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Productivity improvement in a client-based service company through value stream mapping and simulation

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PRODUCTIVITY IMPROVEMENT IN A CLIENT-BASED SERVICE COMPANY THROUGH VALUE STREAM MAPPING AND SIMULATION

By

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Abstract

For many years, productivity improvement through value stream mapping and simulation has been studied in manufacturing industry where the flow of materials is visible and the work can be standardized. In recent years, the service industry has become a new arena for lean operations. Within the service industry, client-based companies have distinct challenges in streamlining their process, as it may not be feasible to standardize the needs of different clients. This thesis focuses on a case from a client-based company in the area of graphic communications and brand point management services. The thesis examines the application of lean principles towards a set of subjective processes and provides directions for improving productivity. Some lean methods utilized in the study include creating process flows, conducting operator interviews to back-up the process flow, collecting data such as processing time and creating a detailed values stream map of the retail packaging process in order to analyze any necessary areas of improvement. Value stream mapping has been used to identify the areas where the non-value-added tasks can be reduced, and simulation models have been used to imitate and predict the company's different scenarios in dealing with bottlenecks, different kinds of wastes, and to assess potential areas for improvements. The analysis of results indicates that it is necessary to have two different streams of the processes; one for a team-based job and another one for a non-team-based job. The proper touch points from each department have been found and value-added and non-value-added times have been determined in order to create the current-state. Furthermore, future-states have been created with some recommendations kept in mind to validate the time savings. The results have been verified through a simulation analysis.

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Borrower's Page

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Dedication

I would like to dedicate this work to my parents, for their never-ending unconditional love and support in all my efforts, and for giving me the foundation to be who I am.

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Chapter 1 Introduction and Literature Review

1.1 Introduction

Lean operation is one of the initiatives that many companies have been trying to adopt in order to satisfy their customers. Value Stream Mapping (VSM) is one of the best tools that could be used to apply lean to manufacturing or service industry. VSM shows both process flow and material flow in an organization. Process and material flows will give the company an opportunity to identify and remove waste. Simulation is another tool to analyze and optimize organizational performance. On the other hand, simulation can also prove verification and validation. Combining simulation with information from VSM makes it possible to test different scenarios without any changes in the real system in order to identify the optimum solution.

Lean mostly applies to manufacturing companies or to those companies that produce the same product repeatedly. Applying lean principles to non-manufacturing companies is a completely different situation. Unlike a manufactured product that is a tangible object that can be created, sold, and be used later, services are intangible. Services are also perishable; they cannot be stored and they forever lost if not immediately used. Furthermore, services are created and consumed simultaneously. The inability to store services precludes using traditional manufacturing strategy of using inventory as a buffer to absorb fluctuations in demand. In addition, services are usually labour intensive; this implies that labour is one of the key resources that determine the effectiveness of the organisation (Fitzsimmons and Fitzsimmons, 2004). In many cases, the skills required of the workers are very high and such workers are often referred to as the knowledge workers. Management of these knowledge workers becomes critical for the success of many service organisations. Services provided to the customers also vary from one customer to another. Quality control of the services becomes critically important to ensure that each customer gets consistent, good service. These differences between manufactured products and services have significant implications for the application of lean manufacturing principles to information intensive services. Many services cannot be entirely divorced from manufactured goods because almost all services are accompanied by facilitating goods (Fitzsimmons and Fitzsimmons, 2004). For example, the facilitating goods such as auto parts are used in auto repair services. In fact, Berry and Parasuraman (1991) argued that an easy dichotomy between manufacturing and service firms does not exist because manufactured goods and services are inextricably related. Well-informed manufacturers are therefore as interested in the quality of their services as of their goods. These companies realise that customers buy products whose core benefit is delivered not by a good or service, but by both. According to Levitt (1976):

"There is no such thing as a service industry. There are only industries whose service components are greater or less than those of other industries are. Everybody is in service."

Lean mostly applies to manufacturing companies or to those companies that produce the same product repeatedly. Appling lean principles to non-manufacturing companies are a completely different situation Most service industries such as bank, healthcare, etc have found to use the same principles, although the use of lean tools is different. Therefore, the first step is to begin investigation into the contingencies surrounding the application of lean production to service operations. To achieve this purpose, lean production principles must be translated into service operations. Womack and Jones (1996) believe that the lean production principle can be divided into seven different parts as follows:

1. Elimination of waste
2. Zero defects
3. Multifunctional teams
4. Pull instead of push
5. Decentralization of responsibilities
6. Vertical information systems
7. Continuous improvement

In manufacturing, this principle is pre-defined, but the question is how this principle could be translated into service industries. To understand better how the lean production principle could be applied to service industries, healthcare and road maintenance are chosen. In Table 1-1, the lean production principals to healthcare and road maintenance are discussed.

The next step after understanding the principle of lean production is to identify the tools which must be used. Tools methodologies that are part of "Lean" are addressed in literature. In (McDonald et al. 2000; Rahn 2001), the pull technique of only producing what is required when it is required is used in the improved phases. The results are less rework and scrap, lower work-in-process, reduced lead-time, increased throughput rate and higher service level. Other tools such as standard work (Cudney and Fargher 2001), quick changeover (Van Goubergen and Van Landeghem, 2001, 2002), 5S (Henderson and Larco 2000), etc. can be referred to the works in the reference. 5S could be use for both manufacturing and service industries. In service industries, all materials should be organized within the reach of operators. Therefore, the operator should not have to leave the work area. The 5S organization allows the operator to continuously utilize any material in front of him/her as well as to keep an eye on a his/her work.

The next tool is line balancing in the system. The line balancing means calculating the optimum utilization using the fewest operators to achieve the result requested. For example, when two tellers in a bank are faced with tasks that requires to work 6 hours out of 8 hours shift per day, the remaining 2 hours are non-value-added and must be eliminated or filled with value-added activities in a standard work format. If the job is not standardized, the two individuals may absorb the time and appear 100% busy. There are many other instances where job combinations are obvious.

One of the best long-term Lean Manufacturing tools in a service industry is the Kaizen[1] event. Kaizen is a method that strives toward perfection by eliminating waste. It eliminates waste by empowering people with tools and a methodology for uncovering improvement

[1] Kaizen is a Japanese word constructed from two ideographs, the first of which represents change and the second goodness or virtue. Kaizen is commonly used to indicate the long-term betterment of something or someone (continuous improvement) as in the phrase *Seikatsu o kaizen suru* which means to "better one's life."

opportunities and making change. Kaizen understands waste to be any activity that is not value-added from the customer's point of view. For example, a Kaizen might be developed to reduce hospital checks in time for testing. The team might include the individuals conducting the check-in, a nurse, manager, and IT representative, and a couple of patients.

If the average check-in time, which means the time from walking into the building until seated in the waiting room, is 35 minutes, the Kaizen objective might be to reduce the check-in time to 20 minutes within 5 days. There are four common elements involved in each kaizen event, which are:

1. Workers who execute a work process
2. Focus on improving the performance of that work process
3. Seek to make incremental improvements
4. Intended to be repeated over time.

Service industries often use Kanban[2]. The same pull systems can be used in service industries as in the manufacturing sector. A distribution centre is one good example. Inventory waste can be reduced using pull systems beginning with the end downstream customer. When implementing Lean Manufacturing in a service industry, it is important to tailor the training to the business. Most single minute exchange of die training is developed using examples of setup activities for equipment. It is easier for people to recognize and see the waste in their processes when the training has clear applicability.

The VSM is an excellent tool for service industries. VSM can be used in each department of a service industry. An example would be the service desk at a department store. VSM begins with the information flow and triggers for an activity, which could be a customer. It then breaks the map into various parts showing the few activities that comprise most of the work, such as merchandise return, request for information, or complaints.

---

[2] Kanban is a tool for realizing just-in-time. For this tool to work fairly well, the production process must be managed to flow as much as possible. This is really the basic condition. Other important conditions are leveling production as much as possible and always working in accordance with standard work methods. (Ohno, 1988)

Table 1-1: Applying lean production principle to service operation in healthcare and road maintenance (Ahlstrom, 2006)

	Healthcare	Road Maintenance
Elimination of waste	Unnecessary surgery or test, overtreatment of patients, unnecessary movement.	Reducing the unnecessary usage of materials such as salt and asphalt that are used to keep roads functioning.
Zero defects	Quality of materials, such as equipment and drugs, is therefore paramount. To achieve zero defects, it is also important that methods, processes, and procedures be well developed.	Increasing dependability, for example, taking action to keep roads open in winter as soon as possible, without unnecessary delays
Multifunctional teams	Physician and nursing teams. It is possible to have a certain amount of flexibility in these teams period. For example, if the physician is busy with another patient the nurse could take care of the job. Nevertheless, flexibility is restricted since there are clearly defined roles for each staff. A nurse does not have the same role and responsibility as a physician	The aim was to change the previously very hierarchical organisation and implement result-oriented teams. Teams of people with different functions were starting to be used. These teams spanned previously quite strict functional boundaries.
Pull instead of push	Scheduling operations and keeping patients in a queue. Striving towards a pure pull system is still desirable, albeit very difficult to achieve	Usage of materials on a pull basis, JIT transports. For example, instead of having large shipments of materials, via ships, the aim was to use smaller shipments, using trains instead.
Decentralization of responsibilities	Appropriate, for instance through decentralisation to teams	Teams given responsibility for parts of the whole
Vertical information systems	An information system plays an important role in healthcare. It is important to share information with value-added parts of an organization.	Clear indications on achievement of different performance measures.
Continuous improvement	In all healthcare settings there are department meetings to check and discuss about healthcare improvements	No involvement of workforce in continuous improvement

Standardized process, such as decision flow diagrams should be utilized to minimize the movement and waiting. If the supervisor is called most of the time, the decision flow diagram needs improvement. Obviously, the 5S and SMED (single minute exchange of die) tools are also relevant, as well as root cause problem solving to eliminate the complaints.

1.2 Literature Review

1.2.1 Lean

"Lean" has been originally created and defined as the elimination of muda[3] in the book "The Machine that Changed the World" by Womack, Jones, and Roos (Womack et al. 1990). Several cases are illustrated in the sequel "Lean Thinking" (Womack and Jones, 1996). Lean focused on pinpointing the major sources of waste, and then using tools such as Just In Time (JIT), production smoothing, setup reduction and others to eliminate the waste to maximize the value-added work. One approach of lean in business improvement is a set of tools that anyone can leverage in order to improve the workplace and work process productivity. The most common lean tools are given below (Monden, 1998; Feld, 2000; Nahmias, 2001);

- Just-in-time (JIT)
- Total preventive maintenance (TPM)
- Total quality management (TQM)
- Setup time reduction
- 5S

JIT is a system where a customer initiates demand, and the demand is then transmitted backward from the final assembly all the way to raw material, thus ''pulling'' all requirements just when they are required. TPM focus is started from fixing breakdowns to preventing them. TQM is a system of continuous improvement employing participative

---

[3] Muda is Japanese term for unproductive. It is activity that is wasteful and does not add any value to the process.

management that is centered on the needs of customers. Setup time reduction is continuously tried to reduce the setup time of the proceeds. 5S uses its process to create and maintain an organized, clean, safe, and efficient setting that enables the highest level of value-added performance.

Hirano (1990) introduces 6s as:

- Sorting
- Set in Order
- Shining
- Standardizing
- Sustaining
- Standardized cleanup

Lean is not a project or an approach that includes instructions. Lean is a continuous concept that does not have an end or destination point. To implement lean and make changes happen, everybody in the organization must accept that lean is a new and a more efficient way of doing things that everyone must be involved in it. To get the maximum advantage of lean, management must be part of the change, and be involved in the monitoring of lean implementation as well as tracking company performance.

Toyota was one of the lean's pioneers that introduced the Toyota Production System (TPS) to improve the customer's values by eliminating the source of waste. Ohno (1988) began to incorporate Ford production and other techniques into TPS. Ohno identified seven sources of waste:

- Over-production
- Unnecessary motion
- Waiting time
- Conveyance
- Unnecessary processing
- Extra inventory
- Rework and scrap

Lean provides a way to make work more satisfying by converting non-value-added into value. Womack and Jones (1996) define five different ways to eliminate the waste or to convert the muda to value.

- *Specify Value:* The most important part of lean is to identify the values. Value can only be defined by the clients and it has to meet the customer's needs at a specific price at a specific time. The value could be expressed in terms of product, service or both.

- *Value Stream:* value stream is detailed action that requires a complete cycle from the time of receiving an order from the customer to the time when the finished good is delivered to the client. The next step is creating a map from the current-state map with both value-added and non-value-added.

- *Flow:* Once the specific value and the value stream have been identified and the wasteful steps eliminated, the next step is creating the flow. All the valuable steps from order taking or from the raw material to the finished product are in the hands of the customers. This is called the production flow.

- *Pull:* Traditionally and before applying lean, most companies define what their customers want or when the customers wanted based on their capacity and capability. After applying lean to a company, the company must make exactly what the customer wants just when the customer wants it, which means throwing away the sales forecast and simply producing what the customer actually requires and wants. That means the customer is pulling the product from the market.

- *Perfection:* There is no end to the process of reducing effort, space, time, cost, and mistakes while offering a product, which is ever more nearly what the customer actually wants.

1.2.2 Value stream mapping

Value stream mapping was the main tool used to identify the opportunities for various lean techniques (Abdulmaleka and Rajgopal, 2007). VSM played an important role in the service and manufacturing industries, as it served as an excellent visual tool to evaluate the value-added and non-value-added time. McDonald et al. (2002) believe VSM is prescribed as part of the lean production portfolio of tools and has been applied in a variety of industries. The VSM was a lean technique used to analyze the flow of materials and information required to complete a cycle from the time of receiving the order from the client to the time of delivering the finished goods to the client. Value-added time was considered to be any processing time that directly adds-value to the final product. Inversely, non-value-added time was defined as any time that did not add value to the finished product, such as transport time, waiting time, etc. Figure 4-1 demonstrated the common VSM icon. Building a VSM offers a detail that goes beyond the amount of information that can be obtained from any standard flow charts. The general method of application for the VSM was to first identify the job process.

1.2.2.1 Kaizen kick-off

The next step is creating the current and future-state maps. To create the current and future maps, Rother and Shook (1999) introduce the three-day VSM Kaizen events, which are as follows:

Day 1: Introduce VSM and determine the process families

Day 2: Draw the current-state map and perform the lean concepts

Day 3: Create the future-state map and develop the draft plan

- **Introduce VSM and determine the process families**

The Process family or the product family is a group of products or services to which the company has to apply the same or similar processing steps. The best way to find the process family is to create the matrix with all the process steps on the first row and all the parts or products in the first column. The process family matrix can save a great amount of time in understanding the value streams, and in showing what step on the process the manufacturer is engaged. The next step is grouping the products that have the same steps and procedures.

- **Draw the current-state map and perform the lean concepts**

The current-state map of the company illustrates how the organization performs in the current situation Walking through the organization is the next step. The purpose of the walk through is to gather more information such as

- The work process,
- The work areas within which it is performed,
- The cycle time of each process,
- Number of operators in each shift
- Inventory level
- Hardcopy and electronic information
- Instances of waste

By collecting all information, the event mission can be defined and the goals can be set. After creating the mission, the current-state map of the organization can be created as it illustrated in Figure 1-2.

- **Create the future-state map and develop the draft plan**

A future-state map is an improved version of the current-state map, with higher values added to the work content and much less waste in the material and information flow. The future-state map of the organization can be created as it illustrated in Figure 1-3.
Rother and Shook (1999) propose key questions for future-state design:

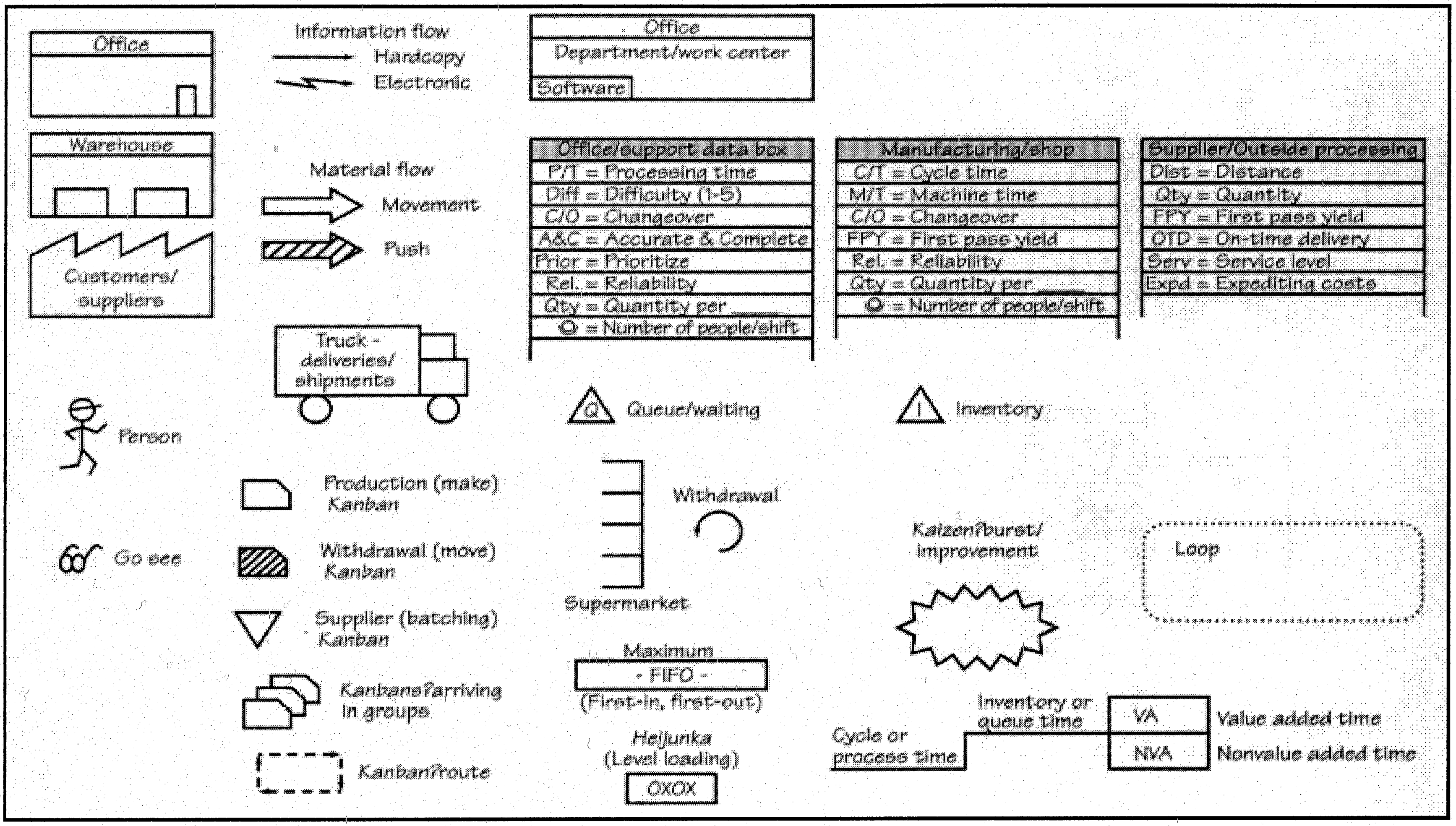

Figure 1-1: Common VSM Icon –Introduction (Manos, 2006)

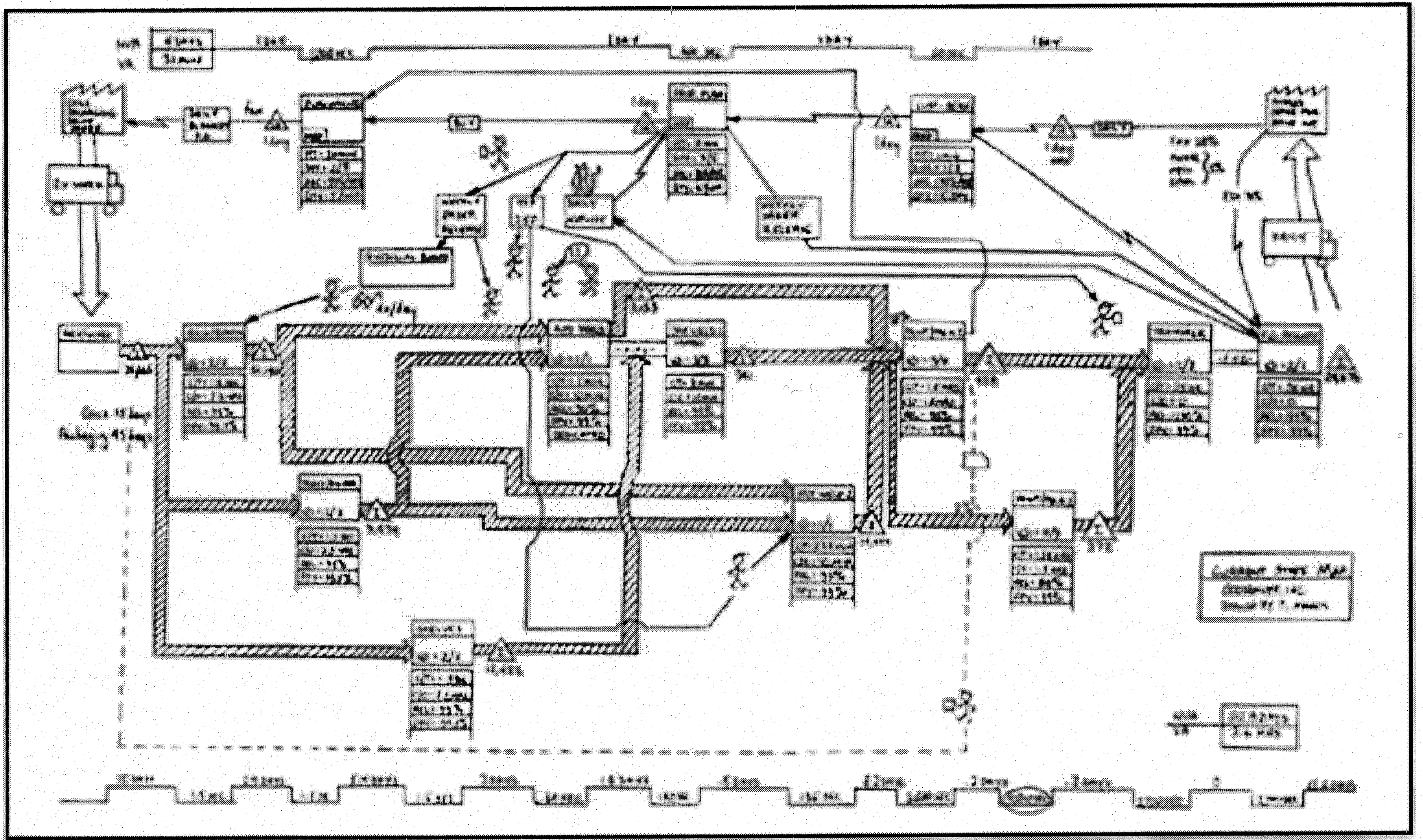

Figure 1-2: A current-state map (From VSM –Introduction (Manos, 2006)

What is Takt[4] time?

Are there bottlenecks or constraints?

Where can inventory (or queue time) be reduced?

Where can the flow be improved?

What improvements are required?

What process improvements will be necessary to have continuous improvement?

To design a future-state, Jones and Womack (2002) suggest, *"Once the current-state map is drawn, ask, which steps create value? which steps are waste? why is order flow so erratic? why is quality so erratic? why is delivery so erratic? and how can value be enhanced for the end-customer?"*

1.2.2.2 Levels of a value streams

Hines and Rich (1997) define seven levels for the VSM as follows:

- Process activity mapping
- Supply chain response matrix
- Production variety funnel
- Quality filter mapping
- Demand amplification mapping
- Decision point analysis efficiency
- Physical structure mapping

Supply chain response matrix

Beesley (1994) and Forza et al. (1993) consider the supply chain response matrix as the second level for the VSM, which is based on logistics and time compression. This matrix is a simple diagram that is based on the critical lead-time constraint for each process. This constraint can be lead-time for the suppliers.

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[4] Takt time is delivered from the German word Takzeit which means the clock cycle. In general, Takt time means the maximum time to producing a product in order to meet demand.

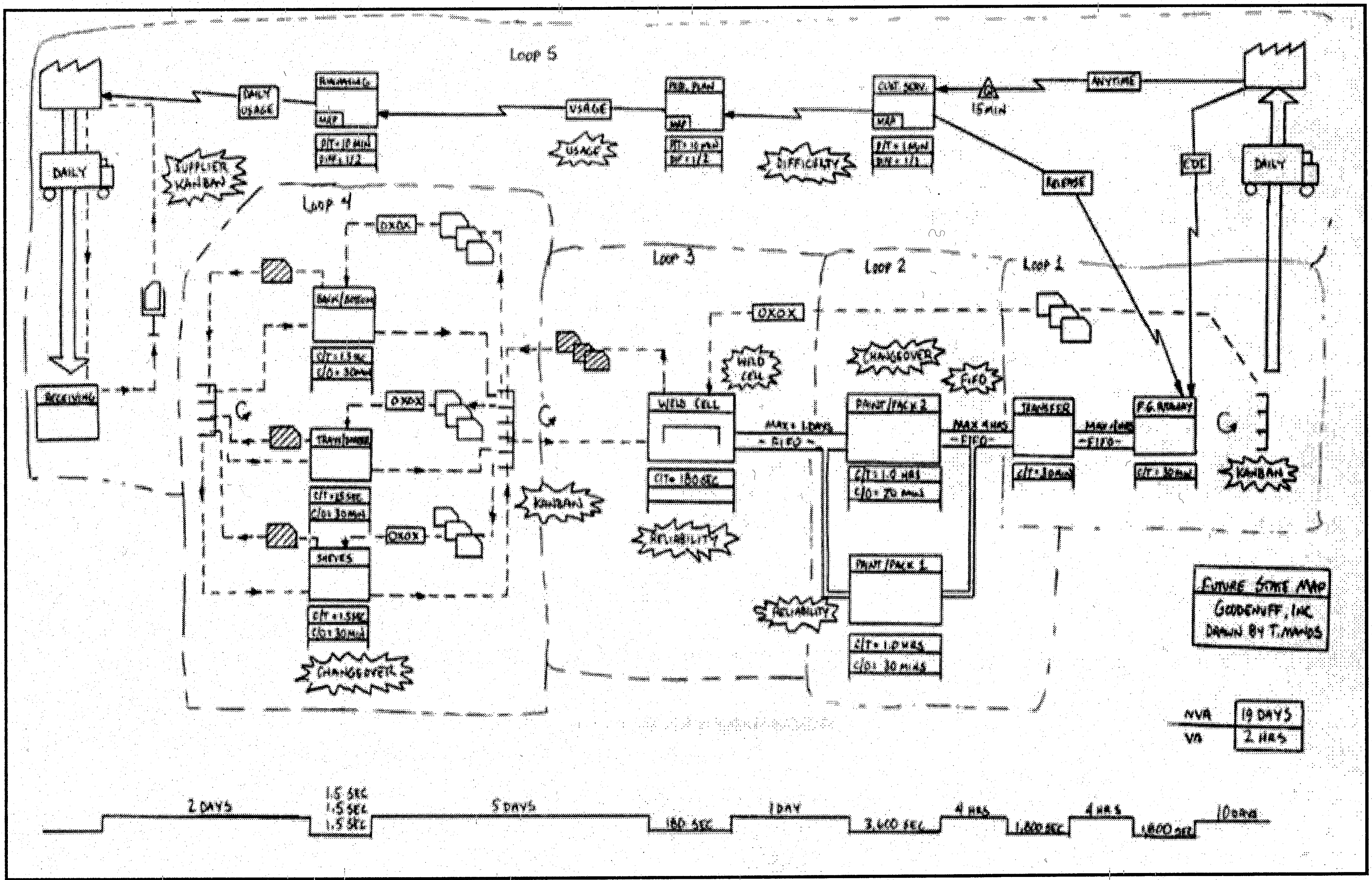

Figure 1-3: Future state map (From VSM –Introduction Manos, 2006)

Production variety funnel

New (1974) consider the production variety funnel originates in the operations management area. Macbeth and Ferguson (1994) believe that the production variety funnel is similar to IVAT analysis and helps to explain how products are produced. IVAT analysis is used to view the internal operations in companies, consisting of activities that conform to I, V, A or T shapes.

"I" plants: Unidirectional production of multiple identical items is called an "I" plants. A chemical plant is an example of an "I" plant.

"V" plants: V plants consist of a group with a few raw materials diverging into the greater group of intermediate items. The group with intermediate material then diverges into the larger group of items and so on until the final process. (e.g. metal fabrication industry)

"A" plants: A plants consist of parts that converge into a subassembly, which, in turn, converges into another subassembly and so on until the final assembly. (e.g. Assembly industry)

"T" plants consist of a large number of end items that are made from common parts. (e.g. Household appliance industry)

The Production variety funnel helps to make changes in the processing products and reduce the inventory level.

Quality filter mapping

Hines and Rich (1997) believe that the quality filters are mappings into another tool to identify the quality of the problem. There are three different types of quality defectiveness in the supply chain, which include:

- *Product defect*: when the defective goods are shipped to the customer and nobody in the assembly or the inspection line caught the problem.

- *Service defect*: Service defects occur when the customer is happy with the product but not happy with the service of the product. Shipping the product late or early is an example of a service defect.

- *Internal scrap:* when the defective goods are identified either during the assembly process or at the end of the production by the line inspectors.

Quality filter mapping tools help the company to identify the defects and discover where these problems occur in the system. Eliminating these problems could help to improve the productivity.

Demand amplification mapping

Demand amplification mapping is another tool to indicate the company how the demand shifts along the supply chain in a period of time. This information can be used in decision making while designing the value stream.

Decision point analysis efficiency

Hoekstra and Romme (1992) believe the decision point is mostly used for 'T" plants or the supply chains which make the same product. At this point products are made according to the forecast demand instead of the actual demand. The purpose of this point is to verify where the process is inclined, whether it tends to the downstream, or the upstream. The push and pull strategy could help to align the process.

Physical structure mapping

Physical structure mapping involves value stream mapping tools that indicate the broad overview regarding the industry level of the company. Physical structure mapping illustrate how the industry is structured and what developments should take place on that level. Volume structure and cost structure are two types of diagrams that can be used in this process. Volume structure diagrams can illustrate all different tiers which that exist in the supply and distribution chain, These help in understanding the entire firm in each area of the value stream. Cost structure is similar to volume structure, but it depicts the value-adding process or cost-adding process in each stage instead of capturing the number of firms involved. Pavnaskar et al. (2003) proposed another scheme of classification for lean manufacturing tools. This scheme of classification is structured around seven levels:

- System
- Object
- Operation
- Activity
- Resource
- Characteristic
- Application

Each level is linked systematically so that lean manufacturing tools and metrics, or manufacturing waste problems, are classified in a meaningful and logical way. The research and application scope increases many times as these tools can be applied individually or in combination depending upon the requirements of value streams in different areas such as manufacturing or supply-chain management. Table 1-2 guides about the areas and key contributors in context to supplier interface characteristics for different value streams.

Table 1-2: Value streams studied regarding supplier interface

Key contributors	**Area of work**
Sako (1992), Lamming (1993), Macbeth and Ferguson (1994)	Supplier relationship and number of suppliers
Womack et al. (1990), Towill (1996, 1999)	Supplier delivery lead time
Harland (1996), Lamming et al. (2000)	Bought-out components
Ohno (1988), Womack et al. (1990, 1994)	Delivery frequency
Stalk and Hout (1990), Towill (1996)	Manufacturing lead-time
Harland (1996), Lamming et al. (2000)	Customer base

1.2.2.3 Value stream management

Hines (1998) defines Value Stream Management as: "*A new strategic and operational approach to the data capture, analysis, planning, and implementation of effective change within the core cross-functional or cross-company processes required to achieve a truly lean enterprise*".

Tapping et al. (2002) describe eight steps of value stream management:

- Commit to lean
- Choose the value stream
- Learn about lean
- Map the current-state
- Determine lean metrics
- Map the future-state
- Create Kaizen plans
- Implement Kaizen plans

Value stream management is communication between the management and the shop floor. By comparing the current state map and the future-state map managements can set target goals and target dates. To achieve these goals, it is critical to have monthly meetings to monitor the process of the progress being made. Employing tools such as value stream mapping and Kaizen will also maintain the development of the future outcomes.

To evaluate potential gains and improvements, simulation model can be used. The purpose of using simulation is to verify and to validate the VSM model as discussed in the next section.

1.2.3 Simulation

Simulation is capable of generating resource requirements and performance statistics whilst remaining flexible to specific organizational details. It can be used to handle uncertainty and create dynamic views of inventory levels, lead-times, and machine utilization for different future state maps. This enables the quantification of payback derived from using the principles of lean manufacturing, and the impact of the latter on the total system. The information provided by the simulation can enable management to compare the expected performance of the lean system relative to that of the existing system it is designed to replace (Detty and Yingling, 2000), and assuming that this is significantly superior, it provides a convincing basis for the adoption of lean.

Kelton (2004) defined simulation as "a broad collection of methods and applications to mimic the behaviour of real systems, usually on a computer with appropriate software." Simulation helps in predicting the system behaviour under varying key factors. It is utilized heavily in different fields, e.g., engineering, education, manufacturing, research and development. It allows us to find out an optimum solution or optimum parameters, even at the design stage itself.

Simulation is defined as numerical technique for solving the complicated dynamical systems or probability models by imitating their behaviour using a mathematical model of the system implemented on a digital computer. Simulation is one the best method for studying complex systems where uncertainty is present. Simulation has been found to be the most frequently used tool of an operations research specialist. Computer modeling and simulation programs may eventually be used more often for industrial planning. Using simulation in manufacturing or service industry may have the general approval of facilities planners. Acceptance will be more common after simulation tools become easier to use and after the word gets around that they can make engineering and management decisions easier (Laughery, 1990).

1.2.3.1 Simulation system type

The first step in simulating the system is to check the types of the systems. Kelton (2004) described different types system .The system can be either statistic or dynamic. A static system is a system in which time is not an important factor in it, such as the Monte Carlo simulation. A dynamic system is similar to the static system where as time is an important factor. A dynamic system could be divided into two different types; discrete or continuous. In state model, changes occur at a separate point in time such as banking or machine shops. Thus, in continuous model, the state changes continuously with respect to time. Reservoir levels and chemical processes are an example of continuous models. The other classification of the system types is stochastic and deterministic. The difference between these two systems is the effect of randomness in the system. Randomness does not affect the behaviour of the deterministic system but does affect on stochastic system.

1.2.3.2 Advantages and disadvantages of simulation

Advantages of using simulation (Craig, 1996; Sadowski et al., 1998) include:

- Flexibility to applying alternative model
- Does not interrupt running system
- Does not consume resources
- Allows uncertainty, no stationary in modeling
- Advances in computing/cost ratios
- Advances in simulation software

The first advantage of simulation is that the designer can give practical feedback to the company. Simulation can allow for determination in correctness and the efficiency of the system before physically constructing the new system. On the other hand, simulation can also provide the company alternative designs or solutions. By analysing the behaviour of the designs and weighing the ramifications of each model, the best design can be elected. In reality, applying different alternative to the system is very costly and time consuming. Simulation, however, can help a designer to verify the problems in the different levels of the company. Therefore, it is better to start the simulation from the higher level. Starting from the higher level will give the designer an opportunity to understand briefly the instruction of all higher-level components in the system. Therefore, they have the capability to fix the complexity of the system. By having the knowledge from the higher-level components, the lower level components can be simulated for verification and performance evaluation. The other advantage of simulation is the way it demonstrates behaviour and relations in the system. Simulator software developers make an intelligent use of computer graphics and animations allowing them to be more visualise and understood by everybody.

Disadvantages of simulation are (Craig, 1996; Sadowski et al., 1998; McDonald et al., 2002):

- Do not get exact answers, only approximations,
- Solves only one scenario at a time,
- Time consuming and costly.

Simulation is the manipulation of a number of variables of a model indicating a real world system. Nevertheless, simulation only solves one circumstance at a time. Using a single variable often means that the reality of the system as a whole can be lost. In reality, some factors have a lot of influence on the system, but they have indistinct relations in the system that cannot be represented in a model. These factors, however, cannot be forgotten in the learning process. The other disadvantage is the fact that many people not believes on what they see, hear, or feel it. Simulation result and output is not exact because the result is in the form of a distribution. In addition, accurate simulation models is time consuming and costly.

1.2.3.3 Simulation tools

There are two types of tools, which can be used to simulate a model; it can be either simulation of languages or using the simulation graphical packages. Simulation of language means using the programming language for simulating the model. Even though using the simulation language is very flexible, it needs the professional programs to make the model as precise as possible.

A simulation package uses graphical building blocks to simulate the model. This tool uses the blocks with the parametrical values instead of using the long programming language. Graphical interface makes these simulation packages to be as easy as possible and user friendly. Arena is an example of simulation packages.

McDonald et al. (2002) believe simulation analysis is a useful and important part of VSM, but they are not proposing that simulation always be utilised with VSM, it can form an integral part of the tool set. Application of the VSM appears to be a perception within the VSM community to developing the best simulation model and not to utilize the simulation. On the other hand using simulation software, results cannot just improve the quality of solutions, but do so in a relatively short time frame (Chan, 1995; Chan and Abhary, 1996; Chan and Jiang, 1999; Mize et al., 1992; Tabucanon et al., 1998; Zahir et al., 2000).

1.2.3.4 Simulation steps

In order to have the best result for the simulation model, the following simulation process can be applied (Altiok and Melamed, 2001; Chung, 2005; Sadowski et al 1998; Ball, 1996).

- *Problem Analysis:* The first step is setting up the goals for the project and defining what needs to be solved to map the solution.
- *Information Collection:* This step involves identifying the input parameter and the performance measurements for the system.
- *Data Collection:* Data collection means collecting all kinds of data to estimate the model input parameters.
- *Model Construction:* This next step is to verify how the real system is working, as well as all the requirements, which need to develop the simulation model.
- *Model Verification:* Verification means to ensure that the model is working accurately that could be done through debugging the system.
- *Model Validation:* Validation means to verify that there is no significant difference between the real world and the simulated model that could be achieved through the statistical analysis. In general, validation means making the right model.

- *Simulation Experiments and Output Analysis:* Simulation experiments means comparing all statistical alternative models with the real systems and subsequently selecting the optimum solution.
- *Final Recommendations:* Based on results, final recommendations are made to clarify and justify the optimum result.

1.3 Objectives of the Thesis

In most previous studies, application of lean was only in manufacturing or service environments where the martial or process flow is visible. However, the challenges of applying lean principles towards a subjective set of processes were not addressed adequately. In some client-based service sectors, the job is more artistic and the procedure cannot be the same for all jobs. The variability of the clients' request, coupled with the creative thought process for completing a product is of an extremely subjective process, where there exist different methods for achieving a standard product. These kinds of jobs have too much creativity in it and employees need the environment to apply their ideas towards the job. In this kind of situations, it is not very practical to standardize each task or perform work measurement and time study that are commonly used in other processes. On the other hand, circulation of the job is through a computer, which means each person must submit the final design or retouched design to the next person through e-mail. Therefore, it is too hard to track either the process flow or the material flow. As a result the objectives of this thesis are listed below:

- Identifying the process flow,
- Finding the bottleneck station and its improvement,
- Improving the productivity by reducing the process cycle time and increasing the customer satisfaction,
- Line balancing and increasing the utilization of each process,
- Studying and designing a new work standard procedure or revising the old work standard procedure, and

- Analyzing the efficiency and reducing waste.

1.4 Organization of the Thesis

The objectives and the motivations of this study were discussed in this chapter. In Chapter 2, a case study from company XYZ is described; the company's problem is defined, and finally the methodology is introduced. Chapter 3 provides the mapping of the current-state. This mapping includes the process flow, data collection, data analysis, and VSM flow and explains extended value stream mapping. Chapter 4 presents the mapping of the future-state. It covers the development of the future state map and analysing the ideal states. Chapter 5 talks about simulation models and use of simulation to answer most of the questions, which cannot be addressed by value stream mapping. Chapter 6 provides the details of the simulation results, discussion, and analysis of this research work. In addition, improvements from every stage of the value stream mapping are compared with each other in this chapter. In Chapter 7, recommendations and concluding remarks are listed.

Chapter 2 Case Study

This chapter introduces the business partner where the study was conducted. Due to privacy and confidentiality issues, the company is referred to as XYZ. This chapter will also provide a discussion of what the problem is and how to approach it.

2.1 Introduction of XYZ

XYZ can best be described as a service company that produces innovative brand imaging solutions that help their clients achieve their own strategic business goals. XYZ specializes in two markets: packaging and advertising. Some of the world's largest companies rely on XYZ to produce quality-branding solutions to stand up to the competitive advertising world. Their services take the raw concepts from their clients and transform these into a finished product by undergoing a series of processes, including printing and plating for the construction of the product.

2.2 Problem Statement

The purpose of the study is to identify and recommend changes that would help improve XYZ's process in the packaging department using Industrial Engineering techniques. Identifying and recommending improvements in XYZ proved to have more obstacles than originally anticipated which is going to be discussed in the next page. The first step is applying lean principles to the subjective set of processes within XYZ. The variability among the request of clients in addition to the need of creative thought process makes it an extremely subjective process. There exist different methods for achieving a standard product. The initial step taken in this study was to meet and discuss with XYZ representatives. The task was to create a standard framework for this subjective process in order to indicate performance measures to help track process improvements within the system. Hence, the following issues arose:

- Unclear and ill-defined process from the beginning to the end,
- Lack of systematic knowledge to optimize the process,
- Too much delay in the system,
- Too much redundancy and lack of efficiency in the system,
- Ill-defined procedures and lack of systematic approach that causes back and forth flow in the system,
- Lack of customer satisfaction due to inability to deliver on time, and
- Lack of balance in operation and poor utilization of resources.

2.3 Solution Approach

In order to solve the problem and achieve the objectives, the primary action was to understand the workflow from start to finish, with the aid of management. As the first step, VSM needed to be applied to all processes within XYZ that would show the big picture to everyone involved. In fact, VSM helps everyone to understand the process flow, responsibilities, and the process time. In addition, VSM highlights the areas which require improvements. The next step was to apply a simulation model to ensure that the VSM findings are accurate and to find other potential areas of improvement. Since the process varied from client to client, it was challenging to design a single flow to represent the work within XYZ in the optimum form. Therefore, it was decided later that two distinct flows would be better suited to capture the processes. Based on each process flow, standard performance measures and an analysis of operator workflows were established in order to perform lean improvements. The next section describes the methodology that has been used to tackle the stated problem.

2.4 Methodology

This study utilizes several Industrial Engineering methods to identify and measure XYZ's retail packaging process. These methods allow for the collection of relevant data to be served as the basis for the analysis. These methods entail creating a process flow, conducting interviews, collecting processing time via timesheets, obtaining data from XYZ Link[5] and creating a VSM. Each of the above will be discussed in detail.

2.4.1 XYZ process flow

The study started with descriptions of the target work process. The descriptions had two components: (1) an overview that captures the purpose of the work process flow from the raw concepts to a finished product and certain details about it (e.g., inputs, outputs, departments with which it coordinates); and (2) a process flow map that highlights the sequence of operations that executed it. The initial process flow has been developed through a series of meeting with management (Figure 2-1). The first process flow contains the following elements:

- Clients:
  - Sending the designs scope and initial design of product to XYZ,
- Account manager/Customer Service Representative (CSR) :
  - Dealing with clients regarding cost, projects deadline, project properties,
  - Distributing the job between operators in team-based process or sending the job to the foreman for non-team-based process,
  - Final quality control.
- Foreman:
  - Scheduling the operators,
  - Distributing the job between operators (in non-team-based process).
- Operator:
  - Designing the files,
  - Preps the products,

[5] XYZ Link: XYZ software data base contains employee's schedules, the number and name of the employee who is working on each job, the duration of each job, the time that each employee spends on each task, the number of replications of each job, complete details of each order, the task on each order and the total cost

- o Quality check,
- o Proofreading

The early work process map was shown to the management team for approval, and necessary corrections were made. Based on their opinions, the study was divided into two categories:

- Team-based (which was originally known as Corporate),
- Non-team-based (originally known as Non-corporate).

Once the process flow for each stream was finalized, interviews were conducted with the personnel that worked on the production floor. Each job position that touched the product was interviewed to obtain a more detailed understanding of the flow and identify opportunities for improvement. Once completed, these interviews provided a new outlook on the overall process flow; hence, more process flows were generated. The process flows for Team-based (Figure 2-2) and non-team-based (Figure 2-3) were revised four times until the final process flows were formed and accepted by management.

2.4.2 Interviews

The work process was closely observed by focusing on and understanding the process from beginning to end. Some observations were made by asking questions and making notes of what account managers, operators, CSR's, and foremen pointed out. After the walk through, informal personal interviews were conducted from each employee (5 CSR, 3 Foreman, 3 Proofreaders and 9 operators in assembly department) in order to gather perception regarding the work process, understand the process, and understand the potential elements of waste in the process and ways to eliminate it. Informal interviews helped to better understand the role and the responsibility of each employee in process. In addition, it helped to realize where/who the job is coming from and where/ who the job going to next. It is concluded that personal informal interviews for gathering workers' judgments had a better outcome than asking the questions during the walk through.

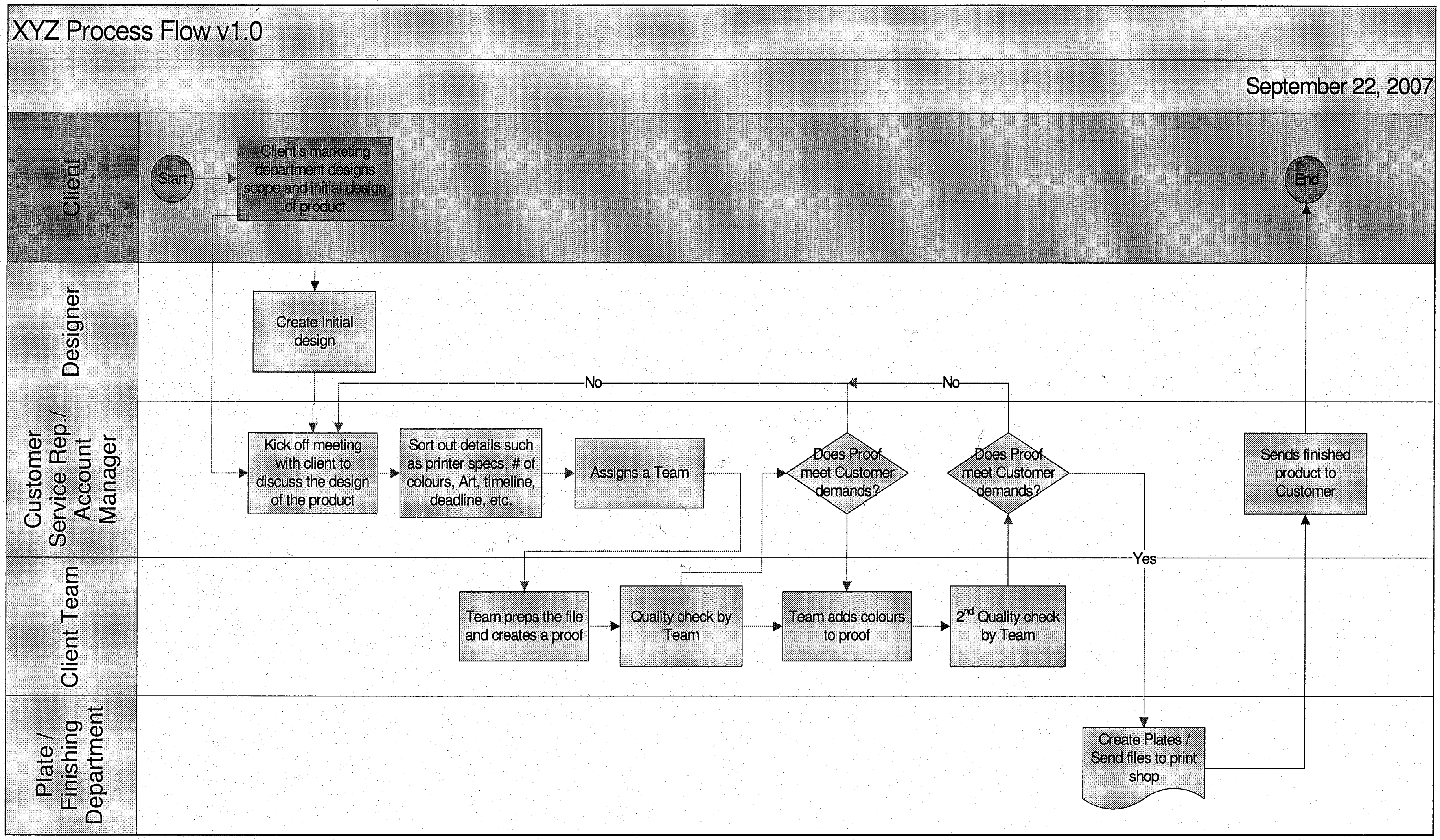

Figure 2-1: XYZ corporate process (team-based process flow)

By interviewing employees, it was also found that there were no standard procedures for each task, and, therefore, the work-order needed to go through several iterations, back and forth between different departments, until the final desired outcome was achieved. Operators' comments brought up the fact that the work-orders were not standardized, which caused them to misunderstand and be unclear about the actual work that needed to be done. Once the interviews were concluded, the data showed inconsistency between what management perceived of the workflow, and what the production floor personnel perceived to be the process flow. These interviews demonstrated more detail about both team-based and non-team-based processes, which are going to be discussed.

Team-based process: The team-based process always starts from account manager task. The account manager filters all incoming files and ensures that they are complete, and then sends them to the CSR for creating pre-flight. Any incomplete file is filtered back to the client for revision. CSR creates pre-flight documentations based on client files and sends them to the operators for assessment. The operators complete the assessment, then send the files back to the CSR. The CSR then sends the pre-fight to the client for approval. The next step is having the kick-off meeting, which involves the CSR, account manager and client to discuss timelines, costs, deadlines and other details for the product. The CSR creates a work-order outlining the precise client requirements for the product. The operator preps the product and converts the file using the illustrator programs. The product is sent to the colour department for colouring after the first quality check, which is performed by the same assembly operator. The product is then given back to the CSR to assign another operator to perform the second quality check. After the second quality check, the product is given back to the CSR, who hands it off to the proofreading department. The proofreader checks the clayture, architecture, and typography of the product according to ISO standards. Any discrepancies are handed back to the CSR. They send the product to the client for final approval. If the client is unsatisfied with the results, the process will start from the beginning. The product (soft copy), proof, and the plates are sent to the client or printer.

Non-team-based process: Team-based and non-team-based processes are identical up to the point that the CSR creates the work-order. In the non-team-based process, the work-order is handed over to the foreman to assess the job and assign it to an operator, based on job complexity, priority, and operator availability. The operators are responsible to prep the product, convert the file using the illustrator program and do the first quality check on the product. The product will be sent to the foreman to be assigned to another operator to perform a second quality check. After completing the second quality check, the product is given back to the foreman to hand it off to the proofreading department. The proofreader checks the clayture, architecture, and typography of the product according to ISO standards; any discrepancies are handed back to the foreman in order to be returned to the CSR. The CSR sends the final product to the client for further approval.

In addition, the employees' points of view were helpful to define the complete process flow. The next step was to identify the elements of the waste and the bottleneck stations in the process. Timesheets were created to collect all data relating to the current-state processing times of each task.

2.4.3 Timesheets

To measure the current-state process of a docket (a single job), a timesheet was developed to identify starting time, handoff time, duration of each task, period of time that the job is idle and nobody is working on it, operator's feedback and so forth. These would serve as the main performance measures to determine system efficiency. A timesheet was attached to each docket and any personnel that worked on the docket would sign off and write the specific heading details on the timesheet. The information would yield the value-added time (the time the production personnel performed changes to the docket) as well as the non-value-added time (the time the docket spent in transport, waiting to be picked up, etc.). This non-value-added time produced waste in the system's efficiency that could be tightened up to increase productivity potential.

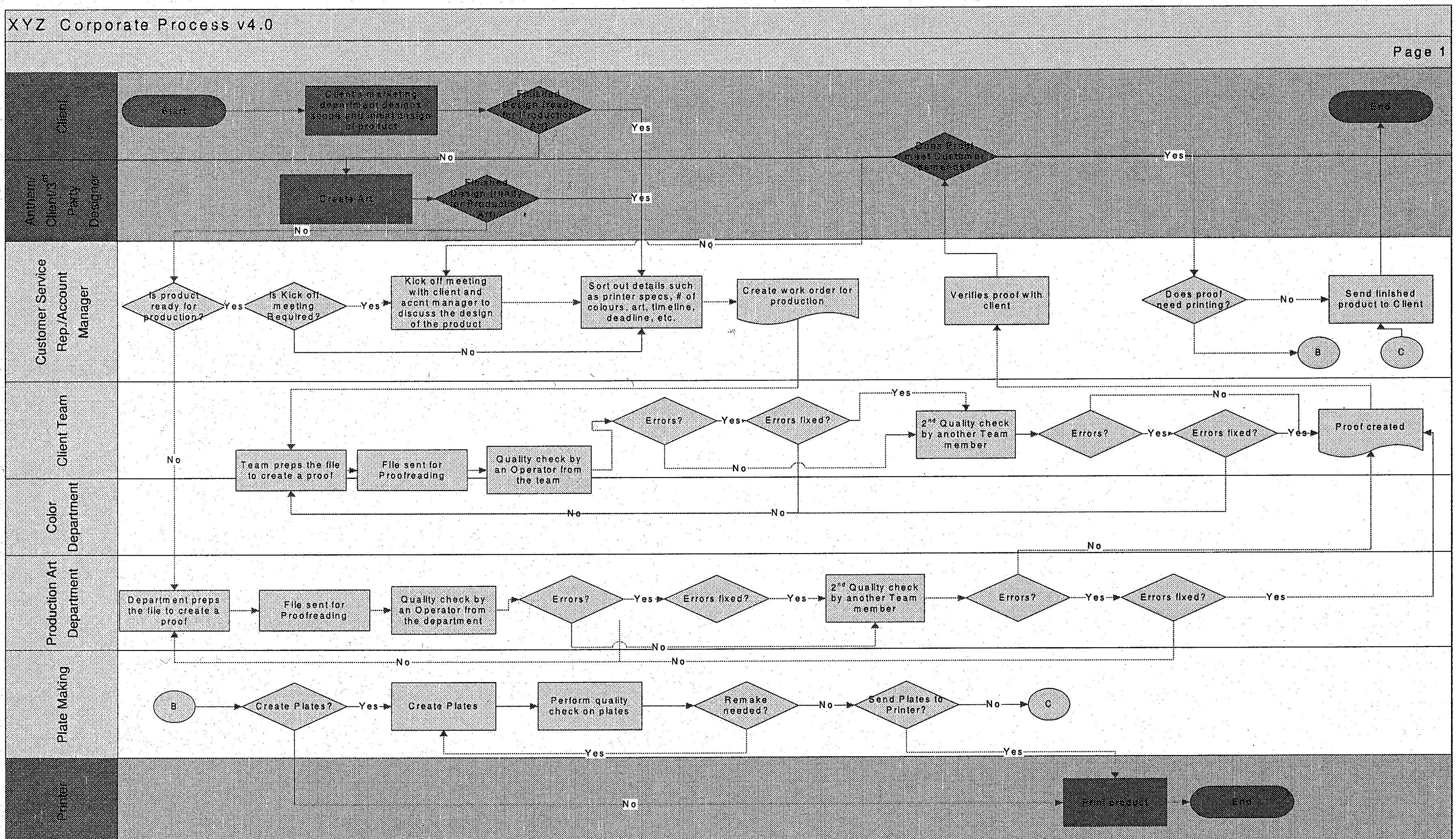

Figure 2-2: XYZ corporate process (team-based process flow)

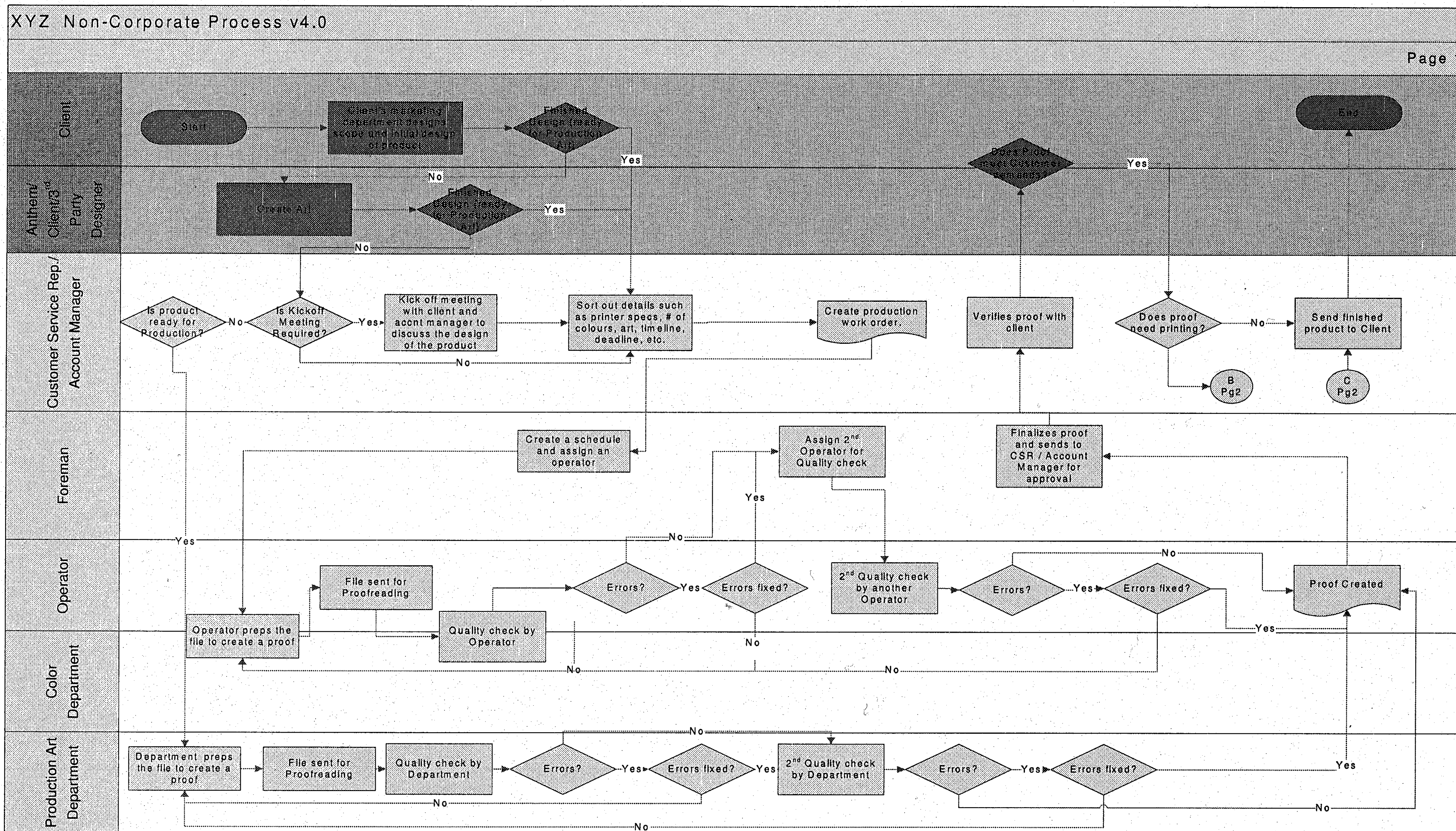

Figure 2-3: XYZ non-corporate process (non-team-based process flow)

The timesheet focused on qualitative data, such as the task involved in an attempt, to categorize the tasks better. The timesheet focused on involving the operator's feedback into the analysis of the collected time. However, the initial form proved to be too complex, and another approach was undertaken to achieve data that is more concise.

The data from new timesheets (Appendix D) yielded an improved output; the employees were able to fill out the forms with the information that was requested. They also produced the quantitative data that was needed for the analysis of the project. Once the timesheets were attached to the work-orders and distributed to the production floor, the employees filled in their tasks and the amount of time spent on each job. In order to validate these findings, data from XYZ Link was compared to the timesheet that employees filled out. Any discrepancies were flagged and were examined later.

2.4.4 XYZ Link

XYZ Link is a software application that is available at the company and it is used to calculate working hours and pay for each employee. In addition it records the duration of each process, the time that each employee spend on each task, the number of revisions of each job and it contains the employee schedule, complete details of each order, the task on each order and the total cost. In order to verify the data obtained from the timesheet, chronological information from XYZ Link was used to ensure that the data on the timesheets were completed at every touch point. This was a crucial step; several inconsistencies were later found that reduced the number of acceptable work-orders. Only work-orders that had matching timesheets and XYZ Link data were used to develop the VSMs. XYZ Link provided the duration of time spent on a particular task e.g. (0.2 hours), and in some cases the actual working times e.g. (17.5 - 18.3). Each line on the timesheets was compared with XYZ Link to verify that the time stamps were correct. The data were compiled into the VSM to obtain the value and non-value-added times, which laid the foundation for the present state and future-state VSM's.

2.4.5 Value stream mapping

The Value Stream Map (VSM) plays an important role in the study as it serves as an excellent visual tool to evaluate value-added and non-value-added time. The VSM is a lean technique that is used to analyze the flow of materials and information required to complete a work-order and deliver the finished goods to the client. Value-added time is considered to be any processing time that directly adds value to the final product. It is categorized as any number of tasks including adding a die line, proofreading, completing a pre-flight, etc. Inversely, non-value-added time is defined as any time that does not add value to the finished product, such as transport time, waiting time, etc. The general method of application for the VSM is to first identify the process to be studied. Once the process is identified, time studies are used to determine the Takt time for a work-order. To gather data for the time studies, timesheets were attached to the work-order and all personnel that 'touched' the work-order were required to document their times and tasks. This data led to the current-state map for the VSM, which provides an overall idea for the production time of one work-order. The current-state maps also allows for the hypothesized development of a future-state map, where certain processing scenarios could be reallocated to eliminate or decrease the production time.

After collecting data from all sources, the next step is to map the current-state in order to calculate all value-added and non-value-added time. This step will be discussed in the next chapter.

Chapter 3 Mapping the Current State

This chapter is about mapping the current-state, which represents the value stream of the company as it is today. VSM is used to identify the processes and set in value-added and non-value-added times. From the knowledge obtained through the interviews and the finalized process flows, a 'map' is created that outlines the general procedural flow that any given docket follows. The systematic approach to mapping the current-state follows three steps that are discussed in this chapter:

- Data collection and analysis
- VSM flow
- Value stream map

3.1 Data Collection and Analysis

Since the criterion of each job is imaginative and artistic, the information and time studies cannot be collected by walking through the process from the account manager's end to the customer's end. Therefore, time sheets are created in order to gather the data. The timesheets are created for two different reasons. The first reason is a qualitative aspect to find more details about each task that every operator is working on, and secondly, it is necessary to measure the time during which each process takes place and the time between each two consecutive tasks. The first timesheet provided less desirable quantitative information than expected; hence, the second timesheet was created. The purpose of the second timesheet is to record the touch times by each person to determine the non-processing time. The timesheet is attached to the work-order in each docket and starting to record data from the point when the CSR creates the work-order until the job is finished and it is ready to be sent to clients. All employees should fill in their tasks and the amount of time spent on the job plus the time it takes to hand the docket to the next person. In order to validate these findings, data from XYZ Link is compared to the timesheets that employees have filled out. This data is verified with the time stamps from XYZ Link later to find cases of inconsistent data. There are cases where the employee enters hours worked into XYZ Link but not on the timesheets, and vice versa. However, the data obtained through XYZ Link proved to be unreliable due to the fact that employees only record the duration of their work, and not the actual hours worked. Work durations are helpful to identify value-added time; however, the non-value-added time or the amount of time that the work-order spent in transit, and waited to be picked up is unknown. Therefore, the completed timesheets are divided into two categories.

The first category is composed of all the data that is used to develop the VSMs. This data consists of all the information that is correctly filled out with valid time stamps and is validated by data collected from XYZ Link. The second category consists of all data that did not fit the criteria needed for the VSM. This data is not included on the VSM because the employees produce incomplete timesheets that cannot be validated by XYZ Link.

Out of 45 time sheets received, 29 had some data. From those 29, 14 time sheets are used for the VSM, and 15 time sheets are unusable because of the lack proper data. Any discrepancies are flagged and examined at a later day.

The next stage is to create the summary sheet for all the collected data. The summary sheets are divided into categories of team-based and non-team-based. The next step is to identify the value-added and non-value-added times for each category. The value-added time is derived from the timesheets and XYZ Link, whereas the non-value-added time is calculated from the timesheets. The non-value-added time is calculated in two ways: the hand-off time from one person to another and the time between receiving the job and the actual start time. When calculating the value-added and non-value-added time for each work-order in each category, the average non-value-added time in the team-based category is found to be 116 hours and 58 minutes. Moreover, the non-value-added time in the non-team-based category is calculated to be 240 hours and 59 minutes, which is more than double the value of the non-value-added time that is found in the team-based category (Table 3-1 and Table 3-2). In general, for team-based and non-team-based, the percentages of the non-value-added time verses the total time are 85% and 95% respectively.

Table 3-1: Total value-added and non-value-added time

Item	Team-based	Non-team-based
Total value-added (min)	6085	7799
Total non-value-added (min)	35094	14639
Average non-value-added (min)	7019	14460
Percentage of non-value-added	85.2 %	94.8 %

3.2 VSM Flow

The first stage of the analysis involves organizing the data from the timesheets. This data is transferred into Excel®. This step involves analysing XYZ's process flow. In each timesheet there is a column entitled "Who is the job going to next?" By using that column, the process flow for each work-order can be found. Meanwhile, by gathering all the common process flow in each work-order, the complete VSM process flow for the company for team-based and non-team-based could be finalized as shown in Figure 3-1 and Figure 3-2.

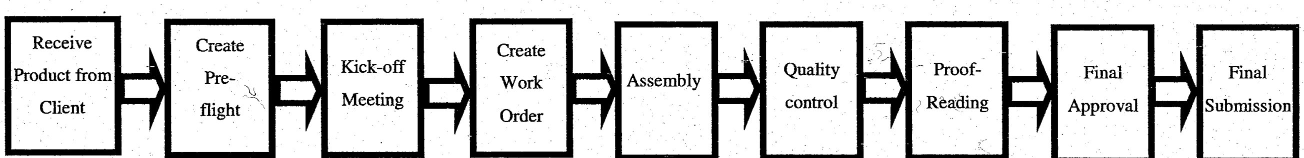

Figure 3-1: VSM flow for team-base process

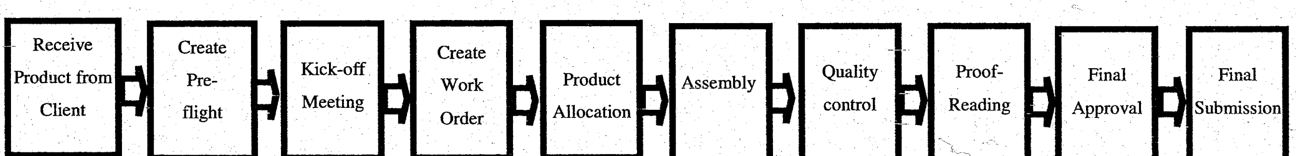

Figure 3-2: VSM flow for non-team-base process

Table 3-2: Value-added and non-value-added for all work-orders

Team Based

Client	ABC	ABC	ABC	ABC	ABC				Total
Work Order	877673*	877755*	877757*	878601	878604				
NVA	298:52:00	127:31:00	133:38:00	7:12:00	17:41:00				584:54:00
VA	38:42:00	26:38:00	30:12:00	1:13:00	4:40:00				101:25:00
Sum	337:34:00	154:09:00	163:50:00	8:25:00	22:21:00				686:19:00
Percentage of of Non-value-added	88.54%	82.72%	81.57%	85.54%	79.12%				85.22%

Non-Team Based

Client	BAA	SAA	SAA	SAA	SAA	SAA	SAA	CAA	BAA	MAA	Total
Work Order	877305	877584	877053	877646	877049	877537	877644	877330	877645	878568	
NVA	336:21:00	238:38:00	322:02:00	245:41:00	281:28:00	382:42:00	369:15:00	9:22:00	186:19:00	38:10:00	2409:58:00
VA	10:54:00	26:32:00	8:58:00	20:12:00	12:23:00	10:38:00	10:58:00	11:01:00	5:26:00	12:57:00	129:59:00
Sum	347:15:00	265:10:00	331:00:00	265:53:00	293:51:00	393:20:00	380:13:00	20:23:00	191:45:00	51:07:00	2539:57:00
Percentage of of Non-value-added	96.86%	89.99%	97.29%	92.40%	95.79%	97.30%	97.12%	45.95%	97.17%	74.67%	94.88%

Average Non-Value Added for Team Based	116:58:48
Average Non-Value Added for Non-Team Based	240:59:48

3.3 Value Stream Mapping

In order to create the value stream map, all the value-added time and non-value-added time for each task is calculated. However, due to the complexity of the current procedures, there is a significant amount of backtracking in the processes. Therefore, the VSM only considers the data that is related to the general process. Backtracking is not included in the VSM (i.e. proofreading to operator) and it is allocated to a separate section labelled "Unknown". By inputting all the values that are related to the general path in the VSM shell, the average non-value-added time and the value-added time for each task are calculated. Figure 3-3 and Figure 3-4 show the current-state map for both team-based and non-team-based processes that are constructed. The small boxes in the map represent the process and the big boxes underneath of them represent the description of each task. In addition, each process has a data box below it, which contains the process cycle time (value-added time). In addition, between each two processes there is a data arrow bar, which represents the production waiting time (non-value-added time) between each two processes. For example, the average process time for CSR to create the work-order in the team-based category is 94 minutes and the average waiting time after creating the work-order until the operator starts to work on it, is 5 hours and 58 minutes. Thus, the average lead-time for a team-based process is around 8 hours and 7 minutes and for a non-team-based category is around 7 hours and 7 minutes. The average non-value-added time for the entire team-based process is 35 hours and 56 minutes. However, the non-value-added time for the non-team-based is 108 hours and 51 minutes; this works out to 11% of the total production lead-time for team-based and 2% of the lead time for non-team-based. Table 3-3 and Table 3-4 illustrate key indicators for the value-added and non value-added time for both the team-based and non-team-based categories on the current-state.

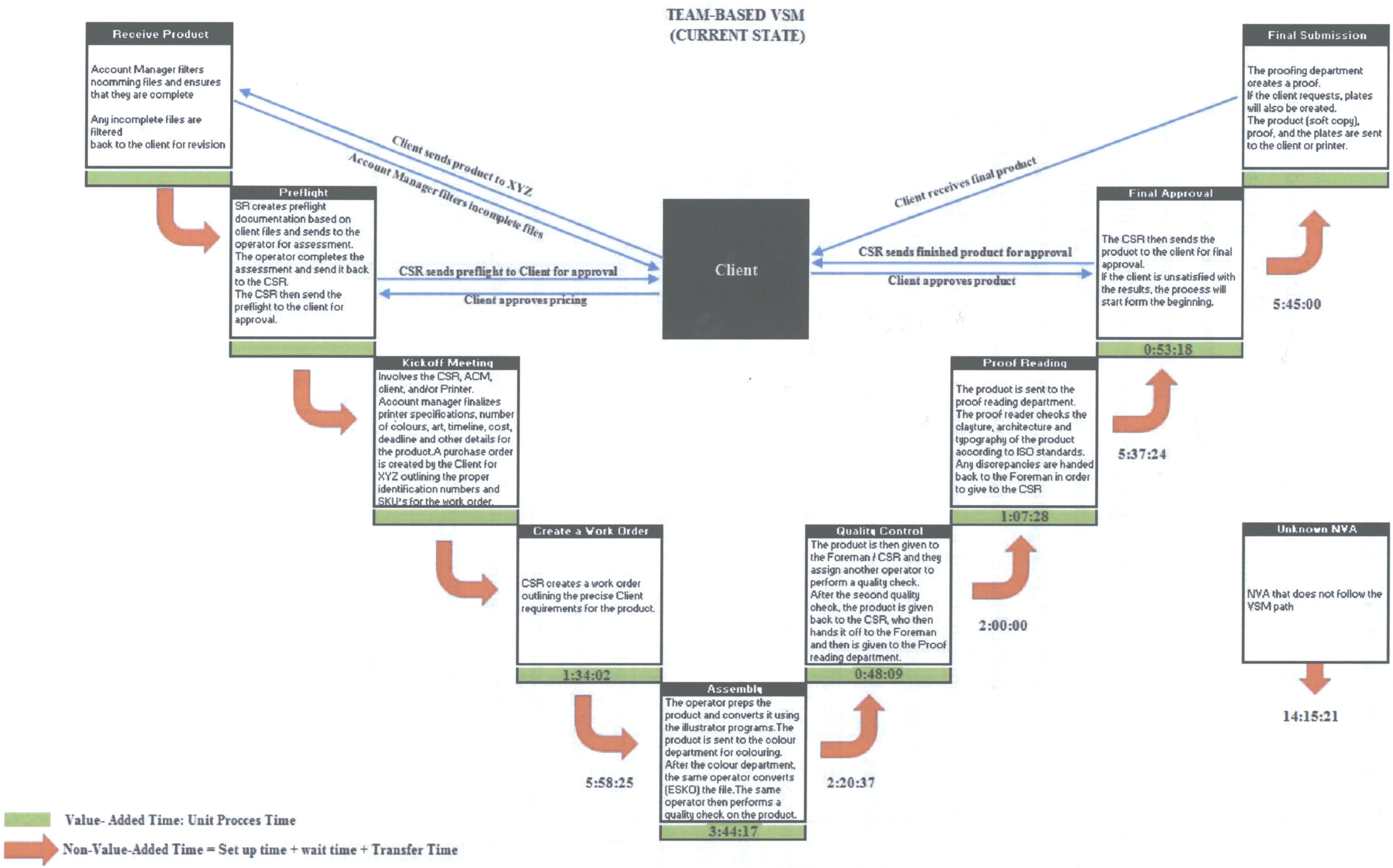

Figure 3-3: VSM for team-based (current-state)

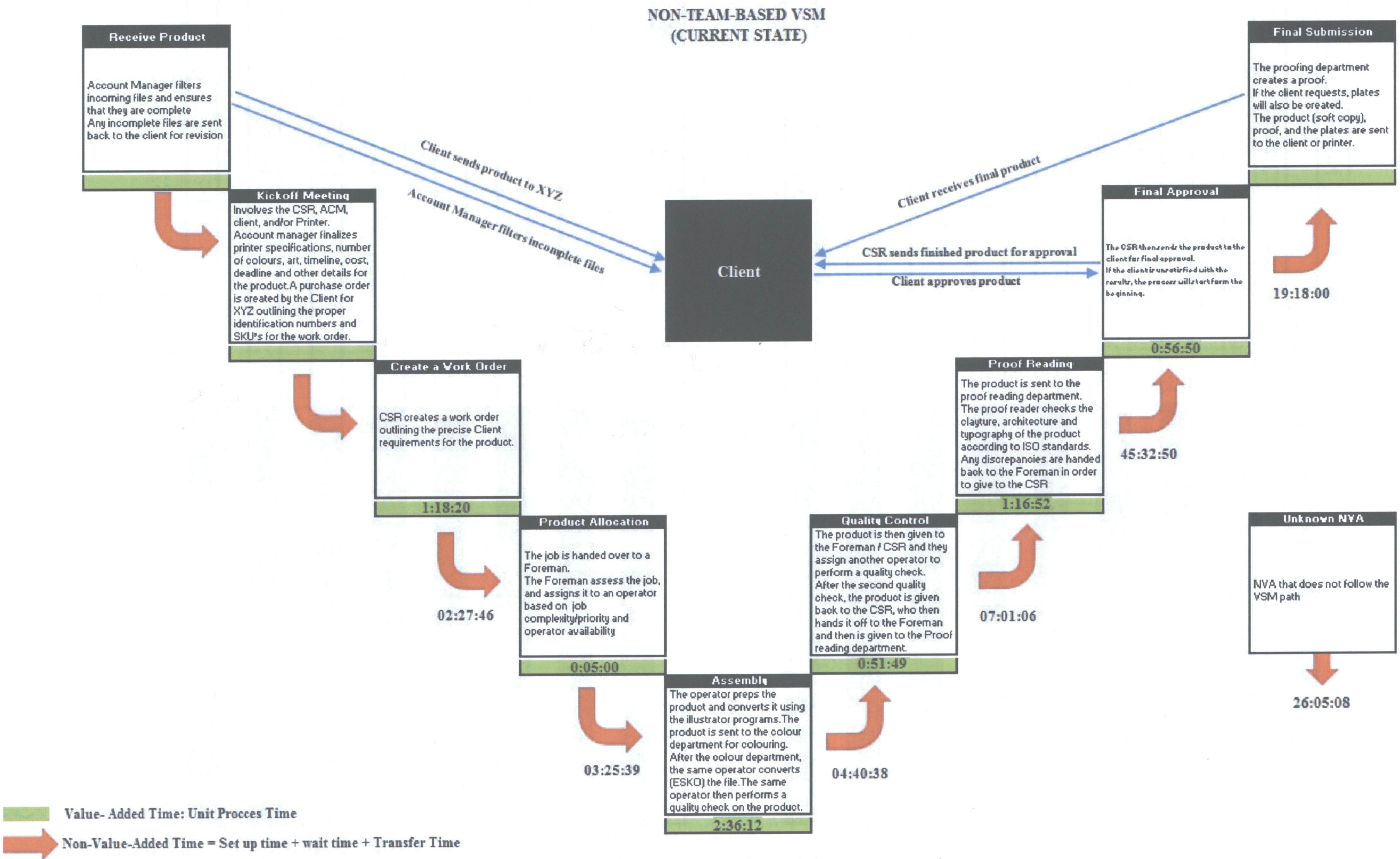

Figure 3-4: VSM for non-team-based (current-state)

Table 3-3: VSM summery for non-team-based

	Value-added	Non-value-added
Create a Work Order	1:18:20	
		2:47:26
Product Allocation	0:05:00	
		3:25:39
Assembly	2:36:12	
		4:40:38
Quality Control	0:51:49	
		7:01:36
Proofreading	1:16:52	
		45:32:50
Final Approval	0:56:50	
		19:18:00
Unknown Non-value-added		26:05:08
Total	7:07:52	108:51:17
Percentage of non-value-added	93%	

Table 3-4: VSM summery for team-based

	Value-added	Non-value-added
Create a Work Order	1:34:02	
		5:58:25
Assembly	3:44:17	
		2:20:37
Quality control	0:48:09	
		2:00:00
Proofreading	1:07:28	
		5:37:24
Final Approval	0:53:18	
		5:45:00
Unknown Non-value-added		14:15:21
Total	8:07:14	35:56:47
Percentage of non-value-added	81%	

By looking over the current-state map VSM, several factors can be identified and are listed below:

- The difference between the total production lead time (36 hours) and the value-added time (8 hours) is fewer than 19% of the total time for team-based. The difference between the total production lead-time (108 hours) and the value-added time (7 hours) is fewer than 6% of the total time for non-team-based category.
- QC2 and proofreading tasks deal with the quality of the product.
- The average non-value-added time in the non-team-based category is more than double the value of the average non-value-added time in the team-based category.
- There is a large amount of non-value-added time between each station.
- CSR must wait for client to respond, this may be a lengthy process.

The first step to create the ideal future-state map is to identify lean manufacturing tools, by looking at the schedule across the entire value stream. Therefore, the following scenarios can be considered which will be discussed in detail in the next chapter:

- Scenario A: Redefining the Quality Control department
- Scenario B: Redefining the foreman task
    - Scenario B.1: Eliminating the foreman task
    - Scenario B.2: Reallocating the foreman and introducing a planner
- Scenario C: Redefining the Quality Control department and eliminating the foreman task

Table 3-5: All different scenarios and their involved elements

	CSR	Foreman	Planner	Assembly	QC2	Proofreading	Quality Control Department
Base-case	✓	✓	-	✓	✓	✓	-
Scenario A	✓	✓	-	✓	-	-	✓
Scenario B.1	✓	-	-	✓	✓	✓	-
Scenario B.2	✓	-	✓	✓	✓	✓	-
Scenario C	✓	-	-	✓	-	-	✓

Chapter 4 Mapping the Future State

4.1 Development of the Future State Map

A future-state map is an improved version of a current-state map. The first step in creating the future-state map is to identify the elements of waste in the current-state map:

- Waiting: due to unbalanced working stations, operators have to wait to receive the job from the previous operators.
- Unutilized processes: to improve the utilization of the workers and the work processes, some steps such as quality control and proofreading must be combined.
- Unnecessary processes: due to various delays in the system, unreliable and unnecessary steps must be revised or eliminated.
- Unnecessary transportation: due to the push system, jobs are moved within and between different stations. Every additional movement of parts involves double handling, which causes waste.

The next step is to follow a systematic procedure where the structured questions can be answered; this allows one to come up with an ideal future-state map that would help to eliminate or at least reduce different types of waste in the current service system.

1. What is the Takt time?

   Takt time refers to the rate which customers receive the product from the company. The unit production rate is needed to match customer's requirements. It is calculated by dividing the total available time per day by the daily customer demand. The average customer demand is 47 orders per month for team-based and 73 orders per month for non-team-based. XYZ continuously runs for 10 hours per day, which translates to 200 working hours per month, so that the Takt time is approximately (200/47) 4.26 hour per order for team-based and (200/73) 2.74 hour per order for non-team-based category.

2. Is there any bottleneck or constrain?

   In this system, the foreman position creates too much delay in the system. Therefore, the foreman position could be called as a bottleneck station.

3. Where the inventory (or queue time) can be reduced?

   The queue time in the system could be reduced through having the standard processing flow and by utilizing all stations. In this case, the process could be utilized by creating a Quality Control department. The Quality Control department will be responsible for both proofreading and controlling the quality of each job.

4. Where the flow can be improved?

   The flow can be improved through having unique process flow, standard working procedures for each station, and having the standard work-orders and standard pre-flights.

5. What improvements are required?

   Service Level Agreement (SLA), which is a contract between clients and XYZ, is required to improve the process. The SLA addresses the conditions for quality of the services, such as response time, availability, and timelines. After reviewing all the worksheets, it is found out that the waiting time for a client to get an approval for the job from the CSR is rather lengthy. In fact, the job shows as being in process, but is not being worked on by anyone. Therefore, by having SLA, the production time of the process could be improved and eliminate some of the non-value-added time of the process.

6. What process improvements will be necessary to have improvement?

   The following are some of the improvements required to reach the future-state:

   - Reduction in change-over time, reworks, defects, and total delays at the foreman station.

- Elimination of waste in Assembly Line, Quality Control, Proofreading, and CSR departments by creating the standard working procedure.
- Reduction of the process cycle time and total work content.
- Elimination of waste by replacing planner instead of foreman.
- Standardization of the pre-flight

4.2 Value Stream Mapping

Since the goal is to identify the potential dynamic gains from implementing lean and to develop a desirable future-state map, four scenarios are going to introduce that can be quantified and modeled objectively. In this section, each of these scenarios will be explained in detail.

4.2.1 Scenario A

The first potential development for improving the process time in each job would be to combine the Quality Control and Proofreading departments. Since both of these tasks deal with the quality of the product to ensure that there are no errors, they complement each other. With the combined department, processing time for the team-based would yield a 5% pessimistic case improvement as illustrated in Table 4-1. Pessimistic case means all the data in the "Unknown" block, which was the combination of value-added time and non-value-added time, was considered as the non-value-added time so there is no value-added time in the "Unknown" block. On the other hand, with the combined department, processing time for the team-based would yield a 46% optimistic case improvement as illustrated in Table 4-2. Optimistic case means, all the data in the "Unknown" block, was considered as the value added time, which added the value to the whole process. Similarly, the improvement with a non-team-based scenario would yield 6% as shown in Table 4-3 for a pessimistic case and 35% for the optimistic case as illustrated in Table 4-4Both proofreading and quality control are also performed toward the end of the set of tasks needed to finalize the docket before the CSR submits it to the client. The formation of the new Quality Control department, which encompasses second quality check and proofreading, allows for better utilization of employees through cross-training and job rotation. In addition, to improved process times, this department provides a better level of accountability as all dockets will be processed through this department. A task for the continuous improvement office team could be the evaluation of the feasibility of having the work-order proofread at the initial stages of production. This would not only identify the client and XYZ errors, but also prevent the errors from traveling through the production line, thereby eliminating the unnecessary time and cost of rework. Hence, the Quality Control department has the potential to improve quality, accountability, personnel utilization, and processing time. Figure 4-1 to Figure 4-4 illustrated the VSM for both team-based and non-team-based category for pessimistic and optimistic cases.

Table 4-1: VSM summery for team-based category with redefining the Quality Control department (pessimistic case)

	Value-added time	Non-value-added time
Create a Work Order	1:34:02	
		5:58:25
Assembly	3:44:17	
		2:20:37
Quality Control Department	1:55:37	
		5:37:24
Final Approval	0:53:18	
		5:37:24
Unknown Non-value-added		14:15:21
Total	8:07:14	33:56:47
Improvement Percentage :	5.6 %	

Table 4-2: VSM summery for team-based category with redefining the Quality Control department (optimistic case)

	Value-added time	Non-value-added time
Create a Work Order	1:34:02	
		5:58:25
Assembly	3:44:17	
		2:20:37
Quality Control Department	1:55:37	
		5:37:24
Final Approval	0:53:18	
Total	8:07:14	19:41:26
Improvement Percentage :	45.3 %	

Table 4-3: VSM summary for non-team-based category with redefining the Quality Control department (pessimistic case)

	Value-added time	Non-value-added time
Create a Work Order	1:18:20	
		2:47:26
Product Allocation	0:05:00	
		3:25:39
Assembly	2:36:12	
		4:40:38
Quality Control Department	2:08:41	
		45:32:50
Final Approval	0:56:50	
		19:18:00
Unknown Non-value-added		26:05:08
Total	7:07:52	101:49:41
Improvement Percentage :	% 6.5	

Table 4-4: VSM summary for non-team-based category with redefining the Quality Control department (optimistic case)

	Value-added time	Non-value-added time
Create a Work Order	1:18:20	
		2:47:26
Product Allocation	0:05:00	
		3:25:39
Assembly	2:36:12	
		4:40:38
Quality Control Department	2:08:41	
		45:32:50
Final Approval	0:56:50	
		19:18:00
Final Submission		
Total	7:07:52	75:44:33
Improvement Percentage :	30.5 %	

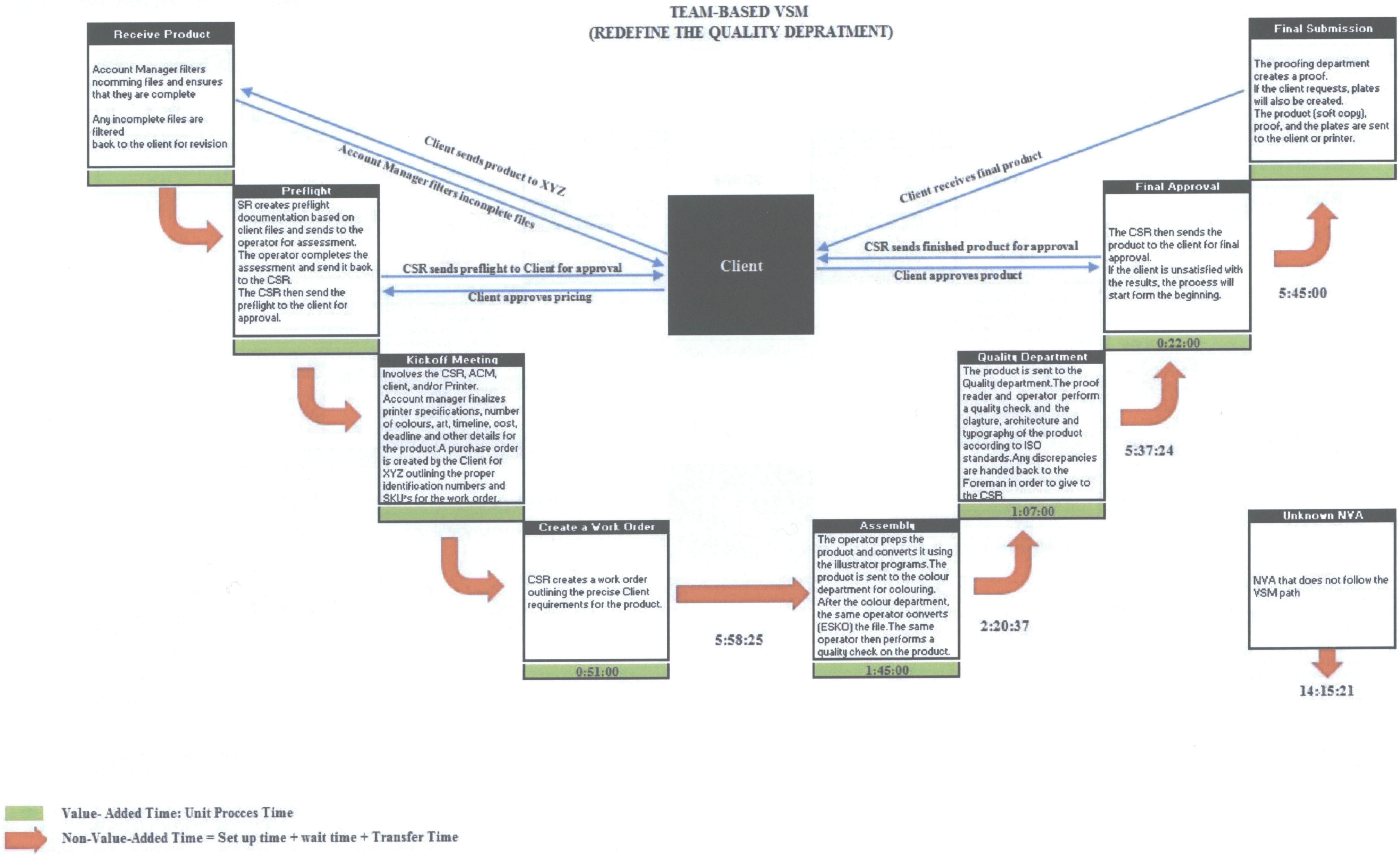

Figure 4-1: VSM for team-based category with redefining the Quality Control department (pessimistic case)

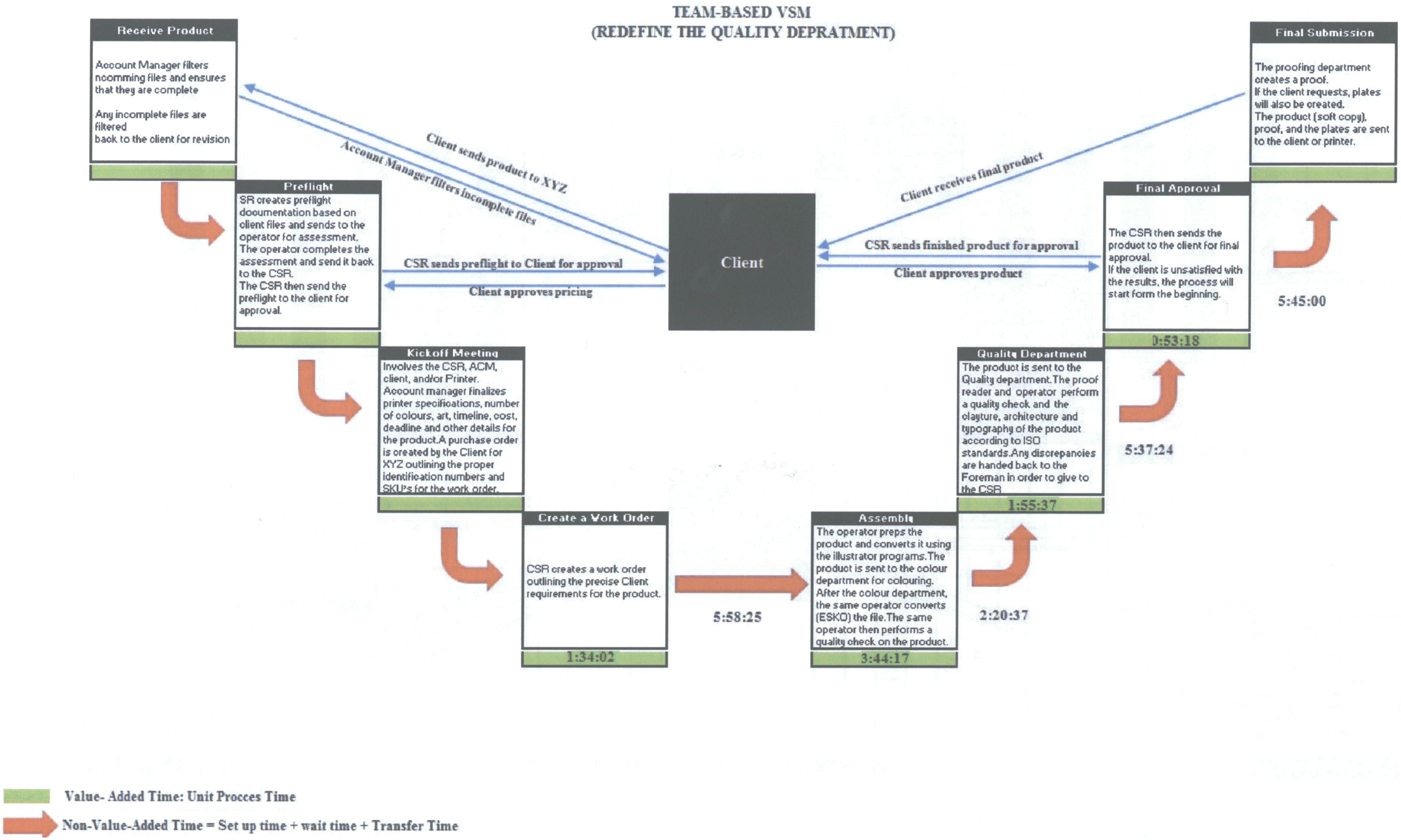

Figure 4-2: VSM for team-based category with redefining the Quality Control department (optimistic case)

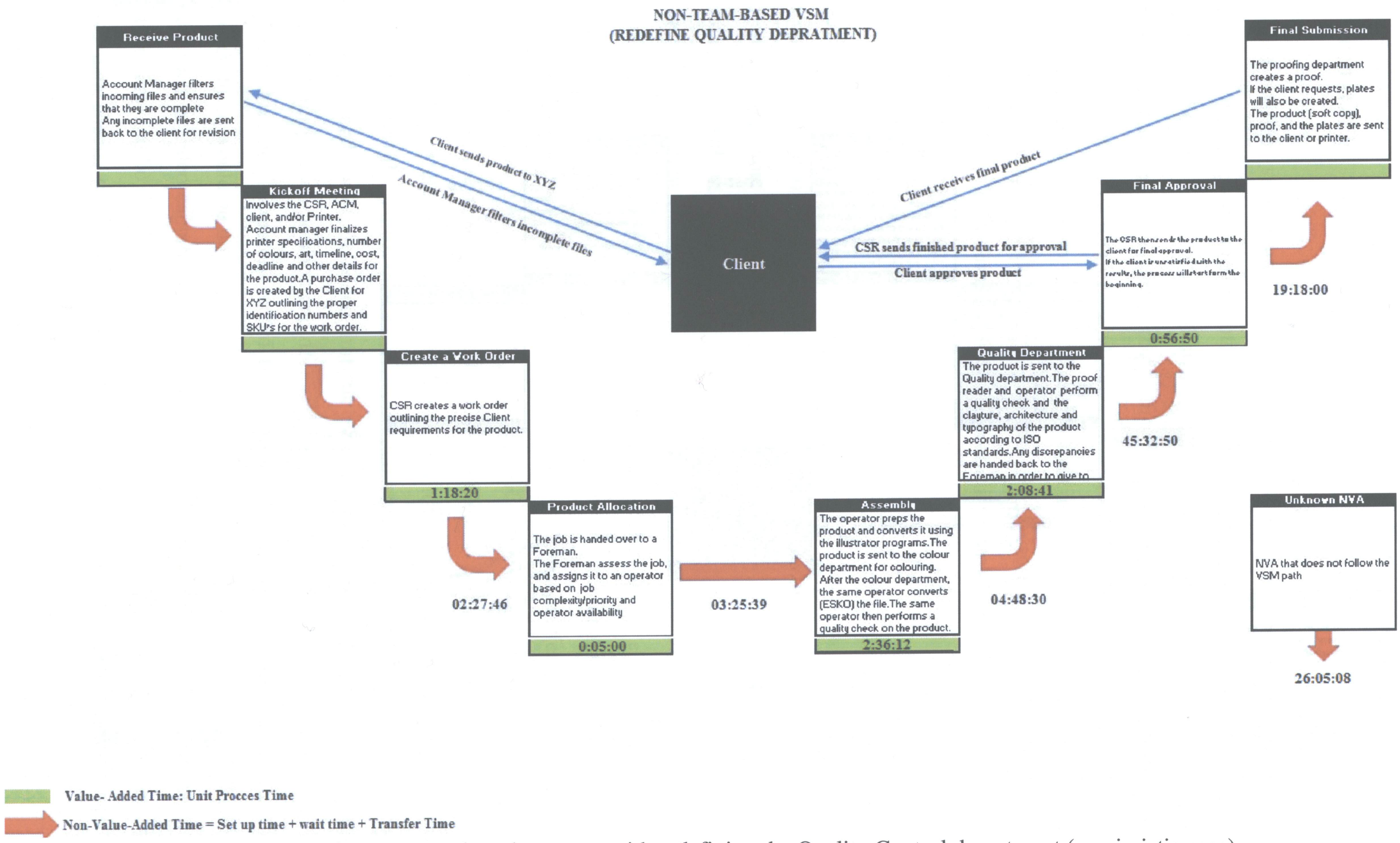

Figure 4-3: VSM for non-team-based category with redefining the Quality Control department (pessimistic case)

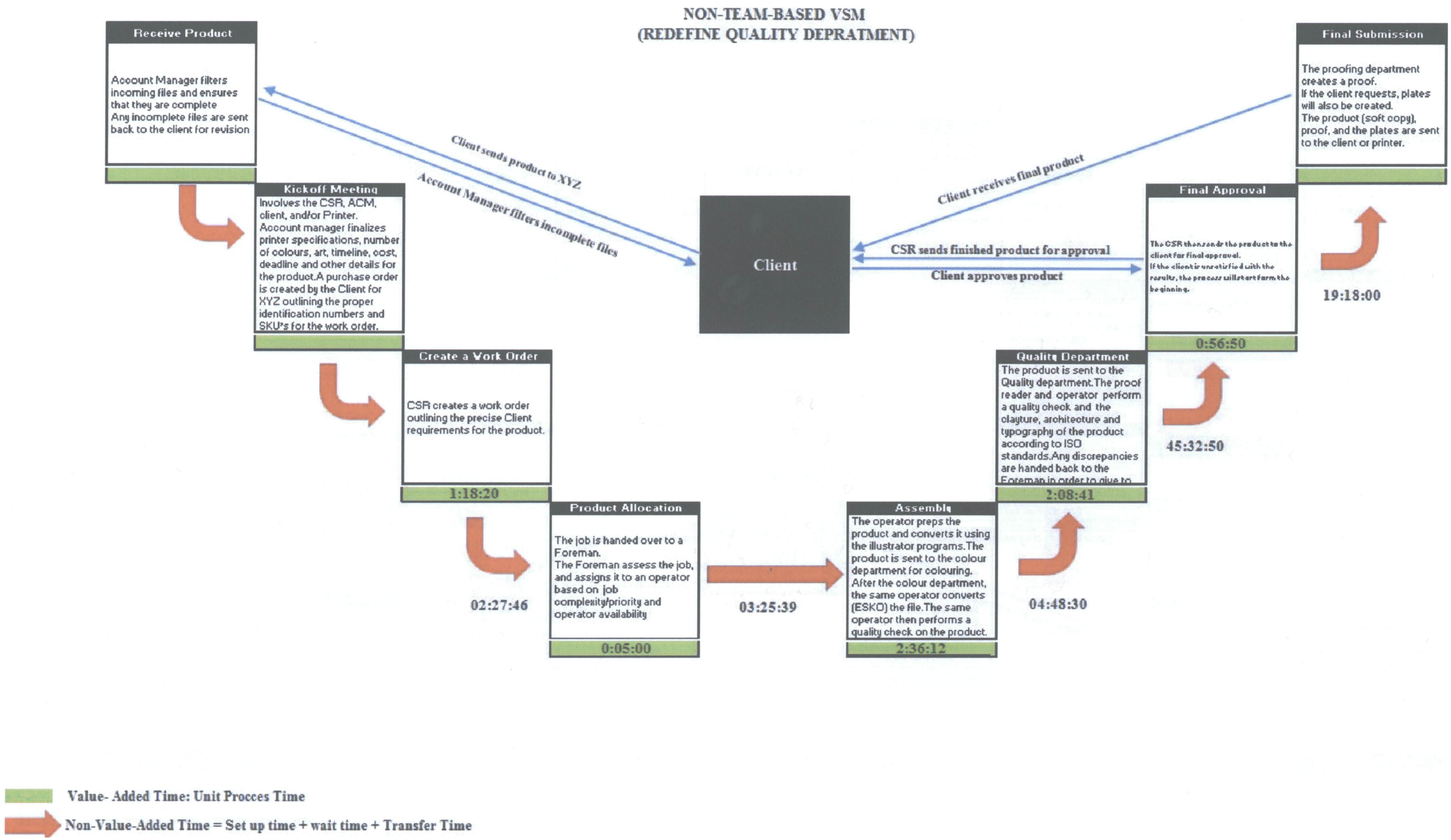

Figure 4-4: VSM for on-team-based category with redefining the Quality Control department (optimistic case)

4.2.2 Scenario B

The second possible step to improve the process is to compare and find the bottleneck stations of the system. By comparing both team-based and non-team-based non-values-added time, one of the first ideas is to eliminate the foreman's role. The foreman has two responsibilities in the current system, these being scheduling the operators and assigning the jobs to each operator. The role of the foreman causes a delay in the system because each operator must submit the job to the foreman, who then has to allocate it to another operator to continue the process. This back and forth in the system causes a huge amount of delay. Therefore, the first idea is to eliminate and the second is to reallocate the foreman position, and both will be discussed in the next section.

4.2.2.1 Scenario B.1

Based on the analysis of the VSMs, it is concluded that a potential method to reduce the overall processing time would be to eliminate and redefine the foreman position. It is determined that with this change, an overall improvement of the process by 3.2% in a pessimistic case as shown in Table 4-5 and 35% in an optimistic case as illustrated in Table 4-6 could be obtained. Redefinition of the foreman position would eliminate a series of unnecessary touch points, thus improving productivity by eliminating the waste time involved. The necessary tasks that the foreman executes could be transferred to the CSR's or operators' duties. With this potential change, the CSR would work with other CSRs and schedule tasks according to job priorities. The CSRs could also perform the necessary quality checks, and transport the files to Proofreading or Quality Control department. This, in turn, would increase the value-added time for the CSRs; however, this increase would be less than the value-added and non-value-added time for the foreman. Still, it should be noted that the foreman is a salary-based position and does not input work hours into XYZ Link. Hence, if the foreman does not accurately record the information in the timesheets attached to the work-order, there would be no data obtained for the task. A broader range of data gathering methods, such as video capture and stopwatch studies could determine what the foreman's daily duties are, and how much time is required for their completion. However, based on the observed data sheets, completed by XYZ's employees, the reallocation of the foreman's duties to operators and CSRs would benefit the work-order process and lead time per docket. Figure 4-5 and Figure 4-6 illustrated the VSM for non-team-based category for both pessimistic and optimistic cases.

Table 4-5: VSM summary for non-team-based category with eliminating foreman (pessimistic case)

	Value-added time	Non-value-added time
Create a Work Order	1:18:20	
		2:47:26
Assembly	2:36:12	
		4:40:38
Quality Control	0:51:49	
		7:01:36
Proofreading	1:16:52	
		45:32:50
Final Approval	0:56:50	
		19:18:00
Unknown Non-value-added		26:05:08
Total	7:07:52	105:25:28
Improvement Percentage :	3.2%	

Table 4-6: VSM summary for non-team-based category with eliminating foreman (optimistic case)

	Value-added time	Non-value-added time
Create a Work Order	1:18:20	
		2:47:26
Assembly	2:36:12	
		4:40:38
Quality Control	0:51:49	
		7:01:36
Proofreading	1:16:52	
		45:32:50
Final Approval	0:56:50	
		19:18:00
Unknown Non-value-added		26:05:08
Total	7:07:52	70:42:40
Improvement Percentage :	35.4%	

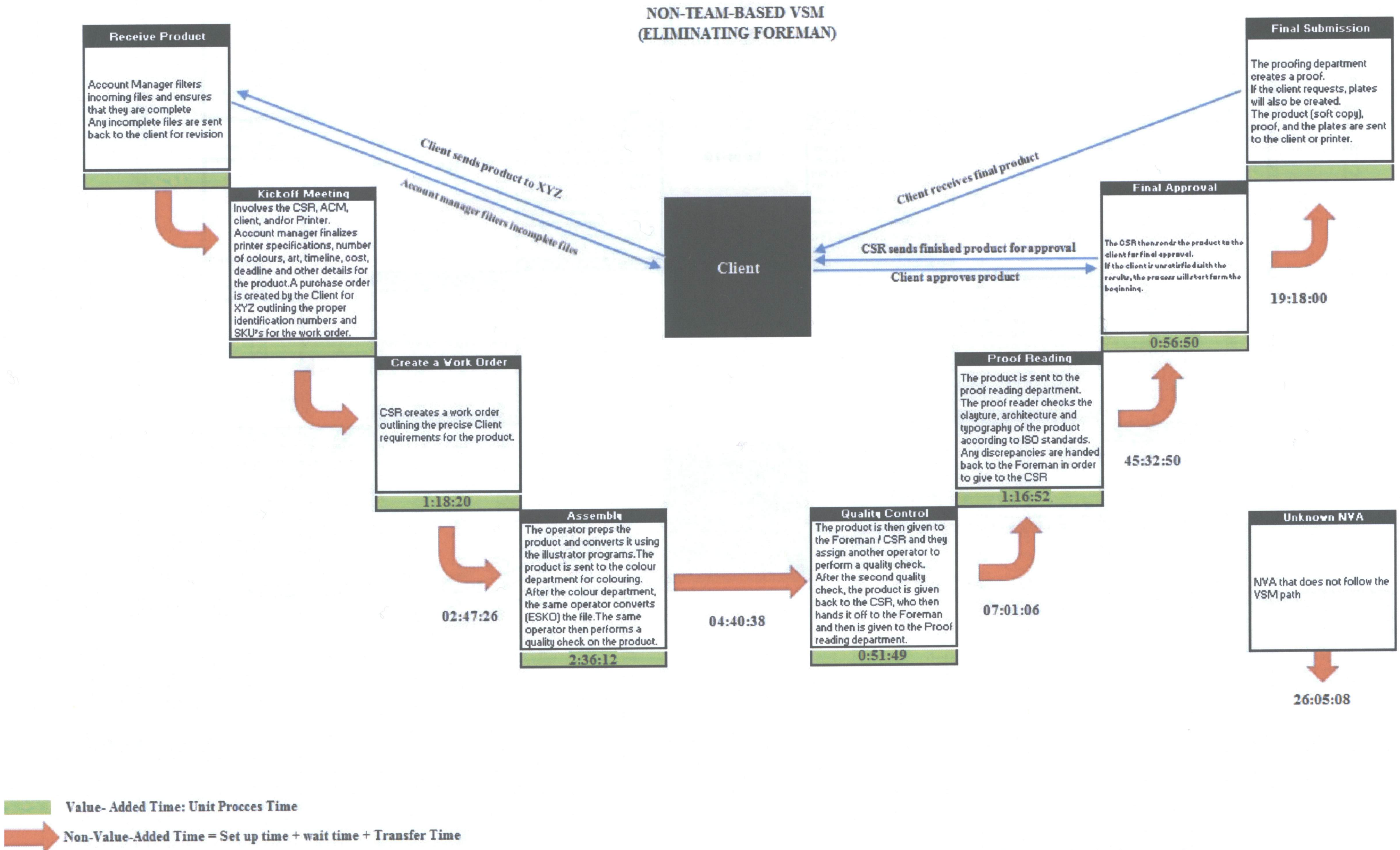

Figure 4-5: VSM for non-team-based category with eliminating foreman task (pessimistic case)

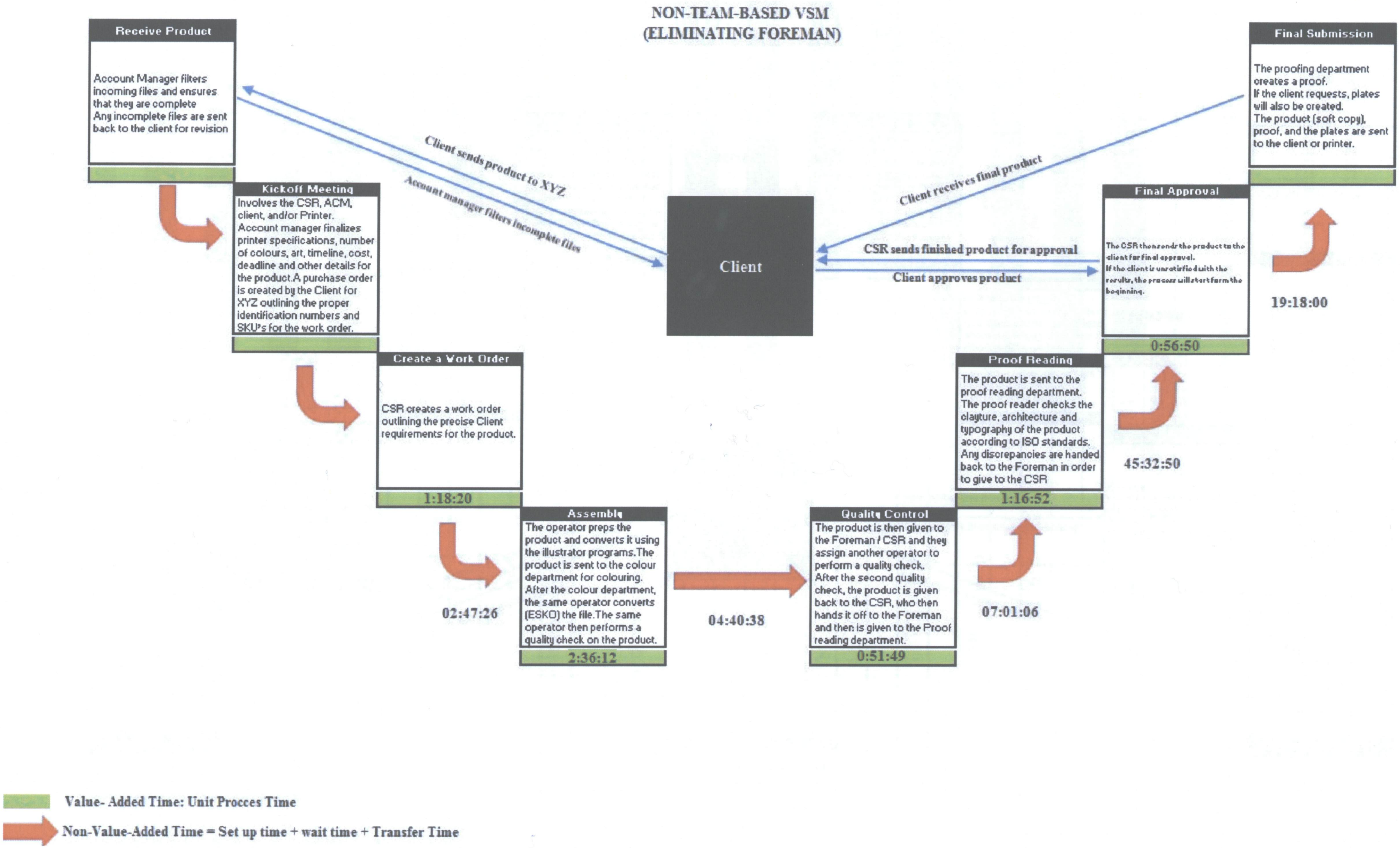

Figure 4-6: VSM for non-team-based category with eliminating foreman task (optimistic case)

4.2.2.2 Scenario B.2

To improve and utilize the process, using the foreman as a planner can work toward the company's advantage. The planner should be well trained to create a schedule for all jobs and XYZ Link, using XYZ Link as a tool to track each job and check the status of the job. Hence, the quality of the job and the time of its completion can be monitored closely. In case of any problem, the person may be able to identify the bottleneck station and resolve the issue. XYZ Link is a powerful tool with great potential, but unfortunately, it is not being utilized properly. The XYZ Link is capable of calculating the cycle-time of each process, and the start and stop time of each task, and not just the duration of the each process. By entering the start and stop time of each task, the planner could follow when the job is idle and is not being worked on. The period of time between shipment and the clients' notification to the company that the job is accepted or needs modification can be measured.

4.2.3 Scenario C

The third scenario would be an amalgamation of the given two recommendations, i.e. creating the Quality Control department and eliminating the foreman role, based on the VSMs. The combined process improvement is 11% in the pessimistic case as indicated in Table 4-7 and 41% in the optimistic case as shown in Table 4-8. This data suggests that elimination of the foreman task could increase the work for operators and CSRs; however, the Quality Control department would offset this higher utilization by absorbing some of the work. Figure 4-8 and Figure 4-9 illustrated the VSM for non-team-based category for both pessimistic and optimistic cases. The general process would then be as follows (Figure 4-7):

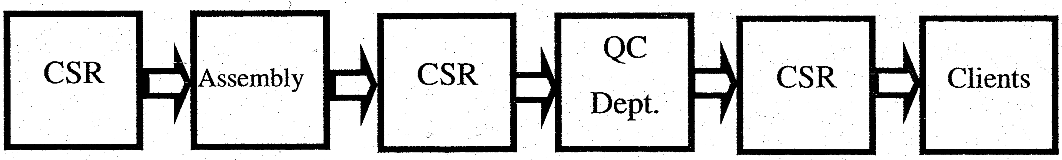

Figure 4-7: General process flow with eliminating of foreman task and creating a Quality Control department

Table 4-7: VSM summary for non-team-based category with eliminating foreman task and redefining the Quality Control department (pessimistic case)

	Value-added time	Non-value-added time
Create a Work Order	1:18:20	
		2:47:26
Assembly	0:56:12	
		4:40:38
Quality Control department	2:08:41	
		45:32:50
Final Approval	0:56:50	
		19:18:00
Unknown Non-value-added		26:05:08
Total	7:07:52	98:24:02
Improvement Percentage :	9.6 %	

Table 4-8: VSM summary for non-team-based category with eliminating foreman task and redefining the Quality Control department (optimistic case)

	Value-added time	Non-value-added time
Create a Work Order	1:18:20	
		2:47:26
Assembly	0:56:12	
		4:40:38
Quality Control Department	2:08:41	
		45:32:50
Final Approval	0:56:50	
		19:18:00
Total	7:07:52	63:41:04
Improvement Percentage :	41.5 %	

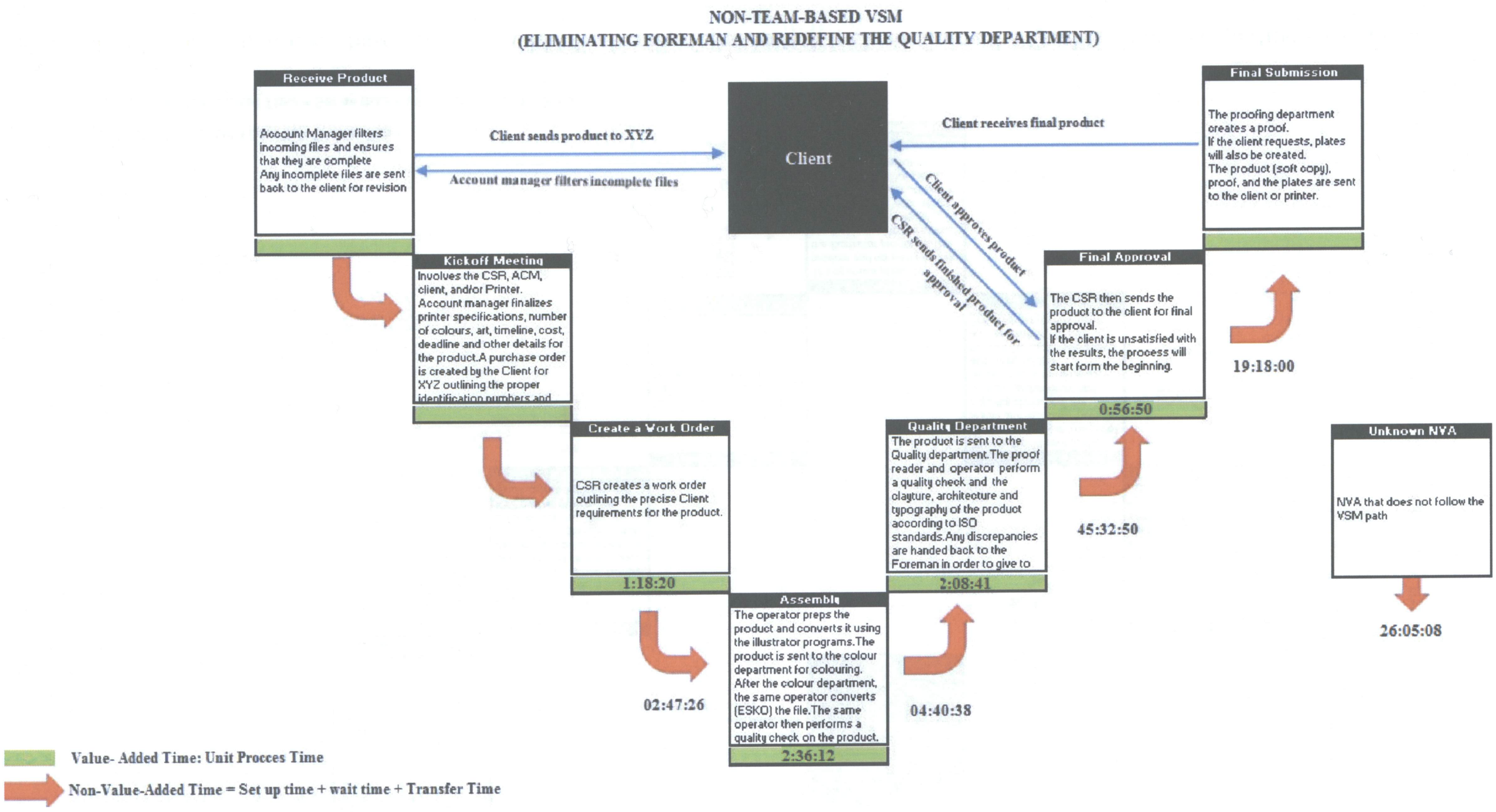

Figure 4-8: VSM for non-team-based category with eliminate foreman and redefining the Quality Control department (pessimistic case)

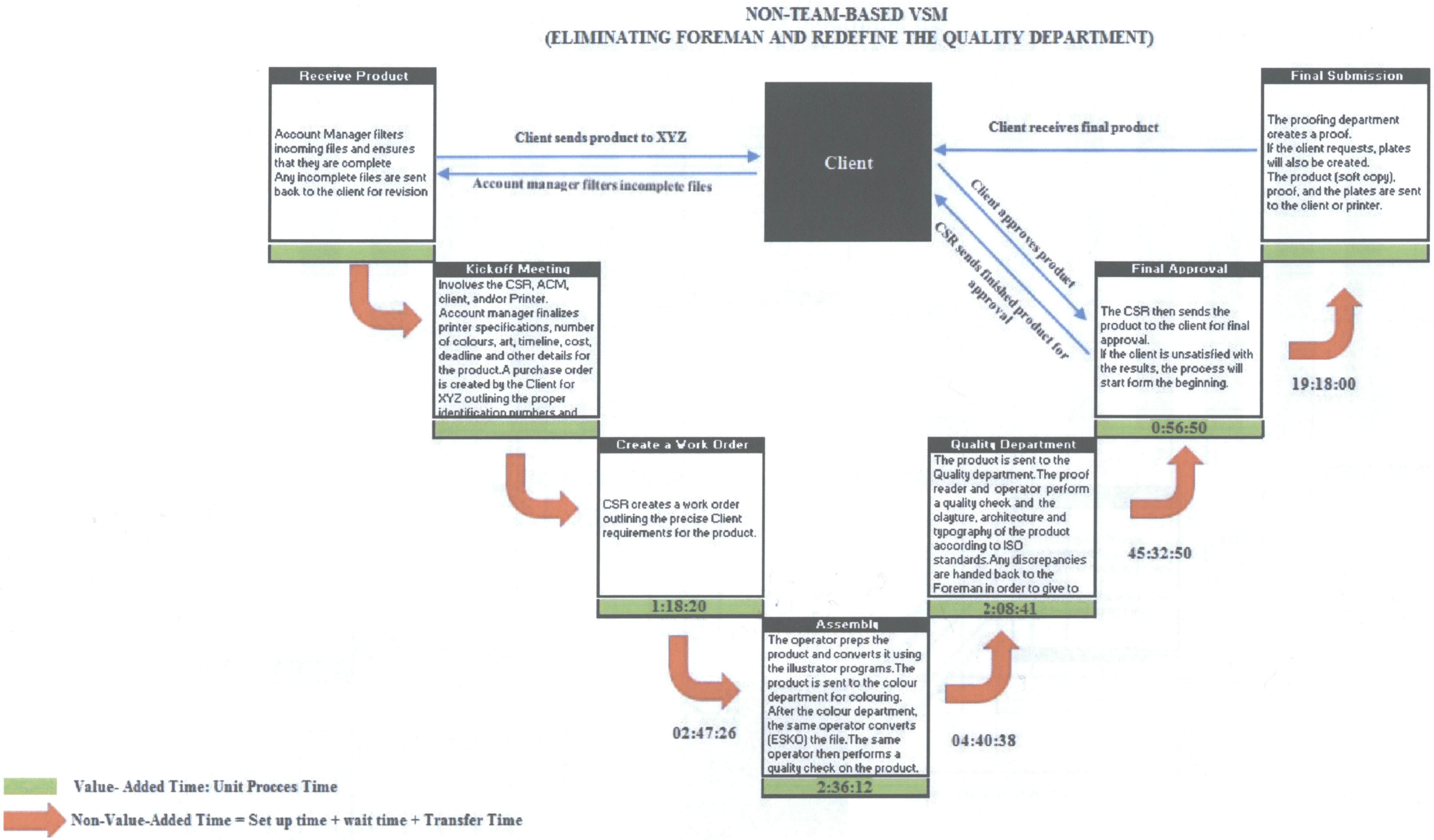

Figure 4-9: VSM for non-team-based category with eliminating foreman task and redefining the Quality Control department (optimistic case)

After creating the VSM for the current-state and the future-state, the next step is to create a model for the current situation, to ensure a similar correlation is present between the model and the real performance. The next chapter will discuss about the current simulation model.

Chapter 5 Simulation Modeling

Following the description of the tools in Chapter 4, this chapter will evaluate the potential gains by developing a detailed simulation model using system modeling corporations' Arena® software.

To do so, the current system is modeled, which is further modified to propose a future-state. However, at first the current-state is to be built and verified to validate the system that further should be debugged to match the real world situation. To create the simulation model; the process flow path must be identified, and furthermore calculations must be made for the task duration as well as the idle time between each of the tasks.

5.1 Process Flow Path Recognition

The XYZ Company does not have any specific path for its work-orders; therefore, it is difficult to track the process flow of each job. Due to the subjectivity of each job and being client based, each work-order has a different path. However, to create the current model a random path for each work-order must be created. To build the random path, the process flow is broken down into smaller tasks and sub-tasks, which help to create a "From-To Matrix" to track down the flow between each of the stations. As a result, by gathering and grouping all the identical paths of each work-order and putting them together, the number of repetitions for each step could be identified. By adding up all steps that have similar starting points, the total number of jobs being distributed from each station could be calculated. Furthermore, to know the percentage of jobs that end up at each station, and the associated ratio of the total number of steps from one station to the next, is calculated by dividing the total number of steps which have the same starting and ending point, by the total number of steps which have just the same starting point (Appendix A).

These ratios are shown in Table 5-1 and Table 5-2, for both team-based and non-team-based processes. The numbers in each chart indicate the ratio of the flow for each work-order from one station to another.

Table 5-1: Job circulation percentage for team-based process (From - To chart)

	CSR	Assembly	QC2	Proofreading	Clients
CSR	13	73	-	-	14
Assembly	49	5	30	16	-
QC2	50	33	-	17	-
Proof	50	20	10	20	-

Table 5-2: Job circulation percentage for non-team-based process (From - To chart)

	CSR	Foreman	Assembly	QC2	Proofreading	Clients
CSR	14	33	36	-	1	16
Foreman	26	-	74	21	2	
Assembly	3	16	9	14	31	
QC2	55	35	-	-	1	
Proof	3	37	26	4	3	

By having a different ratio for each task, the random path for each job is being recognized. Also, the number of the revisions for each job is a random variable, which is determined randomly as is depicted in Appendix A.

5.2 Input Analysis

BestFit® (Version 4.5) is used to determine the quality of fit of probability distribution functions to input data. Its result shows four types of graphs to assess visually the quality of fits i.e.

- Comparison graph: superimposes the input data and the fitted distribution on the same graph.
- Difference graph displays the absolute error between the fitted distribution and the input data.
- Probability-Probability (P-P) graph plots the distribution of the input data vs. the distribution of the result.
- Quantile-Quantile graph plots percentile values of the input distribution vs. percentile values of the result.

It also shows basic statistics (mean, mode, variance etc.) and fit statistics (chi-square, Kolmogorov-Smirnov, Anderson-Darling, and Root-Mean square error) for each fitted distribution.

5.2.1 Distribution analysis for value-added time

The starting point is to identify the Probability Density Function (PDF) for all value-added time of each station for the system at the current-state. To calculate the PDF of each station all the value-added times of each process are imported to the BestFit® software in order to select the best performance (Appendix C). Table 5-3 and Table 5-4 illustrate the PDF of value-added time for each station in team-based and non-team-based processes.

Table 5-3: Distribution fitting for value-added of team-based

	PDF	Mean	Variance
CSR	Normal	32.12	14.08
Assembly	Exponential	50.28	-
Quality control 2	Exponential	31.056	-
Proofreading	Lognormal	27.130	29.39
Final approval by CSR	Exponential	8.333	-

	PDF	Mean	Variance
CSR	Exponential	43	-
Assembly	Exponential	95	-
Foreman	-	-	-
Quality control 2	Exponential	10.6	-
Proofreading	Exponential	35.87	-
Final approval by CSR	Normal	22.35	10.91

Table 5-4: Distribution fitting for value-added of non-team-based

5.2.2 Distribution analysis for non-value-added time

The next step is identifying the PDF for the non-value-added time, which represents all idle time between workstations. In most cases, it is easy to recognize the station that has the non-value-added time; however, in some cases it is hard to pick the station. This situation occurred where the operators do not fill out the time sheets properly; as a result, an unknown non-value-added time is being entered to the system. This event often happens where there are more than two stations getting stations getting involved; this mode is called "Unknown non-value-added".

To simulate a better model all available data is to be used. To get the best result; first the "Unknown non-value-added" events should be distributed between participating stations by considering the calculated average ratios of "Non-value-added" between two stations, and the "Unknown non-value-added" using the former as the base and correcting the latter by applying the former ratio. As a result the "Unknown non-value-added" of each station is being corrected based on the real value of a known non-valued-added, which could be used to calculate the non-value-added probability density function between each two stations of both team-based and non-team-based processes as shown in Table 5-5 and Table 5-6.

Table 5-5: Probability density function for non-value-added of team-based

	CSR	Assembly	Quality Control 2	Proofreading
CSR	Exp (1409)	N (308,227)	-	-
Assembly	Exp (40)	-	N (66.6,27.2)	Exp (107.5)
Quality Control 2	Triangular (20,16,282)	-	-	-
Proofreading	Triangular (3, 47, 215)	-	-	-

Table 5-6: Probability density function for non-value-added of non-team-based

	CSR	Foreman	Assembly	Quality Control 2	Proofreading
CSR	-	Exp (190)	Lognormal (325.66,188.76)	-	-
Foreman	Triangular (5,40,45)	-	N (178.5,177.45)	Triangular (15,90,105)	-
Assembly	Exp (2968.2)	Exp (19.20)	-	-	Lognormal (184.2,410.7)
Quality Control 2	Exp (540)	-	-	-	Exp (112.27)
Proofreading	Exp (97.2)	-	-	-	-

5.3 Building the Simulation Model

The base-case scenario is developed based on the "Current-state" of VSM. To keep the model manageable, it is divided into two sub-models (team-based and non-team-based) as shown in Appendix B and is described as follows:

- Team-based model: Team-based model begins with a "create box" that generates different entities into the system, which assigns each entity a specific label named "job index" that represents the total number of orders received. Moreover, after knowing the number of orders, the actual process starts by assigning the "job sequence" and "work-order number". The "job sequence" shows the path that each entity or job should follow, while "work-order" represents the total number of the revisions for each job. Due to the subjectivity and complexity of the process, each of the jobs has to go through a random path provided by Arena® software imported from the Excel sheet. In addition, it is important to note that each path starts with CSR and ends with clients. There are two or three CSR's in the system that deal with different groups of clients. CSR also has two responsibilities in the system, the first is to review the job and create the new work-order, which at times follows the normal distribution function with a mean of 32.12 minutes and a variance 14.08 minutes. The second is to do the final quality check, which at times follows the exponential distribution function with a mean of 8.333 min.

  The job often follows the given path and it takes either of the following routes: to the assembly station, which at times follows the exponential function with a mean of 50.28 minutes, to quality control, which at times follows the exponential function with a mean of 31.056 minutes, or to proofreading, which at times follows the lognormal function with a mean of 27.130 minutes and a variance of 29.39 minutes. After the job is done in each department, Arena® recognizes them with a specific label. The label specifies which department completed the work. For example, if the job is done by the CSR, Arena® labels it as "Job was finished by CSR". Arena® checks the starting point and the final destination while assigning a non-value-added time, which shows the idle between two points. Non-value-added time was determined by a source and destination station, where the time is taken from a predetermined table (Table 5-5) considering the source and the destination.

CSR distributes the job between operators in assembly departments; however, Arena® assigns an operator randomly to the job based on the operator's availability. Furthermore, there are some restrictions in the process, such as if the work was done by any operator in the assembly station, the docket cannot go back to the same person for the second quality check.

When the job is accepted by clients, it has to go out of the system. However, because there is always some back and forth communication between a CSR and a client, another delay module was created to configure the non-value-added time, which is called client's non-valued-add time. This non-value-added is the time that the CSR or company has to wait to get acceptance, declaration, or modification from the clients. In spite of the fact that the company does not have any ability to eliminate the client's non-valued-added time, the creation of SLA can diminish this non-value-added time.

- Non team-based model: The non-team-based model is very similar to the team-based model; the only difference is the foreman task, which is added to the system. In this case, the foreman is the person who distributes the job between employees. Therefore, the CSR creates the new work-order, which at times follows the exponential function with a mean of 43 minutes. Furthermore, CSR hands off the job to the foreman in order to distribute it between operators. The job often follows the given path and it takes either of the following routes: to the assembly, to second quality check, proofreading, or it goes back to the CSR for revision or for final quality check. The duration of each task is demonstrated in Table 5-5.

After running the system for 300 days, the following information is captured by Arena® (Appendix F). Table 5-7 explains the average value-added time and non-value-added time for both team-based and non-team based categories. As illustrated in Table 5-7, the non-valued-added time for non-team based is approximately double the value of the non-value-added time that is found in the team-based category, which is similar to data that was captured from the VSM. On the other hand, the percentage of non-value-added time in both the team-based and the non-team-based is respectively ($\frac{106}{106+27.27}$) 80% and ($\frac{176.31}{176.31+13.6}$) 93% which is very similar to the ratio that was captured by VSM (81 % for team-based and 93% for non-team-based).

Table 5-7: Average non-value-added time and value-added time for both team-based and non-team process for the base-case scenario

	Average time
Team-based Average non-value-added time (h)	106.09
Non-team-based Average non-value-added time (h)	176.31
Team-based Average Value-Added time (h)	27.27
Non-team-based Average Value-Added time (h)	13.6

Once the simulation model for the current system is verified and validated, it is used to evaluate the future-state map and assess the relative impact of adopting the lean approach detailed in the previous two chapters. The next chapter is going to discuss the modeling of the future-state map and compare all improvement scenarios.

Chapter 6 Simulation Results and Discussions

Chapter 4 discussed three proposals. This chapter will develop these three proposals, and in addition a forth proposal will discussed and developed. The processes will be improved in order to reduce the amount of non-value-added time for each process. All four proposals will be created and afterward validated by utilizing a simulation method.

6.1 Scenario A

The first case scenario is to create a single Quality Control department instead of the present "second quality control check" and" proofreading task" (Figure 6-1). As discussed in the previous chapter both of these tasks, even though one is in charge of quality of design and the other is in charge of proofreading, handle the same job of quality control, Therefore by combing the two tasks the idle time between the two departments is going to be diminished. Following the establishment of a new Quality Control department and running the simulation for 300 day (10 times for 30 days), the total non-value added time for team-based is reduced from 106.09 hours to 79.87 hours, which is a 5% improvement in the system. As well, the non-valued-added time for non-team is reduced from 176.21 hours to 137.45 hours, which shows a 3% improvement as is shown in table 6-1. Moreover, the total number of finished products which are shipped to the clients increased by 28 orders (from originally 546 orders to 574 orders) for team-based, and 5 orders (from originally 916 orders to 921 orders) by non-team-based.

In this case, instead of the job going to either quality control or proofreading stations, it goes to the Quality Control department. The Quality Control department checks the work-order reviews and applies the necessary procedure to each job. On the other hand, either the CSR or the foreman distributes the job among assemblies, based on their availability, the number of jobs in the queue and the total utilization of each station. In this case, without adding any resources or employees to either of the team-based process or the non-team-based process, the non-value-added time of the system is decreased and the utilization of each station is increased as shown in Table 6-7.

Quality Depratment

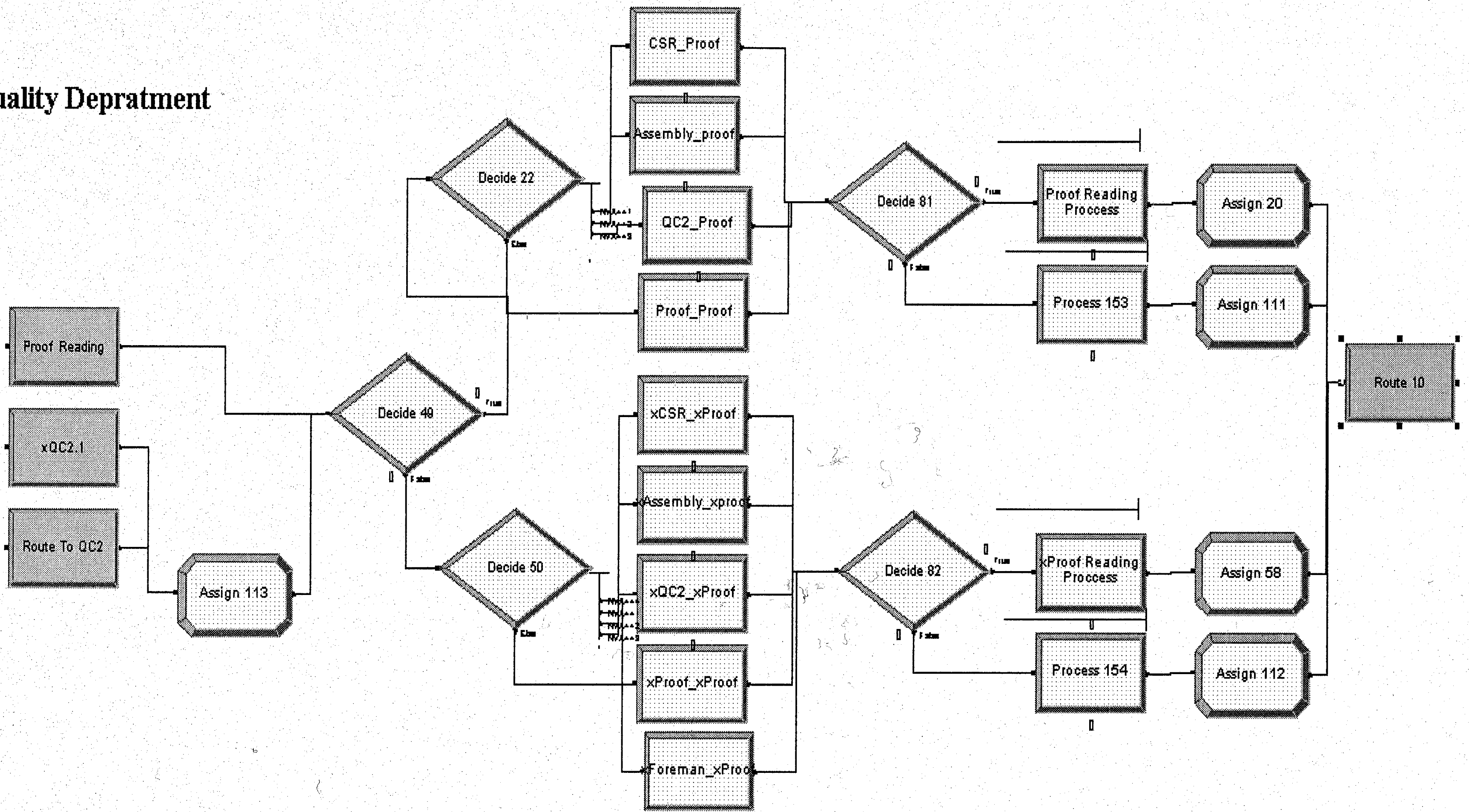

Figure 6-1: Layout of Arena® for Quality Control department

Table 6-1: Average non-value-added time in the current situation vs. redefining Quality Control department

	Current	Scenario A	Improvement
Total number of jobs coming out the system			
Team-based	546	574	**+28**
Non-team-based	916	921	**+5**
Average non-value-added time (h)			
Team-based	106.09	79.87	**5%**
Non-team-based	176.31	137.43	**3%**

6.2 Scenario B.1

In the second scenario, the foreman's position in the non-team-based is being eliminated due to the fact of the comparison, which is done between the non-value-added time of the team-based and the non-team-based. In this comparison, it was observed that the non-value-added in the non-team-based almost doubled the value of the time that is found in the team-based category. Furthermore, by eliminating the foreman from the non-team-based process, the CSR has taken the responsibility to distribute the job among departments. In this situation, the total non-value-added time of the system for non-team-based is reduced from 176 hours to 51.12 hours, which is equal to a 71% improvement as, is shown in Table 6-2. In addition to the above mentioned observation, the number of despatched orders for the team-based has increased from 546 to 564, and for non-team-based raised from 916 to 937.

Table 6-2: Average non-value-added in the current situation vs. eliminating foreman

	Current	Scenario B	Improvement
Total number of jobs coming out the system			
Team-based	546	564	**+18**
Non-team-based	916	937	**+21**
Average non-value-added time (h)			
Team-based	106.09	106.09	**-**
Non-team-based	176.31	51.12	**71%**

6.3 Scenario B.2

To improve and utilize the process effectively, a planner was introduced to the system. To reduce the non-value-added time, the planner's duty is to create different schedules for different jobs and further track and check the status of each job. As a result, the quality has increased drastically while the idle time decreased. The planner is responsible for tracking the idle time of each job. If a job is idle for more than 15 minutes, then the planner should pick the job and release it to the scheduled station (Figure 6-2). On the other hand, the planner with the help of the XYZ Link is able to identify the bottleneck in and between the stations and resolve all the issues by balancing the utilization of each of the stations (Figure 6-3). In this case, the non-valued-added time of the system for the team-based is reduced by 79% (from 106.09 hours to 22.20 hours) and 91% (from 176.31 hours to 14.71 hours) in the non-team-based as illustrated in Table 6-3. In addition to the above mentioned observation, the number of despatched orders for the team-based has increased from 546 to 562, and for non-team-base raised from 916 to 925.

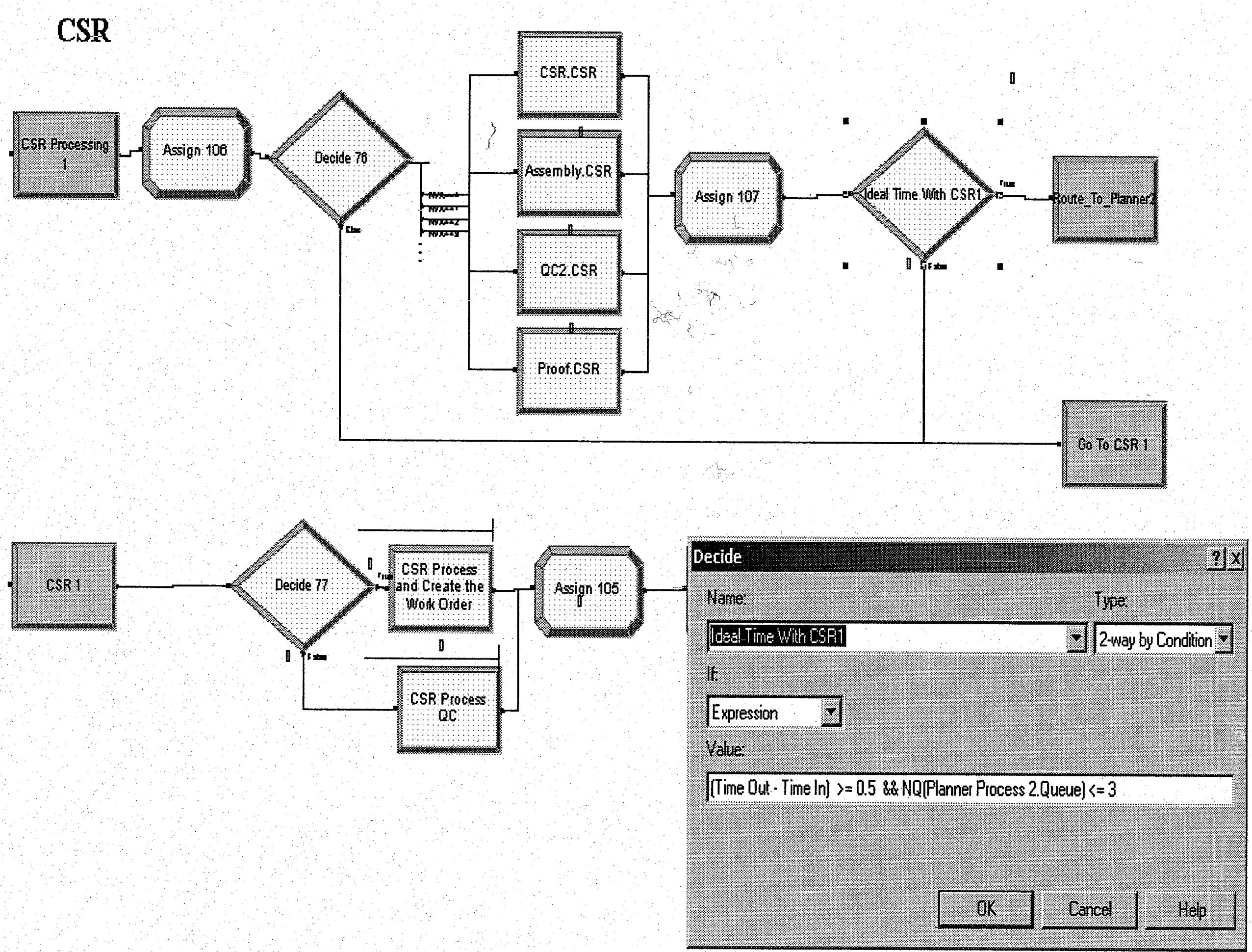

Figure 6-2: Planner checks the ideal time for each process

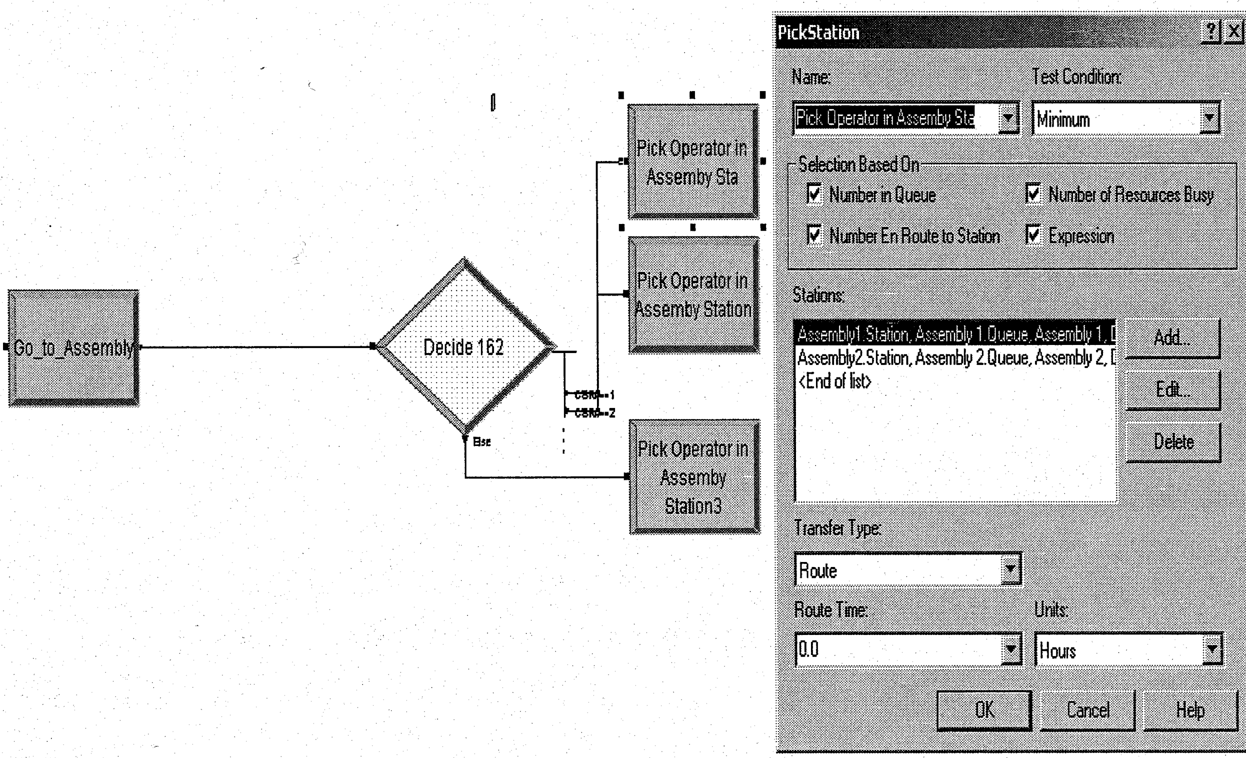

Figure 6-3: Distributing job between operators

Table 6-3: Average non-value-added in the current situation vs. reallocating foreman and using planner

	Current	Scenario B.2	**Improvement**
Total number of jobs coming out the system			
Team-based	546	562	**+16**
Non-team-based	916	925	**+9**
Average non-value-added time (h)			
Team-based	106.09	22.20	**79%**
Non-team-based	176.31	14.71	**91%**

6.4 Scenario C

The forth scenario is a combination of the first two scenarios which eliminates the foreman's task and redefines the Quality Control department. In this case the non-valued-added time of the system for team-based is reduced by 5% (from 106.09 hours to 79.49 hours) and for non-team-based by 72% (from 176.31 hours to 52.25 hours) as illustrated in Table 6-4. In addition to the above mentioned observation, the number of despatched orders for the team-based has increased from 546 to 569, and for non-team-based raised from 916 to 935.

Table 6-4: Average non-value-added in the current situation vs. reallocating foreman and using Quality Control department

Total number of jobs coming out the system			
Team-based	546	569	**+23**
Non-team-based	916	935	**+19**
Average non-value-added time (h)			
Team-based	106.09	79.49	**5%**
Non-team-based	176.31	52.25	**72%**

6.5 Optimum Scenario

Further, in creating the optimum solution, it was decided to use all successful scenarios and combine them together, to create the optimum solution. To do so, the quality department was added, while the foreman position was eliminated and a planner was introduced, then the simulation models with the new inputs were run for 300 days. As a result, the total non-value-added time for the team-based is reduced from 106.09 hours to 14.66 hours, which is an 86% improvement in the system. As well, the non-valued-added time for non-team is reduced from 176.21 hours to 15.50 hours, which shows a 91% improvement as it shows in Table 6-5. Moreover, the total number of finished product which is shipped to the clients increased for team-based by 45 units (from originally 546 to 591), increased for non-team-based by 40 units (from originally 916 to 956).

Table 6-5: Percentage of non-value-added in the current situation vs. reallocating foreman and using Quality Control department

	Current	Scenario C	**Improvement**
Total Number of Jobs Coming Out the System			
Team-based	546	591	**+45**
Non-team-based	916	956	**+40**
Average non-value-added time (h)			
Team-based	106.09	14.66	**86%**
Non-team-based	176.31	15.50	**91%**

After completion of VSM, simulations were applied to validate the judgements and to ensure that the model is working accurately. By applying the simulation model for all different scenarios, the next step was validates the finding of VSM such that there is no significant difference between the real world and the model, as shown in table 6-6. In addition, the percentage of the non-valued-added time, as well as the utilization of each station was calculated, as it shown in Table 6-7 and Table 6-8. By comparing all these scenarios, the best scenario, which is the optimum scenario, was identified as was shown in the previous section the optimum scenario is the combination of introducing the quality department while using a planner instead of a foreman. However, to improve the utilization of each station, each of the CSRs should work with two or three operators of their own group, As well, to utilize the planner position most effectively and to increase the efficiency; the planner should watch for the idle jobs and assign them to the first available station.

Table 6-6: Comparing the VSM and simulation non-value-added time

	% of Non-value-added time for team-based			% of Non-value-added time for non-team-based		
	VSM Pessimistic	VSM Optimistic	Simulation	VSM Pessimistic	VSM Optimistic	Simulation
Base-case	81%		80%	93%		92%
Scenario A	80%	71%	73%	92%	90%	90%
Scenario B.1	80%	80%	79%	93%	79%	78%
Scenario C	80%	71%	72%	93%	88%	78%

Table 6-7: Instantaneous system Utilization for each station

	Base-case	Scenario A	Scenario B.1	Scenario B.2	Scenario C	Optimum Scenario
Team-based						
CSR	35%	40%	35%	37%	38%	57%
Assembly	30%	31%	31%	48%	31%	52%
Non-team-based						
CSR	43%	43%	44%	41%	44%	69%
Foreman	-	-	-	-	-	-
Assembly	39%	43%	40%	49%	43%	53%
Both						
Proofreading	48%	-	48%	56%	-	-
QC department	-	53%	-	-	53%	58%
Planner	-	-	-	70%	-	60%

Table 6-8: Percentage of non-value-added time

	Base-case	Scenario A	Scenario B.1	Scenario B.2	Scenario C	Optimum Scenario
% of Non-value-added time for team-based	80%	73%	79%	61%	72%	33%
% of Non-value-added time for non-team-based	92%	90%	78%	47%	78%	43%
% of total non-value-time added	88%	83%	79%	56%	78%	37%

Chapter 7 Conclusion and Recommendations

7.1 Conclusion

In this research, VSM is applied to the client-based service industry, which the inconsistency of the clients' request is variable, each process is subjective, the procedure of each job is different and the material flow is not visible. Furthermore, it is applied to both team-based and not-team-based processes. The completed VSM provides a big picture in very simple way and shows all the non-value-added time and value-added time for each process. By having all this data the future VSM for the company is created based on three improvement scenarios, i.e. creating the Quality department, eliminating the foreman, creating the Quality department, and eliminating the foreman at the same time.

Following the completion of VSM, the next step was to evaluate the potential gains by developing a detailed simulation model using system modeling corporations' Arena® software. To do so, the current system is modeled, which further is being modified to propose the future-state. However, at first the current-state is to be built and verified to validate the system that further should be debugged to match the real world situation. Due to the subjectivity of each job and the client-based orders, each work-order has a different path. However, to create the current model a random path for each work-order must be created. The next step after creating the current model is to create the future-state models to improve the process and reduce the amount of non-value-added time for each process. All these proposals, and in addition to introducing the planner position, are created and validated afterward by utilizing a simulation method. After creating the model for each scenario and seeing all the improvement percentages in the process, as well as the utilizations of each station, the optimum scenario was identified. Therefore, to have the optimum solution, the quality department was added, while the foreman position was eliminated and a planner was introduced. As a result, the total non-value-added time for the team-based and non-team-based was reduced by 86% and 91% respectively.

7.2 Recommendations and Contributions

This research generates many new opportunities and recommendations. This section outlines some worthy ideas and recommendations.

7.2.1 Service level agreements with the client (SLA)

The first recommendation is to have a Service Level Agreement (SLA), which is a contract between clients and XYZ Company. The SLA addresses the service quality conditions, such as response times, availability, and timelines. After reviewing all the worksheets, it is realized that the waiting time for the client to approve the job is rather lengthy. In fact, the job shows as being in process, while it is not being worked on by anyone. Therefore, by having SLA, the production time of the process could be improved and some of the non-value-added times of the process may be eliminated.

7.2.2 Scorecard tracking

A planner can generate a scorecard with the aid of the Continuous Improvement Office. The application of this office is to set long-term goals and develop solutions for the XYZ Company. To reach the long-term goals, XYZ has to work toward standardizing the processes and reducing the non-value-added times by eliminating waste, such as re-work and waiting times. To achieve this goal, it is crucial to have monthly meetings to monitor the process of the progress being made. Application of the tools, such as VSM and Kaizen will also maintain the development of the future outcomes.

7.2.3 Standardizing procedures

Standardizing the procedures is another recommendation that would aid the production process. It would improve production time by creating a certain production process, which could be done by having a number of pre-determined procedures for certain tasks, thus eliminating any deviation from the production process itself. In addition, using standardized procedures improves the quality and accountability of the work, as the final product would be produced based on a set of standard procedures and processes that are the same every time. As a side advantage, the aforementioned method gives the employer a more efficient and accurate way of measuring employees proficiency. As each employee performs a specific job description and the same set of procedures, it is easier to compare their level of proficiency against other employees who also perform that task. The procedure for the operator should serve as a template for future work instructions for other job titles such as CSR, account manager, quality control, and so forth. This is a crucial step toward implementing Lean through the company. The standard procedure for the assembly station is developed in Appendix E.

7.2.4 Pre-Flight Standardization

Standardizing the pre-flight is another idea that may be used. Operator's comments brought up the fact that the work-orders are not standardized, which leads to misunderstandings and ambiguities about the actual work that needs to be done. As a result, operators need to have the foreman or CSR explain the job to them, which adds to the production time. In this case, the continuous improvement office would go through the work orders and create a standardize pre-flight which include checklists for all the actions required for a specific job. These pre-flights would then be transferred to a database where the CSR would have the ability to select the appropriate checklist and to create the work orders that are proper and standardized, which makes it much easier for the operators to comprehend.

7.2.5 Generalizing the process flow path

In the client-based company, it is hard to track the process flow of each job. Due to the subjectivity of each job and being client based, each job has a different path. However, to create the model a generalization of the path for this kind of companies is the best solution. In this study the random path for each work-order was created and the process flow was broken down into smaller tasks and sub-tasks, which help to create a "From-To Matrix" to track down the flow between each of the stations. In general, in order to apply VSM or simulation for all clients-based industries, the process flow should be generalized. To do so, different performance measurements variable should assigned to the "From-To Matrix" chart. Afterwards by solving the linear programming model the pass could be generalized.

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Appendix A: Creating the Random Path

Table A-1: Cumulative distribution function for each job which is going out of CSR station (team-based)

From	To	Probability	Cumulative Probability
CSR	CSR	0.13	0.13
CSR	Assembly	0.73	0.85
CSR	Clients	0.15	1.00

	Cumulative Probability	Path	Task
[0-0.13)	0.00	1	CSR
[0.13-0.85)	0.13	2	Assembly
[0.85-1)	0.85	5	Clinets
	1		

Table A-2: Cumulative distribution function for each job which is going out of assembly station (team-based)

From	To	Probability	Cumulative Probability
Assembly	CSR	0.49	0.49
Assembly	Assembly	0.05	0.54
Assembly	QC2	0.30	0.84
Assembly	Proof	0.16	1.00

	Cumulative Probability	Path	Task
[0-0.49)	0.00	1	CSR
[0.49-0.54)	0.49	2	Assembly
[0.54-0.84)	0.54	3	QC2
[0.84-1)	0.84	4	Proof
	1		

Table A-3: Cumulative distribution function for each job which is going out of QC2 station (team-based)

From	To	Probability	Cumulative Probability
QC2	CSR	0.50	0.50
QC2	Assembly	0.33	0.83
QC2	Proof	0.17	1.00

	Cumulative Probability	Path	Task
[0-0.50)	0.00	1	CSR
[0.50-0.83)	0.50	2	Assembly
[0.83-1)	0.83	4	Proof
	1		

Table A-4: Cumulative distribution function for each job, which is going out of proofreading station (team-based)

From	To	Probability	Cumulative Probability
Proof	CSR	0.50	0.50
Proof	Assembly	0.20	0.70
Proof	QC2	0.10	0.80
Proof	Proof	0.20	1.00

	Cumulative Probability	Path	Task
[0-0.50)	0.00	1	CSR
[0.50-0.70)	0.50	2	Assembly
[0.70-0.96)	0.70	3	QC2
[0.96-1)	0.96	4	Proof
	1		

Table A-5: Random number generated to identify the random path for each job (team-based)

	Job	Job	Job	Job	Job	Job	Job
Path	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1	CSR	CSR	CSR	CSR	CSR	CSR	CSR
2	Assembly	Assembly	Assembly	Assembly	Assembly	Assembly	Assembly
3	0.4482893	0.969552	0.213070626	0.240320858	0.896608396	0.862421314	0.56859979
4	0.006262	0.425438	0.118150516	0.949809068	0.932897225	0.32182095	0.66071283
5	0.5285749	0.955246	0.554806655	0.609860793	0.723952615	0.36326807	0.73382219
6	0.6545135	0.299119	0.272776472	0.275563436	0.554560753	0.349845887	0.97471026
7	0.1172896	0.667391	0.66911674	0.692855047	0.665054728	0.536662769	0.64391334
8	0.93731	0.003587	0.003012987	0.938819033	0.13903567	0.538814164	0.46408096
9	0.7032935	0.749472	0.06587927	0.272721215	0.290657199	0.200284243	0.18570449
10	0.3950636	0.785392	0.26385233	0.358091627	0.38375361	0.415574878	0.53009197
11	0.8413241	0.763381	0.680173028	0.425425132	0.654647673	0.39225032	0.44127341
12	0.6443937	0.885398	0.245241119	0.180773039	0.153326782	0.770168752	0.68737548
13	0.2237597	0.847762	0.813570604	0.687630638	0.389525782	0.312920831	0.25426071
14	0.6405787	0.04849	0.286287534	0.107110657	0.071223674	0.771196813	0.82848823
15	0.8524822	0.019129	0.490658342	0.293513429	0.783575293	0.18969456	0.53128842
16	0.0359671	0.129866	0.228209328	0.428295205	0.572281788	0.33735148	0.16360073
17	0.7849306	0.752799	0.34493514	0.227379723	0.34636858	0.116278293	0.08449283
18	0.4109455	0.128611	0.705286635	0.884521821	0.380584173	0.218500215	0.35367069
19	0.5792188	0.481601	0.670881221	0.512091144	0.523484281	0.099040605	0.5296047
20	0.2532602	0.880745	0.260787455	0.894984067	0.790885494	0.649353066	0.25641705
21	0.5190117	0.597278	0.734033945	0.829087236	0.284785954	0.573118749	0.40736458
22	0.0088398	0.367156	0.628895811	0.434162731	0.658792452	0.742438095	0.53478352
23	0.90555	0.681502	0.873576709	0.500450026	0.472411653	0.756567888	0.48194076
24	0.6162852	0.586729	0.967878527	0.71412741	0.747319949	0.216558215	0.73373537
25	0.5181047	0.997067	0.996671617	0.107448386	0.351048686	0.547556158	0.85245323
26	0.502476	0.355139	0.879676923	0.706535071	0.368700517	0.828541005	0.09253971
27	0.6966472	0.407387	0.792276862	0.520560083	0.07419133	0.540305015	0.04015142
28	0.1816892	0.183362	0.558154157	0.73445889	0.236348014	0.711281349	0.51857426
29	0.7778139	0.699308	0.099121655	0.527254963	0.61138333	0.290359491	0.58963644
30	0.6502046	0.575312	0.518971253	0.400514799	0.583711565	0.289773658	0.98006659
31	0.1525926	0.311596	0.658117979	0.747274	0.914958355	0.523653592	0.72990479
32	0.6135598	0.353586	0.636640957	0.703025738	0.337625632	0.828678131	0.78884936
33	0.7723188	0.921376	0.852556125	0.208233095	0.152956008	0.9425497	0.20782746
34	0.6460129	0.417244	0.974410162	0.069286813	0.90407017	0.447178882	0.06627929
35	0.9112499	0.018139	0.921628265	0.826140634	0.839893576	0.606973013	0.74592869
36	0.2047833	0.991824	0.113574064	0.147243318	0.828566432	0.52264132	0.65076799
37	0.1350326	0.422824	0.516581732	0.157778	0.820097787	0.419884904	0.186244
38	0.9205543	0.659281	0.676049911	0.643803705	0.809815543	0.36829042	0.10414014
39	0.2827566	0.637355	0.618461851	0.554972429	0.777985613	0.013527208	0.58042484
40	0.1688658	0.489708	0.464306754	0.906011957	0.881248011	0.694550395	0.00197051

Table A-6: Matching the random generated number with probability distribution function for each job (team-based)

Path	Job 1	Job 2	Job 3	Job 4	Job 5	Job 6	Job 7
1	CSR	CSR	CSR	CSR	CSR	CSR	CSR
2	Assembly	Assembly	Assembly	Assembly	Assembly	Assembly	Assembly
3	CSR	Proof	CSR	CSR	Proof	Proof	QC2
4	CSR	CSR	CSR	Assembly	QC2	CSR	Assembly
5	Assembly	Assembly	Assembly	QC2	Assembly	Assembly	QC2
6	QC2	CSR	CSR	CSR	QC2	CSR	Proof
7	CSR	Assembly	Assembly	Assembly	Assembly	Assembly	Assembly
8	Assembly	CSR	CSR	Proof	CSR	Assembly	CSR
9	QC2	Assembly	CSR	CSR	Assembly	CSR	Assembly
10	CSR	QC2	Assembly	Assembly	CSR	Assembly	Assembly
11	Assembly	Assembly	QC2	CSR	Assembly	CSR	CSR
12	QC2	Proof	CSR	Assembly	CSR	Assembly	Assembly
13	CSR	QC2	Assembly	QC2	Assembly	CSR	CSR
14	Assembly	CSR	CSR	CSR	CSR	Assembly	Assembly
15	Proof	CSR	Assembly	Assembly	Assembly	CSR	Assembly
16	CSR	Assembly	CSR	CSR	QC2	Assembly	CSR
17	Assembly	QC2	Assembly	Assembly	CSR	CSR	CSR
18	CSR	CSR	QC2	Proof	Assembly	Assembly	Assembly
19	Assembly	Assembly	Assembly	Assembly	Assembly	CSR	Assembly
20	CSR	Proof	CSR	Proof	QC2	Assembly	CSR
21	Assembly	Assembly	Assembly	QC2	CSR	QC2	Assembly
22	CSR	CSR	QC2	CSR	Assembly	Assembly	Assembly
23	Assembly	Assembly	Proof	Assembly	CSR	QC2	CSR
24	QC2	QC2	Proof	QC2	Assembly	CSR	Assembly
25	Assembly	Proof	Proof	CSR	CSR	Assembly	Proof
26	Assembly	CSR	QC2	Assembly	Assembly	QC2	CSR
27	QC2	Assembly	Assembly	Assembly	CSR	Assembly	CSR
28	CSR	CSR	QC2	QC2	Assembly	QC2	Assembly
29	Assembly	Assembly	CSR	Assembly	QC2	CSR	QC2
30	QC2	QC2	Assembly	CSR	Assembly	Assembly	Proof
31	CSR	CSR	QC2	Assembly	Proof	Assembly	QC2
32	Assembly	Assembly	Assembly	QC2	CSR	QC2	Assembly
33	QC2	Proof	Proof	CSR	Assembly	Proof	CSR
34	Assembly	CSR	Proof	CSR	Proof	CSR	CSR
35	Proof	CSR	QC2	Assembly	QC2	Assembly	Assembly
36	CSR	Assembly	CSR	CSR	Assembly	Assembly	QC2
37	Assembly	CSR	Assembly	Assembly	QC2	CSR	CSR
38	Proof	Assembly	QC2	QC2	Assembly	Assembly	CSR
39	CSR	QC2	Assembly	Assembly	QC2	CSR	Assembly
40	Assembly	CSR	CSR	Proof	Proof	Assembly	CSR

Table A-7: Generated number of iterations for each job (team-based)

=RANDBETWEEN($C$131,$C$190)

1 60

=IF(C264<=$E$258,[redacted],0)

Number of Tasks	39	9	35	16	10	30	39
	Job	Job	Job	Job	Job	Job	Job
Path	1	2	3	4	5	6	7
1	[redacted]	CSR	CSR	CSR	CSR	CSR	CSR
2	Assembly	Assembly	Assembly	Assembly	Assembly	Assembly	Assembly
3	Proof	CSR	QC2	QC2	CSR	CSR	QC2
4	Assembly	Assembly	CSR	CSR	Assembly	CSR	CSR
5	CSR	CSR	CSR	Assembly	Proof	Assembly	Assembly
6	Assembly	Assembly	Assembly	Proof	QC2	CSR	QC2
7	CSR	Proof	CSR	CSR	CSR	Assembly	Proof
8	Assembly	Assembly	Assembly	Assembly	Assembly	QC2	CSR
9	QC2	CSR	QC2	CSR	Proof	Assembly	Assembly
10	CSR	Clients	CSR	Assembly	QC2	Proof	QC2
11	Assembly	0	Assembly	QC2	Clients	CSR	CSR
12	CSR	0	QC2	Proof	0	CSR	Assembly
13	CSR	0	CSR	Assembly	0	Assembly	Proof
14	Assembly	0	Assembly	CSR	0	CSR	CSR
15	Proof	0	CSR	Assembly	0	Assembly	CSR
16	CSR	0	Assembly	CSR	0	CSR	Assembly
17	Assembly	0	QC2	Clients	0	Assembly	QC2
18	Proof	0	CSR	0	0	CSR	Assembly
19	CSR	0	Assembly	0	0	Assembly	CSR
20	Assembly	0	CSR	0	0	CSR	Assembly
21	Proof	0	Assembly	0	0	Assembly	CSR
22	CSR	0	CSR	0	0	QC2	Assembly
23	Assembly	0	Assembly	0	0	Proof	Proof
24	Assembly	0	CSR	0	0	QC2	Assembly
25	CSR	0	Assembly	0	0	Assembly	CSR
26	Assembly	0	QC2	0	0	CSR	Assembly
27	CSR	0	Proof	0	0	Assembly	CSR
28	Assembly	0	CSR	0	0	Proof	CSR
29	QC2	0	Assembly	0	0	Assembly	Assembly
30	CSR	0	CSR	0	0	CSR	Assembly
31	Assembly	0	Assembly	0	0	Clients	CSR
32	CSR	0	CSR	0	0	0	Assembly
33	Assembly	0	Assembly	0	0	0	Proof
34	CSR	0	QC2	0	0	0	CSR
35	Assembly	0	CSR	0	0	0	Assembly
36	CSR	0	Clients	0	0	0	QC2
37	Assembly	0	0	0	0	0	Assembly
38	QC2	0	0	0	0	0	QC2
39	CSR	0	0	0	0	0	CSR
40	Clients	0	0	0	0	0	Clients

Table A-8: Cumulative distribution function for each job which is going out of CSR station (non-team-based)

From	To	Probability	Cumulative Probability
xCSR	xCSR	0.14	0.14
xCSR	xForeman	0.33	0.48
xCSR	xAssembly	0.36	0.84
xCSR	Proof	0.01	0.86
xCSR	Clients	0.14	1.00

	Cumulative Probability	Path	Task
[0-0.14)	0.00	1	xCSR
[0.14-0.48)	0.14	2	xForeman
[0.48-0.84)	0.48	3	xAssembly
[0.84-0.86)	0.84	5	Proof
[0.86-1)	0.86	6	Clients
	1		

Table A-9: Cumulative distribution function for each job which is going out of Assembly station (non-team-based)

From	To	Probability	Cumulative Probability
Assembly	CSR	0.49	0.49
Assembly	Assembly	0.05	0.54
Assembly	QC2	0.30	0.84
Assembly	Proof	0.16	1.00

	Cumulative Probability	Path	Task
[0-0.49)	0.00	1	CSR
[0.49-0.54)	0.49	2	Assembly
[0.54-0.84)	0.54	3	QC2
[0.84-1)	0.84	4	Proof
	1		

Table A-10: Cumulative distribution function for each job which is going out of foreman station (non-team-based)

From	To	Probability	Cumulative Probability
xForeman	xCSR	0.21	0.21
xForeman	xAssembly	0.60	0.81
xForeman	xQC2	0.17	0.98
xForeman	Proof	0.02	1.00

	Cumulative Probability	Path	Task
[0-0.21)	0.00	1	xCSR
[0.21-0.81)	0.21	3	xAssembly
[0.81-0.98)	0.81	4	xQC2
[0.98-1)	0.98	5	Proof
	1		

Table A-11: Cumulative distribution function for each job which is going out of QC2 station (non-team-based)

From	To	Probability	Cumulative Probability
xQC2	xCSR	0.55	0.55
xQC2	xForeman	0.35	0.90
xQC2	Proof	0.10	1.00

	Cumulative Probability	Path	Task
[0-0.55)	0.00	1	xCSR
[0.55-0.90)	0.55	2	xForeman
[0.90-1)	0.90	5	Proof
	1		

Table A-12: Cumulative distribution function for each job, which is going out of proofreading station (non-team-based)

From	To	Probability	Cumulative Probability
Proof	xCSR	0.30	0.30
Proof	xForeman	0.37	0.67
Proof	xAssembly	0.26	0.93
Proof	xQC2	0.04	0.96
Proof	Proof	0.04	1.00

	Cumulative Probability	Path	Task
[0-0.30)	0.00	1	xCSR
[0.30-0.67)	0.30	2	xForeman
[0.67-0.93)	0.67	3	xAssembly
[0.93-0.96)	0.93	4	xQC2
[0.96-1)	0.96	5	Proof
	1		

Table A-13: Generated number of iterations for each job (non-team-based)

=RANDBETWEEN($C$131,$C$190)

1 60

=IF(C264<=$E$258,[redacted],0)

Number of Tasks	31	7	37	15	39	30	27
	Job	Job	Job	Job	Job	Job	Job
Path	xCSR	xCSR	xCSR	xCSR	xCSR	xCSR	xCSR
1	xForeman	xForeman	xForeman	xForeman	xForeman	xForeman	xForeman
2	xQC2	xCSR	xCSR	xAssembly	xAssembly	Proof	xCSR
3	xCSR	xCSR	xAssembly	Proof	xAssembly	xForeman	xAssembly
4	xForeman	xForeman	xCSR	xCSR	xCSR	xAssembly	xCSR
5	xCSR	xCSR	xAssembly	xCSR	xForeman	xForeman	xAssembly
6	xAssembly	xForeman	xCSR	Clients	xCSR	xAssembly	Proof
7	xAssembly	xCSR	xForeman	xCSR	xForeman	Proof	xAssembly
8	xAssembly	Clients	xQC2	xForeman	xAssembly	xCSR	xCSR
9	xQC2	0	Proof	xCSR	xCSR	xForeman	Clients
10	xCSR	0	xCSR	xAssembly	xForeman	xCSR	xCSR
11	xAssembly	0	xForeman	xQC2	xAssembly	xForeman	xForeman
12	Proof	0	xAssembly	xCSR	xCSR	xCSR	xAssembly
13	Proof	0	Proof	xForeman	xForeman	xAssembly	xForeman
14	xAssembly	0	xAssembly	xCSR	xAssembly	xQC2	xQC2
15	Proof	0	xQC2	Clients	xCSR	xForeman	xCSR
16	xForeman	0	xCSR	0	xForeman	xCSR	xForeman
17	xAssembly	0	xCSR	0	xQC2	xForeman	xAssembly
18	xQC2	0	xForeman	0	xCSR	xAssembly	xForeman
19	xCSR	0	xCSR	0	Clients	xCSR	xAssembly
20	xForeman	0	xAssembly	0	xCSR	xCSR	xQC2
21	xCSR	0	Proof	0	xAssembly	xAssembly	xForeman
22	xForeman	0	xForeman	0	xQC2	Proof	xAssembly
23	xCSR	0	xAssembly	0	xForeman	xCSR	xAssembly
24	xForeman	0	xForeman	0	xAssembly	Clients	xCSR
25	xAssembly	0	xCSR	0	xQC2	xCSR	xForeman
26	xForeman	0	Clients	0	xCSR	xAssembly	xQC2
27	xQC2	0	xCSR	0	xForeman	xCSR	xCSR
28	xForeman	0	Clients	0	xQC2	xAssembly	Clients
29	xAssembly	0	xCSR	0	xCSR	Proof	0
30	xQC2	0	xAssembly	0	Clients	xCSR	0
31	xCSR	0	xForeman	0	xCSR	Clients	0
32	Clients	0	xAssembly	0	xForeman	0	0
33	0	0	xAssembly	0	xQC2	0	0
34	0	0	xAssembly	0	xForeman	0	0
35	0	0	xForeman	0	xQC2	0	0
36	0	0	xAssembly	0	Proof	0	0
37	0	0	xCSR	0	xForeman	0	0
38	0	0	Clients	0	xAssembly	0	0
39	0	0	0	0	xCSR	0	0
40	0	0	0	0	Clients	0	0

Appendix B: Layout of Arena® Model

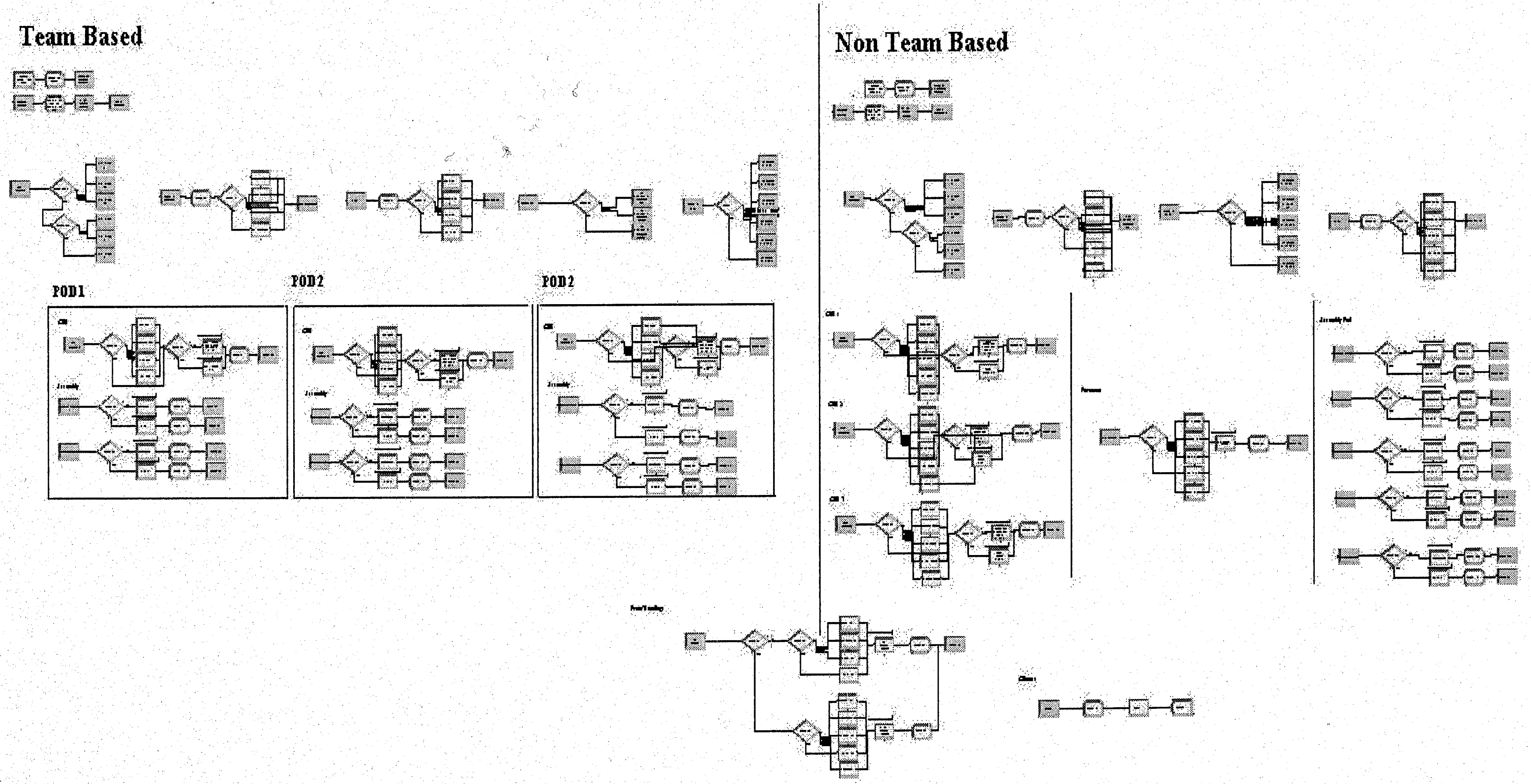


Figure B-1: Layout of Arena® model for current-state

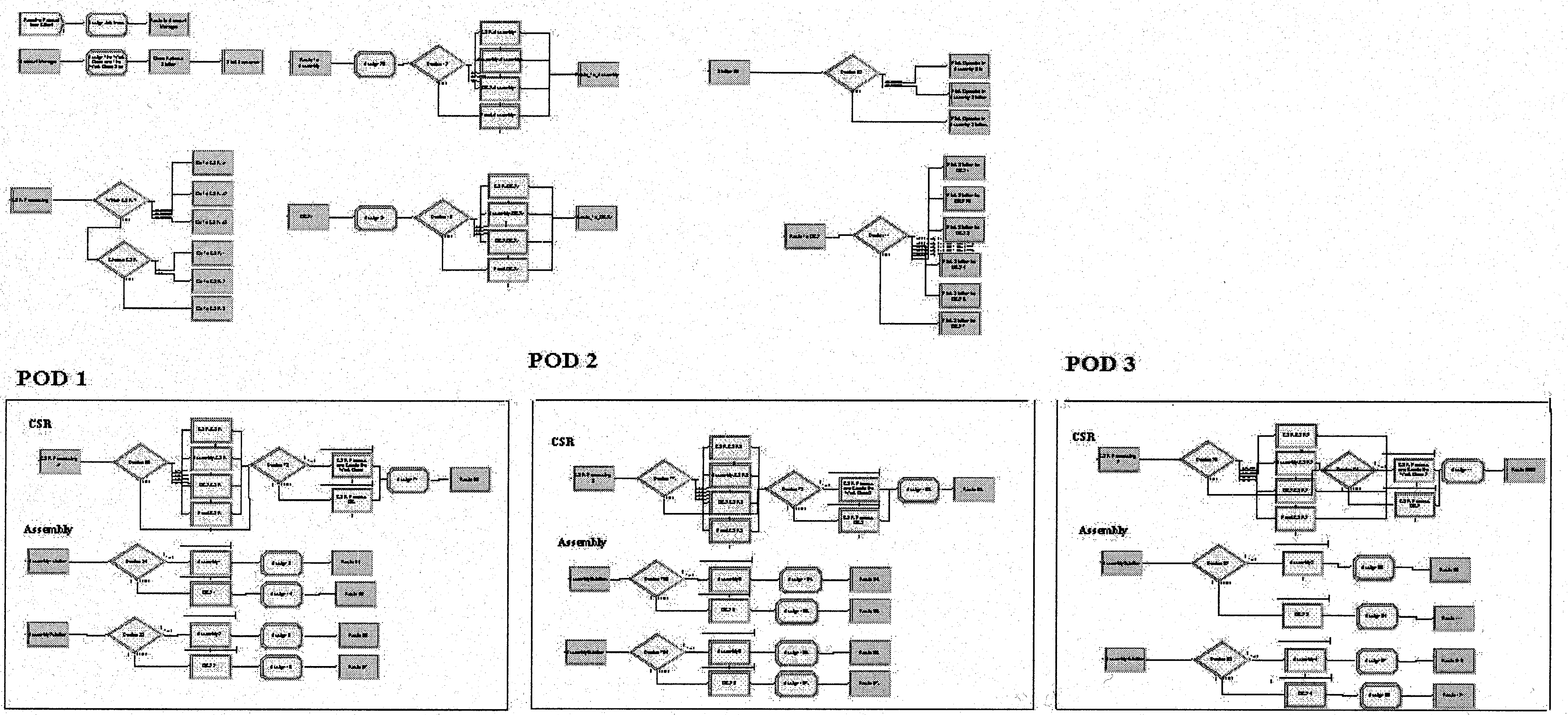


Figure B-2: Team-based category Arena® model for current-state

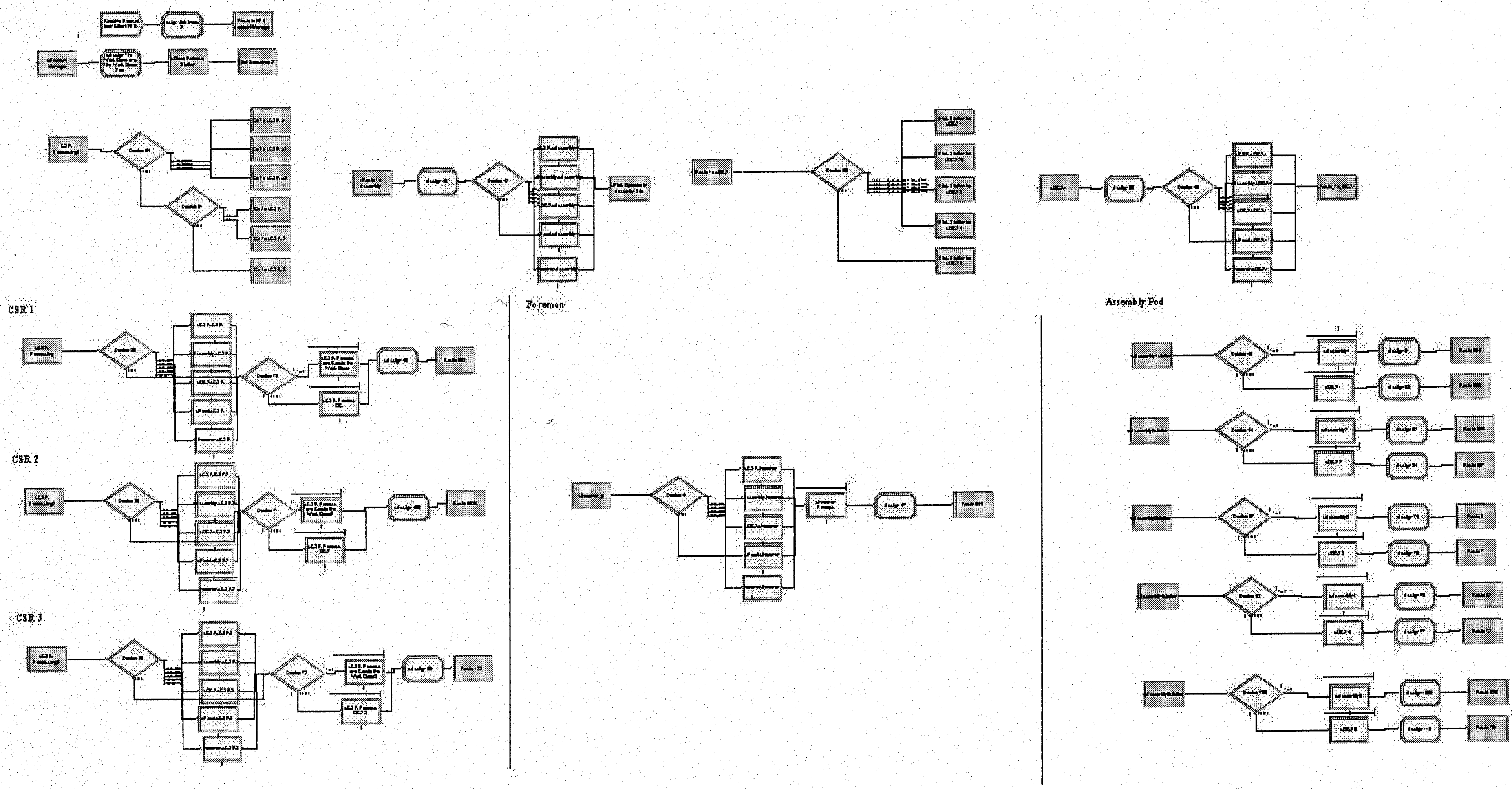


Figure B-3: Non-team-based category Arena® model for current-state

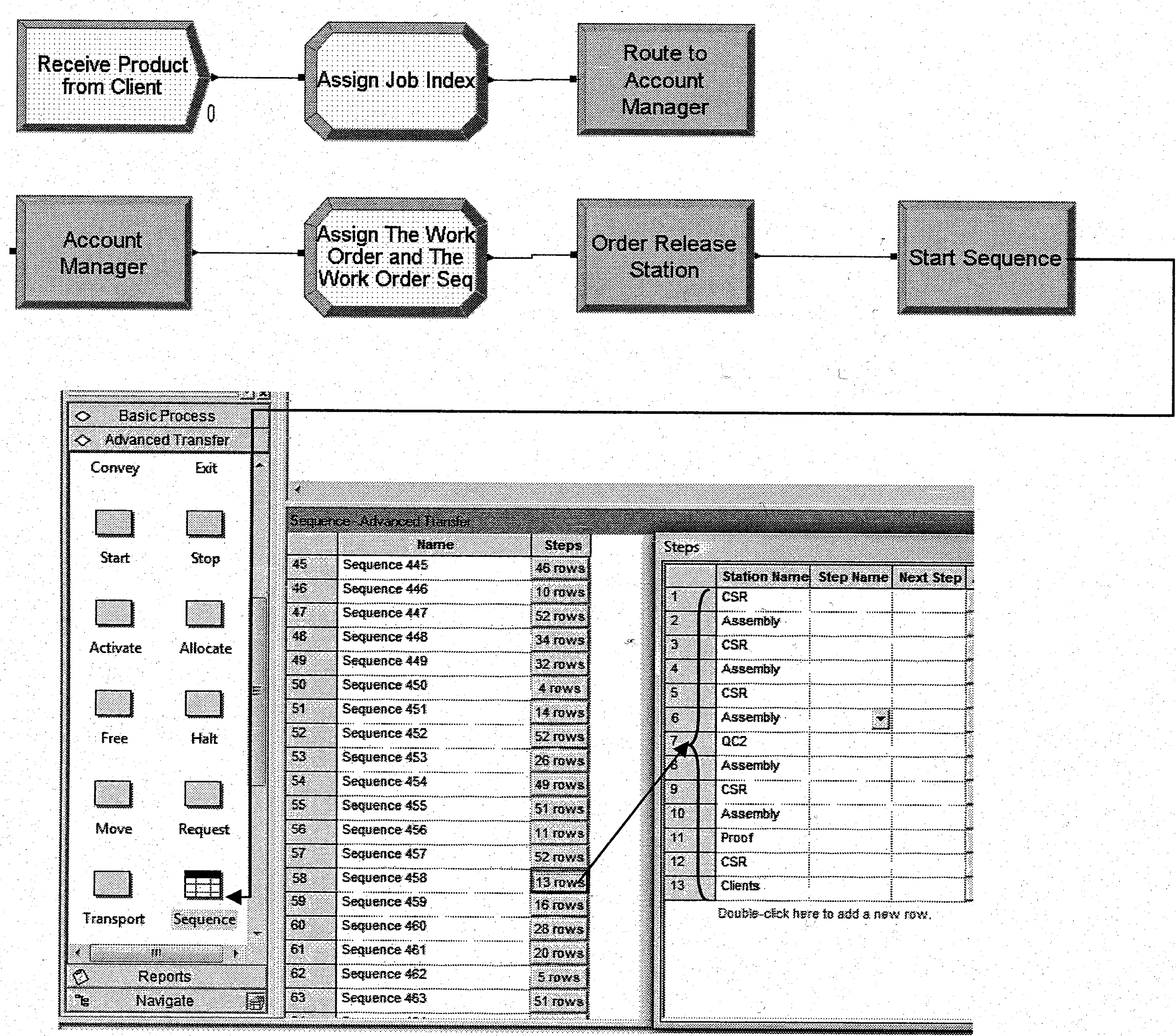


Figure B-4: Layout of Arena® team-based (starting sequences)

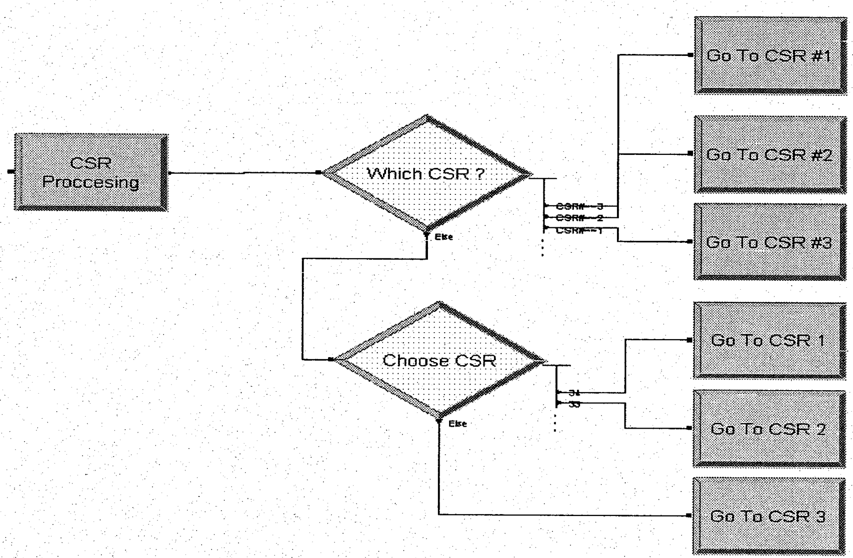


Figure B-5: Layout of Arena® team-based category (route to CSR)

CSR

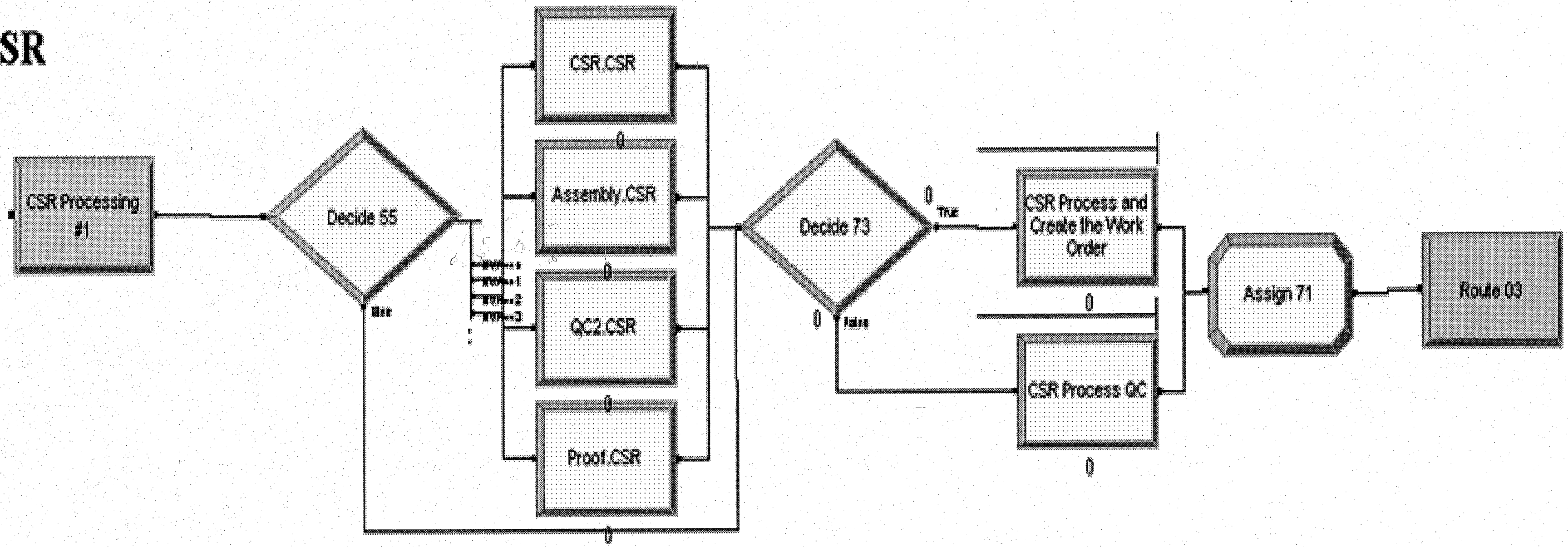


Figure B-6: Layout of Arena® team-based category (CSR processing task)

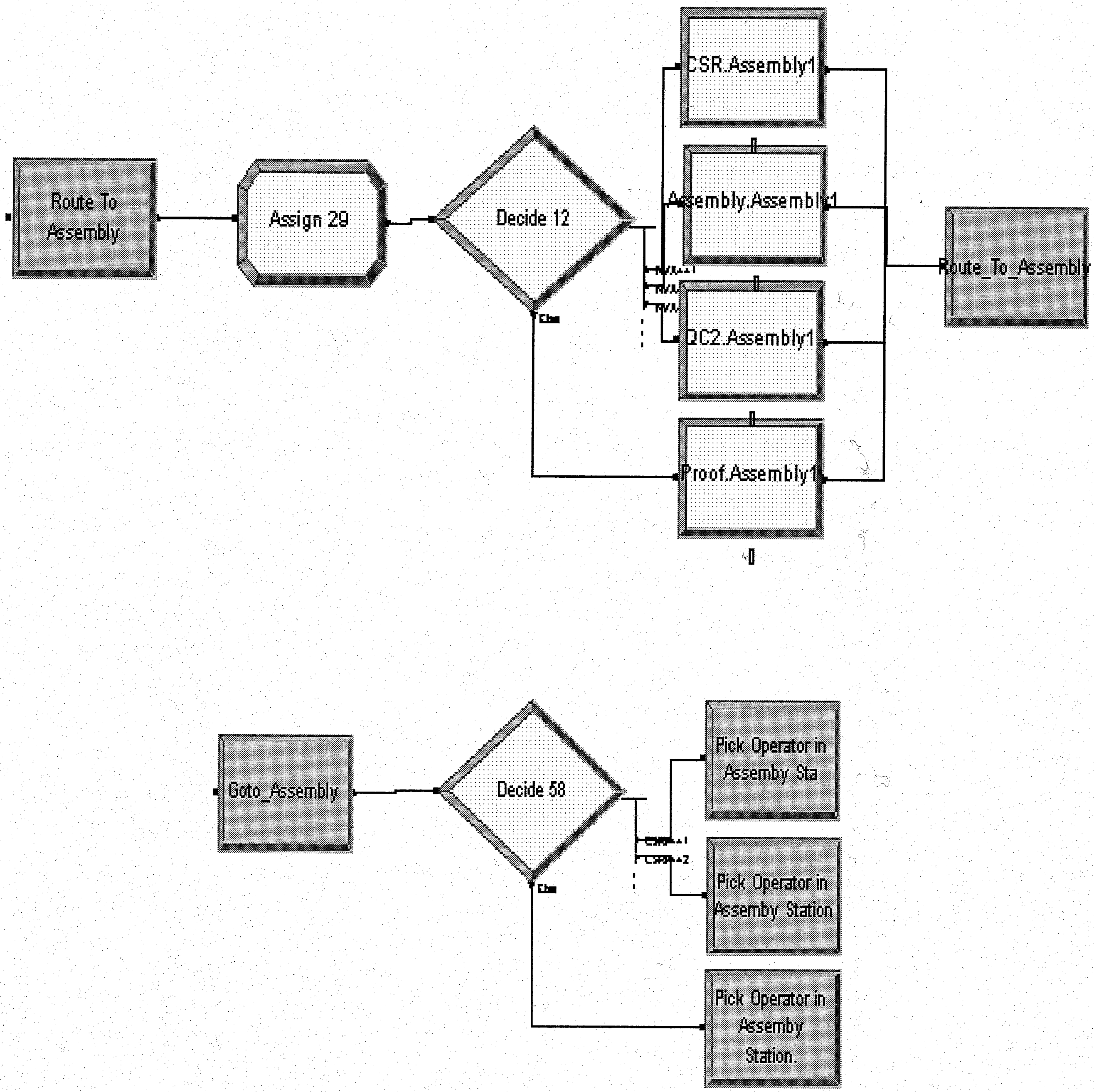


Figure B-7: Layout of Arena® team-base category (route to assembly)

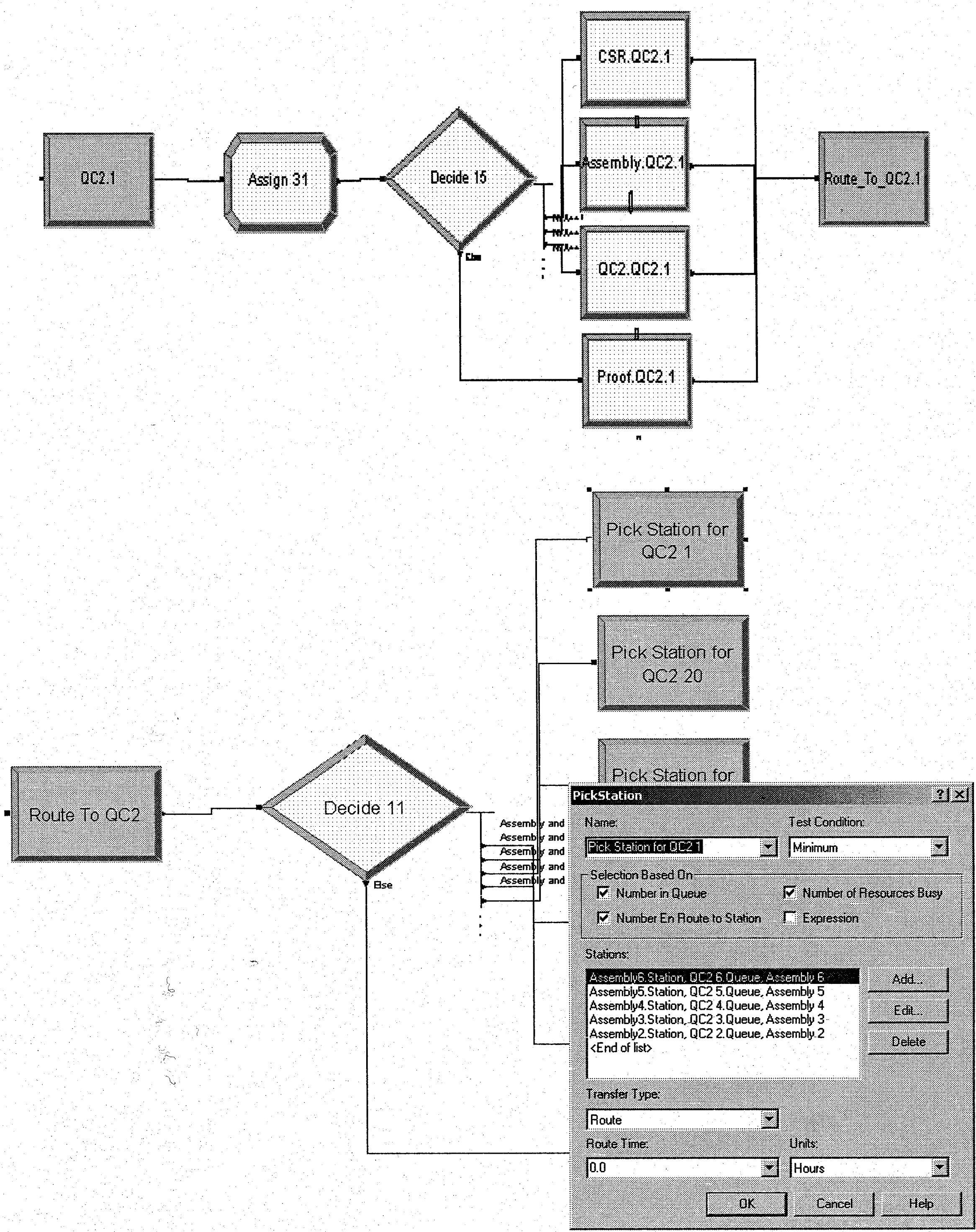


Figure B-8: Layout of Arena® team-base category (route to QC2)

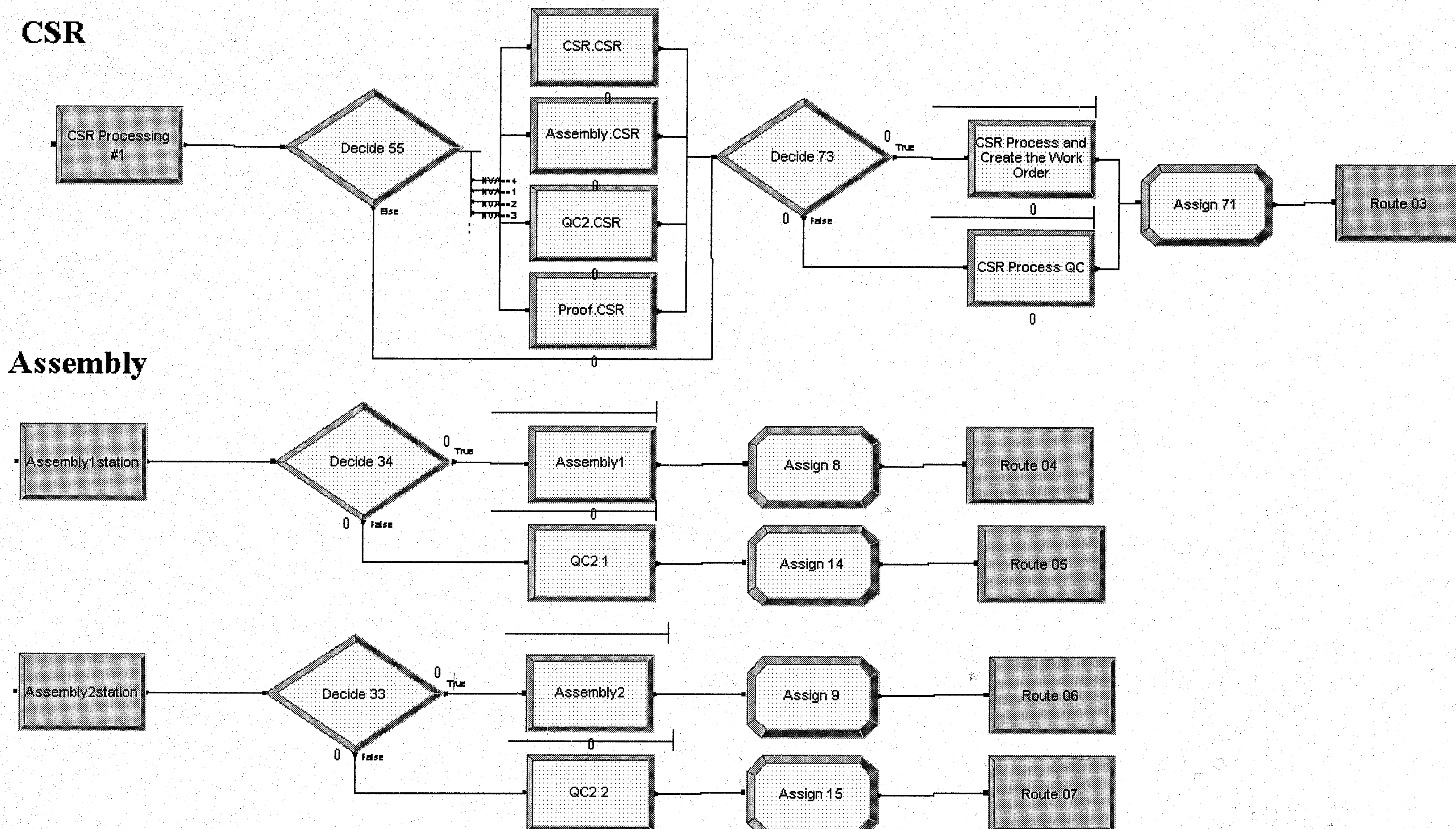


Figure B-9: Layout of Arena® team-based category (POD 1)

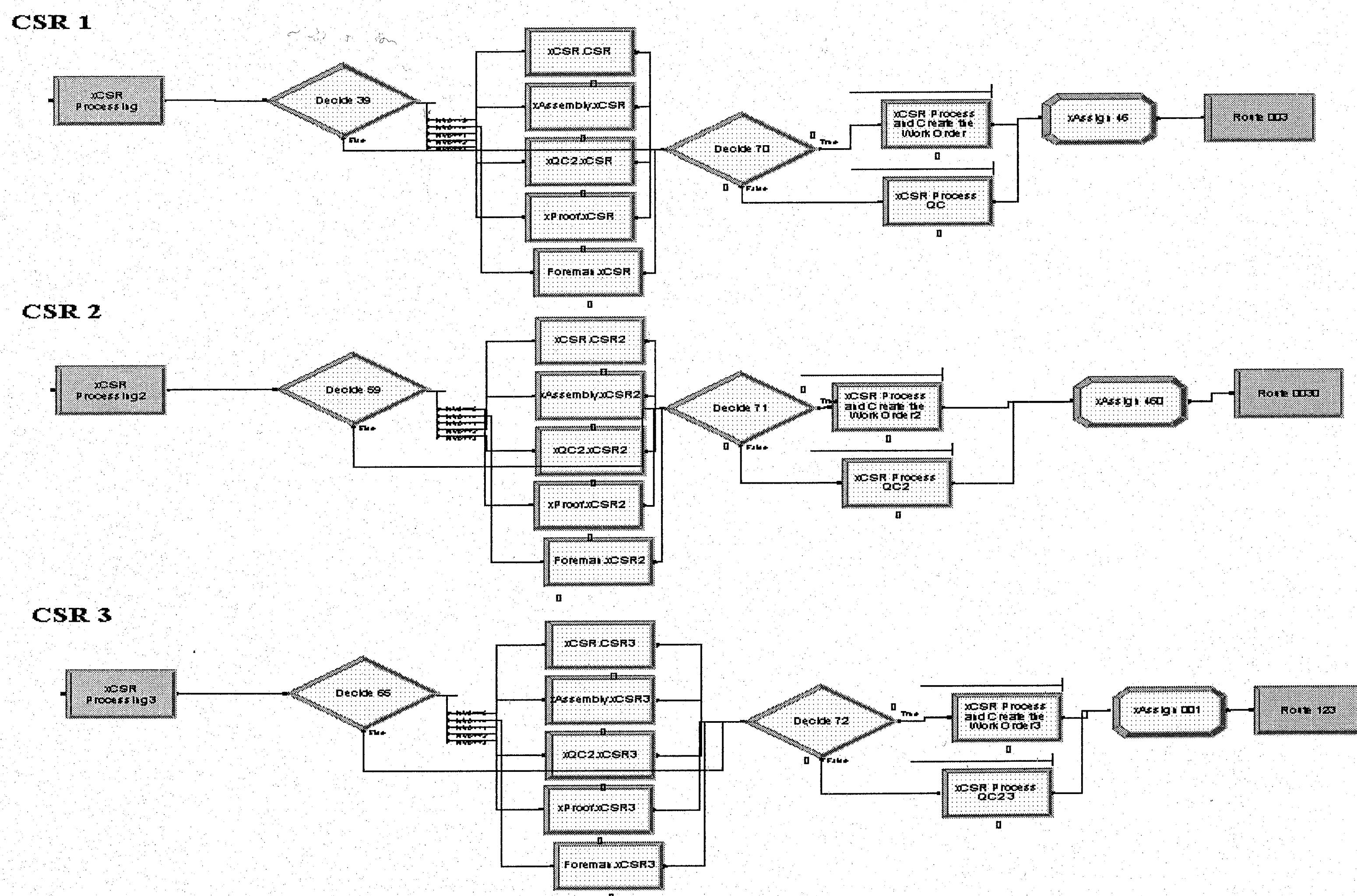


Figure B-10: Layout of Arena® non-team-based category (CSR task)

Foreman

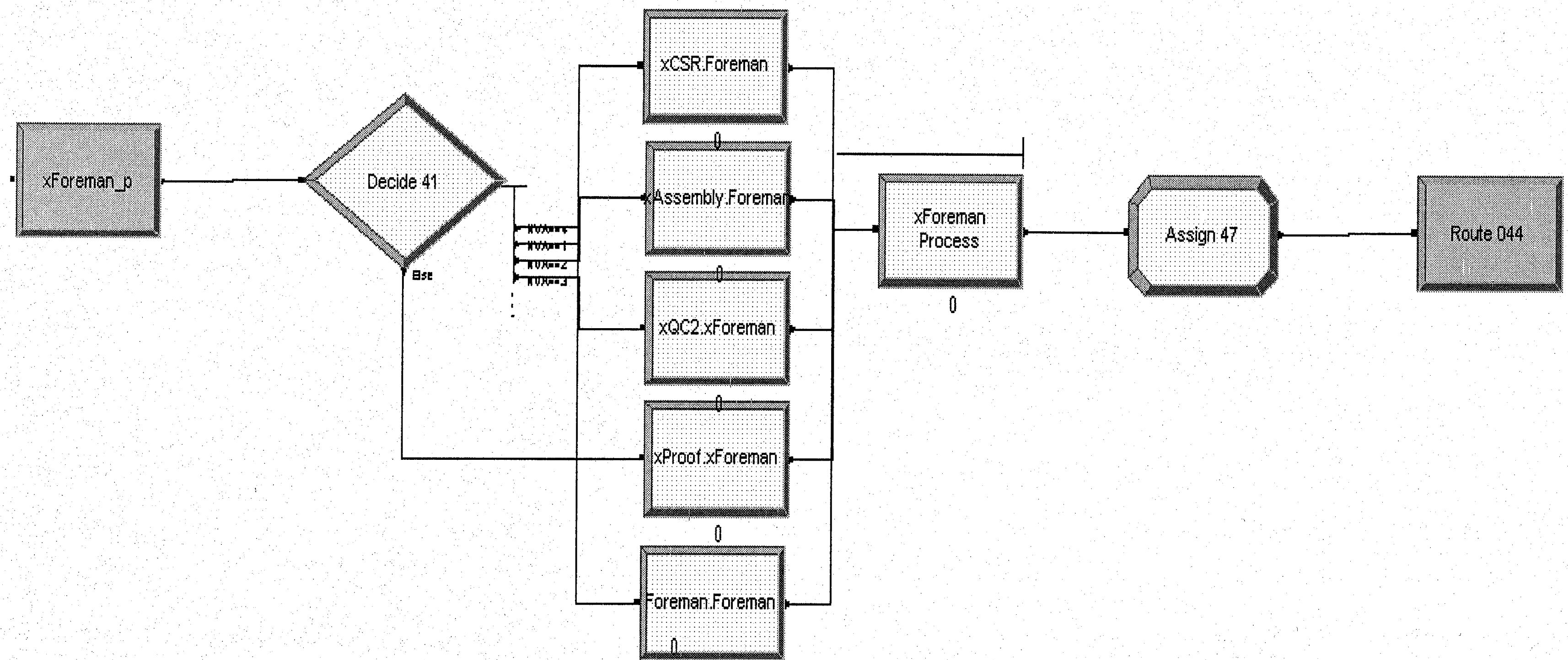


Figure B-11: Layout of Arena® non-team-based category (foreman task)

Assembly Pod

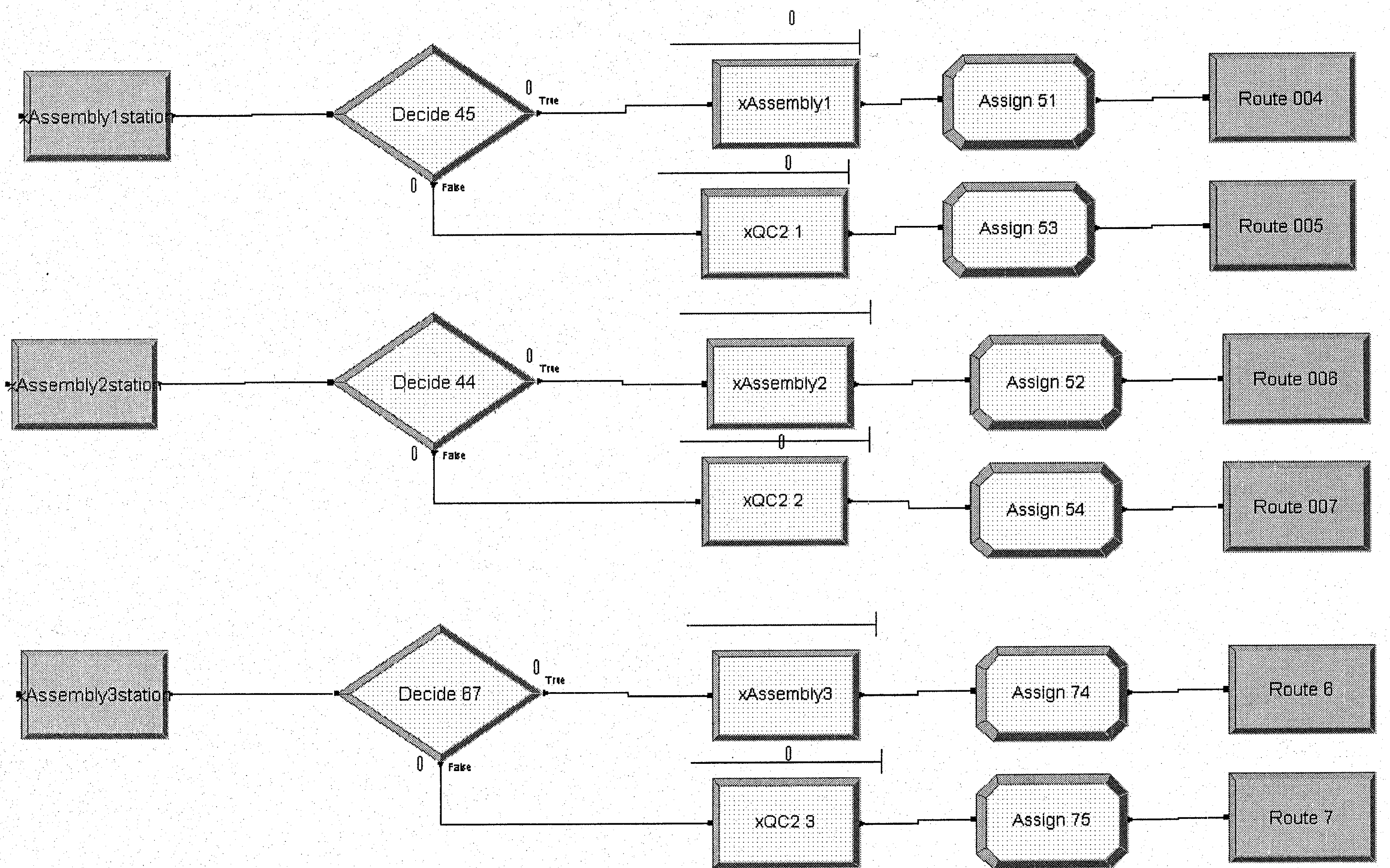


Figure B-12: Layout of Arena® non-team-based category (assembly and QC2)

Proof Reading:

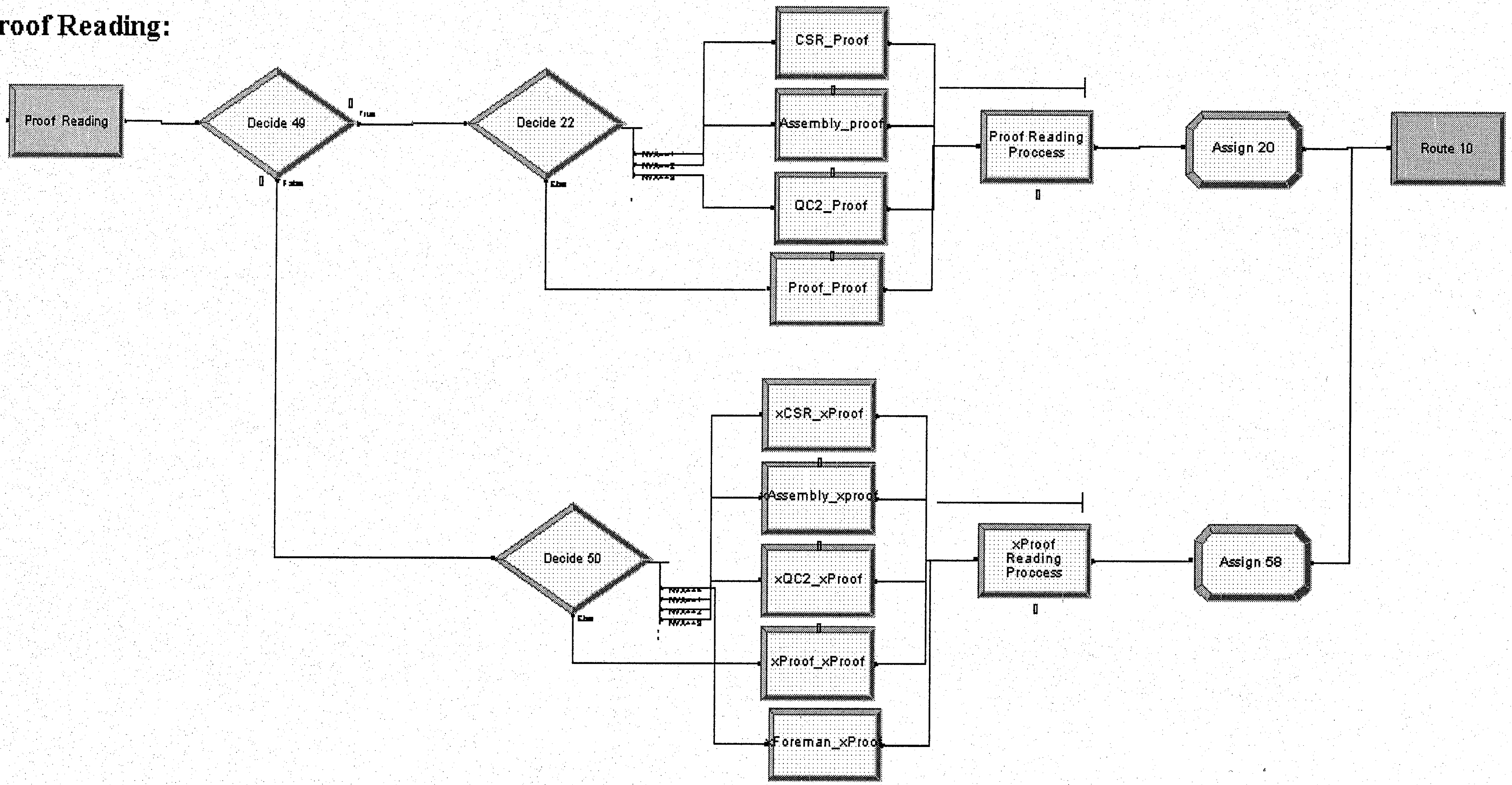
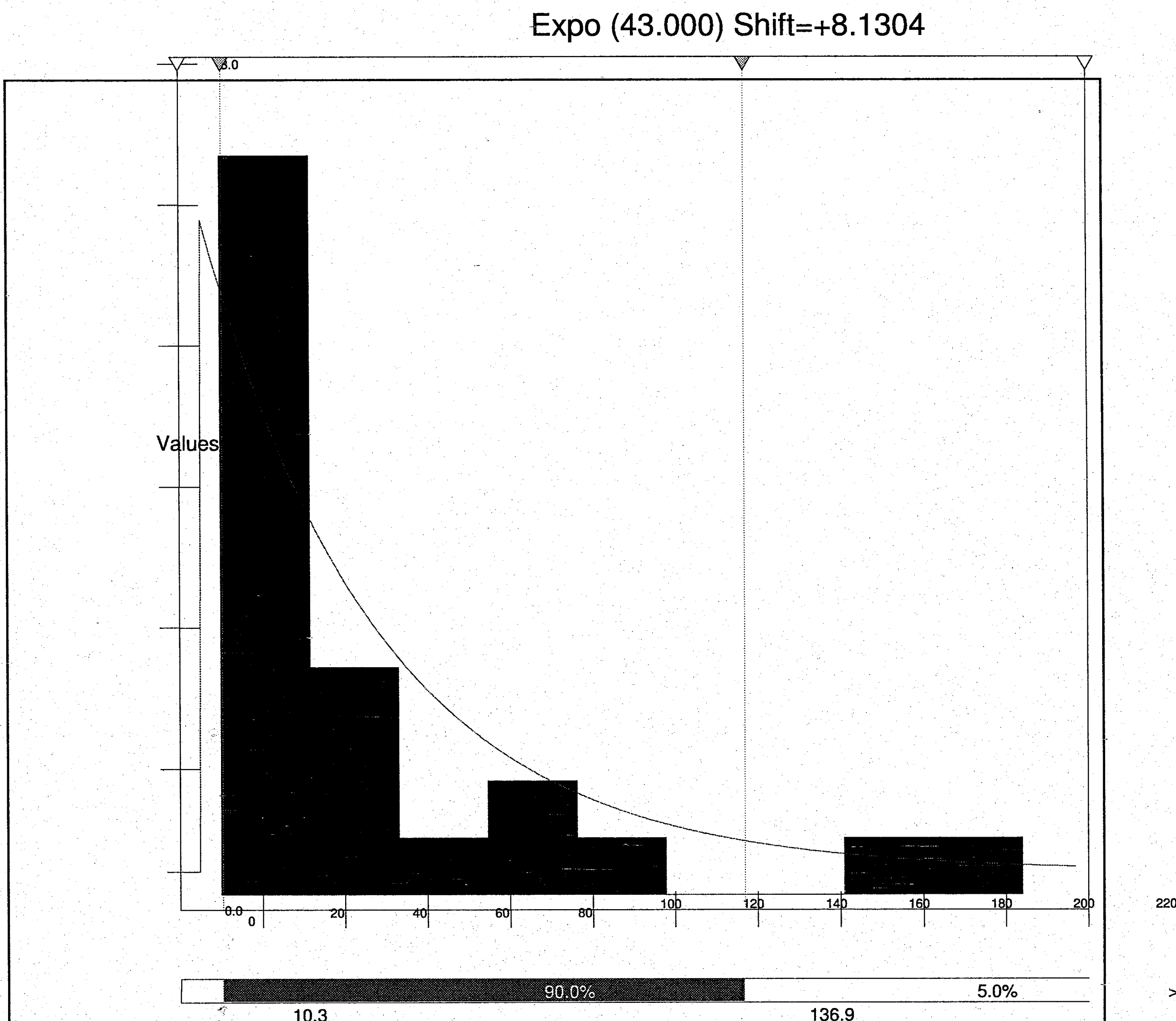


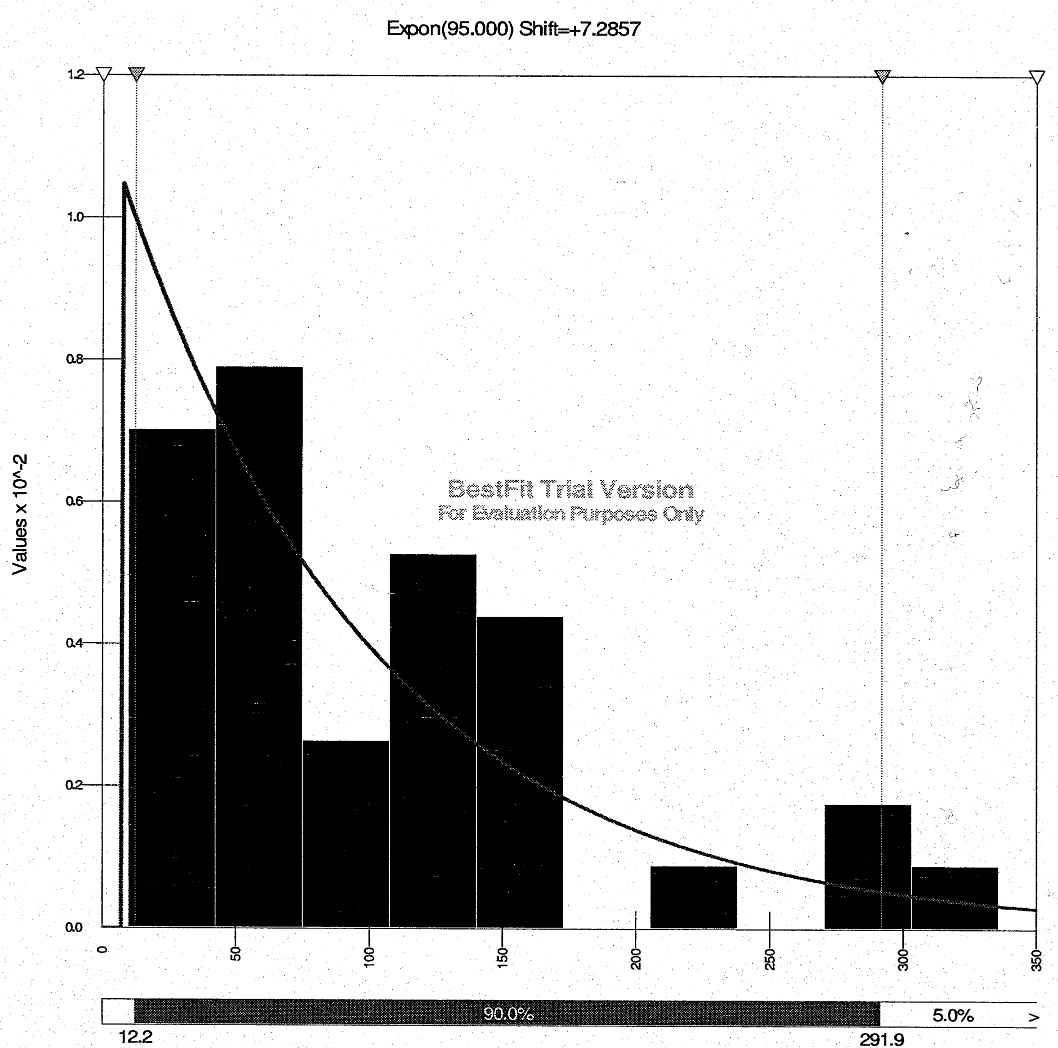
Figure B-13 : Layout of Arena® (proofreading task)

Appendix C: Input Analysis



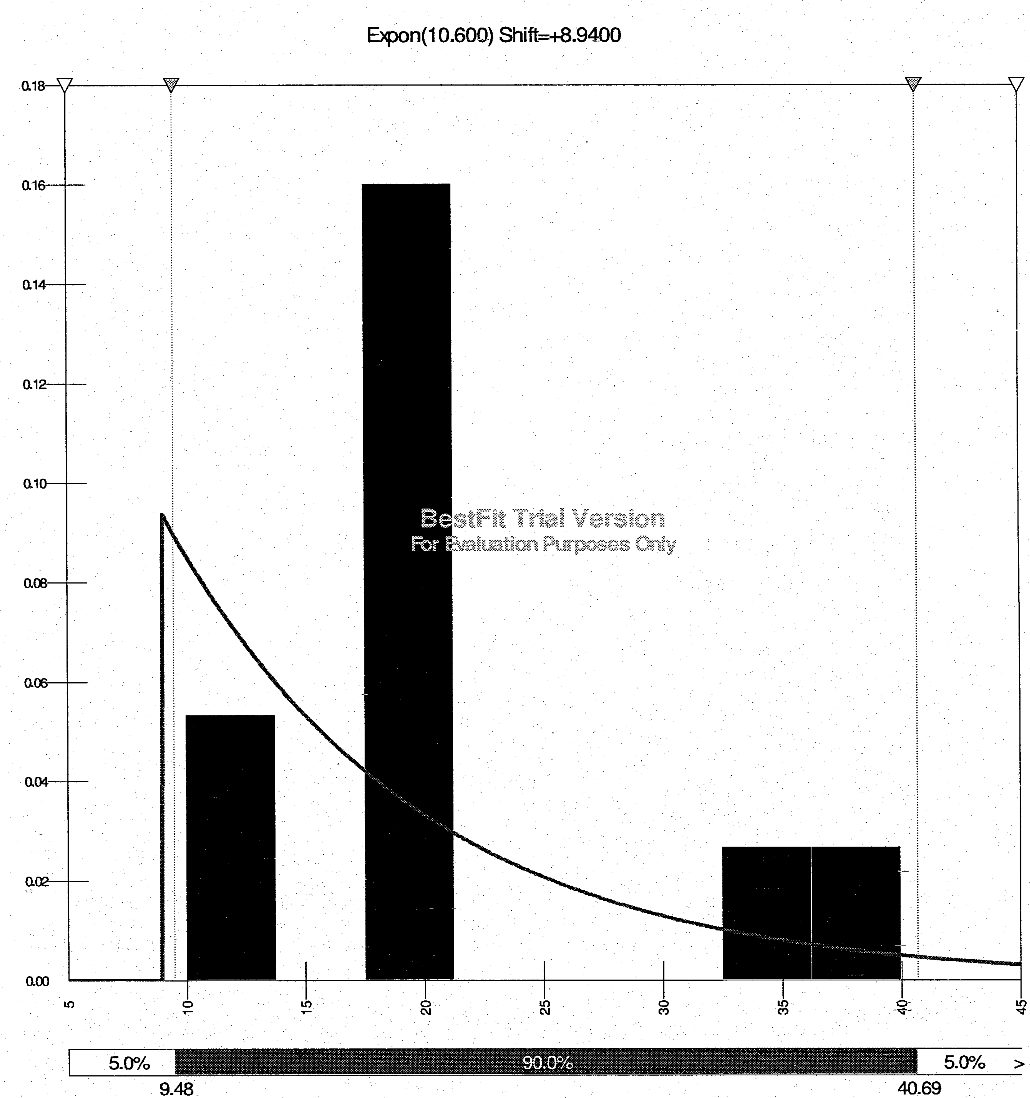
N/A	Chi-Sq	A-D	K-S
Test Value	5.478	0.8733	0.2247
P Value	0.2416	0.025 <= p <= 0.05	0.025 <= p <= 0.05
Rank	1	5	6
C.Val @ 0.75	1.9226	N/A	N/A
C.Val @ 0.5	3.3567	N/A	N/A
C.Val @ 0.25	5.3853	0.4885	0.1653
C.Val @ 0.15	6.7449	0.5925	0.1836
C.Val @ 0.1	7.7794	0.6740	0.1967
C.Val @ 0.05	9.4877	0.8486	0.2169

Figure C-1: Input modeling of the data for value-added time for CSR (non-team-based)



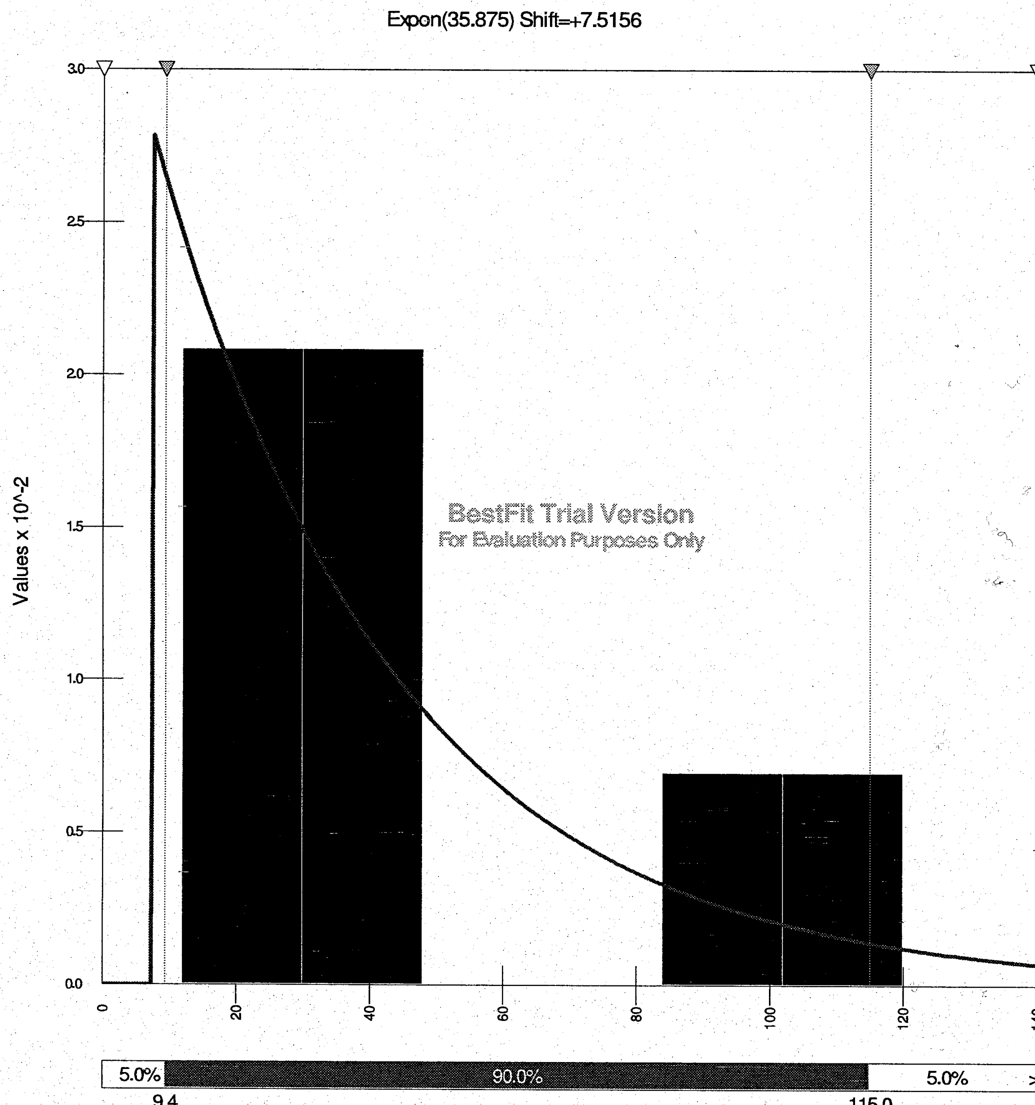
N/A	Chi-Sq	A-D	K-S
Test Value	11.60	0.7636	0.1485
P Value	0.0715	0.05 <= p <= 0.1	0.15 <= p <= 0.25
Rank	9	7	10
C.Val @ 0.75	3.4546	N/A	N/A
C.Val @ 0.5	5.3481	N/A	N/A
C.Val @ 0.25	7.8408	0.5289	0.1357
C.Val @ 0.15	9.4461	0.6417	0.1509
C.Val @ 0.1	10.6446	0.7308	0.1619
C.Val @ 0.05	12.5916	0.9249	0.1787
C.Val @ 0.025	14.4494	1.0697	0.1925
C.Val @ 0.01	16.8119	1.4069	0.2045
C.Val @ 0.005	18.5476	N/A	N/A

Figure C-2: Input modeling of the data for value-added time for assembly (non-team-based)



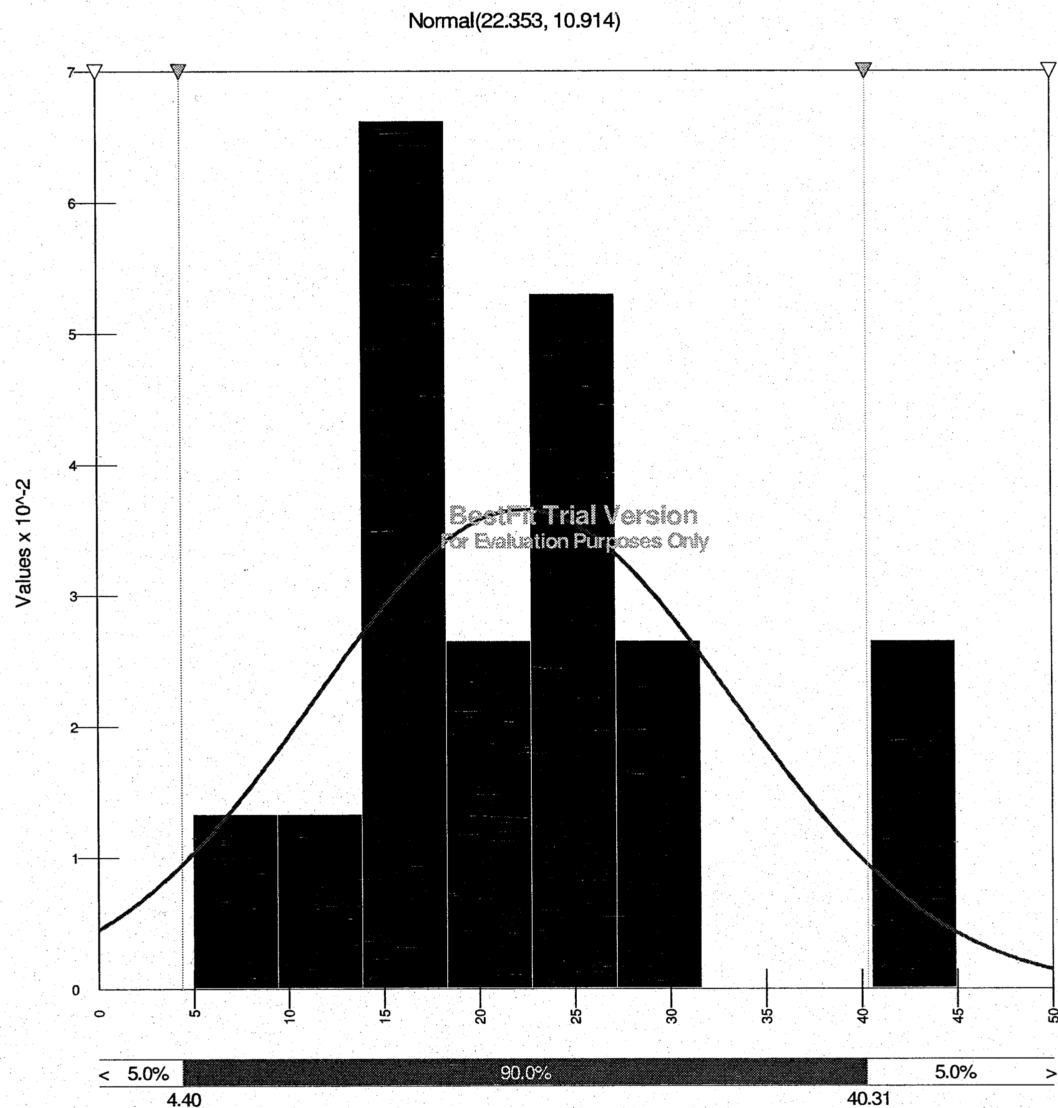
N/A	Chi-Sq	A-D	K-S
Test Value	3.600	1.085	0.3746
P Value	0.0578	< 0.01	< 0.01
Rank	3	4	7
C.Val @ 0.75	0.1015	N/A	N/A
C.Val @ 0.5	0.4549	N/A	N/A
C.Val @ 0.25	1.3233	0.3811	0.2381
C.Val @ 0.15	2.0723	0.4615	0.2634
C.Val @ 0.1	2.7055	0.5224	0.2811
C.Val @ 0.05	3.8415	0.6434	0.3090
C.Val @ 0.025	5.0239	0.7469	0.3314
C.Val @ 0.01	6.6349	0.9455	0.3539
C.Val @ 0.005	7.8794	N/A	N/A
C.Val @ 0.001	10.8276	N/A	N/A

Figure C-3: Input modeling of the data for value-added time for QC2 (non-team-based)



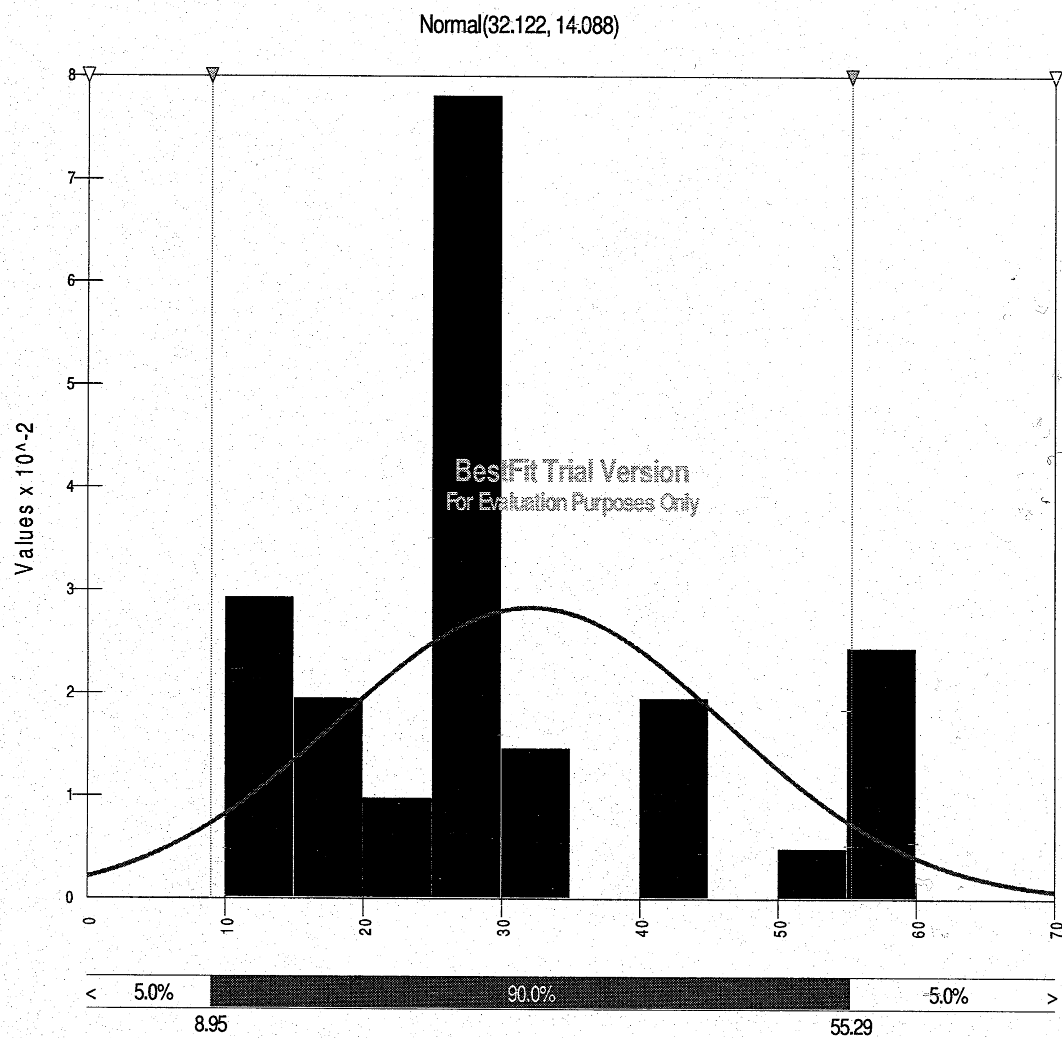
N/A	Chi-Sq	A-D	K-S
Test Value	5.478	0.8733	0.2247
P Value	0.2416	0.025 <= p <= 0.05	0.025 <= p <= 0.05
Rank	1	5	6
C.Val @ 0.75	1.9226	N/A	N/A
C.Val @ 0.5	3.3567	N/A	N/A
C.Val @ 0.25	5.3853	0.4885	0.1653
C.Val @ 0.15	6.7449	0.5925	0.1836
C.Val @ 0.1	7.7794	0.6740	0.1967
C.Val @ 0.05	9.4877	0.8486	0.2169
C.Val @ 0.025	11.1433	0.9822	0.2335
C.Val @ 0.01	13.2767	1.2827	0.2483
C.Val @ 0.005	14.8603	N/A	N/A
C.Val @ 0.001	18.4668	N/A	N/A

Figure C-4: Input modeling of the data for value-added time for proofreading (non-team-based)



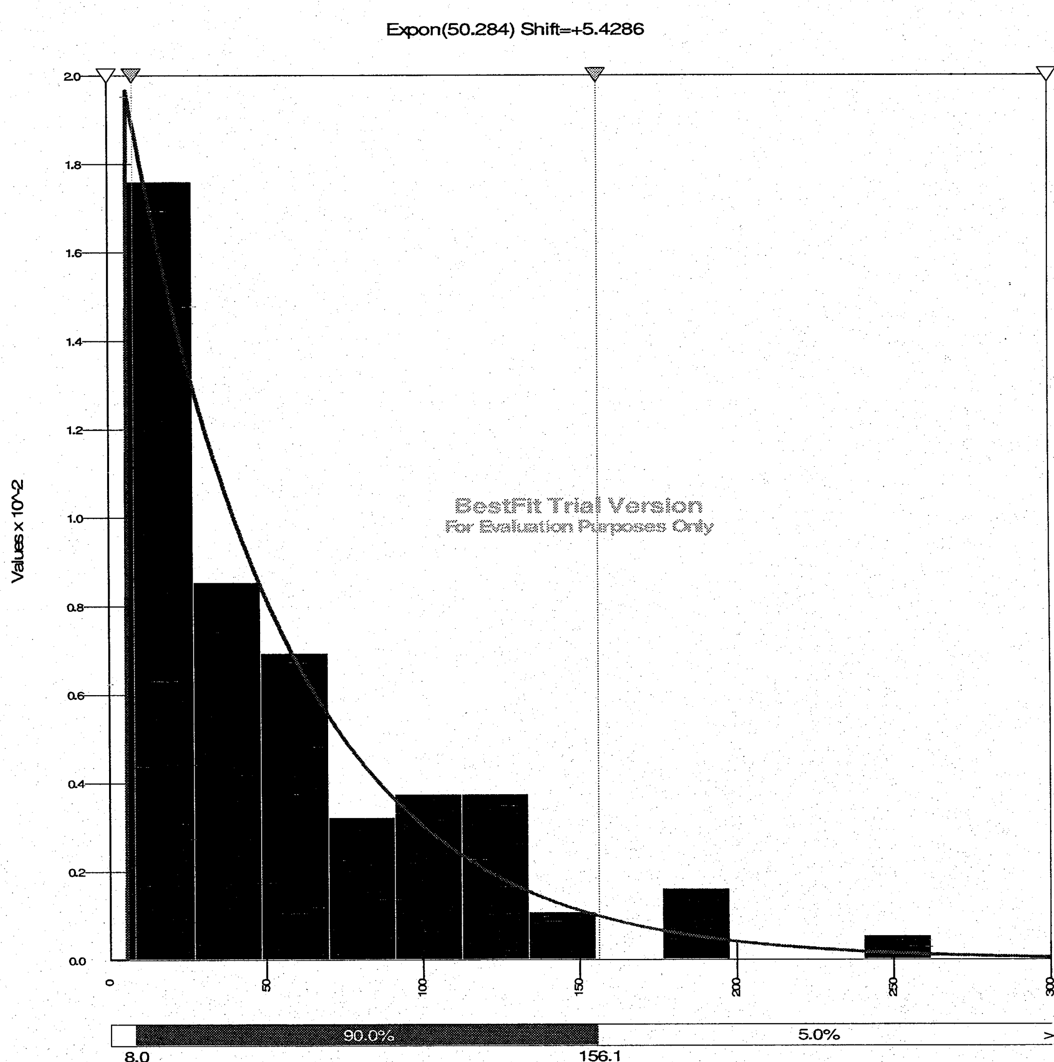
N/A	Chi-Sq	A-D	K-S
Test Value	5.478	0.8733	0.2247
P Value	0.2416	0.025 <= p <= 0.05	0.025 <= p <= 0.05
Rank	1	5	6
C.Val @ 0.75	1.9226	N/A	N/A
C.Val @ 0.5	3.3567	N/A	N/A
C.Val @ 0.25	5.3853	0.4885	0.1653
C.Val @ 0.15	6.7449	0.5925	0.1836
C.Val @ 0.1	7.7794	0.6740	0.1967
C.Val @ 0.05	9.4877	0.8486	0.2169
C.Val @ 0.025	11.1433	0.9822	0.2335
C.Val @ 0.01	13.2767	1.2827	0.2483
C.Val @ 0.005	14.8603	N/A	N/A
C.Val @ 0.001	18.4668	N/A	N/A

Figure C-5: Input modeling of the data for value-added time for final QC (non-team-based)



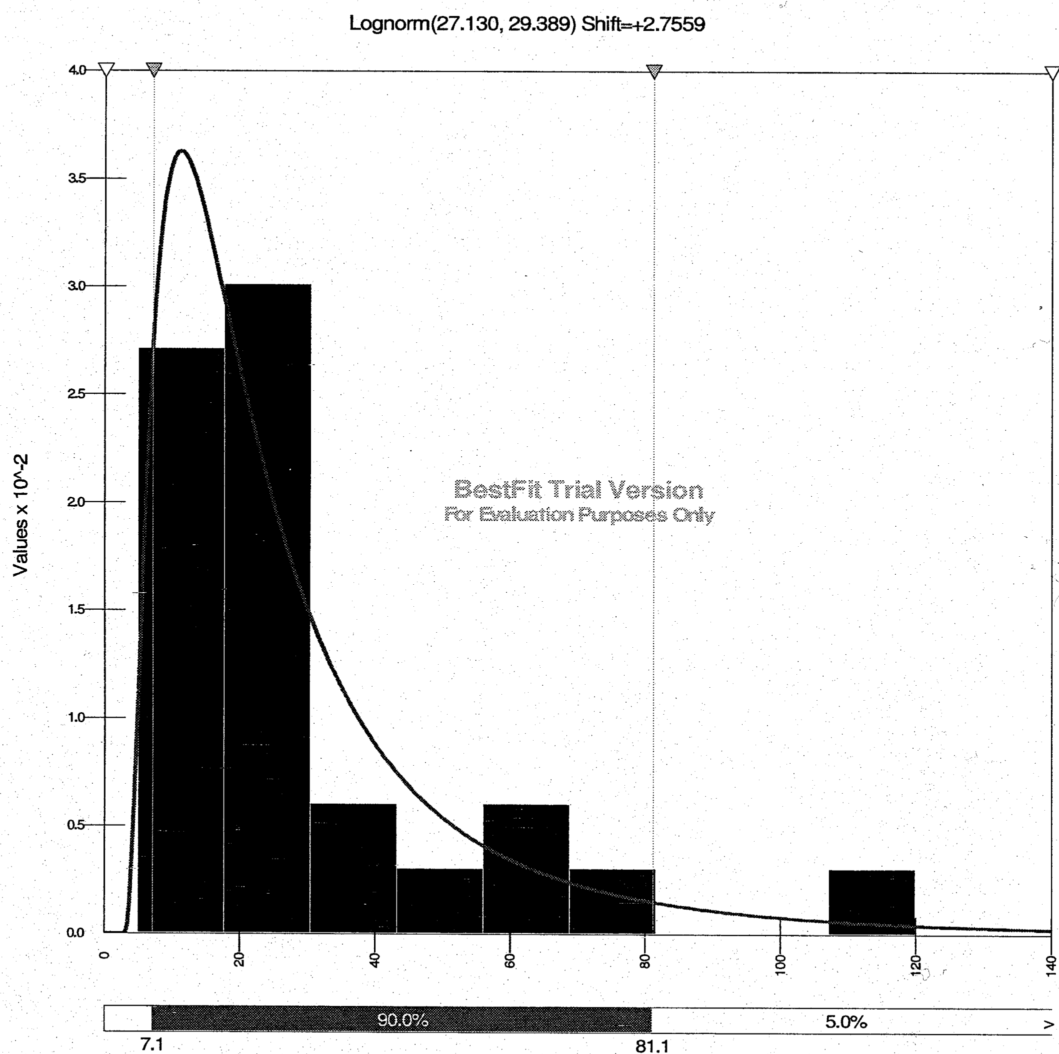
N/A	Chi-Sq	A-D	K-S
Test Value	5.478	0.8733	0.2247
P Value	0.2416	0.025 <= p <= 0.05	0.025 <= p <= 0.05
Rank	1	5	6
C.Val @ 0.75	1.9226	N/A	N/A
C.Val @ 0.5	3.3567	N/A	N/A
C.Val @ 0.25	5.3853	0.4885	0.1653
C.Val @ 0.15	6.7449	0.5925	0.1836
C.Val @ 0.1	7.7794	0.6740	0.1967
C.Val @ 0.05	9.4877	0.8486	0.2169
C.Val @ 0.025	11.1433	0.9822	0.2335
C.Val @ 0.01	13.2767	1.2827	0.2483
C.Val @ 0.005	14.8603	N/A	N/A
C.Val @ 0.001	18.4668	N/A	N/A

Figure C-6: Input modeling of the data for value-added time for CSR (team-based)



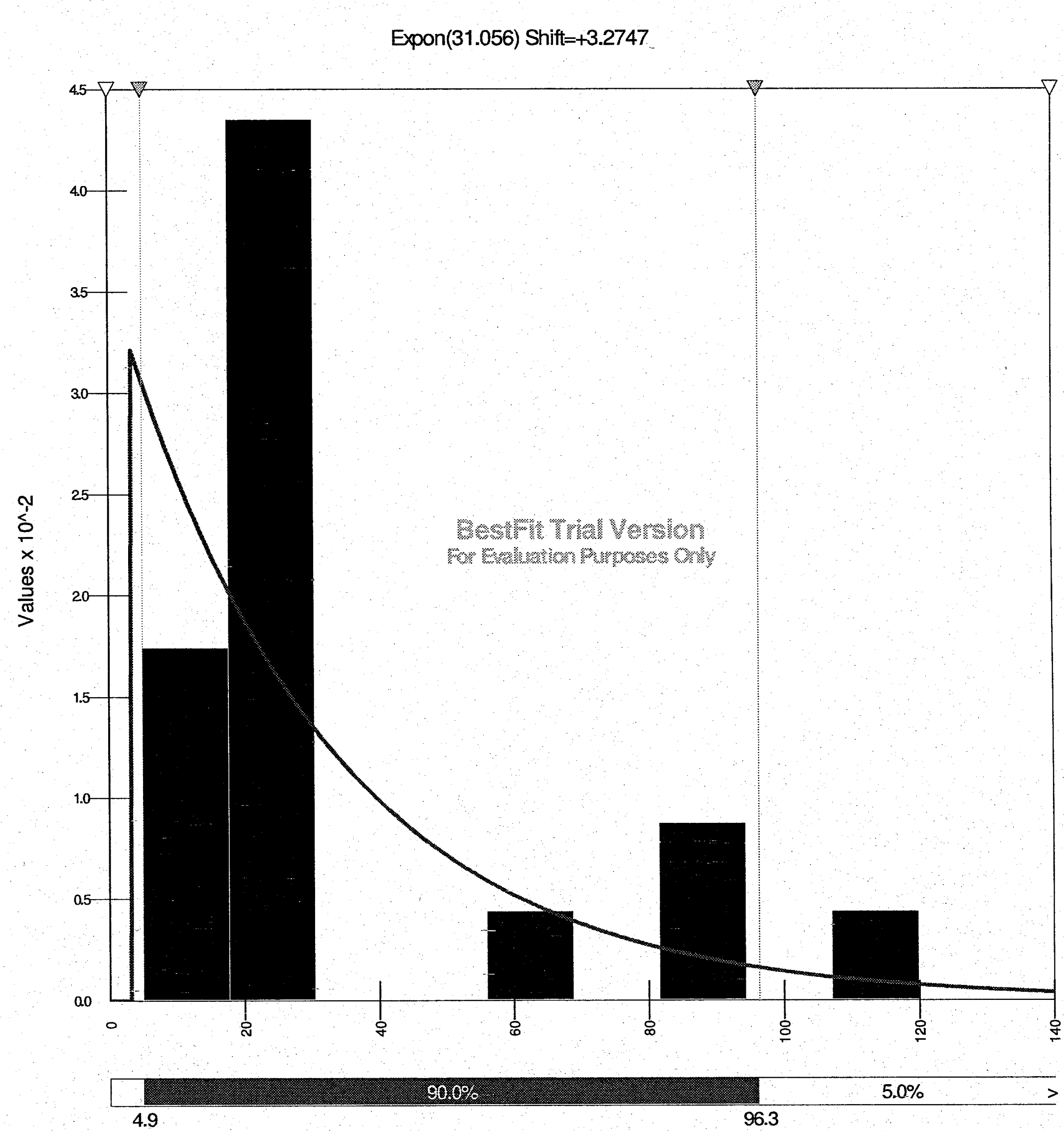
N/A	Chi-Sq	A-D	K-S
Test Value	5.478	0.8733	0.2247
P Value	0.2416	0.025 <= p <= 0.05	0.025 <= p <= 0.05
Rank	1	5	6
C.Val @ 0.75	1.9226	N/A	N/A
C.Val @ 0.5	3.3567	N/A	N/A
C.Val @ 0.25	5.3853	0.4885	0.1653
C.Val @ 0.15	6.7449	0.5925	0.1836
C.Val @ 0.1	7.7794	0.6740	0.1967
C.Val @ 0.05	9.4877	0.8486	0.2169
C.Val @ 0.025	11.1433	0.9822	0.2335
C.Val @ 0.01	13.2767	1.2827	0.2483
C.Val @ 0.005	14.8603	N/A	N/A
C.Val @ 0.001	18.4668	N/A	N/A

Figure C-7: Input modeling of the data for value-added time for assembly (team-based)



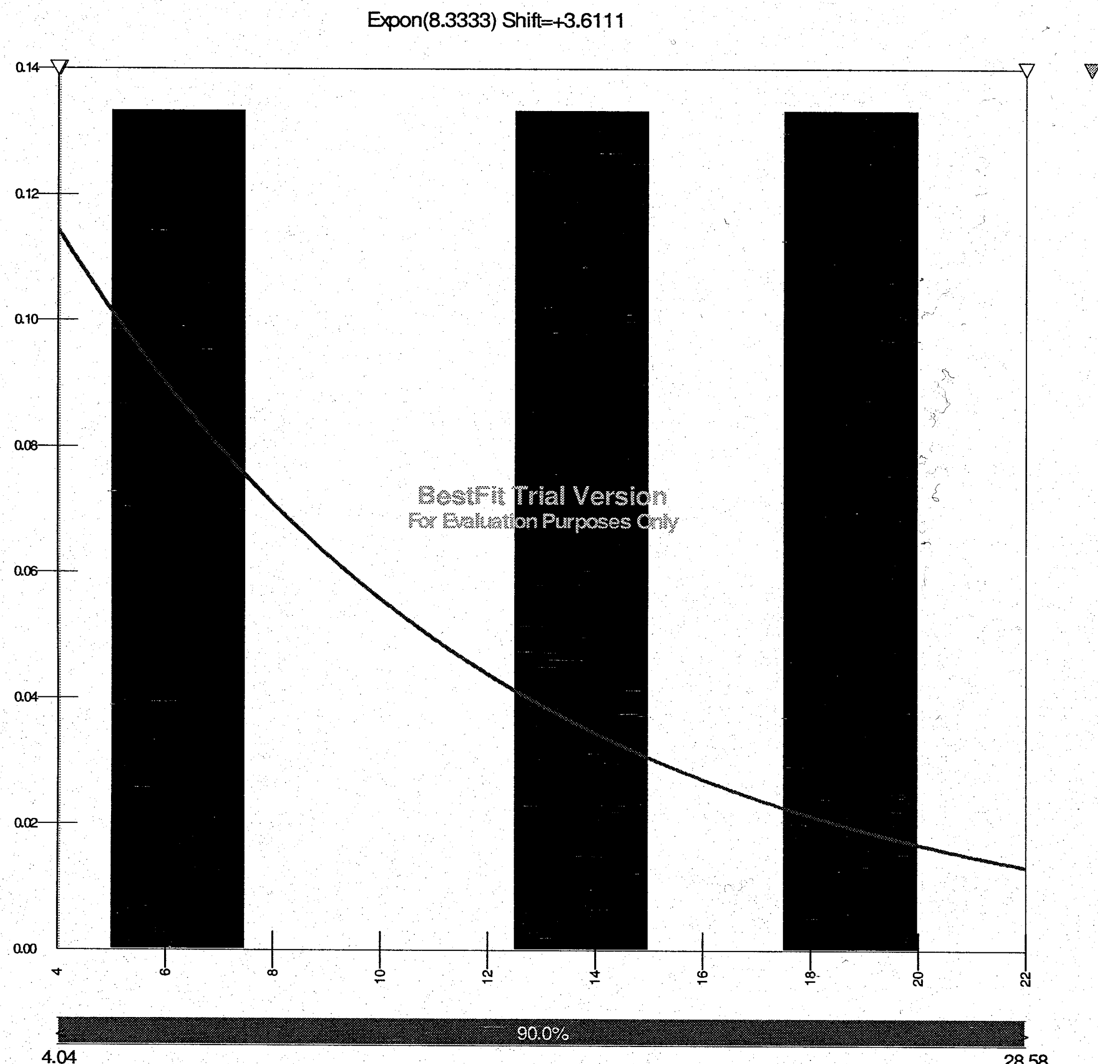
N/A	Chi-Sq	A-D	K-S
Test Value	32.95	1.913	0.2428
P Value	2.7036E-05	< 0.005	< 0.01
Rank	2	9	9
C.Val @ 0.75	4.2549	N/A	N/A
C.Val @ 0.5	6.3458	N/A	N/A
C.Val @ 0.25	9.0371	0.4610	N/A
C.Val @ 0.15	10.7479	0.5502	0.1188
C.Val @ 0.1	12.0170	0.6189	0.1255
C.Val @ 0.05	14.0671	0.7375	0.1371
C.Val @ 0.025	16.0128	0.8562	0.1525
C.Val @ 0.01	18.4753	1.0151	0.1586

Figure C-8: Input modeling of the data for value-added time for proofreading (team-based)



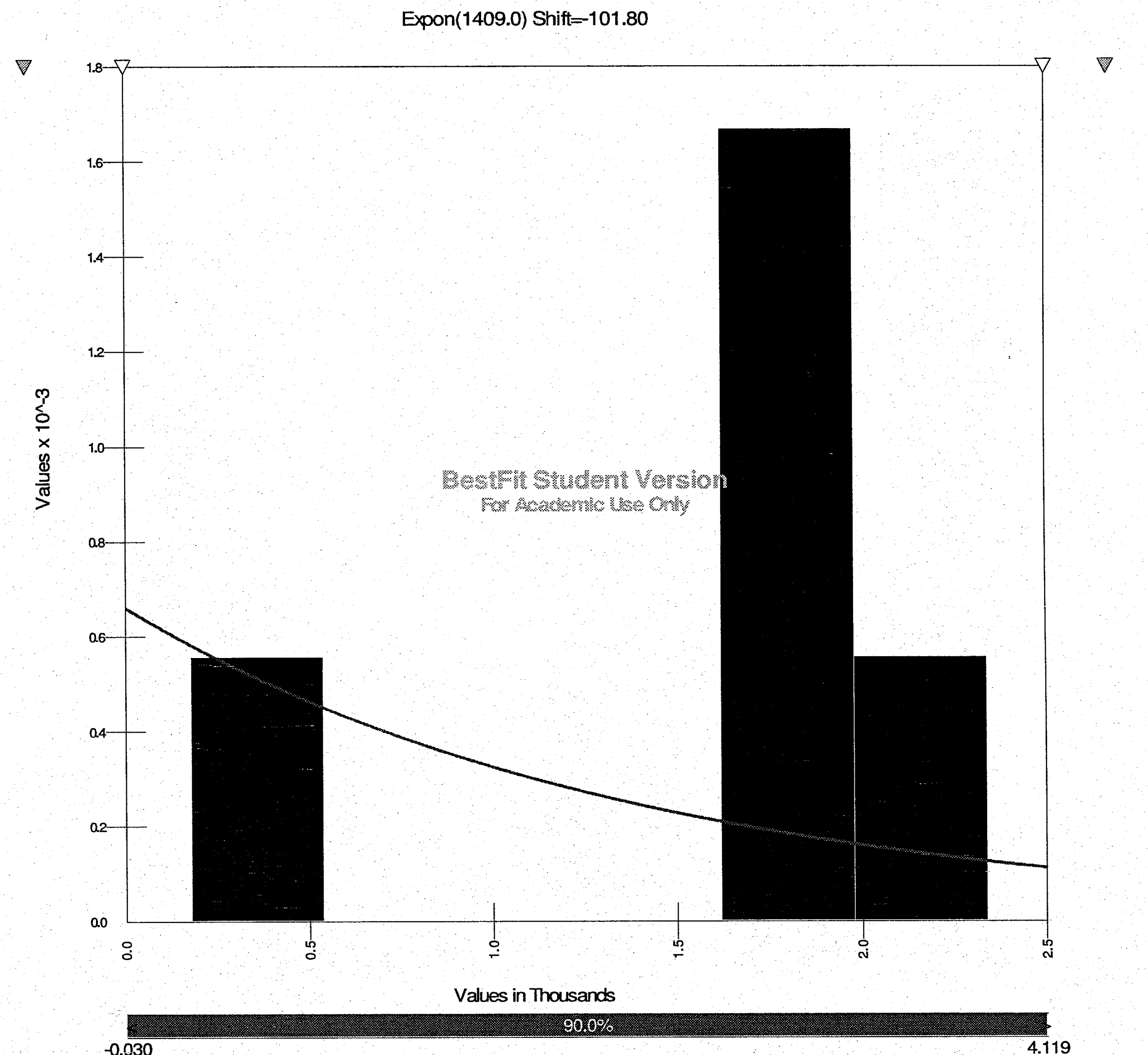
N/A	Chi-Sq	A-D	K-S
Test Value	1.111	0.6287	0.2007
P Value	0.7744	0.1 <= p <= 0.15	0.15 <= p <= 0.25
Rank	2	5	4
C.Val @ 0.75	1.2125	N/A	N/A
C.Val @ 0.5	2.3660	N/A	N/A
C.Val @ 0.25	4.1083	0.4603	0.1848
C.Val @ 0.15	5.3170	0.5582	0.2051
C.Val @ 0.1	6.2514	0.6343	0.2196
C.Val @ 0.05	7.8147	0.7951	0.2420
C.Val @ 0.025	9.3484	0.9208	0.2603
C.Val @ 0.01	11.3449	1.1953	0.2771

Figure C-9: Input modeling of the data for value-added time for QC (team-based)



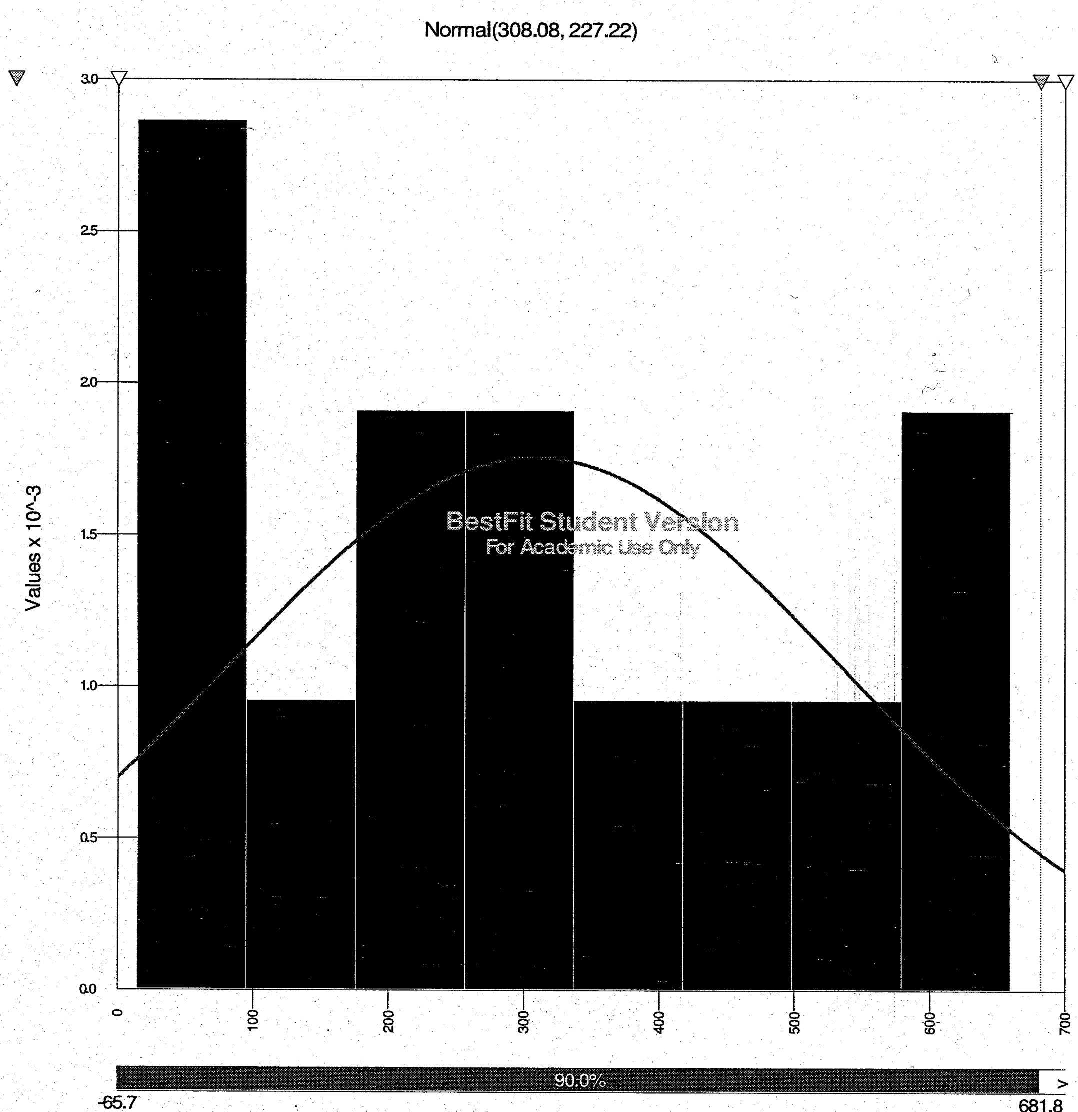
N/A	Chi-Sq	A-D	K-S
Test Value	5.478	0.8733	0.2247
P Value	0.2416	0.025 <= p <= 0.05	0.025 <= p <= 0.05
Rank	1	5	6
C.Val @ 0.75	1.9226	N/A	N/A
C.Val @ 0.5	3.3567	N/A	N/A
C.Val @ 0.25	5.3853	0.4885	0.1653
C.Val @ 0.15	6.7449	0.5925	0.1836
C.Val @ 0.1	7.7794	0.6740	0.1967
C.Val @ 0.05	9.4877	0.8486	0.2169
C.Val @ 0.025	11.1433	0.9822	0.2335
C.Val @ 0.01	13.2767	1.2827	0.2483
C.Val @ 0.005	14.8603	N/A	N/A
C.Val @ 0.001	18.4668	N/A	N/A

Figure C-10: Input modeling of the data for value-added time for final QC (team-based)



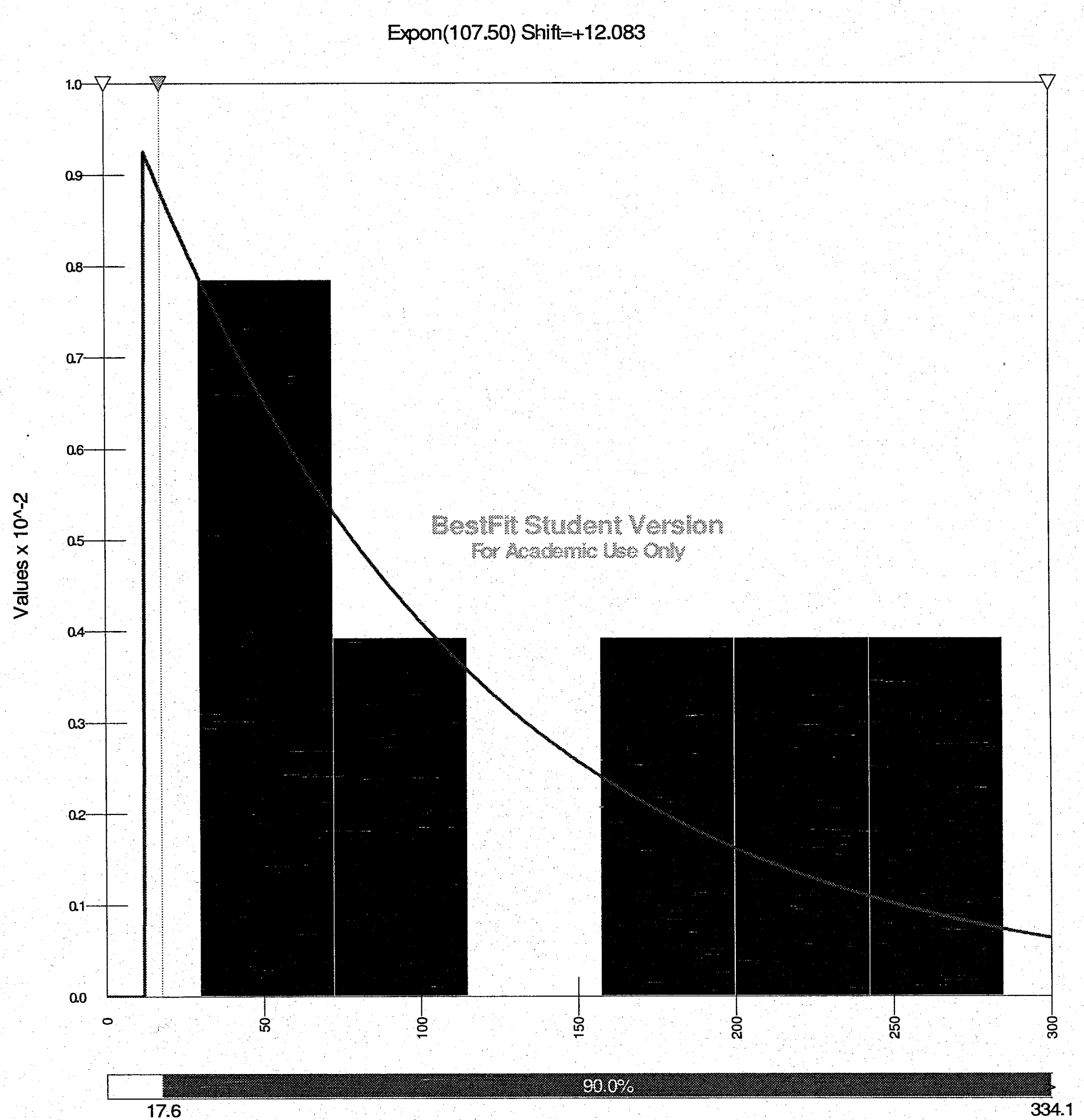
N/A	Chi-Sq	A-D	K-S
Test Value	1.800	1.333	0.5351
P Value	0.1797	< 0.01	< 0.01
Rank	1	6	9
C.Val @ 0.75	0.1015	N/A	N/A
C.Val @ 0.5	0.4549	N/A	N/A
C.Val @ 0.25	1.3233	0.2805	0.3054
C.Val @ 0.15	2.0723	0.3384	0.3350
C.Val @ 0.1	2.7055	0.3787	0.3546
C.Val @ 0.05	3.8415	0.4421	0.3868
C.Val @ 0.025	5.0239	0.5171	0.4119
C.Val @ 0.01	6.6349	0.6030	0.4436
C.Val @ 0.005	7.8794	N/A	N/A
C.Val @ 0.001	10.8276	N/A	N/A

Figure C-11: Input modeling of the data for non-value-added time from CSR-CSR (team-based)



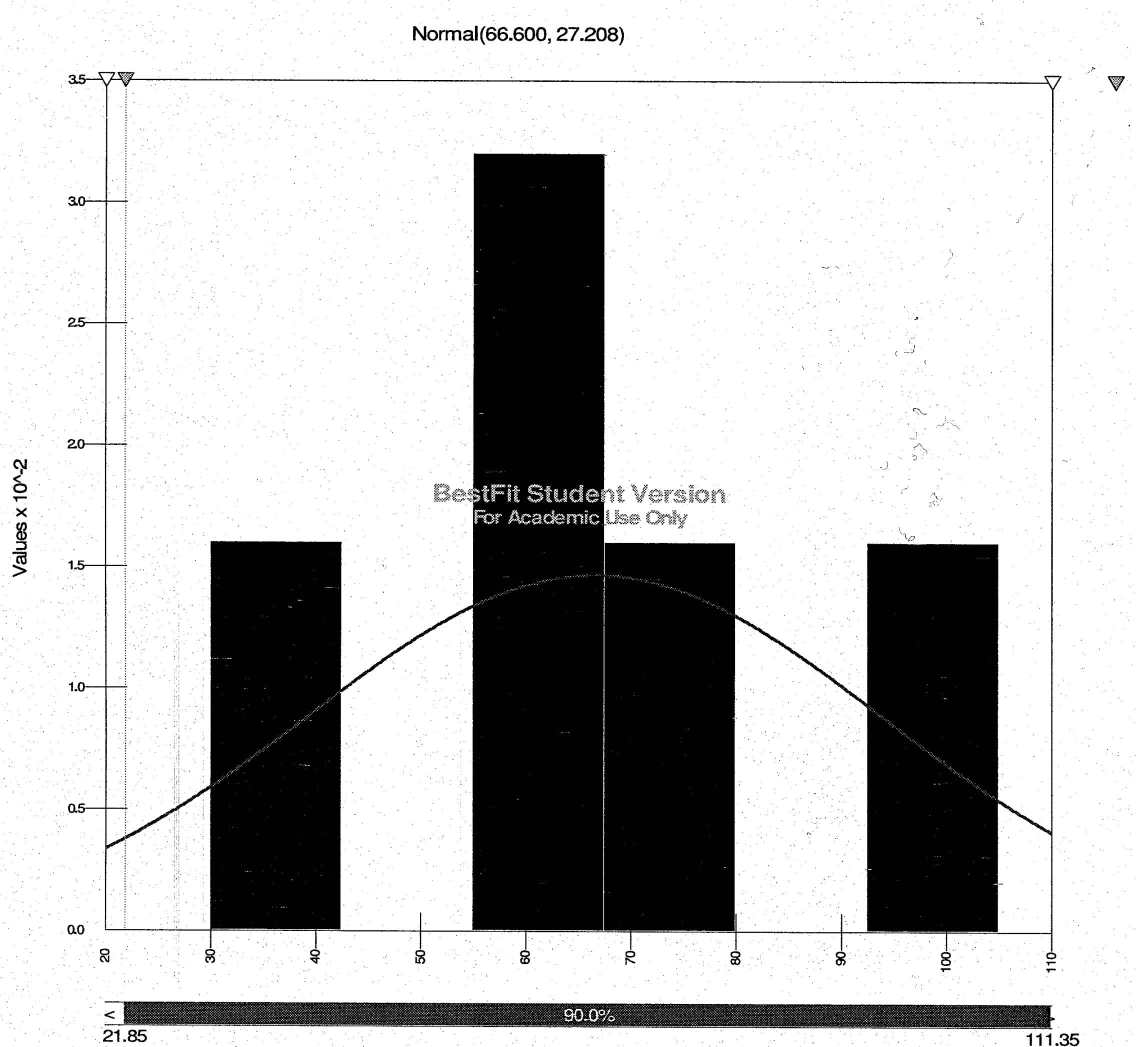
N/A A-C	Chi-Sq	A-D	K-S
Test Value	0.1538	0.2743	0.1203
P Value	0.9260	> 0.25	> 0.15
Rank	5	1	1
C.Val @ 0.75	0.5754	N/A	N/A
C.Val @ 0.5	1.3863	N/A	N/A
C.Val @ 0.25	2.7726	0.4388	N/A
C.Val @ 0.15	3.7942	0.5238	0.2023
C.Val @ 0.1	4.6052	0.5892	0.2138
C.Val @ 0.05	5.9915	0.7021	0.2336
C.Val @ 0.025	7.3778	0.8151	0.2597
C.Val @ 0.01	9.2103	0.9664	0.2701
C.Val @ 0.005	7.8794	N/A	N/A
C.Val @ 0.001	10.8276	N/A	N/A

Figure C-12: Input modeling of the data for non-value-added time from CSR-assembly (team-based)



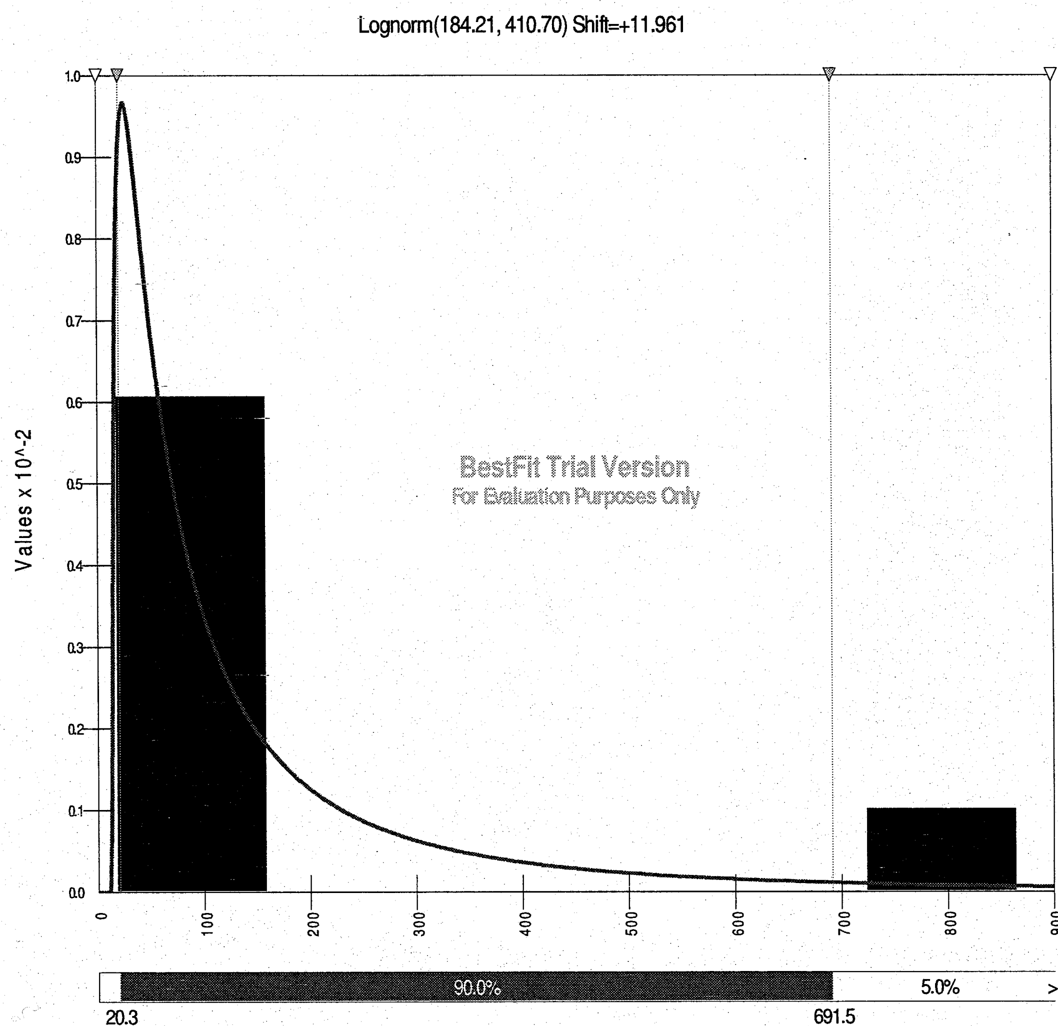
N/A A-P	Chi-Sq	A-D	K-S
Test Value	0.000	0.4199	0.2589
P Value	1.0000	0.05 <= p <= 0.1	> 0.25
Rank	1	7	10
C.Val @ 0.75	0.1015	N/A	N/A
C.Val @ 0.5	0.4549	N/A	N/A
C.Val @ 0.25	1.3233	0.3063	0.2884
C.Val @ 0.15	2.0723	0.3700	0.3172
C.Val @ 0.1	2.7055	0.4158	0.3368
C.Val @ 0.05	3.8415	0.4955	0.3684
C.Val @ 0.025	5.0239	0.5778	0.3933
C.Val @ 0.01	6.6349	0.6962	0.4223
C.Val @ 0.005	7.8794	N/A	N/A
C.Val @ 0.001	10.8276	N/A	N/A

Figure C-13: Input modeling of the data for non-value-added time from assembly-proofreading (team-based)



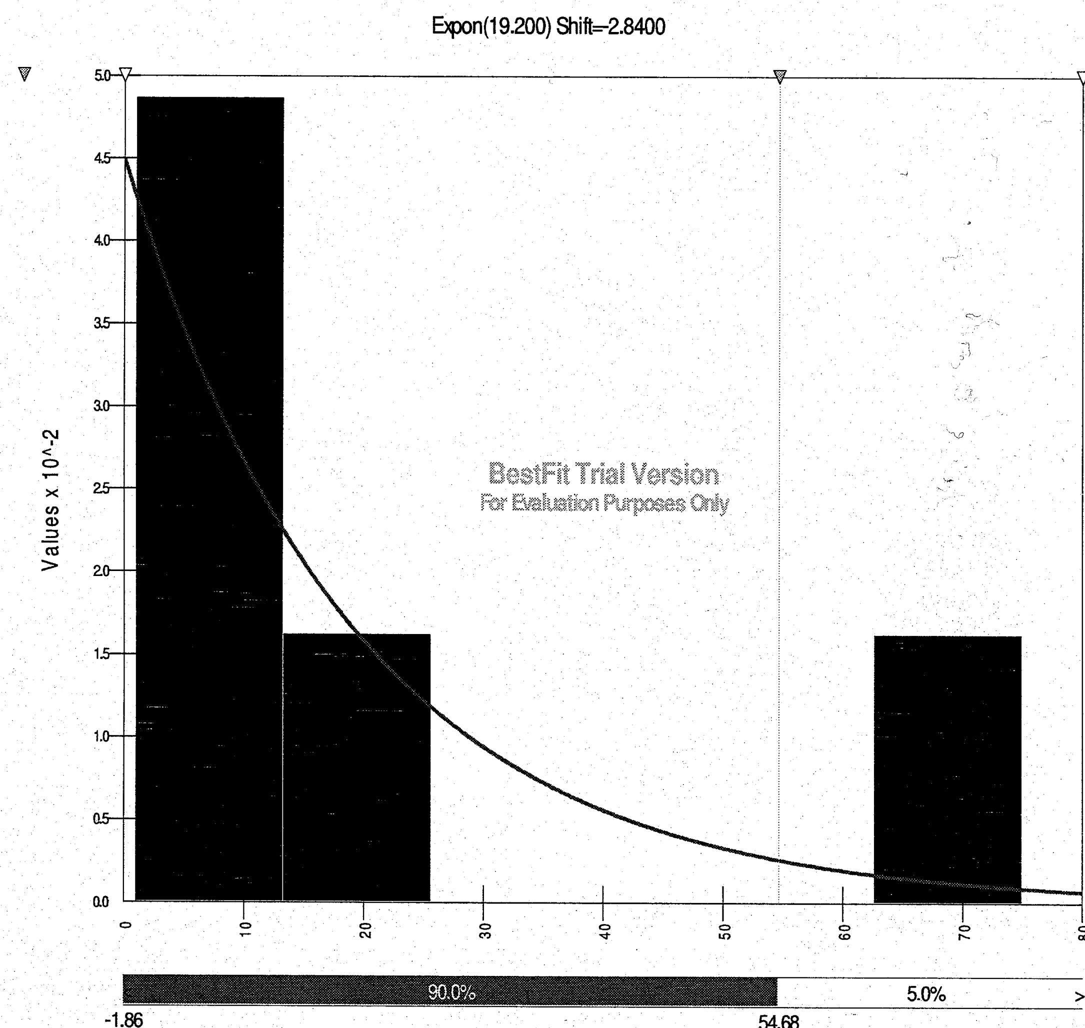
N/A	Chi-Sq	A-D	K-S
Test Value	0.1429	0.4436	0.2351
P Value	0.7055	0.1 <= p <= 0.15	> 0.25
Rank	2	8	11
C.Val @ 0.75	0.1015	N/A	N/A
C.Val @ 0.5	0.4549	N/A	N/A
C.Val @ 0.25	1.3233	0.3288	0.2733
C.Val @ 0.15	2.0723	0.3976	0.3012
C.Val @ 0.1	2.7055	0.4480	0.3205
C.Val @ 0.05	3.8415	0.5407	0.3511
C.Val @ 0.025	5.0239	0.6294	0.3755
C.Val @ 0.01	6.6349	0.7734	0.4024
C.Val @ 0.005	7.8794	N/A	N/A
C.Val @ 0.001	10.8276	N/A	N/A

Figure C-14: Input modeling of the data for non-value-added time from assembly-QC2 (team-based)



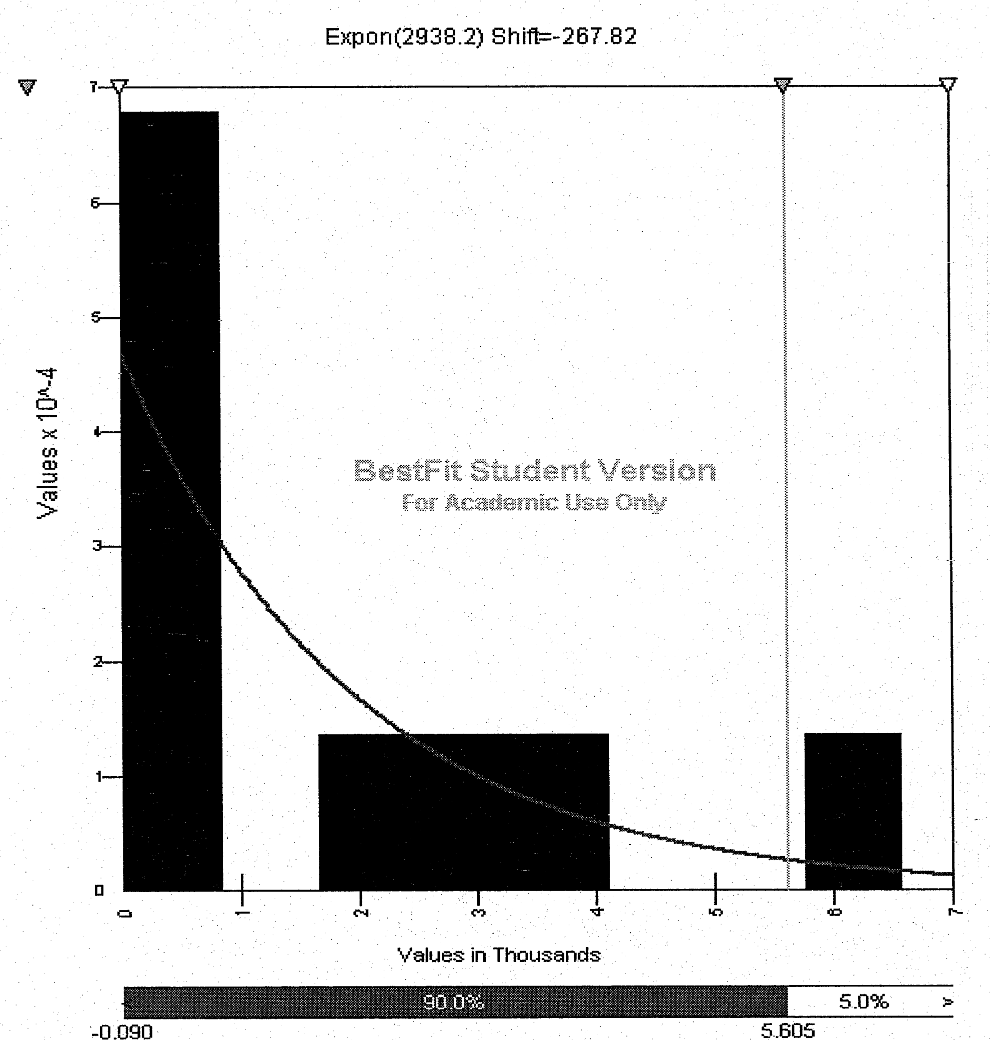
N/A	Chi-Sq	A-D	K-S
Test Value	0.1429	0.5939	0.2796
P Value	0.7055	N/A	N/A
Rank	3	3	3
C.Val @ 0.75	0.1015	N/A	N/A
C.Val @ 0.5	0.4549	N/A	N/A
C.Val @ 0.25	1.3233	N/A	N/A
C.Val @ 0.15	2.0723	N/A	N/A
C.Val @ 0.1	2.7055	N/A	N/A
C.Val @ 0.05	3.8415	N/A	N/A
C.Val @ 0.025	5.0239	N/A	N/A
C.Val @ 0.01	6.6349	N/A	N/A
C.Val @ 0.005	7.8794	N/A	N/A
C.Val @ 0.001	10.8276	N/A	N/A

Figure C-15: Input modeling of the data for non-value-added time from CSR-foreman (non-team-based)



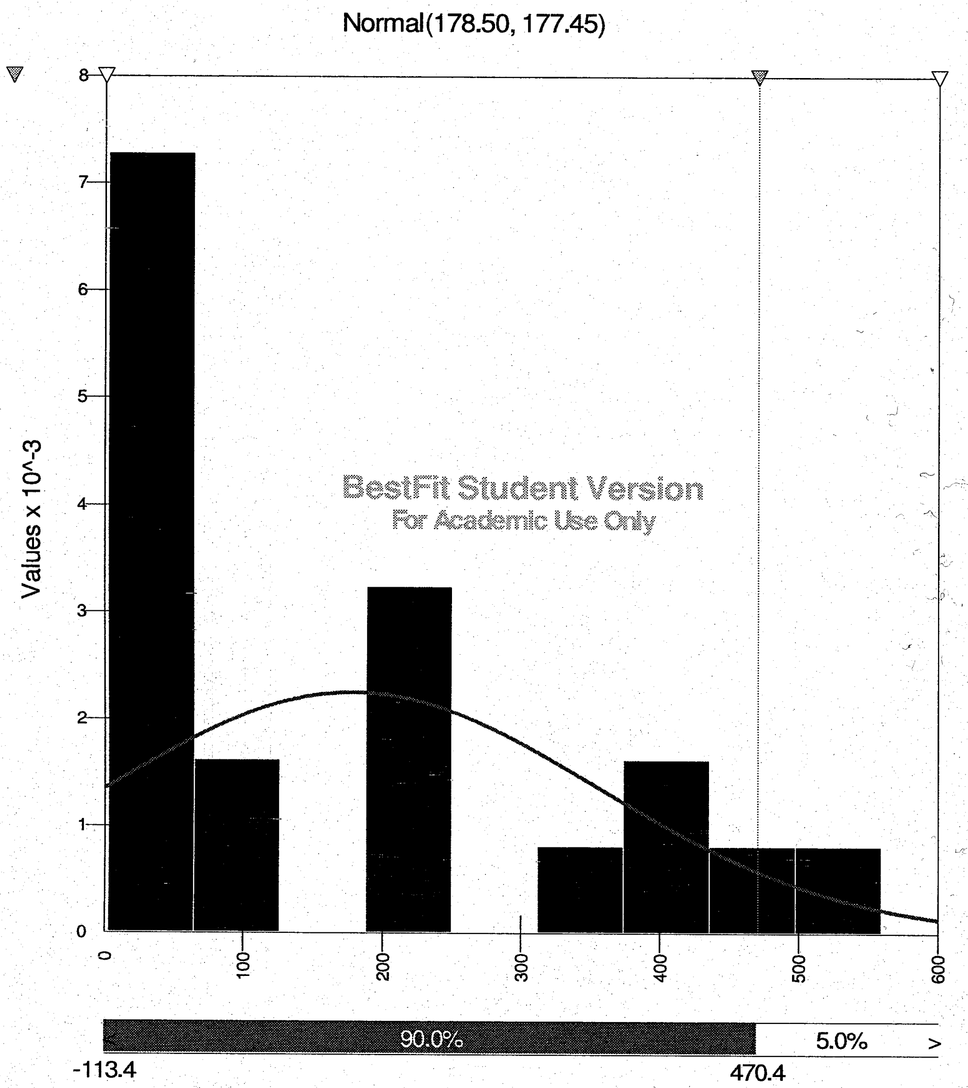
N/A	Chi-Sq	A-D	K-S
Test Value	0.2000	0.5333	0.2648
P Value	0.6547	0.01 <= p <= 0.025	> 0.25
Rank	1	2	2
C.Val @ 0.75	0.1015	N/A	N/A
C.Val @ 0.5	0.4549	N/A	N/A
C.Val @ 0.25	1.3233	0.2805	0.3054
C.Val @ 0.15	2.0723	0.3384	0.3350
C.Val @ 0.1	2.7055	0.3787	0.3546
C.Val @ 0.05	3.8415	0.4421	0.3868
C.Val @ 0.025	5.0239	0.5171	0.4119
C.Val @ 0.01	6.6349	0.6030	0.4436

Figure C-16: Input modeling of the data for non-value-added time from assembly-foreman (non team-based)



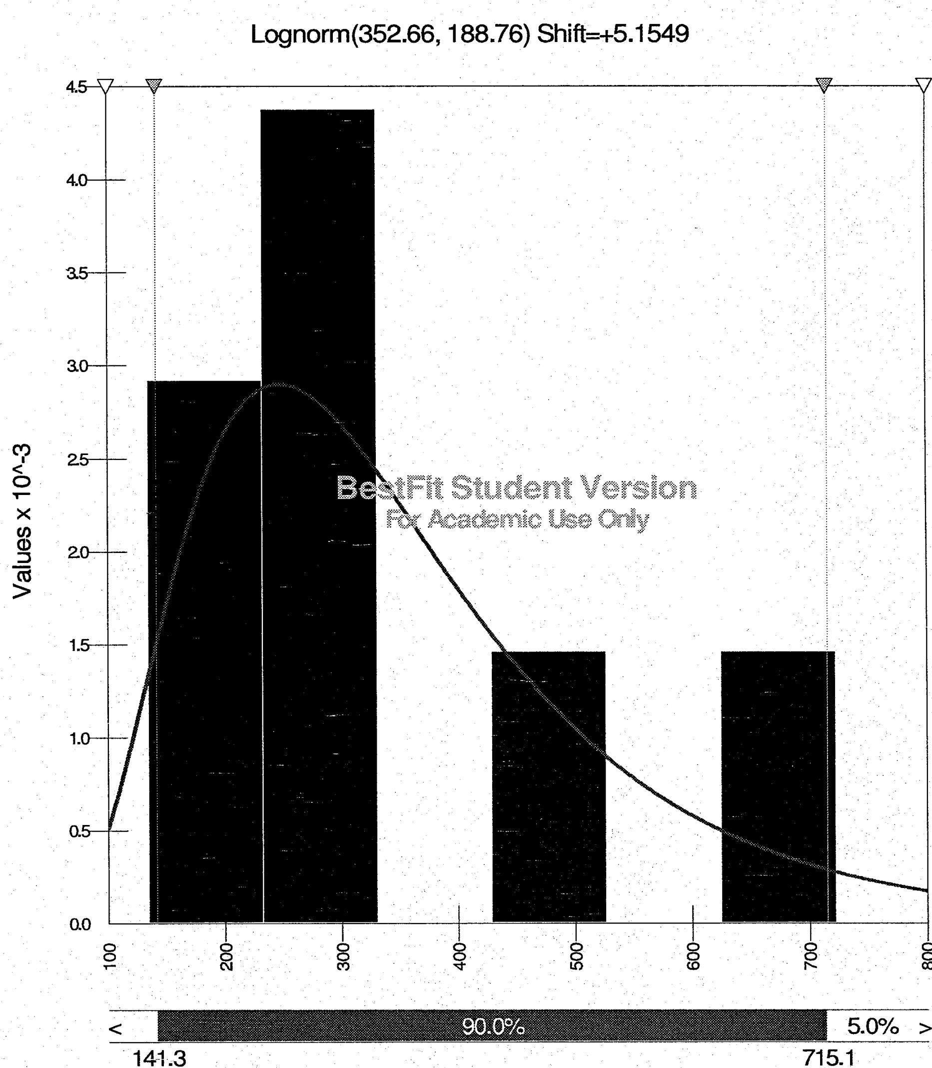
N/A	Chi-Sq	A-D	K-S
Test Value	0.000	0.5110	0.2117
P Value	1.0000	0.1 <= p <= 0.15	> 0.25
Rank	1	3	1
C.Val @ 0.75	0.1015	N/A	N/A
C.Val @ 0.5	0.4549	N/A	N/A
C.Val @ 0.25	1.3233	0.3811	0.2381
C.Val @ 0.15	2.0723	0.4615	0.2634
C.Val @ 0.1	2.7055	0.5224	0.2811
C.Val @ 0.05	3.8415	0.6434	0.3090
C.Val @ 0.025	5.0239	0.7469	0.3314
C.Val @ 0.01	6.6349	0.9455	0.3539
C.Val @ 0.005	7.8794	N/A	N/A
C.Val @ 0.001	10.8276	N/A	N/A

Figure C-17: Input modeling of the data for non-value-added time from assembly-CSR (non-team-based)



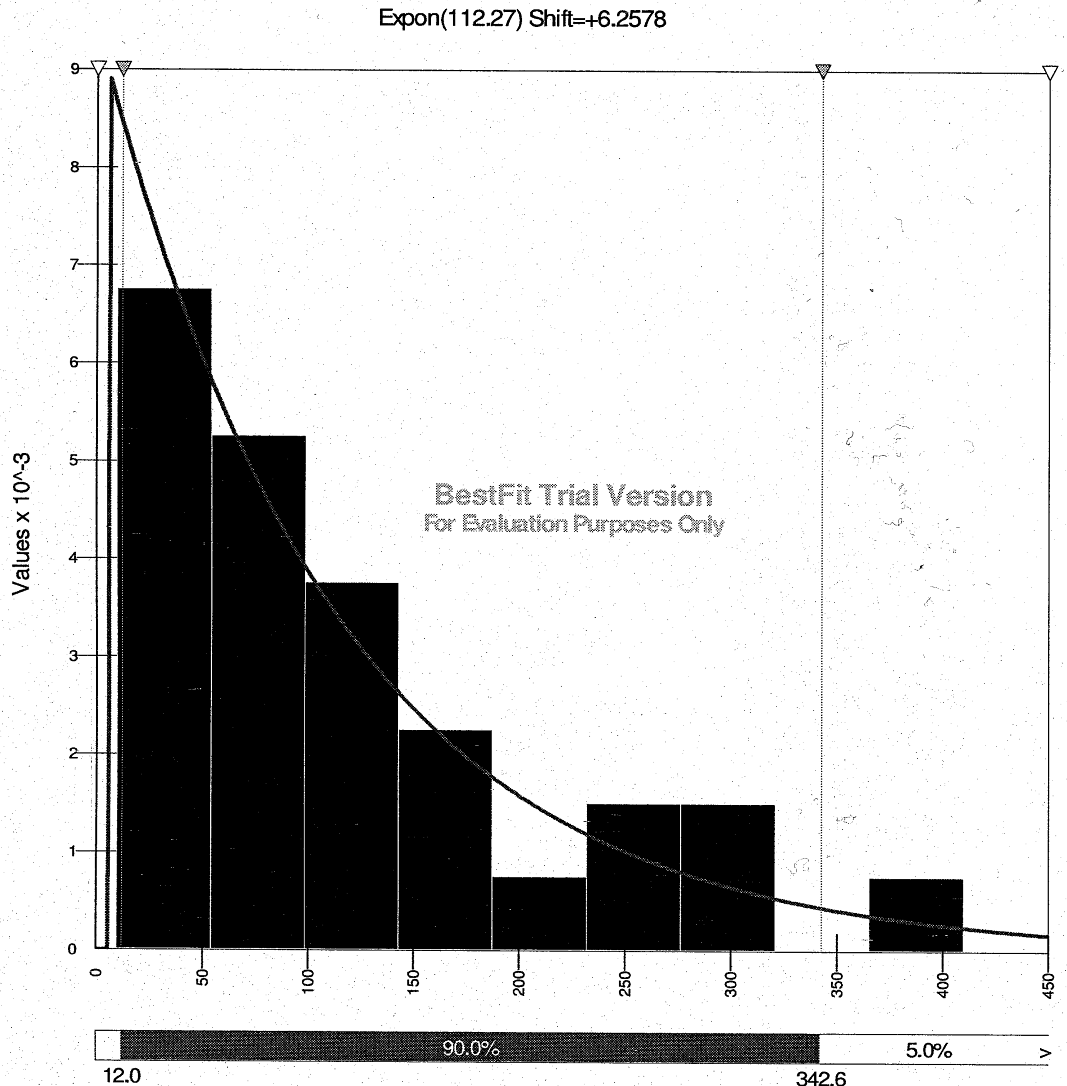
N/A	Chi-Sq	A-D	K-S
Test Value	1.200	0.9494	0.1961
P Value	0.7530	0.01 <= p <= 0.025	0.025 <= p <= 0.05
Rank	3	6	6
C.Val @ 0.75	1.2125	N/A	N/A
C.Val @ 0.5	2.3660	N/A	N/A
C.Val @ 0.25	4.1083	0.4506	N/A
C.Val @ 0.15	5.3170	0.5378	0.1666
C.Val @ 0.1	6.2514	0.6049	0.1760
C.Val @ 0.05	7.8147	0.7209	0.1924
C.Val @ 0.025	9.3484	0.8369	0.2139
C.Val @ 0.01	11.3449	0.9922	0.2225
C.Val @ 0.005	N/A	N/A	7.8794
C.Val @ 0.001	N/A	N/A	10.8276

Figure C-18: Input modeling of the data for non-value-added time from foreman-assembly (non-team-based)



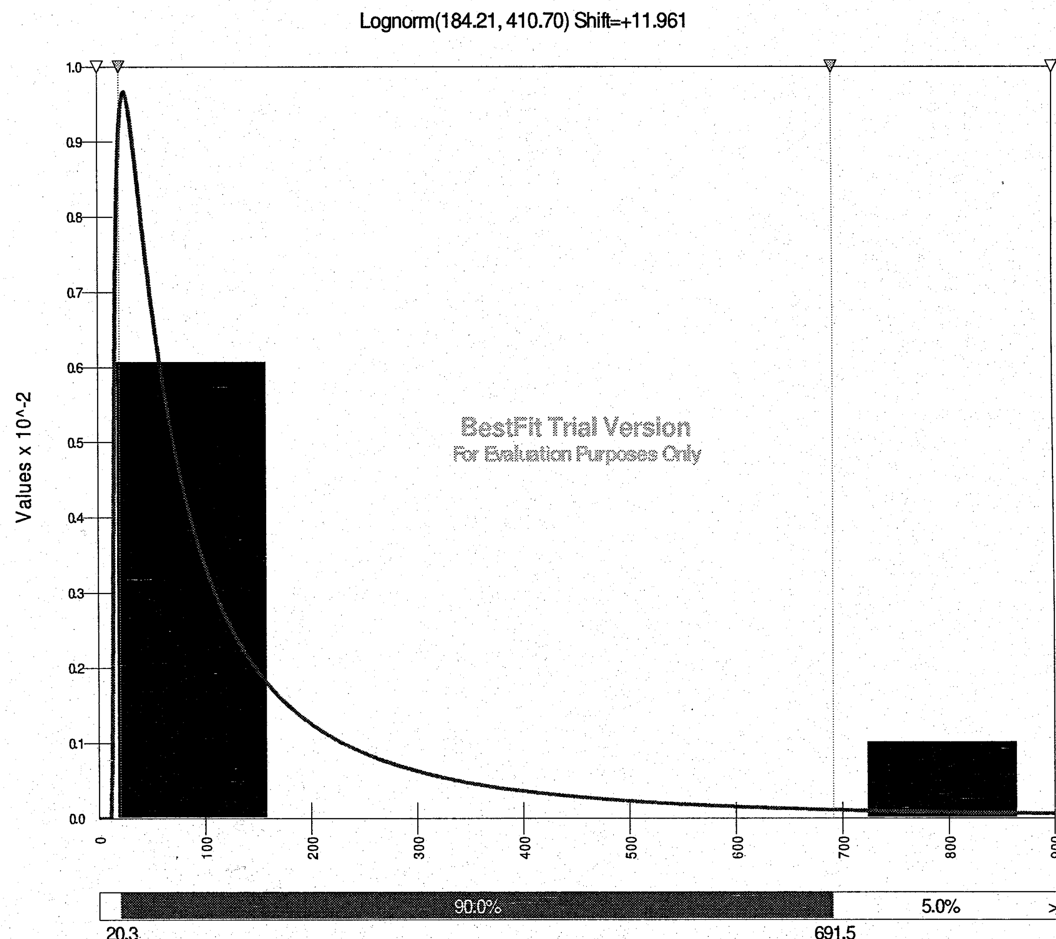
N/A	Chi-Sq	A-D	K-S
Test Value	0.1429	0.2591	0.2115
P Value	0.7055	N/A	N/A
Rank	4	2	3
C.Val @ 0.75	0.1015	N/A	N/A
C.Val @ 0.5	0.4549	N/A	N/A
C.Val @ 0.25	1.3233	N/A	N/A
C.Val @ 0.15	2.0723	N/A	N/A
C.Val @ 0.1	2.7055	N/A	N/A
C.Val @ 0.05	3.8415	N/A	N/A
C.Val @ 0.025	5.0239	N/A	N/A
C.Val @ 0.01	6.6349	N/A	N/A
C.Val @ 0.005	7.8794	N/A	N/A
C.Val @ 0.001	10.8276	N/A	N/A

Figure C-19: Input modeling of the data for non-value-added time from CSR-assembly (non-team-based)



N/A	Chi-Sq	A-D	K-S
Test Value	3.200	0.5494	0.1453
P Value	0.6692	0.15 <= p <= 0.25	> 0.25
Rank	1	5	7
C.Val @ 0.75	2.6746	N/A	N/A
C.Val @ 0.5	4.3515	N/A	N/A
C.Val @ 0.25	6.6257	0.5152	0.1460
C.Val @ 0.15	8.1152	0.6251	0.1623
C.Val @ 0.1	9.2364	0.7116	0.1740
C.Val @ 0.05	11.0705	0.8991	0.1920
C.Val @ 0.025	12.8325	1.0402	0.2068
C.Val @ 0.01	15.0863	1.3650	0.2198
C.Val @ 0.005	16.7496	N/A	N/A
C.Val @ 0.001	20.5150	N/A	N/A

Figure C-20: Input modeling of the data for non-value-added time from QC2-proofreading (non-team-based)



N/A	Chi-Sq	A-D	K-S
Test Value	0.1429	0.5939	0.2796
P Value	0.7055	N/A	N/A
Rank	3	3	3
C.Val @ 0.75	0.1015	N/A	N/A
C.Val @ 0.5	0.4549	N/A	N/A
C.Val @ 0.25	1.3233	N/A	N/A
C.Val @ 0.15	2.0723	N/A	N/A
C.Val @ 0.1	2.7055	N/A	N/A
C.Val @ 0.05	3.8415	N/A	N/A
C.Val @ 0.025	5.0239	N/A	N/A
C.Val @ 0.01	6.6349	N/A	N/A
C.Val @ 0.005	7.8794	N/A	N/A
C.Val @ 0.001	10.8276	N/A	N/A

Figure C-21: Input modeling of the data for non-value-added time from assembly-proofreading (non-team-based)

Appendix D: Sample Timesheet

	Work order Number:			Client Name:							PAGE ______ OF ________
Touch no.	Docket #	Name	Job title	Task performed (if more than 1 write on next line)	Date (mm/dd/yy)	Received Time (hh:mm AM/PM)	Start time (hh:mm AM/PM)	End Time (hh:mm AM/PM)	Who (position) is job going to next?	Hand off time (hh:mm AM/PM)	Notes/Comments/Recommendations
1	01	John Smith	CSR	Create Work order	12/1/2007	9:00am	9:00am	11:30ar	Foreman	11:35an	Hand off time was delayed b/c of phone call
2	02	Linda Daves	Foreman	Assign job to operator	12/1/2007	11:35am	1:20pm	1:22pm			
3	02	"	"	enter job in schawklink	12/1/2007		1:22pm	1:30pm	Operator	1:30pm	
4	02	Rhys Fernandez	Operator	trapping	12/1/2007	2:30pm	3:00pm	3:45pm			
5	02	"	"	QC 1	12/1/2007		4:00pm	4:30pm	Proofreac	5:00pm	Took a break fro 3:45 - 4:00pm
6	02	Michele Chiang	proofreader	proof read product	12/2/2007	9:00am	9:00am	11:30ar	foreman	11:35am	

Figure D-1: Sample timesheet

Appendix E: Standardizing Procedure

Table E-1: Sample operator standard procedure

XYZ	Mississauga Division	
Job Title: Operator	Document No. R-OP-A0001	
Revision No. 001	Rev. Date:23/02/2008	Pg. 1 of 2

Procedure: Assembly Operations

Responsibilities / Duties:

The Operator work collaboratively with the CSR (Customer Service Representative) or Foreman to ensure client satisfaction. The Operator will perform their work in a timely manner, ensure their their work is reasonably free from defects. Operators will be provided adequate tools and training to complete their work order in an effective and efficient manner.

Procedure:

- The CSR / Foreman will hand off a work order to an Operator to be completed by a pre-determined time.
- The Operator preps the file by filling the in the appropriate code and nomenclature
- The file is converted into an illustrator file, and then to ESKO.
- Using templates (if available) the die lines, printer specifications, and color schemes are coded into the file.
- The Operator performs a quality check to make sure the amended file conforms to the client's requests, Printers specifications.
- This first draft is passed back to the CSR / Foreman who then distribute it for a second quality check.
- Once passed the second quality check, the CSR / Foreman hands off the file toteh original Operator
- The Operator convert the One-off to a Step-up (if required)
- Another quality check is performed, and a 1 Bit TIFF file is created
- The Operator releases the file to the CSR / Foreman / Plate Department / Proofer

Rev.	Date	Prepared by	Approved by	Signature
001	23/02/2008	Sam A	Sam Ataei	SAtaei
002				
003				
Approved By:			Date:	
Signature:			Quality Department Signoff:	

XYZ	Mississauga Division	
Job Title: Operator	Document No. R-OP-A0001	
Revision No. 001	Rev. Date:23/02/2008	Pg. 2 of 2

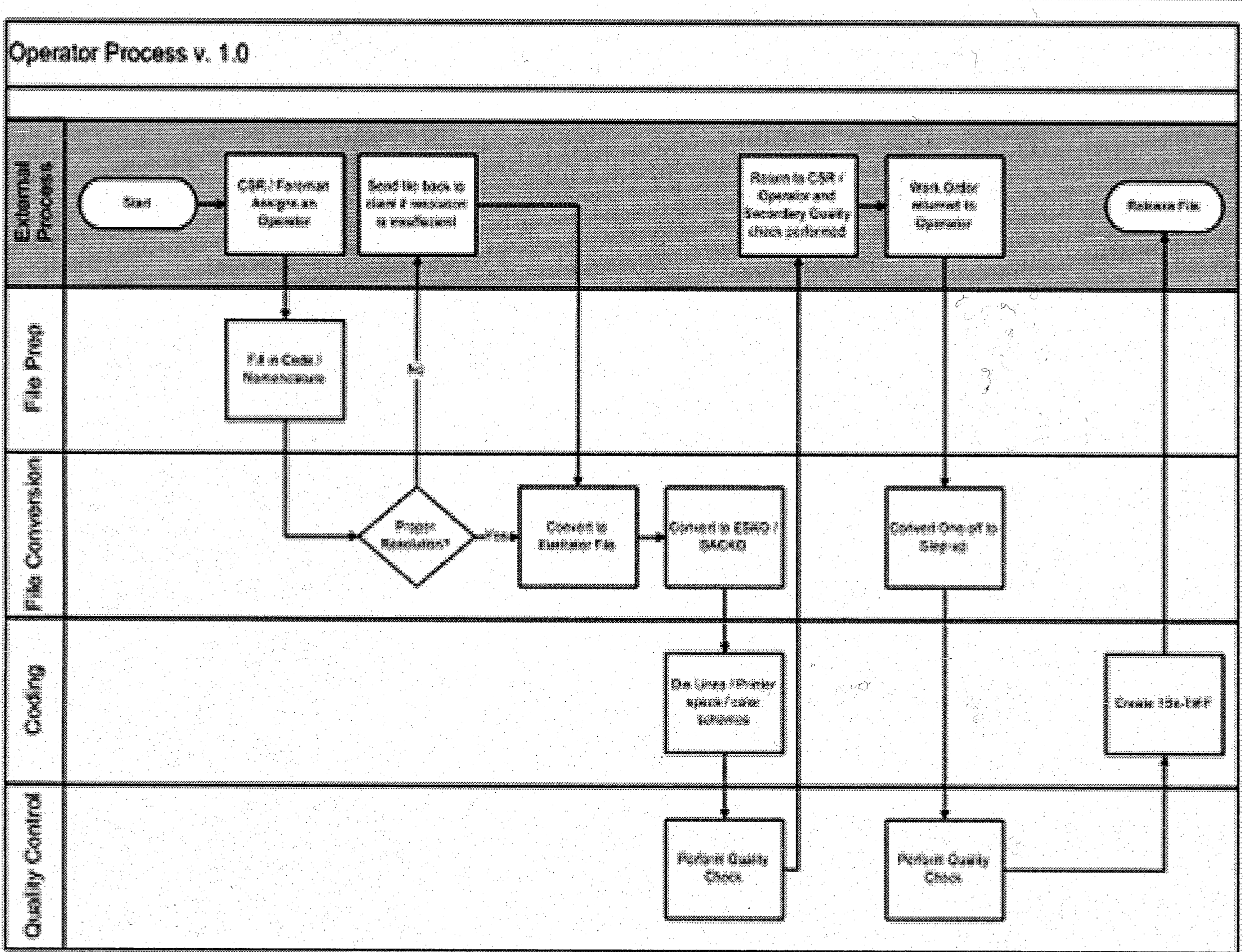


Figure E-1: Operator standard process flow

Appendix F: Output Analysis

In output analysis, total non-value-added time with respect to the number of work-orders is calculated. The system has run for 300 days with five replications. Table F-1 and Table F-4 show the total non-value-added time during each month for a total of 10 month. Table F-2 and Table F-5 illustrate the total number of order, which goes out of the system during each month.

Table F-1: Simulation results for total non-value-added time for each month for team-based category

	Simulation Length (Days)	Total non-value-added time for team-based					Mean Total NVA time
		Run 1	Run 2	Run 3	Run 4	Run 5	
1	0 – 30	4240.542	4863.696	3961.29	4039.68	3952.236	4211.49
2	30 – 60	6323.736	6292.116	6282.714	6472.398	5742.528	6222.70
3	60 – 90	5377.716	6210.546	6257.598	5519.154	6648.342	6002.67
4	90 – 120	6138.81	6219.948	6103.812	5939.982	5702.22	6020.95
5	120 – 150	6144.684	6381.726	5826.426	6777.612	6446.232	6315.34
6	150 – 180	6282.636	5919.15	5737.722	6231.108	6525.936	6139.31
7	180 – 210	7047.936	7289.604	6533.028	7064.112	5985.336	6784.00
8	210 – 240	7170.216	7455.048	7791.192	6377.808	7333.134	7225.48
9	240 – 270	6894.498	6787.74	7366.302	7195.944	6949.572	7038.81
10	270 – 300	7268.124	7390.932	7269.654	7372.896	7470.216	7354.36

Table F-2: Simulation results for total number of complete orders during each month for team-based category

	Simulation Length (Days)	Number of Finished Order					Mean Total Order
		Run 1	Run 2	Run 3	Run 4	Run 5	
1	0 – 30	24	24	24	28	26	25
2	30 – 60	68	68	61	66	68	66
3	60 – 90	48	55	49	55	54	52
4	90 – 120	62	70	69	63	62	65
5	120 – 150	48	46	54	50	49	49
6	150 – 180	66	66	63	68	68	66
7	180 – 210	52	61	49	57	56	55
8	210 – 240	59	57	61	62	63	60
9	240 – 270	62	58	61	61	51	59
10	270 – 300	66	63	69	57	63	64

"Mean unit order non-value-added time" will be calculated trough division of "Mean non-value-added "by "Mean number of finished order". Numbers are shown in the Table F-3 and Table F-6.

Table F-3: Truncations of cumulative means for unit order non-value-added time for team-based category

Mean Unit Order NVA (Y.j)	0-Truncate Cumulative Mean	1-Truncate Cumulative Mean	2-Truncate Cumulative Mean	3-Truncate Cumulative Mean	4-Truncate Cumulative Mean	5-Truncate Cumulative Mean
168.14	168.14					
94.21	131.17	94.21				
115.23	125.86	104.72	115.23			
92.52	117.52	100.65	103.87	92.52		
128.35	119.69	107.58	112.03	110.43	128.35	
92.71	115.19	104.60	107.20	104.53	110.53	92.71
123.84	116.43	107.81	110.53	109.35	114.97	108.27
119.86	116.86	109.53	112.08	111.46	116.19	112.14
120.64	117.28	110.92	113.31	112.99	117.08	114.26
116.14	117.16	111.50	113.66	113.44	116.92	114.64

By plotting different truncations in a chart, it is easy to see the initialization bias. The line which has the least fluctuations is the best truncation and number of batched based on the plot could be skipped. Figure F-1 and F-2 have shown the plotted truncations for both team-based and non-team-based categories.

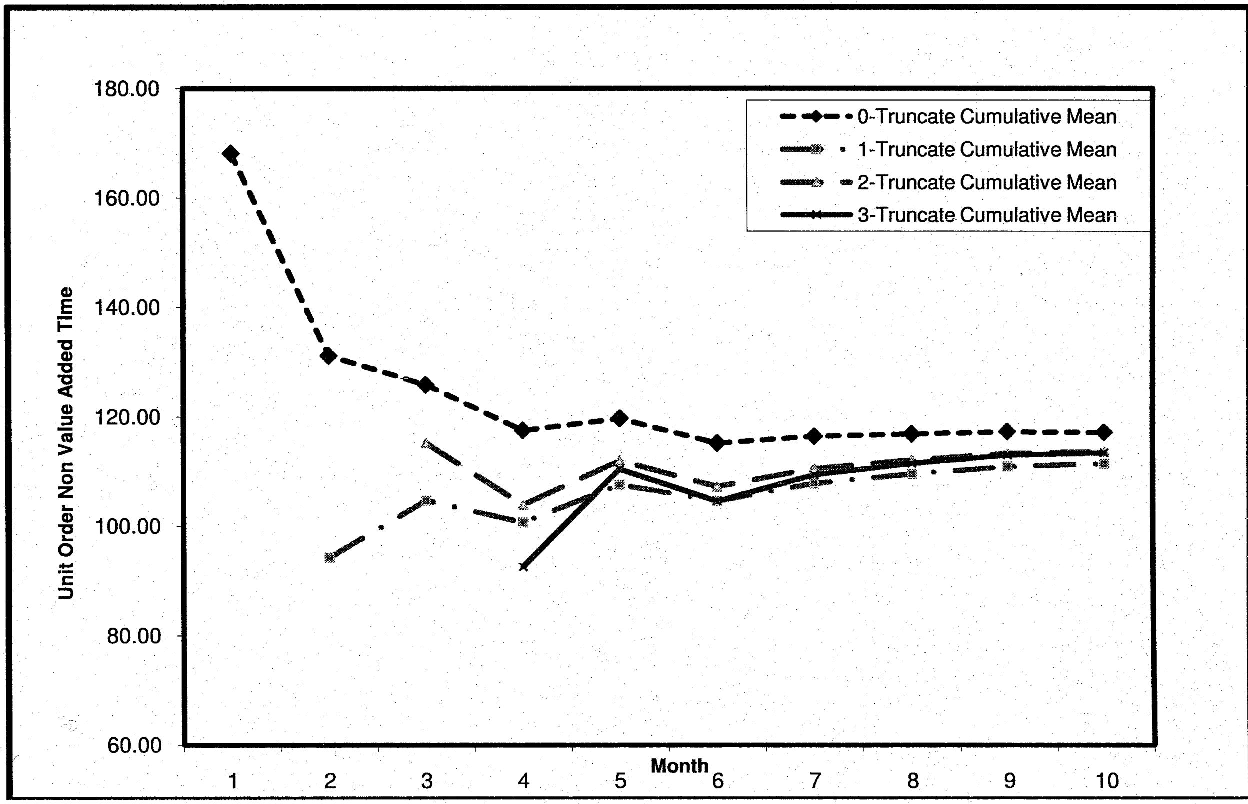


Figure F-1: Unit order non-value-added time for team-based vs. each month

Table F-4: Simulation results for total non-value-added time for each month for non-team-based category

	Simulation Length (Days)	Total non-value-added time for non-team-based					Mean Total NVA time
		Run 1	Run 2	Run 3	Run 4	Run 5	
1	0 – 30	5441.166	4194.186	4644.336	4859.652	4879.308	5441.166
2	30 – 60	8107.326	9334.02	8821.482	8752.812	8925.558	8107.326
3	60 – 90	11187.49	10114.86	10599.08	10812.62	10800.86	11187.49
4	90 – 120	10856.45	12513.01	11095.53	11114.92	11195.72	10856.45
5	120 – 150	10501.76	10976.84	11980.54	11335.37	10891.27	10501.76
6	150 – 180	12594.23	12091.08	12128.87	11499.68	12077.09	12594.23
7	180 – 210	11106.04	10944.91	11399.59	11054.63	10163.1	11106.04
8	210 – 240	10272.61	9284.112	10790.02	11370.37	10888.75	10272.61
9	240 – 270	10738.13	12320.53	10015.87	9453.492	11663.97	10738.13
10	270 – 300	10980.19	10231.99	10867.11	10749.35	11060.03	10980.19

Table F-5: Simulation results for total number of complete orders during each month for non-team-based category

	Simulation Length (Days)	Number of Finished Order					Mean Total NVA time
		Run 1	Run 2	Run 3	Run 4	Run 5	
1	0 – 30	39	31	34	33	37	35
2	30 – 60	81	89	88	86	87	86
3	60 – 90	98	88	98	98	98	96
4	90 – 120	111	96	92	108	95	100
5	120 – 150	92	102	91	101	86	94
6	150 – 180	100	85	92	88	99	93
7	180 – 210	107	125	108	102	117	112
8	210 – 240	95	94	95	101	91	95
9	240 – 270	88	79	89	81	85	84
10	270 – 300	89	97	101	105	102	99

Table F-6: Truncations of cumulative means for unit order non-value-added time for team-based category

Mean Unit Order NVA (Y.j)	0-Truncate Cumulative Mean	1-Truncate Cumulative Mean	2-Truncate Cumulative Mean	3-Truncate Cumulative Mean	4-Truncate Cumulative Mean	5-Truncate Cumulative Mean
138.11	138.11					
101.92	120.01	101.92				
111.56	117.20	106.74	111.56			
113.90	116.37	109.13	112.73	113.90		
118.46	116.79	111.46	114.64	116.18	118.46	
130.54	119.08	115.28	118.62	120.97	124.50	130.54
98.43	116.13	112.47	114.58	115.33	115.81	114.48
110.54	115.43	112.19	113.91	114.37	114.49	113.17
128.89	116.93	114.28	116.05	116.79	117.37	117.10
109.45	116.18	113.74	115.22	115.75	116.05	115.57

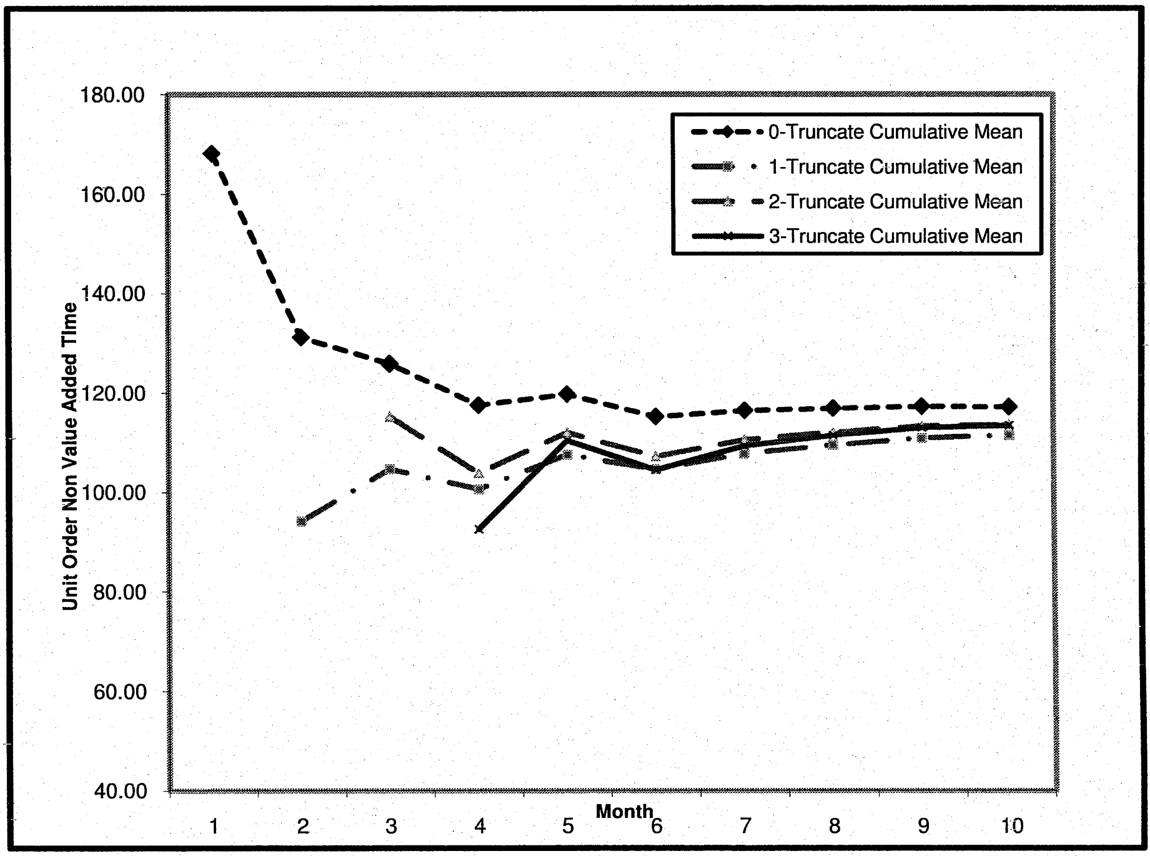


Figure F-2: Unit order non-value-added time for non-team-based category vs. each month

The optimum number of replications and the length of each run have calculated in an Excel sheet and it came to one replication for 800 days for both team-based and non-team-based categories.