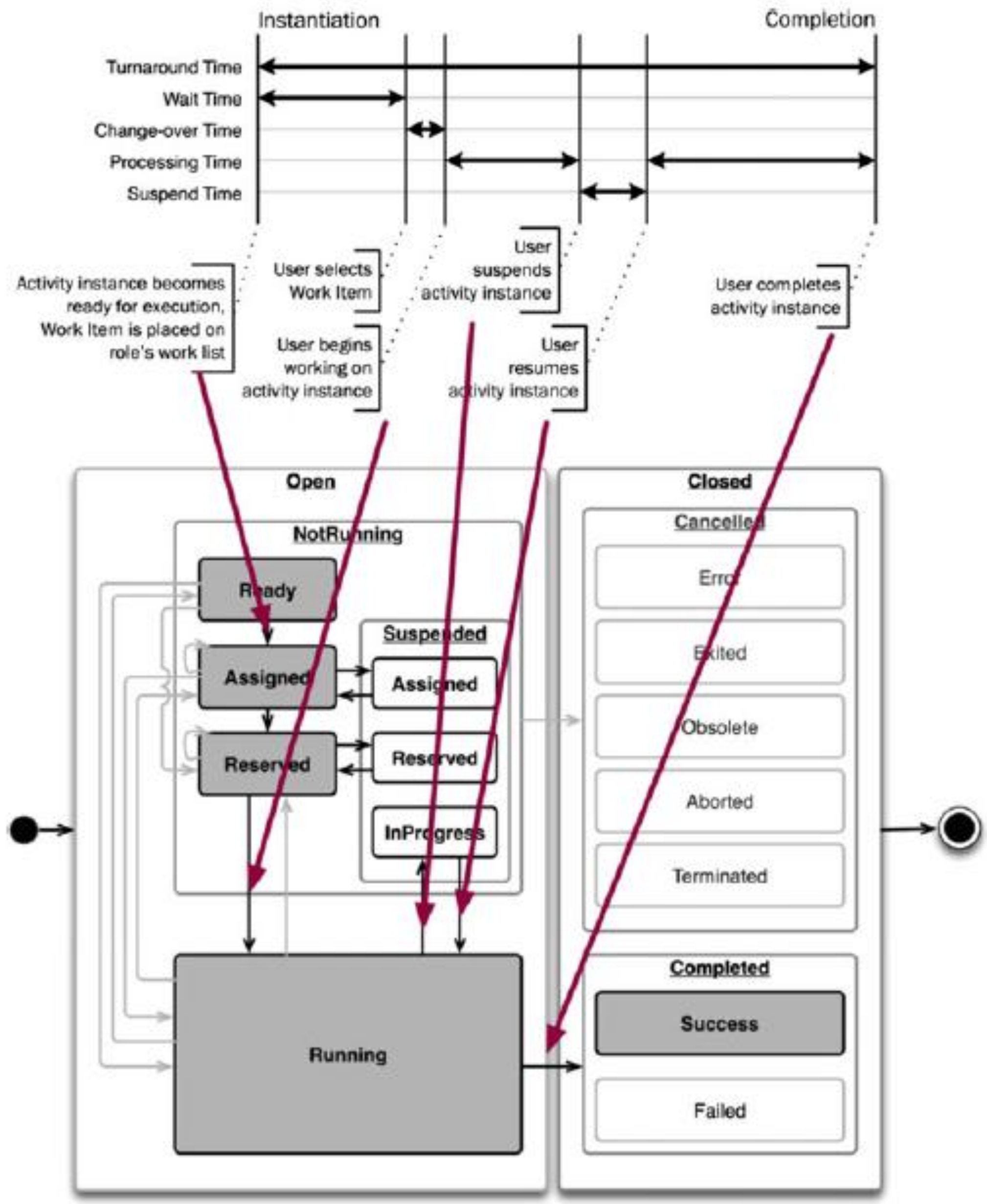

Figure 3.4 Activity instance metrics (zur Muehlen, M.; Shapiro, R, 2010)

3.5. Historical Process Analysis:

After completion of process metrics historical process analysis used when the area of interest is process is used in multiple process instances or time periods (fiscal, quarter … etc.). Importance of this analysis is noticed when an organization needs to understand the behavior of a process and when a process is going to change, the effects of the change need to be analyzed and the effect of this change on overall process metrics. The importance of this type of analysis appears initially in understanding the process performance. Log file and event streams of workflow systems are considered beside other types of transactional process applications as a rich source of data and area where this type of analysis can be effective to gain valuable understanding (zur Muehlen, M.; Shapiro, R, 2010).

3.6. Real-Time Process Analysis

Real-time process analytics focuses on process instances during execution time in the process metrics. A business activity monitoring systems (BAMS) keep updating key performance indicator during the execution of the process. These key performance indicators are defined by business professionals or control engineers. When a rules engine is applied to these indicators, a BAM system can generate alerts and actions which are delivered to the managers or the staff concerned with monitoring the process. If any critical situation appears, it may also alert the behavior of the processes. The purpose of BAMS is to provide real time control over currently active process instances (zur Muehlen, M.; Shapiro, R, 2010).

A dashboard reflects the results of the analysis in visualization, and represents a manufacturing control station. Figure 3.5 gives an example of dashboard from a commercial Business Process Management system. A well designed dashboard allows an analyst to have a deep look into the process instances whose metrics are represented, and to perform on-the-fly modifications like reassignment of a work item (zur Muehlen, M.; Shapiro, R, 2010).

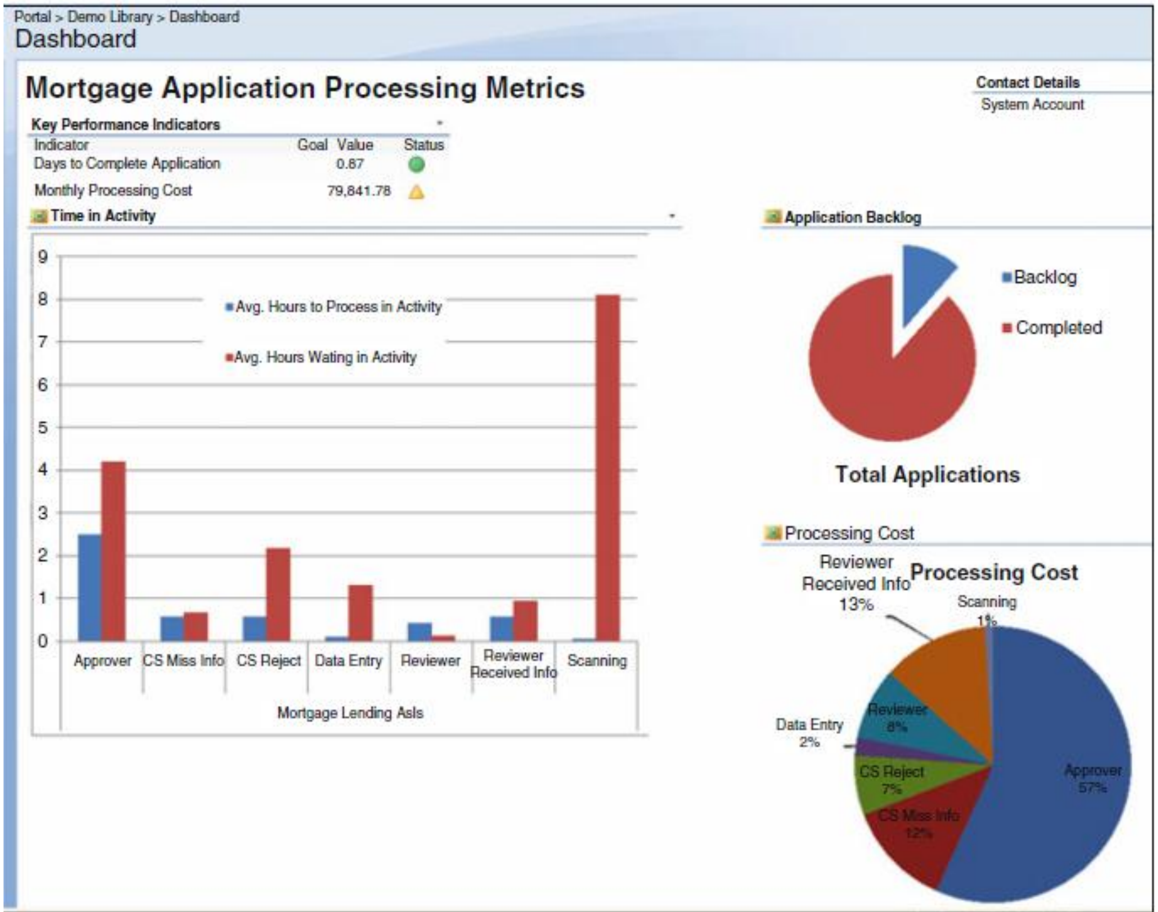

Figure 3.5 Process dashboard (zur Muehlen, M.; Shapiro, R, 2010)

Advanced variant of the BAM systems update embedded rules engine with analytics events that may trigger automated procedure such as automatic reprioritization of activities, end of certain activity, or even sends notifications to management, or stakeholders. This kind of configuration gives the ability of handling certain exceptions and results in the implementation of a simple sense-and-respond environment. BAM systems have an advantage over traditional reporting systems in that they reflect current operations that have not yet concluded. Their information is thus available in timely representation which is more effective than warehouse based system (zur Muehlen, M.; Shapiro, R, 2010).

3.7. Predictive Process Analysis

Predictive process analysis aims at evaluating the impact of changes in process design or behavior on future performance or behavior of process instances. Predictive process analysis can be performed at early stages of designing the process model, for example, to determine the performance trade-off between different process configurations, or after deploying the process model, for example, to determine whether a newly created process instance will complete within a given set of constraints. Three different kinds of predictive process analysis techniques can be distinguished: simulation, data mining, and optimization (zur Muehlen, M.; Shapiro, R, 2010).

3.7.1. Simulation

"***Simulation*** is the imitation of the operation of a real-world process or system over time" (J. Banks et al. 2001). Usage of Simulation models are mainly used to do what-if analysis of process designs before the implementation of them, to measure different behavior in different situation of the process. The simulation gives the ability to track the execution of a process instance to detect potential errors. Simulation mainly focuses on the execution of a several number of process instances together in the process metrics to notice the behavior of the processes and related resources within processes environment. Typical simulation scenarios focus on changes at the resource level, changes of the process structure, or changes in the process context (zur Muehlen, M.; Shapiro, R, 2010).

Figure 3.6 shows the output of a BPMS simulation component (SunGard IPP) that describes a process model with related information such as processing times for the activities and decision gateways. A discrete events simulator is the typical type of simulator to produce predictions in the environment of the processes with related resources and conditions. In general, BPMS is convenient with process simulators because of advancing of process capability. Instead of notifying potential process participants and invoking applications, a simulation engine will simulate the behavior of these resources according to parameters defined in a simulation scenario (zur Muehlen, M.; Shapiro, R, 2010). A process simulation scenario consists of the following:

1. Process Definitions
2. Incoming Work (Arrivals)
3. Resources, Roles, and Work Shifts
4. Routing Information.

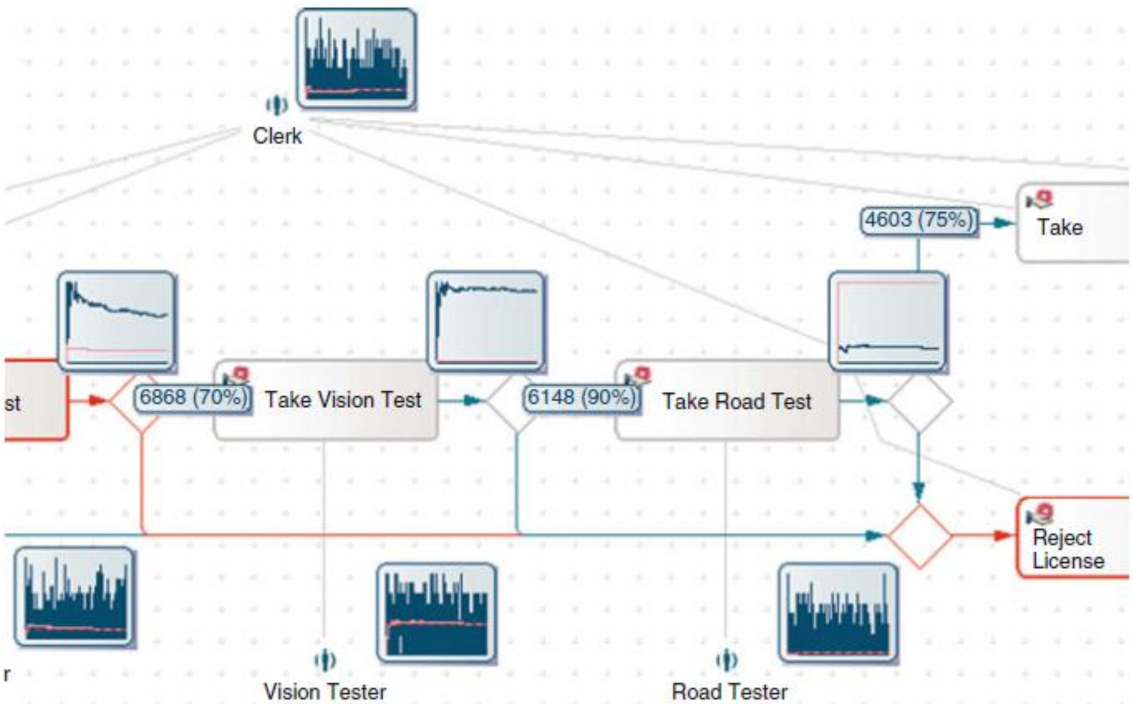

Figure 3.6 Process model with simulation data overlay (zur Muehlen, M.; Shapiro, R, 2010)

3.7.2. Data mining

"Data mining is the analysis step of the Knowledge Discovery in Databases" process, or KDD" (Fyyad et al., 1996). There are factors shaping the behavior of business processes: process design and its rules, availability of resources and skill level, arrival pattern of new instances, the attributes of the business cases processed in each process instance, and other external business factors. Historical process analytics use data to classify and navigate process instances and performance information.

Data mining for process analytics seeks to create correlations between key performance indicators and process-external factors. It is possible to predict the behavior of a process instance, given the current state of the infrastructure and the attributes of the business case to be processed, if these correlations can be established with sufficient accuracy (zur Muehlen, M.; Shapiro, R, 2010).

3.7.3. Process Optimization

Automatic process optimization represents the most advanced application of process intelligence and uses historical process analytics and process simulation to generate and evaluate proposals for achieving a set of goals. The analysis of the process structure in conjunction with historical data about processing delays and resource availability allows for the intelligent exploration of improvement strategies (zur Muehlen, M.; Shapiro, R, 2010).

Optimization is a form of goal-seeking simulation. It uses process goals formulated as key performance indicators, analyzes historical process metrics, and proposes what changes are likely to help in attaining these goals. It can systematically evaluate the proposed changes, using the simulation tool as a forecasting mechanism (zur Muehlen, M.; Shapiro, R, 2010).

Optimization can be performed in a fully automated manner, with the analysis termination upon satisfying the goal or recognizing that no proposed change results in further improvement. A typical example for the application of optimization technology is the optimization of staff schedules while focusing on end-to-end cycle time and processing cost as key performance indicators. Process optimization technology is currently the domain of specialist providers, but the architecture of BPMS suggests that it will find its way into commercial BPMS over time (zur Muehlen, M.; Shapiro, R, 2010).

3.8. Business process mining

Motivation behind the rise and the increasing use of business process mining is the need for organizations to learn more about how their processes operating in the real world (A. Tiwari and C.J. Turner, 2008; Chris J. Turner, et. al., 2012). Process mining is a relative young research field that located between machine learning and data mining on the hand and process modeling and analysis on the other hand (Van der Aalst 2011). The main idea of process mining derives from data mining which is to discover, monitor and improve real processes by extracting data process from event logs, transactional applications, and other information systems such as CRM. Moreover, the aim of business process mining is to extract information in the form of process models from event logs. (Van der Aalst 2007; van der Aalst 2011; A. Tiwari and C.J. Turner, 2008; Chris J. Turner, et. al., 2012).

Figure 3.9 shows the relation between the process and their data on hand and process models on the other hand, this figure also shows the three different types of process mining discovery, conformance, and extension.

3.8.1. Business process mining types:

Process Discovery: process discovery means deriving information about process model, the organizational context, and execution properties from event log without being there is a-priori model (Van der Aalst 2007; van der Aalst 2011; A. Tiwari and C.J. Turner, 2008; Chris J. Turner, et. al., 2012; Saravanan .M.S 2011)

Conformance: conformance means that there is an a-priori-model exists for a process. This model is used to check if reality conforms to the model (Tiwari and C.J. Turner, 2008).

Extension: extension means there is an a-priori model enhanced by the addition of extra parameters detailing a new perspective. Attributes could be data on the cost, performance (Tiwari and C.J. Turner, 2008).

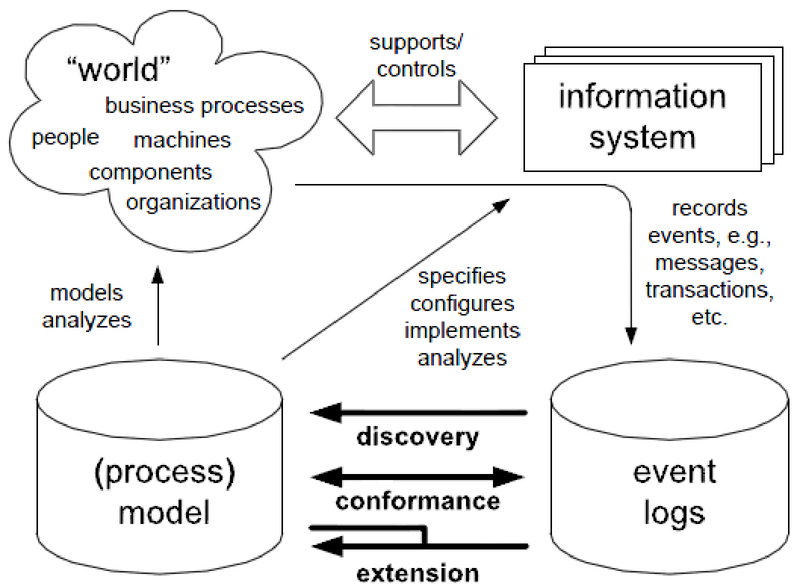

Figure 3.7 Three types of process mining (van der Aalst 2011)

Apart from these three types of process mining, there are also four different kinds of perspectives:

1. Process perspective.
2. Organizational perspective.
3. Case perspective. And
4. Time Perspective (A. Tiwari and C.J. Turner, 2008).

Process perspective: focuses on the ordering of activities. Its aim is to find representation of possible paths within the process metrics, which are represented in terms of a Petri net, Workflow, EPC, BPMN, etc (A. Tiwari and C.J. Turner, 2008; Dustdar et al., 2005).

Organizational perspective: It focuses on the organizational structure and resources like people, systems, roles and departments and how they related. This approach can be used to describe the roles and relationships between elements within process in terms of a social network (A. Tiwari and C.J. Turner, 2008; Dustdar et al., 2005).

Case perspective: This perspective focuses on the details of a case, for example a supplier or the amount of ordered goods (van der Aalst, 2011). Case perspective takes into account the different properties of cases, the attributes that affect the behavior of the process (A. Tiwari and C.J. Turner, 2008).

Time Perspective: this perspective focuses on timing and frequency. This is only possible if the event log contains a time stamp. Using time stamps is one of the advantages of this perspective that can be used to discover bottlenecks (van der Aalst, 2011).

The different types and perspectives can occur orthogonally (van der Aalst, 2011). Figure 3.10 shows the process model using all the process mining perspectives.

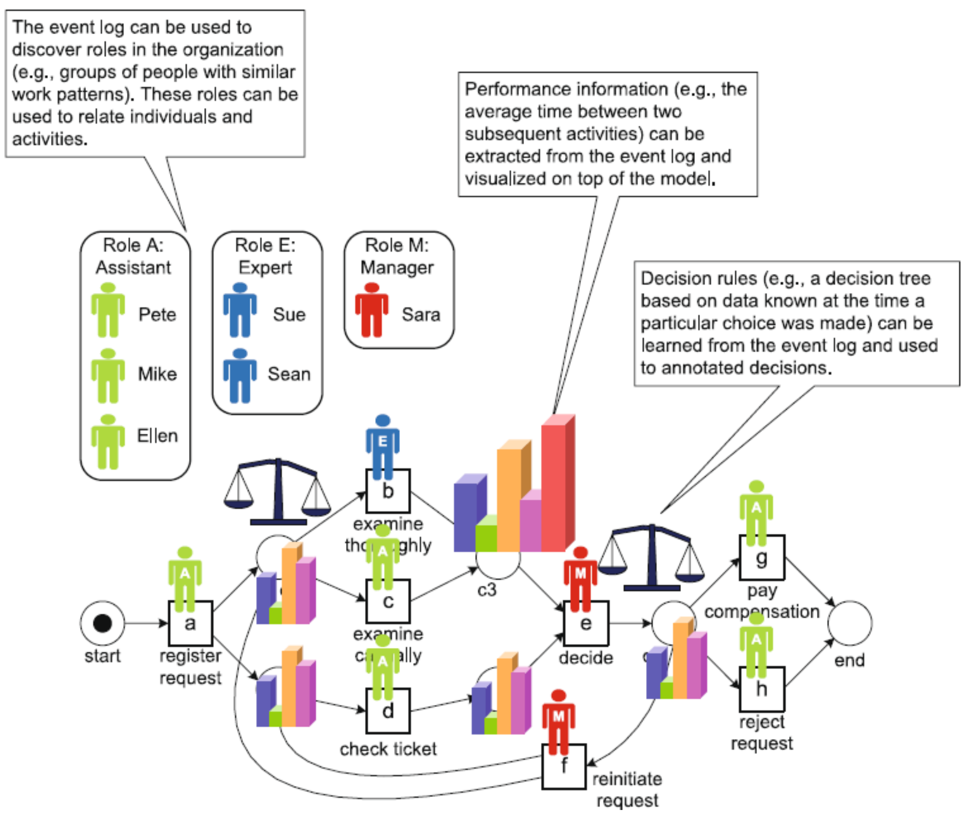

Figure 3.8 The process model extended with additional perspectives (van der Aalst, 2011)

3.8.2. Business process mining techniques:

1. Transition systems and region: the purpose of transition systems and regions is to discover process models from event logs. This technique is to mine models that offer a balance between over fitting (modeling process transitions observed in the event log) and under fitting (modeling process transitions that may be observed from the event log) the event log (A. Tiwari and C.J. Turner, 2008). Figure 3.11 shows a transition system. It models the handling of a request for compensation within an airline. The states are represented by black circles. There is one initial state named *s*1 and one final state named *s*7. Transitions are represented by arcs. Each transition connects two states and is labeled with the name of an activity (Van der Aalst 2011).

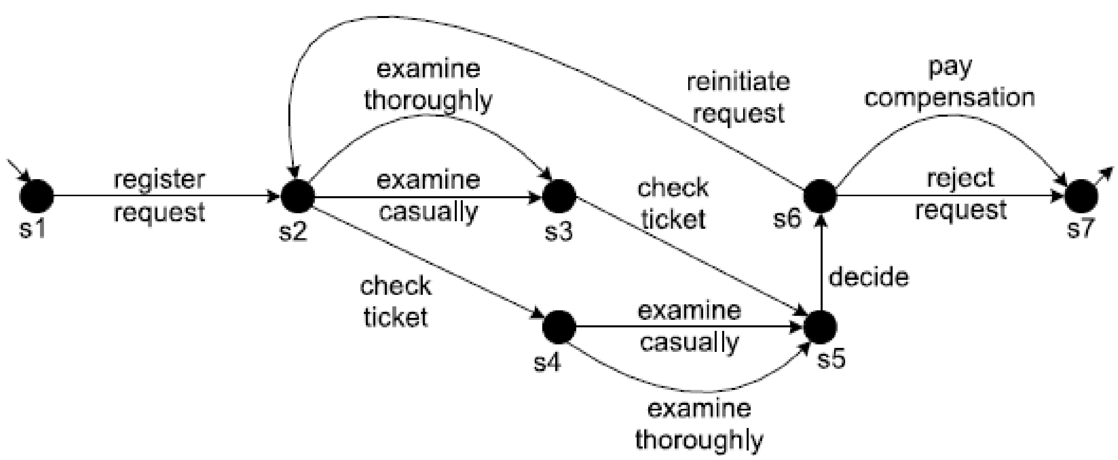

Figure 3.9 a transition system having one initial state and one final state (Van der Aalst 2011)

2. Clustering techniques: Clustering is concerned with grouping instances into clusters. Instances within a cluster should be similar to each other. Clustering uses unlabeled data and, hence, requires an unsupervised learning technique (Van der Aalst 2011). Clustering techniques are mainly used to mine more complex event logs, such as those that contain noise (incorrect and incomplete information about process) (A. Tiwari and C.J. Turner, 2008).

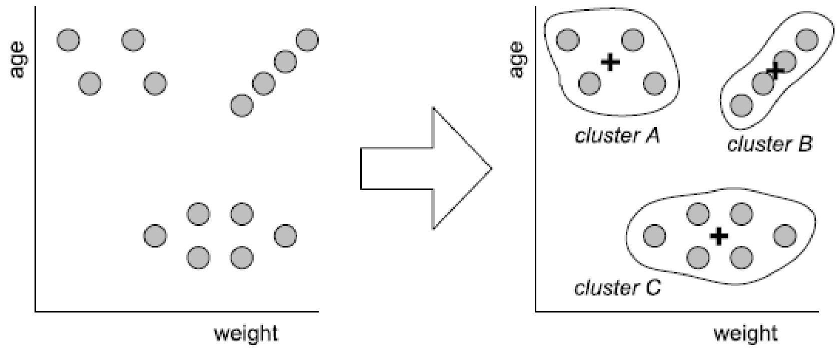

Figure 3.10 Clustering instances in three clusters using k-means (Van der Aalst 2011)

3. Heuristic techniques: a set of rules used to determine the priority between tasks and overall task sequences (A. Tiwari and C.J. Turner, 2008). Heuristic mining techniques are used to construct process model taking into account frequencies of events and sequences. The basic idea behind heuristic mining techniques is that infrequent paths should not be integrated into the model. Both the representational bias provided by causal nets - "causal net are graph where nodes represent activities and arcs represent causal dependencies" van der Aalst (2011) - and the usage of frequencies makes the approach much more powerful than most other approaches. Heuristic techniques can be used to filter the noise (Van der Aalst 2011).

4. Evolutionary techniques: Evolutionary approaches use an iterative procedure to mimic the process of natural evolution. Such approaches are not deterministic and depend on randomization to find new alternatives (Van der Aalst 2011). Evolutionary techniques are used to mine a variety of challenging event logs (containing duplicate tasks and noise).genetic process as an example on such techniques allows for process patterns to be represented as chromosome strings, and successive populations of potential process mining solutions to be generated. Each solution is given a fitness score based on how accurately it describes the event log on which it is based (A. Tiwari and C.J. Turner, 2008).

5. Declarative mining approach: this approach allows for the start-up of artificially operated negative events; these events show that a certain path through a process (or activity recorded in a process trace) is impossible. It is argued in this work that process logs rarely include such negative traces and their introduction can help the task of process findings. Another point in this area is what mentioned about incremental declarative approach, he recognizes that process can change by the time and is able to update the mined model by considering newer process traces the possible deviations they may bring. This technique uses inductive logic techniques in order to update the process models being mined. Another approach in the process mining research is business policy mining within business processes; this approach has not discussed so much. Research by (Li et al.; 2010) presents the concept of using the text mining approach to extract process related business policies from policy documents. The researchers of this approach remark to the core commercial value of being able to extract business process from, sometimes, poorly structured policy documents (A. Tiwari and C.J. Turner, 2008).

3.8.3. Business process modeling languages:

1. **Petri Nets:**

   Petri nets are considered as the best investigated process modeling language it allows for the concurrency modeling (Van der Aalst 2011). Petri nets depict the structure of a system, a Petri net represents a business process model, and its transitions represent activity models (M. Weske 1998).

   Figure 3.13 shows the Petri net representing a single process instance. A Petri net is a bipartite graph consisting of places and transitions. The network structure itself is static, but governed by the firing rule. The state of a Petri net is determined by the distribution of tokens over places and is referred to as its marking (Van der Aalst 2011).

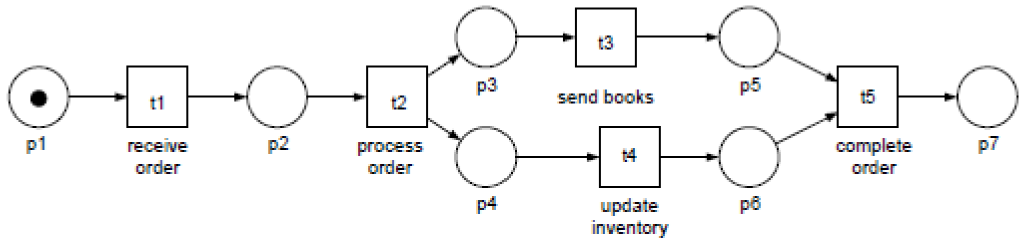

Figure 3.11 Sample Petri net representing single process instance (M. Weske 1998)

2. **Workflow nets:**

   Workflow nets are considered as subclass of petri nets. Workflow nets are Petri net with a dedicated source place where the process starts and a dedicated sink place where the process ends. Moreover, all nodes are on a path from source to sink (Van der Aalst 2011). A Petri net can be considered as a Workflow net if (van der Aalst,2011):

   - The set of places contains an input place *i*;
   - The set of places contains an output place *o*;
   - There is a directed path between any pair of nodes in the Petri net.

3. **Business process modeling notation (BPMN):**

   Recently, the Business Process Modeling Notation (BPMN) has become one of the most widely used languages to model business processes. BPMN is supported by many tools. Figure 3.14 gives an example of BPMN, its similar to petri nets, where the event meets place in petri nets, and event have only one input and output if there any splitting and joining gateways is used (Van der Aalst 2011).

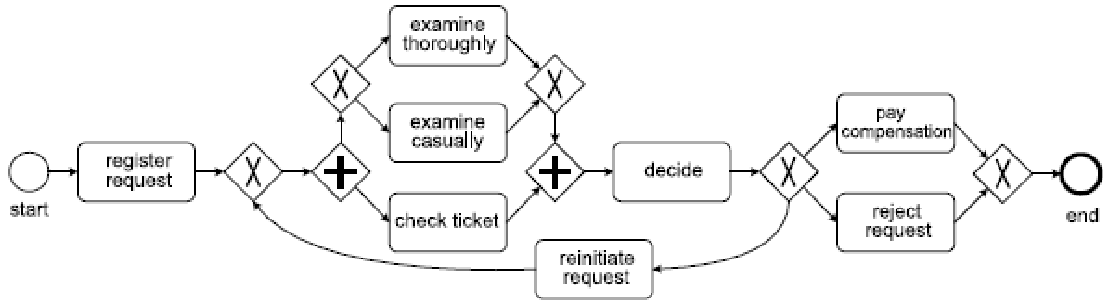

Figure 3.12 Process model using the BPMN notation (Van der Aalst 2011)

4. **Event-driven process chain:**

   Event-driven process chains are an important notation to model the domain aspects of business processes. Event-driven process chains focus on representing domain concepts and processes beside their formal aspects or their technical realization. Process modeling uses event-driven process chains. The main building blocks of event-driven process chains are events, functions, connectors, and control flow edges (M. Weske 1998). EPC is similar to BPMN functions and activities have the same concept. A function can only have one input and one output arc, so the use of joins and splits is required, same logical gates, and events. Figure 3.15 we can see process model using EPC (Van der Aalst 2011).

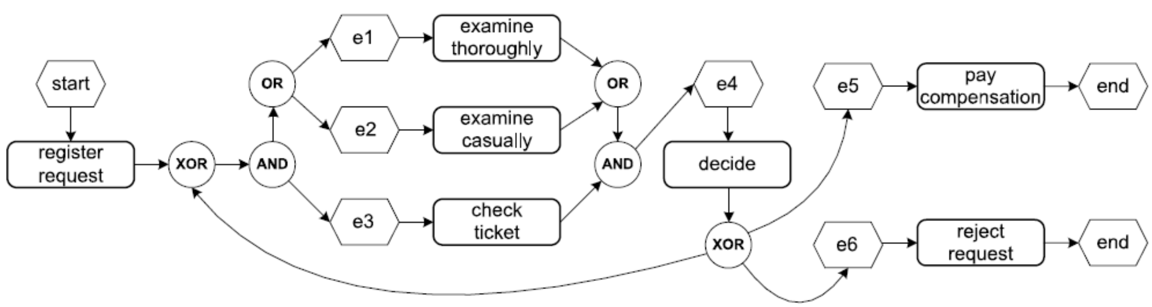

Figure 3.13 Process model using EPC notation (van der Aalst, 2011)

3.9. Statistical Process Control (SPC)

SPC is a set of problems identifying and solving tools that aid in achieving process stability by reduction of variability and defects (Montgomery; 2001). SPC focuses mainly on processes through process metrics. The stability can be achieved after applying different tools in SPC. Each tool has a certain function. Figure 3.16 shows the usage of different SPC tools through the improving of processes (Oakland, J 2002).

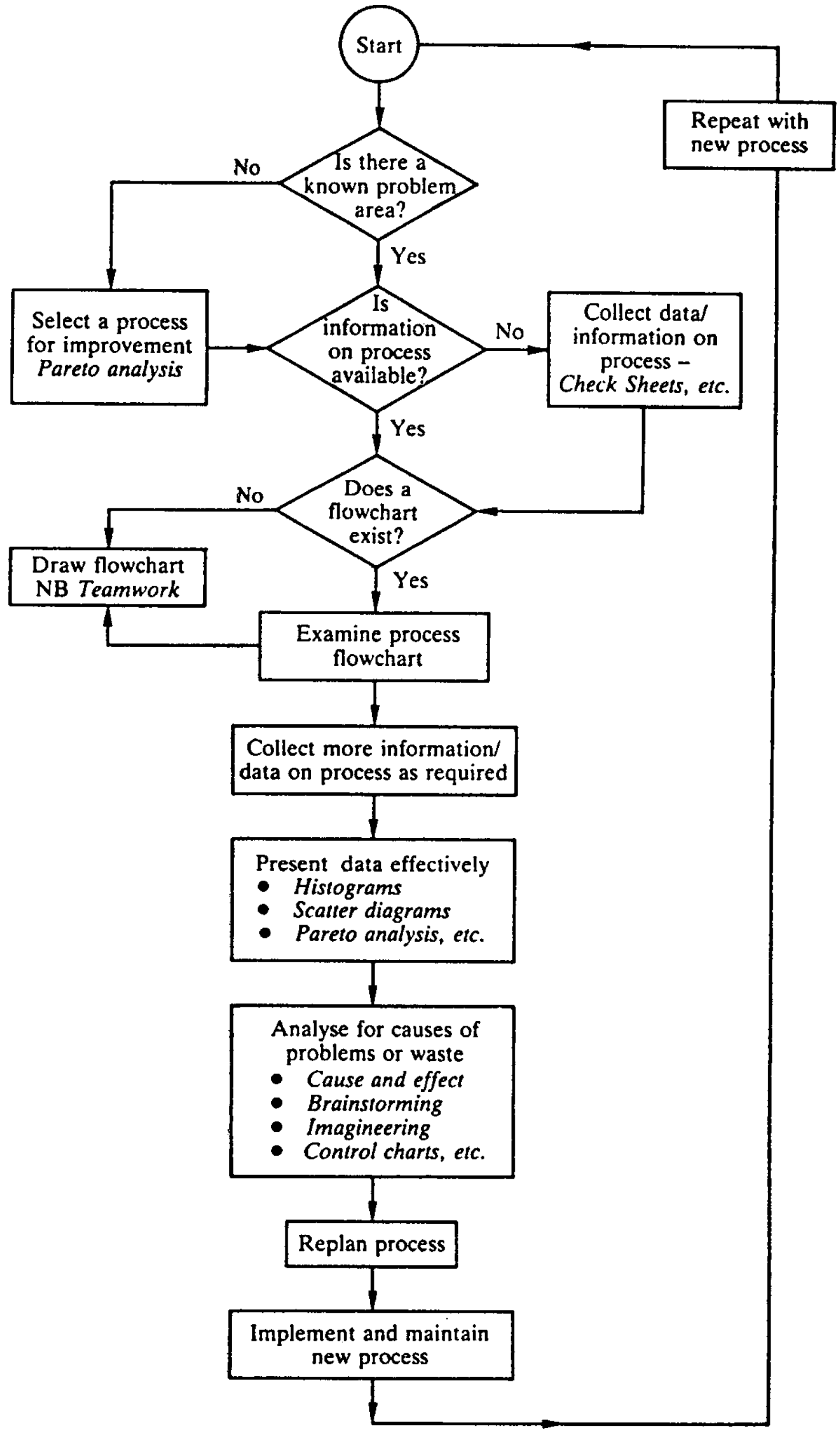

Figure 3.14 Strategy for continuous process improvement (Oakland, J 2002)

3.9.1. Pareto analysis

Pareto distribution was founded by Vilfredo Pareto who discovered the 80-20 rule. Pareto distribution is applied in a wide range of social, geophysical and scientific situations such as manufacturing defects in processes. Pareto analysis's main idea says that 80% of the defects appearing in the production process come from 20% of the causes. Pareto analysis technique is to arrange activities that cause defects according to the importance of the defects (Oakland, J 2002). Pareto analysis consists of five steps:

1. List all the defects: In this step the analysis should be list in elaborative way.

SCRIPTAGREEN – A Plant B		*Batches scrapped/reworked Period 05–07 incl.*		
Batch No.	*Reason for scrap/rework*	*Labour cost (£)*	*Material cost (£)*	*Plant cost (£)*
05–005	Moisture content high	500	50	100
05–011	Excess insoluble matter	500	nil	125
05–018	Dyestuff contamination	4000	22 000	14 000
05–022	Excess insoluble matter	500	nil	125
05–029	Low melting point	1000	500	3 500
05–035	Moisture content high	500	50	100
05–047	Conversion process failure	4000	22 000	14 000
05–058	Excess insoluble matter	500	nil	125
05–064	Excess insoluble matter	500	nil	125
05–066	Excess insoluble matter	500	nil	125
05–076	Low melting point	1000	500	3 500
05–081	Moisture content high	500	50	100
05–086	Moisture content high	500	50	100

Figure 3.15 Example of Defect Listing (Oakland, J 2002)

2. Measure the defects: Measuring step should be done using the same unit for all elements including its time, amount, or number.

Reason for scrap/rework	*Tally*	*Frequency*	*Cost per batch (£)*	*Total cost (£)*
Moisture content high	卌 卌 卌 卌 |||	23	650	14 950
Excess insoluble matter	卌 卌 卌 卌 卌 卌 ||	32	625	20 000
Dyestuff contamination	||||	4	40 000	160 000
Low melting point	卌 卌 |	11	5 000	55 000
Conversion process failure	|||	3	40 000	120 000
High iron content	||	2	2 500	5 000
Phenol content > 1%	||	2	4 800	9 600
Unacceptable application	|	1	10 000	10 000
Unacceptable absorption spectrum	|	1	950	950
Unacceptable chromatogram	|	1	4 500	4 500

Figure 3.16 Example of defect measurement (Oakland, J 2002)

3. Rank the defects: ordering of the defects according to the importance value that resulted from measure step.
4. Create cumulative distributions: The measures are cumulated from the highest ranked to the lowest, and each cumulative frequency is shown as a percentage of the total. The elements are also cumulated and shown as a percentage of the total
5. Draw the Pareto curve: The cumulative percentage distributions are plotted on linear graph.

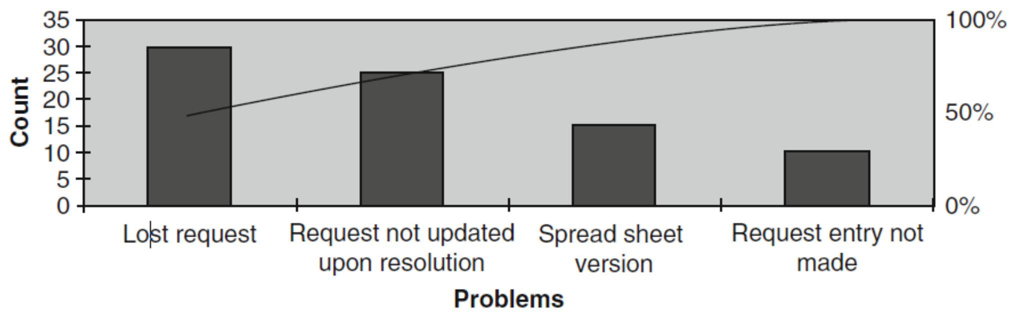

Figure 3.17 Example of Pareto Analysis (Sue Conger 2010)

6. Interpret the Pareto curve: highlighting the main defects.

3.9.2. Cause and effect analysis

After knowing the defects in the system, Cause and Effect analysis tries to figure out the causes of each defect which will spot the light on fields of improvement and action that should be taken to eliminate these effects. Causes and effect analysis is used to extract all possible factors and causes of the effect. The basic form is shown in Figure 3.11. The main causes are listed first then deeper look into the cause to figure out if their sub-causes. This process is continued until true causes are defined (Oakland, J 2002).

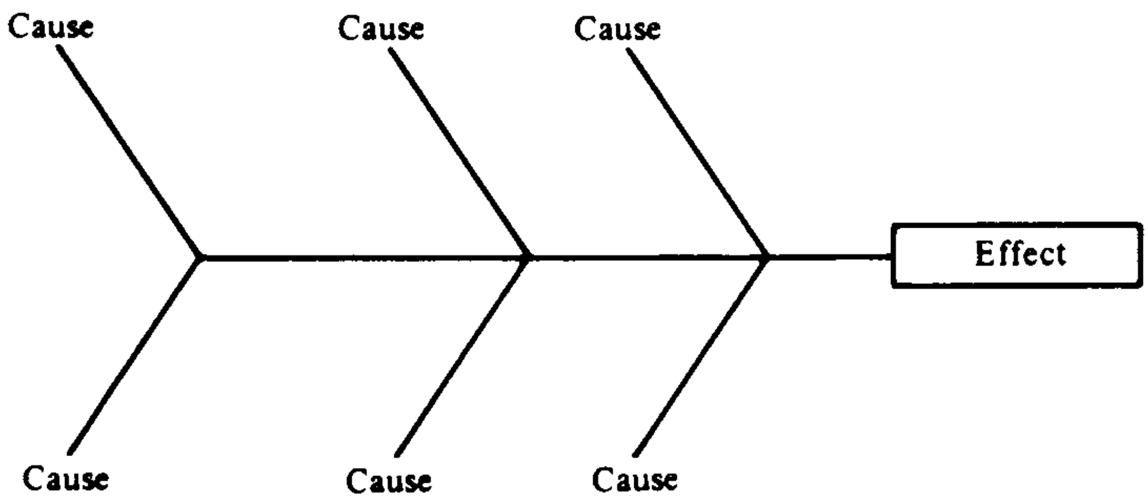

Figure 3.18 Basic form of cause and effect diagram (Oakland, J 2002)

How it works:

1. Identify the effect: it's important to well identify the effects to find out what exactly the cause, and to avoid elimination of non-related causes and the effect still exists.
2. Establish goals: in this step the goals should be stated in terms of measurement related to the problem. This step is important to the people involved to know that their efforts are achieving good results.
3. Construct the diagram framework: in this step, the major categories are listed to identify the sources of causes. The "Ps" of production management is an approach founded by Oakland which state the five components of any operational task:
    - Product (services, materials).
    - Processes or methods of transformation.
    - Plant (tools , machines, buildings)
    - Programs or timetables for operations
    - People, staff or management.

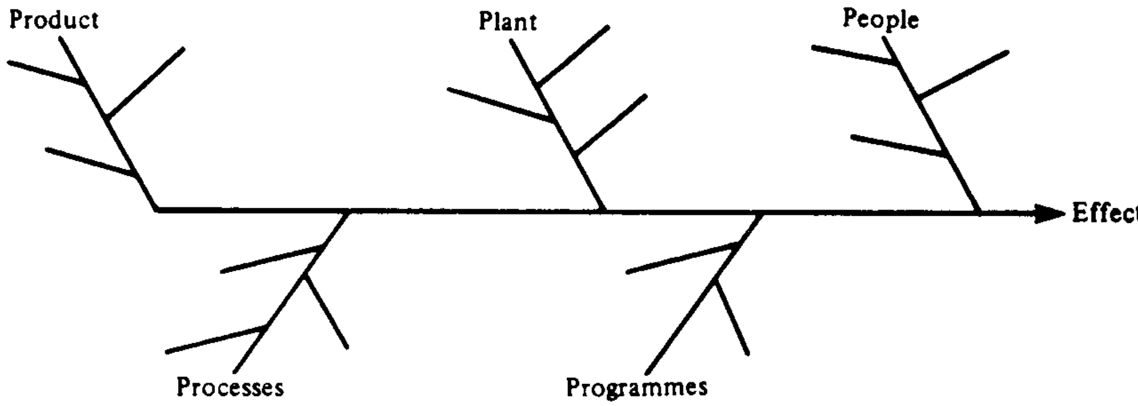

Figure 3.19 Cause and effect analysis and the five 'P's (Oakland, J 2002)

4. Record the causes: in this step, people from different levels, either worker or manager, should be involved in a brainstorming session to suggest causes to be recorded in its category.
5. Incubate and analysis the diagram: again after giving time to the previous step, the group discusses and analyzes the resulted diagram.

3.9.3. Scatter diagrams

"A scatter plot or scatter graph is a type of mathematical diagram using Cartesian coordinates to display values for two variables for a set of data" (Utts, Jessica M ; 2005). It is used to test the relationship between two factors to see if they are related. If they are related to each other by controlling the independent factor, we will control the dependent facto. Figure 3.15 shows that when the process temperature is set at A, a purity results lower than when the temperature is set at B. In Figure 3.16 we can see that tensile strength reaches a maximum for a metal treatment time of B, while a shorter or longer length of treatment will result in lower strength (Oakland, J 2002).

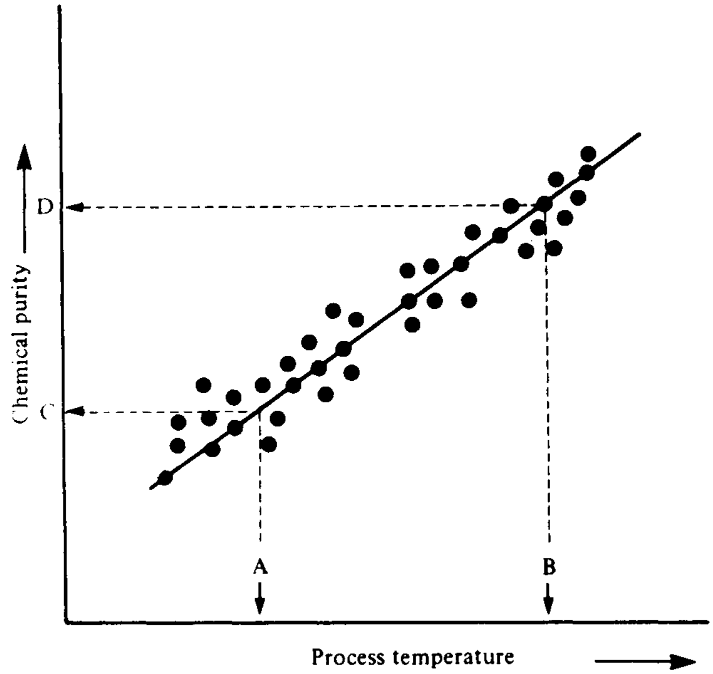

Figure 3.20 Scatter diagram – temperature v. purity (Oakland, J 2002)

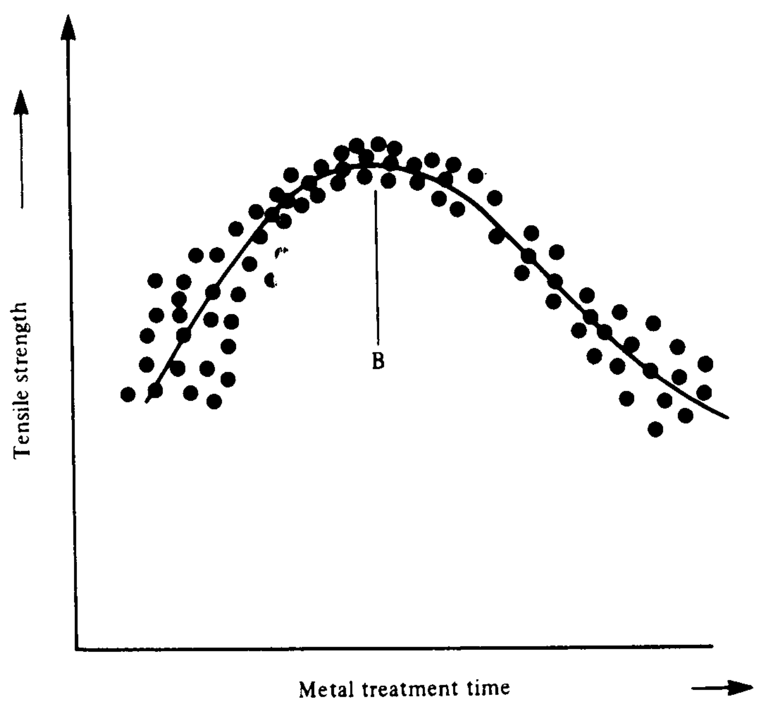

Figure 3.21 Scatter diagram – metal treatment time v. tensile strength (Oakland, J 2002)

How Scatter Diagram Works according to Oakland:

1. Select the dependent and independent factors. The dependent factor may be a cause on a (cause and effect diagram), a specification, a measure of quality, or some other important result or measure. The independent factor is selected because of its potential relationship to the dependent factor.
2. Set up an appropriate recording sheet for data.
3. Choose the values of the independent factor to be observed during the analysis.
4. For the selected values of the independent factor, collect observations for the dependent factor and record on the data sheet.
5. Plot the points on the scatter diagram, using the horizontal axis for the independent factor and the vertical axis for the dependent factor.
6. Analyze the diagram.

3.9.4. Stratification

This method is used to collect a set of data into meaningful groups specially when the data are composed of different characteristics such as age, sex, GPA (Oakland, J 2002).
For example, three shift teams are responsible for the output described by the histogram (a) in Figure 3.17 shift team results the output shown in (a) but when we apply stratification on the histogram will produce histograms (b), (c) and (d).

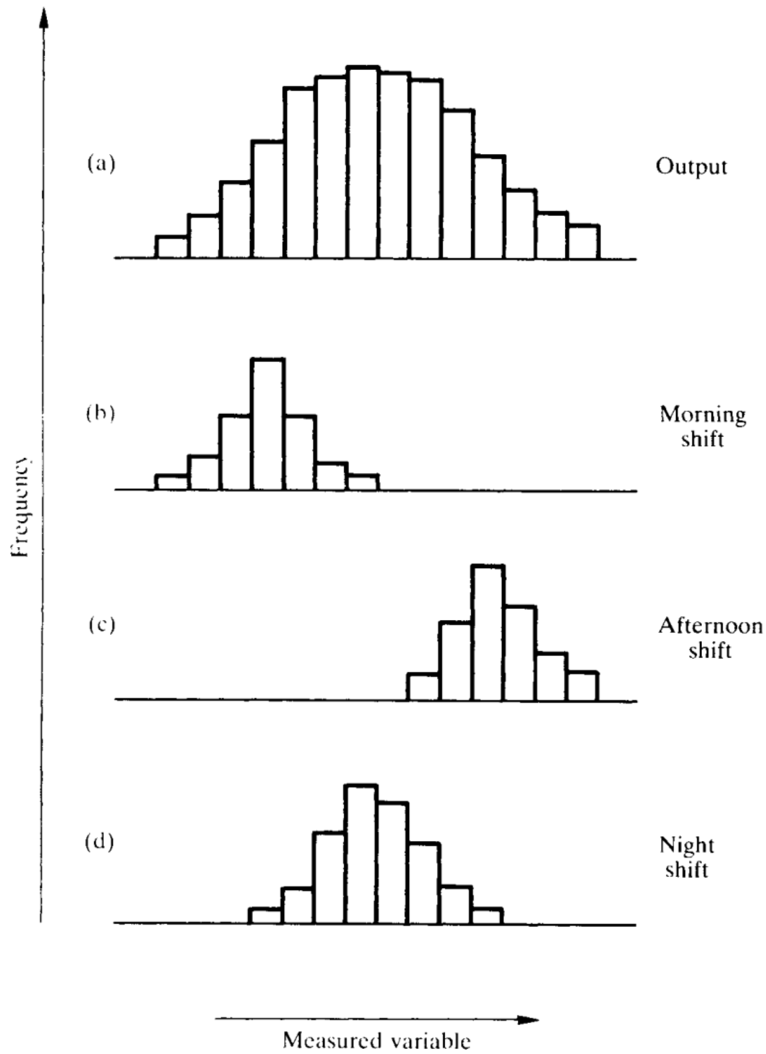

Figure 3.22 Stratification of data into shift teams (Oakland, J 2002)

CHAPTER 4: Lean Manufacturing and Process Analysis

Lean manufacturing has evolved over time. This improvement will not stop due to the complexity of processes and their development (Womack 1990). This study comes in context of this improvement and will try to show the usage of different process analytic techniques within lean manufacturing goals, principles and tools. Lean's manufacturing main goals are elimination of waste to create the value, reduction of lead time, and reduce cost, lean manufacturing come with several tools and principles to achieve these goals, starting from the first step of 5s tool which is sort.

4.1. 5s tool:

Sort is the first step in 5s, whereas the purpose of this step as mentioned in this study is the declaration of waste. Historical process analysis is consider as great approach to support this step through understanding the behavior of the process, when the process is going to change, analyze the effect of the change (which helps to define what is waste) and the performance of the processes within the process metrics, even if the event log is complex has noise or invalid inputs still different process mining techniques able to extract information about processes for that event log. Since reducing lead time is one of lean's manufacturing goals; understanding the performance of the processes will help to define the area of improvements.

The second step in 5s tool is straighten. The purpose of this step as mentioned before is to order the activities in a way to minimize the lead time, so reordering is a repeated process due to changing in the business and the usage of different activities. Before applying any change it's useful to test the effect of the reordering using first different modeling tools, and using simulation approach until achieving the optimal ordering.

The third step in 5s tool is sustain which aims to keep the working environment clean after removing unnecessary waste or non-value added activity. This step can be supported with different process control tools to ensure the flow of processes and defects free processes. This will increase assurance of continuity of the process metrics with no defects. The concept keeping the environment clean means free of defects and any other rubbish input or output resulted during process execution.

The fourth step in 5s tool is systematize which aims to continue working on the previous steps, which is already supported with process analysis tools.

The last step in 5s tool is standardized. The purpose of this step is to implement and standardized procedures that should govern the work, business process modeling will give a great opportunity to support building new procedures which involves different element of the production environment (machines, people, materials, processes, events … Etc.)

4.2. Visual systems

As shown in the previous chapter, Pareto analysis summarized in defect detection and measuring each defect which Lean manufacturing also focuses at. Pareto analysis shows that it’s a useful tool for Lean not only by detecting of the defects, but also showing the most affecting defects in the system. Pareto, by its measuring of the defects feature, can give an overview of the damages of each defect in terms of unit (time, cash value).

4.3. Kanaban

The purpose of Kanaban pull system is to reduce the inventory by keeping the supply chain at the minimum in a way that doesn’t affect the production process.
Here there are two parts where process analysis could help in achieving the purpose; the first is to determine the optimal quantity needed of recourses which grantee the smooth flow of resources and production process. By using historical process analysis we can estimate the quantity of resources needed at each phase of production then we test these quantities using simulation approaches then evaluate the results. The second part is using dashboard approach which needs a business expert to determine the KPIs. Dashboards will give the signal to

upstream that materials are needed for the production which assures the continuity of the production without facing any lack of resources.

Also process mining techniques can take a great role in this tool, by using one of the three types of process mining depending on the current situation. Then, analyze the model generated from case perspective to specify the amount that could be used as a standard. This kind of analysis involves the different elements of the case in account; also time perspective gives a great opportunity especially if the event log includes timestamp, since this perspective can discover bottlenecks.

4.4. Kaizen

The purpose of Kaizen is to improve the environment through process improvement that is accomplished by standards and people involvement. This tool can be supported by cause and effect approach, since cause and effect approach mainly focuses on involvement of people from the different levels then applies the steps of cause and effect analysis identify the effect, establish goals, construct the diagram framework, record the causes, and incubate and analysis the diagram. Similarity can be noticed between the two tools in the purpose and the philosophy which is involvement of the people in the process of elimination of waste and establishment and maintaining the standards.

4.5. Cellular manufacturing

The aim of cellular manufacturing is to divide tools and machines into production cells, so the overall production quantity is divided between these cells in equality. The purpose of this process is to produce the overall quantity in the same time required of the single cell to produce the divided quantity which leads to decrease the lead time.

This process involves reordering the machines and processes, and reengineers the processes to satisfy this process. Here, process analysis techniques can be helpful by modeling the process to be tested and the outcomes be evaluated. Beside simulation can give deep understanding of behavior of the element involved within the production after reengineering.

4.6. Setup time reduction

Setup time reduction is the process of reducing required time for switchover of tools, this time is considered as waste in lean philosophy. What could be a reason for switchover, maintain defected parts, relocate the machines, and other reasons, process analysis can be useful.

At the first place process control and monitoring the processes and the machines while running could give an early alert for possible defects that may happen, so early handling for the defects will reduce setup time.

Second, the switchover process itself, whenever the stuff is trained on the right procedure for the switchover process, the process will finished faster, Perot analysis and brainstorming sessions then analysis for this session will give the staff deeper understanding about what they will do.

Flowcharting and modeling of the procedures and analyzing them will grant best practice of the process.

4.7. Process analysis in elimination of waste:

After the wastes being declared there are sever tools can be used to help in eliminating of these wastes. Process metrics can be generated after analyzing the data event log of the processes using absolute measurements like qualitative measurements such as customer’s feedback, and other measurement like cycle times.

Real time analysis can be useful in this step by monitoring current running process and updating KPIs to alert the managers if critical situation appears. Dashboard is considered as good monitoring tool which represent the process performance in graphical way which give a deep understanding of current running processes.

When the declaration of wastes complete; Pareto analysis helps in the prioritization of these wastes starting from the most affected defect by listing the different defects then measuring these defects using same unit, then ordering these defects according to the value after measurement, then creating cumulative distribution, finally drawing Pareto curve. This approach based on 80-20 rule which says that 80% of the waste coming from 20% of the defects what gives deep understanding of from where start elimination.

After declaration and ordering the wastes, solving these defects is the next step. Here the role of cause and analysis appears which helps in spotting light on the causes of these defects and propose potential solutions. These causes and defects need to be analyzed and measure the relations between them. Scatter diagram helps in giving mathematical analysis for these relations. Stratification approach could be used if there any data which have different characteristics.

Finally, proposed solution can be tested and evaluated using simulation approach to show the effect of these solutions and any other changes on the other activities.

CHAPTER 5: Conclusions and recommendations

5.1. Conclusions

The main goal of this thesis was to explore how different process analysis techniques can aid Lean manufacturing. Based on the previous chapters we are able to formulate conclusion that provides an answer for the research question and sub questions as proposed at the first chapter.

Lean manufacturing is a managerial methodology aims to increase the competitive advantage through converting waste within the organization into value, reduce lead time through increasing the performance of different activities within the organization, and reducing the inventory through applying just in time approach.
Lean manufacturing defines seven types of waste: transport, inventory, motion, waiting, overproduction, over processing, and defects. These seven types are the subject of improvement according to the philosophy of Lean manufacturing.

To achieve goals of Lean manufacturing there are several tools applied through the production process, 5S and visual management, kanban which aim to reduce the inventory through applying the concept of JIT, kaizen which is a total quantity management approach which aims to define different types of wastes beside achieving the involvement of the people through the process of defining, and proposing solutions for the different wastes that related to process, environment, and people.

Process mining has two dimensions. The first dimension is the process mining types. Three different types of process mining can be distinguished: discovery, conformance and enhancement. Discovery means that there is no a-priori model. Conformance means that there is an a-priori model and is used to check if the actual model conforms to the predefined model. Enhancement also means that there is an a-priori model, but here the goal is to enrich the model using information from event logs. The other dimension is the process mining perspectives. There are four different perspectives: the control-flow perspective, the organizational perspective, the case perspective and the time perspective.

Based on what mentioned in the previous chapters and literature review process analytics can help lean manufacturing through the usage of different process analysis techniques within different lean's manufacturing goals and tools that serves these goals.

Use of different process discovery techniques on lean's manufacturing process event log can help in representing proper model of the processes that can be later analyzed using different analysis techniques that process analytics provide to deep understanding of process and their behavior. On the other hand, process analytics give a various tools that help lean manufacturing in declaration of the wastes, their effects and causes.

Process analytics provide tools that can measure and test any proposed solution by modeling and simulating these proposed solutions. Finally, control and monitor the process is one of lean's goals which are supported by process analysis through dashboards and KPIs.

5.2. Recommendations

This study comes up with theoretical linkage between lean manufacturing and process analytics, this linkage has not been tested using real-data. For future research it could be useful to test these results.

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