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Application of Just-In-Time Principles to Financial Services

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To my parents

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Contents

List of Figures

List of Tables

Abstract

This thesis investigates the application of selected Lean Manufacturing concepts to Financial Service operations. First, it overviews the methodology of Just-in-Time in manufacturing applications with emphasis in the Quality at the Source and Cellular Organization techniques. Second, it discusses characteristics of the Financial Services Sector and distinguishing differences from manufacturing. Existing implementations of the JIT methodology to financial services are also presented. Finally, the thesis examines the results of applying the Just-in-Time techniques of Quality at the Source and Cellular Organization to financial services, using simulation experiments. The results reveal if these techniques applied to financial service operations with certain characteristics can increase significantly productivity, by reducing simultaneously cycle time and resource utilization.

1. Thesis Motivation and Objectives

Financial Services (FSs) are recently attracting growing interest due to the competitive pressures resulting from the globalization through numerous mergers, the distribution of their products and services through alternative channels and their shift from products to customers. Thus, banks that provide a wide range of financial services, are dealing with complex processes as well as complex systems that impede productivity and increase operational costs. In fact, banks are becoming less efficient than the recent past; the huge investments in Information Technology systems oftentimes increase complexity and may not result in expected ROIs (Nallicheri, *et al* 2004).

Many researchers are focusing on this sector in order to improve the performance of financial services and reduce associated costs. Researchers hope that financial services can reap similar benefits to those of manufacturing, and seek to close the gap in productivity between financial institutions and manufacturing industries, that borders on 60% (see Figure 1.1). However, services have significant differences from manufacturing and advances in the management of manufacturing systems (e.g. lean manufacturing) cannot be applied directly in the service sector.

A major program in the DeOPSyS Lab of the University of the Aegean is investigating lean banking, i.e. the application of lean principles in banking. Within this concept, the current work focuses on Just-in-Time (JIT), which is one of the important tools of lean manufacturing, and aims to examine the applicability of the JIT technique to banking operations. Specifically, the current thesis focuses on the two specific JIT techniques: *Cellular Design* and *Quality at the source* and aims to quantify and analyze the results of their implementation in banking operations.

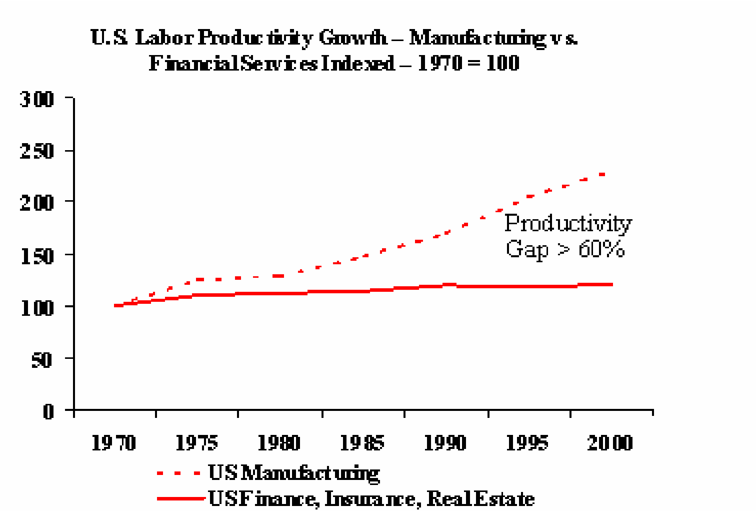

Figure 1.1: Comparison of performance between financial services and manufacturing (source: "*Closing the Productivity Gap Lean Manufacturing for Banks", (Booz Allen Hamilton Publications, 2002))*

The structure of this thesis is as follows:

Chapter 2, introduces JIT, and discuses its origins, principles, tools and guidelines. Moreover, the process for implementing JIT is presented.

Chapter 3 discusses the definition of FSs, their types as well as the types of FSs providers. Furthermore, it presents the significant differences between manufacturing and FSs. Finally it summarizes existing applications of JIT to FSs and overviews relevant examples from the literature.

In Chapter 4, we apply selected JIT techniques to the Personal Loan Approval Process. We analyze the Current State though a simulation and by analyzing the results, we draw conclusions for the Future State.

Finally, in Chapter 5 the conclusions of this research are presented along with directions for further research.

In the appendices of this Thesis for the sake of completion we have included useful material from the literature that is related directly to this work.

2. Just-In-Time (JIT) Methodology

This chapter aims to overview the Just-in-Time methodology. First, a brief description of the history of JIT is presented in the subsequent sections, further analysis of JIT is discussed in the next sections; special emphasis is given to cellular design and quality at the source.

2.1. Origins of JIT

JIT is a manufacturing philosophy, which seeks to eliminate the ultimate source of waste; *Variability*, in all of its forms through out the producing processes, from purchasing through distribution. By eliminating waste, JIT targets production with the minimum lead-time and at the lowest total cost.

The JIT philosophy has its roots after World War II when the Japanese were striving to compete with the U.S. manufacturing system (also known as Mass Production). Taichi Ohno was the founder of this philosophy in the 1940s when he began developing a system that would enable Toyota to compete with U.S. automakers. Note that the environment dominating U.S. manufacturing over the last five decades has been based on the Material Requirements Planning (MRP) formalized by Joseph Orlicky, Oliver Wight, and George Plossl. In an MRP environment, planning is performed based on the independent (customers') demand, in an almost JIT basis. However, shop floor control is performed based on a push philosophy in which manufacturing orders are introduced in the system and pushed through production. This is the fundamental difference between JIT and MRP.

According to Ohno JIT rests on two pillars:

1. *Just-in-time* as it is described in the following chapters and
2. *Autonomation or automation with human touch.* This term refers i) to the installation of one-touch automation so an operator will be able to place a part in a machine, initiate the machine cycle, and move on and ii) "fool proofing" or "poke yoke" which is the incorporation of sensors in the machines to signal abnormal conditions and even automatically stop machines if necessary, so operators don't need to watch machines during their cycle (Hopp and Spearman, 2001).

Ohno formulated the whole idea based on two concepts he encountered during visits in the U.S.: An American supermarket and the cable cars in San Francisco. First, he was impressed by the way American supermarkets supplied merchandise in a simple, productive and, timely manner and attempted to develop a similar concept in manufacturing. Each workstation would become the internal customer for the preceding workstation. The former would simply pick up the required parts from the latter, a supermarket shelf. The second concept was analogous to a simple cable car operation. Ohno observed that the cable car riders were pulling an overhead cord when they wanted to disembark. This cord produced a similar sound signaling the cable car to stop the car. Ohno applied a similar system using machine sensors. An operator will stop the operation of a machine using a cord whenever he/she found a problem (autonomation) (Black and Hunter, 2003).

Another contributor to JIT was Shigeo Shingo, who developed a new methodology for the reduction of setup time. This new method, called Single-Minute-Exchange-of-Dies (SMED) system, seeks to simplify and minimize the time required for the process of changeovers, so setups become simple and fast (Black and Hunter, 2003).

The success of the JIT also rests on the principle of "respect for humanity". According to Sugimori (1977), the Toyota Production System (TPS) makes full use of the workers' capabilities and relies fully on them for the running and continuous improvement of the plant.

2.2. JIT Objectives

The goal of JIT is to create a production environment that enables the customer to purchase products needed at the required time and quantity needed, in a predefined quality, at the lowest cost. This is accomplished by reducing variability in all of its forms.

Thus, JIT focuses on reducing seven commonly accepted wastes as follows:

1. **Overproduction**, is prevented by a) synchronizing all processing steps by using the Pull philosophy and the kanban technique and b) by reducing set-up times

2. **Waiting**, is prevented by a) synchronizing all processing steps by using the Pull philosophy and the kanban technique and b) organizing production in Cells
3. **Transport** of materials, is prevented by organizing production in Cells
4. Rework **processing**, is prevented by a) applying quality at the source and b) redesigning processes
5. Unnecessary **inventory** is prevented by a) synchronizing all processing steps by using the Pull philosophy and the kanban technique and b) by reducing set-up times
6. Unnecessary **movement** of employees is prevented by organizing production in Cells
7. Production of **defective** parts is prevented by a) applying quality at the source and b) redesigning processes

Central themes of JIT are *Flow in Production* and *Pull of Production. Flow* is the idea of processing one single item at a time in a continuous way from raw material to finished product without interruptions, delays, defects or breakdowns. *Pull* as the concept of responding to customer demand by delivering parts to assembly, and finished products to customers in a "Just-in-Time" fashion. The number of orders that are provided to the system is strictly determined by the system's capacity. In this manner, the levels of WIP between the workstations are explicitly limited and as a result, the system overloads are avoided (Black and Hunter, 2003; Hopp and Spearman, 2001; Emiliani, 1998; Womack and Jones, 1996; Hay, 1988). This is the key difference with MRP, in which work orders are provided to the system without considering explicitly the state of the system.

JIT constitutes a strategic weapon for a company because it results in a more efficient and less wasteful manufacturing system. By following the methodology of JIT, setup times are minimized successfully and frequent changeovers are feasible. Direct results include considerable reductions of lot sizes and Work In Process (WIP) and total system's inventory. The end result is the significant reduction of the total manufacturing cost.

Implementation of the Flow and Pull concepts is based on a number of significant methods as shown in Figure 2.1. For example, the implementation of techniques such as Total Quality Management (TQM), Total Productive Maintenance (TPM) help in minimizing costly (both in terms of time and costs) rework or loop-backs. Furthermore, in a JIT environment, a) workers should be trained to obtain multifunctional skills and b) machines should be allocated properly to the re-designed manufacturing cells to cope with unexpected fluctuations in demand.

Thus, manufacturing cannot reap the benefits of JIT unless the above preconditions exist; i.e. multiskilling and problem solving by workers, elimination of rework etc. In addition, supplier networks must support long-term and mutually beneficial relationships in order to achieve synchronization between supplies and production. The above steps interact with one another and thus, must be achieved following an iterative process that continuously reveals waste and ensures continuous improvement or Kaizen in the system.

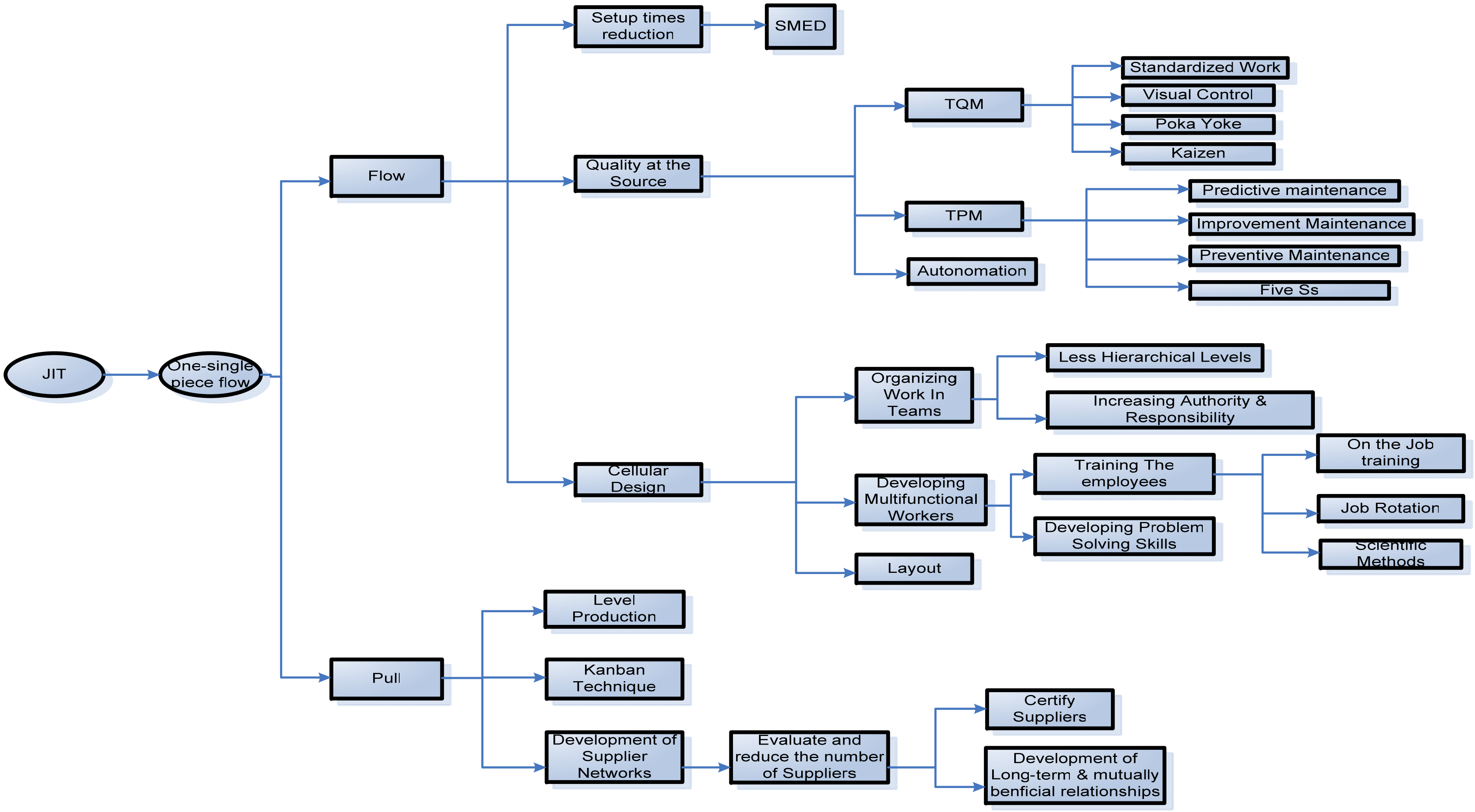

Figure 2.1: The JIT Elements

2.3. The Pillars of JIT

Figure 2.1 summarizes the results of an extensive literature research regarding JIT implementation in manufacturing. This review has shown (as already mentioned above) that JIT is founded on the pillars of: A) Implementation of Flow, and B) Implementation of Pull. Further analysis of these pillars is presented below:

2.3.1. Implementation of Flow

In order to establish flow in a system, three preconditions must exist, which are discussed bellow:

a) Setup Time Reduction

The method of *Setup time reduction* or *Single-Minute-Exchange-of-Dies (SMED)* comprises five steps:

1. *Maintenance, Organization, and Housekeeping*. A typical cause of setup problems is poor housekeeping, poor equipment maintenance and incorrect organization of tools. Proper maintenance, organization, and housekeeping are easy to be enforced and result in significant benefits.
2. *Separate Internal elements from External and convert them to External*. Internal (or mainline) elements are the processes that occur when the machine is not working, while external (or offline) elements are the processes that can be worked out while the machine is operating. The notion here is to convert as many internal elements as possible to external. Chief among internal elements that can be converted to external are *searching time* looking for the correct die, tools, carts, etc, *waiting time* for instructions, carts etc, and *setting times* for setting dies, fixtures, etc.
3. *Improve Elements*. Examine of each element and try to find methods of eliminating waste.
4. *Eliminate Adjustments*. A short period of time is required to enforce a new adjustment but a long period of time is required to make this adjustment to function properly.
5. *Abolish Setup*. This composes the ultimate goal of the SMED method and it could be achieved by either redesigning the products and make them uniform, so the same parts are required for various products or producing various parts in parallel

at the same time (Black and Hunter, 2003; Hopp and Spearman, 2001; Hay, 1988).

b) Quality at the Source

Quality at the Source according to JIT constitutes of two main principles: Total Productive Maintenance (TPM), and Total Quality Management (TQM). TPM includes the techniques of preventive maintenance, predictive maintenance, improvement maintenance, and 5Ss maintenance while TQM include standardized work, visual control, poke yoke, and kaizen. Further analysis of these principles is presented in Section 2.5

c) Cellular Layout

Cellular Layout is the organization of the manufacturing facility (people, materials, machines, and design) in cells, dedicated or semi-dedicated in product families. Further analysis is given in Section 2.4.

2.3.2. Implementation of Pull

The pull production system according to Crabill, *et al* (2000) is defined as "*a two sub-system linkage in a supply chain. The producing operation does not produce until the standard Work-In-Process (WIP) between the two sub-systems is less than the set point. When the standard WIP is below the set point, this condition signals the need to replenish. Information flows in the reverse direction from product flow to signal production by the upstream cell or manufacturing process*". Pull represents a production system that explicitly limits the level of WIP in contrast to the push production system (Hopp and Spearman, 2001). According to Smalley (2004), three main types of pull systems exist: the *replenishment pull system* in which production is triggered when the stored end items are consumed, the *sequential pull system* in which the production rate is regulated according to the demand with the pacemaker to be usually established in the first process step at the beginning of the value stream map, and the *mixed pull system,* which is the combination of the replenishment and the sequential pull systems. Table 2.1 describes the basic differences between Pull and Push production systems.

Table 2.1: Basic Differences between Pull and Push Manufacturing

Pull Conditions	Push Conditions
The final assembly workstation requests from the upstream cells parts to be produced in order to replenish the inventory (parts are "pulled"). *As a result…* - One scheduling point for the overall value stream, thus there is no confusion over the "right" schedule and everyone is marching to the same beat.	Each workstation forwards its producing parts to the final assembly workstation irrespective to the demand (parts are "pushed"). *As a result…* - Several scheduling points in the overall value stream, thus confusion over the "right" schedule.
Flow of production is fully accomplished (No Setup Time, No rework) *As a result…* - Lot sizes are minimized, thus less inventory is required	Flow of production is not fully accomplished *As a result…* - Orders are produced in large batch sizes, thus more inventory is required to cover breakdowns, delays or forecast mistakes (Black and Hunter, 2003).
All production processes, machines and workers are organized properly to produce at the rate given by Takt Time: *As a result…* - There is production smoothing and leveling of demand between the manufacturing cells and cycle time is reduced, thus items are paced and built in accordance with demand	The production is accomplished irrelevant of the Takt Time: *As a result…* - The line is not balanced according to demand and items are paced and built irrelevant to the demand.

Pull Conditions	Push Conditions
No production process begins unless three prerequisites are fulfilled: 1. Demand (available kanban card) 2. Raw material 3. A Free Server *As a result…* - System's capacity defines the number of the orders (system is not overloaded), thus the WIP is explicitly stated and it is small (a closed queuing network).	No conditions exist for setting out the production process. Orders continue to be added in the system with no limits on WIP. *As a result…* - Orders are pushed in the system irrespective of its capacity (bottlenecks occur), thus the WIP is alleged and it is large (an open queuing network) (Hopp and Spearman, 2004).

In order to implement pull, as it was shown earlier, *Flow* must be established. After that a series of three additional techniques can be applied in order to realize pull production. These techniques are described bellow:

a) Level Production

Level or Smoothing Production attempts to eliminate fluctuation in final assembly by eliminating variation or fluctuation in feeder processes. It represents a scheduling technique for balancing a production line by changing a) the production volume; i.e. parts are produced one single-piece at a time, and b) the production sequence of parts. Level production can improve the line performance by specifying which products are to be produced at each time interval. It is often preferred to implement level production firstly in the assembly operations, and secondly to adjust the cycle time to be equal or slightly less than the takt time (see Appendices A.3 and B).

The Japanese created a visual scheduling tool called the heijunka box. Heijunka is generally a wall schedule, which is divided into a grid of boxes, each one representing equally established time intervals during shifts which indicate what products and in what quantity should be produced during the corresponding time interval. In this box, daily orders (kanbans) are inserted by production control in order to pull products of the right mix and provide instructions to the system about sequential planning. Additional information for leveling the production can be found in the work of Black and Hunter (2003) as well as in A. Smalley's (2004).

b) Kanban Technique

The lean method of production and inventory control is a pull system widely known as the kanban system (kan means signal and ban means card in Japanese). Kanban cards represent a visual control tool that regulates the flow of materials between cells and aim to respond to demand by delivering parts and products Just-in-Time. Therefore, it is a method of controlling the flow of information between the workstations while eliminating the WIP levels. In general, the kanban method functions as described in the following paragraph:

The downstream customer, either internal or external, pulls parts (downstream flow of parts) from the upstream supplier (internal or external) as needed. Empty product containers are a signal (upstream flow of information) for replenishment. The above is accomplished by using different kinds of kanban cards, such as production cards, move or withdrawal cards, signal cards, etc. and it comprises a significant method of production control and controlling levels of WIP.

Appendix A describes in detail the most four significant types of kanban systems as well as the existing types of kanban cards.

c) Development of Supplier Networks

Finally, according to the literature of JIT, *supplier networks* must be developed. The integration of suppliers seeks to transfer the technological knowledge from the customer to the supplier and convert the latter to a lean manufacturer. As a consequence, suppliers evolve into remote cells in the linked-cell manufacturing system and deliveries are becoming synchronized with the buyer's production schedule.

The supplier networks must consist of fewer and better suppliers and the contracts should be long-term and mutually beneficial. The rule here is to create single sourcing supplies for each component or subassembly by certifying the related suppliers. (Black and Hunter, 2003; Wu, 2003; Waters-Fuller, 1995; Hay, 1988).

2.4. Cellular Manufacturing

The *cellular system* also known as *lean shop with linked-cell design* is considered to be a basic component of the lean-production philosophy (Black and Hunter, 2003). Nevertheless, alternative types of manufacturing systems also exist depending on the product characteristics and mix, the type of manufacturing philosophy, etc. The existing layout types are divided mainly into four categories (Tompkins, 1996):

- The *Fixed Product Layout* is best applied in low volume production processes with low standardization and stable demand. It is the method of combining all workstations required to produce one product such as an aircraft, ship etc. within the area required for staging the product. A typical characteristic of this facility layout is that workstations are brought to the material since the referred product is usually very large and bulky.

- The *Product Layout* is best applied in high volume production processes with high standardization and stable demand. It is the method of combining all workstations required to produce one product with *continuous flow* processing. Thus, the processing sequence is linear with the products flowing from one workstation to another.

- The *Group Family Product Layout (Assembly Line)* is best implemented in medium volume production with medium process standardization. In this case, few products are produced at the same time under varying demand. The products are grouped into families and each family is treated as a pseudo product. Equipment is dedicated or semi-dedicated to manufacturing each family.

- The *Process Layout* is more practical in low volume production with low process standardization. In this case, the demand is usually unstable. The production is conducted in *batches* and identical workstations are combined into departments. In this case what determine the layout is the process and not the product.

The Product Layout and the Group Family Product Layout are the two types that mostly fit the lean philosophy. Further analysis of the cellular system is presented in detail in the following paragraphs.

Cellular Layout

Lean-production cells are designed to operate at less-than-full-capacity. The workstations within a cell are typically arranged in a U-shape for flexibility, so that workers may move from machine to machine, loading and unloading them with parts, following the shortest walk distance with the least possible obstacles. In a JIT manufacturing cell, one operator is able to run two, three or more different machines, all performing operations on the same part, moving this part from operation to operation in sequence one-single piece at a time. This is due to the fact that a U-line layout enables the operators to be physically together side-by-side, back-to-back without interrupting, annoying or hindering each other.

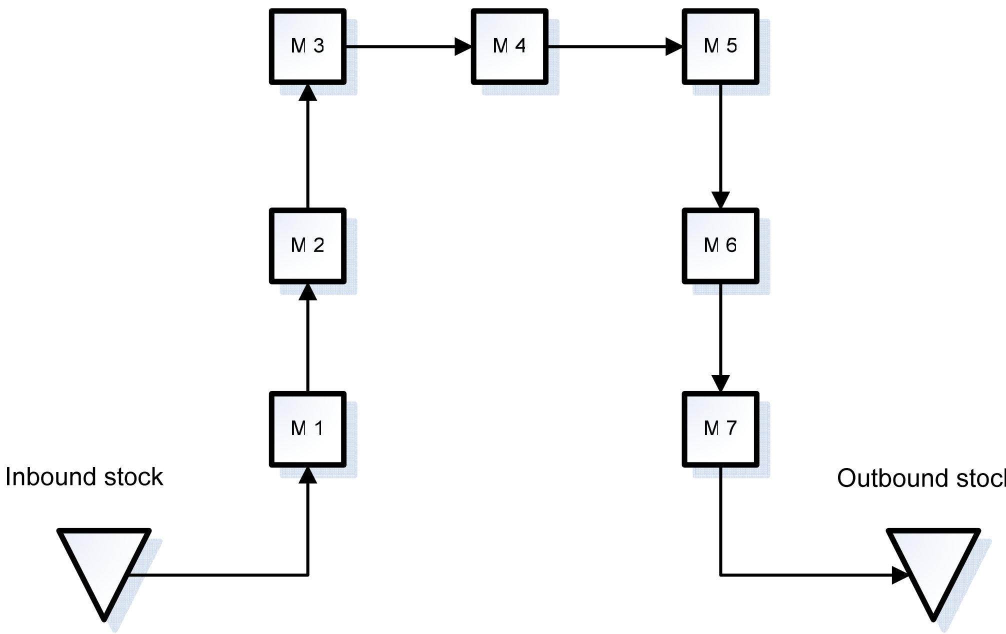

Figure 2.2: A U-shaped Cellular Layout (source: Hopp and Spearman, 2001)

The workstations that perform successive operations are located close to each other, so that products and parts can flow easily from one to another. Moreover, this kind of layout supports flexibility in the number of workers since one worker may operate more than one (and possible all) workstations within the cell. Therefore, the number of workers can be easily adjusted to the demand and to the calculated cycle time (or takt time if the cell is the final assembly station) (see appendix B).

However, in order to fully exploit the benefits of cellular manufacturing certain conditions must hold: a) cells must be staffed with multifunctional workers[1],

[1] Multifunctional means a worker that can perform various tasks such as setup reduction, operating properly the machines, implementing preventive maintenance and continuous improvement et al.

organized in teams, and b) automation should be an integral part of all workers and other resources within the cell.

In order to organize the available machines properly in manufacturing cells one has to fully analyze the product (and part) characteristics and form appropriate part families. There are many methods of cell formation. A typical one is the one presented by Braglia, *et al* (2006) and includes the following steps:

1. Specify which machines are used by which parts
2. Use the “Jaccard” similarity function to estimate the similarity of the products via the machine part matrix:

$$S_{ij} = \frac{X_{ij} + \sqrt{X_{ij} \cdot Y_{ij}}}{X_{ij} + X_i + X_j + \sqrt{X_{ij} \cdot Y_{ij}}}, \quad (2.1)$$

   Where $0 \le S_{ij} \le 1$,

   X_{ij} = number of machines used by both part ‘i’ and part ‘j’ (number of matches),

   X_i = number of machines used by part ‘i’ only,

   X_j = number of machines used by part ‘j’ only,

   Y_{ij} = number of machines that are used neither by part ‘i’ nor by part ‘j’ (number of misses).

3. Accumulate the results in a similarity matrix and assemble the follow-on part-group dendrogramm.
4. Reorganize the machine part-matrix by determining the machine sharing. The norms are: i) the machines that are not shared should be positioned into a cell, in order to accomplish continuous flow processing, ii) for the machines that are shared use the “Signal Kanban” (see Appendix A).

Having formed a cell, capacity or cycle time (or takt time) is adjusted to respond to changes in the customer demand: It is set to produce parts at exactly the rate set by the parent subassembly, no faster or slower.

Cellular design results in significant benefits. Reductions in setup times, raw materials, WIP, number of defects; as well as reduction of the cycle time variability.

As a result, quality is improved and total manufacturing costs are reduced. Finally, a smoother and faster flow of products through operations is achieved.

2.5. Quality at the Source

The implementation of *Quality at the Source* techniques aim to reduce significantly manufacturing costs (e.g costs occurring by the shorter life cycle of the machines, major equipment repairs, etc) while upgrading the quality of the products at the same time. As referred previously, Quality at the Source rests on two principles: a) the Total Productive Maintenance (TPM), which aims to preserve and enhance equipment reliability, and b) Total Quality Management which focuses on qualitative management by fostering an overall environment supportive of quality improvement. Below are described the tools of TPM and TQM.

The techniques of achieving TPM focus on:

- Preventive Maintenance which is the scheduled maintenance to avoid breakdowns,
- Predictive Maintenance which is the prediction of pending machine breakdowns, and appropriate intervention to prevent them
- Improvement Maintenance which is the upgrading of a workstation to prevent a problem before its reappearance,
- 5 Ss maintenance: the *Seiri*, *Seiton*, *Seiso*, *Seiketsu*, and *Shitsuke*. *Seiri* is the segregation of unnecessary tools from the necessary and the elimination of what is not needed. *Seiton* is the process of arranging the tools in the production space in a way that simplifies access and use. *Seiso* is the process of daily cleanliness, which enhances the quality level. *Seiketsu* is the frequent revisiting and the standardization of the above three steps. *Shitsuke* is the motivation to sustain and the promotion of adherence through visual performance measurement tools. (Crabill and Harmon, *et al*, 2000; Womack and Jones, 2003).

The techniques of TQM focus on the following:

- *Standardized Work* is attained by applying the takt time (see appendix A) to the final assembly. This is accomplished by defining the sequence of the processes and tasks, designing properly the cell and establishing the minimum number of pieces (stock-on-hand) needed to maintain a smooth flow of work so that the cycle time to be equal or slightly less than the takt time (Black, Hunter, 2003). Time studies and work methods techniques are used to determine the minimum amount of work needed to perform a task. Process standardization is applied to expose problems and motivate their solution by implementing new methods. In this manner, inherent sources of variation are eliminated.

- *Visual Control* is referred to the design of a production system that controls itself by clearly identifying where the problems are, and by creating a sense of urgency wherever is necessary. In particular, visual means of control should be designed in order for each worker to assume actions for maintaining the control of the production system (Crabill, *et al*, 2000). Autonomation is one example, in which andon light systems are installed to warn the workers when a problem occurs, or even stop the machines if necessary. Kanban cards and the heijunka box represent other visual control means to inform the system at any time about the level of WIP, the rate of the production process, the production targets, etc. In summary, visual control establishes the means to visualize whether the state of the system is within acceptable limits, and to pinpoint waste (Crabill, *et al*, 2000).
- *Poka Yoke (or mistake proofing)* is a device or a process for defect prevention that aims to avoid errors in the receiving of orders or in the manufacturing process. The whole idea is to produce zero defective products by using the poka yoke, a bunch of small devices that are used to either detect or prevent defects from occurring in the first place. An example is a beam of photocells on the material boxes along an assembly line that blocks the product flow to the next step if some components are missing. If the beam of cells is not switched off in each container that contains each part of the product, the flow of the product towards the next workstation is blocked.
- *Kaizen (or Kaizen Event (Blitz))* is a Japanese term meaning continuous and unending improvement in the processes in order to eliminate waste and to enhance value. Kaizen operates mainly in two levels: a) in an on-going process of identifying opportunities for improvement and b) in short-term projects (Kaizen Event). The kaizen technique aims in reducing non-value added activities such as setup times, unnecessary transport of materials, etc. This kind of improvement is mainly attained by training properly the employees in order to obtain problem

solving skills and thus, to be able to identify and implement potential improvements (Womack and Jones, 2003; Crabill, *et al*, 2000).

The frequent and scheduled implementation of the above quality at the source techniques has long-term benefits. Operators are more recognizable with production equipment and pending problems. The application of visual controls improves the quality of the products since processes are in better control. Consequently, system's reliability, flexibility, and capability are improved by eliminating the level of WIP at the same time and by extension the total manufacturing costs.

3. An Overview of Financial Services

This chapter overviews financial services and identifies specific characteristics of both services and financial services. By defining those characteristics, one may determine the differences between other services and FSs and distinguish the differences of FSs vs. manufacturing. This comparison is a prerequisite in determining proper adjustments of the JIT techniques to FSs.

Before starting this analysis, it is useful to present a definition of FSs. According to Meidan (1972), "Financial Services are defined as activities, benefits and satisfactions, connected with the sale of money, that offer to users and customers financial-related value". FSs are provided by the finance industry, which includes a wide variety of institutions such as banks, investment companies, insurance companies etc, and aim to the sale and management of the money.

3.1. Characteristics of Services

Services have distinct characteristics from manufacturing. These characteristics are classified in four areas: Object of Transformation, Service Production, and Service Output. *Object of transformation* refers to the customer, the information, and the materials, with information being the dominant object in services. S*ervice production* refers to the interaction with the customer and the production process. Finally, by using the object of transformation and by taking under consideration the customer requirements the *service output* is produced.

Object of Transformation

1. The objects of transformation in FSs are the customers, the information, and finally the material. According to Apte *et al*. (1999), financial services such as banking, insurance etc. are widely known as *information intensive services* due to the fact that are characterized by information intensity. Information intensive services mainly involve gathering, elaboration, and propagation of information.

Service Production

2. *Server dependence* represents another characteristic of services, since in most cases the server is required in order to a service to be produced and the service

performance depends on the skills and attitudes of the performer (Apte et al, 1999).

3. *Customer Participation*. In most services the customer also has significant participation and is able to intervene in the entire provision process of the service, as well as to the nature of the output. The level of the customer participation affects the level of *uncertainty*. This may happen due to incomplete or missing information required to perform a task.

4. *Insepararability* characterizes the simultaneity of production and consumption. Difficulties exist in managing the customer-performer interface since both of them participate intensively in the production process. Therefore, effective communication is a prerequisite for the successful completion of the process and the avoidance of uncertainty (Lievens and Moenaert, 2001).

5. *Perishability* is referred to the nature of the produced products. The inseparability of the production and consumption lead to the logical consequence that services cannot be stored and kept in stock due to the fact that by the time the service production process has finished, the product-service has already been consumed by the customer (perishability in the result of the process) (Lievens and Moenaert, 2001).

Service Output

6. *Intangibility* is another specific characteristic that distinguishes services from manufacturing. The service effectiveness is directly depended on the server-customer communication, and, by extension, on the degree of intangibility of the service. Thus, uncertainty as regard to intangibility is contingent upon the ambiguity in the relationship between the service provider and the customer (Lievens and Moenaert, 2001).

7. *Heterogeneity* largely characterises the nature of services. The customer's involvement renders unfeasible the standardization of the output. The wider the human involvement in the servicing and delivery process, the higher the potential for heterogeneity in quality since different technical and interpersonal skills are

required for the provision of the service (Daft and Weick, 1984; Moenaert and Souder, 1990a; Mahajan *et al*., 1994).

3.2. Types of Financial Services

We distinguish two approaches in classifying FS. The first approach is due to Harrison (2000), which classifies FS as direct and indirect services. The second approach is based on the Standard Industrial Classification Code or North American Classification System (NAICS) (www.census.gov/eos/www/napcs/papers/52.pdf). Bellow we provide essential information on each approach in order to identify the existing types of FSs.

The classification of FSs according to Harrison is the following:

Table 3.1: Classification of the Types of the FSs.

#	**Direct financial services**	**Indirect financial services**
1.	Loans	Cash Accessibility
2.	Investment Services	Asset Security
3.	Insurance Services	Money Transfer
4.	Pension Services	Deferred Payment
5.	Real Estate Services	Financial Advice

A more detailed table can be found in Appendix C

The term *direct* refers to the final product-service that a financial institution offers and a customer is motivated to purchase, while the term indirect refers to the services that are indirectly offered during the purchase of the final product-service without further payment. For example, the process of a loan provision includes both direct and indirect FSs. The loan, which is the final product-service that a client purchases, represents the direct FS. However, the provision of such a direct service involves financial advice for the selection of a product as well as the possibility for deferred payment. These represent the indirect FSs.

The classification of FSs according to NAICS is summarized in Table 3.2:

Table 3.2: Classification of the Types of the FSs according to NAICS

1. Financial products	2. Related services
1.1 Financing products	2.1 Spot trading of commodities
1.2 Brokering and dealing products	2.2 Reselling services for merchandise, retail
1.3 Financing related to insurance	2.3 Securities information products
1.4 Trading securities and commodity contracts on own account	2.4 Databases and other collections of customer information
1.5 Account and cash management products	2.5 Rental or real estate
1.6 Products supporting FSs	2.6 Real estate appraisal services
1.7 Insurance Products	2.7 Safe deposit boxes
1.8 Financial system regulatory products	2.8 Tax preparation and representation services
	2.9 Electronic tax payments
	2.10 Payroll services
	2.11 Legal services for wills, estates and trusts
	2.12 Notary public service
	2.13 Notary and accounting support products for funds
	2.14 General administration of companies
	2.15 Collection of delinquent accounts
	2.16 Formulation and implementation of economic policy

The detailed table can be found in Appendix C

NAICS classifies FSs into two main categories, 1) financial products and 2) related services. The *financial products* are services that involve the collaboration of the customer and the provider. Both participate intensively in the production process. On the other hand, *the related FSs* are minor services that a provider offers to a customer. These services support the main FS provision and aim at offering a greater level of satisfaction to the customer. Further details as well as definitions for each type of FSs are provided in Appendix C.

3.3. Types of FS Providers

The above types of FSs are provided by a wide variety of institutions that qualify as financial institutions. According to the categorization of the US statistic agency, FSs providers are grouped into two categories: the Authorized Deposit-taking institutions (ADIs) and non-ADIs financial institutions. The ADIs are financial corporations that are authorized under the Banking Act of 1959, and the non ADIs (www.wamu.com). Further analysis is presented in Table 3.3:

Table 3.3: Classification of the Types of the FS providers

1. Authorized Deposit-taking Institutions (ADIs)	**2. Non Authorized Deposit-taking Institutions (Non-ADIs)**
1. Banks	1. Securitizers
2. Building Societies	2. Finance Companies
3. Credit Unions	3. Money market corporations (merchant banks
	4. Life insurance companies
	5. General insurance companies
	6. Superannuation and approved deposit funds
	7. Public unit trusts
	8. Friendly societies
	9. Common funds.
	10. Cash management trusts

A more detailed table can be found in Appendix C

In the ADIs mainly belong banks, building societies as well as credit unions while the non-ADIs include a wider variety of FSs. The ADIs function according to prudential standards and guidelines that were determined by the Banking Act in contrary to the non-ADIs. Further description of this classification of the FSs providers as well definitions of each type are presented in Appendix C.

3.4. Distinguishing Characteristics of FSs

As referred previously, FSs deal with the management and sale of money. The generic characteristics of services apply to FSs; however, the degree of applicability may vary in some cases. For example ATM and e-banking do not depend on a line server. However, FSs also present additional characteristics, as follows:

1. *Risk* is intrinsic to all FSs and can be classified into three main categories: Market Risk, Credit Risk, and Operational Risk. *Market Risk* results from exposure to the fluctuations of market prices and foreign exchange rates. *Credit or Default Risk* is the risk of a lender associated with loss of capital and the related accrued interest (Swank, 1996). *Operational Risk* is *associated with* the loss due to process failures, management failures, inadequate controls, and human errors (Basel Committee on Banking Supervision, 2006; Santomero, 1997). There is no doubt that the *danger of fraud* by both the server and client, due to the large amounts of money that are handled, enhances this type of risk (Hefferman, 2005).
2. Risk leads to another characteristic of FSs, *fiduciary responsibility.* The latter is the responsibility of a financial institution towards the customer in managing the customer’s funds (Batiz-Lazo and Wood, 1999).
3. The *Two-way information flows* represent another distinguishing characteristic of FSs, according to Batil-Lazo and Wood (1999). Financial transactions require a great deal of information exchange. Thus, information is updated frequently in order to establish and continue a mutually beneficial communication over extended periods of time.
4. *Confidentiality* is related to information and, particularly, personal information, which should be kept in security and not be disclosed (Mackneil, 1980).
5. The *role of contracts* is significant in FSs in defining, managing, and regulating the obligations and the rights of all parties involved (Macneil, 1974).

3.5. Differences between Manufacturing and FSs Operations

Significant differences exist between manufacturing and FSs. According to Levvit (1972), the main difference between manufacturing and services and therefore, FSs “*is the fact that service is presumed to be performed by individuals for other individuals whereas manufacturing is presumed to be performed by machines*”. We distinguish the differences between manufacturing and FSs operations into three categories concerning the types of inputs, the production process, and the types of outputs.

Production Input

In *FSs* the objects being processed are the *customer* and *information* (intangible), while in *manufacturing* the objects being processed are mainly the *material* and *information*. It should be mentioned that although, information processing operations exist in both areas, this is more pronounced in FSs.

Production

In FSs intensive *customer participation* exists and influences the production process while in manufacturing this participation is limited (in comparison) or none. Moreover, in most cases *server dependence* exists in FSs, while in manufacturing production depends heavily on machines. I*nseparability* between production and consumption exists in most types of FSs, since by the time the process has finished; the service has already been consumed by the customer. Therefore, FSs could be characterized as *perishable* due to the irrelevance of inventory.

Production Output

The output of production in FSs is characterized in most cases by *heterogeneity* (variability) and *intangibility*. The final product in the case of FSs is the service itself, while in manufacturing the final product is a tangible good. Furthermore, production of FSs *depends and is depended by the customer*, and thus, standardization is difficult to accomplish, while in manufacturing standardization is a central concept. The nature of a FS is such that *no ownership of the provided service* exists in contrast to manufacturing where the produced products are purchased and owned by the customer. Finally, contracts are used to regulate the rights of all parts involved while in manufacturing usually only an order composition is required.

3.6. JIT in Financial Services

This Section presents existing work on the application of the JIT principles to FSs. We identify those concepts of JIT that are applicable to FSs, and those that are not. Note that the existing attempts are minimal and no extensive literature was found. The following paragraphs summarize these methods based on the guidelines of a roadmap introduced by Crabill, *et al* (2000) (see also Apte, *et al.,* 2004; Cuatrecasas, 2004; Swank, 2003; Allway, *et al.,* 2002; Duclos, *et al*., 2000; Bowen, *et al.,* 1998; Lummus, 1995; Mehra, *et al.,* 1990; Shostack, 1984; Levitt, 1972).

Standardization. It refers to the elimination of the heterogeneity in services in order to simplify, improve and standardize processes and the related performance of the employees involved. Many service scholars support that in services, standardization is limited or can be dangerous due to the different appreciation of the service by the customer; however, all Banks have examples, where the standardization of certain job activities resulted in significant productivity increases by reducing the time required to complete an activity and standardizing the service output (e.g. money transfers). Thus, we could conclude that standardization with limiting power to customer options during the customer – server interface could cause dissatisfaction; on the contrary standardize activities in back office operations could lead to substantial benefits.

Level Production. Distributing and properly sequencing the tasks in each team could achieve workload leveling. The goal is to have each activity completed in a predefined cycle time, which must be equal to takt time. While this is a common practice in manufacturing organizations, there are not many examples found in FSs. However, some exceptions exist, such as the insurance company referred by Swank (2003).

*Cellular Organization. C*ell layout is comprised of staff performing a variety of tasks working on a family of financial products with similar characteristics. This could be accomplished by cross training the employees and rotating them. While in several banks this is a common practice, we couldn't suggest that all financial organizations apply the cellular organization in all of their activities. This is mainly because the activities involved are too specialised, requiring extensive experience for their execution (e.g. Treasury Operations).

The Table 3.4 summarizes examples of JIT practices implemented in FSs as found in the literature. The next chapter aims to examine the applicability of two JIT practices, the *Cellular Organization* and *Quality at the Source* in FSs. The conclusions of this Chapter will illustrate the benefits than can be obtained by their application.

Table 3.4: Applicability of JIT elements in FSs

JIT Element	Applicability in FSs
1. Quality at the source	Several Examples exist, such as failsafe techniques that facilitate self-inspection, visual control, standardized work etc.
2. Cellular design	Limited examples found for aggregating staff into cells, processes, and products into families.
3. Setup times reduction	No applicability since setups (i.e. quantity independent time spent) typically don't exist in FSs.
4. Kanban technique	No application found in the literature search. However, this is an interesting area that may have significant improvements in certain types of FSs operations.
5. Level production	Limited examples found for setting a common tempo and producing at a rate set by the Takt Time.
6. Development of supplier networks	No application was found in the literature search. This element is not applicable since in the case of FSs, the main supplier is the customer itself who provides the proper information and his consent for the start of the production procedure.

4. Case Study: JIT Application in Banking Services

The current chapter aims to apply two important JIT concepts in a banking process, the Personal Loan Approval. This process was selected not only because personal loans are amongst the most typical banking products, but also because of the criticality of the loan approval process; operational problems in this process may lead to immediate losses for the bank (credit risk). The JIT concepts selected for this process are: *Quality at the Source* and *Cellular Structure*. The first concept was selected since inferior quality in the process (e.g. incomplete or applications mistakes, or missing documents) has been identified as one of the most important sources of waste, since it can lead to unnecessary repeated work (rework) or wrong decisions (bad loans). The second concept was selected in order to evaluate a latest trend in banking operations; that is the shift from traditional personnel arrangement (e.g. product structure) to more successful methods of organising work, such as those used in lean manufacturing (Cellular Structure). Other JIT concepts were considered either not relevant to banking services (e.g. set-up time reduction, development of suppliers) or less critical (e.g. Kanban mechanism).

The implementation of the above JIT concepts was performed through simulation. We modelled and analyzed the operations of the Credit Department (back office operations). The Credit Department receives daily a number of loan applications submitted electronically (through a workflow system) from the Bank's distribution channels. The applications along with the necessary documentation are processed and evaluated by authorized credit personnel (according to predefined thresholds) and either get approved or rejected. The decision is sent back electronically, notifying the customer either through the Branch Network or through other alternative channels.

The data used to construct the model were not based on direct observations. However, the assumptions as well as the data of the simulation model have been confirmed by banking executives through in depth interviews. The tool used for the simulation was the most recent version of the Arena Rockwell Simulation Software (version 11.0) (www.arenasimulation.com).

4.1. Loan Approval Simulation Model

In the loan approval model, applications arrive randomly following a Poisson[2] distribution. Each application may correspond to a different type of loan. Specifically, there are three loan families A, B and C, each one consisting of four types of loans (A_n, B_n, C_n, n=1,…,4) according to the amount requested:

- Loan family A represents *Amortized Loans*, which are loans that are repaid in a series of instalments each of which contains a portion that is applied to reduce the principal amount of the loan and a portion that is applied to interest.
- Loan family B represents *Revolving Loans* which are loans that allow a customer to borrow against a pre-approved line of credit when purchasing goods and services. Items purchased using this line of credit may be paid in full upon receipt of a monthly statement, or paid in several instalments, for which an interest charge is added.
- Loan family C represents *Secured Loans (or Collateral Loans*) which are protected by an asset or collateral of some sort. The item purchased (e.g. car), can be used as collateral, and a lien can be placed on such purchases. The bank will hold the deed or title until the loan has been paid in full, including interest and all applicable fees. Other items such as stocks, bonds, or personal property can be put up as collaterals.

Each loan follows a certain processing sequence through the different stages of approval. For each stage, the service time is modelled by an exponential random variable which is specific to the stage-loan type combination. Thus, the above models are stochastic and discrete.

We have modelled three types of structures with different arrangement of resources but similar inputs. To analyze these models we have varied key parameters. Significant features of the simulation models include the following:

- *Entities:*

- Loans: Three types of loan applications exist, *Loan A*, *Loan B*, and *Loan C*. Each is further divided to four subtypes according to the loan amount (see Table 4.1)

[2] The number of the random events occurs in a fixed interval of time.

- Servers: Three types of servers exist: Loan officers, Head Clerks, and Managers. Furthermore, two types of systems were used; High Capacity System and Low Capacity system (see Tables 4.3, 4.7, 4.8).

- *Events (instantaneous activities that affect the state of the simulation model):*

- Arrival: As mentioned previously a Poisson distribution was used with a mean inter arrival interval of 2.57 min. (480 working minutes / 187 required loan applications daily)
- Departure: The loan applications leave the system as soon as the approval process is completed.

- *Activities:*

- Service – Approval: The approval process steps follow Exponential[3] distributions. The mean values of each process step for the three types of structures are presented in Tables 4.2 and 4.6 (see also Figures 4.2, 4.3, 4.4).

- *Assumptions:*

  1. Specified number of servers
  2. Known arrival process
  3. Specified sequence of operations per product
  4. Known service time distributions
  5. Infinite length of the queue
  6. Queue sequencing: FIFO (First In – First Out)
  7. Specified percentage of rework

There is a direct equivalence between the simulation model and the real system (see Figure 4.1) in terms of the inputs (see point 1) and the assigned parameters (see point 2) in the system. The goal is to analyze the outputs of the simulation (see point 3).

[3] The approval processes have constant occurrence rate.

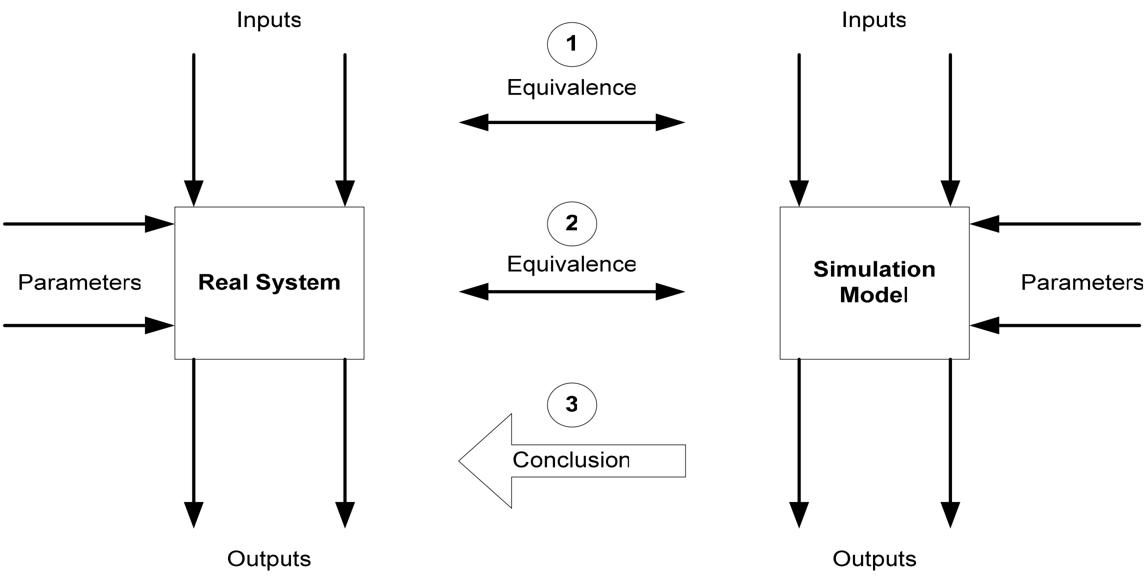

Figure 4.1: Equivalence between Real System and Simulation Model

Table 4.1 : The Types of Loans and Average Daily Demand

Product	Thresholds	Average Daily Demand
A_1	0€<x<2000€	60
A_2	2000€<x<10000€	40
A_3	10000€<x<50000€	22
A_4	50000€<x	10
B_1	0€<x<2000€	16
B_2	2000€<x<10000€	10
B_3	10000€<x<50000€	6
B_4	50000€<x	3
C_1	0€<x<2000€	8
C_2	2000€<x<10000€	6
C_3	10000€<x<50000€	4
C_4	50000€<x	2
	Total	**187**

4.2. Description of the Simulation Models

The examined types of Structures are the: *Product Structure*, *Threshold Structure*, and *Lean Structure*. Further description of each type of Structure is presented below. The processes in each structure were presented using a common technique for process documentation i.e. *Flowcharting*. However, other techniques could be used as well, such as *Process Activity Mapping, Petri-Nets,* and the *SIPOC (Supplier, Input, Process, Output, and Customer) Flowcharting* (more for these techniques can be found in en.wikipedia.org). Additionally, other advanced methodologies and platforms for *Business Process Management (BPM)* could be used (e.g. ARIS platform) which entails Information Systems, Documents management, Resources, etc. (www.ids-scheer.com).

4.2.1. The Product Structure

It represents a traditional structure of credit operations. In this type of structure (see Figure 4.2), there are three different groups of employees. Each group is assigned a specific type of loan, A, B, C, independently of the amount requested. Each group consists of a) three loan officers who perform the first evaluation process, b) one head clerk who performs the second evaluation process and c) one manager who performs the third evaluation process, if this is necessary.

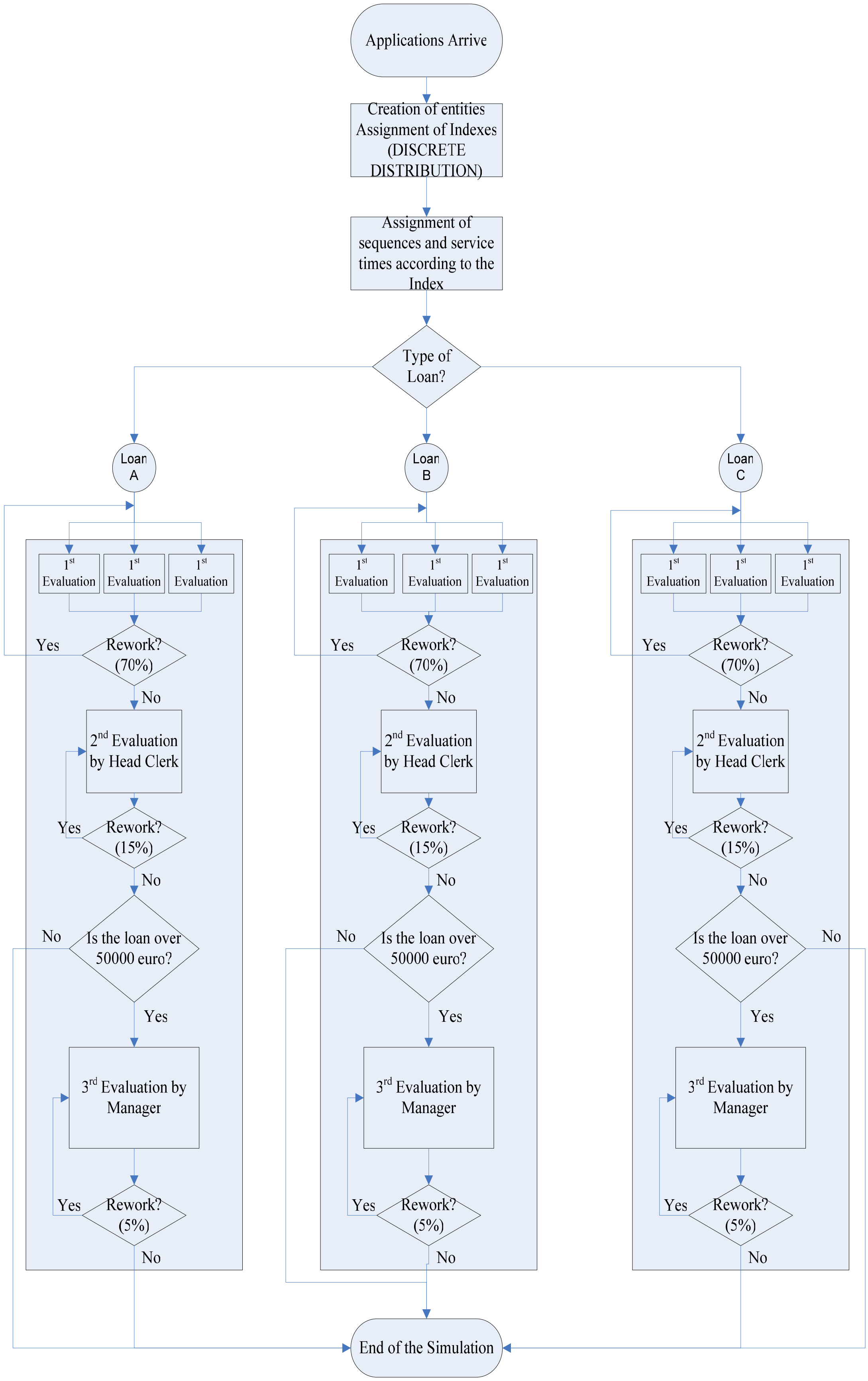

Figure 4.2: The Product Structure

Note that each stage performs quality assurance on its own output. Thus, the defects are reprocessed by the same workstations (as shown in Figure 4.2).

Table 4.2 shows the mean service time of each loan type at each stage of the process (loan officers, head clerks, manager). These parameters have been determined through interviews with appropriate staff of a Greek bank.

As mentioned previously, for each type of structure we analyzed two types in terms of capacity: a) high and b) low. In the two cases we used the number of employees per group shown in Table 4.3.

Table 4.2: The Average Process Times (min) of Loan Approval at each Process stage of Product Structure

Product	**Thresholds**	**Average Process Times of 1st Evaluation Stage (min)**	**Average Process Times of 2nd Evaluation Stage (min)**	**Average Process Times of 3rd Evaluation Stage (min)**	**Sum of Average Process Times (min)**
A_1	0€<x<2000€	6	6		12
A_2	2000€<x<10000€	12	8		20
A_3	10000€<x<50000€	24	26		40
A_4	50000€<x	60	36	24	120
B_1	0€<x<2000€	12	12		24
B_2	2000€<x<10000€	24	16		40
B_3	10000€<x<50000€	30	20		50
B_4	50000€<x	45	27	18	90
C_1	0€<x<2000€	9	9		18
C_2	2000€<x<10000€	18	12		30
C_3	10000€<x<50000€	36	24		60
C_4	50000€<x	75	45	30	150

Table 4.3: The Number of Servers per Group in the Product Structure

	HIGH CAPACITY			LOW CAPACITY		
	Loan officers	**Head Clerks**	**Managers**	**Loan officers**	**Head Clerks**	**Managers**
1st Group	18	6	6	13	4	4
2nd Group	6	2	2	5	2	1
3rd Group	6	2	2	5	1	1
Total	30	10	10	23	7	6

4.2.2. The Threshold Structure

It represents a new structure in which each of the three groups processes all types of loans within a certain range of loan amount(s). Therefore, the sequence of the loan applications is different (vs. the Product Structure) as shown in Figure 4.3. For example, products A_1, B_1, and C_1 don't pass through the head loan officer workstation. As a consequence, the corresponding service times of this workstation are not considered (see Table 4.6). In this case, the distribution of employees per group is determined based on the workload, and the number of servers was reduced accordingly.

This reduction was accomplished by the steps presented below:

1. We estimated the total working minutes for each process and each product as shown in Table 4.4 by multiplying the average daily demand (see Table 4.1) with the corresponding time duration (see Table 4.2).
2. We calculated the percentage of the eliminated working minutes (624 min = 360 + 192 + 72) which is 27% (624 reduced working minutes / 2275 working minutes in the 2nd process). We then reduced the total number of head loan officers by 27% (see Table 4.3). This corresponds to three fewer head loan officers. Thus, the total number of employees is equal to 47.

We then redistributed the workers within the groups in order to achieve a uniform workload within each group. Table 4.5 presents the calculated workload (first part), and the respective workload percentage (second part). The number of employees in each group was estimated by multiplying the corresponding percentage with the total number of employees (47) (e.g. for group 1 this amounts to 0,28 * 47 ≈ 14). Finally, the number of scheduled servers is as in Table 4.7.

Table 4.4: The Workload for each Product and Process in the Threshold Structure

Product	**Limits**	**Process 1 (min)**	**Process 2 (min)**	**Process 3 (min)**
$\mathbf{A}_1$	0<x<2.000	360	*360*	
$\mathbf{A}_2$	2.000<x<10.000	480	320	
$\mathbf{A}_3$	10.000<x<50.000	528	352	
$\mathbf{A}_4$	50.000<x	600	360	240
$\mathbf{B}_1$	0<x<2.000	192	*192*	
$\mathbf{B}_2$	2.000<x<10.000	240	160	
$\mathbf{B}_3$	10.000<x<50.000	180	120	
$\mathbf{B}_4$	50.000<x	135	81	54
$\mathbf{C}_1$	0<x<2.000	72	*72*	
$\mathbf{C}_2$	2.000<x<10.000	108	72	
$\mathbf{C}_3$	10.000<x<50.000	144	96	
$\mathbf{C}_4$	50.000<x	150	90	60
Total		3189	2275	354

Table 4.5: The workload in minutes and % of the threshold structure

		Process 1	**Process 2**	**Process 3**	**Sum of workload (min) per group**
Workload (min)	**Group 1**	1452	552		2004
	Group 2	852	568		1420
	Group 3	885	531	354	1770
	Total				5194
Workload (%)	**Group 1**	28%	11%		39%
	Group 2	16%	11%		27%
	Group 3	17%	10%	7%	34%
	Total				100%

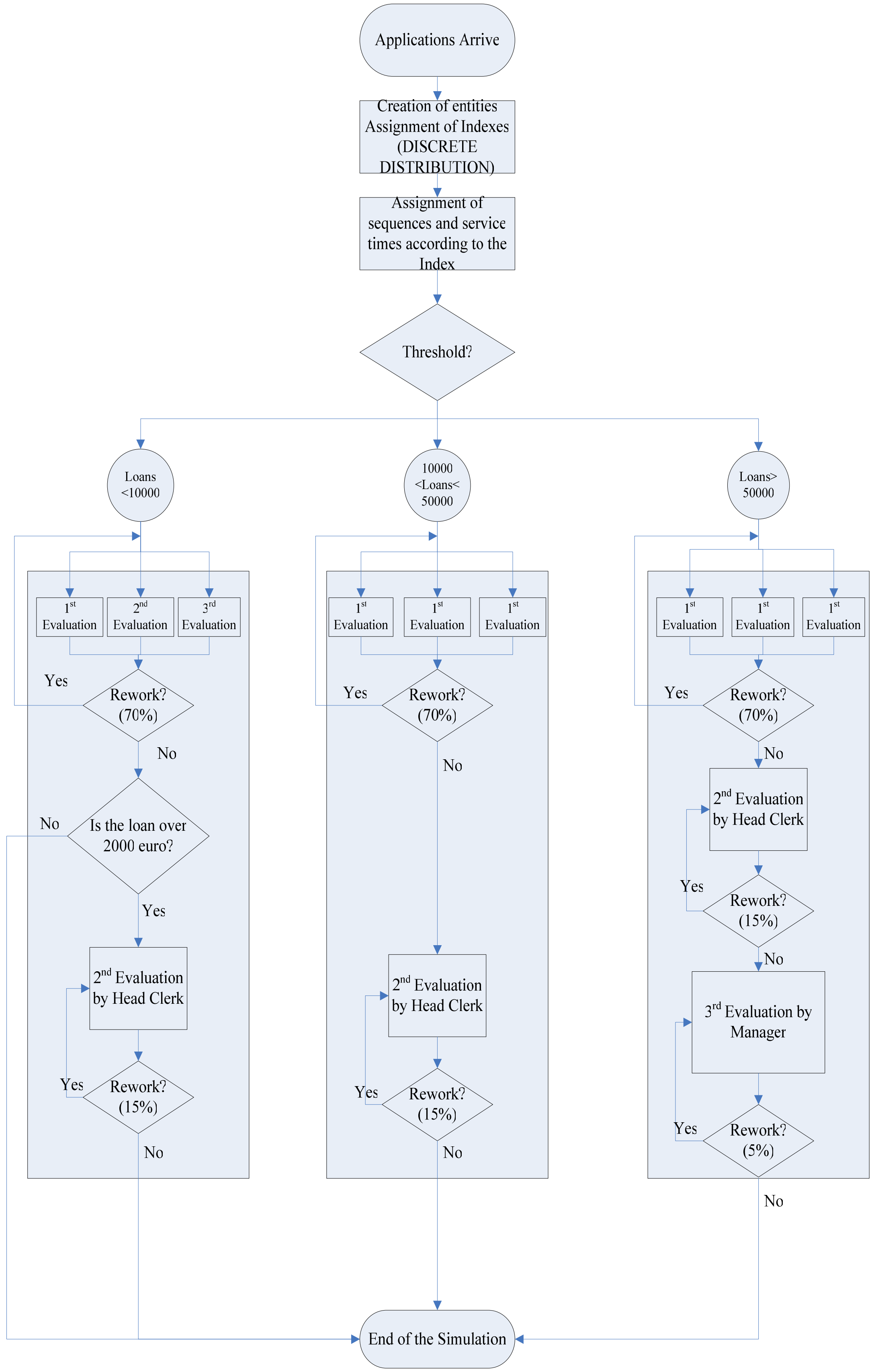

Figure 4.3: The Threshold Structure

Table 4.6: Average Process Times of Loan Approval at each Process Stage of the Threshold Structure

Product	Thresholds	Average Process time of 1st Evaluation Stage (min)	Average Process time of 2nd Evaluation Stage (min)	Average Process time of 3rd Evaluation Stage (min)	Average Sum of Process times (min)
A_1	0€<x<2000€	6			6
A_2	2000€<x<10000€	12	8		20
A_3	10000€<x<50000€	24	26		40
A_4	50000€<x	60	36	24	120
B_1	0€<x<2000€	12			12
B_2	2000€<x<10000€	24	16		40
B_3	10000€<x<50000€	30	20		50
B_4	50000€<x	45	27	18	90
C_1	0€<x<2000€	9			9
C_2	2000€<x<10000€	18	12		30
C_3	10000€<x<50000€	36	24		60
C_4	50000€<x	75	45	30	150

Table 4.7: The Number of Servers per Group in the Threshold Structure

	HIGH CAPACITY			LOW CAPACITY		
	Loan officers	Head Clerks	Managers	Loan officers	Head Clerks	Managers
1st Group	14	4		10	3	
2nd Group	8	5		6	3	
3rd Group	9	4	3	6	3	2
Total	31	13	3	22	9	2

4.2.3. The Lean Structure

This structure is based on the guidelines of lean operations with regard to multifunctional workers. In this case, only one group of employees exists, which is cross-trained to handle all types of loans with all thresholds included. The servers in both the high and low capacity cases were distributed in a similar manner to the threshold structure. The number of employees for this type of structure is presented in Table 4.8 and the flowchart of operations in Figure 4.4.

Table 4.8: The Scheduled Number of Servers in the Lean Structure

	HIGH CAPACITY			**LOW CAPACITY**		
	Loan officers	**Head Loan officers**	**Managers**	**Loan officers**	**Head Loan officers**	**Managers**
1st Group	31	13	3	22	9	2

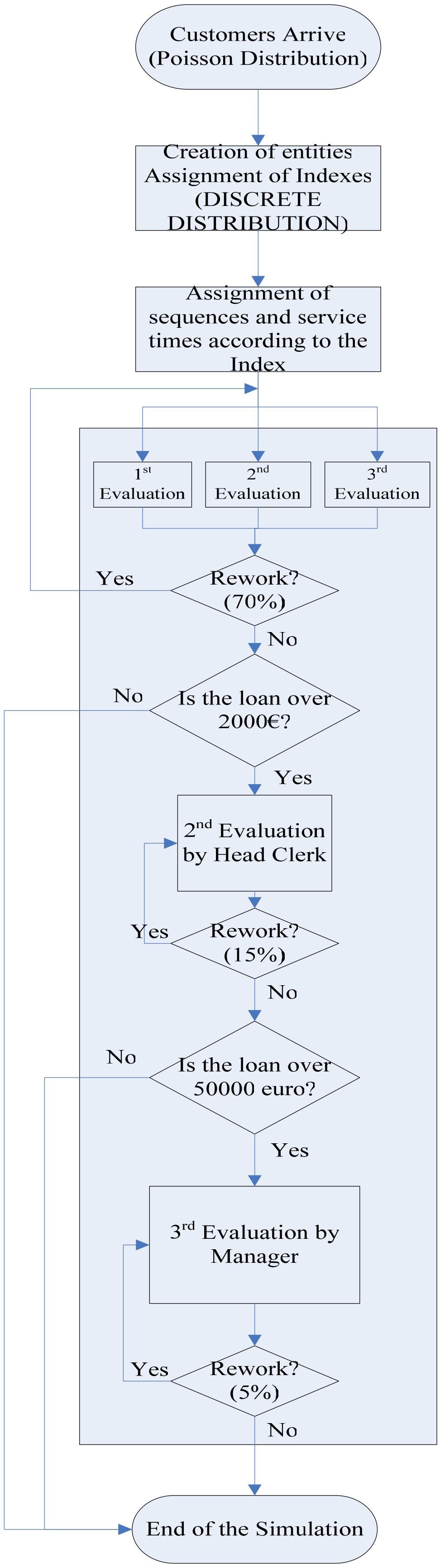

Figure 4.4: The Lean Structure

4.3. Lean Performance Indicators

The performance of each case of the simulation model was evaluated with respect to Key Performance Indicators. These indicators were selected from the Lean literature. These are: Cycle Time (CT), % of Value Added (VA) Time, Level of WIP, Resource Utilization, % Productivity Ratio. The selected lean indicators are presented in detail in Table 4.9:

Table 4.9: The Lean Performance Indicators

	:	**Description**
Key Performance Indicator	:	**Cycle Time**
Definition	:	It represents the average sum of the processing time per loan plus the wait time the loan remains in the corresponding queue.
Calculation	:	$Average\ Value\ Added\ Time + Average\ Wait\ Time$
Unit of Measure	:	Number (minutes)
Level of Analysis	:	Average Value
Key Performance Indicator	:	**% of Value Added Time**
Definition	:	It presents the average percentage of the Value Added time to the total Cycle Time.
Calculation	:	$\frac{AverageValueAddedTime}{AverageCycleTime}$
Unit of Measure	:	%
Level of Analysis	:	Average Value
Key Performance Indicator	:	**Level of WIP**
Definition	:	It represents the average level of WIP that remains in the system during the simulation.
Calculation	:	$TotalWIP$
Unit of Measure	:	Total WIP in the system
Level of Analysis	:	Sum
Key Performance Indicator	:	**Resource Utilization**
Definition	:	It presents the total number of employees that are utilized during the simulation.
Calculation		$TotalNumberBusy$
Unit of Measure	:	Number of employees
Level of Analysis	:	Sum
Key Performance Indicator	:	**Productivity Ratio**
Definition	:	It estimates the average number of produced entities per busy employee.

	:	**Description**
Calculation	:	$\frac{NumberOut}{ResourceUtilization}$
Unit of Measure	:	Average Number of products per employee
Level of Analysis	:	Average Value

The CT includes the VA time and the average waiting time in queue. The VA time represents the processing time of an entity and is modeled by using an exponential distribution. Therefore, the reduction of the average CT leads to the reduction of the average waiting time and as a consequence to the reduction of the average WIP. Furthermore, the reduction of the average CT decreases the average resource utilization while increases the average productivity ratio per employee simultaneously.

To sum up, the desirable objectives are:

1. Reduction of the average CT.
2. Increase of the average percentage of VA time.
3. Reduction of the average WIP.
4. Increase of the average productivity ratio per employee.

4.4. Analysis of the Simulation Results

A number of experiments were performed in order to evaluate the structure discussed above. The first set of experiments compare the performance of the three Structure types under two levels of conditions i) under high capacity or low capacity, and ii) with the presence of rework or when rework is eliminated (see Table 4.10).

Table 4.10: Performance Evaluation between the Types of Structures under different capacity and rework values

		Capacity	
		High	**Low**
Rework	**With Rework**	√	√
	No Rework	√	√
√= Experiment executed			

The second set of experiments evaluated the performance of the Lean Structure against Progressive Reduction of Rework (from 50% to zero) in i) a high capacity and ii) low capacity situation (see Table 4.11).

Table 4.11: Performance Evaluation of the Lean Structure against Progressive Reduction of Rework

		Capacity	
		High	**Low**
Rework	**With Rework**	√	√
	Rework (50% reduction)	√	√
	No Rework (100% reduction)	√	√
√= Experiment executed			

It is noted that each one of the above experiments was repeated ten times by using ten different seed numbers at each repetition in order to increase the result reliability.

4.4.1. Performance Evaluation between the Different Types of Structures under High and Low Capacity

In this experiment we compare the three types of structures against the lean performance indicators under high and low capacity conditions. Furthermore, we test the effect of rework and the benefits obtained by its elimination.

Figures 4.5 and 4.6 show the cycle time under high and low capacity condition. In the case of rework existence, the CT in the high capacity situation is reduced by 31% in the threshold structure and 36%, in the lean structure when compared to the production structure. In the low capacity situation, this reduction is 78% and 87%, respectively. On the other hand, when rework is eliminated, in the high capacity situation the CT is reduced by 11% in both structures, while in the low capacity condition it is reduced by 7% and 9%. These results are due to the fact that different and more effective distribution of the servers is accomplished in the threshold and product structure. Therefore, the number of the loan applications in the queue is significantly reduced.

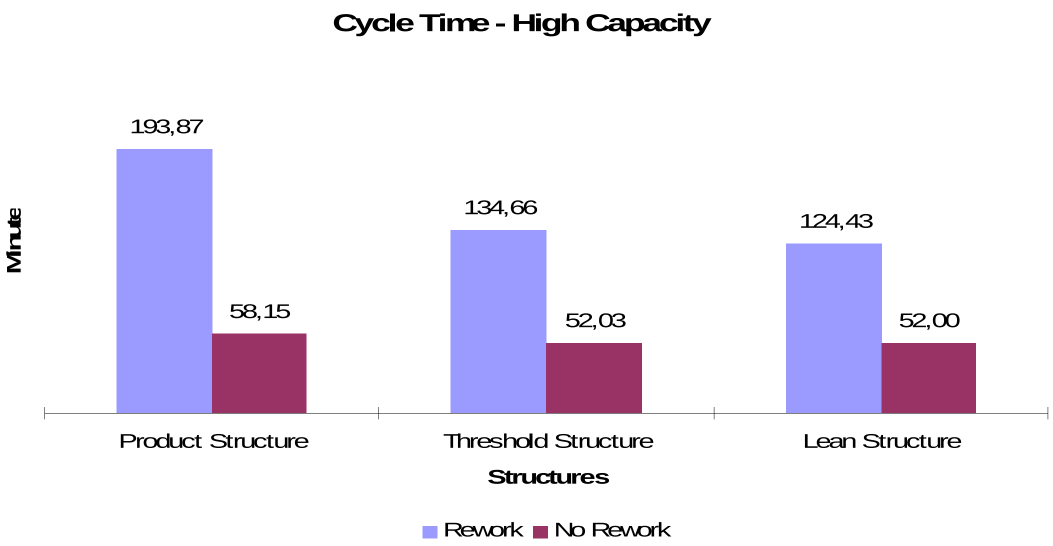

Figure 4.5: Cycle Time under High Capacity

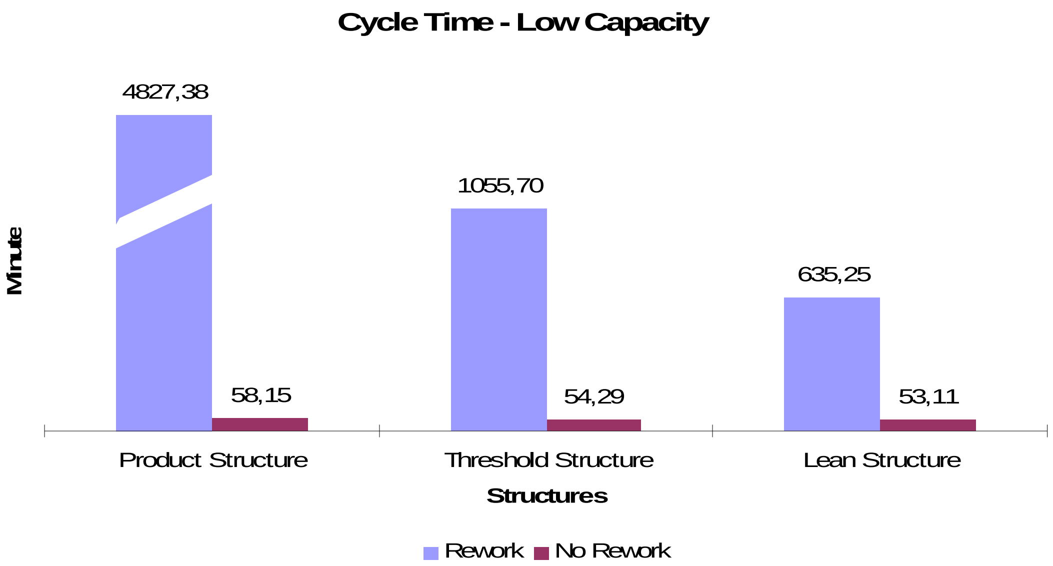

Figure 4.6: Cycle Time under Low Capacity

Figures 4.7 and 4.8 present the percentage of the average VA time comparatively with the average CT. In the case of rework existence, the % of VA time in the high capacity situation was raised by 31% in the threshold and 40% in the lean structure. In the low capacity situation this percentage increases by 257% and 493%, respectively. When rework is eliminated the corresponding increase borders on 9% in the high capacity situation for both structures and 6% and 8% in the low capacity situation.

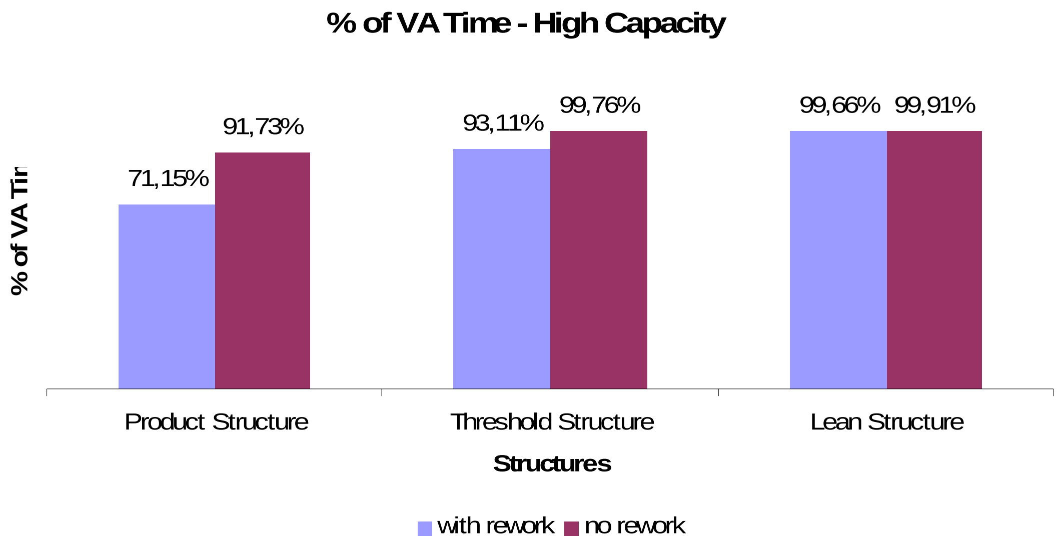

Figure 4.7: % of Value Added Time under High Capacity

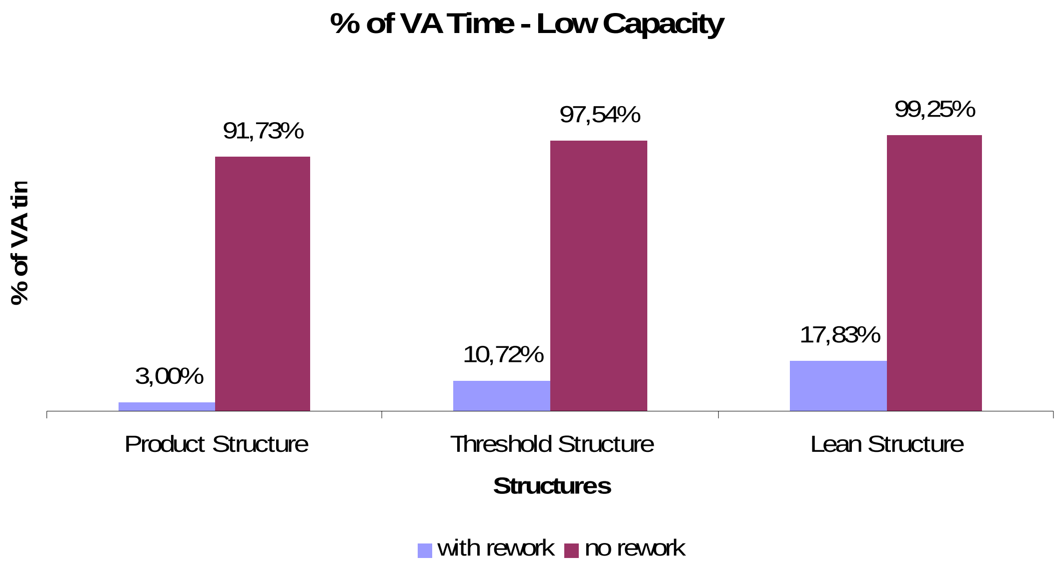

Figure 4.8: % of Value Added Time under Low Capacity

Figures 4.9 and 4.10 show the average level of WIP during operation. In case of rework, the WIP in the high capacity situation is reduced by 31% for the threshold structure and 37% for the lean structure. In the low capacity situation the reduction is 77% and 83%, respectively. When the rework is eliminated this reduction is 17% in the high capacity situation for both structures and on 14% and 16% correspondingly in the low capacity situation.

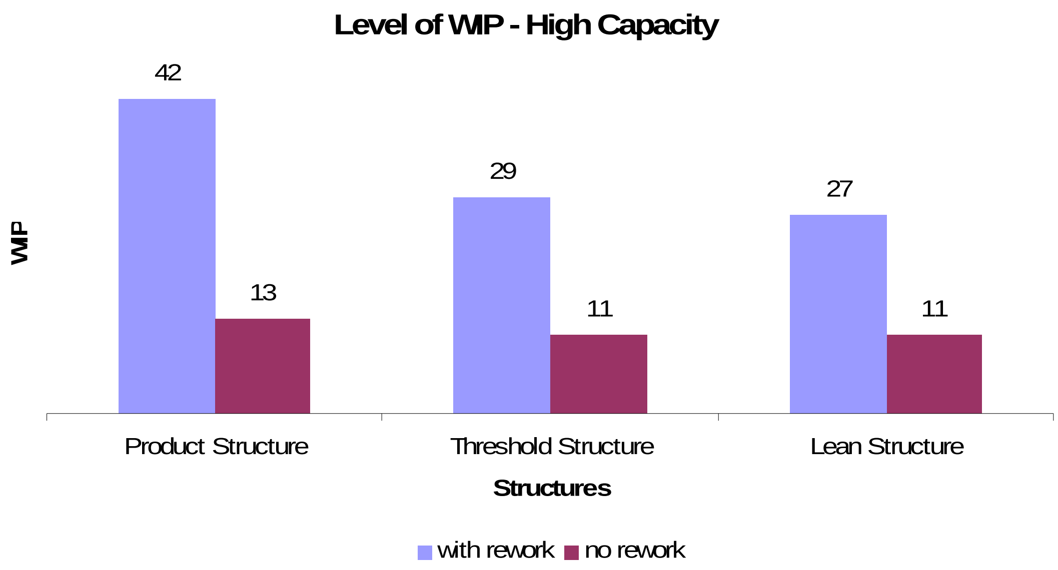

Figure 4.9: Level of WIP under High Capacity

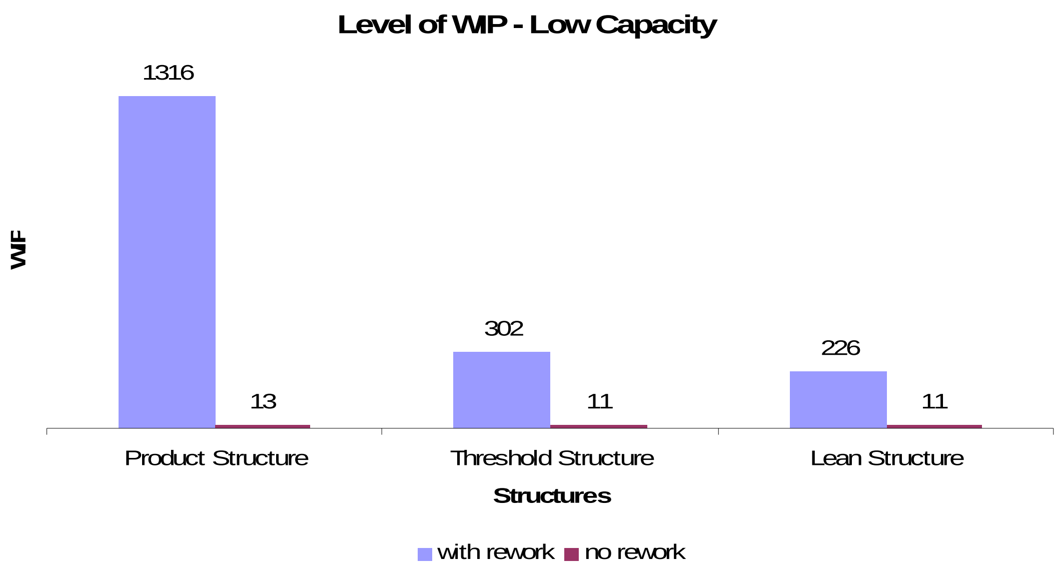

Figure 4.10: Level of WIP under Low Capacity

Figures 4.11 and 4.12 show the total number of busy employees during the simulation. In the rework rate, the number of busy employees in the high capacity situation is reduced by 5% in the threshold structure and 6% in the lean structure. With zero rework this reduction is 11% for both structures. On the other hand, in the low capacity situation, when rework exists, the resource utilization is reduced by 2 % in the threshold structure and by 1% in the lean while in the case of rework elimination this reduction borders on 11% for both structures. Note that, in both the high and low capacity situations the number of busy employees is constant per each structure-rework combination. This is expected, since the system load is the same for both situations.

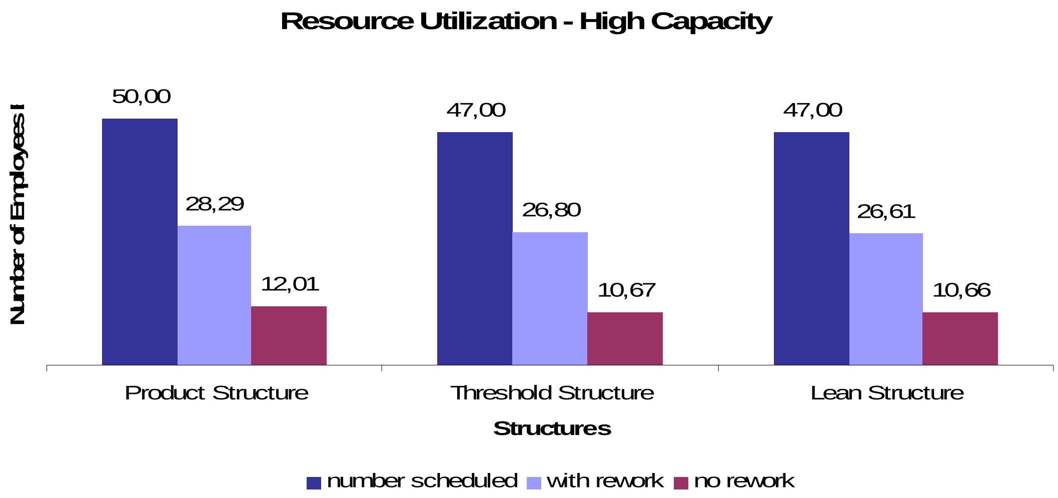

Figure 4.11: The Resource Utilization under High Capacity

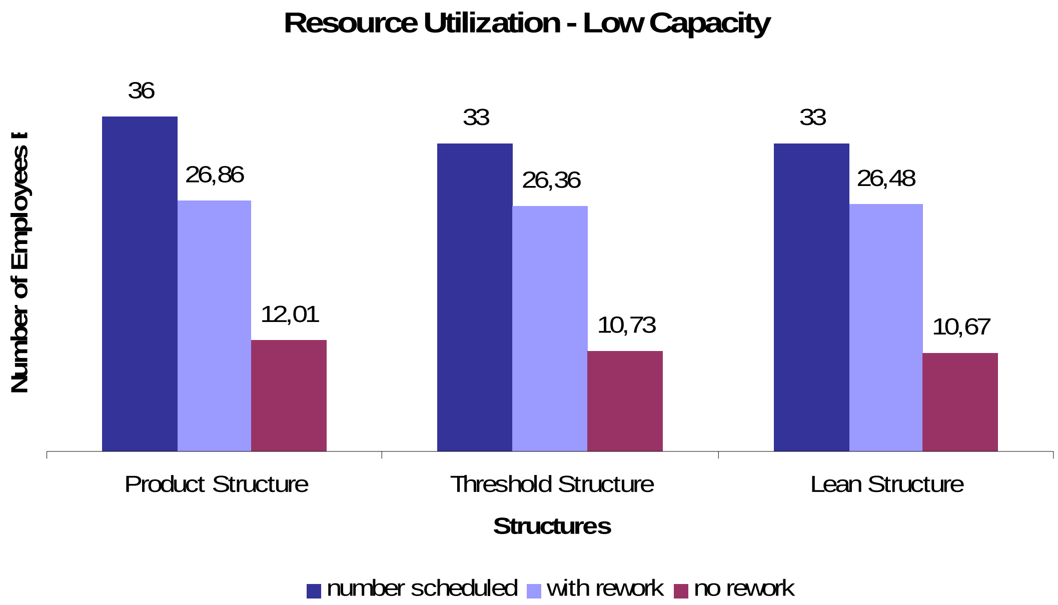

Figure 4.12: The Resource Utilization under Low Capacity

Figures 4.13 and 4.14 present the average productivity ratio per server. With rework the productivity ratio in the high capacity situation is increased by 5% in the threshold structure and 6% in the lean structure. In the low capacity situation it is increased by 7% and 6% respectively. On the other hand, without rework, the corresponding increase of productivity is 13% for both structures and for the two capacity situations.

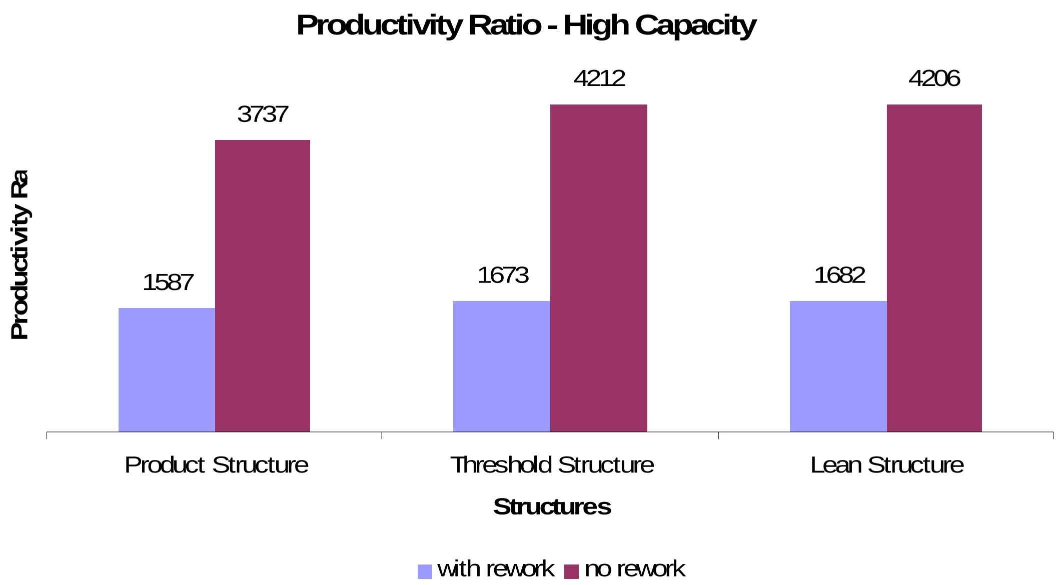

Figure 4.13: Average Productivity Ratio per Employee under High Capacity

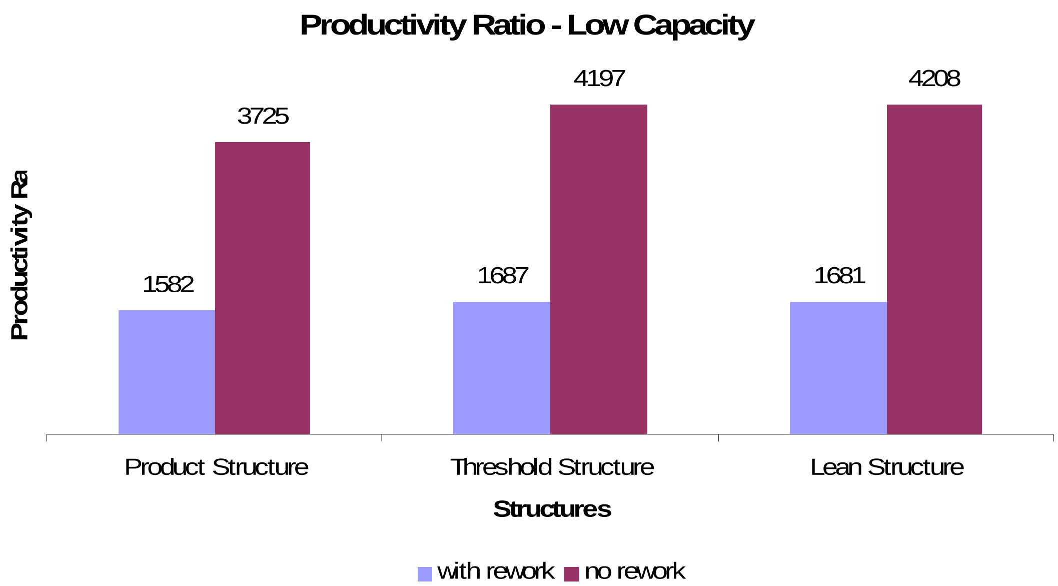

Figure 4.14: Average Productivity Ratio per Employee under Low Capacity

In summary, the results of the above comparison lead to the following conclusions:

- Rework increases significantly the cycle time, the level of WIP in the system, and the resource utilization while it reduces the VA time, and the productivity ratio in all the types of the structures.
- The elimination of rework improves the lean indicators in all the three structures.

- The reduction of the number of the servers (low capacity) increases dramatically the queue length in the first two structures while the lean structure seems to be maintained unaffected in most of the lean indicators.
- When rework exists, the lean structure appears to have the highest performance with respect to all lean indicators.
- When the rework is eliminated, the performance indicators in the threshold and lean structures are similar.

4.4.2. Performance Evaluation of the Lean Structure against Progressive Reduction of Rework

The above analysis leads to the conclusion that the lean structure seems to have the highest performance among the three types of structure. The performance of this structure is further studied when rework is reduced progressively in both the high and low capacity situations.

Figures 4.15 and 4.16 depict the cycle time of the lean structure when the rework (see Figures 4.2, 4.3, .4.4) is gradually reduced to 50% and to 0. When the rework decreases to 50% in the high capacity situation the cycle time is reduced by 44%, while in the case of zero rework, it is reduced by 58%. Correspondingly, in the low capacity situation this reduction is 89% and 92%.

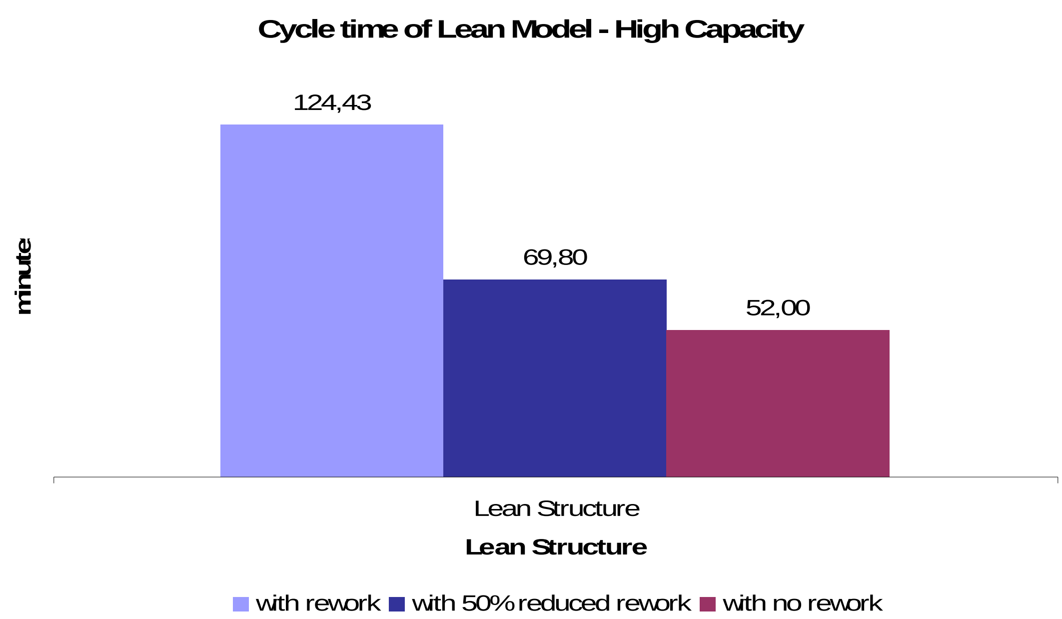

Figure 4.15: The Cycle Time of the Lean Structure under High Capacity

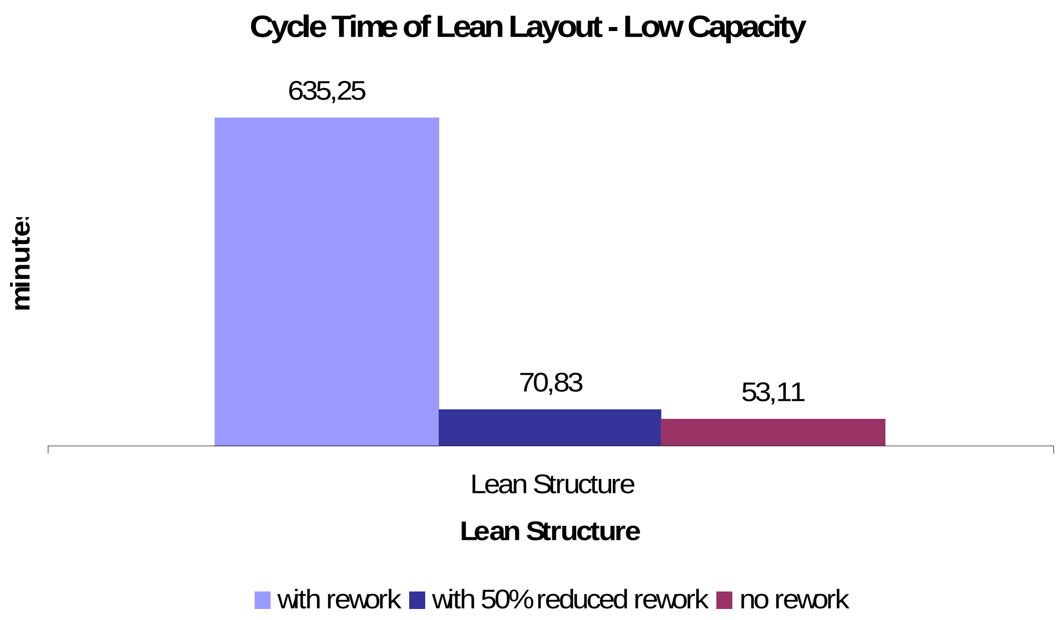

Figure 4.16: The Cycle Time of the Lean Structure under Low Capacity

Figures 4.17 and 4.18 show the percentage of the VA time in the CT. When the rework decreases to 50% and to zero in the high capacity situation the percentage of the VA time increase is 0.3%. Correspondingly, in the low capacity situation this increase is 457% for both cases.

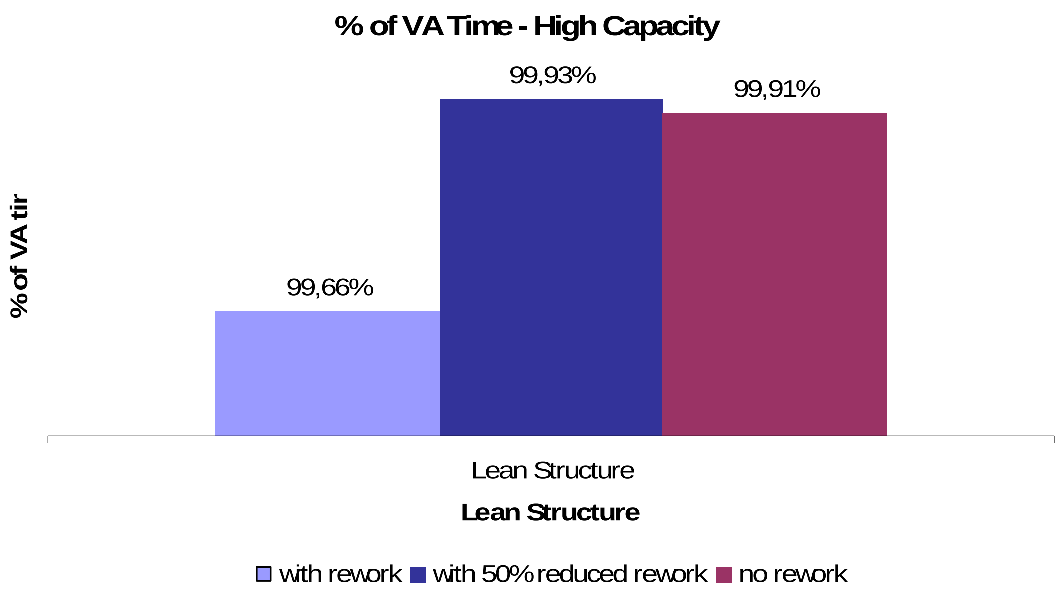

Figure 4.17: The % of VA Time of the Lean Structure under High Capacity

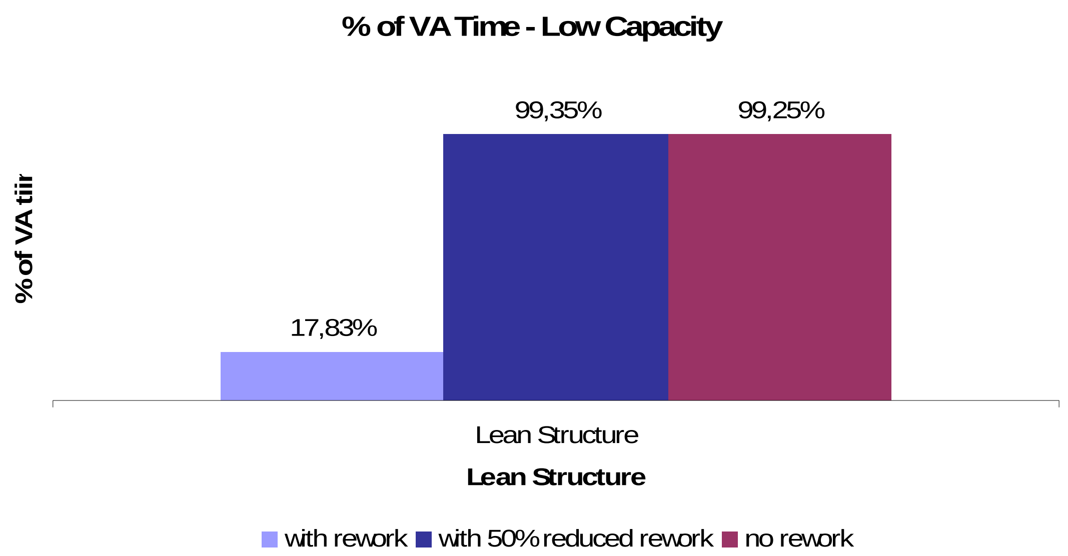

Figure 4.18: The % of VA Time of the Lean Structure under Low Capacity

Figures 4.19 and 4.20 depict the average level of WIP during the operation. In the high capacity situation this level decreases by 44% when rework is reduced to 50% and by 60% when rework is eliminated. Respectively, the reduction in the low capacity situation borders on 93% and 95%.

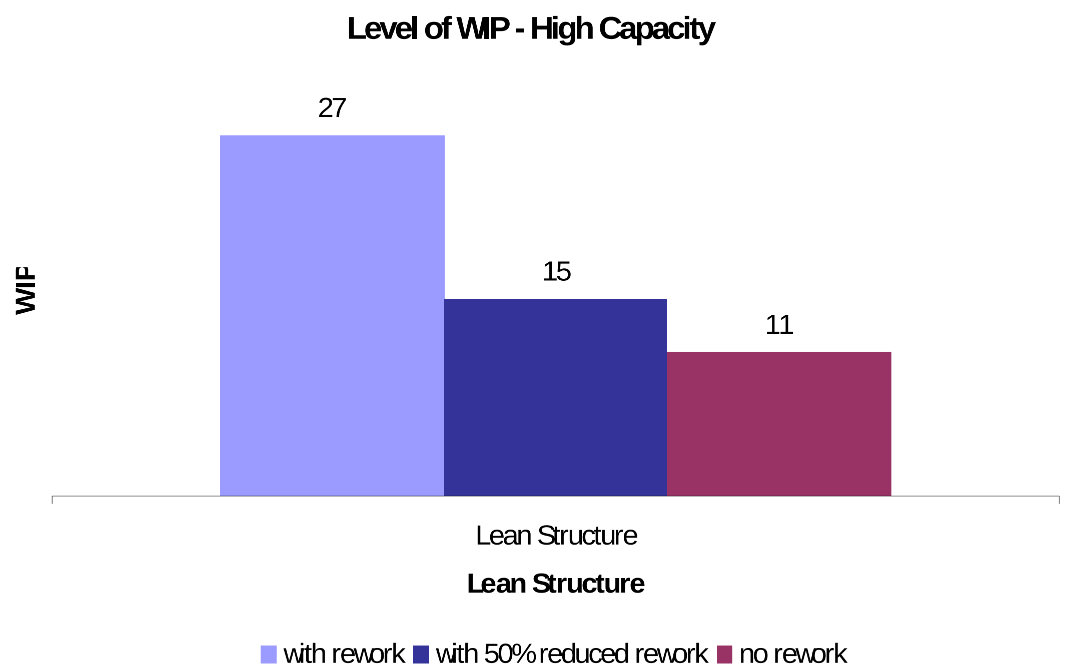

Figure 4.19: The Level of WIP of the Lean Structure under High Capacity

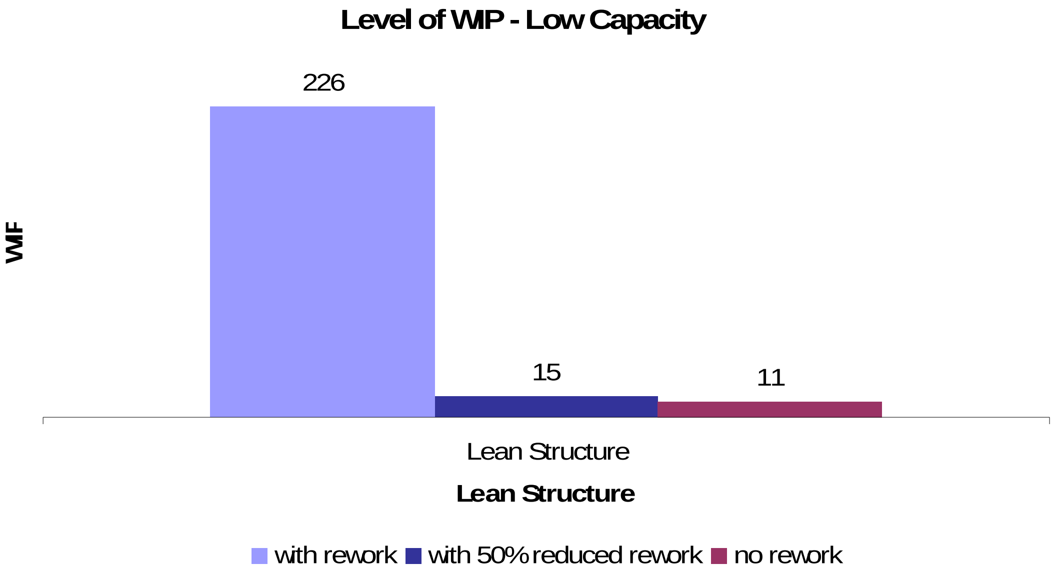

Figure 4.20: The Level of WIP of the Lean Structure under the Low Capacity

Figures 4.21 and 4.22 show the average resource utilization during the simulation. In both high capacity and low capacity situations, utilization is reduced by 45% when rework is decreased to 50% and by 60% when rework is eliminated.

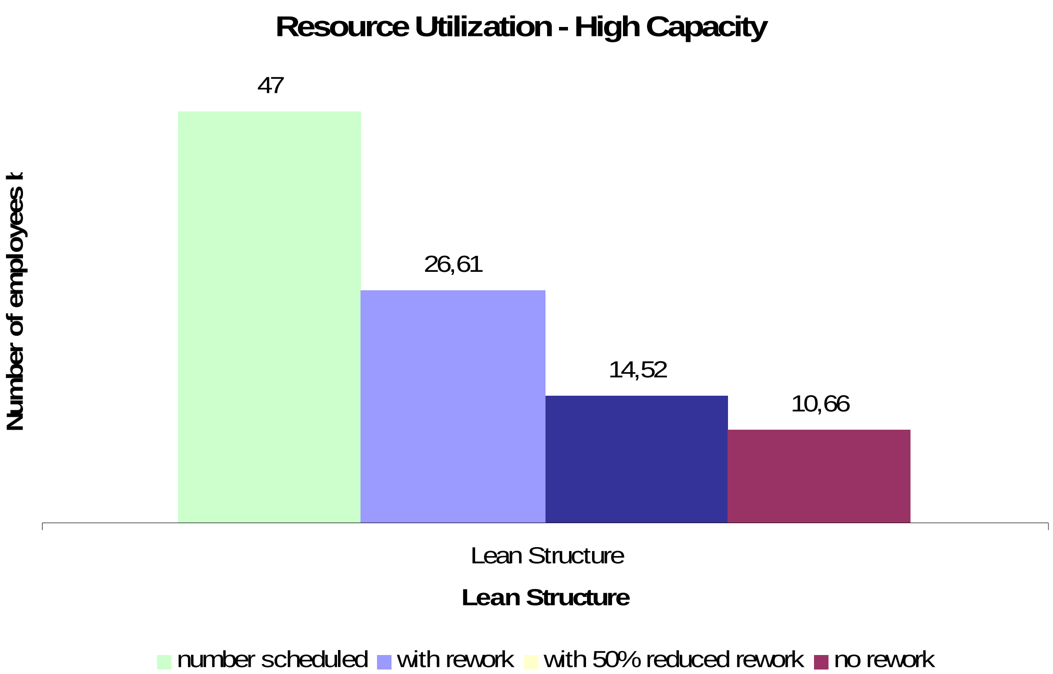

Figure 4.21: The Resource Utilization of the Lean Structure under High Capacity

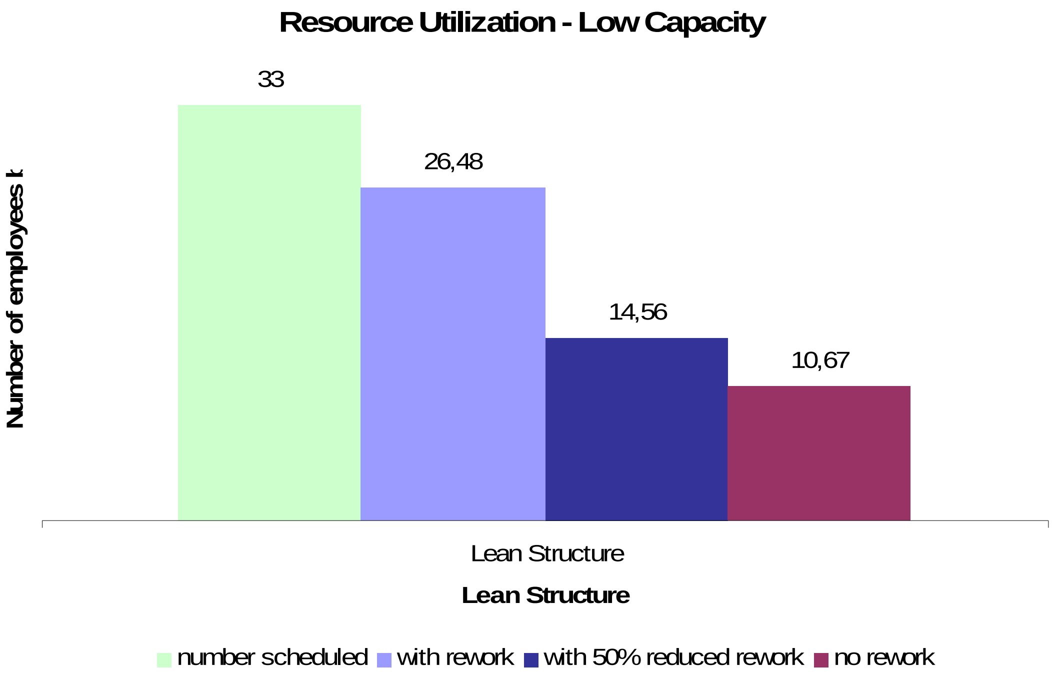

Figure 4.22: The Resource Utilization of the Lean Structure under Low Capacity

Figures 4.23 and 4.24 show the average productivity ratio per employee. Both in the high capacity and low capacity situations this ratio is increased by 83% when rework is decreased to 50% and by 150% when the rework is eliminated. This is due to the fact that the number of the busy employees maintain unaffected by the capacity variation (see figures 4.25, 4.26).

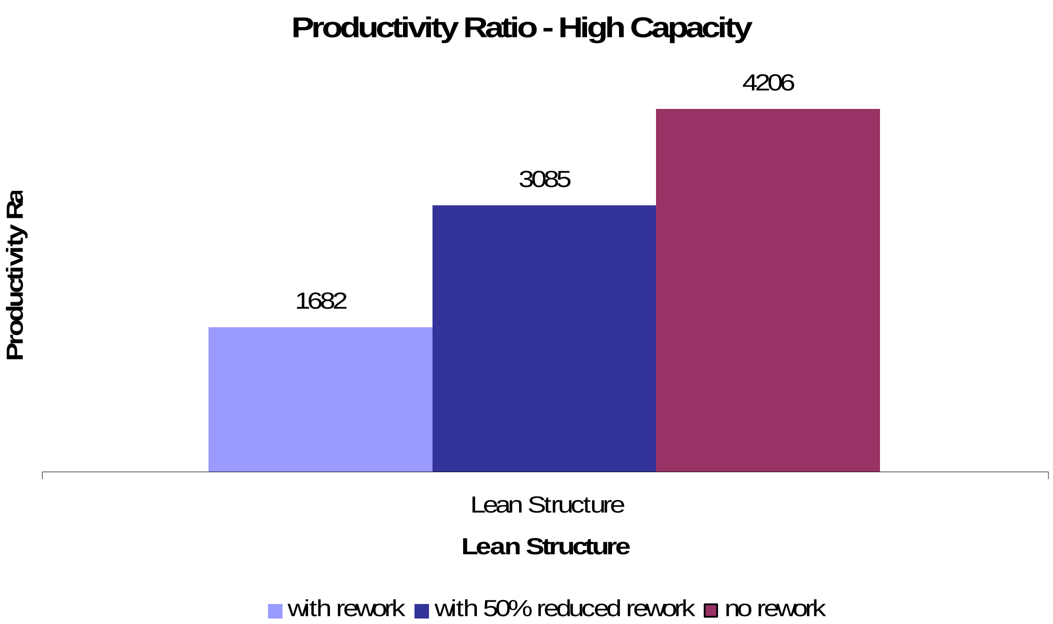

Figure 4.23: The Productivity Ratio of the Lean Structure under High Capacity

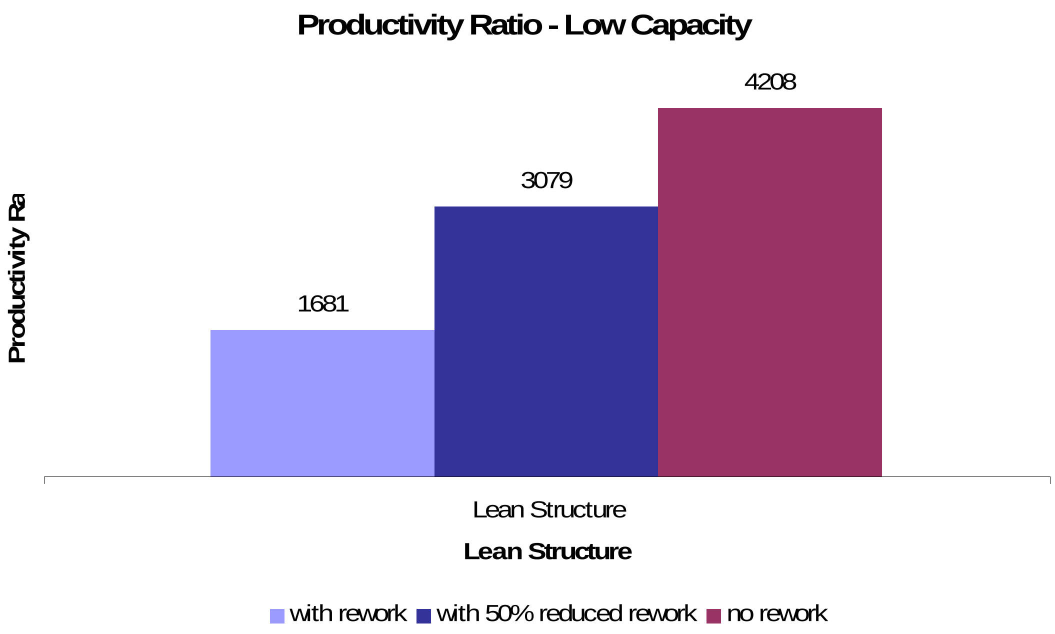

Figure 4.24: The Productivity Ratio of the Lean Structure under Low Capacity

In summary, the conclusions of the above analysis are the following:

- The elimination of rework in a low capacity situation increases significantly the percentage of VA time and the productivity ratio, while it reduces drastically the CT and the level of WIP.
- The decrease of rework improves significantly the entire system's performance.
- Capacity reduction is feasible when rework has been reduced, since the system is not overloaded.
- Rework reduction increases productivity ratio by the same ratio for both the low and high capacity cases.

4.5. Conclusions

The comparison of the three types of structures led to the conclusion that the Threshold and Lean Structures improve significantly the system performance. Specifically, the lean structure exhibits the highest performance, since it enables capacity reduction without overloading the system.

The lean structure, which implements key guidelines of JIT methodology, allows for better distribution of work among the employees inside the system, since at each stage every new application is submitted to the first available employee. In the lean structure, resources may be reduced without affecting the productivity ratio nor the quality of the provided service.

However, the lean structure may be effective if all elements of the cellular structure are taken under consideration. For example, proper training and the development of team spirit are prerequisites in a multifunctional environment. Multifunctional employees will enhance the performance of the lean structure by deterring defects, balancing the workload, standardizing work, and permit production to flow smoothly and approach the target rate.

Finally, the simulation results showed that rework elimination improves significantly the capability of the lean structure. This indicates the necessity for applying quality at the source techniques, which will enable productivity improvement and simultaneous reduction of required resources.

5. Conclusions and Directions for Future Research

The present diploma thesis investigated the application of Lean Manufacturing concepts to Financial Service operations. Initially we presented the JIT methodology and its elements as applied to the manufacturing sector. Special emphasis was given to the Quality at the Source and Cellular Design principles. Moreover, we overviewed the Financial Services Sector with emphasis on comprehending those special characteristics that distinguish services from manufacturing.

The major contribution of this work is the application of the two JIT concepts to financial operations. We examined the effects of introducing cellular organization and quality at the source principles in loan application operations. The analysis was conducted through a series of simulation experiments. These experiments compared the performance of three types of structures, the Product Structure, the Threshold Structure, and the Lean Structure under : a) rework and no rework conditions, and b) high and low capacity situation. This analysis led to the selection of the best performing structure. Furthermore, we tested the performance of the latter by reducing progressively the percentage of rework in both low and high capacity situations.

The simulation results indicated that:

a) The Lean Structure was the best performing one among the three types of structures in the presence of rework.
b) If no rework exists the Threshold Structure and the Lean Structure have similar performance. However, the Lean Structure presents greater flexibility when capacity is reduced by 30%.
c) Rework deteriorates the performance of the system at a more than proportional manner.

In summary, the reassignment of the human resources to multiple activities, as showed in Chapter 4, increases the value added time while at the same time decreases the wait time. As a consequence, the average cycle time was reduced significantly. Furthermore, the lean structure reduces considerably the average resource utilization and, as a consequence, the number of required employees. Moreover, reduction or elimination of rework improves performance substantially. In order to achieve such reductions, lean techniques, such as the Poka Yoke (devices or processes applied to detect or prevent errors), Visual Management of processes, 5Ss, Standardized work etc. must be applied. Due to the increased involvement of the customer in the creation of the service, applying quality techniques in the customer-server interface is challenging. However, from the server's perspective, the interface between the front and back office has to be fully synchronized and defect free in order for the process to flow without interruptions or loop backs. Thus, discipline in quality standards and multiskilling are becoming crucial for gaining the benefits of Quality at the Source and Cellular Organization.

Other JIT methods that have not been examined in this thesis may also be applicable to, or can adapted for the FSs sector. For example, the responsiveness of Pull may contribute significantly to improving financial service operations. Leveling the production and establishing a work in process and queue control mechanism are two elements that should be investigated. Simulation is critical in such an investigation.

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Appendix A

A. 1. Common Types of Kanban Systems

Two – Card Kanban System

In a dual card Kanban system two types of cards exist:

- A production order kanban (POK) that signals a cell to begin the production process and specifies the part type and the quantity that the cell must produce
- A move or withdrawal kanban (WLK) that links two cells and represents the demand for replenishment. A WLK specifies the part type and the quantity that a downstream cell must withdraw from an upstream cell.

There are precisely one POK and one WLK for each container. The containers with the attached WLKs move in a circuit between two manufacturing cells. The full containers are moved from the upstream cell to the downstream cell and the empty containers are returned back to the upstream cell; this is a signal for its replenishment. No partially full containers are allowed. Shipping services coordinators exist for the removal of the containers as well as for the proper distribution and assignment of the kanban cards (WLKs and POKs).

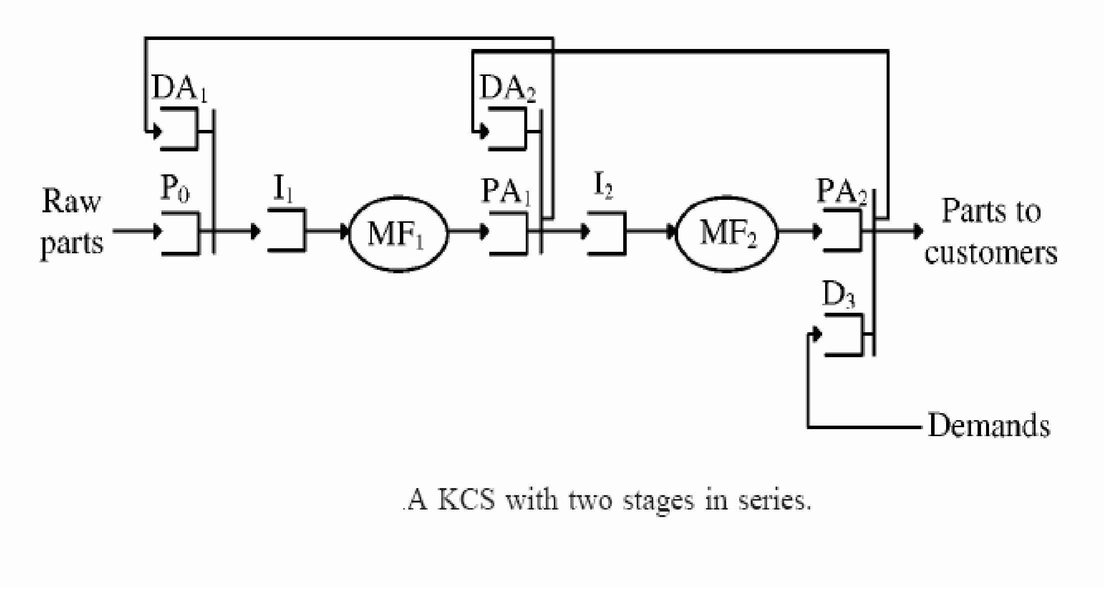


Figure A.1: A Kanban Control System with two Workstations in Series (source: Liberopoulos and Dallery, 2000)

Figure A1 shows a kanban control system (KCS) with two manufacturing cells in series (MF_1 and the MF_2). D_3 is the demand queue while PA_1 and PA_2 are the outbound stock points of MF_1 and MF_2 respectively. Likewise, I_1 and I_2 are the inbound stock points and DA_1 and DA_2 are the special boxes for withdrawal kanban cards.

When a customer demand arrives it joins queue D_3 and thereby finished products from PA_2 are required and withdrawn. If a finished product is available, the shipping services coordinator detaches the WLK and releases the finished product to the customer. Thereafter, the shipping services coordinator, according to the guidelines of the heijunka box, returns the detached WLK card in DA_2 if further demand for the specific finished product exists, or withdraws completely the card.

A similar process is conducted between the MF_1 and MF_2. Starting at stock-point I_2, a full container of parts is moved into MF_2. The WLK is detached from the container and it is placed in the kanban collection box for the stock-point of MF_2. The shipping services coordinator visits frequently the kanban collection boxes and collects the WLKs. The most recently emptied container in MF_2 is transported back to the stock point I_2 where a WLK is attached by the shipping services coordinator. Thereafter, the shipping services coordinator returns the empty container with the attached WLK to stock-point DA_2, detaches the WLK from the empty container and looks for the full container to replenish the empty one. This amounts to withdrawal of information (demand) from the downstream cell by the upstream cell. Each full container is accompanied by a POK, which was attached by the workers at each work station after production. The full container with the attached POK is placed at PA_1. The shipping services coordinator replaces the POK with the WLK (the WLK that was detached from the empty container of the previous step) and returns the POK back to the production line of MF_1. The full container with the WLK is sent to inbound stock-point I_2. This amounts to the withdrawal of material from the upstream cell by the downstream cell). The workers in MF_2 detach the WLK, place it in the collection box for stock-point of MF_2, and the process is repeated. A POK replaces the WLK and the cell staff begin production according to the instruction included in the POK.

The above process and sequence is repeated during a day according to the demand. The number of kanban cards is usually calculated in a weekly or monthly base. This is a management decision and a method of tightly controlling the WIP inventory levels. The initial number of kanban cards can be computed by the following equation (Black and Hunter, 2003):

$$K = \frac{(D \times L \times S)}{a} \qquad (2.2)$$

Where,
K: number of kanban cards (the number of the POKs or the WLKs)
D: expected demand for parts, per day
L: lead time (processing time + delay time + lot delay and process delay[4] + conveyance time)
a: container capacity (usually about 10% of daily demand)
S: safety stock (usually 10% or less of D x L)

The two-card kanban control system is an effective way of controlling WIP. Nevertheless, certain limitations exist. For example, the kanban system should be implemented in a manufacturing process that has been designed according to the JIT philosophy (setup time reduction, cellular design, flow of production etc).

- ***Constant Work In Process (CONWIP)***

CONWIP composes a hybrid push-and-pull system, since it limits WIP via cards that are similar to kanban cards. The containers are of standard size but are line specific, in contrast to the part number specific containers of the two-card kanban system. Furthermore, CONWIP attains to control the total WIP of the system but does not achieve the demand-prompted pulling of materials between manufacturing cells.

4 Lot Delay: the first part produced cannot be conveyed to the next cell or process until the last item in the lot is produced
Process delay: stoppages due to machine tool failure, broken tools, defective parts, and other manufacturing problems, delays in the throughput time (processing time > cycle time)

Figure A.2 illustrates the manner that CONWIP functions vs. a kanban control system.

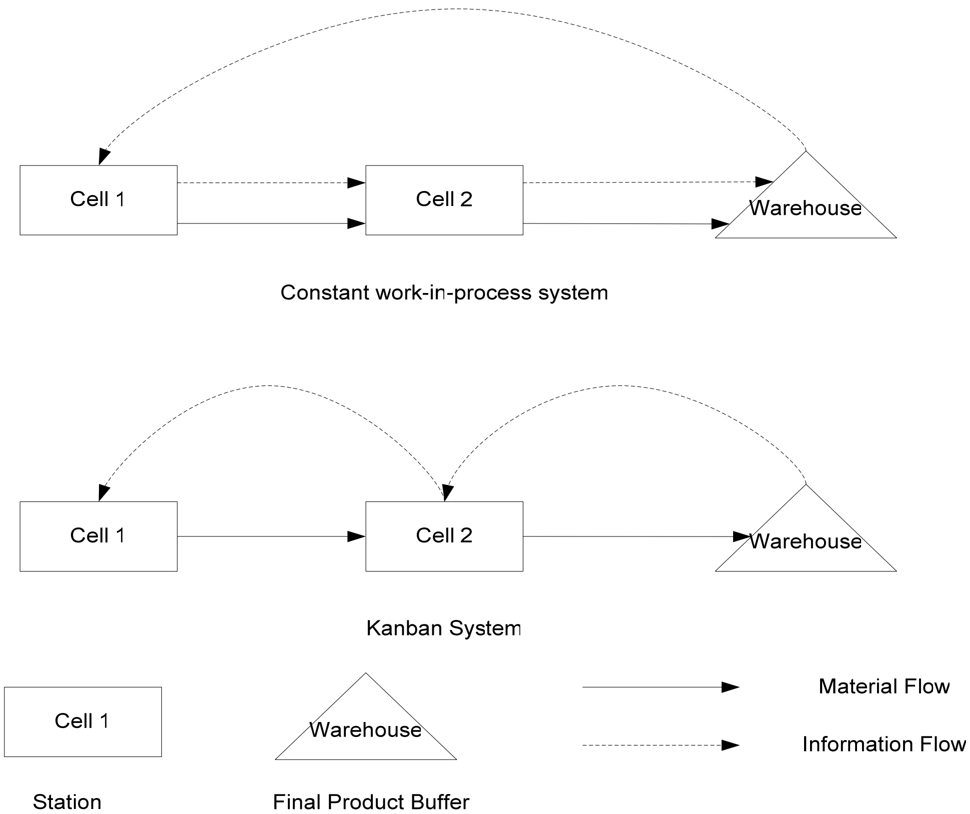


Figure A.2: Differences between Kanban and CONWIP (source: Black and Hunter, 2003)

In CONWIP, a pull system exists between the final product shipping station and the first station in the facility. Starting from the first station, materials are pushed through the manufacturing system. A card follows the product through the manufacturing process until the final product is delivered to the external customer. When a container of final products is delivered to the external customer the card that was attached to that container is detached and returned to the first manufacturing cell. The return of this card (in the first workstation) signals the introduction of a new container of raw materials. Once the materials are introduced, production of a new product begins without waiting for withdrawal from the downstream cell. This process is repeated every time a final product leaves the final (assembly) cell.

It is obvious that no blocking in the manufacturing process exists. A constant level of work-in-process is maintained in the buffers between workstations. The production only stops when raw materials are disrupted in the upstream workstation. CONWIP represents a system that is easy to control since the only variable in the system is the total WIP. The CONWIP system works smoothly with a large variety of parts since the containers are line-specific and not part specific. Consequently, there is no need to have one container for each part type and thus, the WIP is not affected by the number of part types that the system is capable of producing. Another advantage of CONWIP is that it can perform well even in unbalanced lines. Finally, bottlenecks near the end of the production line are not devastating, since raw materials will continue to be introduced at the beginning of the line and the upstream cells will not be affected and disrupted.

Nonetheless, the application of CONWIP has certain limitations. In particular, if production lines are balanced, CONWIP constitutes an inferior system in contrast to the kanban system. Performance is poor if bottlenecks occur near the beginning of the production line. This will cause further delays in the downstream cells. Finally, if some parts do not require similar processes, then a routing-control methodology may be required.

- ***Other Kanban Card Systems***

i) Only WLK. The single-card kanban system represents a push-and-pull production system. The only card needed is a WLK, which circulates between the upstream stock point and the downstream cell in order to pull parts from the upstream cell only as needed from the downstream cell. No input stock points exist, since the full containers are delivered directly to the downstream cell. Accumulation of WIP exists only in the output of the upstream cells. The production process is accomplished by a daily schedule that is delivered to each cell rather than by the signal of a POK as in the pure pull system.

In summary, the one card kanban system functions as follows:

Every full container that is transferred from an upstream to a downstream cell is accompanied by a WLK. When the full container arrives to the downstream cell the WLK is detached and placed in a kanban collection box. Every time a full container with an attached WLK arrives in the downstream cell a WLK is taken from the downstream collection box and is delivered to the upstream cell. Empty containers are then returned to the upstream cell and wait to be refilled according to the daily production schedule. Finally, a WLK is attached to the new full container and both of them are delivered to the downstream cell.

The single-card kanban system is closer to a push-type manufacturing system. However, the implementation is simple since there is only one kanban card. Usually, the single-card kanban system comprises an intermediary step in the development of the dual-card kanban system (Black and Hunter, 2003).

ii) Only POK. When the workstations in a system are close to one another it is feasible to use only POKs. The production process is accomplished according to the information included into those POKs and only if the required materials are available. After the completion of the production process, the POK (instead of the WLK) is attached to the full container. Then, both of them are moved to the next cell. Each time the inventory in the downstream stock point falls below a determined level, POKs are freed up, authorizing the station to replenish the buffer (Hopp and Spearman, 2001).

A.2 Types of Kanbans

Two main types of Kanban cards are typical used. These are:

- *Production Ordering Kanban (POK) or Production Instruction Kanban or Production Kanban*. It is used as a signal for the production beginning.
- *Withdrawal Kanban (WLK) or Parts Withdrawal Kanban or Move Kanban.* It is used as a signal for a part / product removal.

The figures A.3 and A.4 depict the information that these two kanban types contain:

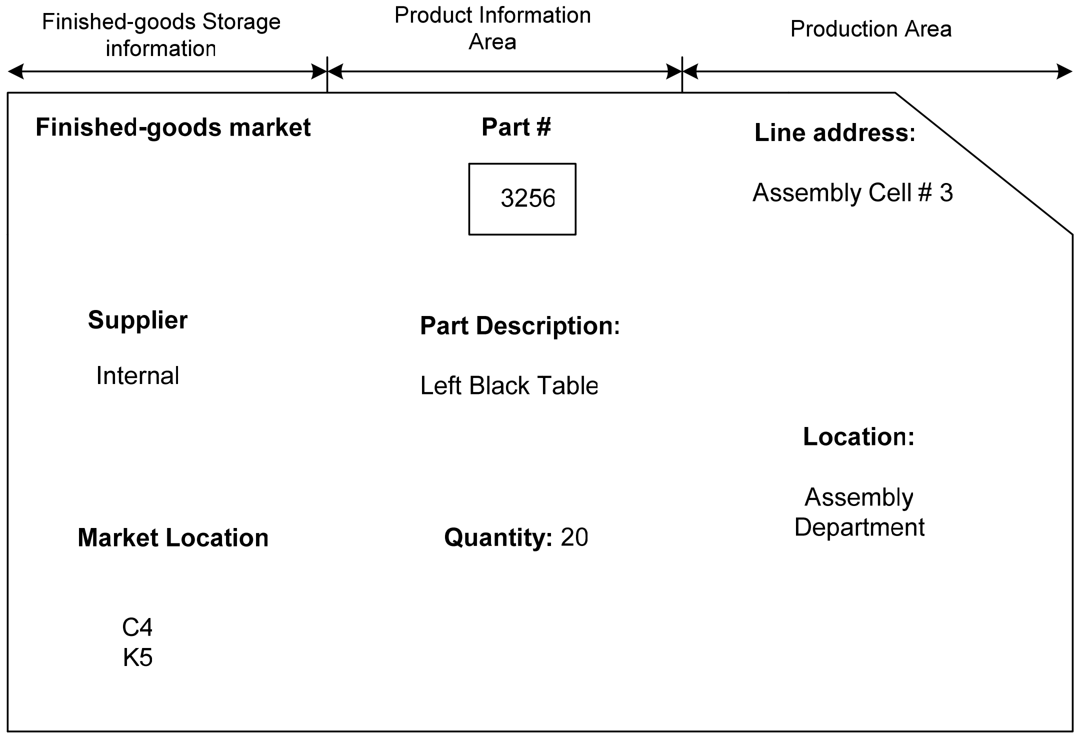


Figure A.3: Production Ordering Kanban (source: Smalley, 2004; Black and Hunter, 2003)

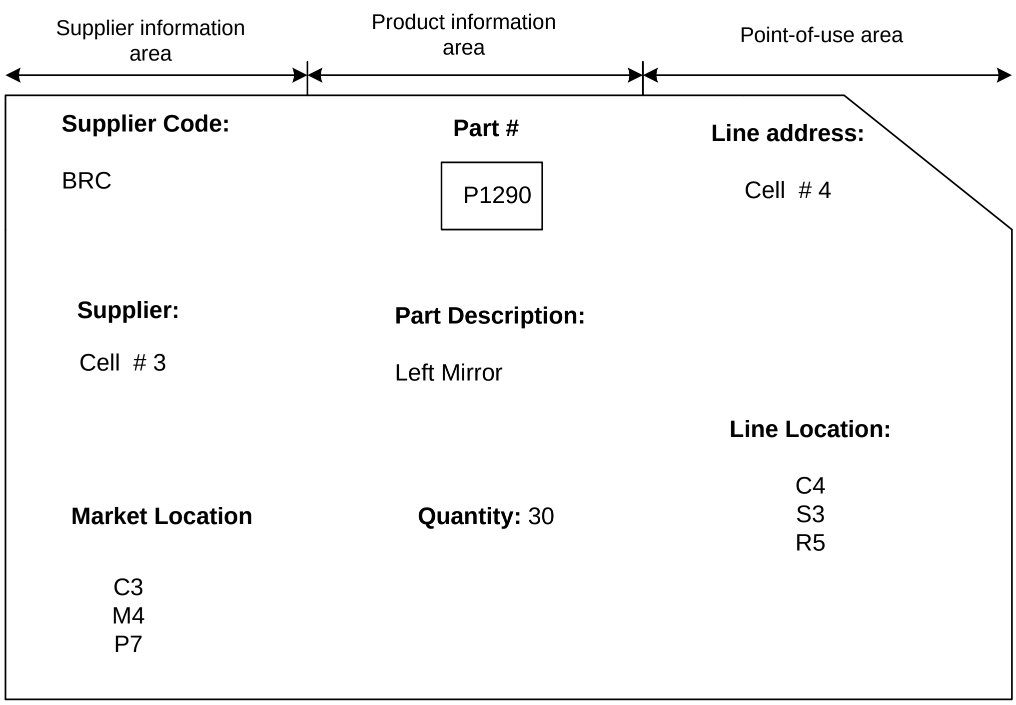
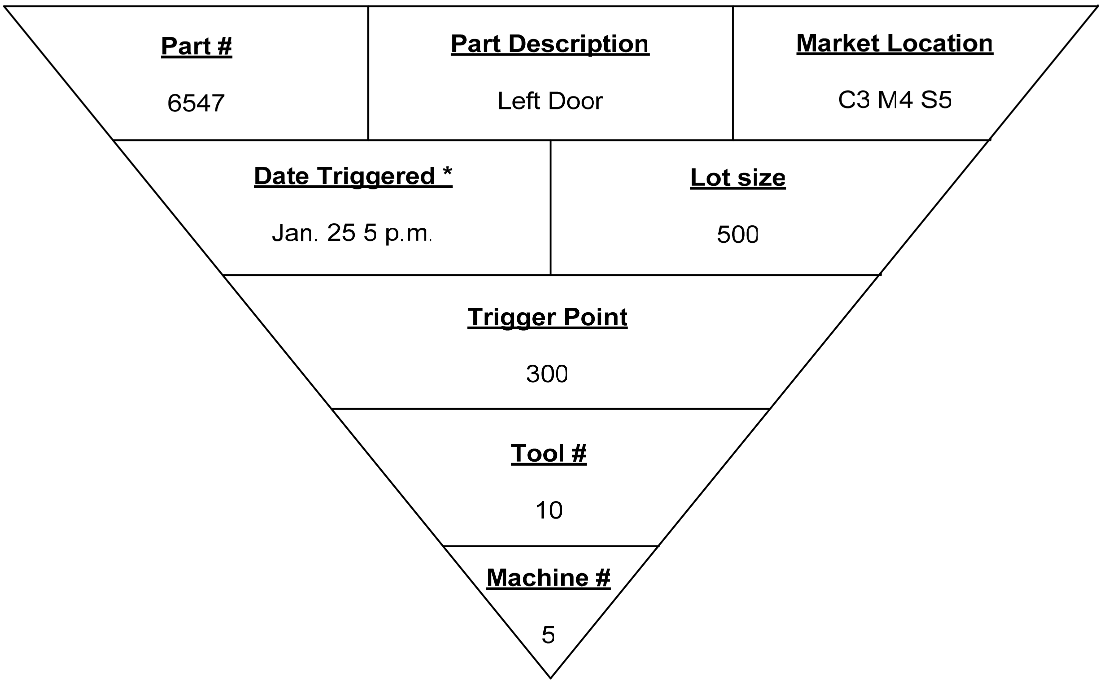


Figure A.4: Withdrawal Kanban (source: Smalley, 2004; Black and Hunter, 2003)

However, other alternative types of kanban cards are also used frequently. The most commonly known are:

1. *Signal Kanban or Triangle Kanban*. The name comes from its distinct triangular shape (see figure A.5). This type of kanban is used to convey instructions for the production of large batches from a machine that is shared by more than one family of products. It is attached to a pallet or stack of containers at the reorder point. When the stock quantity of a product comes near to the reorder point, a signal kanban is delivered to the previous machine to replenish the quantity that was consumed.
2. *Supplier or Vendor Kanban*. It is used to withdraw parts from an external and subcontracted supplier. Delivery times, receiving gate, and daily frequency of deliveries are indicated on a supplier kanban. As shown in figure A.6, a vendor kanban also indicates the "kanban cycle". For example, the notation 1:3:3 included in the vendor kanban indicates that for a particular part number the supplier in *one* day will deliver that part and pick up kanban *three* times, and the kanban picked up on any given cycle will be returned with the requested parts *three* trips later. In this case, since there are three deliveries each day (at eight-hour intervals) the requested material will return in 24 hours.
3. *Emergency or Temporary Kanban*. This type of card is issued temporarily and only for extraordinary reasons such as defective work, extra insertions or spurts in demand. An expiration date is recorded and they are collected and drawn out immediately after their usage (Smalley, 2004; Black and Hunter, 2003).



* The point in time at which the kanban is placed on the signal kanban rail. This aids production management in assessing status of the process and reduces the possibility of getting kanban out of sequence.

Figure A.5: Triangle Kanban (source: Smalley, 2004; Black, Hunter, 2003)

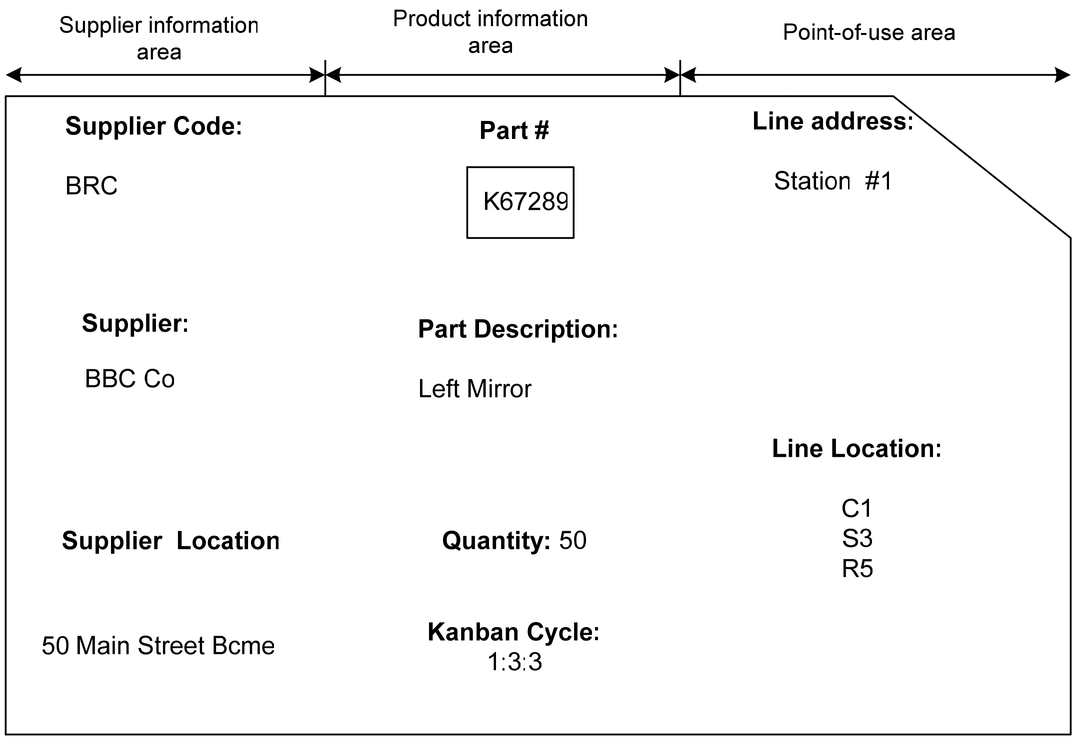


Figure A.6: Supplier or Vendor Kanban (source: Smalley, 2004; Black, Hunter, 2003)

A.3. Example of leveling production

50000 units are to be produced during a monthly period (20 working days) consisted of 50% (25000) product A, 25% (12500) product B, and 25% (12500) product C. The daily production of 2500 units should consist of

0.5 x 2500 = 1250 of units A

0.25 x 2500 = 625 of units B

0.25 x 2500 = 625 of units C

Therefore, the sequence on the production line should be

A-B-A-C-A-B-A-C-A-B-A-C-A-B-A-C...

in order a 50-25-25 mix of A, B, and C to be maintained overtime. Furthermore, if two shifts per day exist with 480 minutes at each shift, the average time between outputs will have to be 2*480 / 2500 = 0.38 minutes per unit. This time interval represents the rate of production (Smalley, 2001; Black and Hunter, 2003; Hopp and Spearman, 2001).

Appendix B

Time Definitions

The following table reproduced by the corresponding resources referred to each definition.

Table B.1: **Time Definitions**red to each definition.

Table B.2: **Time Definitionsinitions**red to each definition.

Table B.3: Time Definitions

#	Type	Unit of Measurement	Definition	Source
1.	Queue Time or Waiting Time	Time/ Unit	The time that a product waits for the next step in the designing, the reception of orders or the manufacture.	J.P.Womack, D.T.Jones, *Lean Thinking,* 1996
2.	Processing time (or Run Time, Value Added Time)	Time/ Unit	The duration of time that a product is actually being treated in the planning or in the production, and that an order is being treated. Time that value is actually added in the product or services.	J.P.Womack, D.T.Jones, *Lean Thinking,* 1996
3.	Storage Time	Time/ Unit	The duration of time that a product or service is waiting in a queue or a warehouse. In this case, there is no activity due to: a) waiting for being processed by the downstream process and b) waiting for being delivered to the end-customer.	P.Hines, D.Taylor, *Going Lean*, 2000
4.	Transportation Time	Time	The duration of time that an operator/product travels without actually being required to perform a specific process (usually due to poor layout) and adds no value to the product.	R.A.Khanolkar, "Role of Robots in Lean Manufacturing", *Applied Manufacturing technologies*, 2007
5.	Change over	Time/Batch	The time measured to switch from producing one	J.P.Womack, D.T.Jones,

#	Type	Unit of Measurement	Definition	Source
	Time (or Set-Up Time)		product/operation type to another.	*Learning to See,* 2003
6.	Throughput time (Processing Time + Queue Time)	Time/ Unit	The time that is required in order to advance a product from the arrest in the circulation, from the order in the delivery or from raw material in the hands of customer. It includes time of treatment (processing time) as well as queuing time. According to Black and Hunter, throughput time depends on cycle time and is calculated as follows: $T_T = C_T \times C$ Where, T_T =throughput time, minutes C=number of cycles that the part was in the cell	J.P.Womack, D.T.Jones,, *Lean Thinking,* 1996 J T. Black, Steve L. Hunter, *Lean Manufacturing Systems and Cell Design*, 2003
7.	Cycle time (Transportation Time +Set-up time + Processing Time)	Time	Cycle Time is a very confusing term because it is used in multiple ways. For some authors Cycle Time is an interval of time during which a sequence of recurring succession of events or phenomena is completed. Other authors define cycle time as synonymous to takt time. However, others view cycle time as the time required to produce one product by a machine, station and/or operator. It is the time required to repeat a given sequence of operations or events. According to Black and Hunter, cycle time is calculated as follows: $C_T = (M_T + O) + (W_T \times W_C)$ Where, C_T= cycle time, minutes	J. Crabill, ED Harmon, et al, "Production Operations Level Transition-To-Lean Roadmap", *Massachusetts Institute of Technology*, June 2000 J T. Black, Steve L. Hunter, *Lean Manufacturing Systems and Cell Design*, 2003

#	Type	Unit of Measuremen t	Definition	Source
			M_T =worker-manual time, minutes O=number of operations W_T =walk time, seconds W_C =number of walk cycles Or $\frac{1}{P_R}$ where P_R = production rate, parts /hour	
1.	Lead time (Storage Time + Queue Time + Cycle Times)	Time/ Unit	The total time that a customer should wait for in order to receive a product from the moment that he gives an order	J.P.Womack, D.T.Jones, *Lean Thinking*, 1996
2.	Uptime/% Avail	(%)	The time that machines and employees are performing work properly	Millard, L.R., "Value Stream Analysis and Mapping for Product Development", *Massachusetts Institute of Technology*, June 2001
3.	Takt time	Time/Unit	Takt Time is a goal that must be reached to satisfy demand. It is the available production time divided by the rate of consumer demand (consumption). Takt Time is used to synchronize the rate of production to consumer demand/sales. *Example*: If the monthly demand is 8000 items of product A,	J. Crabill, ED Harmon, et al, "Production Operations Level Transition-To-Lean Roadmap", *Massachusetts Institute of Technolo*gy, June 2000

#	Type	Unit of Measurement	Definition	Source
			6000 items of B, 4000 items of C, and 2000 items of D, the total demand is 20000 items/month. Let the working days be 20 working days/month. The daily demand is: 400 items of A 300 items of B 200 items of C 100 items of D For two 8-hour shifts per day the available daily work time is 960 min/day Takt time= 960min/ (400+300+200+100) = 0, 96 min This means that the customer is buying this product at a rate of one every 0, 96 minutes.	

Appendix C

C.1. Types of Financial Services

The above table was reproduced by Harrison (c2000) and the links that are referred inside the table:

Table C.1: Types of FSs

Direct Services	Indirect Services
1. *Loans*. A loan is a type of debt. Like all debt instruments, a loan entails the redistribution of financial assets over time, between the borrower and the lender. The borrower initially receives an amount of money from the lender, which they pay back, usually but not always in regular installments, to the lender. This service is generally provided at a cost, referred to as interest on the debt. There are personal loans, which are unsecured loans usually made for the purpose of debt consolidation, vacation or the purchase of durable goods, and mortgage loans, which are loans to buy real estate. (en.wikipedia.org). Moreover**,** there is a type of services in loans known as an overdraft facility, by which a limit usually is set on the amount that can be borrowed. The account holder	*Cash accessibility*. It refers to the customers' need to have frequent access to cash. There are a range of money transmission services that cater for this need, such as ATM's, credit cards and cheques as telephone banking which enables quick and easy movement of fund.

can draw his account down to the pre-agreed amount. There is often no repayment schedule, and no interest has to be paid as long as loans and accrued interest do not exceed the agreed-upon borrowing limit (www.garyascott.com). Finally, loans can include leasing which refers to contract granting use of real estate, equipment, or other fixed assets for a specified time in exchange for payment, usually in the form of rent. The owner of the leased property is called the lessor and the user is the lessee. (strategis.ic.gc.ca)	
2. *Investment services* offer the public securities that can be held indefinitely as a long-term investment or sold quickly when the customer needs his or her funds returned. Investment includes mutual stock funds, bond funds, and money market funds. Mutual fund or open-ended fund is a collection of stocks, from different companies, combined (or co-mingled) together to provide one single investment. The mutual fund attracts money from many investors and manages the "mix" of stocks, often for a fee. (Pages.prodigy.com/wealth/term.htm). Investment services	*Asset security*. This relates to two sub-needs. The first is the need for physical security of one's assets (i.e. protection from theft). One of the most basic functions of banks is that of safe-keeping. The other sub-need is to protect one's assets from depreciation. Thus, consumers have a need to earn a return on their money.

can also be establishments primarily engaged in the purchase, sale, and brokerage of securities, and those, generally known as investment bankers, primarily engaged in originating, underwriting, and distributing issues of securities (www.libraries.psu).	
3. *Insurance services* are a plan in which individuals and organizations who are concerned about potential risks will pay premiums to an insurance company, who in return, will reimburse them if there is a loss. To generate a profit, the insurer will invest the premiums it receives (www.enviromentalinvestors.com). There are three sub-sectors of insurance sector: Insurance brokerage. Insurance brokers shop for insurance (generally corporate property and casualty insurance) on behalf of customers. Insurance underwriting. Personal line insurance underwriters actually underwrite insurance for individuals a service still offered primarily through agents, insurance	*Money transfer*. This refers to the need to be able to move money around. Significant technological developments have made this possible and also reduced our reliance on cash.

brokers and stock brokers. Underwriters may also offer similar commercial lines of coverage for businesses. Activities include insurance and annuities, life insurance, retirement insurance, health insurance and property and casualty insurance. Reinsurance. Reinsurance is insurance sold to insurers themselves, to protect them from mega catastrophic losses (en.wikipedia.org).	
4. *Pension services.* A pension (also known as superannuation) is a retirement plan intended to provide a person with a secure income for life. Although a lottery may provide a pension, the common use of the term is to describe the payments a person receives upon retirement (en.wikipedia.org).	*Deferred payment* is the need to delay payment of goods and services at a reasonable cost in increasingly important as a means to acquiring goods and services. The range of credit cards, loans and mortgages cater to this need.
5. *Real estate services* are services ranges from site selection and analysis to assistance in acquisition all the way through to securing the necessary approvals (www.theboldtcompany.com). The real estate itself serves as collateral to provide repayment in case of default	*Financial advice*. It has been observed up to now that as financial products increase in number and complexity, consumers have a greater need for information and advice in order to make appropriate purchase decisions. Financial advice in itself is not necessarily a solution, but may be instrumental in finding one.

(www.investordictionary.com).	

The above table was reproduced by Standard Industrial Classification Code (NAICS) (http://www.census.gov/eos/www/napcs/papers/52.pdf):

Table C.2: Types FSs according to NAICS

Financial products	Related services
1.1 Financing products: Services that provide money or credit to businesses, consumers and governments.	**2.1 Spot trading of commodities:** Spot trading of commodities.
1.2 Brokering and dealing products: Services related to conducting trades in securities and commodity contracts, by brokering or dealing, on behalf of others. Includes both brokerage services (receiving a commission or fee) and dealing or market making services (earning a spread). Includes trading on exchanges and over-the-counter. Includes correspondent services rendered between brokers. Excludes services of exchanges (e.g., provision of facilities, trade execution services provided by exchanges to brokers and dealers). Excludes trading securities and commodity contracts on own account. Excludes origination or secondary distribution of securities.	**2.2 Reselling services for merchandise, retail:** Retailing of merchandise purchased on own account for resale or sold on a fee or commission basis for others. Includes reselling of apparel, memorabilia, publications, prepackaged foods and beverages, and other merchandise. Also includes vending machine sales. Revenue for this product includes the gross margin, fees, and commissions earned on sales.
1.3 Financing related to insurance: Services that provide financing related to trading and dealing in securities. These services generally involve the use of securities as collateral, either to fund trading in the securities themselves, or to provide financing for other purposes.	**2.3 Securities information products:** Services that provide information about trading activities on stock and commodity exchanges. These include quotation information about individual stocks, including latest trade price and volume, current bid and offer prices, as well as the values of summary indexes. The information is sold by the exchanges themselves and by resellers such as financial news services.

1.4 Trading securities and commodity contracts on own account: Gains made from buying and selling security and commodity contracts, on own account.	**2.4 Databases and other collections of customer information:** Providing collections of data or bodies of information on customers, in which the primary content is other than contact information, to third parties. For example a database prepared for telemarketing companies may include information on the demographic characteristics of, services currently being consumed by, and contact information for the provider's customers. Databases are usually designed and organized for rapid retrieval by computer. Custom designed databases are included. The provider may receive a flat fee or may earn commissions on sales made by the purchasing company.
1.5 Account and cash management products: Money management services, provided to customers by means of deposit accounts, such as checking, saving and time accounts, and specialized cash management services that enable businesses to handle cash, transfer monies, and in general make and receive payments.	**2.5 Rental of real estate:** Rental or leasing of own-account land, residential buildings and other facilities used as residences, and non-residential buildings and other facilities.
1.6 Products supporting financial services: Products that support the provision of financial services, such as trust services, stock exchanges, clearing and settlement systems, financial planning services, and investment management services.	**2.6 Real estate appraisal services:** roviding assessments of the value of real estate, in order to assist clients in buying, selling, or financing the purchase of real estate, or in dealing with tax matters. Includes general real estate appraisals, reviews of others' appraisals and appraisals for taxation purposes. Exclusions: consulting about appraisal issues.
1.7 Insurance products: Products providing insurance or supporting the provision of insurance. Insurance transfers risk from individuals to	**2.7 Safe deposit boxes:** The renting of secure boxes, of various sizes, where one can store relatively small items of value such as cash, gold,

a larger group. Includes both direct underwriting services and reinsurance services. Includes support activities such as insurance agent and broker services.	jewelry or documents.
1.8 Financial system regulatory products: Services provided by central banks, other government agencies, and selfregulatory bodies such as stock exchanges, to regulate financial systems and markets, and the participants in those systems and markets. Includes certifying participants and enforcing regulations. Excludes policy-making activities of central banks.	**2.8 Tax preparation and representation services:** One or more of the following services: preparation of income and other tax returns; review of returns prepared by others; filing of returns; preparation of supplementary documents associated with returns; preparation for and representation at tax audits and appeals. Includes compilation of financial statements when provided as a package with tax preparation for a single fee.
	2.9 Electronic tax payments: Electronic filing of Federal tax returns with the Internal Revenue Service
	2.10 Payroll services: Payroll processing, withholding deductions, remitting deductions and employer's contributions to government-mandated and other plans, and filing reports.
	2.11 Legal services for wills, estates and trusts: The preparation of: (a) simple (non-trust) wills; (b) wills with non-tax trusts; (c) wills with tax-related trusts; and (d) inter vivos funded third party (revocable living) trusts. Services include all conferences; preparation of documents; and attendance at execution of documents. Providing legal advice, representation, drafting of documents and related services concerning estates and trusts. Additional charges may be made for unusual services such as numerous client conferences, designation of beneficiaries, changes in documents, unusual trusts (e.g., charitable

	trusts) and so forth. Excludes:criminal law legal services, civil negligence legal services.
	2.12 Notary public service: Services that attest to the validity of documents.
	2.13 Legal and accounting support products for funds: Providing legal and accounting support services for funds beyond the mere recording of simple debits and credits to funds held in trust by the bank. Examples of this service include detailing the legal and tax status of transactions and the maintenance of detailed debits and credits in various charts of accounts for the benefit of clients.
	2.14 General administration of companies: The process of assisting a company in establishing a tax-friendly environment (sometimes through the establishment of an offshore facility), through the use of accounting, legal services and other administrative services.
	2.15 Collection of delinquent accounts: Collection of delinquent accounts. Excludes collection of payments as part of normal loan servicing.
	2.16 Formulation and implementation of economic policy: Services produced by governments in the course of formulating and implementing economic policy.

C.2 Types of Financial Services Providers

The following table reproduced by the link (www.wamu.com) and the links and references that are included in the table:

Table C.3: Types of FSs Providers

Authorized Deposit-taking Institutions (ADIs)	Non Authorized Deposit-taking Institutions (Non-ADIs)
1 *Banks*. Provide a wide range of financial services to all sectors of the economy, including (through subsidiaries) funds management and insurance services. The mainly categories of Banks are: Retail Banks, Investment Banks, and both Retail and Investment Banks combined: 1.1 Retail Banks 4. *Commercial Banks* refer to banks or a division of banks that mostly deal with deposits and loans from corporations or large businesses. Furthermore, is used as the arena for investigating the managerial usefulness of relational contract theory in a business-to-business service context. Commercial banking relationships are characterized primarily by the dyad of the account manager and the company-client representative (Berry and Thompson, 1982; Moriarty et al., 1983; Perrien et	*Securitisers.* Special-purpose vehicles that issue securities backed by pools of assets (e.g. mortgage based housing loans). The securities are usually credit enhanced (e.g. through use of guarantees from third parties).

al., 1993; Watson 1986). E.g. Emporiki Bank, Citigroup (http://en.wikipedia.org) - *Community Banks* are locally operated financial institutions that empower employees to make local decisions to serve their customers (http://en.wikipedia.org). e.g. First Community Bank (http://www.fcbnm.com) - *Postal Savings Banks* are savings banks associated with national postal systems (http://en.wikipedia.org). e.g. Greek Postal Saving Bank - *Private Banks* manage the assets of high net worth individuals. They offer banking services to affluent individuals or households. This term is simply a marketing term for a bank or a division of a financial services company targeted towards wealthy individuals. Often it is used to describe specifically the lending services targeted towards this group, such as large margin loans. E.g. Merrill Lynch (http://en.wikipedia.org) - *Offshore Banks* are banks located outside the country of residence of the depositor, typically in a low tax jurisdiction (or tax haven) that provides financial and legal advantages. These advantages typically include some or all of: strong	

privacy, less restrictive legal regulation, low or no taxation, easy access to deposits (at least in terms of regulation), protection against local political or financial instability. Many offshore banks are essentially private banks (http://en.wikipedia.org) e.g. Bank of Cyprus Group, Egnatia Bank S.A (http://www.escapeartist.com) - *Savings Banks.* Their original objective was to provide easily accessible savings products to all strata of the population. In some countries, savings banks were created on public initiative, while in others socially committed individuals created foundations to put in place the necessary infrastructure. Nowadays, European savings banks have kept their focus on retail banking: payments, savings products, credits and insurances for individuals or small and medium-sized enterprises. Apart from this retail focus, they also differ from commercial banks by their broadly decentralised distribution network, providing local and regional outreach and by their socially responsible approach to business and society. They draw upon individual and family savings as their principle source of funds and invest those funds mainly in mortgages	

and corporate bonds, and occasionally in common stock (http://en.wikipedia.org) e.g Greek Postal Savings Bank (http://www.escapeartist.com) - *Savings and Loan Associations (SLA)* are financial institutions that were created to accept savings from private investors and provide home mortgage services for residential borrowers. In the 1980s, deregulatory measures allowed SLAs to participate in riskier loans, thus creating recent financial failure (www.info-authority.com). E.g. Freehold (www.freeholdsavingsandloan.com) - *Building Societies* are financial institutions, owned by its members, that offers banking and other financial services, especially mortgage lending. E.g. Abbey National (http://en.wikipedia.org) - *Ethical Banks* are banks that prioritize the transparency of all operations and make only social-responsible investments (http://en.wikipedia.org). e.g. Triodos Bank (http://www.foe-scotland.org.uk) - *Credit Unions* are another kind of depository institution. Most credit unions are formed by people with a common bond, such	

as those who work for the same company or belong to the same labour union or church. Members pool their savings and, when they need money, they may borrow from the credit union, often at a lower interest rate than that demanded by other financial institutions (www.bls.gov) e.g. Mountain America Credit Union (www.allegiance.com) 1.2 <u>Investment Banks</u> - Investment Banks "underwrite" (guarantee the sale of) stock and bond issues, trade for their own accounts, make markets, and advise corporations on capital markets activities such as mergers and acquisitions (http://en.wikipedia.org). E.g. Merrill Lynch, Salomon Smith Barney/Citigroup, Morgan Stanley/Dean Witter (http://www.careers-in-finance.com). - *Merchant Banks* refer to banks which provide capital to firms in the form of shares rather than loans. Unlike Venture capital firms, they tend not to invest in new companies (http://en.wikipedia.org) e.g. Rand Merchant Bank (http://www.rmb.co.za) 1.3 <u>Both Combined</u> - *Universal Banks* more commonly known as a financial services	

company, engage in several of the above activities. In Europe and Asia, big banks are much diversified groups that, among other services, also distribute insurance, hence the term bancassurance e.g. First Bank (http://en.wikipedia.org) 1.4. Other Types of Banks - *Industrial Banks* accept smaller consumer savings deposits and make certain types of loans, principally cash loans to wage earners (http://en.wikipedia.org). e.g. Merrill Lynch Bank USA, UBS Bank USA and American Express Centurion Bank (http://www.financialservicesfacts.org) - *Islamic Banks* adhere to the concepts of Islamic law. Islamic banking revolves around several well established concepts which are based on Islamic canons. Since the concept of interest is forbidden in Islam, all banking activities must avoid interest. Instead of interest, the bank earns profit (mark-up) and fees on financing facilities that it extends to the customers. Also, deposit makers earn a share of the bank's profit as opposed to a predetermined interest e.g. Bahrain Islamic Bank, ABC Islamic Bank. (http://en.wikipedia.org) - *Federal Reserve Banks* are Government agencies that perform	

many financial services for the Government. Their chief responsibilities are to regulate the banking industry and to help implement our Nation's monetary policy so our economy can run more efficiently by controlling the Nation's money supply—the total quantity of money in the country, including cash and bank deposits (www.bls.gov) e.g. Central Bank of Greece - *Online Banks* provide much the same services as more traditional high street banks or Building Societies through the use of electronic banking and the Internet. Furthermore, this type of banks does not have branches for their customers to use (www.intersites.co) e.g. American Bank Online (www.pcbanker.com)	
2. *Building societies*. Building societies raise funds primarily by accepting deposits from households; provide loans (mainly mortgage finance for owner-occupied housing) and payments services. Traditionally mutually owned institutions, building societies increasingly are issuing share capital.	2 *Finance companies* (including general financiers and pastoral finance companies). Provide loans to households and small- to medium-sized businesses. Finance companies raise funds from wholesale markets and, using debentures and unsecured notes, from retail investors.

3. *Credit unions.* Mutually owned institutions, credit unions provide deposit, personal/housing loan and payment services to members.	3. *Money market corporations (merchant banks).* Operate primarily in wholesale markets, borrowing from, and lending to, large corporations and government agencies. Other services, including advisory, relate to corporate finance, capital markets, foreign exchange and investment management.
	4. *Life insurance companies.* Provide life, accident and disability insurance, annuities, investment and superannuation products. Assets are managed in statutory funds on a fiduciary basis, and are mostly invested in equities and debt securities.
	5. *General insurance companies.* Provide insurance for property, motor vehicles, employers' liability, etc. Assets are invested mainly in deposits and loans, government securities and equities.
	6. *Superannuation and approved deposit funds.* Superannuation funds accept and manage contributions from employers (incl. self-

	employed) and/or employees to provide retirement income benefits. Funds are controlled by trustees, who often use professional funds managers/advisers. ADFs are generally managed by professional funds managers and, as with super funds, may accept superannuation lump sums and eligible redundancy payments when a person resigns, retires or is retrenched. Superannuation funds and ADFs usually invest in a range of assets (equities, property, debt securities, and deposits).
	7. *Public unit trusts.* Unit trusts pool investors' funds, usually into specific types of assets (e.g. cash, equities, property, money market investments, mortgages, overseas securities). Most unit trusts are managed by subsidiaries of banks, insurance companies or merchant banks.
	8. *Friendly societies*. Mutually owned co-operative financial institutions offering benefits to members through a trust-like structure. Benefits include: investment products through insurance or education bonds; funeral; accident; sickness; or other benefits.

	9. *Common funds*. Trustee companies pool into common funds money received from the general public, or held on behalf of estates or under powers of attorney. Funds are usually invested in specific types of assets (e.g. money market investments, equities, mortgages).
	10. *Cash management trusts*. Cash management trusts are unit trusts which are governed by a trust deed and open to the public and generally confine their investments (as authorised by the trust deed) to financial securities available through the short-term money market.

Appendix D

The following Tables present the analytical lean performance indicators resulted form the simulation experiments:

Table D.1: The CT per Product under High Capacity with no Rework

		Product Stucture with no rework (1)	Threshold Stucture with no rework (2)	Lean Stucture with no rework (3)	Deviation A (4)=[(2)-(1)]/1	Deviation B (5)=[(3)-(1)]/(1)
1. Cycle Time - High Capacity - no rework (minutes)	**Product A1**	12,2658	6,0012	5,9596	-51,07%	-51,41%
	Product A2	20,2105	20,0615	20,0152	-0,74%	-0,97%
	Product A3	40,3070	40,1402	39,9989	-0,41%	-0,76%
	Product A4	120,16	119,81	120,57	-0,29%	0,35%
	Product B1	33,1636	12,0495	12,0162	-63,67%	-63,77%
	Product B2	49,1477	40,1747	40,1058	-18,26%	-18,40%
	Product B3	59,4305	49,7384	50,5298	-16,31%	-14,98%
	Product B4	98,5718	90,2466	90,6208	-8,45%	-8,07%
	Product C1	20,2900	9,0025	8,8556	-55,63%	-56,35%
	Product C2	32,3018	29,9987	29,9351	-7,13%	-7,33%
	Product C3	61,9762	59,9203	58,8069	-3,32%	-5,11%
	Product C4	150,03	147,18	146,57	-1,90%	-2,30%
	Average	58,1539	52,0268	51,9989	-10,54%	-10,58%

Table D.2: The CT per Product under High Capacity with Rework

		Product Stucture with rework (1)	Threshold Stucture with rework (2)	Lean Stucture with rework (3)	% Deviation A (4)=[(2)-(1)]/1	% Deviation B (5)=[(3)-(1)]/(1)
1. Cycle Time - High Capacity - with rework (minutes)	**Product A1**	29,8641	21,5663	20,2688	-27,79%	-32,13%
	Product A2	51,5737	51,1912	49,6134	-0,74%	-3,80%
	Product A3	100,15	116,93	98,0615	16,75%	-2,08%
	Product A4	265,59	290,16	265,68	9,25%	0,03%
	Product B1	213,80	42,1146	40,5512	-80,30%	-81,03%
	Product B2	259,90	101,55	98,7692	-60,93%	-62,00%
	Product B3	285,39	139,16	121,57	-51,24%	-57,40%
	Product B4	364,43	225,21	205,47	-38,20%	-43,62%
	Product C1	68,8829	31,2062	29,8546	-54,70%	-56,66%
	Product C2	111,09	74,9718	74,3566	-32,51%	-33,07%
	Product C3	197,99	161,39	147,15	-18,48%	-25,68%
	Product C4	377,79	360,45	341,86	-4,59%	-9,51%
	Average	193,87	134,66	124,43	-30,54%	-35,82%

Table D.3: The % of VA Time per Product under High Capacity with no Rework

		Product Stucture with no rework (1)	Threshold Stucture with no rework (2)	Lean Stucture with no rework (3)	% Deviation A (4)=[(2)-(1)]/1	% Deviation B (5)=[(3)-(1)]/(1)
2. % of Value Added Time - High Capacity - no rework	Product A1	97,67%	100,00%	100,00%	2,39%	2,39%
	Product A2	98,66%	99,59%	100,00%	0,94%	1,36%
	Product A3	99,31%	99,94%	100,00%	0,63%	0,70%
	Product A4	99,75%	99,46%	99,65%	-0,29%	-0,10%
	Product B1	72,37%	100,00%	100,00%	38,18%	38,18%
	Product B2	81,58%	99,80%	100,00%	22,34%	22,59%
	Product B3	84,74%	99,95%	100,00%	17,95%	18,01%
	Product B4	90,77%	99,23%	99,57%	9,32%	9,69%
	Product C1	88,42%	100,00%	100,00%	13,09%	13,09%
	Product C2	92,66%	99,68%	100,00%	7,57%	7,92%
	Product C3	96,36%	99,95%	100,00%	3,73%	3,78%
	Product C4	98,44%	99,47%	99,67%	1,05%	1,26%
	Average	91,73%	99,76%	99,91%	8,75%	8,92%

Table D.4: The % of VA Time per Product under High Capacity with Rework

		Product Stucture with rework (1)	Threshold Stucture with rework (2)	Lean Stucture with rework (3)	Deviation A (4)=[(2)-(1)]/2	Deviation B (5)=[(3)-(1)]/(1)
2. % of Value Added Time - High Capacity - with rework	**Product A1**	88,41%	92,74%	99,09%	4,89%	12,08%
	Product A2	93,12%	96,33%	99,62%	3,44%	6,98%
	Product A3	96,32%	85,54%	99,79%	-11,19%	3,60%
	Product A4	98,49%	93,36%	99,75%	-5,21%	1,28%
	Product B1	25,25%	96,04%	99,53%	280,38%	294,22%
	Product B2	38,40%	98,06%	99,81%	155,41%	159,95%
	Product B3	43,47%	88,07%	99,83%	102,61%	129,67%
	Product B4	55,16%	91,35%	99,68%	65,61%	80,71%
	Product C1	61,32%	94,79%	99,39%	54,59%	62,10%
	Product C2	74,99%	97,52%	99,71%	30,05%	32,98%
	Product C3	86,27%	89,62%	99,87%	3,89%	15,76%
	Product C4	92,59%	93,89%	99,79%	1,40%	7,77%
	Average	71,15%	93,11%	99,66%	30,87%	40,07%

Table D.5: Level of WIP per Product under High Capacity with no Rework

		Product Stucture with no rework (1)	Threshold Stucture with no rework (2)	Lean Stucture with no rework (3)	% Deviation A (4)=[(1)-(2)]/1	% Deviation B (5)=[(1)-(3)]/(1)
3. WIP - High Capacity - no rework	**Product A1**	1,5308	0,7532	0,7431	-50,79%	-51,46%
	Product A2	1,7310	1,7199	1,7176	-0,64%	-0,78%
	Product A3	1,8834	1,8772	1,8487	-0,33%	-1,84%
	Product A4	2,3504	2,3254	2,3442	-1,06%	-0,26%
	Product B1	1,1545	0,4213	0,4214	-63,50%	-63,50%
	Product B2	0,9629	0,7872	0,7816	-18,25%	-18,83%
	Product B3	0,6912	0,5838	0,5986	-15,53%	-13,39%
	Product B4	0,7800	0,7055	0,7064	-9,55%	-9,44%
	Product C1	0,3134	0,1386	0,1373	-55,78%	-56,19%
	Product C2	0,3768	0,3474	0,3513	-7,80%	-6,77%
	Product C3	0,4911	0,4677	0,4586	-4,77%	-6,62%
	Product C4	0,5869	0,5767	0,5628	-1,73%	-4,11%
	Total/Average	12,8524	10,7041	10,6714	-16,72%	-16,97%

Table D.6: Level of WIP per Product under High Capacity with no Rework

		Product Stucture with rework (1)	Threshold Stucture with rework (2)	Lean Stucture with rework (3)	Deviation A (4)=[(2)-(1)]/1	Deviation B (5)=[(3)-(1)]/(1)
3. WIP - High Capacity - with rework	**Product A1**	3,7142	2,6888	2,5238	-27,61%	-32,05%
	Product A2	4,4182	4,3856	4,2410	-0,74%	-4,01%
	Product A3	4,7382	5,4704	4,5728	15,45%	-3,49%
	Product A4	5,1961	5,6090	5,1692	7,95%	-0,52%
	Product B1	7,5075	1,4906	1,4175	-80,14%	-81,12%
	Product B2	5,0681	1,9815	1,9245	-60,90%	-62,03%
	Product B3	3,3967	1,6393	1,4226	-51,74%	-58,12%
	Product B4	2,8491	1,7787	1,6084	-37,57%	-43,55%
	Product C1	1,0756	0,4810	0,4628	-55,28%	-56,97%
	Product C2	1,2890	0,8592	0,8629	-33,34%	-33,06%
	Product C3	1,5602	1,2536	1,1514	-19,65%	-26,20%
	Product C4	1,4728	1,3946	1,3424	-5,31%	-8,86%
	Total/Average	42,2858	29,0323	26,6994	-31,34%	-36,86%

Table D.7: The Resource Utilization under High Capacity with no Rework

		Product Stucture with no rework (1)	Threshold Stucture with no rework (2)	Lean Stucture with no rework (3)	Deviation A (4)=[(2)-(1)]/1	Deviation B (5)=[(3)-(1)]/(1)
4. Number Busy - High Capacity- no rework	Loan officers_A	4,0656	3,0178	6,5591		
	Loan officers_B	1,5912	1,7575			
	Loan officers_C	0,9195	1,7867			
	Head Loan officers_A	2,8796	1,1399	3,3760		
	Head Loan officers_B	1,1822	1,1695			
	Head Loan officers_C	0,6413	1,0804			
	Manager_A	0,4727		0,7231		
	Manager_B	0,1419				
	Manager_C	0,1165	0,7195			
	Sum	12,0103	10,6714	10,6583	-11,15%	-11,26%

Table D.8: The Resource Utilization under High Capacity with Rework

		Product Stucture with rework (1)	Threshold Stucture with rework (2)	Lean Stucture with rework (3)	Deviation A (4)=[(2)-(1)]/1	Deviation B (5)=[(3)-(1)]/(1)
4. Number Busy - High Capacity - with rework	**Loan officers_A**	13,5465	10,0517	21,8784		
	Loan officers_B	5,3464	5,8651			
	Loan officers_C	3,0743	6,1298			
	Head Loan officers_A	3,0442	1,3349	3,9730		
	Head Loan officers_B	1,3824	1,3786			
	Head Loan officers_C	1,1576	1,2787			
	Manager_A	0,4895		0,7591		
	Manager_B	0,1476				
	Manager_C	0,1040	0,7613			
	Sum	28,2924	26,8001	26,6106	-5,27%	-5,94%

Table D.9: The CT per Product under Low Capacity with no Rework

		Product Stucture with no rework (1)	Threshold Stucture with no rework (2)	Lean Stucture with no rework (3)	Deviation A (4)=[(2)-(1)]/1	Deviation B (5)=[(3)-(1)]/(1)
1. Cycle Time - Low Capacity - no rework (minutes)	**Product A1**	12,2658	5,9665	6,0163	-51,36%	-50,95%
	Product A2	20,2105	20,5932	19,9923	1,89%	-1,08%
	Product A3	40,3070	41,4832	40,0185	2,92%	-0,72%
	Product A4	120,16	126,45	123,29	5,23%	2,61%
	Product B1	33,1636	12,0238	12,1243	-63,74%	-63,44%
	Product B2	49,1477	40,8495	39,9925	-16,88%	-18,63%
	Product B3	59,4305	51,1348	49,8972	-13,96%	-16,04%
	Product B4	98,5718	95,2023	92,6857	-3,42%	-5,97%
	Product C1	20,2900	8,9445	8,9332	-55,92%	-55,97%
	Product C2	32,3018	30,3577	29,8753	-6,02%	-7,51%
	Product C3	61,9762	61,0550	60,6265	-1,49%	-2,18%
	Product C4	150,03	157,38	153,84	4,90%	2,54%
	Average	58,1539	54,2860	53,1081	-6,65%	-8,68%

Table D.10: The CT per Product under Low Capacity with Rework

		Product Stucture with rework (1)	Threshold Stucture with rework (2)	Lean Stucture with rework (3)	Deviation A (4)=[(2)-(1)]/1	Deviation B (5)=[(3)-(1)]/(1)
1. Cycle Time - Low Capacity - with rework (minutes)	**Product A1**	2378,85	593,32	533,07	-75,06%	-77,59%
	Product A2	2402,18	625,46	560,07	-73,96%	-76,68%
	Product A3	2445,39	843,96	607,82	-65,49%	-75,14%
	Product A4	2554,81	2087,00	779,10	-18,31%	-69,50%
	Product B1	4016,30	614,12	544,49	-84,71%	-86,44%
	Product B2	4082,13	672,51	600,12	-83,53%	-85,30%
	Product B3	4121,87	869,74	631,31	-78,90%	-84,68%
	Product B4	4274,07	2065,64	727,62	-51,67%	-82,98%
	Product C1	7811,47	596,49	532,14	-92,36%	-93,19%
	Product C2	7869,64	653,57	589,34	-91,70%	-92,51%
	Product C3	7925,21	886,51	667,66	-88,81%	-91,58%
	Product C4	8046,66	2160,14	850,24	-73,15%	-89,43%
	Average	4827,38	1055,70	635,25	-78,13%	-86,84%

Table D.11: The % of VA Time per Product under Low Capacity with no Rework

		Product Stucture with no rework (1)	Threshold Stucture with no rework (2)	Lean Stucture with no rework (3)	Deviation A (4)=[(2)-(1)]/1	Deviation B (5)=[(3)-(1)]/(1)
2. % of Value Added Time - Low Capacity - no rework	**Product A1**	97,67%	99,99%	100,00%	2,38%	2,39%
	Product A2	98,66%	97,15%	99,92%	-1,53%	1,28%
	Product A3	99,31%	96,85%	99,95%	-2,48%	0,65%
	Product A4	99,75%	95,17%	97,23%	-4,59%	-2,53%
	Product B1	72,37%	100,00%	100,00%	38,18%	38,18%
	Product B2	81,58%	98,52%	99,96%	20,77%	22,54%
	Product B3	84,74%	97,39%	99,96%	14,93%	17,97%
	Product B4	90,77%	93,45%	96,52%	2,96%	6,33%
	Product C1	88,42%	100,00%	100,00%	13,09%	13,09%
	Product C2	92,66%	97,97%	99,93%	5,73%	7,84%
	Product C3	96,36%	97,87%	99,97%	1,57%	3,75%
	Product C4	98,44%	96,10%	97,56%	-2,37%	-0,89%
	Average	91,73%	97,54%	99,25%	6,34%	8,20%

Table D.12: The % of VA Time per Product under Low Capacity with Rework

		Product Stucture with rework (1)	Threshold Stucture with rework (2)	Lean Stucture with rework (3)	Deviation A (4)=[(2)-(1)]/1	Deviation B (5)=[(3)-(1)]/(1)
2. % of Value Added Time - Low Capacity - with rework	**Product A1**	1,09%	3,35%	3,73%	207,91%	242,91%
	Product A2	1,96%	7,80%	8,80%	297,25%	348,08%
	Product A3	3,87%	11,72%	16,19%	202,40%	317,81%
	Product A4	9,90%	12,69%	34,20%	28,15%	245,42%
	Product B1	1,30%	6,49%	7,30%	398,46%	460,89%
	Product B2	2,35%	14,54%	16,30%	519,75%	594,88%
	Product B3	2,87%	14,36%	19,57%	401,13%	582,75%
	Product B4	4,65%	9,63%	28,06%	107,14%	503,65%
	Product C1	0,54%	4,88%	5,57%	801,88%	929,86%
	Product C2	1,06%	11,19%	12,39%	957,15%	1069,68%
	Product C3	2,12%	16,76%	22,03%	689,81%	938,30%
	Product C4	4,35%	15,24%	39,84%	250,54%	816,45%
	Average	3,00%	10,72%	17,83%	256,78%	493,42%

Table D.13: The Level of WIP per Product under Low Capacity with no Rework

		Product Stucture with no rework (1)	Threshold Stucture with no rework (2)	Lean Stucture with no rework (3)	Deviation A (4)=[(2)-(1)]/1	Deviation B (5)=[(3)-(1)]/(1)
3. WIP - Low Capacity - no rework	**Product A1**	1,5308	0,7465	0,7528	-51,23%	-50,82%
	Product A2	1,7310	1,7674	1,7197	2,10%	-0,65%
	Product A3	1,8834	1,9451	1,8611	3,28%	-1,19%
	Product A4	2,3504	2,4524	2,4016	4,34%	2,18%
	Product B1	1,1545	0,4246	0,4229	-63,22%	-63,37%
	Product B2	0,9629	0,8052	0,7776	-16,37%	-19,25%
	Product B3	0,6912	0,6016	0,5756	-12,96%	-16,72%
	Product B4	0,7800	0,7513	0,7196	-3,68%	-7,75%
	Product C1	0,3134	0,1397	0,1391	-55,42%	-55,62%
	Product C2	0,3768	0,3553	0,3493	-5,70%	-7,30%
	Product C3	0,4911	0,4833	0,4774	-1,59%	-2,80%
	Product C4	0,5869	0,6058	0,5787	3,21%	-1,39%
	Total/Average	12,8524	11,0782	10,7753	-13,80%	-16,16%

Table D.14: The Level of WIP per Product under Low Capacity with Rework

		Product Stucture with no rework (1)	Threshold Stucture with no rework (2)	Lean Stucture with no rework (3)	Deviation A (4)=[(2)-(1)]/1	Deviation B (5)=[(3)-(1)]/(1)
3. WIP - Low Capacity - with rework	**Product A1**	305,78	74,1203	66,8015	-75,76%	-78,15%
	Product A2	211,21	53,9672	47,7727	-74,45%	-77,38%
	Product A3	116,86	39,5388	28,6130	-66,17%	-75,51%
	Product A4	50,7148	40,7459	15,1167	-19,66%	-70,19%
	Product B1	150,49	21,7402	18,8987	-85,55%	-87,44%
	Product B2	84,9583	13,2657	11,7929	-84,39%	-86,12%
	Product B3	50,4973	10,2112	7,4095	-79,78%	-85,33%
	Product B4	35,1461	16,0122	5,6603	-54,44%	-83,89%
	Product C1	124,54	9,3142	8,3157	-92,52%	-93,32%
	Product C2	92,3251	7,6672	6,7507	-91,70%	-92,69%
	Product C3	62,9873	7,0368	5,1529	-88,83%	-91,82%
	Product C4	30,9375	8,7113	3,2435	-71,84%	-89,52%
	Total/Average	1316,44	302,3311	225,5282	-77,03%	-82,87%

Table D.15: The Resource Utilization under Low Capacity with no Rework

		Product Stucture with no rework (1)	Threshold Stucture with no rework (2)	Lean Stucture with no rework (3)	Deviation A (4)=[(2)-(1)]/1	Deviation B (5)=[(3)-(1)]/(1)
4. Number Busy - Low Capacity - no rework	Loan officers_A	4,07	3,03	6,56		
	Loan officers_B	1,59	1,76			
	Loan officers_C	0,92	1,80			
	Head Loan officers_A	2,88	1,14	3,38		
	Head Loan officers_B	1,18	1,18			
	Head Loan officers_C	0,64	1,09			
	Manager_A	0,47		0,72		
	Manager_B	0,14				
	Manager_C	0,12	0,73			
	Sum	12,01	10,73	10,67	-10,66%	-11,19%

Table D.16: The Resource Utilization under Low Capacity with Rework

		Product Stucture with rework (1)	Threshold Stucture with rework (2)	Lean Stucture with rework (3)	Deviation A (4)=[(2)-(1)]/1	Deviation B (5)=[(3)-(1)]/(1)
4. Number Busy - Low Capacity - with rework	Loan officers_A	12,96	9,9253	21,76		
	Loan officers_B	4,98	5,8667			
	Loan officers_C	3,02	5,8959			
	Head Loan officers_A	2,93	1,3328	3,96		
	Head Loan officers_B	1,27	1,3664			
	Head Loan officers_C	1,00	1,2346			
	Manager_A	0,47		0,75		
	Manager_B	0,14				
	Manager_C	0,09	0,7424			
	Sum	26,86	26,36	26,48	-1,83%	-1,41%

Table D.17: The CT per Product of the Lean Structure under Low Capacity

		Lean Stucture with rework (1)	Lean Stucture with 50% reduced rework (2)	Lean Stucture with no rework (3)	% Deviation (4) = [(2)-(1)]/(1)	% Deviation (5) = [(3)-(1)]/(1)
1. Cycle Time - Lean Structure- Low Capacity (minutes)	**Product A1**	533,07	9,2332	6,0163	-98,27%	-98,87%
	Product A2	560,07	27,0936	19,9923	-95,16%	-96,43%
	Product A3	607,82	54,0544	40,0185	-91,11%	-93,42%
	Product A4	779,10	160,75	123,29	-79,37%	-84,17%
	Product B1	544,49	18,4427	12,1243	-96,61%	-97,77%
	Product B2	600,12	54,2326	39,9925	-90,96%	-93,34%
	Product B3	631,31	67,7340	49,8972	-89,27%	-92,10%
	Product B4	727,62	122,48	92,6857	-83,17%	-87,26%
	Product C1	532,14	13,9339	8,9332	-97,38%	-98,32%
	Product C2	589,34	40,6153	29,8753	-93,11%	-94,93%
	Product C3	667,66	81,1444	60,6265	-87,85%	-90,92%
	Product C4	850,24	200,30	153,84	-76,44%	-81,91%
	Average	635,25	70,8347	53,1081	-88,85%	-91,64%

Table D.18: The % of VA Time per Product of the Lean Structure under Low Capacity

		Lean Stucture with rework (1)	Lean Stucture with 50% reduced rework (2)	Lean Stucture with no rework (3)	% Deviation (4) = [(2)-(1)]/(1)	% Deviation (5) = [(3)-(1)]/(1)
2. % of Value Added Time - Lean Structure - Low Capacity	**Product A1**	3,73%	99,99%	100,00%	2579,62%	2579,79%
	Product A2	8,80%	99,85%	99,92%	1034,72%	1035,57%
	Product A3	16,19%	99,92%	99,95%	517,19%	517,37%
	Product A4	34,20%	97,65%	97,23%	185,57%	184,33%
	Product B1	7,30%	100,00%	100,00%	1269,01%	1269,03%
	Product B2	16,30%	99,92%	99,96%	512,83%	513,11%
	Product B3	19,57%	99,94%	99,96%	410,77%	410,91%
	Product B4	28,06%	97,05%	96,52%	245,85%	243,96%
	Product C1	5,57%	100,00%	100,00%	1695,17%	1695,24%
	Product C2	12,39%	99,87%	99,93%	706,33%	706,84%
	Product C3	22,03%	99,95%	99,97%	353,64%	353,74%
	Product C4	39,84%	98,04%	97,56%	146,11%	144,89%
	Average	17,83%	99,35%	99,25%	457,15%	456,60%

Table D.19: The Level of WIP per Product of the Lean Structure under Low Capacity

		Lean Stucture with rework (1)	Lean Stucture with 50% reduced rework (2)	Lean Stucture with no rework (3)	% Deviation (4) = [(2)-(1)]/(1)	% Deviation (5) = [(3)-(1)]/(1)
3. WIP - Lean Structure - Low Capacity	**Product A1**	66,8015	1,1491	0,7528	-98,28%	-98,87%
	Product A2	47,7727	2,3229	1,7197	-95,14%	-96,40%
	Product A3	28,6130	2,5319	1,8611	-91,15%	-93,50%
	Product A4	15,1167	3,1323	2,4016	-79,28%	-84,11%
	Product B1	18,8987	0,6464	0,4229	-96,58%	-97,76%
	Product B2	11,7929	1,0568	0,7776	-91,04%	-93,41%
	Product B3	7,4095	0,7970	0,5756	-89,24%	-92,23%
	Product B4	5,6603	0,9583	0,7196	-83,07%	-87,29%
	Product C1	8,3157	0,2175	0,1391	-97,38%	-98,33%
	Product C2	6,7507	0,4647	0,3493	-93,12%	-94,83%
	Product C3	5,1529	0,6403	0,4774	-87,57%	-90,74%
	Product C4	3,2435	0,7724	0,5787	-76,19%	-82,16%
	Total/Average	225,5282	14,6897	10,7753	-93,49%	-95,22%

Table D.20: The Resource Utilization of the Lean Structure under Low Capacity

		Lean Stucture with rework (1)	Lean Stucture with 50% reduced rework (2)	Lean Stucture with no rework (3)	% Deviation (4) = [(2)-(1)]/(1)	% Deviation (5) = [(3)-(1)]/(1)
4. Number Busy - Lean Structure- Low Capacity	**Loan officers_A**	21,76	10,15	6,56		
	Head Loan officers_A	3,96	3,68	3,38		
	Manager_A	0,75	0,74	0,72		
	Sum	26,48	14,56	10,67	-44,99%	-59,72%

Table D.21: The CT per Product of the Lean Structure under High Capacity with 50% Reduced Rework

		Lean Stucture, 50%↓ rework
1. Cycle Time - High Capacity, 50%↓ rework (minutes)	**Product A1**	9,2584
	Product A2	27,0327
	Product A3	54,1409
	Product A4	156,96
	Product B1	18,3960
	Product B2	54,3889
	Product B3	67,8671
	Product B4	116,61
	Product C1	13,8386
	Product C2	41,0842
	Product C3	81,9174
	Product C4	196,15
	Average	69,8038

Table D.22: The % of VA Time per Product of the Lean Structure Under High Capacity with 50% Reduced Rework

		Lean Stucture, 50%↓ rework
2. % of Value Added Time - High Capacity - 50%↓ rework	**Product A1**	100,00%
	Product A2	100,00%
	Product A3	100,00%
	Product A4	99,72%
	Product B1	100,00%
	Product B2	100,00%
	Product B3	100,00%
	Product B4	99,59%
	Product C1	100,00%
	Product C2	100,00%
	Product C3	100,00%
	Product C4	99,80%
	Average	99,93%

Table D.23: The Level of WIP per Product of the Lean Structure under High Capacity with 50% Reduced Rework

		Lean Stucture, 50%↓ rework
3. WIP - High Capacity- 50%↓ rework	**Product A1**	1,1522
	Product A2	2,3130
	Product A3	2,5347
	Product A4	3,0209
	Product B1	0,6396
	Product B2	1,0694
	Product B3	0,7939
	Product B4	0,9156
	Product C1	0,2164
	Product C2	0,4744
	Product C3	0,6511
	Product C4	0,7563
	Total/Average	14,5376

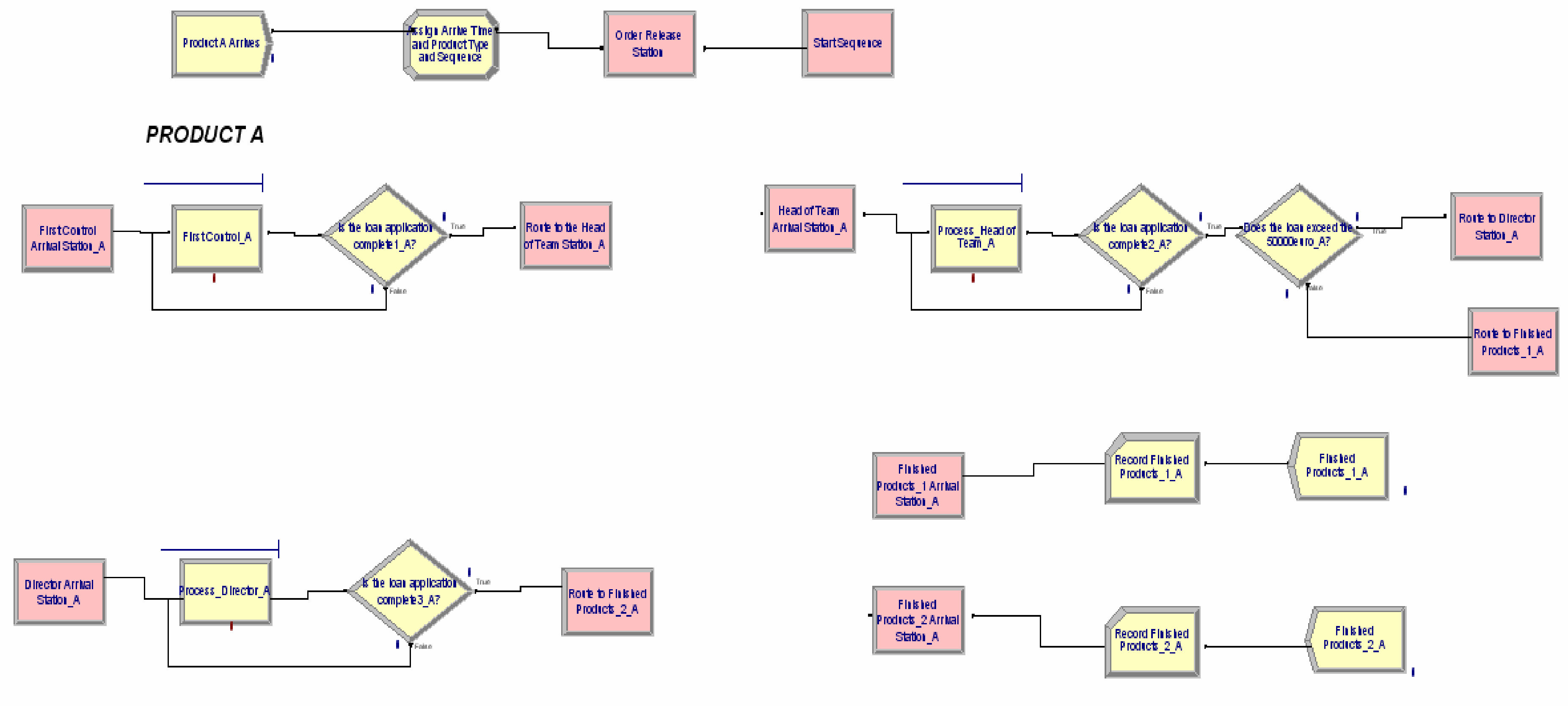
Table D.24: The Resource Utilization of the Lean Structure under High Capacity with 50% Reduced Rework

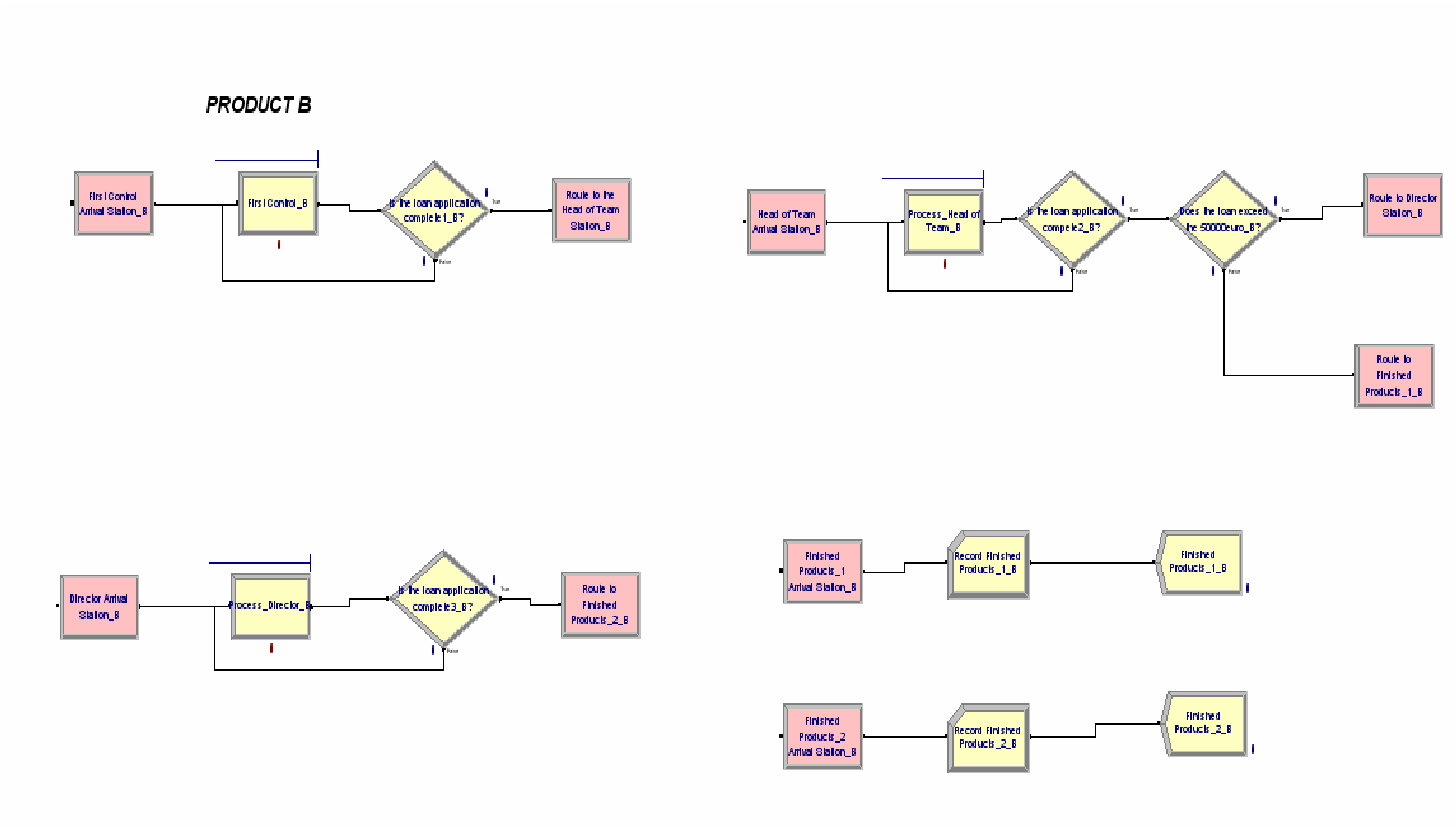
		Lean Stucture, 50%↓ rework
4. Number Busy - Lean Structure- High Capacity	**Loan officers_A**	10,1163
	Head Loan officers_A	3,6709
	Manager_A	0,7365
	Sum	14,5238

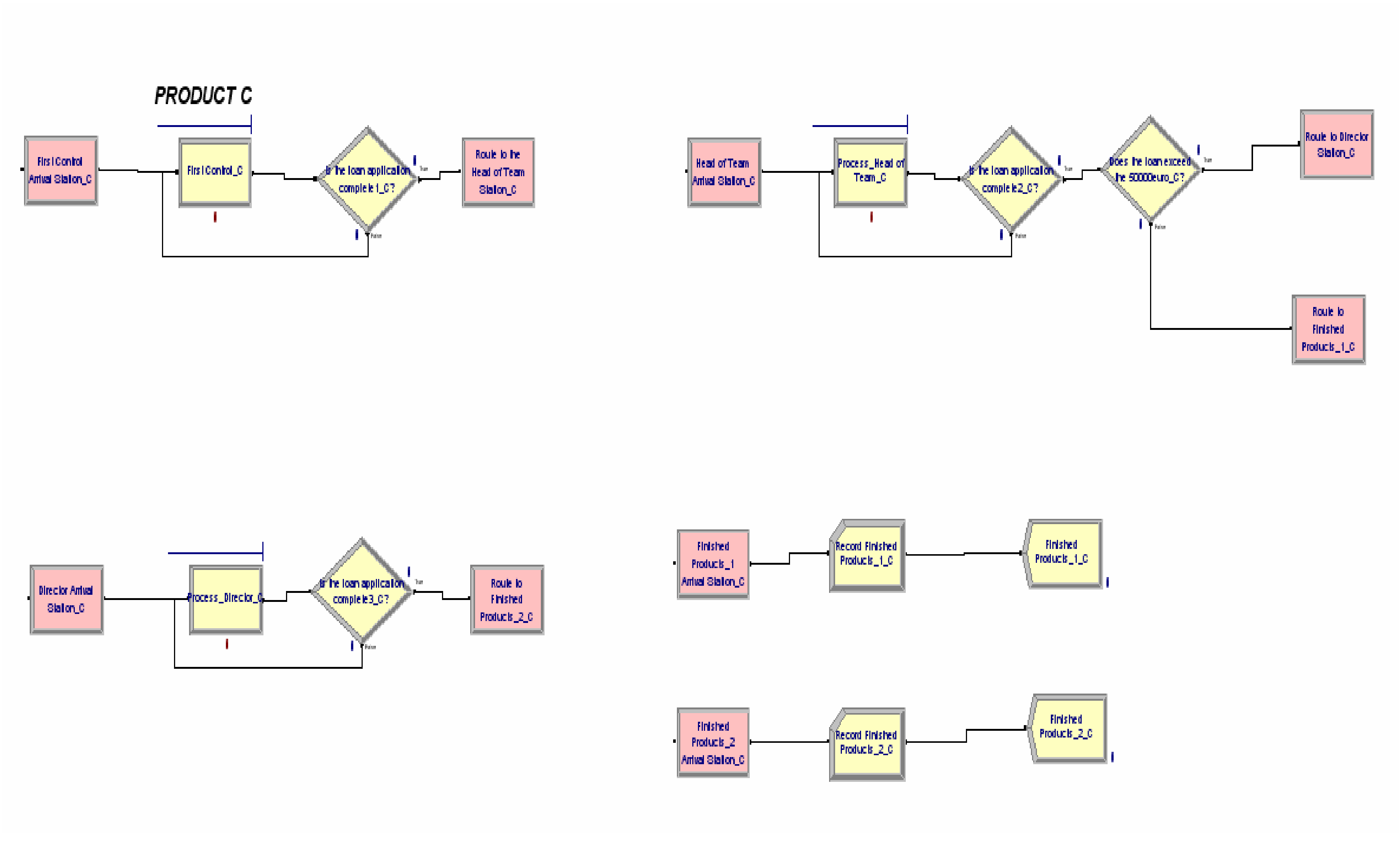
Appendix E

The following figures show the simulation model for the Product Structure when rework exists. The Threshold and the Lean Structure were modeled with a similar manner.

Figure E.1: The simulation model of the Product Structure




PRODUCT B
First Control Arrival Station_B
First Control_B
Is the loan application complete1_B?
Route to the Head of Team Station_B
Head of Team Arrival Station_B
Process_Head of Team_B
Is the loan application complete2_B?
Does the loan exceed the 50000euro_B?
Route to Director Station_B
Route to Finished Products_1_B
Director Arrival Station_B
Process_Director_B
Is the loan application complete3_B?
Route to Finished Products_2_B
Finished Products_1 Arrival Station_B
Record Finished Products_1_B
Finished Products_1_B
Finished Products_2 Arrival Station_B
Record Finished Products_2_B
Finished Products_2_B


PRODUCT C
First Control Arrival Station_C
First Control_C
Is the loan application complete1_C?
Route to the Head of Team Station_C
Head of Team Arrival Station_C
Process_Head of Team_C
Is the loan application complete2_C?
Does the loan exceed the 50000euro_C?
Route to Director Station_C
Route to Finished Products_1_C
Director Arrival Station_C
Process_Director_C
Is the loan application complete3_C?
Route to Finished Products_2_C
Finished Products_1 Arrival Station_C
Record Finished Products_1_C
Finished Products_1_C
Finished Products_2 Arrival Station_C
Record Finished Products_2_C
Finished Products_2_C