SIMULATION MODELING OF SHOP FLOOR ACTIVITIES FOR SMEs IN VIRTUAL ENTERPRISES

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

MUSTAFA BAHTİYAR

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
MECHANICAL ENGINEERING

JUNE 2005

Approval of the Graduate School of Natural and Applied Sciences

Prof. Dr. Canan ÖZGEN
Director

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

Prof. Dr. Kemal İDER
Head of the Department

This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

Prof. Dr. S.Engin KILIÇ
Supervisor

Examining Committee Members

Prof. Dr. Metin AKKÖK	(METU,ME)	
Prof. Dr. S.Engin KILIÇ	(METU,ME)	
Prof. Dr. Ömer ANLAĞAN	(METU,ME)	
Prof. Dr. Mustafa İ.GÖKLER	(METU,ME)	
Assoc. Prof. Dr. Tayyar ŞEN	(METU,IE)	

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Mustafa BAHTİYAR

Signature:

ABSTRACT

SIMULATION MODELING OF
SHOP FLOOR ACTIVITIES FOR SMEs
IN VIRTUAL ENTERPRISES

Bahtiyar, Mustafa
M. Sc., Department of Mechanical Engineering
Supervisor: Prof. Dr. S.Engin KILIÇ

June 2005, 144 pages

The globalization of the markets and the worldwide competition forces the SMEs to implement new technologies and organize themselves using new concepts in order to maintain their competitivity. This type of temporary alliance is called as Virtual Enterprise (VE). SMEs seem to be appropriate units for building this type of temporary alliances when their properties (such as flexibility, adaptability and agility) are taken into account. This study is concerned with the simulation modeling of shop floor activities for SMEs in VEs. Analyzing the SMEs with their current and new work load over the existing one by using simulation tool may help the VE management unit to see the most appropriate SMEs for the projects. Because of mentioned advantages, this thesis will test whether the simulation tool will or will not be used in the selection of the VE partner.

The simulation methodology for modeling shop floor activities of SMEs was developed by using ARENA simulation tool in this thesis. A hydraulic cylinder company was selected for pilot application. Manufacturing of twelve basic hydraulic cylinders was studied in the developed model. Four different queue rules were

applied to the developed model to optimize the system efficiency. By analyzing the output statistical results of ARENA which were obtained with the usage of the input variables of SME (such as resource capacities, process times, setup and remove times of parts, variables wrt to workers, etc.) best manufacturing policy for pilot SME was able to be found. To see the response of the system under different circumstances, grinding and hardening operations for a drive shaft manufacturing were assigned to the company. This new job was applied on two models (Base Model and Optimized System Model) and the statistical results of each were examined.

Keywords: Simulation, Modeling, Virtual Enterprise System, Partner Selection.

ÖZ

SANAL İŞLETMELERDEKİ KOBİLERİN ATELYE FAALİYETLERİNİN BENZETİM MODELLENMESİ

Bahtiyar, Mustafa
Yüksek Lisans, Makine Mühendisligi Bölümü
Tez Yöneticisi: Prof. Dr. S. Engin KILIÇ

Haziran 2005, 144 sayfa

Piyasaların küreselleşmesi ve dünya çapındaki rekabet, KOBİleri bu rekabetin içerisinde yer alabilmeleri için, yeni teknolojileri uygulamaya ve kendilerini yeni konseptlere uyarlamaya zorlamıştır. KOBİler küreselleşmiş iş olanaklarına en etkin yanıtı verebilmek için sahip oldukları yetenekleri paylaşarak geçici ortaklıklar kurmalıdırlar. Bu tarz kurulan ortaklık sistemine Sanal Ortaklık Sistemi denir. KOBİlerin özellikleri (esneklik, uyum ve çeviklik) gözönüne alındığında bu tür geçici ortaklıklar için en uygun birimler oldukları ortaya çıkmaktadır. Bu çalışma, Sanal Ortaklık Sisteminde yer alacak KOBİlerin atelye faaliyetlerinin simülasyon modellemeleriyle ilgilidir. Oluşturulan modellerin anlık ve sonradan eklenmiş iş yükleri altında incelenmesi Sanal Ortaklık yönetimine en uygun KOBİ yi seçimi esnasında yardımcı olacaktır. Belirtilen bu avantajlar ışığında, bu tez, simülasyon aracının Sanal Ortaklık Sisteminde yer alacak partner KOBİlerin seçimi sırasında kullanılıp kullanılmayacağını test edecektir.

Bu tezde, KOBİlerin atelye faaliyetlerini modellemek için ARENA simulasyon aracı baz alınarak bir simülasyon metodolojisi çıkartılmıştır. Pilot uygulama için bir hidrolik silindir şirketi seçilmiştir. Toplam oniki adet temel hidrolik silindir üretimi oluşturulan modelde denenmiştir. Sistemi en iyi şekilde optimize edebilmek için 4 farklı kuyruk kuralı test edilmiştir. Modelleme esnasında tanımlanan giriş değişkenlerini (kaynak kapasiteleri, proses zamanları, parça yükleme çıkarma zamanları, işçilere ait değişkenler, vs.) kullanarak ARENA'nın elde ettiği istatistiksel sonuçlar incelenerek en şirket için en uygun üretim politikası bulunmuştur. Oluşturulan modelin değişik durumlarda verdiği tepkileri gözlemlemek için dişli mil üretimi sırasında uygulanan taşlama ve yüzey sertleştirme operasyonları, hazırlanan iki modele (Ana Model ve Optimize Edilmiş Sistem Modeli) girilmiştir. Bu iki deneyin istatistiksel sonuçları incelenmiştir. Bu çalışma sırasında ARENA simülasyon programı kullanılmıştır.

Anahtar Kelimeler: Simülasyon, Modelleme, Sanal Ortaklık Sistemi, Partner Seçimi.

To My Lovely Family

ACKNOWLEDGMENTS

I would like to thank my thesis supervisor Prof. Dr. S.Engin KILIÇ for his continuous support and guidance throughout my work.

I would like to thank Erdemler Hydraulic Cylinder Company for their support while developing my simulation model.

I am indebted to my friends Gülgün Aktakka, Onur Yazıcı, N. Deniz Yücel and Burak Sarı for their continuous support.

I am also grateful to Ege Erşen and Berrin Erşen for their endless support throughout this hard work.

Finally, my greatest thanks go to my parents who shaped me with their never ending patience.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE

LIST OF TABLES

TABLE

CHAPTER 1

INTRODUCTION

The globalization of the markets and the worldwide competition, forces the enterprises to implement new technologies and organize themselves using new concepts in order to maintain their competitivity.

Apart from being a part of a well organized formation, enterprises will have no chance to step forward even though they renew themselves. The firm that can not grow is forced to disappear since it does not comply with the requirements of the global world market. There are some partnership systems which are used to overcome these difficulties. The essential one of them is the virtual enterprise concept. Virtual enterprise concept is a temporary network or strategic alliances of independent companies or enterprises that can quickly bring together a set of core competencies to take the advantage of market opportunity.

SMEs (Small-medium size enterprises) seem to be appropriate units for building this type of temporary alliances when their properties (such as flexibility, adaptability and agility) are taken into account. In our country, although, almost every region has industrial manufacturing areas which are composed of many SMEs, these do not normally involve in big projects, either work as subcontractors of large companies or order basis or work independently due to some reasons which are peculiar to our country (economical conditions, resource insufficiencies in manufacturing technologies, etc.). The IMTRG group in the structure of the ODTU CIM Laboratory aimed to establish a virtual enterprise system that contains the SMEs in the OSTIM industrial area in Ankara as to see the applicability of this concept in Turkey.

The objective of this thesis is to develop a simulation methodology and to construct simulation models for Small Medium Size Enterprises (SMEs) for helping partner selection of VE model. The important factors in selecting a VE member can be stated as availability, risk, cost and performance. The simulation tool will be useful in utilizing the resource availabilities of the enterprises, analyzing how the new work order opportunities might change the system workload to determine the time constraints that will be assigned for the new project.

A small company which produces hydraulic units was selected as the pilot company to carry out the study. The company is believed to represent a typical SME in OSTIM with its properties such as manufacturing policy, size and resource capability. For simulation modeling of SME, ARENA® simulation tool was used and its sketch was prepared by using MS Visio. The following sub-sections contain brief definitions of modeling and simulation. Detailed explanation of the main subjects can be found in Chapter 2.

1.1 Definition of Modeling

As it is described above, the pilot SME will be modeled and simulated for different conditions to see how the system will react under different circumstances. Model and simulation concept will be briefly described, in order to help understand the objective of this study.

A model is a representation of the construction and working of some system of interest. It is similar to but simpler than the system it represents. One purpose of a model is to enable the analyst to predict the effect of changes on the system. On the one hand, a model should be a close approximation to the real system and incorporate most of its important features. On the other hand, it should be clear and easy to comprehend and experiment with it.

An important issue in modeling is model validity. The real system output must be similar to the model output. Methodology helps, models to be prepared similar to real system so that what we learn about the model will be a real reflection of what we would have learned about the system by playing with it directly.

Models can be classified into two groups.

- Physical (iconic) models
    - Tabletop material-handling models
    - Mock-ups of fast-food restaurants
    - Flight simulators

- Logical (mathematical) models
    - Approximations and assumptions about a system's operation
    - Often represented via computer program in appropriate software
    - Exercise the program to try things, get results, learn about model behavior

1.2 Definition of Simulation

A simulation of a system is the operation of a model of the system. Simulation is a tool to evaluate the performance of a system, existing or proposed, under different configurations of interest and over long periods of real time. This property will help users see various results on the computer screen. Since it may be impossible expensive or impractical to go through the same changes in the system it represents. Simulation tool is also used for a new system which will be built to help reduce the chances of failure to meet specifications, eliminate unexpected bottlenecks, prevent under or over-utilization of resources, and optimize system performance. Detailed explanation about simulation will be discussed in Chapter 2.

1.3 Scope

The scope of this study is to develop a simulation methodology for modeling SMEs and to construct simulation model of a pilot SME. Different experiments were done on this sample model and response of the system was observed statistically. As it is mentioned above, these results will be used in partner determination part of the VE model.

1.4 Outline

In Chapter 2, detailed explanations of Virtual Enterprise concept, definition and advantages of simulation modeling topics can be found. In Chapter 3, "Simulation Methodology for SME" topic was studied. In Chapter 4, application for this methodology at a pilot SME was studied and experimental simulation runs were analyzed and discussed in Chapter 5.

CHAPTER 2

LITERATURE SURVEY

In this chapter the related literature and the historical background for Virtual Enterprise evolution will be presented. Literature on simulation and modeling of manufacturing systems, available tools, and the methodology will also be discussed in this chapter.

2.1 Development of VE Concept

In the beginning of 20th century, Henry Ford introduced the revolutionary concept of "Mass Production". The main idea of this concept was to produce the same product in large scale and perfecting the skills of laborers on a particular job by means of division of labor. For many years, this paradigm was widely accepted and implemented, but in last decades it could not respond to the challenges of modern, dynamic and worldwide business. The mass production concept can no longer fulfill the demanding but many times contradicting requirements of the new world order, which aims reducing prices and costs but yet increasing product quality, production rate and offering diversity of products. Nowadays, each product has several models and even each model can be highly customized according to the liking of customers at affordable prices. This could only be possible by means of new manufacturing systems and technologies developed by merging the good sides of job-shop with those of mass production through the use of flexible automation and the information technologies, in an integrated manner. The companies are now obliged to adapt to this manufacturing era in order to survive.

In the 80s, Japanese companies introduced a new paradigm, called Lean Manufacturing. The main idea of this concept was to shorten the time line between the customer order and shipment, by eliminating waste. The Elimination of waste process was achieved through;

- Less time to design
- Less inventory
- Less defects
- Reduction of setups, etc.

Lean Manufacturing is an extension of "Just in Time" concept, which consists in having the right material at right place at right time, eliminating stocks, and using very simple control and scheduling systems. The three main areas in Lean Manufacturing are [1]:

- Manufacturing management excellence,
- Organizational learning,
- Principles and practices of lean manufacturing.

The USA responds to this paradigm by the Agile Manufacturing. Agile Manufacturing is the ability to adapt quickly and profitably to continuous and unexpected changes in the manufacturing environment. Agile Manufacturing has been expressed as having four underlying principles:

- Delivery of value to the customer;
- Ability to react to changes;
- Value of human knowledge and skills
- Ability to constitute virtual partnerships.

The first three principles can be found in lean manufacturing too but the forth principle makes the difference between Lean and Agile Manufacturing. In Agile Manufacturing the companies make temporary alliances with other companies, even competitors, to react to unexpected situations, with mutual benefits for all companies [1].

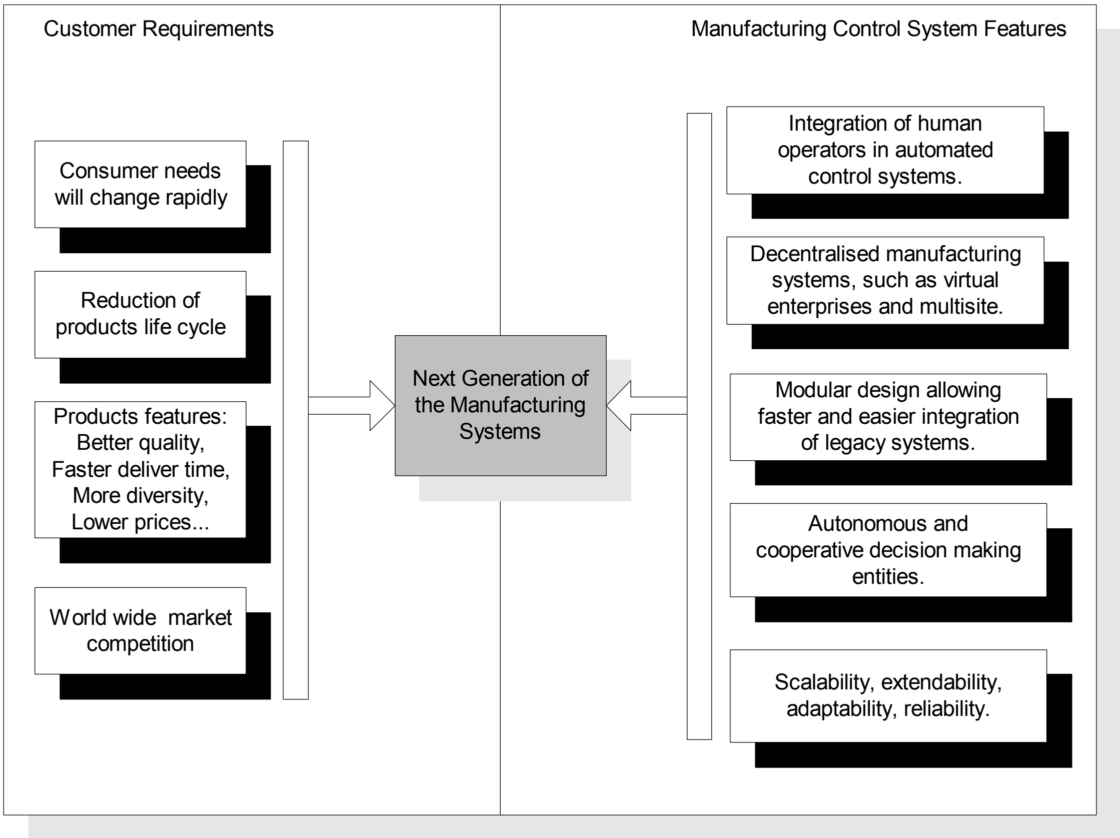


Figure 2.1 Requirements and Features of Future Manufacturing Systems [1].

The concept of virtual enterprise was actually born in the late 1800s. In the late 1800s, firms were organized along functional lines often referred to as unitary form or (U-form) organizations. The principal operating units in the U-form firm are the functional divisions (e.g. sales, finance, manufacturing, etc.). Faced with the types of internal operating problems that emerge as the U-form enterprise increases in size and complexity, to achieve these difficulties the multidivisional (M-form) structure was devised in the early 1920s. This organizational innovation involved substituting quasi-autonomous operating divisions (organized mainly along product, brand, or geographic lines for the functional divisions) of the U-form structure as the principal basis for dividing up the task and assigning responsibility. Each of these operating divisions is subsequently divided along functional lines; one might characterize these operating divisions as scaled down, specialized U-form structures [2].

Today, the worldwide market competition implies that manufacturing enterprises can no longer be seen acting stand-alone. They must react to customer demands promptly and properly. Virtual Enterprise concept (V-form) strives with the hope for achieving these objectives. In many cases it is replacing the M-form structure, just as the M-form structure replaced the U-form structure, because of the need for firms to remain competitive under given environmental changes. Several factors are driving businesses to adopt the virtual organizational structure. First, the pace of business is continually increasing with shorter product life cycles requiring quicker response to market opportunities. Second, the cost of market entry is often lower than the previous one, especially in the information services and other technology-driven industries. Third, corporations are now driven more by customer demands than by internal needs. And finally, there is an increased need for globalization to remain competitive [3]. Properties of VE structure and its advantages are described in the sub-section below.

In literature, Virtual Enterprise concept is defined in various ways;

“A Virtual Enterprise is an organization fundamentally customer-oriented which accomplish the customer needs in a particular way and which is extremely time and cost effective [4].”

“A Virtual Corporation is a temporary network of independent companies – suppliers, customers, even rivals – linked by information technology (IT) to share skills, costs and access to one another’s markets. It will have neither central office nor organization chart. It will have no hierarchy, no vertical integration [5].”

“Virtual corporates are fluid, on-line partnerships comprised of the best practices from various companies that bring together their individual core competencies to create a new product or service during a market window of opportunity. Once the life cycle of the product or service ends, they will separate and go about their businesses [6].”

“A Virtual Enterprise is not really different from a traditional enterprise other than the fact that it can append and shed processes quickly. There are more legal regulatory issues than technical issues when removing barriers to virtual enterprise operations [7].”

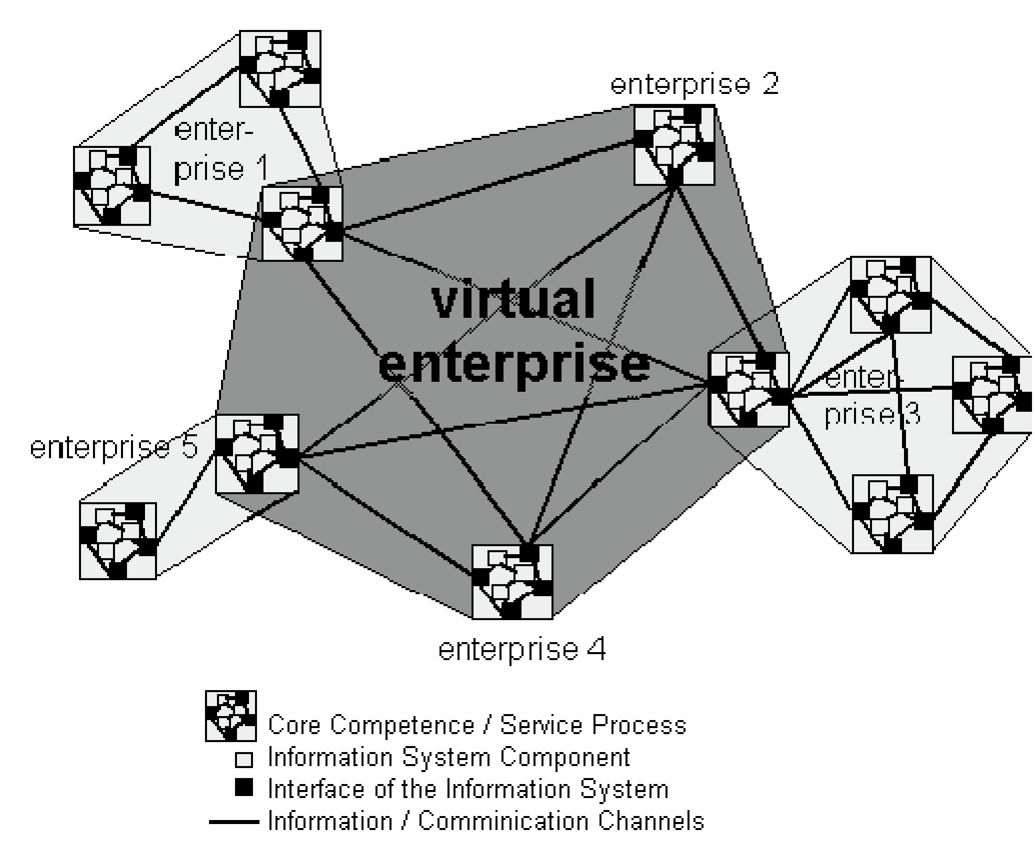


Figure 2.2 Virtual Enterprise [9].

Briefly, Virtual Enterprise concept is a paradigm that can be defined as a temporary alliance of enterprises that come together to share skills and resources in order to better respond to business opportunities and whose co-operation is supported by computer networks [8]. The term Virtual Enterprise is to indicate that in spite of having all the attributes of an enterprise, it would not be a permanent organization. A joint venture, for instance, is a type of Virtual Enterprise; where some enterprises group together in order to achieve a particular and common goal.

Today, large companies usually form partnerships with smaller firms. The smaller companies become subcontractors to the larger companies; they routinely and continually supply the same items and conduct the same duties for the same firms. These kinds of partnerships are known as production networks. The main difference between production network and virtual enterprise concepts can be clarified by giving the Boeing Company example. Boeing Company designs, assembles and markets the aircraft, while an international network of suppliers makes the components. This is a typical example for production network because Boeing generally uses the same partner for the same job. But in the virtual enterprise concept, the firms and jobs are totally changed by new projects. The partner firms are selected from the developed network by examining the availability, risk, cost and performance analysis of each of them.

2.2 Properties of Virtual Enterprise Concept

VE has some important properties and behaviors which distinguish it from other operating systems. Firstly, VE organization can be defined as flexible, adaptable and agile. Actually these properties belong to SMEs. VE organizations are generally working with SMEs because of their properties. With more details, it can be expressed as SMEs has less level of bureaucracy, which allows the inter-firm alliance to react more quickly. Moreover, these firms will be more specialized in a particular task. For example, two smaller firms specializing in manufacturing and distribution may be better at these separate tasks than one large firm that attempts to do both. Agility can be defined as giving quick response to customer orders. In order to give better responses to customer orders, VE should have adequate number of members. Firms can be added to or removed from the system in a dynamic way. This is called flexibility. Besides this, ability to create new branches shows the system flexibility in job breeding. If any firm gives up the job which is initially assigned, system should search and find another firm which will be suitable for the job left undone. This property shows system adaptability.

Secondly, resource (including money, technology, labor, etc.) capacity of VE organization must be stated. VEs resource capacity can be defined as infinite. By the help of partner firms, VE structure will have high production variety. In this way, VE can overcome difficulties in dealing with different types of works effectively through the desired conditions. It is clearly seen that resource capability of VE structure is always better than those of individual companies.

Thirdly, VE allows partner firms to concentrate on their core competence. In fact, these core competencies are the reason why firms would be chosen as partners. As companies of the past learned the value of specialization of labor, virtual organization partnerships improve efficiency and effectiveness through firm specialization. This specialization may result in a synergistic situation where the overall alliance has much better performance than the sum of the individual partner's separate performances. Various combinations of firms may be uniquely suited to working together.

Finally, the VE organizations give an advantage to SMEs for globalization. Firms that want to take advantage of a global market opportunity can ally themselves with a firm that has expertise or market share in a given region or country. Most of the advantages of virtual organizations come from their ability to modularize. A modular organization is one in which embedded coordination permits organizational processes to be carried out within a loosely-coupled organization structure in which each participating organizational unit can function autonomously and concurrently. It has been suggested that a modular organization structure would have a superior ability to quickly link together the resources and capabilities of many organizations to form product development 'resource chains' that can respond flexibly. It is clear that VEs attempt to incorporate many of the principles of modular organizations.

2.3 Review of Virtual Enterprise Concept

As a result, there are several reasons for choosing the VE structure. This concept has some revolutionary properties which change the ordinary company to a globally developed one.

The four advantages which are explained above make the virtual enterprise structure a viable and powerful choice for many companies. Although the concept has several advantages, the result of internet searches shows that there is no VE organization implemented in Turkish industry. SMEs rarely come together to share skills and resources. Firms have insufficient technology and management structure in Turkey. Mostly because they don't want to leave their traditional manufacturing process and they are scared of entering the global market.

In Ankara OSTIM, the management wants to improve the member SMEs by finding them new job opportunities. But it is clearly seen that their limited capability has hindered the implementation of VE concept effectively. The IMTRG group in the structure of the ODTU CIM Laboratory has aimed at establishing a Virtual Enterprise system that contains the SMEs in OSTIM industrial area in Ankara as to see the applicability of this concept in Turkey.

2.4 Modeling

In this thesis, the simulation tool will be tested during the VE partner selection. After a brief explanation of the VE concept, it might be helpful to clarify the terms of modeling and simulation. Modeling is the process of producing a model; a model is a representation of the construction and working of some system of interest. A model is similar to, but simpler than the system it represents. A purpose of a model is to enable the analyst to predict the effect of changes to the system. On the one hand, a model should be a close approximation to the real system and incorporate most of its salient features. On the other hand, it should not be so complex that it is impossible to understand and experiment with it. A perfect model will be a judicious tradeoff between realism and simplicity. An important issue in modeling is the model validity. Model validation techniques include simulating the model under known input conditions and comparing model output with system output. Generally, a model intended for a simulation study is a mathematical model developed with the help of simulation software. Types of models can be specified into two groups. They are physical (iconic) and logical (or mathematical) models [11]. In physical (iconic) models, the modeler makes a physical replica or scale model of the system. For example, miniature versions of the facility, simulated control, physical flight simulators etc. A logical model is usually represented in a computer program that is exercised to address questions about the model's behavior. If a model is a valid representation of a system, system's behavior will be learned, too.

2.4.1 System to be modeled

As described above computer simulation deals with models of systems. A system is a facility or process, either actual or planned, such as [11]:

- A manufacturing plant with machines, people, transport devices, conveyor belts, and storage space.
- A bank or other personal-service operation, with different kinds of customers, servers, and facilities like teller windows, automated teller machines (ATMs), loan desks, and safety deposit boxes.
- A distribution network of plants, warehouses, and transportation links.
- An emergency facility in a hospital, including personnel, rooms, equipment, supplies, and patient transport.
- A field service operation for appliances or office equipment, with potential customers scattered across a geographic area, service technicians with different qualifications, trucks with different parts and tools, and a central depot and dispatch center.
- A computer network with servers, clients, disk drives, tape drives, printers, networking capabilities, and operators.
- A freeway system of road segments, interchanges, controls, and traffic.
- A central insurance claims office where a lot of paperwork is received, reviewed, copied, filed, and mailed by people and machines.
- A criminal justice system of courts, judges, support staff, probation officers, parole agents, defendants, plaintiffs, convicted offenders, and schedules.
- A chemical products plant with storage tanks, pipelines, reactor vessels, and railway tanker cars in which to ship the finished product.

- A fast-food restaurant with workers of different types, customers, equipment, and supplies.
- A supermarket with inventory control, checkout, and customer service.
- A theme park with rides, stores, restaurants, workers, guests, and parking lots.
- The response of emergency personnel to the occurrence of a catastrophic event.

This thesis will emphasize the manufacturing area of simulation. This is an area in which people often study a system to measure its performance, improve its operation, or design if the system doesn't exist. Managers or controllers of a system might also like to have a readily available aid for day-to-day operations, such as help in deciding what to do in a factory if an important machine goes down [11]. Often simulation analysts find that the process of defining how the system works, which must be done before one can start developing the simulation model, provides great insight into what changes need to be made.

2.5 Simulation

A simulation of a system is the operation of a model of the system. The model can be reconfigured and experimented with; usually, this is impossible, too expensive or impractical to do in the system it represents. Simulation is a tool to evaluate the performance of a system, existing or proposed, under different configurations of interest and over long periods of real time. Simulation is used before an existing system is altered or a new system built, to reduce the chances of failure to meet specifications, to eliminate unforeseen bottlenecks, to prevent under or over-utilization of resources, and to optimize system performance [12].

In the late 1950s and 1960s, simulation was a very expensive and specialized tool that was generally used only by large corporations that required large capital investments. Typical simulation users were found in steel and aerospace industry. Only specialized persons like Ph.D.s, who would develop large, complex simulation models using available languages, such as FORTRAN, would use simulation tools. The use of simulation as we know it today began during the 1970s and early 1980s [12]. Computers were becoming faster and cheaper, and the value of simulation was being discovered by other industries. However, simulation was seldom considered until there was a problem (bottleneck) in manufacturing line. It became the tool of choice for many companies, notably in the automotive and heavy industries, for determining why the problem occurred. By using simulation tool companies had performed a good sensitivity analysis on these questionable data and the problem had been uncovered and resolved well before implementation. Meanwhile, simulation also found a home in academia as a standard part of industrial engineering and operations research area. By the end of the 1980s, the value of simulation was recognized by many larger firms. However, it was still not in widespread use and was rarely used by smaller firms. Simulation really began to mature during the 1990s [12]. Better animations, ease of use, faster computers and easy integration with other packages have all helped simulations become a standard tool in many companies.

Simulation model can be classified as deterministic (input and output variables are fixed values) or stochastic (at least one of the input or output variables is probabilistic); static (time is not taken into account) or dynamic (time-varying interactions among variables are taken into account); discrete system (state variable(s) change only at a discrete set of points in time) or continuous system (state variable(s) change continuously or smoothly over time). Typically, simulation models are discrete system, stochastic and dynamic. Discrete event simulation can be defined as a less detailed system (coarser in its smallest time unit) but it is much simpler to implement, and hence, is used in a wide variety of situations.

In a simulation study, human decision making is required at all stages, namely, model development, experiment design, output analysis, conclusion formulation, and making decisions to alter the system under study. The only stage where human intervention is not required is the running of the simulations, which most simulation software packages perform efficiently.

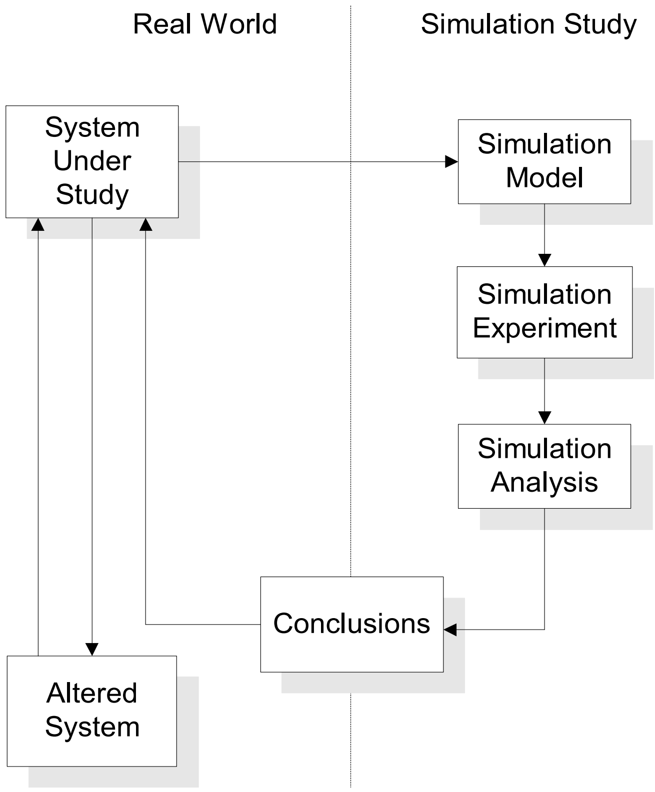


Figure 2.3 Simulation Study Schematic [12].

Briefly, steps involved in developing a simulation model, can be explained designing a simulation experiment, and performing simulation analysis [12]: Identify the problem, determine the objectives and overall project plan, collect and process real system data, formulate and develop a model, validate the model, select appropriate experimental design, establish experimental conditions for runs and perform simulation runs, documentation and reporting and implementation.

Although this is a logical ordering of steps in a simulation study, additional steps at various sub-stages may be required before the objectives of a simulation study are achieved. Also not all the steps may be possible or required. The modified methodology for modeling SMEs -objective of thesis- will be discussed in following chapter.

2.5.1 Benefits of Simulation Modeling and Analysis

Simulation modeling and analysis is one of the most frequently used operations research techniques. When used judiciously, simulation modeling and analysis makes it possible to [12]:

- Obtain a better understanding of the system by developing a mathematical model of a system of interest, and observing the system's operation in detail over long periods of time.
- Study the internal interactions of a complex (sub)-system.
- Test hypotheses about the system for feasibility.
- Compress time to observe certain task over long periods or expand time to observe a complex task in detail.
- Study the effects of certain informational, organizational, environmental and policy changes on the operation of a system by altering the system's model; this can be done without disrupting the real system and significantly reduces the risk of experimenting with the real system.
- Allow training & learning at a lower cost.
- Experiment with new or unknown situations about which only weak information is available.
- Identify bottlenecks of system (material, people, etc.)
- Improve system through model building.
- Use multiple performance metrics for analyzing system configurations.
- Understand & verify analytic solutions.
- Employ a systems approach to problem solving.
- Visualize operations through animation.
- Develop well designed and robust systems and reduce system development time.

2.5.2 Disadvantages of Simulation

Despite its advantages, simulation may not be a perfect tool for system analysis. This is because many real systems are affected by uncontrollable and random inputs, many simulation models involve random, or stochastic, input components, causing their output to be random too. Although modelers think carefully about designing and analyzing simulation experiments, simulation output may still be uncertain. This uncertainty might be solved by making a lot of over-simplifying assumptions about the system. Unfortunately, though, such an over-simplified model will probably not be a valid representation of the system. In general, modelers would prefer an approximate answer to the right problem rather than an exact answer to the wrong problem.

2.5.3 Pitfalls to Guard against in Simulation

Simulation can be a time consuming and complex exercise, from modeling through output analysis that necessitates the involvement of experts and decision makers in the entire process. Following is a checklist of pitfalls to guard against [12].

- Unclear objective.
- Using simulation when an analytic solution is appropriate.
- Invalid model.
- Simulation model too complex or too simple.
- Erroneous assumptions.
- Undocumented assumptions. This is extremely important and it is strongly suggested that assumptions made at each stage of the simulation modeling and analysis exercise be documented thoroughly.
- Using the wrong input probability distribution.
- Replacing a distribution (stochastic) by its mean (deterministic).
- Using the wrong performance measure.
- Bugs in the simulation program.

- Using standard statistical formulas that assume independence in simulation output analysis.
- Initial bias in output data.
- Making one simulation run for a configuration.
- Poor schedule and budget planning.
- Poor communication among the personnel involved in the simulation study.

2.6 Usage of Simulation Tool under VE System.

The simulation tool is generally used in system utilization and optimization in the manufacturing area. By the help of this tool, the bottlenecks that take place in the modeling companies can easily be reflected both statistically and visually to the user. These developed models can work in the preferred simulation parameters and the responses that it gives on various work loads can be indicated. Because of these mentioned advantages, this thesis will test whether the simulation tool will or will not be used in the selection of the VE partner.

As it is seen clearly, “VE partner selection” is a great research subject on its own. With a brief explanation, the partner selection is done by the VE management in terms of the risk, cost, performance and availability analysis. In this analysis, VE management unit gives grades to these properties with respect to their goals. After this determination, some calculation steps are done and the closest SMEs with respect to the management’s goal will be chosen. The literature survey revealed that the simulation tool wasn’t used in this type of analysis. Chapter 4 will focus on the testing of the positive sides of the simulation tool in SME analysis.

In this work it is aimed to develop a simulation methodology and to construct simulation models for Small Medium Size Enterprises (SMEs) for helping the SME selection of the VE model. The reason for the usage of the simulation tool is to get realistic statistical results which are used in the selection part of the general model (Figure 2.4).

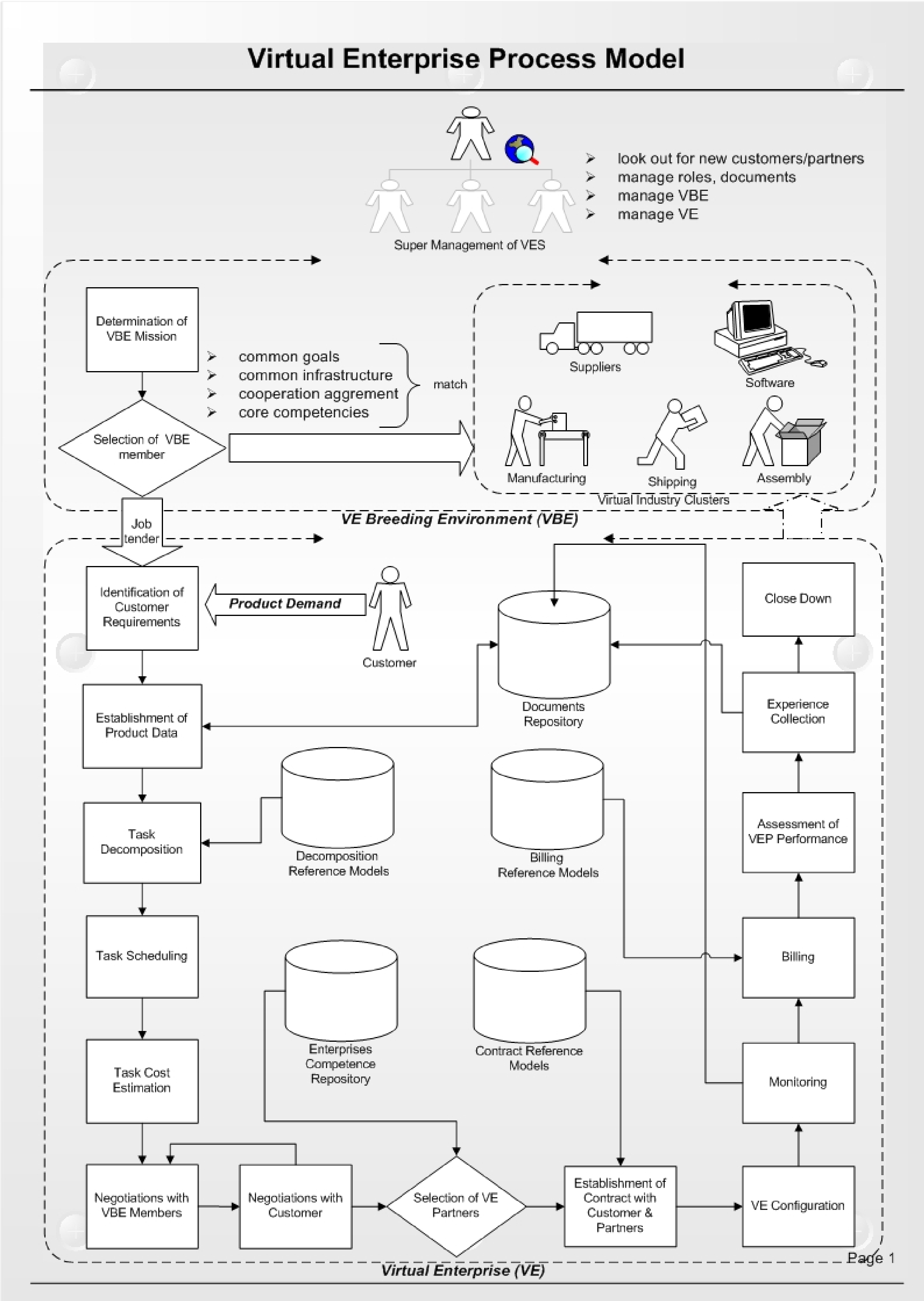


Figure 2.4 Virtual Enterprise Process Model [10]

2.7 Selection of Simulation Software

The two types of simulation packages are simulation languages and application-oriented simulators (Table 2.1). Simulation languages offer more flexibility than the application-oriented simulators. On the other hand, languages require varying amounts of programming expertise. Application-oriented simulators are easier to learn and have modeling constructs closely related to the application. Most simulation packages incorporate animation which is excellent for communication and can be used to debug the simulation program; a "correct looking" animation, however, is not a guarantee of a valid model. More importantly, animation is not a substitute for output analysis.

Table 2.1 Simulation Packages [12].

Type Of Simulation Package	**Examples**
Simulation languages	Arena (previously SIMAN), AweSim! (previously SLAM II), Extend, GPSS, Micro Saint, SIMSCRIPT, SLX Object-oriented software: MODSIM III, SIMPLE++ Animation software: Proof Animation
Application-Oriented Simulators	Manufacturing: AutoMod, Extend+MFG, FACTOR/AIM, ManSim/X, MP$IM, ProModel, QUEST, Taylor II, WITNESS Communications/computer: COMNET III, NETWORK II.5, OPNET Modeler, OPNET Planner, SES/Strategizer, SES/workbench Business: BP$IM, Extend+BPR, ProcessModel, ServiceModel, SIMPROCESS, Time machine Health Care: MedModel

Although statistics seem to be more important than animation, animation property is indispensable for modeler too. Entities and resources can be easily traced by modeler. First of all, simulation tool should be selected by modeler. When all data implement into selected program “a simulation model” will be formed.. In this study, ARENA® Simulation Tool was used to develop the model. This tool was selected because of its distinct properties which are explained below.

2.7.1 ARENA®

The Arena modeling system from Systems Modeling Corporation is a flexible and powerful tool that allows analysts to create animated simulation models that accurately represent virtually any system. First released in 1993, Arena employs an object - oriented design for entirely graphical model development. Simulation analysts place graphical objects, called modules, on a layout in order to define system components such as machines, operators, and material handling devices. Arena is built on the SIMAN simulation language. After creating a simulation model graphically, Arena automatically generates the underlying SIMAN model used to perform simulation runs [13].

2.7.2 SIMAN

The core technology of Arena is the SIMAN simulation language. The modules contained in the Arena template were created using SIMAN’s modeling blocks as their components. SIMAN blocks are made available to all Arena users in the SIMAN template. SIMAN modules provide the user with increased flexibility and increased control of detailed system logic. Those users who have become accustomed to writing SIMAN code directly in a text editor are able to do so within Arena. In this case, Arena provides an option for directly recognizing this code, which is contained in a file external to the Arena graphical modeling environment [13].

2.7.3 ARENA® Template

The Arena template is the core collection of more than 60 modules provided as part of the general Arena system. It was designed to provide a general-purpose collection of modeling features for all types of applications. In addition to providing core features for resources, queuing, inspection, system logic, and external file interface, the Arena template provides modules specifically focused on specific aspects of manufacturing and material handling. For manufacturing, it contains modules that incorporate such features as machine downtime and maintenance schedules. For material handling applications, modules exist for representing conveyors (synchronous and asynchronous) and various types of transportation devices. Three panels compose the Arena template: the Common panel, containing modules representing fundamental simulation processes such as arrivals, service, and departures; the Support panel, containing supplemental modules for specific actions and decision logic; and the Transfer panel, whose modules are used to model the transfer (or flow) of entities through the system. In order to develop a simulation model using the Arena template, the user simply picks a module, places it in the model, and then is prompted for the necessary information. For example, when placing the Server module from the Arena template, the user is asked for such information as how long entities spend at the server, the server's operating schedule, and where entities should go. After responding with the appropriate information, the user closes the dialog to accept the completed module. Animation is automatically included with many of the modules in the Arena template. Graphics symbols that are automatically provided when placing a module from the Arena template can be changed with Arena's built-in graphics tools (similar to CAD systems) or can be replaced with icons from Arena's symbol library or from external applications (e.g., clip art , M.S Visio) [13].

2.7.4 Animation in ARENA®

Arena animations can be run concurrently with the executing simulation model. Animations can be created in several ways: they can be created entirely using Arena's graphics drawing tools, they can be created from AutoCAD or other .DXF file formats, they can be created in other tools and imported to Arena via Active X (formerly known as OLE), they can be created by using other Windows®-compliant drawing systems that can be pasted into Arena layouts, or any combination of the above. Arena's drawing tools include all standard CAD objects (e.g., rectangle, ellipse, arc, text, etc.) and provide virtually unlimited color selection. Arena's interface with .DXF file formats was developed to allow for a direct import of CAD drawings to provide the animation background and dynamic icons. Arena includes various animation options for real time display of model statistics. For example, the user can place dynamic plots, histograms, levels, and time clocks directly within a simulation in order to illustrate system status as the model performs [13].

2.7.5 Flowchart Model Development in ARENA®

Arena was designed to make creating simulation models an entirely graphical process. All system behaviors are represented by using the graphical modules described above. For system logic such as IF/THEN/ELSE-type branching and queue selection rules, the user creates a flowchart of his/her system by placing the appropriate graphical modules on the Arena layout and directly connecting these modules [13].

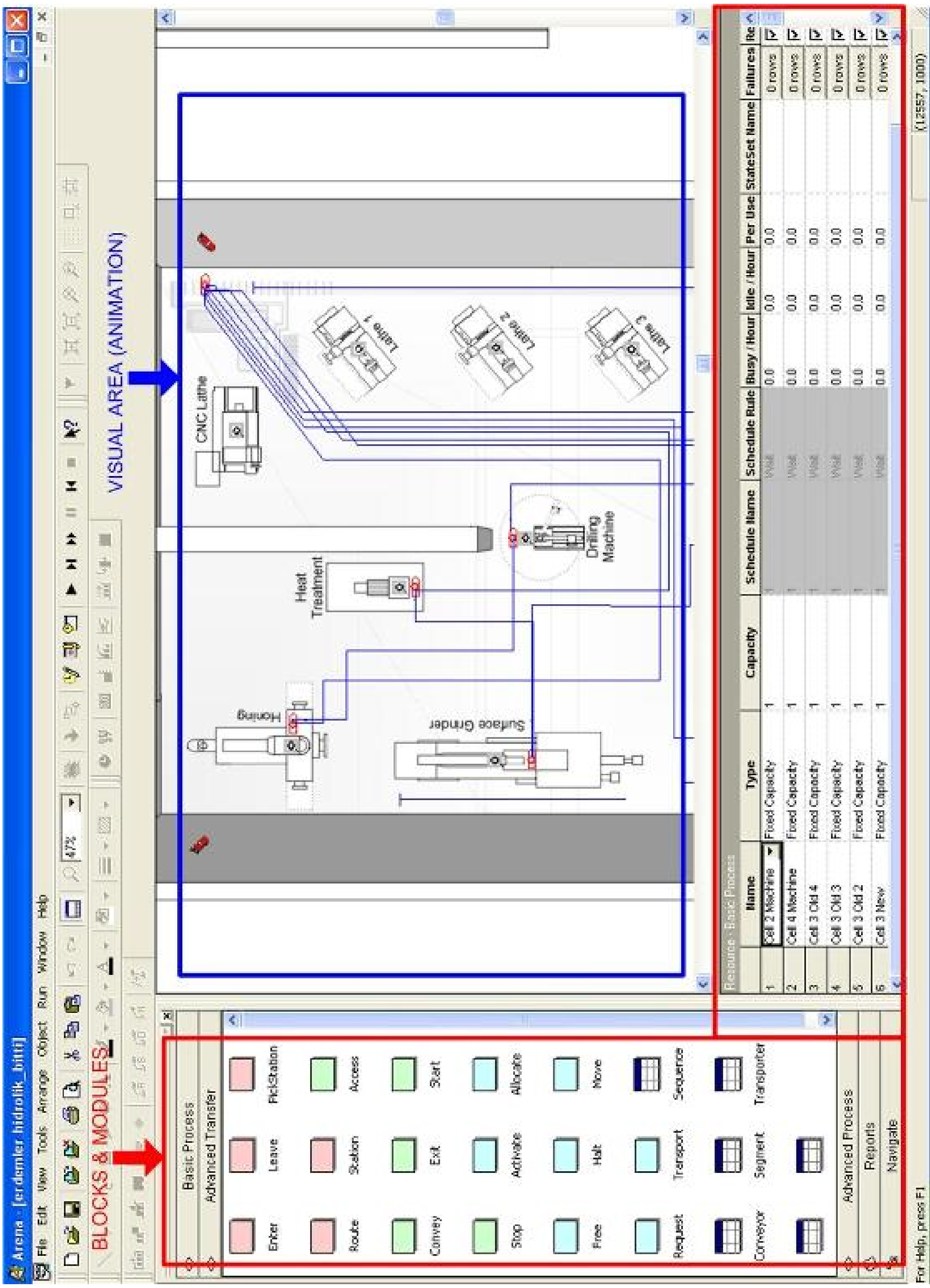


Figure 2.5 General View of Arena Simulation Tool

2.7.6 Integration via ActiveX, DAO and ODBC

Arena is a Microsoft® Windows® 95, 98, Me, XP and Windows® NT compliant product. The entire product was developed using Microsoft's Foundation Classes (MFC) and is written in object-oriented Visual C++™. Arena is also Microsoft® Office compliant that means that it utilizes all of the standard user interface options (e.g., toolbar buttons, function keys, etc.) that are in use in all Microsoft® Office products. Arena's support of Active X (formerly known as OLE) allows the user to embed other technologies such as Excel® spreadsheets, Microsoft® Word files, clipart, and Microsoft® PowerPoint® presentations within simulation models. Arena's support of DAO (Data Access Objects) and ODBC (Open Database Connectivity) allows the user to integrate all database systems that are compliant with Microsoft's ODBC standard. Model data contained in products like FoxPro® database, Excel®, Oracle®, Informix®, and many others can easily be read into an Arena model without taking the time to enter it manually [13].

CHAPTER 3

METHODOLOGY FOR SIMULATION MODELING OF SMEs WITH ARENA®

3.1 Overview

In this chapter, the simulation methodology (the process of applying the simulation technique) issue will be described step by step to simulate real manufacturing companies by the ARENA® simulation tool. Many papers have appeared in the past on the simulation methodology. These papers include only necessary steps for the general simulation methodology. These generally accepted steps for a simulation study can be listed as the following;

- Identify the problem.
- Determine the objectives and overall project plan.
- Collect and process real system data.
- Formulate and develop a model.
- Validate the model.
- Select appropriate experimental design.
- Establish experimental conditions for runs and perform simulation runs.
- Documentation and reporting.
- Implementation.

In this thesis, this general simulation methodology is adapted for studying SMEs as part of a Virtual Enterprise. With the help of prepared methodology simulation modeling of SMEs is becoming an easy task for modeler. The required steps to follow for modeling SMEs will be explained in detail in the following sections.

3.2 Collecting General System (Company Properties) Data

The main issue for this study can be stated as finding the most appropriate firm(s) to fulfill a defined manufacturing task. To achieve this objective, firstly candidate SMEs should be modeled with their current work load. Then new manufacturing tasks will be experimented in the developed model. To construct the model, steps which are explained below will be followed by the modeler. Before starting to collect real system data (process data), the identification tag of the company (name of the company), its location (address of the company), activity domain (activity field of the firm), its size and work hour should be defined by the modeler.

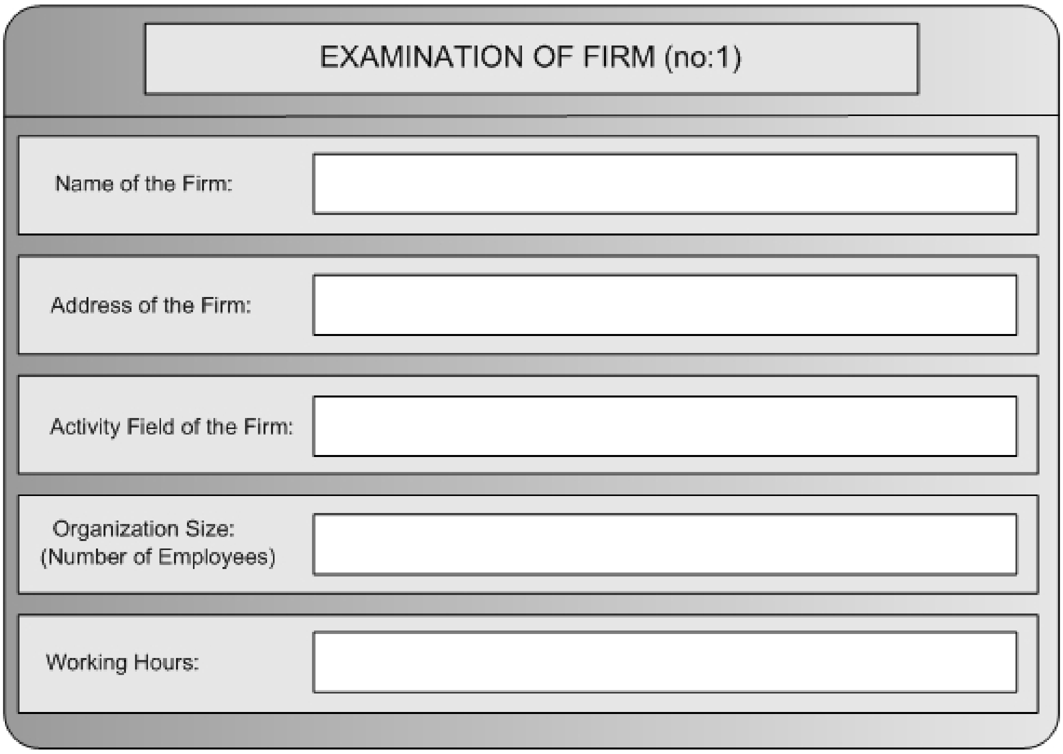


Figure 3.1 Examination of Firm:No1

To get realistic and accurate results, the model must be successfully developed. Model development job can be divided into two main parts. One of them is blocks/modules section which is programming part of tool and the other one is animation part where animation of simulation is shown. (Figure 2.5) after determination of main properties of firm the functional description of the system's components and their interactions with incoming jobs should be created. To achieve this objective some essential data must be collected. These collected data will be used for either programming part or animation part of the model. Steps that modeler should follow for collecting data are;

- Determination of Simulation Parameters: Worker schedule
- Identification of Resource (labor and machine) Capabilities of the Firm: The resource list must be prepared. Specialization of the workers and machine types should be written in this list. In this country, because of economical disadvantages, SMEs occasionally prefer workers who are specialized in different machines. Because of this disadvantage modeler should pay attention while collecting the properties of workers. By collected data, entities should be seized according to related worker before machining.
- Examination of Machines and Machining Sequences of the Parts: The data about machines give information to the modeler about sequencing rule for machining.
- Preparation of the Sketch: Sketch of the firm must be drawn as exactly the same. This sketch will be used for background of the animation. Arena allows the user to embed MS VISIO® or AutoCAD® sketches within simulation models.

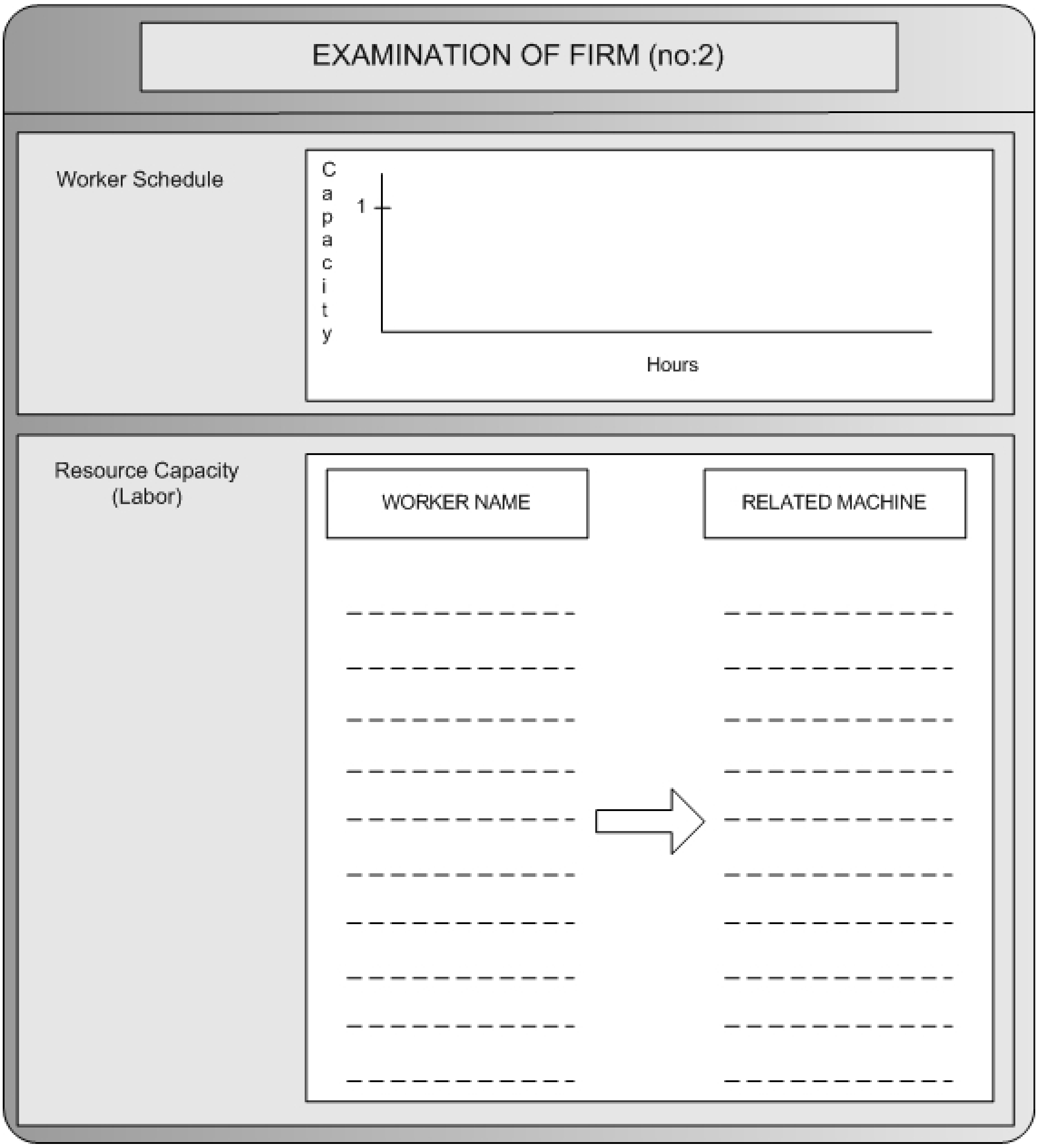


Figure 3.2 Examination of Firm:No2

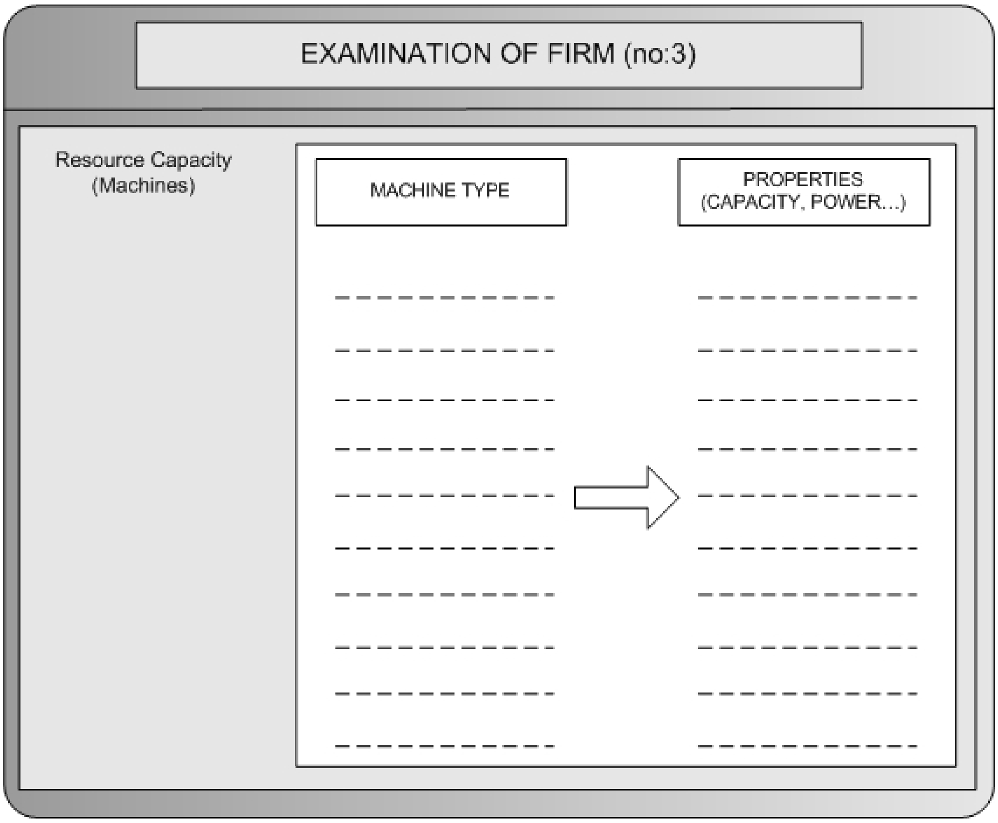


Figure 3.3 Examination of Firm:No3

3.3 Collecting and Processing Real System (Shop-Floor) Data

In this step, essential minority and a trivial majority which mainly determine system behavior should be identified. Data preparation should be organized very carefully in this step. A well known simulation principle is "Garbage In – Garbage Out", which means that even a well developed model could not produce close-to-reality results, if its input data differ from what is present in reality. Statistical considerations should be taken into account, when describing random factors, e.g., random variables. Also this step includes types of probability distributions which are used to describe random input variables. The items that should be done step by step while collecting data are the following in sequence;

- Type of entity and its process cycle should be described.
- Parts of entity and their process sequences should be determined.
    - Part List Table should be prepared.
    - Process Plan should be analyzed. (Prepared by Flowchart)
- Machining times and input distributions should be determined: The SMEs in Turkey usually don't have archives of the business they had, the production times and product sales. Because of these disadvantages, machining times should be obtained from operators. Generally exact process time could not be taken from operators but using different distribution formulas, this difficulty could be handled. There are different kinds of statistical distribution types which are used by Arena. General usage of statistical distribution can be summarized in Table 3.4;

Table 3.1 Statistical Distributions and Their Application Areas [11].

Distributions	Applications
Beta	Because of its ability to take on a wide variety of shapes, this distribution is often used as rough model in the absence of data.
Continuous	This distribution can be used as an alternative to a theoretical distribution that has been fitted to the data, such as in data that have a multimodal profile or where there are significant outliers.
Discrete	This distribution is frequently used for discrete assignments such as the job type, the visitation sequence, or the batch size for arriving entity
Erlang	The Erlang distribution is used in situations in which an activity occurs in successive phases and each phase has an exponential distribution.
Exponential	This distribution is often used to model inter-event times in random arrival and break-down process but it is generally inappropriate for modeling process delay times.

Gamma	The gamma is often used to represent the time required to complete some task (e.g. a machining time or machine repair time).
Lognormal	The lognormal distribution is used in situations in which the quantity is the product of a large number of random quantities. It is also frequently used to represent task times that have a distribution skewed to the right.
Normal	The normal distribution is used in situations in which the central limit theorem applies (i.e. quantities that are sums of other quantities.) because the theoretical range is from -∞ to +∞, the distribution should not be used for positive quantities like processing times.
Poison	The Poisson distribution is a discrete distribution that is often used to model the number of random events occurring in a fixed interval of time. If the time between successive events is exponentially distributed, than the number of events that occur in a fixed time interval has a Poisson distribution.
Triangular	The triangular distribution is commonly used in situations in which the exact form of the distribution is not known, but estimates (or guesses) for the minimum, maximum, and most likely are available. The triangular distribution is easier to use and explain than other distributions that may be used in this situation (e.g. the beta, gamma, etc., distribution.)
Uniform	The uniform distribution is used when all values over a finite range are considered to be equally likely. The uniform distribution has a larger variance than the other distributions that are used when information is lacking.
Weibull	The Weibull distribution is widely used in reliability models to represent the lifetime of a device. This distribution is also used to represent non-negative task times that are skewed to the left.

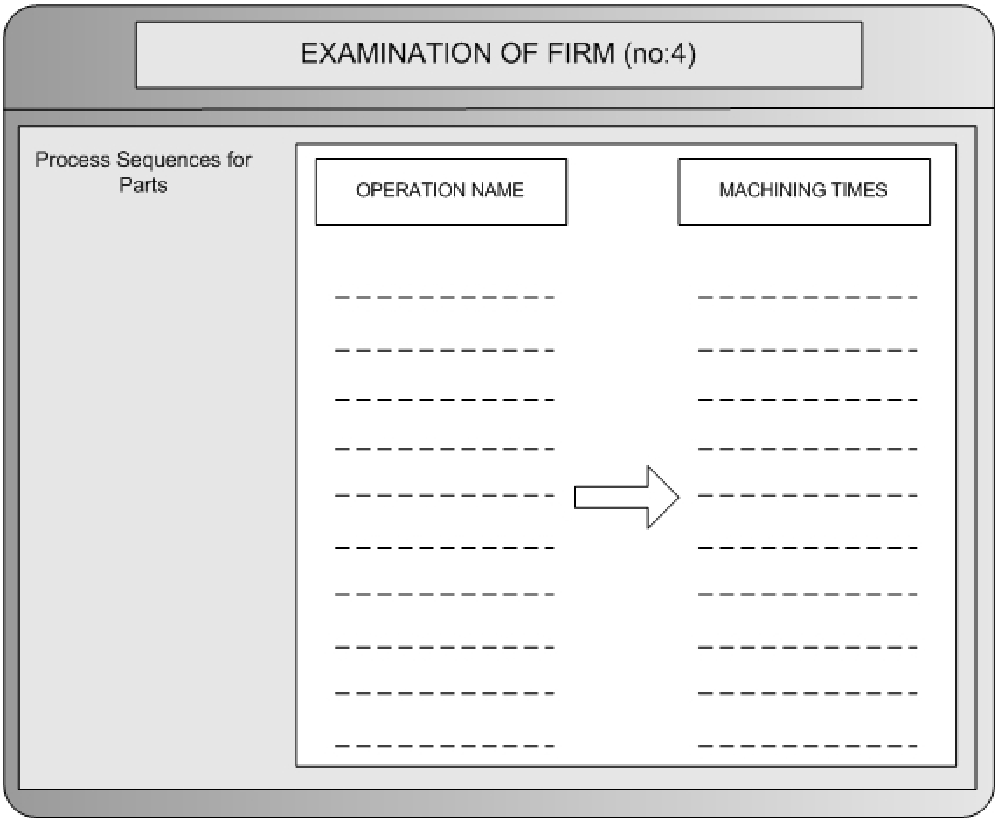


Figure 3.4 Examination of Firm:No4

- Also arrival times, transfer times between machines, setup times and working hours should be taken into account by the modeler. Number of hand lifts and overhead cranes should be determined.

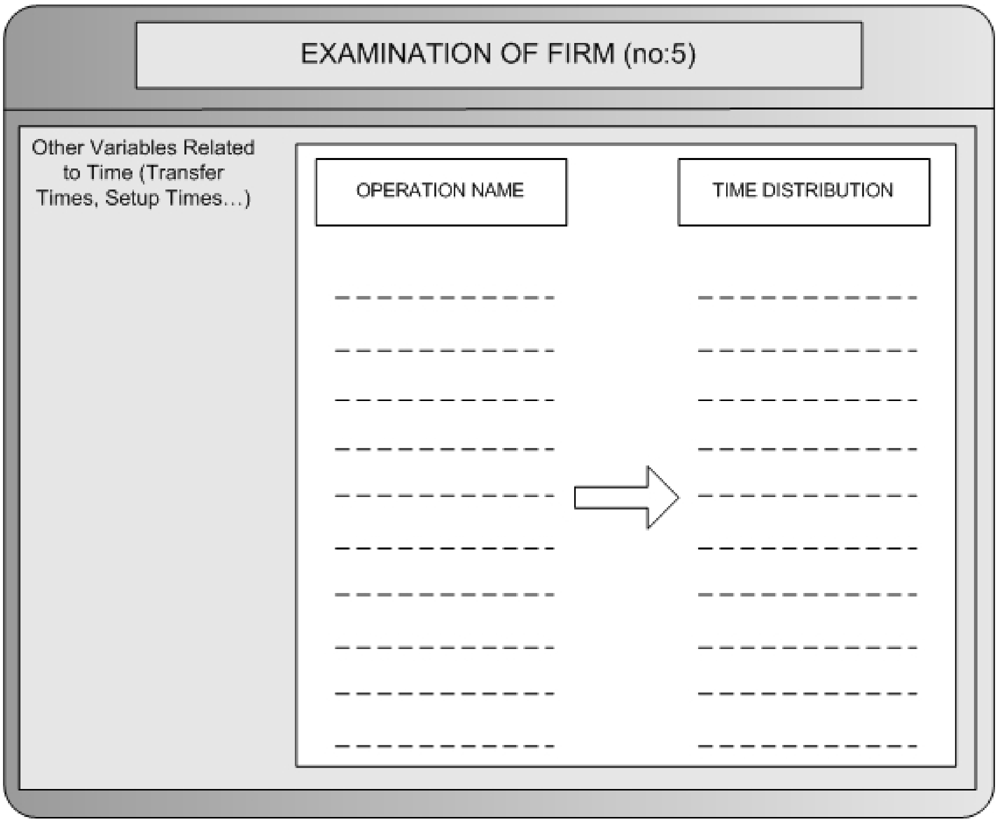


Figure 3.5 Examination of Firm:No5

3.4 Formulate and Develop a Model

In this step, first of all software program should be selected by modeler. When all data implement into selected program "a simulation model" will be formed. A choice between using simulation packages and application-oriented simulators should be made at this stage.

3.5 Verification & Validation

Verification means checking if the developed program indeed realizes the operational algorithm of the simulated system. At this stage the modeler should justify if the developed model operates as the original system does. Validation is the second stage (after verification) where the developed model is checked for adequate presenting of the modeled system. In this case operation of the model is compared with that of the modeled system. By testing model with probability distributions (random input variables), the question if the developed model operates as the original system does should be answered. A positive answer to that question would mean that simulation results indeed reflect operation of the modeled system in a corresponding situation. Comparison between real system's response and simulation model's response will help the modeler to see if the simulation run is valid or not.

As it was mentioned in the first step, modeler must collect the historical data (machining times, production sales, etc.) about SME. Validation and verification analysis should be only done by making comparison between old data or known data and experimental results. Old data could be taken from operators in this situation. Modeler can also collect his/her own data (machining times) by using chronometer for production of specific entity.

3.6 Establish Experimental Conditions for Model

Experiments are performed on the simulation at this stage in accordance with the developed plans. Experimental models can be defined as the running conditions of a simulation model. The Modeler will control the model with intended situations. These situations can be changed according to the utilization of resources or foreseeing the future of manufacturing the desired product. In this study, the main objective of using the simulation tool was to determine the suitable partner for the VE model. Work load utilization is an important issue while selecting a partner for VE. While getting information about the partner SME, Super Management of VE Department would want to see the responses of the company to the different situations. To see the effect of different scenarios some experiments must be applied on the model. Firstly, the main manufacturing scenario should be entered into the model then the modeler will change the system according to the goal of his/her research. After the verification and validation analysis of the main model, response of the system under different scenarios will be examined.

3.7 Analysis and Interpretation of Simulation Results

Simulation results are analyzed and interpreted at this stage that is a basis for making corresponding decisions (e.g., deciding about the best values of parameters of the modeled system, or choosing the best control algorithm).

CHAPTER 4

A SAMPLE APPLICATION FOR SIMULATION MODELING WITH ARENA®

4.1 Overview

In this chapter, application for simulation methodology will be described by simulating a real manufacturing company. For a pilot application, a hydraulic cylinder company in Ankara OSTIM was selected. As mentioned before, model of SMEs will be used while selecting a partner for virtual enterprise model. This chapter will guide the modeler while developing a simulation model of SMEs. Screenshots of templates were used for understanding the development process better.

The basic model and some experimental models will be developed in this chapter. After checking validation of system, experiments will be done by changing sequencing rules of queues. By using the basic model, new products, new process sequences, new queue rules, etc. could be added to the system.

The aim of this study is to develop the model of SMEs in order to use them to see the response of the system under desired conditions. In this study several experiments are done for optimizing the system performance. In addition to these experiments, the system was forced by new entity task to see the system response. As mentioned above a hydraulic cylinder company was selected for sample modeling. The VE management system selects the partner firms for a project by searching their resource capabilities. In this thesis it is assumed that drive shaft production job will enter the VE system and operations will be assigned to different companies with respect to their resource capabilities. Again it is assumed that the grinding and heat treatment operations for five drive shafts manufacturing will be assigned to this particular hydraulic company. By adding this new entity to the system, the modeler will see the system response before assigning the job in the real life. Implementation of experiments and results obtained from these experiments will be explained below

4.2 Collecting General System (Company Properties) Data

The hydraulic cylinder company was selected for this thesis. The main activity field of the company is manufacturing hydraulic cylinders. The company indicated that they are also interested in surface hardening and grinding operations of any other products.

The hydraulic company operates on make-to-order basis. The modeled system under consideration is a discrete parts manufacturing system. All operations for manufacturing of hydraulic cylinders are done in the company except “Chrome Plating” process. Piston Rods should be coated to decrease the effects of atmospheric conditions and frictional forces. To optimize the system efficiency, all potential problems should be determined before developing the model.

The hydraulic cylinder company’s manufacturing policy is based on make-to-order basis; most ordered products were taken as an entity for simulation modeling. Detailed data of entities will be collected in the next step. Worker schedule was defined as 8:00 a.m. to 6:00 p.m. with 30 minutes lunch break. If lunch break comes before the worker finishes his job, he takes his 30 minute break after completing the work (Figure 4.1).

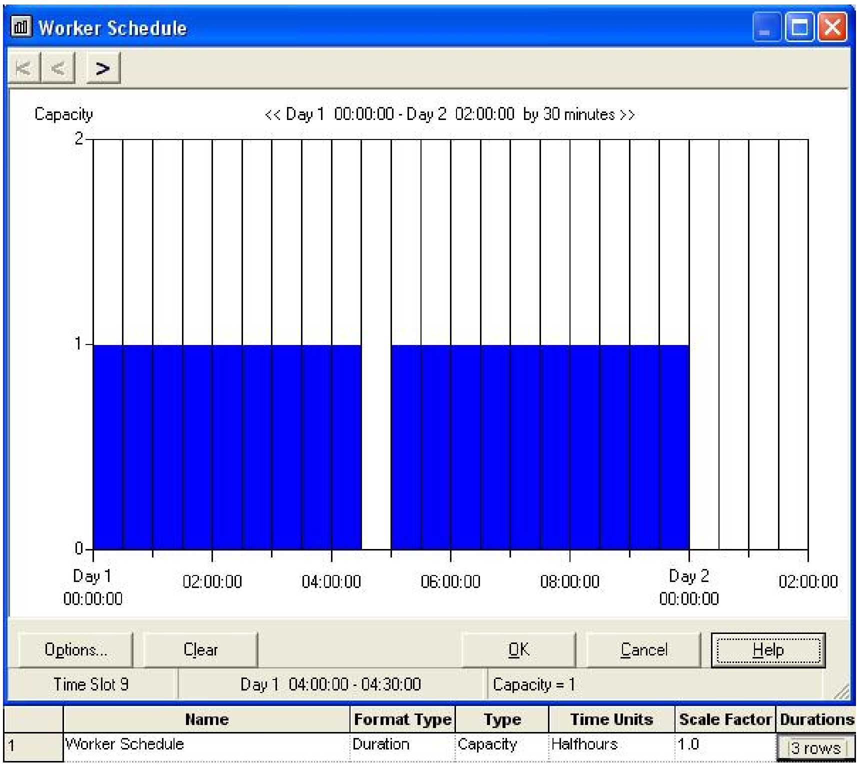


Figure 4.1 Worker Schedule

The firms that selected the make-to-order basis couldn't be modeled on a limited time basis. In these types of SMEs, models must be built on a number of entity basis. This means, the simulation run will finish when the manufacturing of the desired number of parts is completed. Ten replications will be done in this simulation and simulation will finish when twelve hydraulic cylinders are produced (Figure 4.2). In the Initialize between Replication tab, statistics and system check boxes were checked. By this marking, simulation will result in 10 statistically independent and identical replications and reports, each starting with an empty system at time 0 and each will finish when the manufacturing process will be done (Replication Length = Infinite). The random number generator just keeps on going between replications, making them independent and identically distributed (IID). In this example base time unit is selected as minutes.

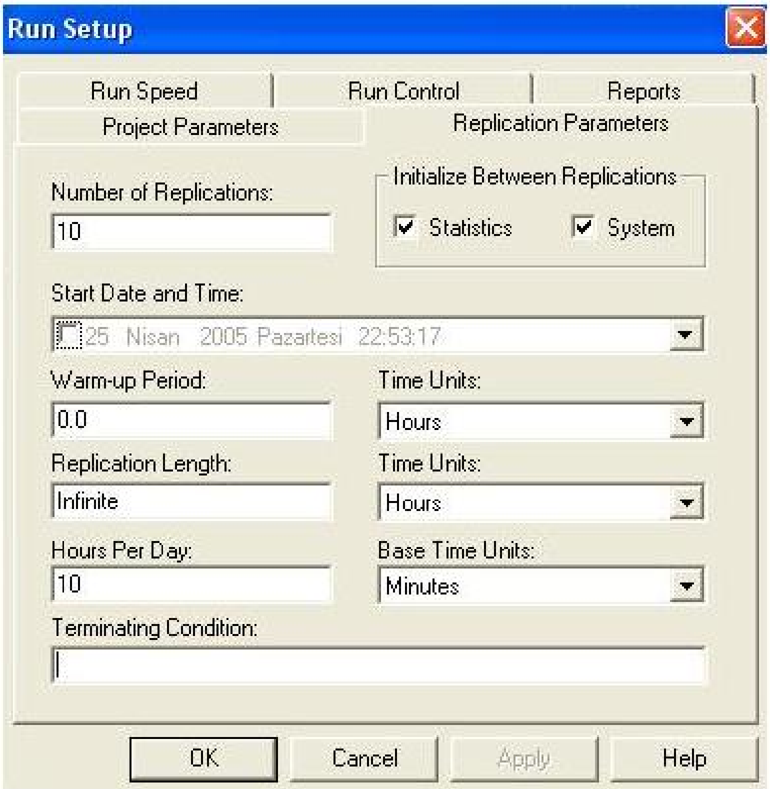


Figure 4.2 Run Setup Menu

After determination of general properties of the SME, resource capabilities (machines and workers) of firm should be determined. The company has four manual (Ø250x1500 mm, Ø250x2500 mm, Ø300x3000 mm, Ø400x3000 mm) and one CNC turning (Ø400x630 mm), one honing (Ø300x2200 mm), one heat treatment (mid-freq 10 kHz), one grinding (Ø280x2000 mm), one cutting, one drilling and one MIG welding machine (Table 4.2). Pictures of machines are given in Appendix A. Layout of the company is shown in Figure B.5. There are also nine technicians working in this company. Each of them is specialized on a different machine.

Table 4.1 Workers -Processes Table

	Turning Machine	Grinding Machine	Heat Treatment	Cutting	Honing Machine	Drilling Machine	Welding	Cleaning	Assembling
Worker 1	●			●		●		●	●
Worker 2	●			●		●		●	●
Worker 3	●			●		●		●	●
Worker 4	●			●		●		●	●
Worker 5	●			●		●		●	●
Worker 6		●		●		●		●	●
Worker 7				●	●	●		●	●
Worker 8				●			●	●	
Worker 9			●	●				●	

Table 4.2 Machine Capabilities

Machines Category and Type	**Capacity**	**Power**
CNC Turning Machine	Ø400x630 mm	10 kW
Lathe Machine 1	Ø250x1500 mm	5.5 kW
Lathe Machine 2	Ø250x2500 mm	5.5 kW
Lathe Machine 3	Ø300x3000 mm	7.5 kW
Lathe Machine 4	Ø400x3000 mm	10 kW
Grinding Machine	Ø280x2000 mm	6 kW
Honing Machine	Ø300x2200 mm	5 kW
Vertical Drilling Machine	0-26 mm	2 kW
Circular Saw	Ø350 mm	2 kW
MGAW Machine	500 amp	15kvA
Heat Treatment Machine	mid-freq 10 kHz	200 kW

4.2.1 Turning Operation

There are four universal and one CNC turning machine (Table 4.2) (Figure A.1 – A.5) in the company. Because of some advantages like lower setup times, higher operating speed, etc, CNC turning machine's operating time is approximately three times lower than other lathes. Five technicians work in this section. Weld edge preparation, rough turning (Face & Longitudinal), threading and grooving operations are done by lathe machines.

4.2.2 Welding Operation

Different kinds of bearings can be welded to piston rods. These bearings are requested by customer according to their usage area. One welding operator works with MGAW (Metal Gas Arc Welding) machine.

4.2.3 Heat Treatment Process (Induction Surface Hardening)

This operation is done in order to get a hard surface. Especially, parts which are exposed to tough working conditions will be hardened in industry. In the hydraulic company, there is one surface hardening machine which has 10 kHz frequency and 200 kW power (Figure A.8). In hydraulic cylinder manufacturing, piston rods must be hardened before, the grinding operation. If it is requested, gears (with modulus 5-40, diameter between 25-3000 mm), pins, bushes, spools, automotive equipments (with length 30-3000 mm), etc. will be hardened by EMA induction hardening machine. One technician works with this machine.

4.2.4 Grinding Operation

To get a smooth surface before sending rod batch to chrome plating, piston rods must be well ground. There is one cylindrical grinding machine which has Ø280x2000 mm capacity with 6 kW power (Figure A.9). One technician works with this machine.

4.2.5 Chrome Plating Process

Rods are exposed to atmospheric conditions that corrode them. To overcome this disturbance, after grinding operation, piston rods are sent for chrome plating.

Since there is no plating capability in the hydraulic company; rods are sent to another company which works on Chrome Plating Operations.

4.2.6 Pipe Cutting Process

Pipe cutting process is done by band saw machine which has 920 mm maximum cutting height. Cylinder barrel length is arranged with respect to stroke length.

4.2.7 Honing Operation

The honing machine was designed and manufactured by the company. This machine (Figure A.6, A.7) can operate on a cylinder barrel which has 300 mm diameter with 2200 mm length. Machine spindle speed can reach maximum 450 rev/mm. There are several honing heads (honing holes dia. 30~300 mm.) which are mounted to spindle. The machine is used to get well smooth inner surface (For better contact between seals (Figure 4.3).). One honing operator works with this machine.

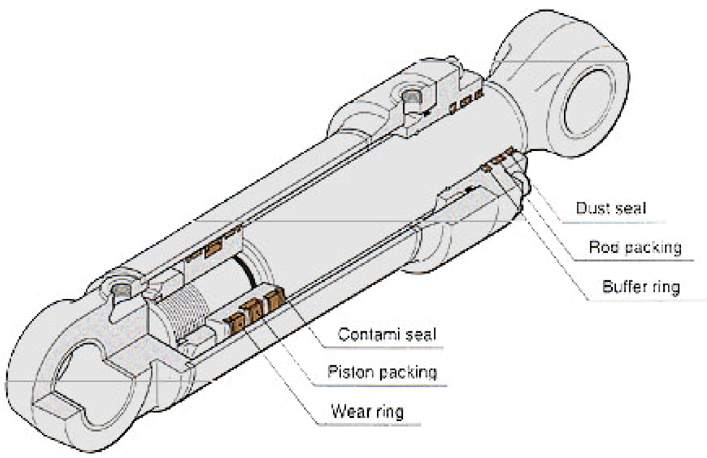


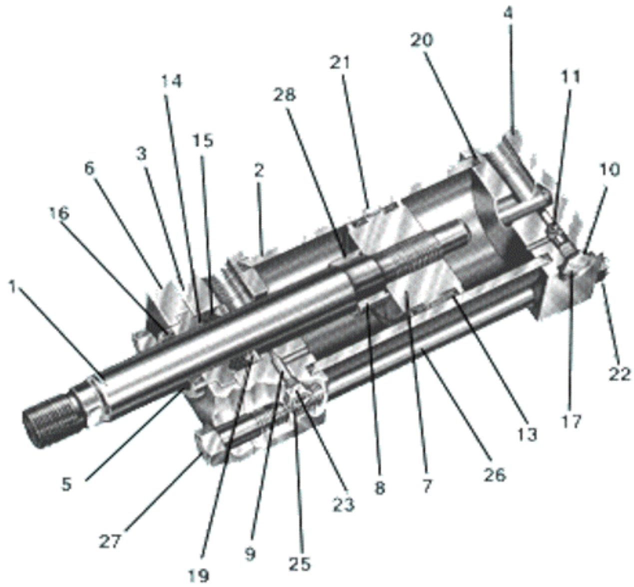
Figure 4.3 Hydraulic Cylinder Sealing Parts [14]

4.2.8 Drilling Operation

Cylinder barrel must be drilled and a mechanism must be mounted these holes to provide oil flow between gaps. This mechanism adjusts the movement of the hydraulic cylinders. The hydraulic cylinder types can be divided into two groups according to their movement types. These are single or double acting hydraulic cylinders. In single acting cylinders, return of piston rod action is done by the weight of construction whereas in double acting cylinders, movement of piston rod is done by pumps. These pumps are usually mounted on to the machine where the pistons are used. Machine operators will control the movement of hydraulic pistons by feeding oil to the gaps using these pumps.

4.3 Collecting and Processing Real System (Shop-Floor) Data

In this model, manufacturing process will be studied so it is believed that all type of entity and its process cycle should be described first. As it is mentioned above hydraulic cylinder company was selected for this study and their manufacturing policy is make–to-order policy. Figure A.13 – A.16 shows the firm product variety. For this model, most requested type which has Ø100 mm internal barrel diameter and 500 mm stroke was selected. The company has a capacity to produce different types of cylinders with minimum Ø63 mm and maximum Ø300 mm external diameter and maximum 2200 mm length. After the determination of entity type, parts of entity and their process plans should be determined. Hydraulic cylinder's standard parts list is shown in Figure 4.4.



Item No.	Description	Item No.	Description
1	Piston Rod	15	Packing Washer
2	Cylinder Barrel	16	Rod Wiper
3	Head end Cap	17	"O" Ring Seal for Ball Check Retainer
4	Cap end cap	18	N/A
5	Rod Bushing	19	Wave Spring
6	Retainer Plate	20	Cylinder Barrel O-Ring
7	Piston	21	Wear Ring
8	Cushion Plunger	22	Tie Rod Flex Loc Nut
9	Cushion adj. Needle	23	Teflon Ring Seal for Cushion adj. Needle
10	Ball Check Retainer	24	N/A
11	Ball Check	25	Jam Nut for Cushion adj. Needle
12	N/A	26	Tie Rod
13	Block Vee Packing	27	Self-Locking Cap Screw
14	Rod Vee Ring Set	28	O-Ring for Floating Cushion

Figure 4.4 Standard Part List [15]

Main part of basic cylinder can be described as;

- Piston rod. (Part 1)
- Piston. (Part 2)
- Cylinder barrel. (Part 3)
- Head end cap. (Part 4)
- Cap end cap. (Part 5)

Process plan for main parts is shown in Figure 4.5;

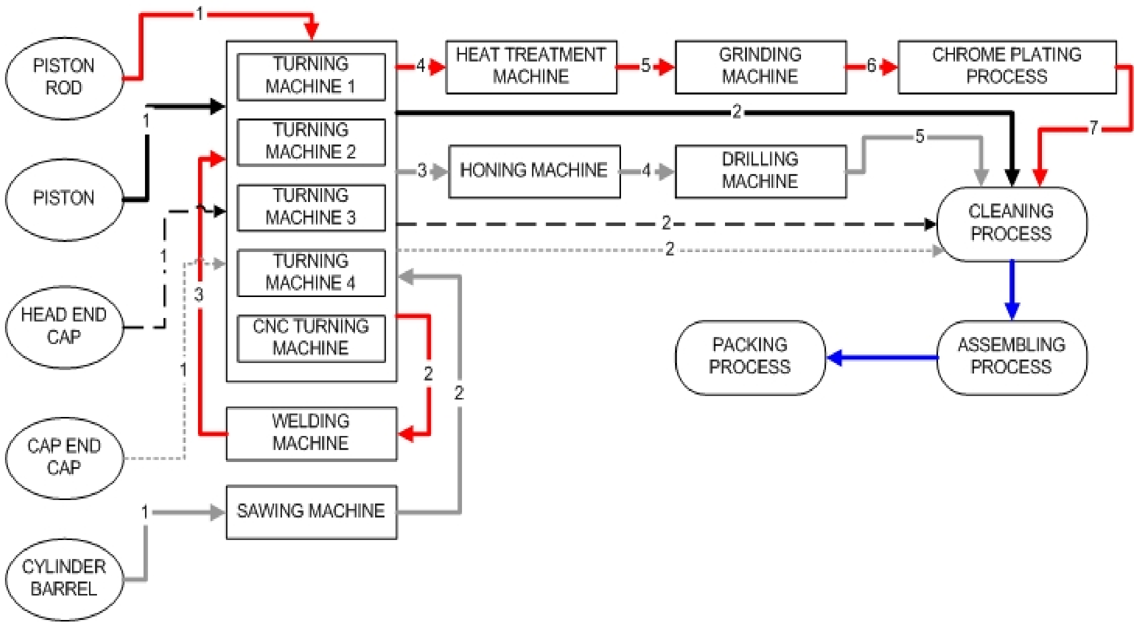


Figure 4.5 Process Plan

Machining times were taken from workers or it can be defined by using chronometer. Generally exact process time should not be taken from operators but using different distribution formulas may solve this problem. Triangular distribution is the most suitable distribution type for machining times. The triangular distribution is commonly used in situations in which the exact form of the distribution is not known, but estimates (or guesses) for the minimum, maximum, and most likely are available. Operators could give maximum and minimum process times. By using this distribution, ARENA® could calculate average values for operation times. For this pilot application, base time unit was selected as minute.

Table 4.3 Process Sequence for Piston Rod (Part 1)

Process Sequence for Piston Rod (in minutes)	
Turning operation	TRIA(7, 10, 15)
Welding operation	TRIA(13, 15, 21)
Turning operation	TRIA(70, 80, 110)
Heat treatment operation	TRIA(8, 10, 13)
Grinding operation	TRIA (22, 25, 32)
Chrome plating operation	TRIA (360, 720, 1080)
Cleaning operation	TRIA(10, 15, 20)
Assembling operation	TRIA(30, 45, 60)

Table 4.4 Process Sequence for Piston (Part 2)

Process Sequence for Piston (in minutes)	
Turning operation	TRIA(54, 60, 75)
Cleaning operation	TRIA(10, 15, 20)
Assembling operation	TRIA(30, 45, 60)

Table 4.5 Process Sequence for Cylinder Barrel (Part 3)

Process Sequence for Cylinder Barrel (in minutes)	
Pipe cutting operation	TRIA(7, 10, 12)
Turning operation	TRIA(130, 145, 155)
Honing operation	TRIA(60, 75, 80)
Drilling operation	TRIA(5,10,12)
Cleaning operation	TRIA(10, 15, 20)
Assembling operation	TRIA(30, 45, 60)

Table 4.6 Process Sequence for Head End Cap (Part 4)

Process Sequence for Head End Cap (in minutes)	
Turning operation	TRIA(120, 150, 165)
Cleaning operation	TRIA(10, 15, 20)
Assembling operation	TRIA(30, 45, 60)

Table 4.7 Process Sequence for Cap End Cap (Part 5)

Process Sequence for Cap End Cap (in minutes)	
Turning operation	TRIA(15, 20, 25)
Cleaning operation	TRIA(10, 15, 20)
Assembling operation	TRIA(30, 45, 60)

Arrival times, transfer times (Table 4.8-4.12), setup times of entities, and working hours should also be taken into account by modeler. Generally transportation process in the company is done by hand lifts but there are also two overhead cranes in the workshop. The values (minimum, mean and maximum transportation time) are determined by using chronometer.

Table 4.8 Transfer Time Distributions to Stations for Piston Rod

Transfer Time Distributions to Stations for Piston Rod		
Station Name	Route Time	Unit
Route From Turning	TRIA(12,15,17)	Minutes
Route From Welding	TRIA(3,4,6)	Minutes
Route From Turning	TRIA(12,15,17)	Minutes
Route From Hardening	TRIA(3,4,6)	Minutes
Route From Grinding	TRIA(50,60,75)	Minutes
Route From Plating	TRIA(50,60,75)	Minutes
Route From Cleaning	TRIA(2,3,4)	Minutes
Route From Assembling	TRIA(1,2,3)	Minutes

Table 4.9 Transfer Time Distributions to Stations for Piston

Transfer Time Distributions to Stations for Piston		
Station Name	Route Time	Unit
Route From Turning	TRIA(12,15,17)	Minutes
Route From Cleaning	TRIA(2,3,4)	Minutes
Route From Assembling	TRIA(1,2,3)	Minutes

Table 4.10 Transfer Time Distributions to Stations for Cylinder Barrel

Transfer Time Distributions to Stations for Cylinder Barrel		
Station Name	Route Time	Unit
Route From Sawing	TRIA(3,4,6)	Minutes
Route From Turning	TRIA(12,15,17)	Minutes
Route From Honing	TRIA(9,11,13)	Minutes
Route From Drilling	TRIA(3,5,7)	Minutes
Route From Cleaning	TRIA(2,3,4)	Minutes
Route From Assembling	TRIA(1,2,3)	Minutes

Table 4.11 Transfer Time Distributions to Stations for Head End Cap

Transfer Time Distributions to Stations for Head End Cap		
Station Name	Route Time	Unit
Route From Turning	TRIA(12,15,17)	Minutes
Route From Cleaning	TRIA(2,3,4)	Minutes
Route From Assembling	TRIA(1,2,3)	Minutes

Table 4.12 Transfer Time Distributions to Stations for Cap End Cap

Transfer Time Distributions to Stations for Cap End Cap		
Station Name	Route Time	Unit
Route From Turning	TRIA(12,15,17)	Minutes
Route From Cleaning	TRIA(2,3,4)	Minutes
Route From Assembling	TRIA(1,2,3)	Minutes

4.4 Formulate and Develop a Model

In this study, ARENA® Simulation Tool was used to develop the model. Statistics and data which were collected in previous steps are entered into Arena®'s menus. In the basic model, manufacturing of twelve basic hydraulic cylinder types was modeled. Queue mentality was taken as "Process Type" queue discipline in the basic model. It means every part will be queued with respect to their process type.

There are some important points which should be taken into consideration while modeling this pilot SME. First the modeler must determine his/her modeling mentality. There are two main simulation methods which could be selected by the modeler. As it is mentioned before Arena Templates have several modules and blocks. By the help of these modules and blocks models can be developed. Modules could be arranged consecutively or separately. Consecutive arrangements are generally used for basic type of modeling. Since these types of models are non-flexible, much complex models can not be developed by consecutive block arrangement. Modeler should use separate block groups to model a firm like SME. These separate block arrangement can be used for representing each operation. By this property, machining sequences can be changed or a new entity which has different and independent machining process can be added to the system. In this study, machining process was done by using "Station" and "Route" blocks. As it is clearly seen in Figure B.2 and Figure B.3, there is no link between machine block groups. Entities are seized by related machines by using sequence module of Arena. Resources (labor & machine capabilities) of firm should be entered to the Resource module of Arena. By the help of this module Arena will determine related machine and the worker with respect to the job type. Because some works (e.g. cleaning, drilling, etc.) in workshop which do not need specialization can be done by experienced workers who may be free at that time. When a new entity waits for its machine, technician should return to his own work after finishing the work he has without taking the second one. For a sample illustration, in Figure 4.6, the expanded case of the Arena's Set Module is shown. Here, the sequence of the workers that can work incase of being idle in the band saw machine (Cell 1), can be seen. Same list should be prepared for all machines (cells) to determine the corresponding worker(s).

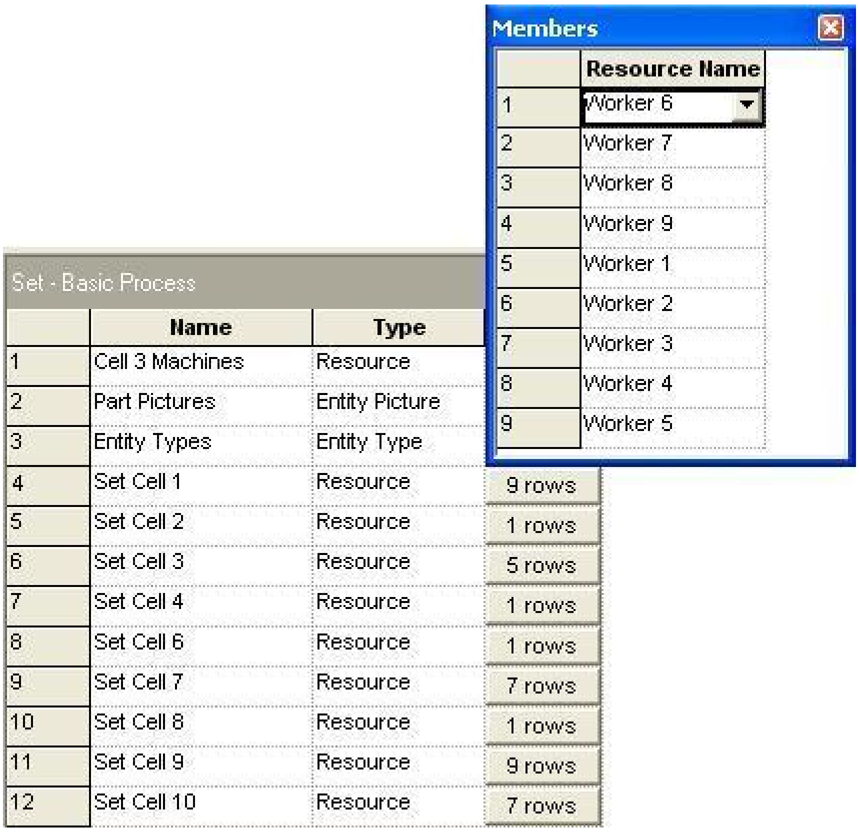


Figure 4.6 Set Module

Second important point while modeling the pilot SME is developing the batch for chrome plating process. As it is mentioned above company sends all Piston Rods which are ready for chrome plating by making batches. Arena uses the Batch & Separate modules to accomplish this task. This module is intended as the grouping mechanism within the simulation model. Batches of entities can be permanently or temporarily grouped. Temporary batches must later be split using the Separate module. Batches may be made with any specified number of entering entities or may be matched together based on an attribute. Entities arriving at the Batch module are placed in a queue until the required number of entities has accumulated. Once accumulated, a new representative entity is created.

The modeler must also be careful while modeling the assembly operation. Arena takes all or specific entity with respect to desired number while making batch operation. But in the assembly operation, Arena should seize one entity from every part. To achieve this task, entities should be separated according to their types. The Match block could be used for synchronizing the entities located in different, detached queues. When operand Match Attribute is specified, the Match block synchronizes the advance of entities with matching values of Match Attribute. Two or more detached queues, each with its own Queue Label, are used in conjunction with the Match block. When an entity arrives at one of these detached queues, Siman assigns the value of Match Attribute as the entity's match code. When all detached queues associated with a Match block have one or more entities with the same match code, these entities are released to the Destination Label corresponding to each Queue Label, or are disposed if no Destination Label is specified. When operand Match Attribute is defaulted, Siman waits until each of the detached queues associated with the Match block has one or more entities in it before releasing or disposing the entities.

In this study, model was built on three main sections which are part arrival, manufacturing and part disposal.

4.4.1 Part Arrival Section

In the Part arrival section (Figure B.1), entities are created and some attributes are assigned. After assigning the attributes, entities are routed to their related machines, by using their process sequences.

4.4.2 Manufacturing Section

In the manufacturing sub-model, all manufacturing processes, related with machines were modeled separately (Table 4.13). Machining sequences are taken from "Sequence" module of ARENA®.

Table 4.13 Resource Names in ARENA®

Resource Names (ARENA®)	Processes & Machines
Cell 1	Band Saw Machine
Cell 2	Heat Treatment Process
Cell 3	Turning Machines
Cell 4	Grinding Machine
Cell 5	Chrome Plating Process
Cell 6	Welding Machine
Cell 7	Drilling Machine
Cell 8	Honing Machine
Cell 9	Cleaning Process
Cell 10	Assembling Process

4.4.2.1 Sub-Model of Band Saw Machine

Pipe cutting process is done in this stage. Workers who have this ability and availability can work with this machine. Setup time for cutting process was taken as TRIA (8,10,12). By "Route from Cell 1" module, parts are transferred to next related machine.

4.4.2.2 Sub-Model of Heat Treatment Process

This stage deals with the Surface Hardening process done at this stage. "Worker 9" works with this machine. Setup time for heat treatment process was taken as TRIA (5,7,9). Parts are removed from this machine approximately in 2 minutes. By "Route from Cell 2" module, parts are transferred to the next related machine.

4.4.2.3 Sub-Model of Turning Machines

This is the stage of turning operations done at this stage. Five workers (Worker 1, Worker 2, Worker 3, Worker 4 and Worker 5) work on lathes. Each of them works at his own related machine. CNC turning machine's operating speed is approximately three times higher than other lathes. Therefore, machining times for CNC machine is multiplied by 0.3 constant by ARENA®. Setup time for turning process was taken as TRIA (12,15,17). Part removal time was taken as TRIA (3,5,8). By “Route from Cell 3” module, parts are transferred to the next related machine.

4.4.2.4 Sub-Model of Grinding Machines

Grinding operations are done at this stage. “Worker 6” works on this machine. Setup time for grinding process was taken as TRIA (12,15,17). Part remove time was taken as TRIA (3,5,8). By “Route from Cell 4” module, parts are transferred to the next related machine.

4.4.2.5 Sub-Model of Chrome Plating Process

Chrome plating process in which piston rods are sent to chrome plating company takes place in this stage. Before sending piston rods for plating process, rods are batched. This process takes minimum six hours and maximum approximately two days. It depends on company’s work load. Statistical distribution for this process was taken as TRIA (360,720,1080). By “Route from Cell 5” module, parts are transferred to the next related machine.

4.4.2.6 Sub-Model of Welding Process

Welding process is done at this stage and “Worker 8” works at this machine. Statistical distribution for this process was taken as TRIA (13,15,21). By “Route from Cell 6” module, parts are transferred to the next related machine.

4.4.2.7 Sub-Model of Drilling Machine

Drilling process is done at this stage. Workers who have this ability and availability can operate this machine. Setup time for drilling process was taken as

TRIA (8,10,12). By “Route from Cell 7” module, parts are transferred to the next related machine.

4.4.2.8 Sub-Model of Honing Machine

Honing process is done at this stage. “Worker 7” operates this machine. Setup time for honing process was taken as TRIA (14,18,20). Part remove time was taken as TRIA(5,9,11). By “Route from Cell 8” module, parts are transferred to the next related machine.

4.4.2.9 Sub-Model of Cleaning Process

Cleaning process is done at this stage in which all workers, who are idle, can clean and checks the finished parts. Statistical distribution for this process was taken as TRIA (10,15,20). By “Route from Cell 9” module, parts are transferred to the next related machine.

4.4.2.10 Sub-Model of Assembling Process

Assembling process is done at this stage. Workers who have this ability and availability can assemble the finished parts. All finished parts are separated according to entity type, and then entities are seized one by one for assembling process. Statistical distribution for this process was taken as TRIA (30,45,60). By “Route from Cell 10” module, parts are transferred to disposal stage.

4.4.3 Disposal Section

In the disposal section (Figure 4.4), entities are disposed and some statistics about queues, entities, processes and resources are taken. Detailed explanation, graphical results and statistics can be found in APPENDIX C.1 for basic model.

4.5 Verification & Validation

Ten replications were done for each model. By using half width, minimum and maximum values of results, Arena takes the average of each result and gives one statistical result for each. During validation, owing to the unavailability of data, these output statistics can only be compared against the conjectural manufacturing time which is taken from the owner of the company. It can be summarized that twelve basic cylinder manufacturing approximately takes 4.5 - 5 days. When this information is compared with the results of "Process Type" experiment (Company's manufacturing policy), it can be easily seen that the basic model is valid.

4.6 Experimental Models and Their Results

As it was mentioned before, the main parts of the hydraulic cylinder are "the piston rod", "the piston", "the cylinder barrel", "the head end cap" and "the cap end cap". When the company's resource capacity is taken into account, these five parts can be produced without the occurring of any bottleneck except the turning operation queue. These five main parts have different production plans. Among the plans of these parts, the only common operation is the turning operation. The piston rod goes through the turning operation queue twice and the other parts go through once. So it can clearly be seen that the turning operation's queue is the place that all parts are waiting for machining. The modeler can change the responses of the system by changing the order mentality of the turning operation queue. The firm manager's selection for the turning operation queue is "Process Type". Firstly, this scenario with ten independent replications was studied. The results of the "Process Type" experiment can be briefly shown as;

Table 4.14 Value-Added Time for Entities

Entity Time VA Time (Minute)	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	906.66	66,69	753.76	1026.30	707.14	1063.86
Part 2	104.38	2,29	97.4473	108.55	62.8794	139.27
Part 3	257.17	4,00	248.95	264.96	181.01	317.25
Part 4	157.18	4,19	147.70	165.27	91.8302	230.09
Part 5	72.3359	2,51	66.9127	76.6641	51.4983	90.6125

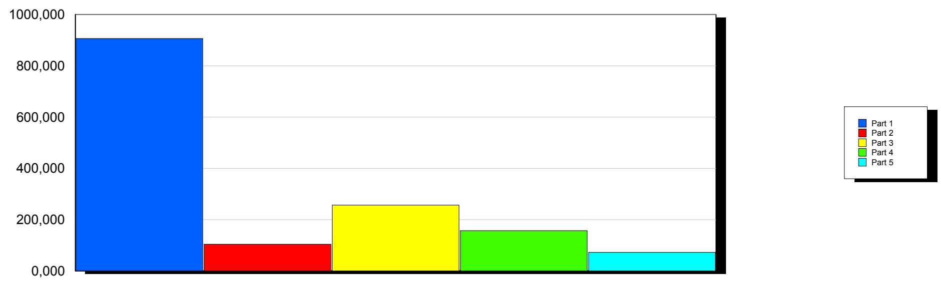


Figure 4.7 Value-Added Time for Entities

Table 4.15 Waiting Time for Entities

Entity Time Wait Time (Minute)	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	1289.23	25,35	1240.61	1331.34	970.97	1606.50
Part 2	2244.63	73,77	2048.94	2396.56	1879.91	2590.81
Part 3	2067.13	63,92	1915.82	2206.94	1654.55	2383.94
Part 4	2186.19	77,34	2006.25	2381.38	1802.57	2573.90
Part 5	2266.96	71,94	2083.52	2445.84	1890.68	2672.72

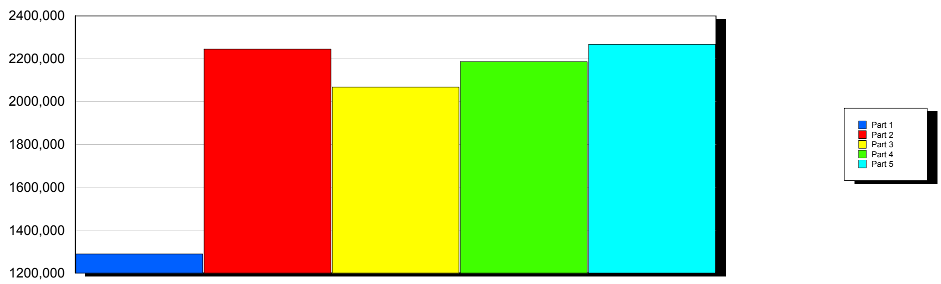


Figure 4.8 Waiting Time for Entities

Table 4.16 Transfer Time for Entities

Entity Time Transfer Time (Minute)	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	174.98	4,3	167.27	183.69	156.83	195.14
Part 2	27.1469	0,26	26.5448	27.7745	23.9937	30.1519
Part 3	47.2340	0,55	46.3876	48.7167	43.0453	52.0912
Part 4	27.2439	0,25	26.7963	27.9240	24.2148	30.7154
Part 5	26.8100	0,31	26.0860	27.3291	23.7454	30.8853

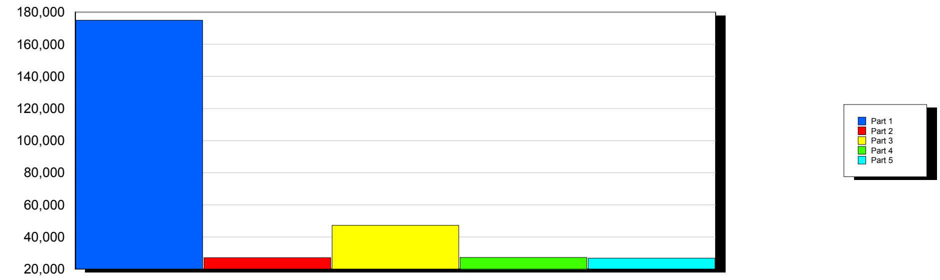


Figure 4.9 Transfer Time for Entities

Table 4.17 Total Time for Entities

Entity Time Total Time (Minute)	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	2370.87	69,99	2184.78	2528.99	1967.93	2765.72
Part 2	2376.16	73,96	2176.66	2528.50	1984.43	2752.94
Part 3	2371.53	64,56	2218.76	2518.82	1992.46	2729.61
Part 4	2370.62	75,58	2195.82	2565.50	1973.42	2811.20
Part 5	2366.11	73,75	2176.61	2549.03	1992.37	2786.17

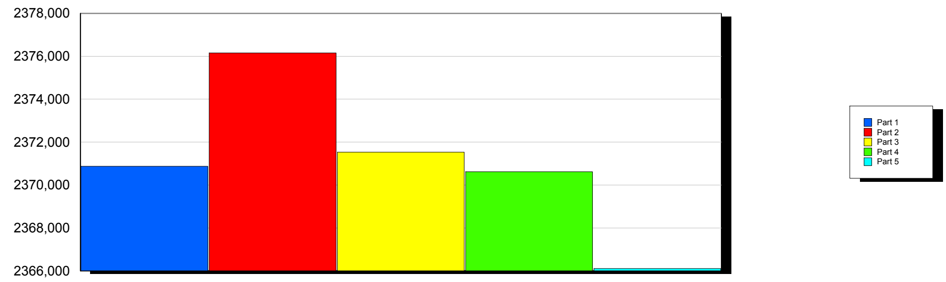


Figure 4.10 Total Time for Entities

Table 4.18 Process Times wrt Machines

Processes Time Accumulated VA Time (Minutes)				
	Average	Half Width	Minimum Average	Maximum Average
Cell 1	117.82	2,56	111.34	122.35
Cell 2	124.62	2,64	118.72	131.53
Cell 3	3913.94	47,67	3806.87	3998.66
Cell 4	317.30	2,65	311.69	323.33
Cell 5	725.36	66,91	574.01	843.60
Cell 6	194.13	3,29	188.10	200.83
Cell 7	108.99	3,69	100.22	117.73
Cell 8	858.69	14,14	817.77	881.55
Cell 9	885.84	12,1	865.34	908.97
Cell 10	549.41	18,65	513.33	599.72

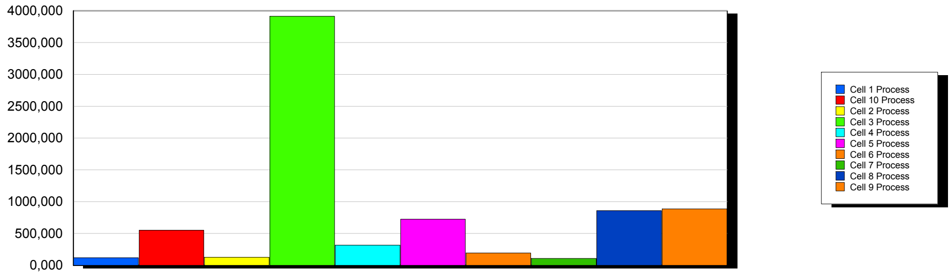


Figure 4.11 Process Times wrt Machines

When the results above are examined, it can be seen that total time for manufacturing of piston rods (Part1) takes 906.66 minutes. The highest value which follows it belongs to cylinder barrels (Part 3) which is 257.17 minutes. When the Table 4.18 is examined, it is seen that chrome plating operation (Cell 5) takes 725.36 minutes. So, it is now clearly seen that this huge difference between production time of piston rods and the other parts is occurred because of chrome plating operation.

When Table 4.16 is examined, it is clearly seen that the transfer time has no remarkable effect on the total process time. All machines except lathes are placed in one part of the company and the replacements between them will not seriously affect the transfer times of the parts. By this manner, it can be recognized that placements of machines are appropriate to the work flow of the hydraulic cylinder company. In the Table 4.16, piston rod's (Part 1) transfer time – 174.998 minutes - may attract attention. The most of this time passes at transferring between the hydraulic company and the plating company. Since the firm is not directly related with this loss time, the company can not make any better optimization to decrease the transfer times.

When the process times are taken into account it is seen that turning machines (Cell 3) are the most utilized machines. Replacing the universal turning machines with the new CNC machines will decrease the total process time of turning operation. This replacement will also help the company to decrease the total production time of hydraulic cylinders.

When the waiting times are examined from Table 4.16, it can be seen that piston rods wait for machining less than the other parts. But still there are other possibilities to decrease the waiting time of piston rods. To decrease total time for hydraulic cylinders, different sequencing rules can be tried on the turning queue. The other developed experiments for optimizing the system are;

- FIFO (First-In-First-Out)
- Piston rods have first priority for turning operation
- Arrange the parts with respect to their process times
    - SPT (Shortest Processing Time First)
    - LPT (Longest Processing Time First)

These four scenarios were studied with ten independent replications. Detailed results of these experiments can be found in Appendix C. In order to make a comparison between company's manufacturing policy (Process Type) and the other four experiments, total manufacturing time and waiting time data are listed in Table 4.19.

Table 4.19 Comparison between Simulation Results.

Base time unit: Minute	**FIFO (First In First Out)**	**Part Priority (Piston Rods First)**	**SPT (Shortest Processing Time First)**	**LPT (Longest Processing Time First)**	**Process Type**
Total Time	2595	2172	2481	2805	2808
Part 1 Waiting Time	1096.89	646.54	842.82	1359.45	1289.23
Part 2 Waiting Time	2043.19	1593.48	1851.24	2240.33	2244.63
Part 3 Waiting Time	1886.17	1430.39	1695.76	2075.22	2067.13
Part 4 Waiting Time	1984.99	1526.19	1791.71	2179.36	2186.19
Part 5 Waiting Time	2068.99	1614.64	1879.79	2263.57	2266.96

As it is clearly seen in Table 4.19, “Part Priority” queue mentality gives the best response for hydraulic cylinder manufacturing. In this manufacturing policy, piston rods have priority to be machined in turning operation over the other parts. As it was mentioned before, piston rods are batched and sent to the chrome plating company which takes minimum six hours to plate. Consequently, giving priority to the piston rods for turning operation is the best choice for company. By this way, plating of the piston rods is done simultaneously with manufacturing of other parts. Among all the sequencing rules analyzed, the “Process Type” sequencing rule has the worse results compared to the other sequencing rules.

4.7 Experiments for VE Organization

The drive shaft production is tested in the second part of the experiments even though the "drive shaft”, isn’t offered in the wide range of products at the pilot company. As it is mentioned above, the company also is interested in surface hardening by induction and grinding. In this part of the study, it is assumed that grinding and heat treatment operations of five new entities are assigned to the hydraulic cylinder company by the VE management unit. It is also assumed that this job was assigned 300 minutes after the company started to produce twelve hydraulic cylinders. This new entity and its process sequences have been experimented on "Process Type" and "Part Priority" models which were prepared beforehand. Detailed results of each experiment can be found in Appendix C. The results which are tabulated for comparison are;

Table 4.20 Comparison between Simulation Results 2.

	Process Type	Drive Shaft Manuf. wrt Process Type	Part Priority (Piston Rods First)	Drive Shaft Manuf. wrt Part Priority
Total Time	2808	2706	2172	2082
Part 1 Process Time	906.66	894.48	899.11	818.19
Part 2 Process Time	104.38	103.91	103.19	103.16
Part 3 Process Time	257.17	256.71	243.21	242.94
Part 4 Process Time	157.18	157.30	165.86	166.00
Part 5 Process Time	72.3359	71.8896	74.2937	73.9340
Part 6 Process Time	---	49.3255	---	49.1808
Part 1 Wait Time	1289.23	1299.02	646.54	645.42
Part 2 Wait Time	2244.63	2240.19	1593.48	1510.73
Part 3 Wait Time	2067.13	2062.70	1430.39	1347.87
Part 4 Wait Time	2186.19	2181.52	1526.19	1443.30
Part 5 Wait Time	2266.96	2262.34	1614.64	1532.00
Part 6 Wait Time	---	89.4652	---	345.18
Process Time Cell 1	117.82	117.82	118.44	118.44
Process Time Cell 2	124.62	216.00	122.61	215.00
Process Time Cell 3	3913.94	3913.94	3908.91	3908.91
Process Time Cell 4	317.30	471.42	311.43	468.22
Process Time Cell 5	725.36	713.84	719.85	638.70
Process Time Cell 6	194.13	194.13	194.35	194.35
Process Time Cell 7	108.99	110.75	106.36	109.34
Process Time Cell 8	858.69	855.44	861.28	860.48
Process Time Cell 9	885.84	893.67	890.63	894.51
Process Time Cell 10	549.41	543.76	535.16	532.60
Total Time of Part 6	---	150.50	---	406.07

New entity (Drive Shaft) was represented as Part 6 in Table 4.20. When the Table 4.20 is examined it is clearly seen that process times for parts are approximately same. When the total production time of drive shafts is taken into account, it is seen that assigned job is finished earlier in “Process Type” mentality. If the grinding and hardening operations are examined this situation will come out clearly. Piston rods have priority for machining in grinding and hardening operations in both queue mentalities. With detailed explanation, in these queues piston rods take the first place and drive shafts take the second place for machining. In the “Process Type” model, operation of drive shaft task is almost finished just before the piston rods arrive. But in the “Part Priority” model, when the drive shafts arrive to the system, piston rods have already been queued for grinding or hardening operations. This situation creates the differences in waiting times of the drive shafts. The company must choose its queue mentality for grinding and hardening machines according to an assigned due date. It is clearly seen in Table 4.20 that operations of manufacturing five drive shafts does not affect the total manufacturing time too much. So VE management can clearly understand that this task would easily be accomplished by this company. Detailed statistical results and their graphs can be found in APPENDIX C.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The appropriateness of the simulation tool to partner SME selection process of the VE model was tested in this study. As it was mentioned before, Small-Medium Size Enterprises (SMEs) seems to be appropriate units to behave like VE partners due to their lean structure, adaptability to market evolution, active involvement of versatile human resources, ability to establish sub-contracting relations and good technological level of their products.

In this study, ARENA simulation tool was used for developing the model of shop floor activities of pilot SME to see the appropriateness of candidate SMEs for VE organization. VE management unit will use this tool while making pre-elimination of SMEs, optimizing the manufacturing plan of the member SMEs, analyzing the member SMEs with their current and new work load over the existing one. VE management will analyze these virtual models by checking the output statistics of ARENA. The default ARENA installation automatically brings up the Category Overview Report, which gives the modeler access to most important statistical results such as cost, resource, queues, activity areas, processes, stations, conveyors, transporters and entity statistics. But also these variables must be defined while developing the model. The modeler can also keep his/her own tallies by defining them in his/her model. In this study, firstly, a pilot SME's shop floor activity, with its current workload, was modeled and examined. Then four different scenarios were tested on this base model. By examining the statistical outputs of the all developed model, the best queue rule which gives better response to given circumstances, the most utilized resources (machines and workers) and the bottlenecks which were occurred during the manufacturing of main parts of hydraulic cylinder were determined.

Also in this thesis, new jobs were assigned to the company to see the response of the system under their current workload. According to the goal of the VE management unit output statistics can be defined while developing the model. By analyzing the statistical output results of new model, VE management unit can easily make decision about appropriateness of candidate SMEs. For instance, if VE management unit examines the total production time of new part which was subsequently assigned to the candidate SMEs, the most appropriate firm according to due date of new job can be easily seen. Finally, this study shows that simulation tool provides remarkable advantages while choosing the partner firm (SME) for VE System.

The major benefits of this study can be defined as follows;

- Examining member firm with current and assigned work load.
- Give an opportunity to optimize the system's resources.
- Give an opportunity to select most appropriate firm for the project.
- Give an opportunity to examine the system with respect to the goal of VE management unit.
- By the developed simulation methodology, modeling of new SME will be done easily and accurately.

The literature survey revealed that the simulation tool was not used as a part of VE partner selection process. Since this thesis is the first of its kind and considering that its subject of the simulation tool was not implemented in the IMTRG (Integrated Manufacturing Technologies Research Group) before, this subject has strong prospects for future researches. In the future, this subject can be further developed in various ways. The following topics are suggested as future works of this thesis;

- The usage of simulation tool can be expanded for all types of SMEs. More complicated manufacturing types can be modeled in order to specialize in simulation.
- An object-oriented program can be developed and integrated into the ARENA program in order to develop and edit the model easily.
- If a control unit is developed for the VE system, the simulation tool can be integrated into this unit by developing a VBasic based program.

REFERENCES

[1] Paul Kidd, "Agile Manufacturing: Forging New Frontiers", Addison-Wesley, 1994.

[2] M. T. Martinez, P. Fouletier, K. H. Park, J. Favrel, *"Virtual Enterprise-organisation,evolution and control"*, Int. J. Production Economics, 74, 225-238, 2001

[3] S.E. Bleeker, *"The virtual organization"*, Futurist 28, 2, 1994

[4] Davidow WH, Malone MS. The Virtual Corporation: Structuring and Revitalizing the Corporation for the 21st Century. New York: HarperCollins; 1992

[5] Byrne J. The Virtual Corporation: the Company of the Future will be the Ultimate in Adaptability, Business Week 1993; 8:37-41

[6] Hormozi AM. Agile Manufacturing: In Proceedings of the 37th International Conference, American Production and Inventory Control Society, San Diego; 1994.

[7] Nell JG. Enterprise Representation: An analysis of Standards Issues; 1998. Available at http://www.mel.nist.gov/msidlibrary/doc/jimnell95.pdf

[8] L. Camarinha-Matos, R. Carelli, J. Pellicer, M. Martín, "Towards to the Virtual Enterprise Food Industry", in Proceedings of International Conference on Integrated and Sustainable Industrial Production, Edited by Luis Camarinha-Matos, Chapman & Hall, Lisboa, Maio de 1997, pp 73-84.

[9] VE system [On-line], 2003, Available at
http://mis.postech.ac.kr/topic/ve_e.html#_top

[10] Sarı, B.,Kılıç. S. E., “Development of an SME-Based Virtual Enterprise”, 11th International Conference on Machine Design and Production, 11th International Machine Design and Production Conference, Antalya, Turkey, 13-15 October 2004, pp.79-93.

[11] W. David Kelton, Randall P. Sadowski, Deborah A. Sadowski, “Simulation with Arena”, McGRAW-HILL International Editions, 2002

[12] S. Andradóttir, K. J. Healy, D. H. Withers, and B. L. Nelson, “Introduction to Modeling and Simulatıon”, Proceedings of the 1997 Winter Simulation Conference ed., Binghamton, NY 13902-6000, U.S.A, 1997, pp.7-12.

[13] David A. Takus, David M. Profozich, “Arena® Software Tutorial”, Proceedings of the 1997 Winter Simulation Conference , Sewickley, Pennsylvania, USA, 1997, pp 541-543.

[14] kianho.com [On-line], 2005, Available at
http://www.kianho.com.sg/hydraulic_cyclinder.gif

[15] flodraulic.com [On-line], 2005, Available at
http://www.flodraulic.com/uah/products/milwaukee.htm

[16] Product Catalog of Erdemler Hydraulic Company, Ankara, Turkey, 2005

APPENDIX A

MACHINERY CAPABILITIES & PRODUCT TYPES OF ERDEMLER HYDRAULIC COMPANY

A.1 Machinery Capabilities

The company has four manual lathes (Ø250x1500 mm, Ø250x2500 mm, Ø300x3000 mm and Ø400x3000 mm), one CNC turning (Ø400x630 mm), one honing (Ø300x2200 mm), one heat treatment (mid-freq 10 kHz), one grinding (Ø280x2000 mm), one drilling, one band saw, and one MIG welding machine.

Figure A1 A View of Lathe 1

Figure A.2 A View of Lathe 2

Figure A.3 A View of Lathe 3

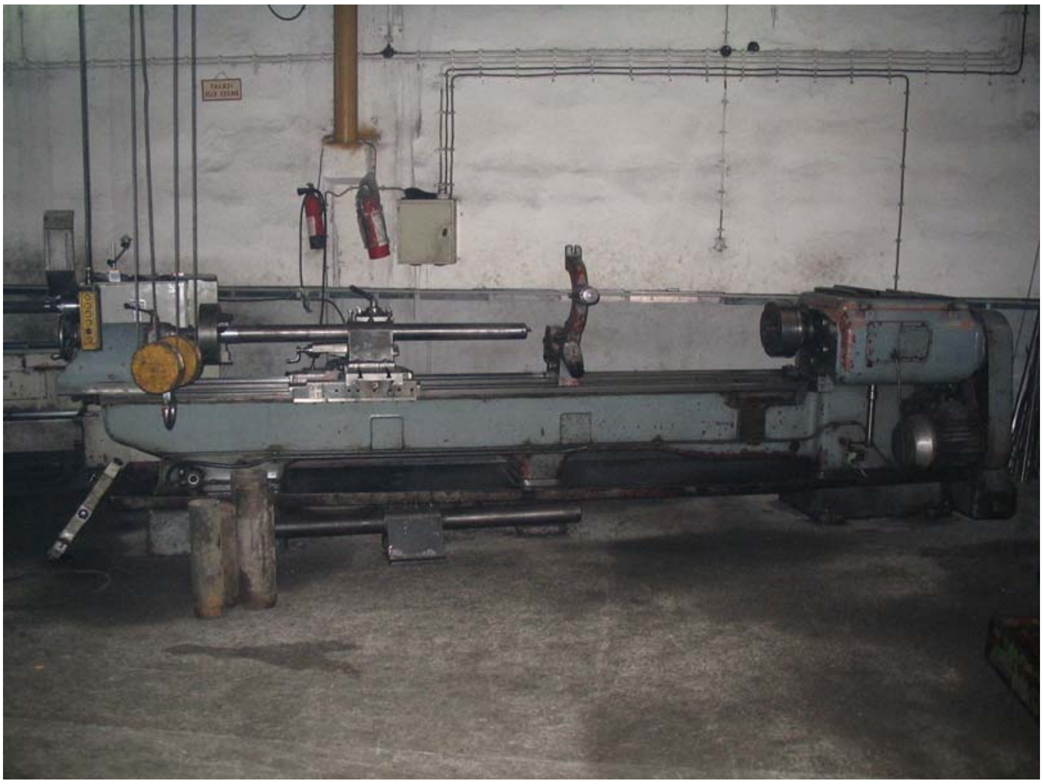


Figure A.4 A View of Lathe 4

Figure A.5 A View of CNC Lathe

Figure A.6 A View of Honing Machine

Figure A.7 A View of Honing Operation

Figure A.8 A View of Heat Treatment Machine

Figure A.9 A View of Grinding Machine

Figure A.10 A View of Vertical Drilling Machine

Figure A.11 General View of Workshop_1

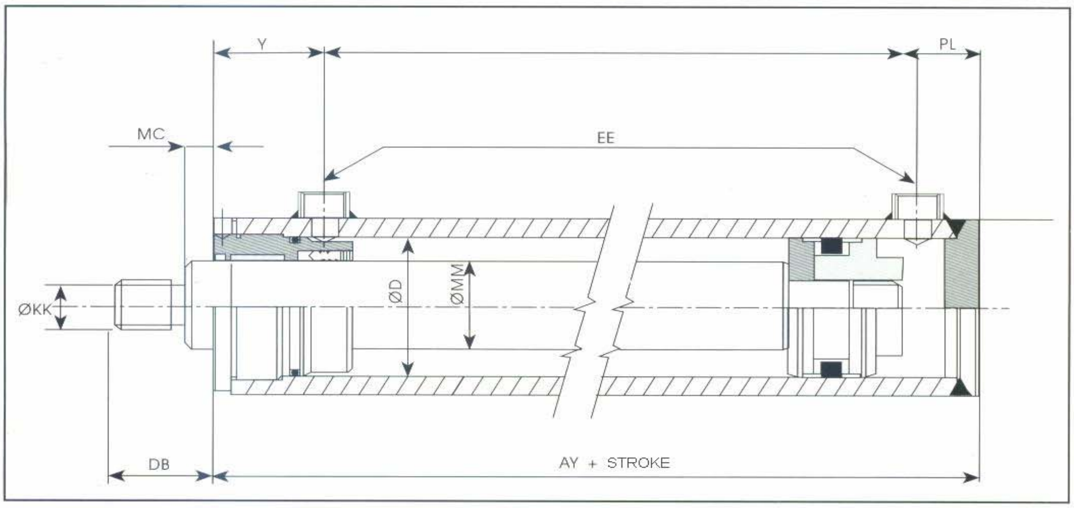
Figure A.12 General View of Workshop_2

A.2 Product Variety

Following catalogs represent the product variety of company. However much these catalogs show the appropriate dimensions for hydraulic cylinder, stroke dimensions can be changed according to customer orders.

ERDEMLER

BASIC HYDRAULIC CYLINDER



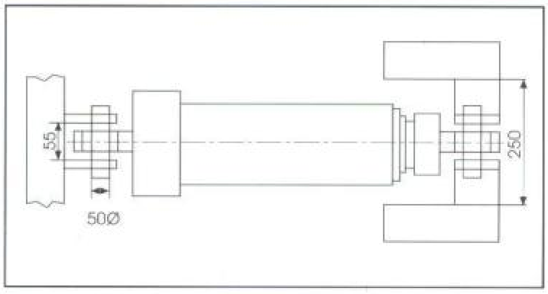
ØD	MM	AY	KK	DB	MC	Y	PL	EE
40	20	133	16x1.5	16	10	62	15	3/8"
50	25	141	20x1.5	20	12	67	21	3/8"
63	35	145	27x2	25	15	70	22	3/8"
80	50	158	33x2	30	20	75	28	1/2"
100	60	175	42x2	38	25	85	30	1/2"
115	70	190	42x2	38	25	100	30	3/4"
125	80	202	52x2	50	25	106	35	3/4"
140	90	224	52x2	50	30	112	40	3/4"
160	100	243	56x2	60	35	115	45	1"
180	110	294	68x3	65	38	136	55	1"
200	125	294	68x3	65	38	136	55	1"

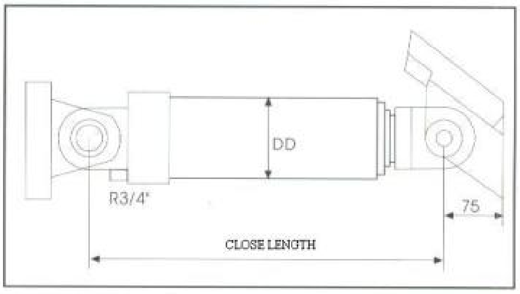
Figure A.13 Basic Hydraulic Cylinders [16]

ERDEMLER

TELESCOPIC CYLINDERS

3 STAGE TELESCOPIC CYLINDERS





ETL. 3x3500x160

STROKE mm	CLOSE LENGTH mm	EXT DIA. mm	CYLINDER WEIGHT kg	WORKING PRESSURE bar
3500	1500	160	145	135

STAGE	BARREL DIA mm	THRUST FORCE ton	LITER	STROKE mm
1	140	20.8	17.8	1160
2	120	15.3	13.2	1170
3	100	10.6	9.2	1170
			40.2	3500

ETL. 3x3700x160

STROKE mm	CLOSE LENGTH mm	EXT DIA. mm	CYLINDER WEIGHT kg	WORKING PRESSURE bar
3700	1600	160	155	135

STAGE	BARREL DIA mm	THRUST FORCE ton	LITER	STROKE mm
1	140	20.8	18.9	1230
2	120	15.3	13.9	1235
3	100	10.6	9.7	1235
			42.5	3700

ETL. 3x4000x160

STROKE mm	CLOSE LENGTH mm	EXT DIA. mm	CYLINDER WEIGHT kg	WORKING PRESSURE bar
4000	1760	160	175	135

STAGE	BARREL DIA mm	THRUST FORCE ton	LITER	STROKE mm
1	140	20.8	20.46	1330
2	120	15.3	15.9	1335
3	100	10.6	10.48	1335
			46.84	4000

ETL. 3x3500x190

STROKE mm	CLOSE LENGTH mm	EXT DIA. mm	CYLINDER WEIGHT kg	WORKING PRESSURE bar
3500	1500	190	200	135

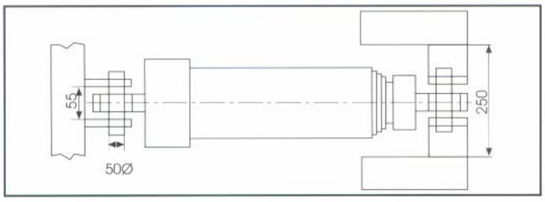
STAGE	BARREL DIA mm	THRUST FORCE ton	LITER	STROKE mm
1	165	24.8	24.8	1160
2	140	18	18.0	1170
3	120	13.2	13.2	1170
			56.0	3500

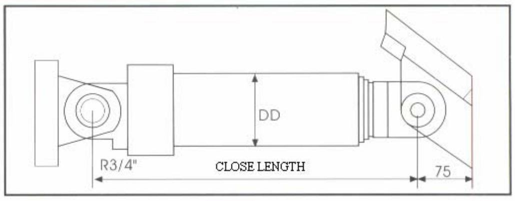
Figure A.14 Three Stage Telescopic Cylinders [16]

ERDEMLER

TELESCOPIC CYLINDERS

4 STAGE TELESCOPIC CYLINDERS





ETL. 4x3500x160

STROKE mm	CLOSE LENGTH mm	EXT DIA. mm	CYLINDER WEIGHT kg	WORKING PRESSURE bar
3500	1250	160	140	135

STAGE	BARREL DIA mm	THRUST FORCE ton	LITER	STROKE mm
1	140	20.8	13.46	875
2	120	15.3	9.89	875
3	100	10.6	6.87	875
4	80	16.78	4.4	875
			34.62	3500

ETL. 4x3500x190

STROKE mm	CLOSE LENGTH mm	DIŞ ÇAP mm	CYLINDER WEIGHT kg	WORKING PRESSURE bar
3500	1250	190	175	135

STAGE	BARREL DIA mm	THRUST FORCE ton	LITER	STROKE mm
1	165	28.85	18.7	875
2	140	20.8	13.46	875
3	120	15.3	9.89	875
4	100	10.67	6.87	875
			48.92	3500

ETL. 4x4120x190

STROKE mm	CLOSE LENGTH mm	DIŞ ÇAP mm	CYLINDER WEIGHT kg	WORKING PRESSURE bar
4120	1400	190	210	135

STAGE	BARREL DIA mm	THRUST FORCE ton	LITER	STROKE mm
1	165	28.85	22.01	1030
2	140	20.8	15.85	1030
3	120	15.3	11.64	1030
4	100	10.6	8.08	1030
			57.58	4120

ETL. 4x4400x190

STROKE mm	CLOSE LENGTH mm	DIŞ ÇAP mm	CYLINDER WEIGHT kg	WORKING PRESSURE bar
4400	1500	190	220	135

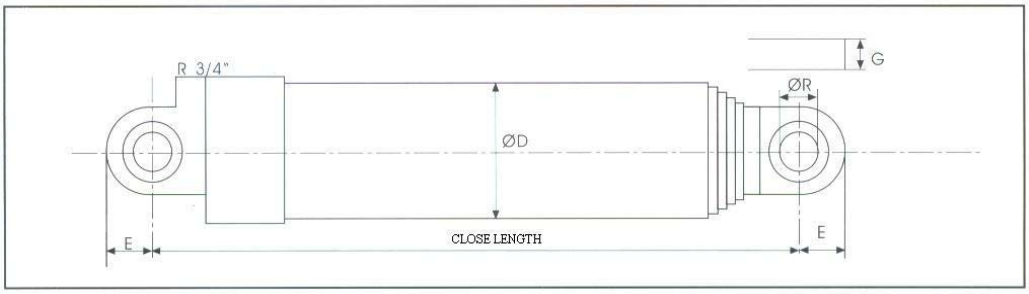
STAGE	BARREL DIA mm	THRUST FORCE ton	LITER	STROKE mm
1	165	28.85	24.15	1100
2	140	20.8	17.38	1100
3	120	15.3	12.77	1100
4	100	10.6	8.87	1100
			63.17	4400

Figure A.15 Four Stage Telescopic Cylinders [16]

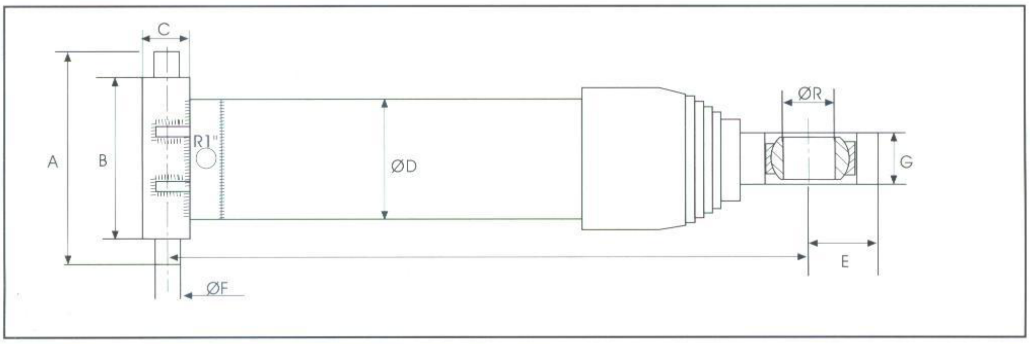
ERDEMLER

TELESCOPIC CYLINDERS

5 STAGE TELESCOPIC CYLINDERS



STROKE (mm)	CLOSE LENGTH (mm)	EXTERNAL DIAMETER (mm)	CYLINDER WEIGHT (Kg)	WORKING PRESSURE (Bar)	STAGE	CYLINDER BARREL DIAMETER (mm)	THRUST FORCE (Ton) (135 Bar)	LITER	STROKE (mm)
5700	1520	220	320	135	1	190	38.25	40.38	1140
					2	165	28.85	30.45	1140
					3	140	20.8	21.92	1140
DIMENSIONS					4	120	15.26	16.1	1140
	ØR	G	E	ØD	5	100	10.6	11.18	1140
	60	50	65	220				120.03	5700



STROKE (mm)	CLOSE LENGTH (mm)	EXTERNAL DIAMETER (mm)	CYLINDER WEIGHT (Kg)	WORKING PRESSURE (Bar)	STAGE	CYLINDER BARREL DIAMETER (mm)	THRUST FORCE (Ton) (135 Bar)	LITER	STROKE (mm)
5700	1520	245	460	135	1	220	51.29	54.14	1140
					2	190	38.25	40.38	1140
					3	165	28.85	30.45	1140
DIMENSIONS					4	140	20.8	21.92	1140
					5	120	10.6	16.1	1140
								162.99	5700

A	B	C	ØF	ØR	E	G
410	270	100	70	60	65	55

Figure A.16 Five Stage Telescopic Cylinders [16]

APPENDIX B

MODEL DEVELOPMENT OF ERDEMLER HYDRAULIC CYLINDER COMPANY

B.1 Modules of Simulation

The basic building blocks for ARENA® models are called modules. These are the flow chart and data objects that define the process to be simulated and are chosen from panels in the Project Bar. Modules can be divided into two main groups; Flowchart and Data. Flowchart modules describe the dynamic processes in the model.

Flowchart modules are defined as nodes or places through which entities flow, or where entities originate or leave the model. In ARENA® 6.0, there are several templates (Panels) for developing the models. In the Basic Process panel, the kinds of flowchart modules available are Create, Dispose, Process, Decide, Batch, Separate, Assign, and Record; other panels have many additional kinds of flowchart modules. Each type of flowchart module in the Basic Process panel has a distinctive shape, similar to classical flowcharting. But in other panels (such as the Advanced Process panel), there are many more flowchart-module types than there are reasonable shapes, so they're all represented by simple rectangles. Some panels (like Advanced Transfer) use colors in the rectangles to distinguish different types of flowchart modules, and some panels (like the specialized ones for contact centers and packaging) use more elaborate graphics for them. One way to edit a flowchart module is to double-click on it once it's been placed in the flowchart view of the model window, to bring up a dialog pertaining to it. Another way to edit flowchart modules is to select a module type (e.g., click on a Create or a Process module), either in the Project Bar or in the flowchart view of the model window, and a line for each flowchart module of that type in the model shows up in the spreadsheet view of the model window, where modeler can edit the entries [11].

Data modules define the characteristics of various process elements, like entities, resources, and queues. They can also set up variables and other types of numerical values and expressions that pertain to the whole model. Icons for data modules in the Project Bar look like little spreadsheets. The Basic Process panel's data modules are Entity, Queue, Resource, Variable, Schedule, and Set (other panels contain additional kinds of data modules). Entities don't flow through data modules, and data modules aren't dragged into the model window; rather, data modules exist "behind the scenes" in a model to define different kinds of values, expressions, and conditions [11].

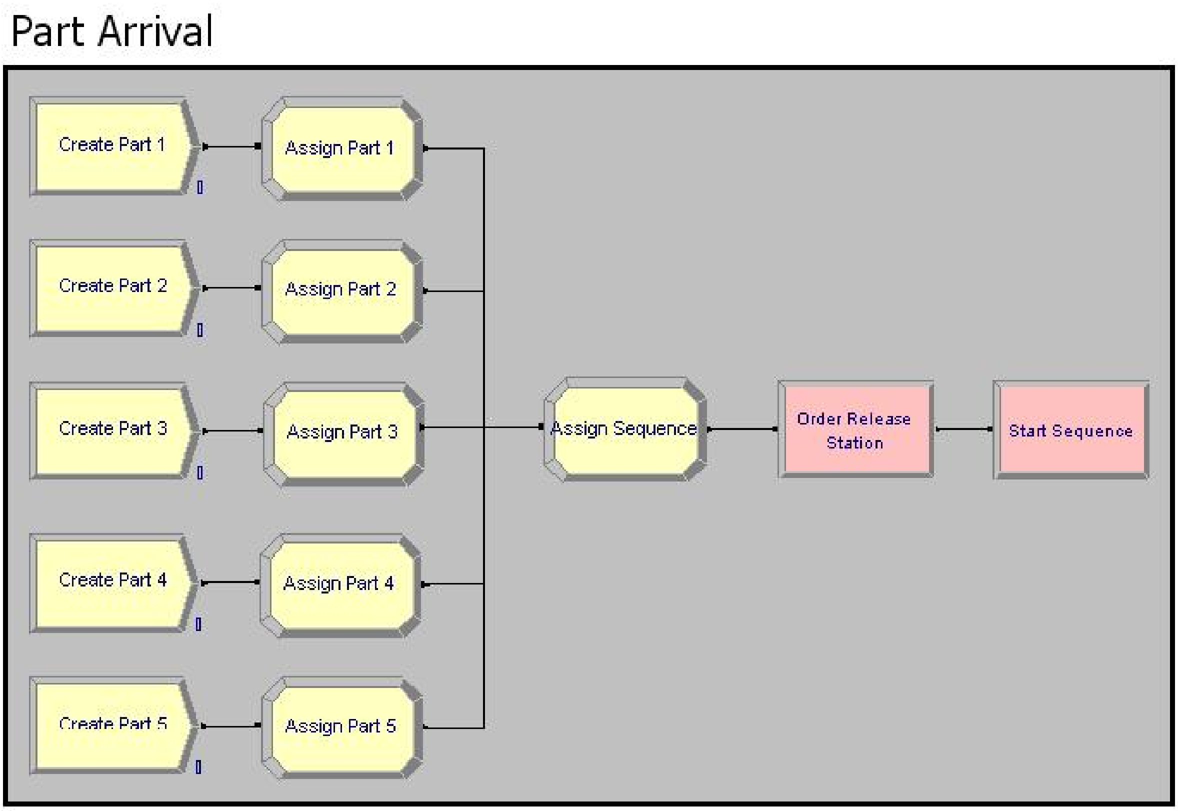


Figure B.1 Part Arrival Modules

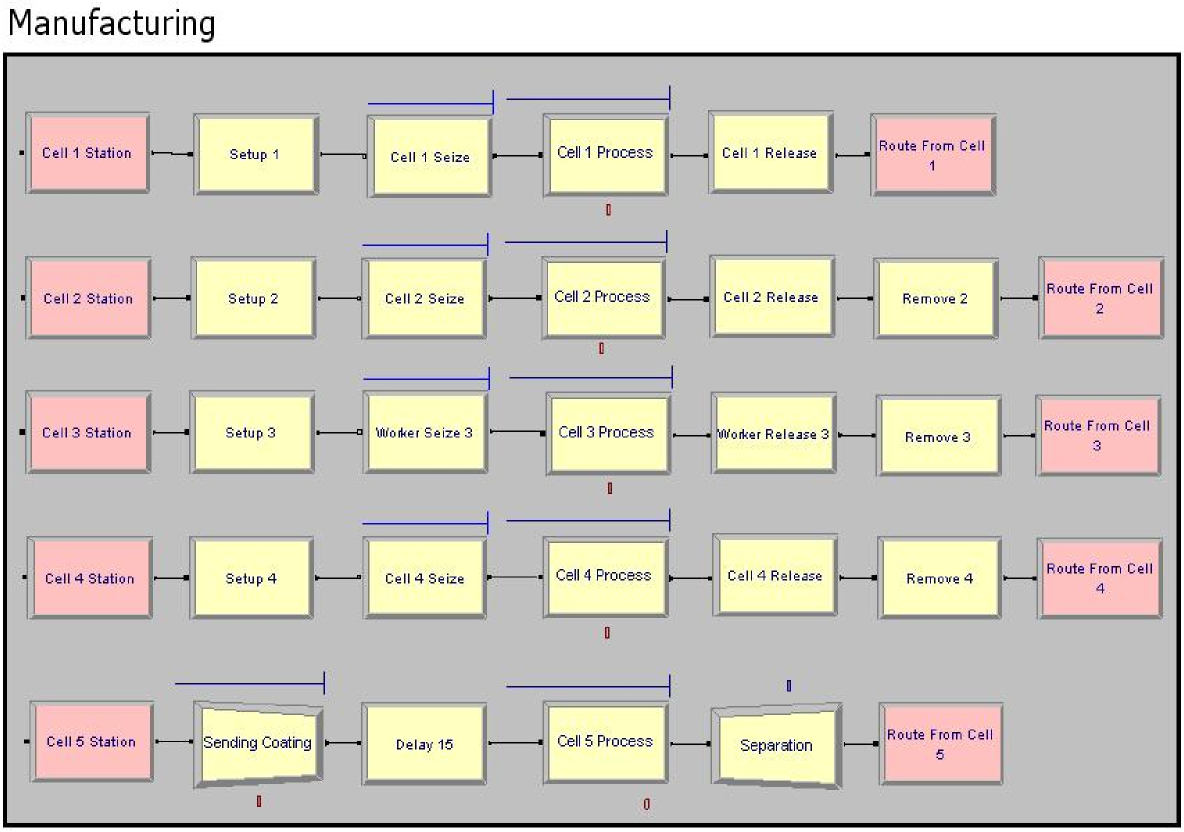


Figure B.2 Manufacturing Modules Part_1

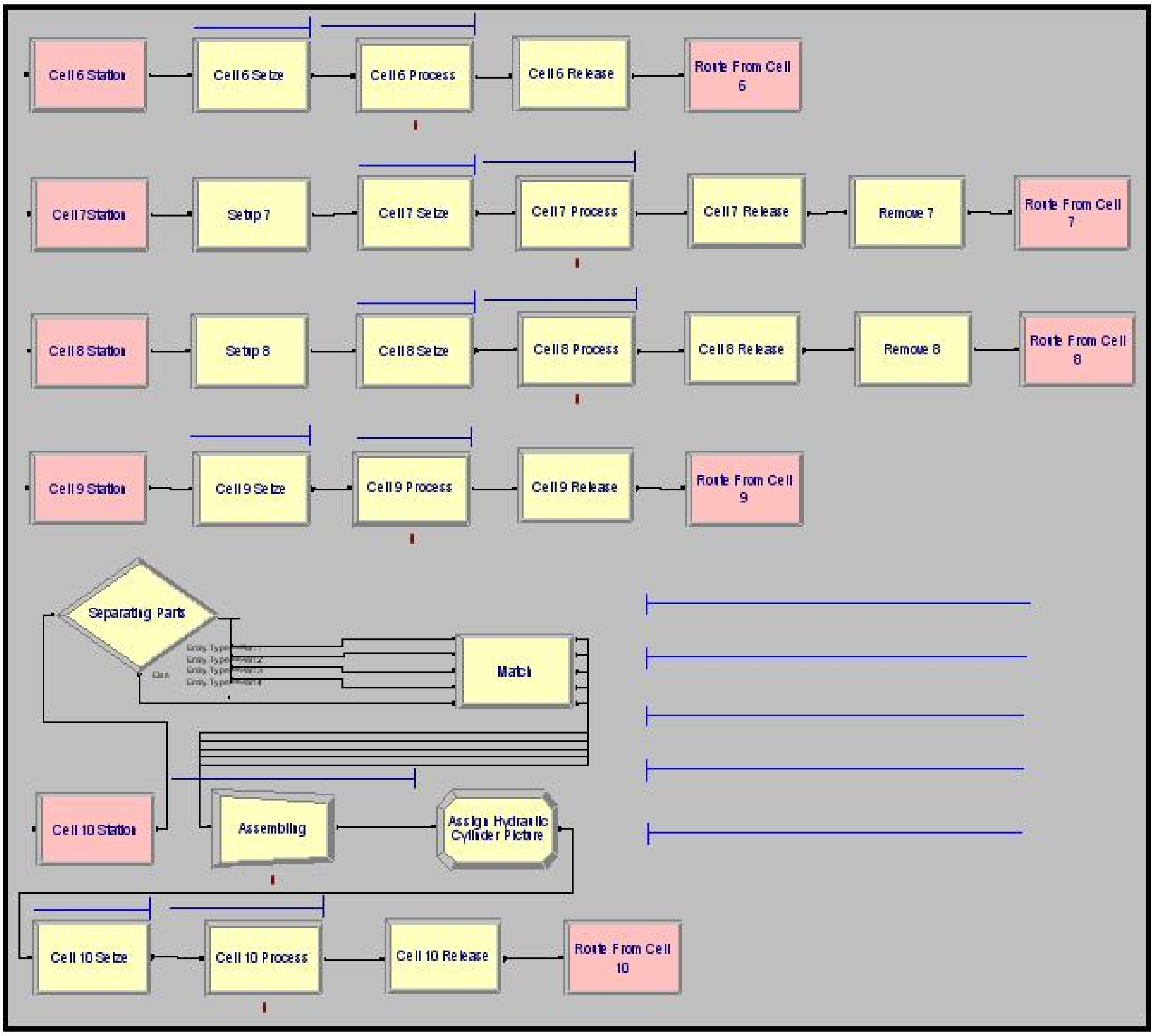


Figure B.3 Manufacturing Modules Part_2

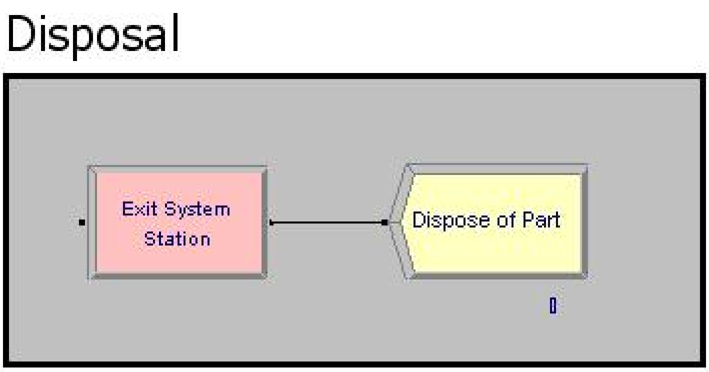


Figure B.4 Part Disposal Modules

B.2 Animation of Simulation

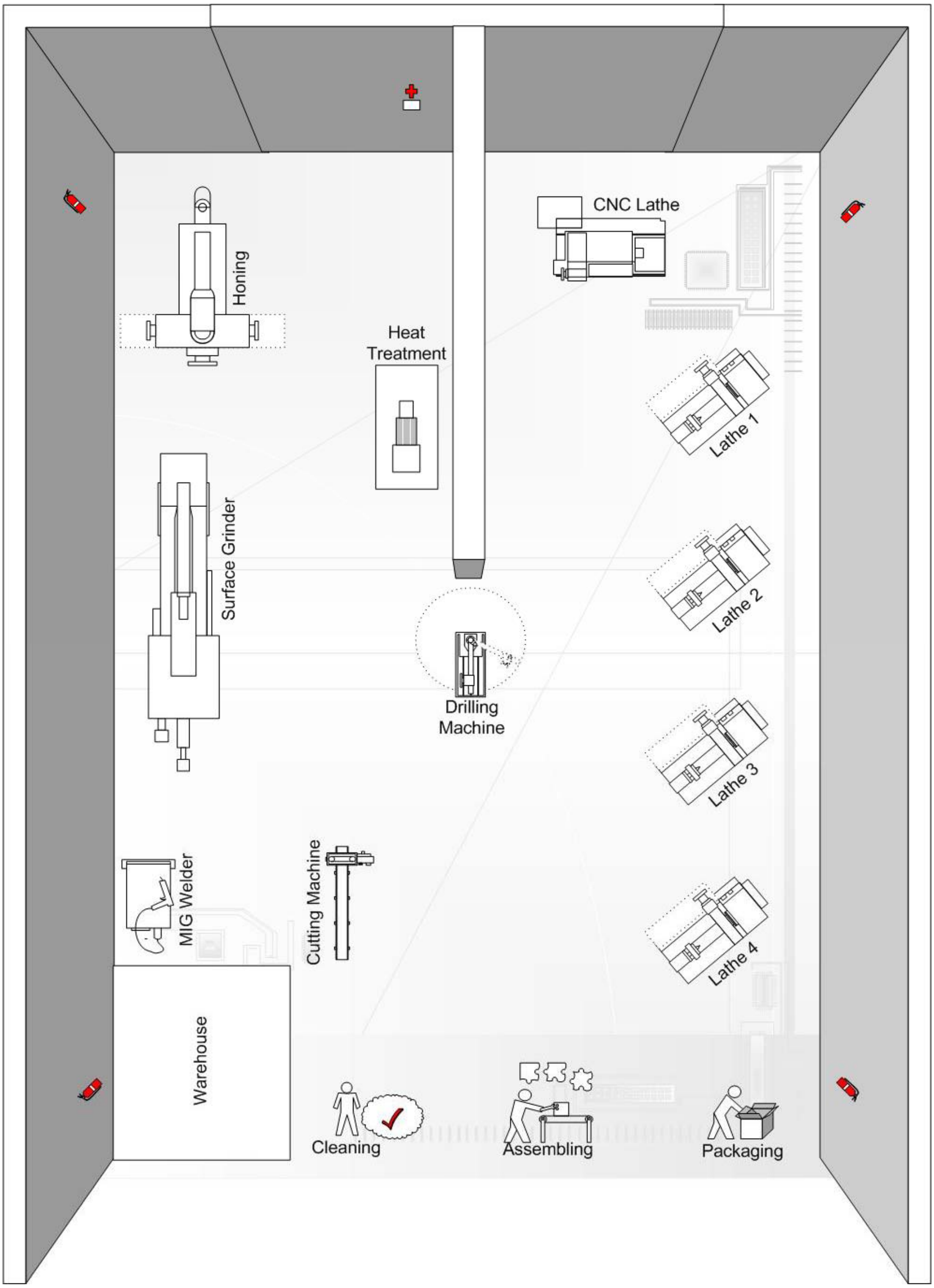


Figure B.5 Layout of Erdemler Hydraulic Company

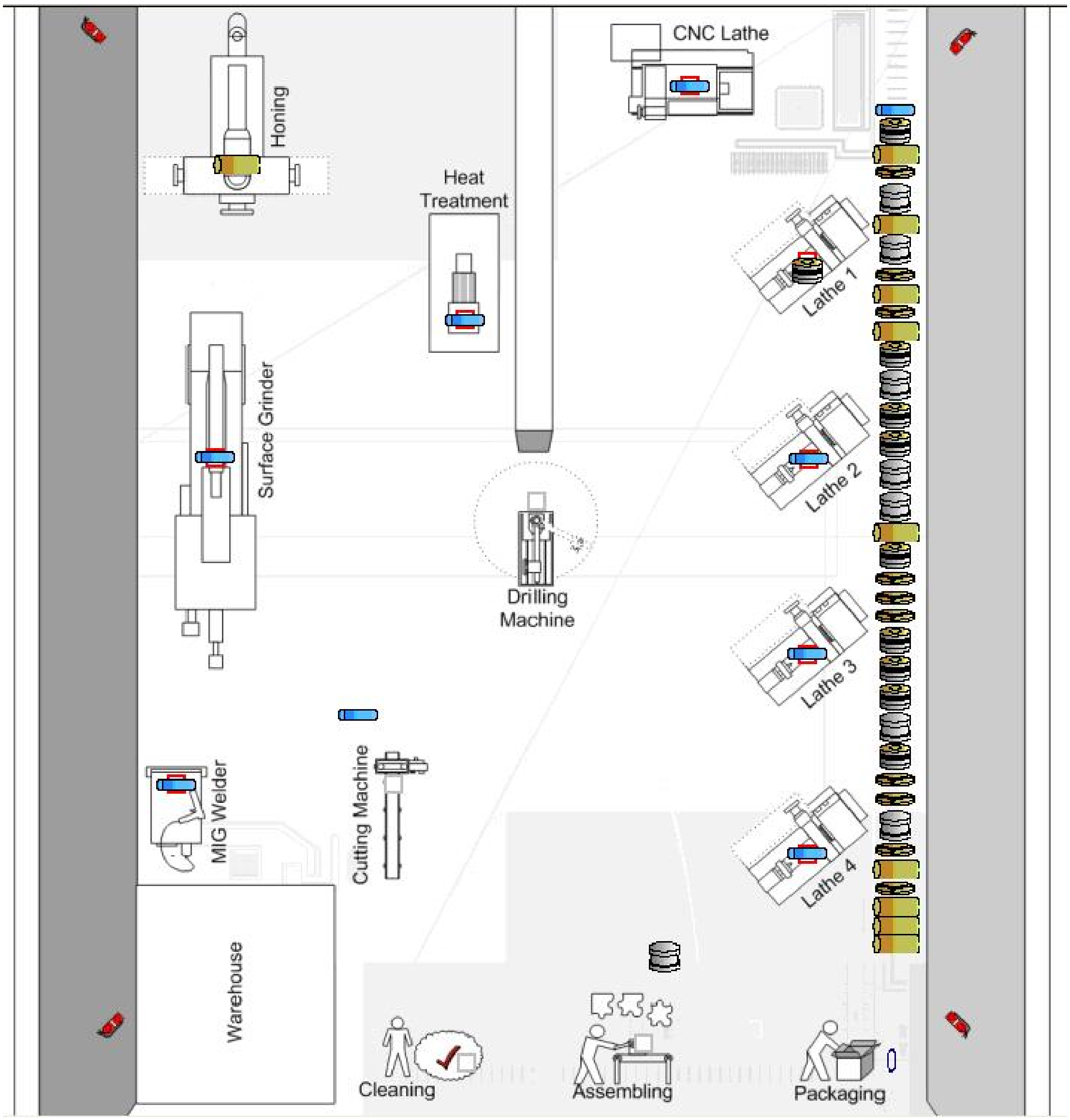


Figure B.6 Screen Shot of Simulation

APPENDIX C

STATISTIC RESULTS OF EXPERIMENTAL RUNS

C.1 Statistical Results of "Process Type" Experiment (Time units: Minute)

Entity

Time

VA Time	Average	HaHalf Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	906.66	66,69	753.76	1026.30	707.14	1063.86
Part 2	104.38	2,29	97.4473	108.55	62.8794	139.27
Part 3	257.17	4,00	248.95	264.96	181.01	317.25
Part 4	157.18	4,19	147.70	165.27	91.8302	230.09
Part 5	72.3359	2,51	66.9127	76.6641	51.4983	90.6125

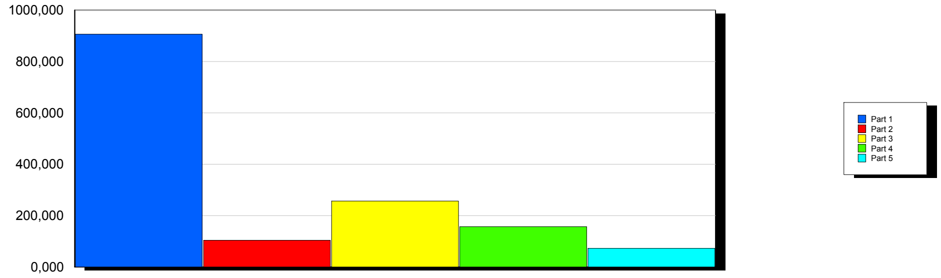


Figure C.1 Entity-Value Added Time

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	1289.23	25,35	1240.61	1331.34	970.97	1606.50
Part 2	2244.63	73,77	2048.94	2396.56	1879.91	2590.81
Part 3	2067.13	63,92	1915.82	2206.94	1654.55	2383.94
Part 4	2186.19	77,34	2006.25	2381.38	1802.57	2573.90
Part 5	2266.96	71,94	2083.52	2445.84	1890.68	2672.72

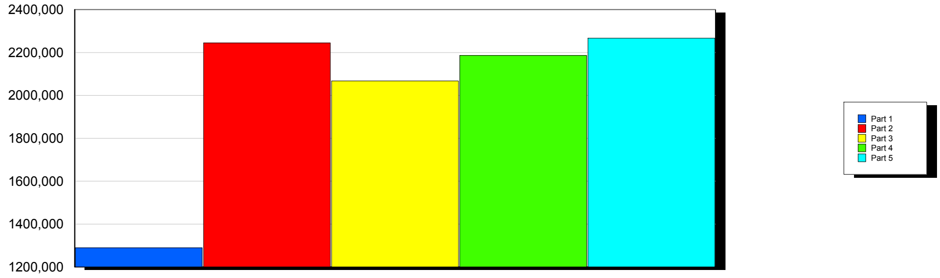


Figure C.2 Entity-Wait Time

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	174.98	4,30	167.27	183.69	156.83	195.14
Part 2	27.1469	0,26	26.5448	27.7745	23.9937	30.1519
Part 3	47.2340	0,55	46.3876	48.7167	43.0453	52.0912
Part 4	27.2439	0,25	26.7963	27.9240	24.2148	30.7154
Part 5	26.8100	0,31	26.0860	27.3291	23.7454	30.8853

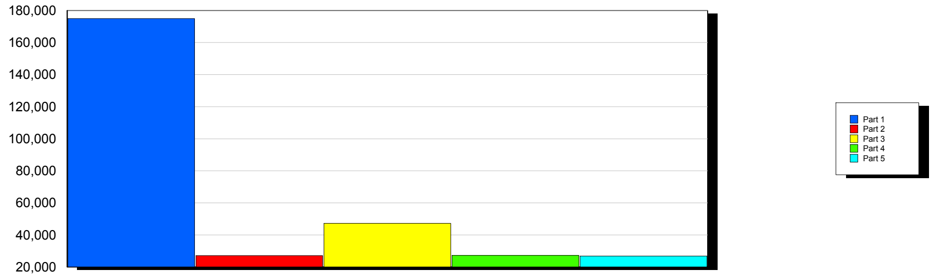


Figure C.3 Entity-Transfer Time

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	2370.87	69,99	2184.78	2528.99	1967.93	2765.72
Part 2	2376.16	73,96	2176.66	2528.50	1984.43	2752.94
Part 3	2371.53	64,56	2218.76	2518.82	1992.46	2729.61
Part 4	2370.62	75,58	2195.82	2565.50	1973.42	2811.20
Part 5	2366.11	73,75	2176.61	2549.03	1992.37	2786.17

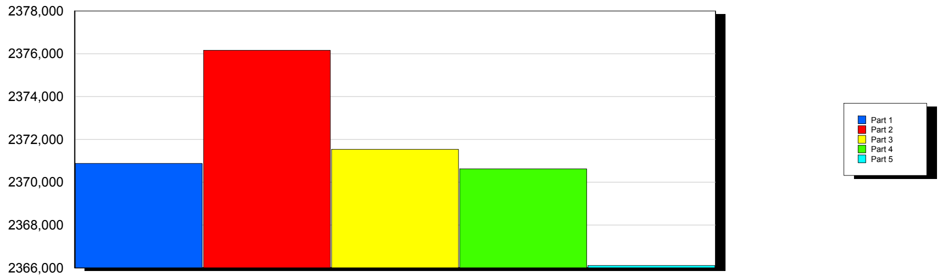


Figure C.4 Entity-Total Time

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	9.8185	0,21	9.2783	10.1959	7.2477	11.8391
Cell 10 Process	45.7841	1,55	42.7776	49.9765	30.9991	58.7537
Cell 2 Process	10.3852	0,22	9.8936	10.9609	8.6019	12.8300
Cell 3 Process	54.3603	0,66	52.8731	55.5369	2.1895	160.83
Cell 4 Process	26.4414	0,22	25.9744	26.9445	22.1020	31.8891
Cell 5 Process	725.36	66,91	574.01	843.60	574.01	843.60
Cell 6 Process	16.1777	0,27	15.6752	16.7358	13.4167	20.6857
Cell 7 Process	9.0828	0,31	8.3516	9.8108	5.2613	11.3955
Cell 8 Process	71.5576	1,18	68.1474	73.4626	62.5028	79.4422
Cell 9 Process	14.7640	0,20	14.4223	15.1495	10.3648	19.7326

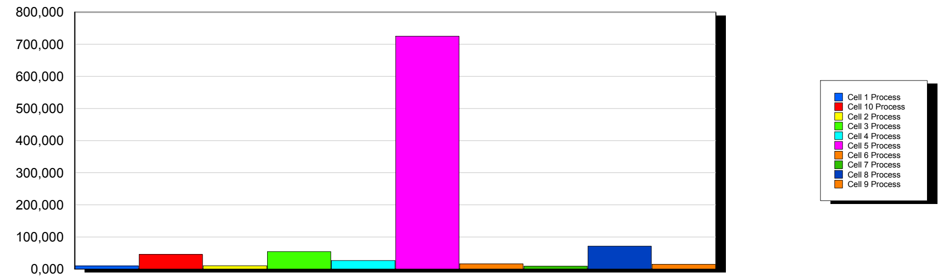


Figure C.5 Process-VA Time (Per Entity)

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	17.3788	3,20	12.9929	27.4544	7.2477	40.0744
Cell 10 Process	214.84	9,61	195.05	237.43	34.9146	353.12
Cell 2 Process	10.3852	0,22	9.8936	10.9609	8.6019	12.8300
Cell 3 Process	54.3603	0,66	52.8731	55.5369	2.1895	160.83
Cell 4 Process	26.4414	0,22	25.9744	26.9445	22.1020	31.8891
Cell 5 Process	725.36	66,91	574.01	843.60	574.01	843.60
Cell 6 Process	16.1777	0,27	15.6752	16.7358	13.4167	20.6857
Cell 7 Process	9.1810	0,28	8.5576	9.8108	5.2613	14.5314
Cell 8 Process	71.5576	1,18	68.1474	73.4626	62.5028	79.4422
Cell 9 Process	43.5447	0,99	41.7080	45.6272	10.4219	144.59

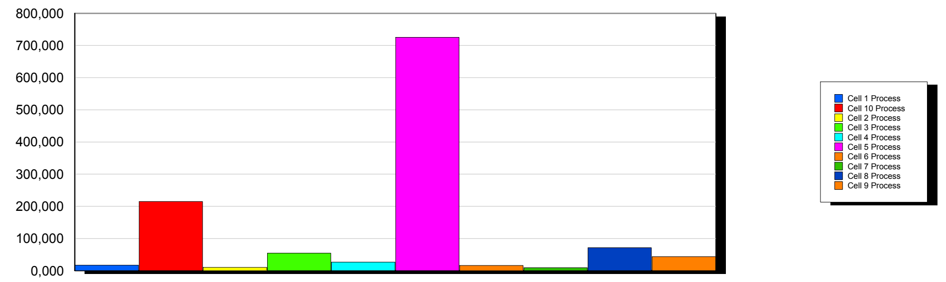


Figure C.6 Process-Total Time (Per Entity)

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Process	117.82	2,56	111.34	122.35
Cell 10 Process	549.41	18,65	513.33	599.72
Cell 2 Process	124.62	2,64	118.72	131.53
Cell 3 Process	3913.94	47,67	3806.87	3998.66
Cell 4 Process	317.30	2,65	311.69	323.33
Cell 5 Process	725.36	66,91	574.01	843.60
Cell 6 Process	194.13	3,29	188.10	200.83
Cell 7 Process	108.99	3,69	100.22	117.73
Cell 8 Process	858.69	14,14	817.77	881.55
Cell 9 Process	885.84	12,10	865.34	908.97

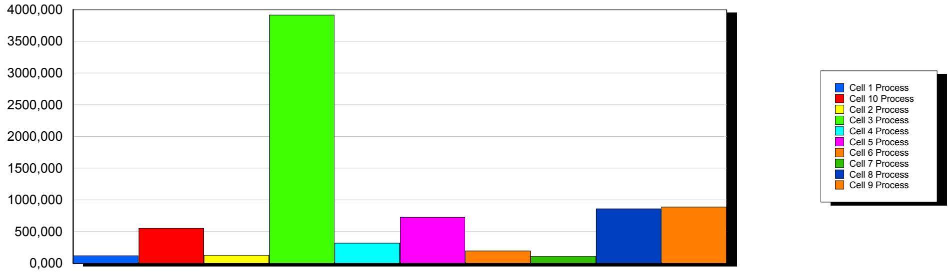


Figure C.7 Acc. Time-VA Time

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Assembling.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 1 Process.Queue	7.5603	3,28	2.8213	18.1761	0.00	29.6363
Cell 1 Seize.Queue	1.8877	1,43	0.05422150	7.3291	0.00	29.4176
Cell 10 Process.Queue	169.05	8,47	149.21	189.79	0.00	305.50
Cell 10 Seize.Queue	57.6109	8,68	26.9862	72.6034	10.3890	161.08
Cell 2 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 2 Seize.Queue	112.27	18,51	67.8224	156.62	46.0436	177.60
Cell 3 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Seize.Queue	99.06	12,74	78.7022	130.16	1.1876	203.85
Cell 5 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Seize.Queue	43.9427	10,87	20.4109	68.5200	0.00	123.89
Cell 7 Process.Queue	0.0982	0,12	0.00	0.4627	0.00	5.5523
Cell 7 Seize.Queue	16.0859	1,34	13.3646	19.1149	0.00	124.24
Cell 8 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 8 Seize.Queue	284.45	23,31	217.27	326.35	4.9990	623.59
Cell 9 Process.Queue	28.7807	0,95	27.0686	30.6829	0.00	129.57
Cell 9 Seize.Queue	16.9075	1,26	14.5591	19.9008	0.00	112.44
Match.Queue1	0.00	0,00	0.00	0.00	0.00	0.00
Match.Queue2	1935.96	76,26	1711.86	2073.27	1689.02	2083.20
Match.Queue3	1284.39	66,74	1137.08	1419.01	875.84	1766.24
Match.Queue4	1581.12	78,21	1388.77	1752.69	1144.64	2095.56
Match.Queue5	1475.58	74,18	1268.25	1649.97	1211.15	2126.57
Sending Coating.Queue	146.87	1,79	143.26	150.37	0.00	312.28
Worker Seize 3.Queue	251.20	7,54	235.08	269.37	0.00	580.09

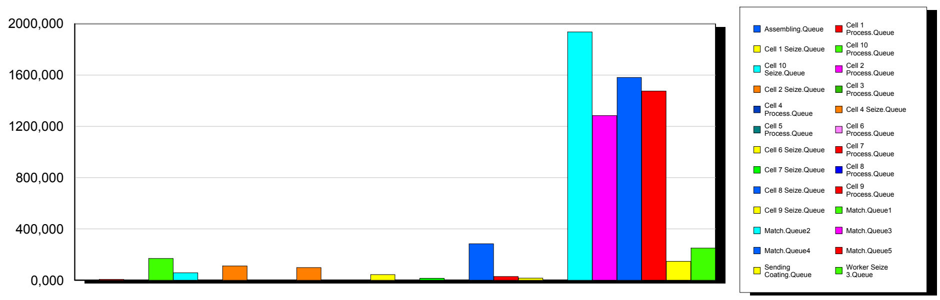


Figure C.8 Waiting Time in Queue

Resource

Usage

Number Busy

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Machine	0.04206595	0,00	0.03849521	0.04569837	0.00	1.0000
Cell 10 Machine	0.1962	0,01	0.1743	0.2124	0.00	1.0000
Cell 2 Machine	0.04448825	0,00	0.04072562	0.04707418	0.00	1.0000
Cell 3 New	0.2618	0,01	0.2417	0.2800	0.00	1.0000
Cell 3 Old 1	0.2845	0,02	0.2429	0.3079	0.00	1.0000
Cell 3 Old 2	0.2841	0,01	0.2456	0.3057	0.00	1.0000
Cell 3 Old 3	0.2833	0,02	0.2555	0.3103	0.00	1.0000
Cell 3 Old 4	0.2848	0,02	0.2553	0.3140	0.00	1.0000
Cell 4 Machine	0.1133	0,00	0.1058	0.1211	0.00	1.0000
Cell 5 Machine	0.2578	0,02	0.2150	0.2825	0.00	1.0000
Cell 6 Machine	0.06939450	0,00	0.06270093	0.07521695	0.00	1.0000
Cell 7 Machine	0.03894491	0,00	0.03340633	0.04227824	0.00	1.0000
Cell 8 Machine	0.3067	0,01	0.2830	0.3283	0.00	1.0000
Cell 9 Machine	0.3165	0,01	0.2884	0.3404	0.00	1.0000
Worker 1	0.5205	0,02	0.4627	0.5601	0.00	1.0000
Worker 2	0.4768	0,03	0.4086	0.5561	0.00	1.0000
Worker 3	0.4844	0,02	0.4336	0.5298	0.00	1.0000
Worker 4	0.4967	0,03	0.4088	0.5400	0.00	1.0000
Worker 5	0.4251	0,03	0.3852	0.5145	0.00	1.0000
Worker 6	0.4706	0,02	0.4250	0.5107	0.00	1.0000
Worker 7	0.5468	0,02	0.5031	0.5840	0.00	1.0000
Worker 8	0.2741	0,01	0.2470	0.3019	0.00	1.0000
Worker 9	0.2047	0,02	0.1758	0.2674	0.00	1.0000

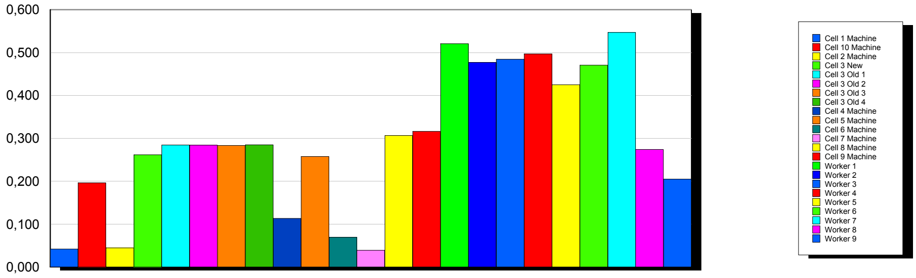


Figure C.9 Number of Busy Status

Total Number Seized

	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Machine	12.0000	0,00	12.0000	12.0000
Cell 10 Machine	12.0000	0,00	12.0000	12.0000
Cell 2 Machine	12.0000	0,00	12.0000	12.0000
Cell 3 New	34.3000	2,50	28.0000	40.0000
Cell 3 Old 1	10.1000	1,56	7.0000	14.0000
Cell 3 Old 2	9.4000	0,97	7.0000	11.0000
Cell 3 Old 3	9.2000	1,16	8.0000	12.0000
Cell 3 Old 4	9.0000	1,26	6.0000	11.0000
Cell 4 Machine	12.0000	0,00	12.0000	12.0000
Cell 5 Machine	1.0000	0,00	1.0000	1.0000
Cell 6 Machine	12.0000	0,00	12.0000	12.0000
Cell 7 Machine	12.0000	0,00	12.0000	12.0000
Cell 8 Machine	12.0000	0,00	12.0000	12.0000
Cell 9 Machine	60.0000	0,00	60.0000	60.0000
Worker 1	29.3000	9,19	17.0000	50.0000
Worker 2	17.6000	6,26	13.0000	42.0000
Worker 3	15.6000	6,45	10.0000	41.0000
Worker 4	16.9000	6,57	10.0000	35.0000
Worker 5	18.4000	7,85	9.0000	41.0000
Worker 6	41.7000	1,07	40.0000	44.0000
Worker 7	24.9000	0,79	23.0000	27.0000
Worker 8	27.3000	0,59	26.0000	29.0000
Worker 9	24.3000	0,83	23.0000	26.0000

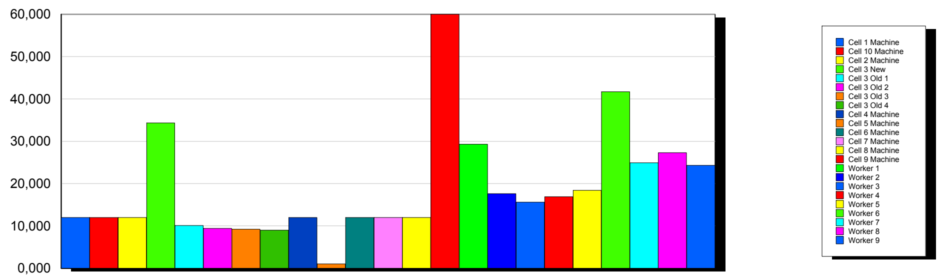


Figure C.10 Total Number Seized (Resources)

C.2 Statistical Results of "FIFO" Experiment (Time units: Minute)

Entity

Time

VA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	899.19	76,56	754.27	1097.23	711.93	1151.96
Part 2	104.58	5,86	89.5653	115.46	66.4546	141.39
Part 3	244.54	8,90	228.53	268.11	171.04	316.26
Part 4	161.28	10,79	133.19	185.11	91.0010	219.97
Part 5	72.6920	1,94	68.4945	76.4258	48.5268	96.8139

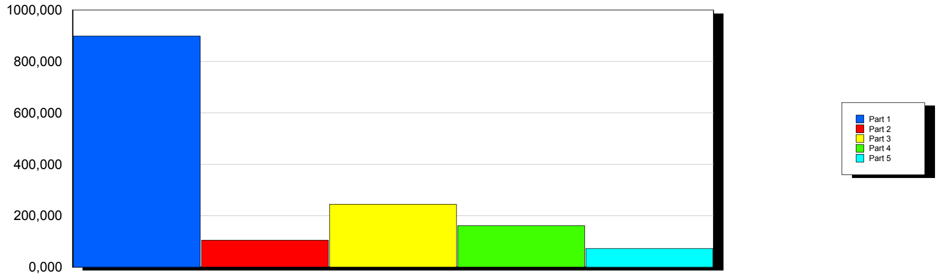


Figure C.11 Entity-Value Added Time

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	1096.89	24,10	1066.96	1165.88	775.21	1472.48
Part 2	2043.19	86,35	1903.83	2297.65	1699.68	2492.13
Part 3	1886.17	93,62	1726.47	2144.83	1525.48	2354.34
Part 4	1984.99	84,06	1834.24	2241.21	1676.76	2393.06
Part 5	2068.99	92,48	1880.42	2333.90	1738.26	2536.64

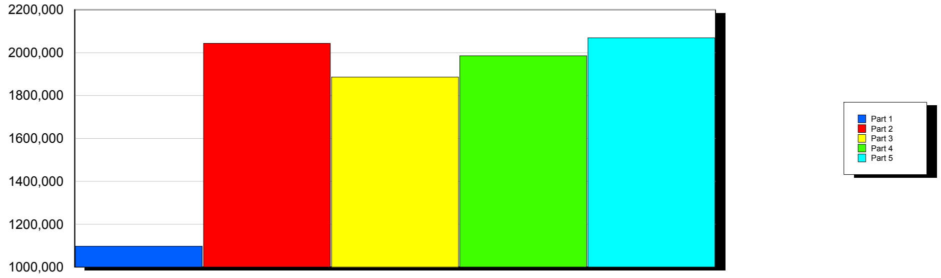


Figure C.12 Entity-Wait Time

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	174.29	3,53	167.65	183.47	158.38	193.62
Part 2	27.0021	0,23	26.4316	27.6021	23.7739	31.5931
Part 3	47.2090	0,44	46.3365	48.0856	42.8026	51.4526
Part 4	27.1930	0,31	26.5079	27.7697	24.1868	30.6048
Part 5	26.9492	0,23	26.1754	27.3029	23.1966	30.4493

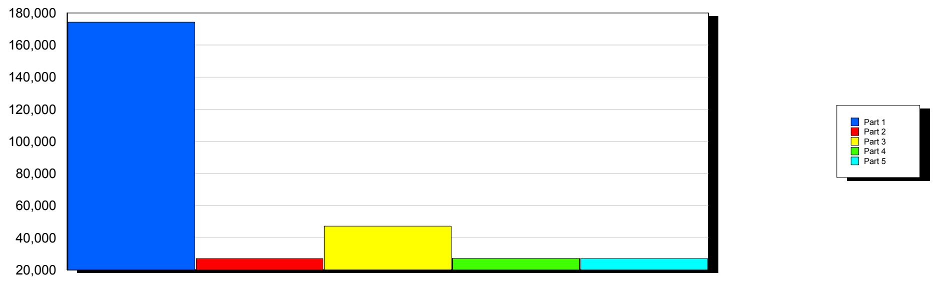


Figure C.13 Entity-Transfer Time

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	2170.37	90,26	2016.87	2435.50	1757.30	2693.01
Part 2	2174.77	88,02	2041.39	2435.81	1834.82	2628.86
Part 3	2177.92	90,17	2025.25	2433.03	1835.35	2621.92
Part 4	2173.46	84,03	2033.60	2418.68	1835.48	2605.93
Part 5	2168.63	92,39	1984.02	2437.05	1835.06	2625.79

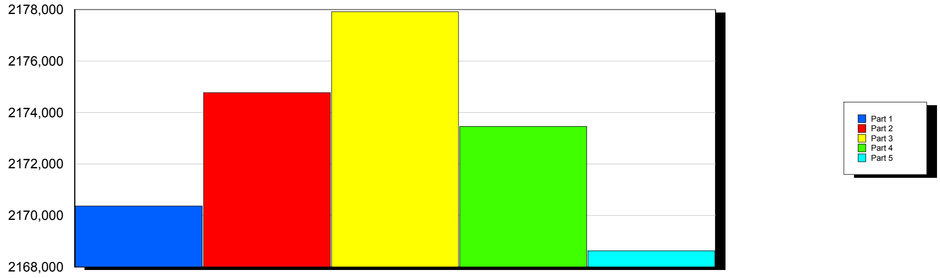


Figure C.14 Entity-Total Time

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	9.8916	0,29	9.1266	10.4523	7.2477	11.8375
Cell 10 Process	43.2486	1,36	40.4138	46.2739	31.2931	58.7703
Cell 2 Process	10.1689	0,23	9.6451	10.7015	8.2762	12.3591
Cell 3 Process	53.9265	0,26	53.3301	54.3116	2.1818	163.68
Cell 4 Process	26.5040	0,28	25.7441	26.9779	22.2580	31.7334
Cell 5 Process	724.86	77,02	574.61	921.25	574.61	921.25
Cell 6 Process	16.3889	0,22	15.9118	16.8848	13.7156	20.4682
Cell 7 Process	8.7797	0,32	8.3675	9.6042	5.3566	11.5503
Cell 8 Process	71.0823	0,98	69.0980	73.5098	61.6205	79.1723
Cell 9 Process	14.9636	0,09	14.8512	15.2914	10.1405	19.7326

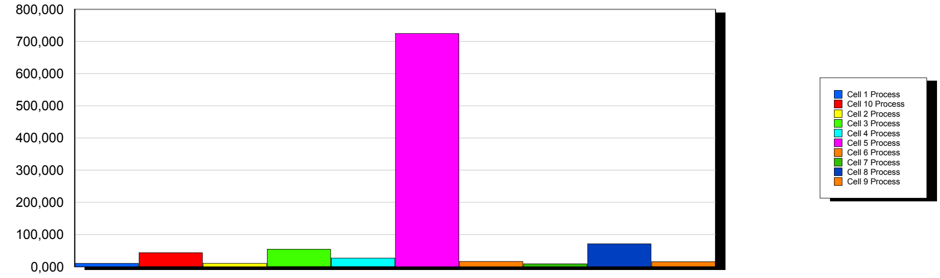


Figure C.15 Process-VA Time (Per Entity)

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	19.0909	2,35	14.5239	25.9779	7.2477	40.0744
Cell 10 Process	200.41	8,61	174.23	216.57	39.0839	329.51
Cell 2 Process	10.1689	0,23	9.6451	10.7015	8.2762	12.3591
Cell 3 Process	53.9265	0,26	53.3301	54.3116	2.1818	163.68
Cell 4 Process	26.5040	0,28	25.7441	26.9779	22.2580	31.7334
Cell 5 Process	724.86	77,02	574.61	921.25	574.61	921.25
Cell 6 Process	16.3889	0,22	15.9118	16.8848	13.7156	20.4682
Cell 7 Process	8.7797	0,32	8.3675	9.6042	5.3566	11.5503
Cell 8 Process	71.0823	0,98	69.0980	73.5098	61.6205	79.1723
Cell 9 Process	40.5685	1,96	36.6917	44.8125	10.3123	144.59

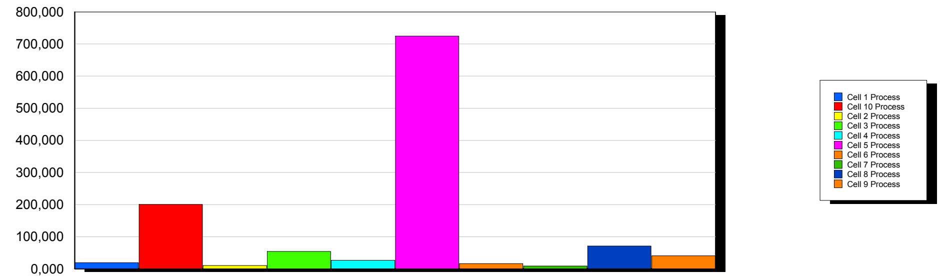


Figure C.16 Process-Total Time (Per Entity)

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Process	118.70	3,49	109.52	125.43
Cell 10 Process	518.98	16,28	484.97	555.29
Cell 2 Process	122.03	2,74	115.74	128.42
Cell 3 Process	3882.71	18,43	3839.77	3910.44
Cell 4 Process	318.05	3,40	308.93	323.73
Cell 5 Process	724.86	77,02	574.61	921.25
Cell 6 Process	196.67	2,66	190.94	202.62
Cell 7 Process	105.36	3,78	100.41	115.25
Cell 8 Process	852.99	11,71	829.18	882.12
Cell 9 Process	897.82	5,62	891.07	917.49

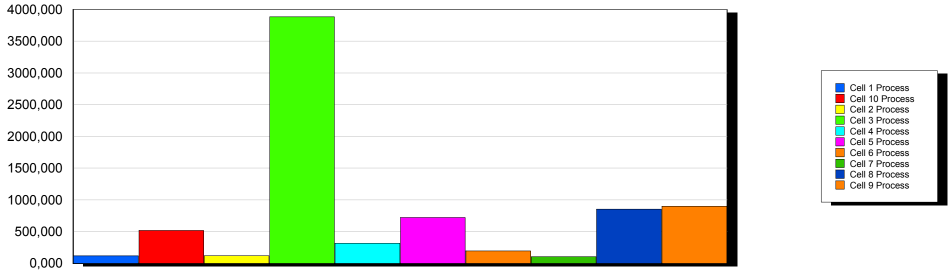


Figure C.17 Acc. Time-VA Time

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Assembling.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 1 Process.Queue	9.1993	2,48	5.2457	16.8513	0.00	29.6363
Cell 1 Seize.Queue	2.6304	2,04	0.3041	8.5332	0.00	36.3656
Cell 10 Process.Queue	157.16	7,56	132.57	170.29	0.00	285.54
Cell 10 Seize.Queue	53.3867	7,18	25.4302	60.7270	12.2516	131.29
Cell 2 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 2 Seize.Queue	10.9598	4,53	4.6173	27.6063	0.00	77.1093
Cell 3 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Seize.Queue	39.3009	10,39	20.8226	71.8776	0.00	144.44
Cell 5 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Seize.Queue	34.4766	9,38	13.0140	55.4004	0.00	91.1284
Cell 7 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 7 Seize.Queue	11.5151	3,93	3.7100	24.7263	0.00	82.2914
Cell 8 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 8 Seize.Queue	151.41	24,15	84.9378	203.57	0.00	406.07
Cell 9 Process.Queue	25.6048	1,96	21.7497	29.9010	0.00	129.57
Cell 9 Seize.Queue	9.8119	3,71	2.2948	18.4932	0.00	85.4239
Match.Queue1	0.00	0,00	0.00	0.00	0.00	0.00
Match.Queue2	1603.78	99,83	1470.05	1876.94	1231.37	1964.86
Match.Queue3	1133.81	96,10	963.87	1371.30	647.20	1734.21
Match.Queue4	1549.10	82,67	1360.57	1751.19	1212.64	2006.52
Match.Queue5	1602.14	113,56	1315.37	1909.44	1198.83	2040.34
Sending Coating.Queue	175.32	8,38	156.25	189.94	0.00	633.72
Worker Seize 3.Queue	221.74	10,21	199.00	247.48	0.00	507.41

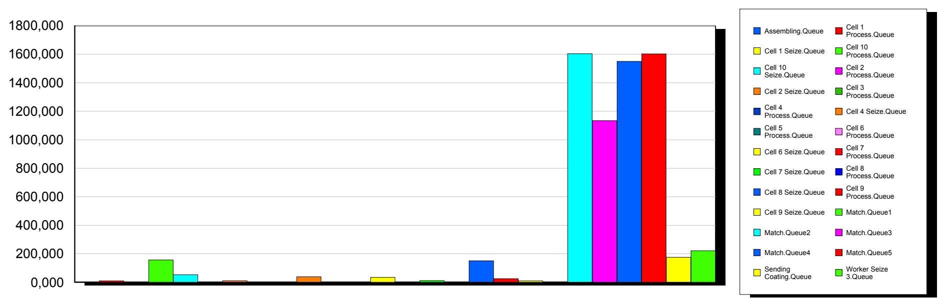


Figure C.18 Waiting Time in Queue

Resource

Usage

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Machine	0.04602584	0,00	0.03995802	0.05226155	0.00	1.0000
Cell 10 Machine	0.2011	0,01	0.1728	0.2248	0.00	1.0000
Cell 2 Machine	0.04732111	0,00	0.03918250	0.05350735	0.00	1.0000
Cell 3 New	0.2871	0,01	0.2519	0.3082	0.00	1.0000
Cell 3 Old 1	0.3063	0,02	0.2642	0.3437	0.00	1.0000
Cell 3 Old 2	0.3066	0,02	0.2694	0.3435	0.00	1.0000
Cell 3 Old 3	0.2998	0,02	0.2452	0.3476	0.00	1.0000
Cell 3 Old 4	0.3042	0,02	0.2494	0.3477	0.00	1.0000
Cell 4 Machine	0.1232	0,01	0.1079	0.1344	0.00	1.0000
Cell 5 Machine	0.2781	0,02	0.2394	0.3071	0.00	1.0000
Cell 6 Machine	0.07612542	0,00	0.06592406	0.08222363	0.00	1.0000
Cell 7 Machine	0.04073814	0,00	0.03760961	0.04606951	0.00	1.0000
Cell 8 Machine	0.3304	0,02	0.2822	0.3626	0.00	1.0000
Cell 9 Machine	0.3476	0,02	0.2996	0.3736	0.00	1.0000
Worker 1	0.5235	0,03	0.4385	0.5727	0.00	1.0000
Worker 2	0.4740	0,02	0.4103	0.5187	0.00	1.0000
Worker 3	0.5019	0,03	0.4393	0.5610	0.00	1.0000
Worker 4	0.5087	0,05	0.3858	0.5928	0.00	1.0000
Worker 5	0.4237	0,03	0.3656	0.4818	0.00	1.0000
Worker 6	0.5131	0,03	0.4409	0.5634	0.00	1.0000
Worker 7	0.5809	0,04	0.5240	0.6705	0.00	1.0000
Worker 8	0.3050	0,02	0.2789	0.3633	0.00	1.0000
Worker 9	0.2530	0,02	0.2152	0.3021	0.00	1.0000

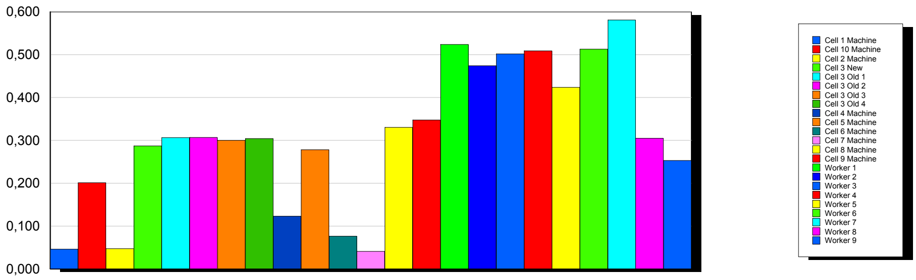


Figure C.19 Number of Busy Status

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Machine	12.0000	0,00	12.0000	12.0000
Cell 10 Machine	12.0000	0,00	12.0000	12.0000
Cell 2 Machine	12.0000	0,00	12.0000	12.0000
Cell 3 New	31.4000	2,08	25.0000	35.0000
Cell 3 Old 1	10.2000	1,30	7.0000	12.0000
Cell 3 Old 2	10.1000	1,53	7.0000	14.0000
Cell 3 Old 3	11.1000	1,28	9.0000	14.0000
Cell 3 Old 4	9.2000	1,30	6.0000	11.0000
Cell 4 Machine	12.0000	0,00	12.0000	12.0000
Cell 5 Machine	1.0000	0,00	1.0000	1.0000
Cell 6 Machine	12.0000	0,00	12.0000	12.0000
Cell 7 Machine	12.0000	0,00	12.0000	12.0000
Cell 8 Machine	12.0000	0,00	12.0000	12.0000
Cell 9 Machine	60.0000	0,00	60.0000	60.0000
Worker 1	27.0000	7,80	14.0000	39.0000
Worker 2	17.2000	6,41	10.0000	39.0000
Worker 3	13.3000	1,58	10.0000	17.0000
Worker 4	13.9000	1,53	11.0000	17.0000
Worker 5	19.5000	7,30	10.0000	35.0000
Worker 6	45.3000	1,17	42.0000	48.0000
Worker 7	23.2000	1,16	21.0000	26.0000
Worker 8	29.8000	1,11	27.0000	31.0000
Worker 9	26.8000	0,94	25.0000	29.0000

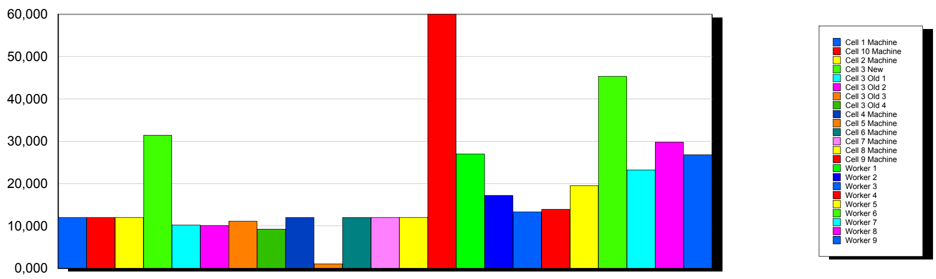


Figure C.20 Total Number Seized (Resources)

C.3 Statistical Results of “LPT” Experiment (Time units: Minute)

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	834.09	92,05	664.03	1021.83	612.91	1051.68
Part 2	103.43	2,49	99.12	110.93	66.4833	141.43
Part 3	250.35	7,81	236.51	270.18	177.55	314.86
Part 4	161.84	10,92	133.88	180.44	90.9149	229.83
Part 5	71.1902	1,90	67.1710	74.8541	52.3367	91.4705

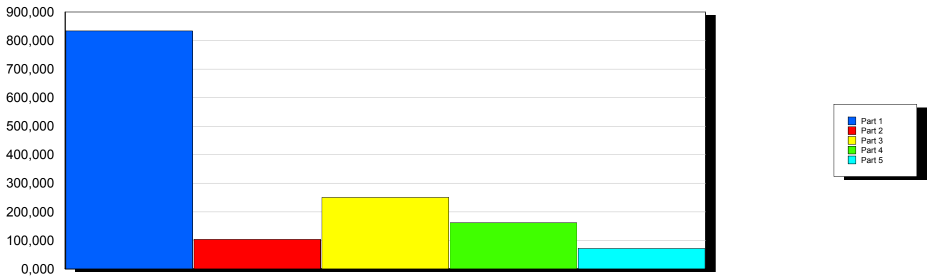


Figure C.21 Entity-Value Added Time

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	1359.45	20,65	1317.51	1403.63	1052.78	1734.46
Part 2	2240.33	82,01	2097.18	2394.43	1865.14	2615.74
Part 3	2075.22	76,28	1923.00	2234.69	1676.35	2474.50
Part 4	2179.36	87,34	2011.64	2348.94	1842.33	2558.63
Part 5	2263.57	69,55	2128.43	2408.36	1896.70	2650.48

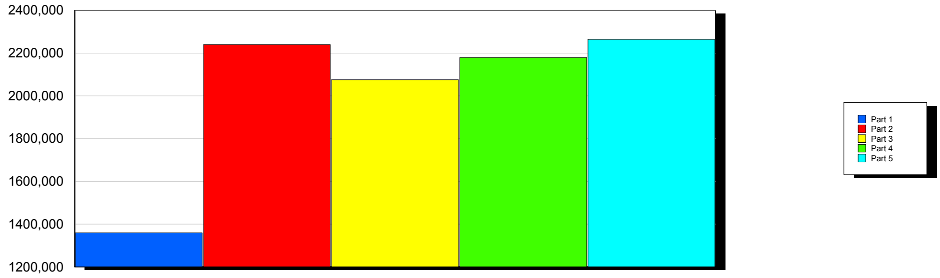


Figure C.22 Entity-Wait Time

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	171.76	2,86	165.95	179.34	157.97	190.46
Part 2	27.2115	0,25	26.7483	27.8099	24.5772	31.4286
Part 3	46.8610	0,25	46.3452	47.4245	41.9606	51.9621
Part 4	26.9428	0,24	26.4290	27.5911	23.3938	29.7942
Part 5	26.8869	0,46	25.7572	27.6244	23.1377	30.6754

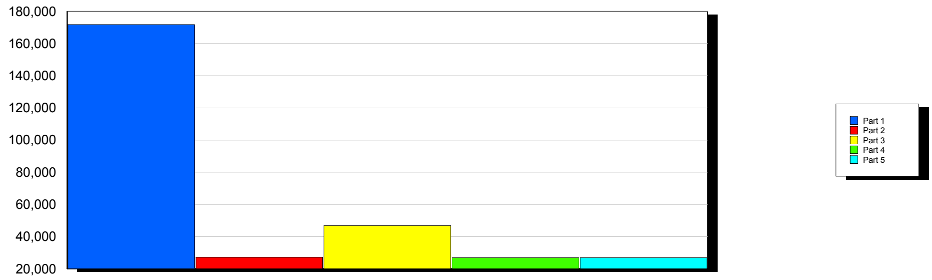


Figure C.23 Entity-Transfer Time

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	2365.30	78,79	2220.29	2526.13	1971.22	2818.39
Part 2	2370.98	83,00	2224.92	2526.58	2014.08	2759.73
Part 3	2372.42	80,10	2213.11	2533.03	1994.46	2819.07
Part 4	2368.14	81,64	2204.00	2515.91	1974.53	2776.45
Part 5	2361.65	68,70	2227.89	2508.32	1990.67	2749.84

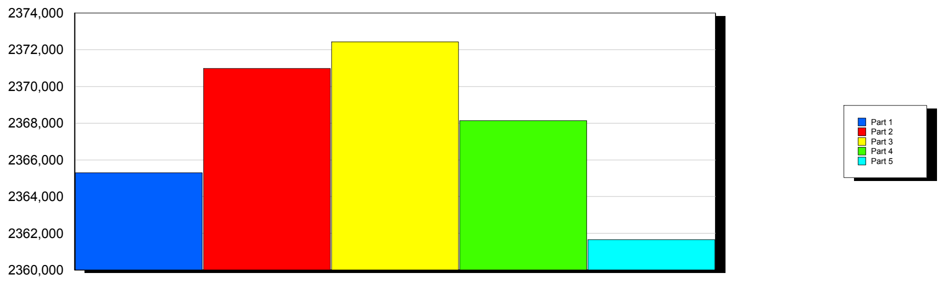


Figure C.24 Entity-Total Time

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	9.8853	0,27	9.1266	10.3895	7.2477	11.8375
Cell 10 Process	45.0453	1,04	43.2120	47.1681	33.8167	56.9494
Cell 2 Process	10.2998	0,28	9.4181	10.8156	8.1664	12.3887
Cell 3 Process	54.8115	0,33	54.1431	55.5945	2.3663	160.83
Cell 4 Process	26.3116	0,42	25.5116	27.2520	22.2580	31.7146
Cell 5 Process	648.47	92,55	475.73	836.75	475.73	836.75
Cell 6 Process	16.1299	0,39	15.1030	16.8753	13.3859	20.1673
Cell 7 Process	8.9082	0,20	8.5592	9.4144	5.9743	11.7557
Cell 8 Process	71.7930	0,58	70.6200	73.2115	60.2889	79.5464
Cell 9 Process	15.0016	0,18	14.5434	15.3595	10.2575	19.7326

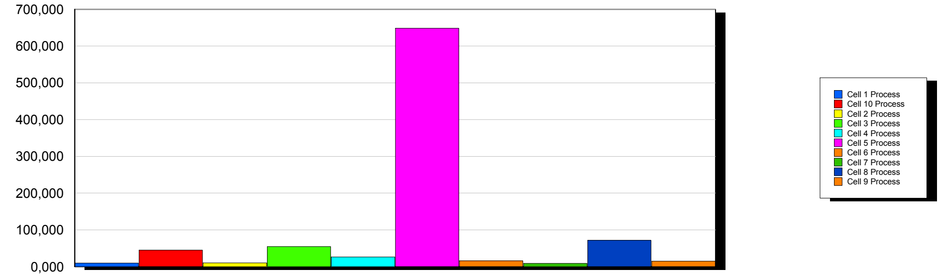


Figure C.25 Process-VA Time (Per Entity)

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	19.5211	2,41	16.7055	27.5971	7.2477	40.0744
Cell 10 Process	207.84	7,79	185.47	220.74	37.7737	338.30
Cell 2 Process	10.2998	0,28	9.4181	10.8156	8.1664	12.3887
Cell 3 Process	54.8115	0,33	54.1431	55.5945	2.3663	160.83
Cell 4 Process	26.3116	0,42	25.5116	27.2520	22.2580	31.7146
Cell 5 Process	648.47	92,55	475.73	836.75	475.73	836.75
Cell 6 Process	16.1299	0,39	15.1030	16.8753	13.3859	20.1673
Cell 7 Process	8.9849	0,20	8.5592	9.4144	5.9743	13.0568
Cell 8 Process	71.7930	0,58	70.6200	73.2115	60.2889	79.5464
Cell 9 Process	56.8726	1,73	54.1037	61.0516	10.4764	144.59

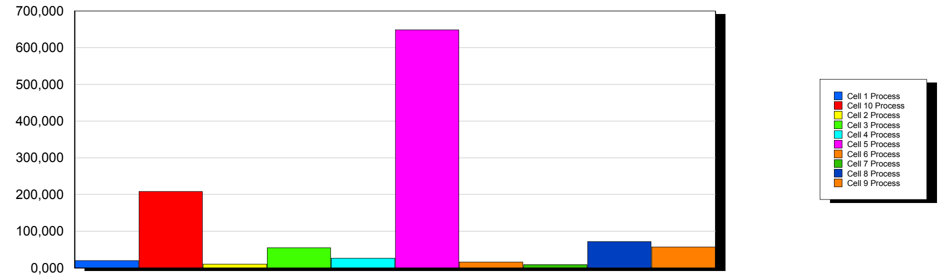


Figure C.26 Process-Total Time (Per Entity)

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Process	118.62	3,22	109.52	124.67
Cell 10 Process	540.54	12,48	518.54	566.02
Cell 2 Process	123.60	3,37	113.02	129.79
Cell 3 Process	3946.43	23,58	3898.31	4002.80
Cell 4 Process	315.74	5,06	306.14	327.02
Cell 5 Process	648.47	92,55	475.73	836.75
Cell 6 Process	193.56	4,74	181.24	202.50
Cell 7 Process	106.90	2,44	102.71	112.97
Cell 8 Process	861.52	7,00	847.44	878.54
Cell 9 Process	900.10	10,73	872.60	921.57

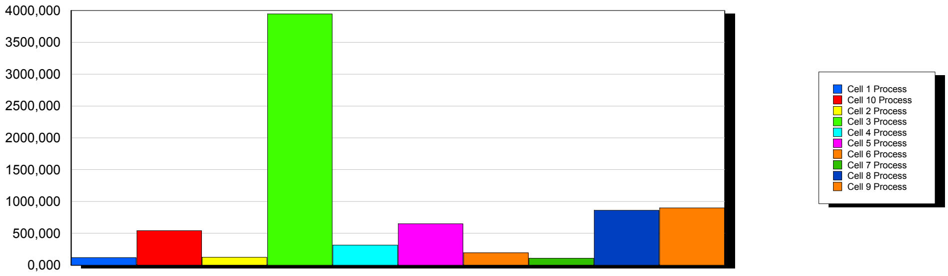


Figure C.27 Acc. Time-VA Time

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Assembling.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 1 Process.Queue	9.6358	2,54	7.0203	18.4705	0.00	29.7453
Cell 1 Seize.Queue	1.1414	1,46	0.00	6.8416	0.00	28.0363
Cell 10 Process.Queue	162.80	6,93	142.26	173.57	0.00	296.33
Cell 10 Seize.Queue	55.8379	7,91	26.5668	65.2487	4.9093	153.18
Cell 2 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 2 Seize.Queue	3.3244	1,37	1.7174	7.0431	0.00	38.3241
Cell 3 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Seize.Queue	44.3412	5,48	33.4935	59.6733	0.00	129.26
Cell 5 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Seize.Queue	194.31	23,83	126.39	240.29	0.00	350.65
Cell 7 Process.Queue	0.07672821	0,10	0.00	0.3507	0.00	4.2078
Cell 7 Seize.Queue	22.1177	3,03	13.7867	27.8230	0.00	146.15
Cell 8 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 8 Seize.Queue	212.79	25,53	175.09	285.19	0.00	539.07
Cell 9 Process.Queue	41.8710	1,67	39.0878	45.8704	0.00	129.57
Cell 9 Seize.Queue	14.5212	2,20	11.0651	19.8698	0.00	138.31
Match.Queue1	0.00	0,00	0.00	0.00	0.00	0.00
Match.Queue2	1548.37	102,45	1356.93	1749.12	1173.67	2134.62
Match.Queue3	1334.25	85,88	1169.96	1498.12	893.00	1899.30
Match.Queue4	1800.59	80,96	1659.22	1934.33	1405.89	2099.61
Match.Queue5	1437.32	110,43	1236.28	1669.51	1143.94	2161.95
Sending Coating.Queue	191.81	12,92	170.81	214.39	0.00	743.60
Worker Seize 3.Queue	291.09	10,25	268.73	314.74	0.00	650.98

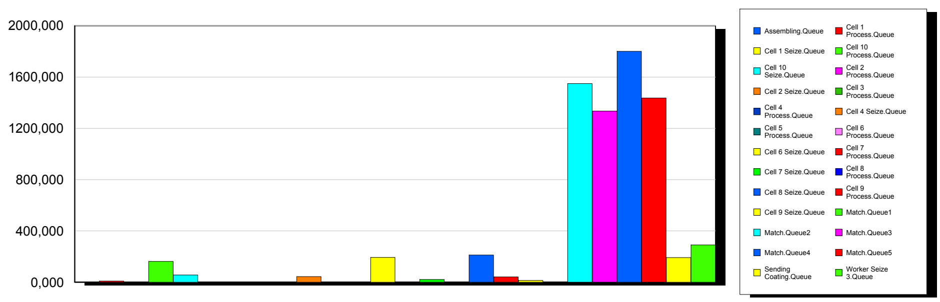


Figure C.28 Waiting Time in Queue

Resource

Usage

Number Busy

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Machine	0.04242394	0,00	0.03852163	0.04669416	0.00	1.0000
Cell 10 Machine	0.1935	0,01	0.1731	0.2120	0.00	1.0000
Cell 2 Machine	0.04421608	0,00	0.03767254	0.04860949	0.00	1.0000
Cell 3 New	0.2560	0,01	0.2315	0.2787	0.00	1.0000
Cell 3 Old 1	0.2911	0,02	0.2519	0.3131	0.00	1.0000
Cell 3 Old 2	0.2881	0,01	0.2700	0.3147	0.00	1.0000
Cell 3 Old 3	0.2866	0,01	0.2695	0.3087	0.00	1.0000
Cell 3 Old 4	0.2896	0,02	0.2491	0.3179	0.00	1.0000
Cell 4 Machine	0.1129	0,00	0.1038	0.1210	0.00	1.0000
Cell 5 Machine	0.2298	0,03	0.1782	0.2789	0.00	1.0000
Cell 6 Machine	0.06917913	0,00	0.06441149	0.07500140	0.00	1.0000
Cell 7 Machine	0.03822276	0,00	0.03480842	0.04153037	0.00	1.0000
Cell 8 Machine	0.3081	0,01	0.2835	0.3276	0.00	1.0000
Cell 9 Machine	0.3218	0,01	0.2938	0.3412	0.00	1.0000
Worker 1	0.5730	0,03	0.5086	0.6371	0.00	1.0000
Worker 2	0.5365	0,04	0.4698	0.5979	0.00	1.0000
Worker 3	0.5614	0,03	0.4912	0.6160	0.00	1.0000
Worker 4	0.5594	0,03	0.4954	0.6157	0.00	1.0000
Worker 5	0.4776	0,03	0.4305	0.5231	0.00	1.0000
Worker 6	0.4808	0,03	0.4312	0.5404	0.00	1.0000
Worker 7	0.5150	0,02	0.4761	0.5526	0.00	1.0000
Worker 8	0.2714	0,02	0.2353	0.3025	0.00	1.0000
Worker 9	0.2081	0,02	0.1678	0.2733	0.00	1.0000

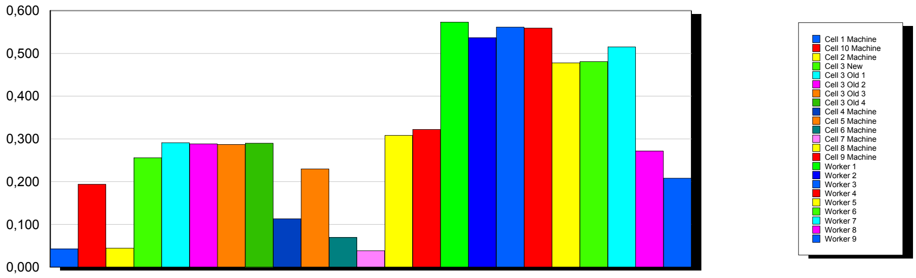


Figure C.29 Number of Busy Status

Total Number Seized

	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Machine	12.0000	0,00	12.0000	12.0000
Cell 10 Machine	12.0000	0,00	12.0000	12.0000
Cell 2 Machine	12.0000	0,00	12.0000	12.0000
Cell 3 New	32.4000	0,90	30.0000	34.0000
Cell 3 Old 1	10.4000	0,84	8.0000	12.0000
Cell 3 Old 2	10.1000	0,63	9.0000	11.0000
Cell 3 Old 3	9.7000	0,48	9.0000	11.0000
Cell 3 Old 4	9.4000	0,69	8.0000	11.0000
Cell 4 Machine	12.0000	0,00	12.0000	12.0000
Cell 5 Machine	1.0000	0,00	1.0000	1.0000
Cell 6 Machine	12.0000	0,00	12.0000	12.0000
Cell 7 Machine	12.0000	0,00	12.0000	12.0000
Cell 8 Machine	12.0000	0,00	12.0000	12.0000
Cell 9 Machine	60.0000	0,00	60.0000	60.0000
Worker 1	28.5000	7,65	18.0000	41.0000
Worker 2	19.0000	4,94	14.0000	38.0000
Worker 3	16.0000	0,83	14.0000	18.0000
Worker 4	16.3000	1,39	15.0000	20.0000
Worker 5	23.9000	8,41	14.0000	39.0000
Worker 6	42.3000	1,22	40.0000	45.0000
Worker 7	22.5000	0,38	22.0000	23.0000
Worker 8	26.3000	1,01	24.0000	28.0000
Worker 9	21.2000	0,74	20.0000	23.0000

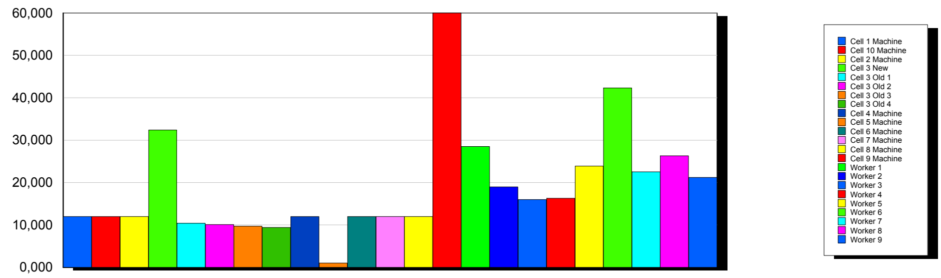


Figure C.30 Total Number Seized (Resources)

C.4 Statistical Results of "SPT" Experiment (Time units: Minute)

Entity

Time

VA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	963.31	123,44	768.39	1236.55	715.34	1274.23
Part 2	107.48	2,79	102.66	114.17	62.3582	135.86
Part 3	243.28	8,94	233.03	272.02	176.79	312.67
Part 4	165.37	9,54	144.64	181.32	89.4096	230.75
Part 5	72.4923	1,89	69.9560	77.3442	50.8373	90.8096

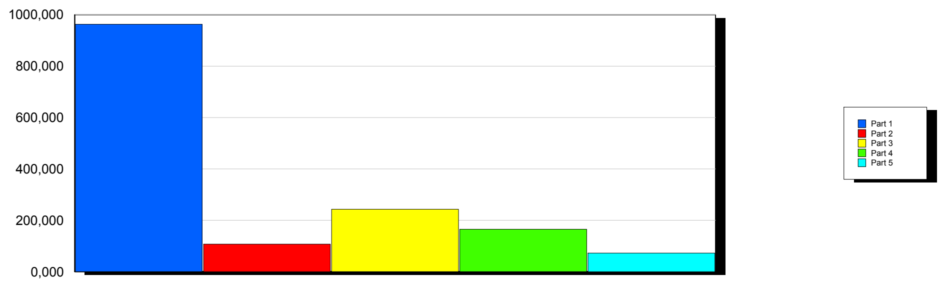


Figure C.31 Entity-Value Added Time

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	842.82	28,65	788.29	905.41	507.74	1246.30
Part 2	1851.24	117,99	1664.18	2085.35	1464.52	2345.69
Part 3	1695.76	112,99	1518.23	1922.04	1268.33	2150.34
Part 4	1791.71	128,66	1584.24	2096.57	1392.40	2295.52
Part 5	1879.79	111,70	1713.74	2154.71	1501.97	2349.95

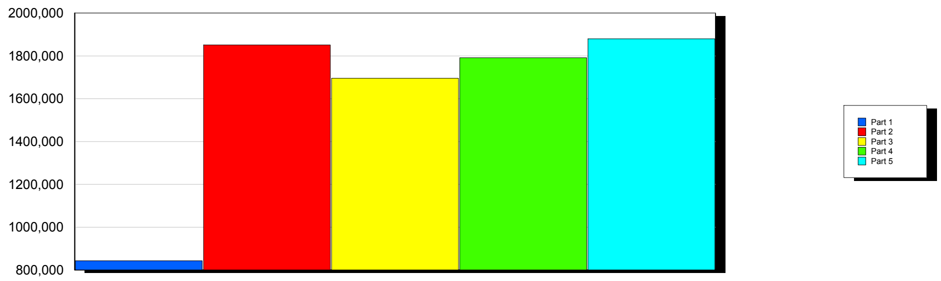


Figure C.32 Entity-Wait Time

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	174.69	1,99	170.97	178.16	161.72	188.76
Part 2	27.0608	0,28	26.4192	27.6557	23.5437	31.0411
Part 3	47.1873	0,39	46.1519	48.0283	42.8284	50.7811
Part 4	27.0681	0,28	26.5564	27.6688	23.8761	29.9698
Part 5	26.8090	0,21	26.1915	27.1985	23.3595	30.6498

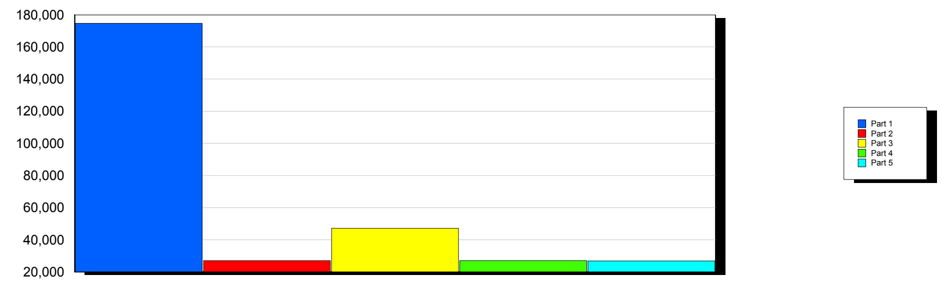


Figure C.33 Entity-Transfer Time

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	1980.82	115,52	1799.95	2227.94	1560.49	2504.14
Part 2	1985.78	118,60	1802.12	2221.53	1598.59	2501.97
Part 3	1986.23	114,03	1807.42	2227.61	1501.77	2429.81
Part 4	1984.14	125,81	1778.23	2268.88	1549.43	2472.55
Part 5	1979.09	111,40	1818.29	2254.61	1599.45	2459.07

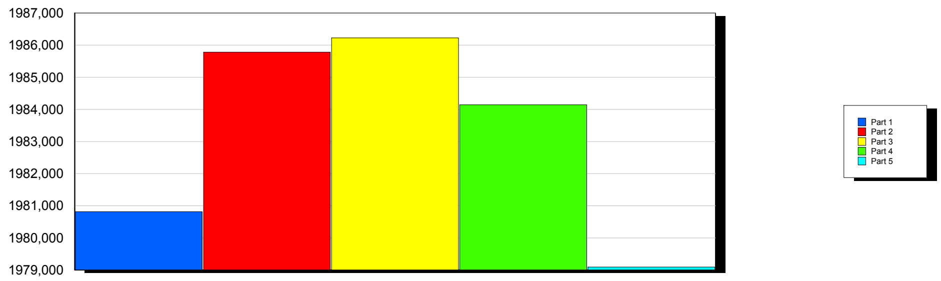


Figure C.34 Entity-Total Time

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	9.8251	0,29	9.2783	10.6049	7.2477	11.8375
Cell 10 Process	43.8706	1,29	40.6872	47.2828	31.8357	57.4432
Cell 2 Process	10.3535	0,18	10.0757	10.8262	8.4289	12.3244
Cell 3 Process	56.2461	0,55	55.0253	57.5691	2.1818	163.50
Cell 4 Process	26.6081	0,53	25.1841	27.6701	22.3233	31.3075
Cell 5 Process	777.27	123,75	574.68	1050.09	574.68	1050.09
Cell 6 Process	16.1985	0,38	15.5037	17.1940	13.6076	19.7220
Cell 7 Process	8.6818	0,30	8.0920	9.5201	5.2423	11.4853
Cell 8 Process	71.6199	1,29	69.5691	74.5526	60.3102	79.0853
Cell 9 Process	14.9092	0,17	14.5559	15.2515	10.1180	19.7326

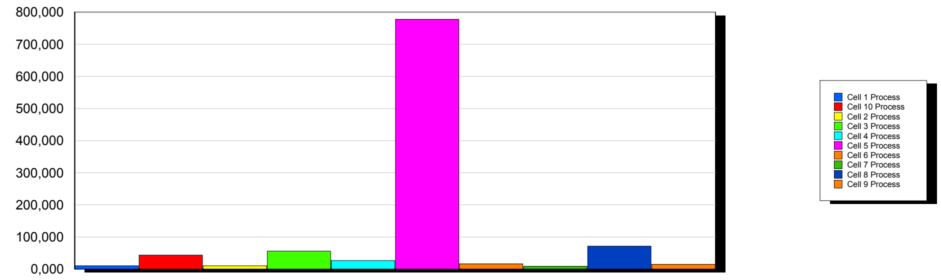


Figure C.35 Process-VA Time (Per Entity)

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	17.5587	3,40	12.6907	27.8400	7.2477	40.0744
Cell 10 Process	200.35	6,28	187.60	216.30	34.9146	348.00
Cell 2 Process	10.3535	0,18	10.0757	10.8262	8.4289	12.3244
Cell 3 Process	56.2461	0,55	55.0253	57.5691	2.1818	163.50
Cell 4 Process	26.6081	0,53	25.1841	27.6701	22.3233	31.3075
Cell 5 Process	777.27	123,75	574.68	1050.09	574.68	1050.09
Cell 6 Process	16.1985	0,38	15.5037	17.1940	13.6076	19.7220
Cell 7 Process	8.7648	0,30	8.0920	9.5201	5.2423	18.8100
Cell 8 Process	71.6199	1,29	69.5691	74.5526	60.3102	79.0853
Cell 9 Process	48.5762	0,72	47.4460	50.8955	10.6221	145.97

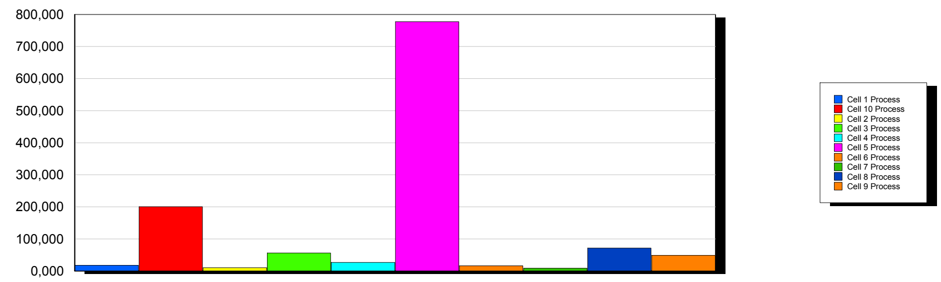


Figure C.36 Process-Total Time (Per Entity)

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Process	117.90	3,49	111.34	127.26
Cell 10 Process	526.45	15,46	488.25	567.39
Cell 2 Process	124.24	2,18	120.91	129.91
Cell 3 Process	4049.72	39,95	3961.82	4144.98
Cell 4 Process	319.30	6,41	302.21	332.04
Cell 5 Process	777.27	123,75	574.68	1050.09
Cell 6 Process	194.38	4,57	186.04	206.33
Cell 7 Process	104.18	3,59	97.1041	114.24
Cell 8 Process	859.44	15,50	834.83	894.63
Cell 9 Process	894.55	9,93	873.36	915.09

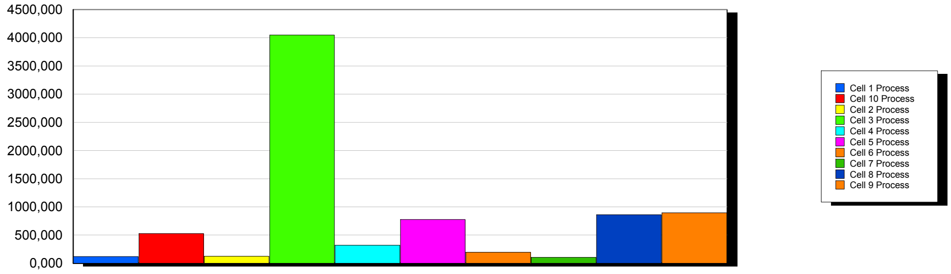


Figure C.37 Acc. Time-VA Time

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Assembling.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 1 Process.Queue	7.7336	3,46	2.8910	18.5617	0.00	29.6363
Cell 1 Seize.Queue	5.7435	2,42	2.1670	12.3793	0.00	63.3997
Cell 10 Process.Queue	156.48	5,37	146.92	169.02	0.00	298.11
Cell 10 Seize.Queue	51.3830	6,74	31.1368	62.7469	12.2516	130.63
Cell 2 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 2 Seize.Queue	29.6130	16,97	11.2234	81.7446	0.00	152.89
Cell 3 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Seize.Queue	85.8876	10,45	51.9671	108.39	0.00	184.29
Cell 5 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Seize.Queue	53.7534	8,79	33.2130	73.0872	0.00	138.09
Cell 7 Process.Queue	0.08302308	0,19	0.00	0.8302	0.00	8.4629
Cell 7 Seize.Queue	10.4889	5,29	0.2029	27.9553	0.00	176.45
Cell 8 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 8 Seize.Queue	213.58	21,56	163.37	269.75	0.00	518.80
Cell 9 Process.Queue	33.6670	0,71	32.5538	36.0340	0.00	129.57
Cell 9 Seize.Queue	14.4346	3,98	8.4121	24.8969	0.00	116.77
Match.Queue1	0.00	0,00	0.00	0.00	0.00	0.00
Match.Queue2	1443.28	135,68	1250.34	1735.41	1204.01	1808.95
Match.Queue3	652.35	123,82	473.43	890.45	13.1262	1159.60
Match.Queue4	1078.46	131,45	829.14	1352.58	581.69	1823.59
Match.Queue5	1571.63	112,47	1389.54	1837.30	1350.61	1866.45
Sending Coating.Queue	146.17	3,97	132.36	153.18	0.00	361.29
Worker Seize 3.Queue	214.46	8,48	202.63	234.97	0.00	869.55

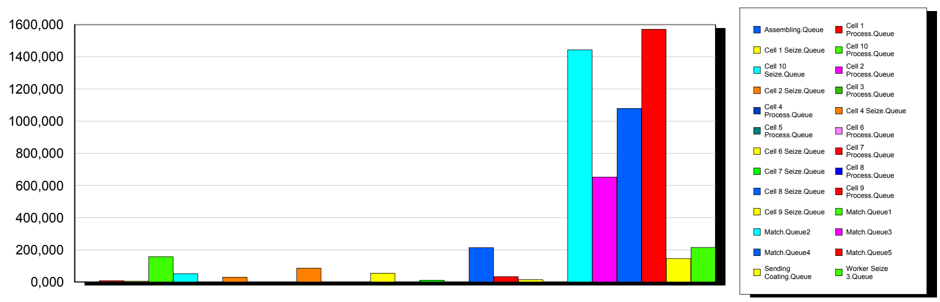


Figure C.38 Waiting Time in Queue

Resource

Usage

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Machine	0.04766179	0,00	0.04288051	0.05302468	0.00	1.0000
Cell 10 Machine	0.2128	0,01	0.1925	0.2364	0.00	1.0000
Cell 2 Machine	0.05020358	0,00	0.04560787	0.05413084	0.00	1.0000
Cell 3 New	0.2722	0,01	0.2399	0.3016	0.00	1.0000
Cell 3 Old 1	0.3415	0,02	0.3037	0.3842	0.00	1.0000
Cell 3 Old 2	0.3423	0,02	0.3044	0.3867	0.00	1.0000
Cell 3 Old 3	0.3435	0,02	0.3129	0.3831	0.00	1.0000
Cell 3 Old 4	0.3362	0,01	0.3110	0.3837	0.00	1.0000
Cell 4 Machine	0.1290	0,01	0.1132	0.1364	0.00	1.0000
Cell 5 Machine	0.3113	0,04	0.2394	0.3933	0.00	1.0000
Cell 6 Machine	0.07855659	0,00	0.07205239	0.08596976	0.00	1.0000
Cell 7 Machine	0.04210823	0,00	0.03744838	0.04760039	0.00	1.0000
Cell 8 Machine	0.3472	0,01	0.3199	0.3728	0.00	1.0000
Cell 9 Machine	0.3614	0,01	0.3271	0.3800	0.00	1.0000
Worker 1	0.5836	0,04	0.4654	0.6676	0.00	1.0000
Worker 2	0.5473	0,03	0.4861	0.6278	0.00	1.0000
Worker 3	0.5649	0,02	0.5186	0.6128	0.00	1.0000
Worker 4	0.5805	0,04	0.4500	0.6627	0.00	1.0000
Worker 5	0.5157	0,03	0.4655	0.6114	0.00	1.0000
Worker 6	0.5493	0,02	0.5075	0.5874	0.00	1.0000
Worker 7	0.6733	0,03	0.6213	0.7225	0.00	1.0000
Worker 8	0.2610	0,02	0.2243	0.3087	0.00	1.0000
Worker 9	0.2423	0,02	0.2085	0.2868	0.00	1.0000

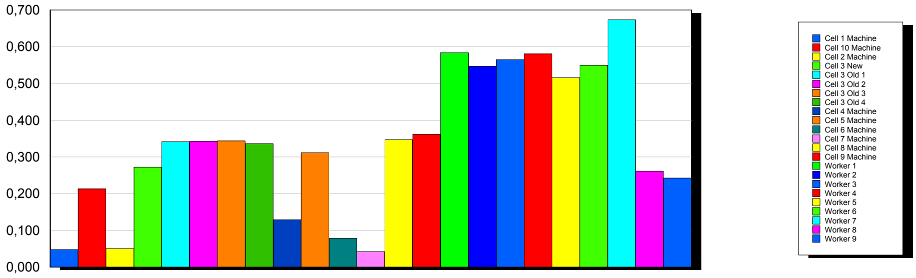


Figure C.39 Number of Busy Status

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Machine	12.0000	0,00	12.0000	12.0000
Cell 10 Machine	12.0000	0,00	12.0000	12.0000
Cell 2 Machine	12.0000	0,00	12.0000	12.0000
Cell 3 New	29.3000	2,26	25.0000	33.0000
Cell 3 Old 1	10.7000	1,91	7.0000	16.0000
Cell 3 Old 2	10.7000	1,43	7.0000	13.0000
Cell 3 Old 3	10.8000	1,68	8.0000	15.0000
Cell 3 Old 4	10.5000	1,63	7.0000	13.0000
Cell 4 Machine	12.0000	0,00	12.0000	12.0000
Cell 5 Machine	1.0000	0,00	1.0000	1.0000
Cell 6 Machine	12.0000	0,00	12.0000	12.0000
Cell 7 Machine	12.0000	0,00	12.0000	12.0000
Cell 8 Machine	12.0000	0,00	12.0000	12.0000
Cell 9 Machine	60.0000	0,00	60.0000	60.0000
Worker 1	22.8000	2,36	19.0000	30.0000
Worker 2	17.8000	4,48	11.0000	30.0000
Worker 3	17.7000	3,49	11.0000	27.0000
Worker 4	17.8000	3,83	12.0000	27.0000
Worker 5	20.7000	4,19	11.0000	29.0000
Worker 6	47.7000	1,07	46.0000	51.0000
Worker 7	25.7000	1,07	24.0000	28.0000
Worker 8	23.5000	1,23	20.0000	26.0000
Worker 9	22.3000	1,01	20.0000	24.0000

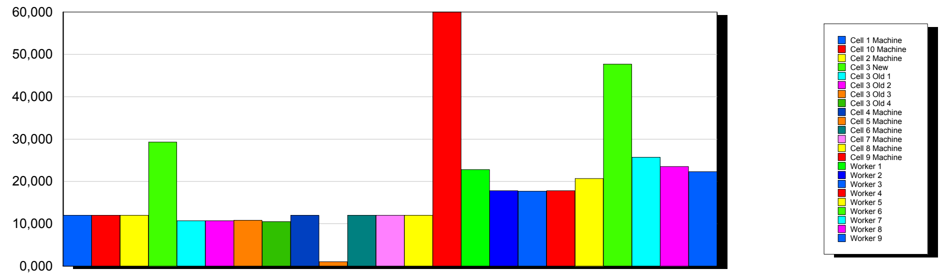


Figure C.40 Total Number Seized (Resources)

C.5 Statistical Results of “Part Priority” Experiment (Time units: Minute)

Entity

Time

VA Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	899.11	84,38	695.26	1072.18	648.49	1118.93
Part 2	103.19	3,83	96.9019	113.62	63.9702	140.50
Part 3	243.21	10,42	213.88	268.65	171.90	313.10
Part 4	165.86	8,81	146.23	179.83	86.8038	228.11
Part 5	74.2937	1,62	71.6465	78.7814	56.5203	94.0810

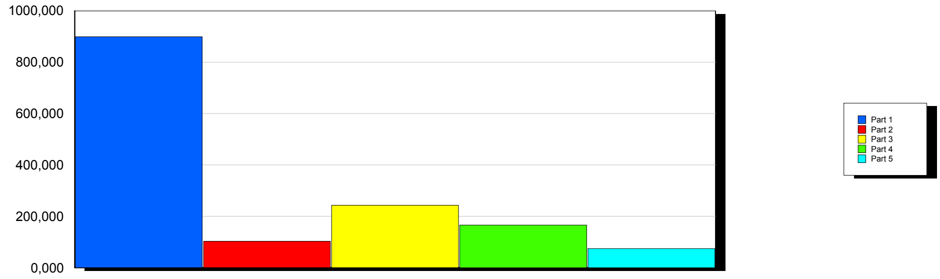


Figure C.41 Entity-Value Added Time

Wait Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	646.54	17,06	617.39	692.82	334.99	1023.33
Part 2	1593.48	90,70	1372.72	1760.03	1151.98	1979.36
Part 3	1430.39	89,44	1211.62	1617.00	1061.32	1781.04
Part 4	1526.19	92,29	1292.85	1690.82	1119.90	1860.07
Part 5	1614.64	96,17	1383.70	1810.60	1206.94	2006.75

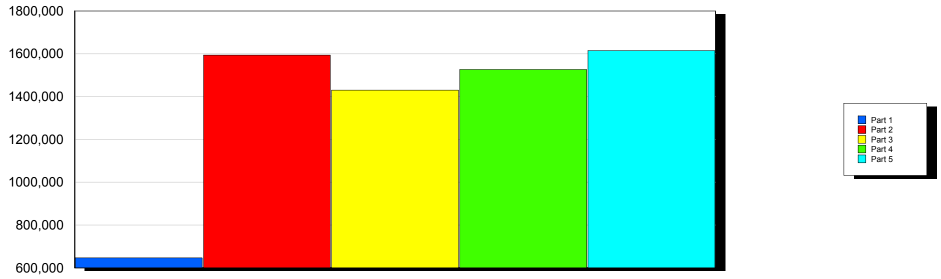


Figure C.42 Entity-Wait Time

Transfer Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	174.01	3,96	166.89	182.82	156.80	194.38
Part 2	27.2307	0,15	26.9331	27.5444	23.8396	30.1725
Part 3	47.1820	0,49	46.1896	48.6206	42.6337	52.5006
Part 4	27.2315	0,33	26.6256	28.0234	24.2811	30.4435
Part 5	26.7538	0,37	26.0017	27.4144	23.7518	30.7118

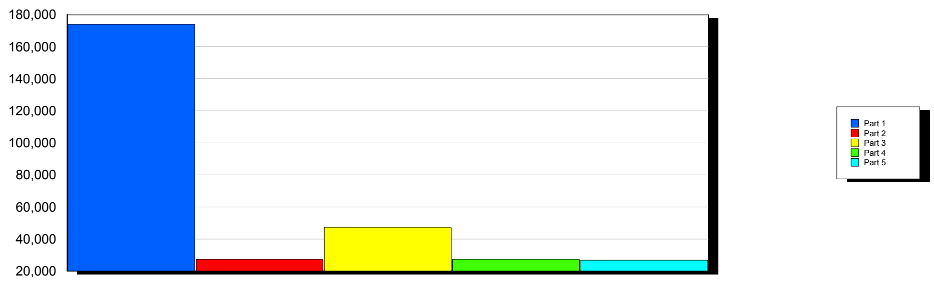


Figure C.43 Entity-Transfer Time

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	1719.66	92,33	1510.85	1899.56	1237.79	2145.07
Part 2	1723.91	91,34	1506.83	1894.01	1306.59	2081.24
Part 3	1720.79	91,40	1496.20	1903.56	1306.13	2103.11
Part 4	1719.28	88,70	1488.43	1880.00	1293.60	2078.24
Part 5	1715.68	96,19	1485.46	1913.32	1304.94	2098.91

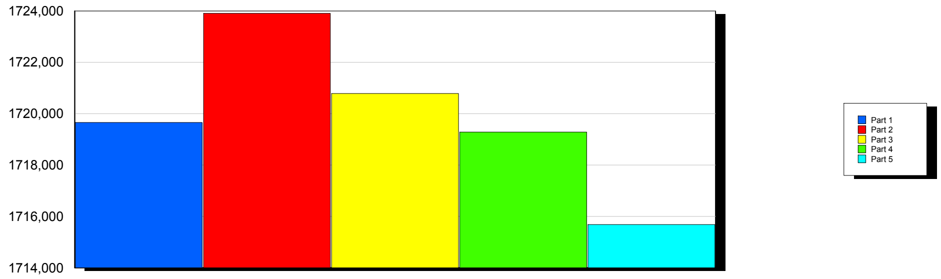


Figure C.44 Entity-Total Time

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	9.8702	0,22	9.2783	10.3056	7.2477	11.8391
Cell 10 Process	44.5963	1,10	42.8600	47.1676	31.4217	55.3361
Cell 2 Process	10.2172	0,19	9.7192	10.6702	8.2288	12.7338
Cell 3 Process	54.2904	0,44	53.4434	55.6857	2.2375	163.50
Cell 4 Process	25.9524	0,43	25.1298	26.8204	22.1088	31.6588
Cell 5 Process	719.85	86,31	509.00	889.10	509.00	889.10
Cell 6 Process	16.1954	0,27	15.6698	16.8609	13.3607	20.6857
Cell 7 Process	8.8637	0,26	8.2711	9.4625	5.2423	11.3915
Cell 8 Process	71.7731	1,21	68.9116	73.9331	61.4553	79.5609
Cell 9 Process	14.8438	0,21	14.2179	15.2449	10.1266	19.7326

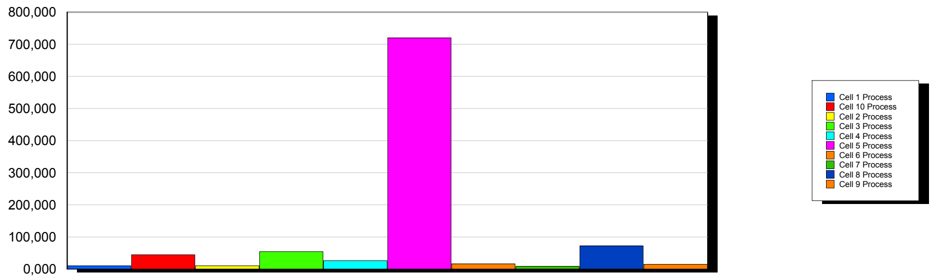


Figure C.45 Process-VA Time (Per Entity)

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	17.4123	3,32	12.7821	27.4544	7.2477	40.0744
Cell 10 Process	204.84	6,08	193.45	217.73	34.9146	332.05
Cell 2 Process	10.2172	0,19	9.7192	10.6702	8.2288	12.7338
Cell 3 Process	54.2904	0,44	53.4434	55.6857	2.2375	163.50
Cell 4 Process	25.9524	0,43	25.1298	26.8204	22.1088	31.6588
Cell 5 Process	719.85	86,31	509.00	889.10	509.00	889.10
Cell 6 Process	16.1954	0,27	15.6698	16.8609	13.3607	20.6857
Cell 7 Process	8.8637	0,26	8.2711	9.4625	5.2423	11.3915
Cell 8 Process	71.7731	1,21	68.9116	73.9331	61.4553	79.5609
Cell 9 Process	37.5082	1,43	33.6654	40.2316	10.2103	144.59

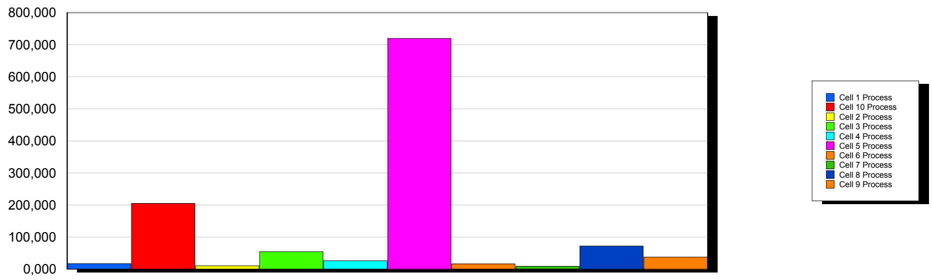


Figure C.46 Process-Total Time (Per Entity)

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Process	118.44	2,70	111.34	123.67
Cell 10 Process	535.16	13,14	514.32	566.01
Cell 2 Process	122.61	2,27	116.63	128.04
Cell 3 Process	3908.91	31,80	3847.92	4009.37
Cell 4 Process	311.43	5,17	301.56	321.85
Cell 5 Process	719.85	86,31	509.00	889.10
Cell 6 Process	194.35	3,23	188.04	202.33
Cell 7 Process	106.36	3,12	99.25	113.55
Cell 8 Process	861.28	14,47	826.94	887.20
Cell 9 Process	890.63	12,67	853.07	914.70

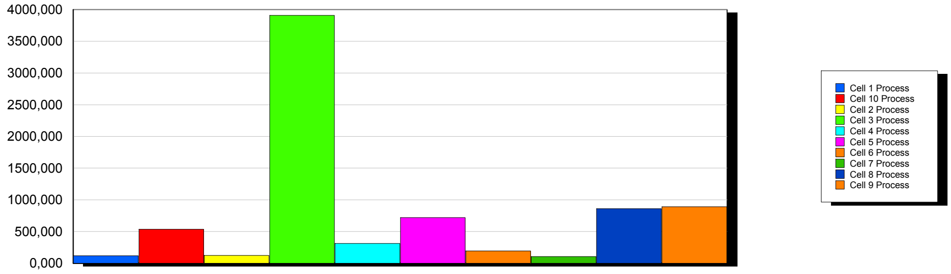


Figure C.47 Acc. Time-VA Time

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Assembling.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 1 Process.Queue	7.5421	3,40	2.8510	18.1761	0.00	29.6363
Cell 1 Seize.Queue	1.5637	1,57	0.06079119	7.3291	0.00	29.4176
Cell 10 Process.Queue	160.25	5,22	150.52	172.14	0.00	287.57
Cell 10 Seize.Queue	54.0486	3,45	44.8789	62.0702	22.4141	128.15
Cell 2 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 2 Seize.Queue	9.6781	4,80	2.6472	24.8371	0.00	63.9563
Cell 3 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Seize.Queue	53.9374	8,89	38.1651	79.6057	0.00	122.41
Cell 5 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Seize.Queue	41.5254	14,61	8.8189	72.0444	0.00	124.64
Cell 7 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 7 Seize.Queue	7.8328	3,31	1.5411	15.4517	0.00	58.8866
Cell 8 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 8 Seize.Queue	140.32	36,22	82.0376	208.93	0.00	446.60
Cell 9 Process.Queue	22.6644	1,30	19.4475	25.0318	0.00	129.57
Cell 9 Seize.Queue	4.2183	2,32	2.0620	12.2540	0.00	63.8170
Match.Queue1	1.5074	3,13	0.00	13.9123	0.00	83.9826
Match.Queue2	1066.39	111,81	834.79	1242.20	641.51	1451.86
Match.Queue3	562.63	110,07	276.50	800.45	0.00	1228.16
Match.Queue4	987.20	97,97	715.54	1175.78	576.20	1498.88
Match.Queue5	1037.23	140,92	804.97	1367.98	527.82	1532.29
Sending Coating.Queue	148.70	2,99	142.47	155.22	0.00	379.14
Worker Seize 3.Queue	223.78	12,00	194.99	251.85	0.00	619.69

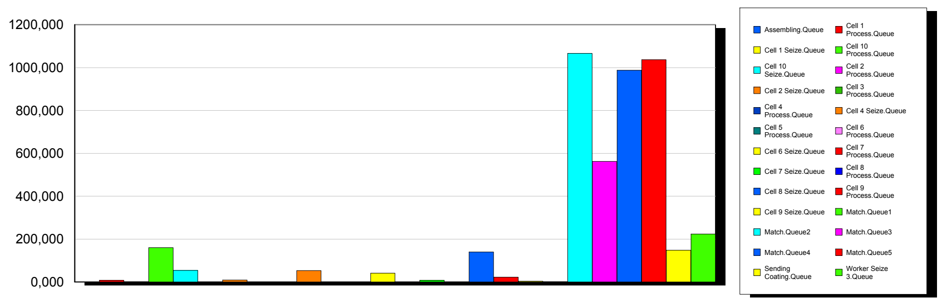


Figure C.48 Waiting Time in Queue

Resource

Usage

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Machine	0.05475624	0,00	0.04844302	0.05897988	0.00	1.0000
Cell 10 Machine	0.2476	0,01	0.2155	0.2734	0.00	1.0000
Cell 2 Machine	0.05670502	0,00	0.05052191	0.06185619	0.00	1.0000
Cell 3 New	0.3380	0,02	0.2957	0.3687	0.00	1.0000
Cell 3 Old 1	0.3678	0,01	0.3381	0.4000	0.00	1.0000
Cell 3 Old 2	0.3570	0,03	0.2872	0.4182	0.00	1.0000
Cell 3 Old 3	0.3678	0,02	0.3161	0.4061	0.00	1.0000
Cell 3 Old 4	0.3766	0,02	0.3484	0.4214	0.00	1.0000
Cell 4 Machine	0.1441	0,01	0.1261	0.1555	0.00	1.0000
Cell 5 Machine	0.3305	0,03	0.2459	0.3967	0.00	1.0000
Cell 6 Machine	0.08984724	0,00	0.07834914	0.0959	0.00	1.0000
Cell 7 Machine	0.04920510	0,00	0.04275448	0.05407141	0.00	1.0000
Cell 8 Machine	0.3987	0,02	0.3446	0.4286	0.00	1.0000
Cell 9 Machine	0.4118	0,02	0.3652	0.4419	0.00	1.0000
Worker 1	0.6204	0,04	0.5154	0.6731	0.00	1.0000
Worker 2	0.5656	0,03	0.5019	0.6238	0.00	1.0000
Worker 3	0.6104	0,04	0.5167	0.6736	0.00	1.0000
Worker 4	0.6176	0,05	0.4965	0.6793	0.00	1.0000
Worker 5	0.5374	0,05	0.4243	0.6833	0.00	1.0000
Worker 6	0.5689	0,04	0.4736	0.6183	0.00	1.0000
Worker 7	0.7073	0,05	0.5875	0.8139	0.00	1.0000
Worker 8	0.3295	0,03	0.2725	0.3967	0.00	1.0000
Worker 9	0.2638	0,03	0.2041	0.3042	0.00	1.0000

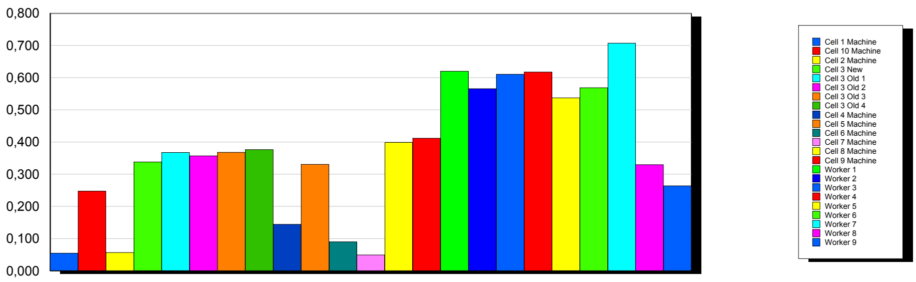


Figure C.49 Number of Busy Status

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Machine	12.0000	0,00	12.0000	12.0000
Cell 10 Machine	12.0000	0,00	12.0000	12.0000
Cell 2 Machine	12.0000	0,00	12.0000	12.0000
Cell 3 New	30.8000	3,05	25.0000	38.0000
Cell 3 Old 1	10.8000	1,71	7.0000	15.0000
Cell 3 Old 2	10.2000	2,26	6.0000	16.0000
Cell 3 Old 3	10.2000	1,87	7.0000	14.0000
Cell 3 Old 4	10.0000	1,22	8.0000	14.0000
Cell 4 Machine	12.0000	0,00	12.0000	12.0000
Cell 5 Machine	1.0000	0,00	1.0000	1.0000
Cell 6 Machine	12.0000	0,00	12.0000	12.0000
Cell 7 Machine	12.0000	0,00	12.0000	12.0000
Cell 8 Machine	12.0000	0,00	12.0000	12.0000
Cell 9 Machine	60.0000	0,00	60.0000	60.0000
Worker 1	20.9000	5,88	12.0000	37.0000
Worker 2	17.3000	4,03	10.0000	28.0000
Worker 3	17.8000	5,36	9.0000	31.0000
Worker 4	14.4000	3,49	10.0000	27.0000
Worker 5	20.1000	6,06	11.0000	37.0000
Worker 6	46.1000	1,63	43.0000	50.0000
Worker 7	27.6000	1,73	23.0000	31.0000
Worker 8	26.4000	1,66	22.0000	30.0000
Worker 9	25.4000	1,13	23.0000	28.0000

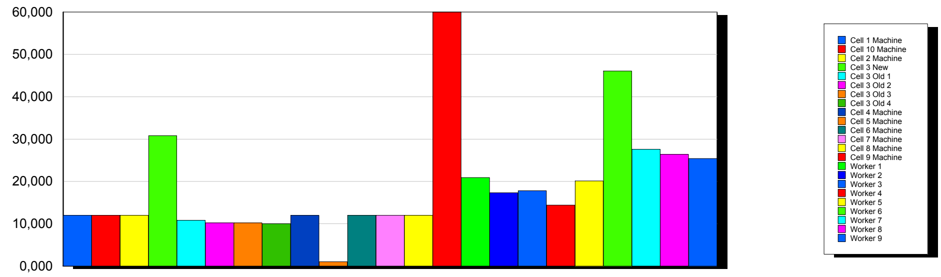


Figure C.50 Total Number Seized (Resources)

C.6 Statistical Results of Drive Shaft manufacturing under "Process Type" Experiment (Time units: Minute)

Entity

Time

VA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	894.48	91,29	669.04	1131.20	625.62	1169.19
Part 2	103.91	2,16	99.93	108.00	63.1553	138.16
Part 3	256.71	3,48	248.33	262.87	182.10	313.27
Part 4	157.30	5,13	144.93	165.97	88.9234	227.16
Part 5	71.8896	2,41	66.4051	77.3461	48.8610	94.9645
Part 6	49.3255	1,38	47.2289	53.8822	42.3375	58.7045

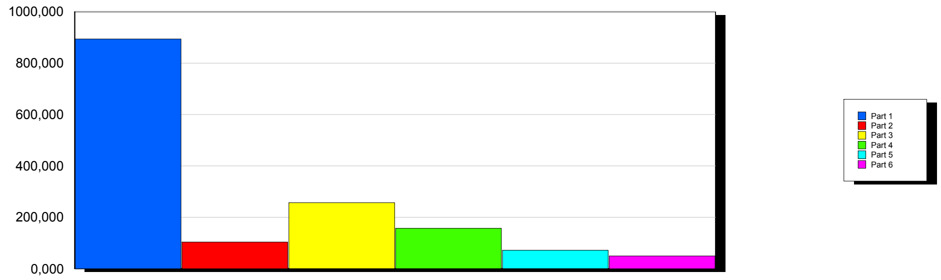


Figure C.51 Entity-Value Added Time

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	1299.02	21,36	1247.92	1355.27	969.65	1678.86
Part 2	2240.19	85,95	2042.42	2424.87	1830.64	2622.99
Part 3	2062.70	83,42	1864.60	2235.95	1719.81	2382.08
Part 4	2181.52	90,56	1982.40	2381.61	1776.05	2529.80
Part 5	2262.34	86,45	2035.97	2429.84	1870.99	2606.02
Part 6	89.4652	2,22	84.7536	93.8689	26.4837	174.85

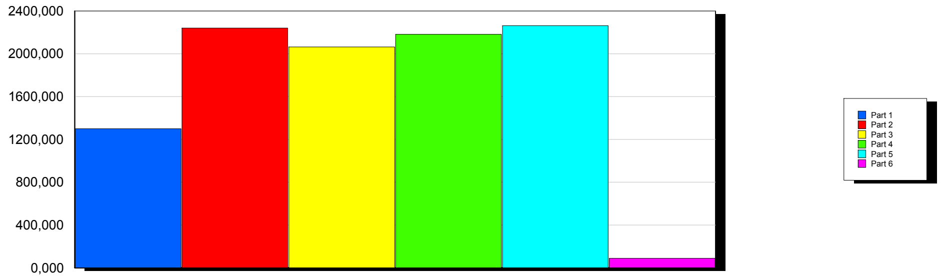


Figure C.52 Entity-Wait Time

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	172.44	2,41	167.50	176.63	156.15	186.47
Part 2	27.1352	0,27	26.5575	27.5060	23.8775	30.1364
Part 3	47.2574	0,57	46.0621	48.5231	41.9034	51.2275
Part 4	26.8448	0,23	26.3481	27.2322	23.4869	30.1191
Part 5	27.0532	0,26	26.6137	27.7139	23.8026	29.7328
Part 6	11.7133	0,23	11.2612	12.2121	9.6216	13.5322

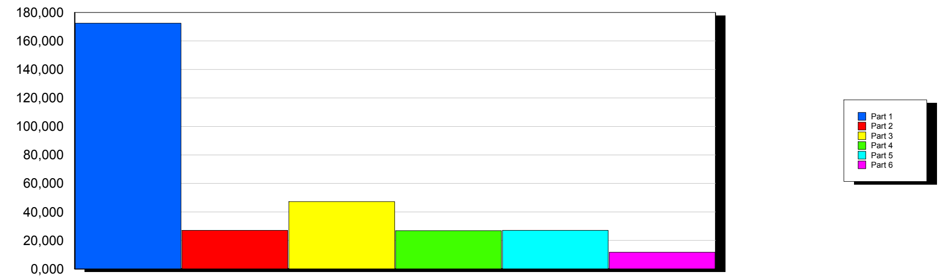


Figure C.53 Entity-Transfer Time

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	2365.94	87,56	2153.98	2566.86	1919.49	2816.68
Part 2	2371.23	86,24	2176.12	2559.77	1972.51	2787.59
Part 3	2366.67	83,15	2160.44	2534.25	1957.66	2692.84
Part 4	2365.66	92,77	2161.98	2572.63	1971.18	2776.81
Part 5	2361.29	86,49	2135.47	2523.24	1971.94	2705.75
Part 6	150.50	2,89	145.69	159.71	82.2884	243.35

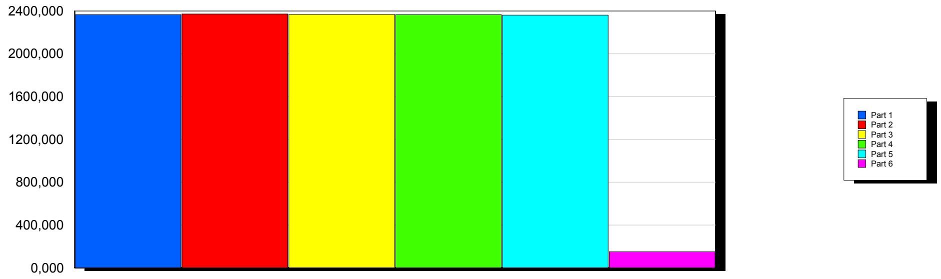


Figure C.54 Entity-Total Time

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	9.8185	0,21	9.2783	10.1959	7.2477	11.8391
Cell 10 Process	45.3131	1,25	42.5730	47.7990	30.3799	58.0596
Cell 2 Process	12.7061	0,34	12.2873	13.4850	8.1397	24.9209
Cell 3 Process	54.3603	0,66	52.8731	55.5369	2.1895	160.83
Cell 4 Process	27.7305	0,36	26.9995	28.5613	22.4413	35.8572
Cell 5 Process	713.84	91,35	491.83	956.69	491.83	956.69
Cell 6 Process	16.1777	0,27	15.6752	16.7358	13.4167	20.6857
Cell 7 Process	9.2293	0,23	8.6280	9.8734	5.8779	11.7115
Cell 8 Process	71.2868	0,93	69.0618	73.2587	61.9178	79.0318
Cell 9 Process	14.8945	0,17	14.6112	15.2724	10.1317	19.6895

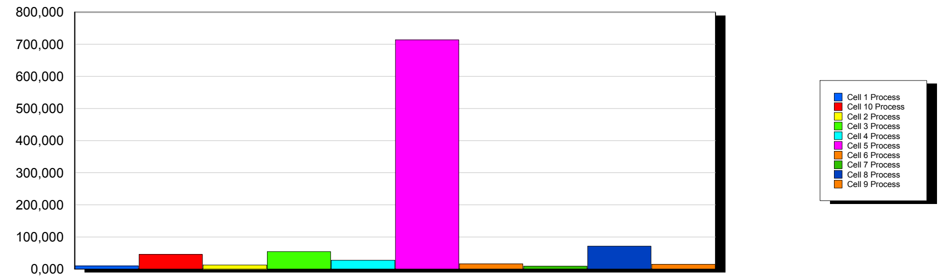


Figure C.55 Process-VA Time (Per Entity)

Total Time Per Entity

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	17.3788	3,20	12.9929	27.4544	7.2477	40.0744
Cell 10 Process	210.04	7,02	197.23	227.27	34.9146	352.65
Cell 2 Process	12.7061	0,34	12.2873	13.4850	8.1397	24.9209
Cell 3 Process	54.3603	0,66	52.8731	55.5369	2.1895	160.83
Cell 4 Process	27.7305	0,36	26.9995	28.5613	22.4413	35.8572
Cell 5 Process	713.84	91,35	491.83	956.69	491.83	956.69
Cell 6 Process	16.1777	0,27	15.6752	16.7358	13.4167	20.6857
Cell 7 Process	9.4108	0,33	8.6280	10.1505	5.8779	16.2894
Cell 8 Process	71.2868	0,93	69.0618	73.2587	61.9178	79.0318
Cell 9 Process	44.3362	1,05	41.9028	46.2805	11.0727	143.63

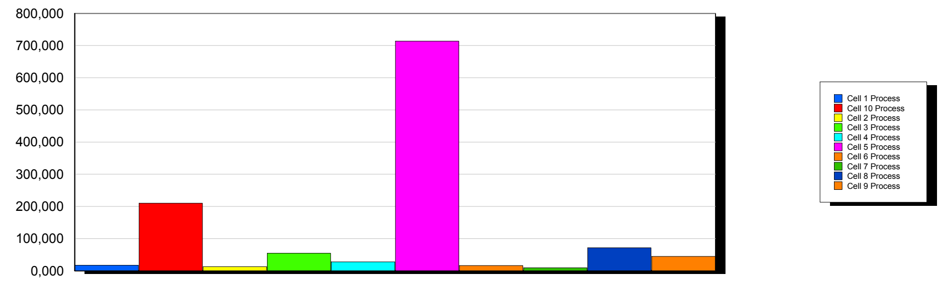


Figure C.56 Process-Total Time (Per Entity)

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Process	117.82	2,56	111.34	122.35
Cell 10 Process	543.76	15,02	510.88	573.59
Cell 2 Process	216.00	5,74	208.88	229.25
Cell 3 Process	3913.94	47,67	3806.87	3998.66
Cell 4 Process	471.42	6,06	458.99	485.54
Cell 5 Process	713.84	91,35	491.83	956.69
Cell 6 Process	194.13	3,29	188.10	200.83
Cell 7 Process	110.75	2,78	103.54	118.48
Cell 8 Process	855.44	11,19	828.74	879.10
Cell 9 Process	893.67	10,24	876.67	916.34

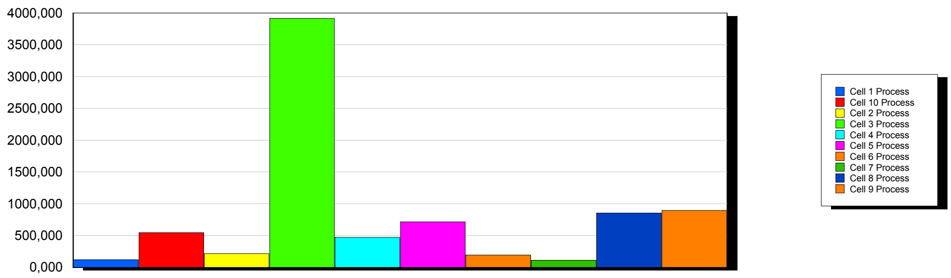


Figure C.57 Acc. Time-VA Time

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Assembling.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 1 Process.Queue	7.5603	3,28	2.8213	18.1761	0.00	29.6363
Cell 1 Seize.Queue	1.8877	1,43	0.05422150	7.3291	0.00	29.4176
Cell 10 Process.Queue	164.73	6,75	151.31	182.30	0.00	300.40
Cell 10 Seize.Queue	57.4504	6,44	35.5892	72.2156	0.00	161.26
Cell 2 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 2 Seize.Queue	94.9702	17,74	47.2757	127.45	0.00	209.23
Cell 3 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Seize.Queue	83.2353	9,53	65.0463	107.35	0.00	198.77
Cell 5 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Seize.Queue	43.9427	10,87	20.4109	68.5200	0.00	123.89
Cell 7 Process.Queue	0.1815	0,17	0.00	0.6464	0.00	7.7570
Cell 7 Seize.Queue	23.5721	3,27	16.1549	31.2077	0.00	117.25
Cell 8 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 8 Seize.Queue	286.72	20,93	230.56	316.36	4.9990	602.03
Cell 9 Process.Queue	29.4417	0,97	27.1994	31.3166	0.00	128.14
Cell 9 Seize.Queue	16.9829	1,34	14.8218	20.6537	0.00	122.55
Match.Queue1	0.00	0,00	0.00	0.00	0.00	0.00
Match.Queue2	1936.00	86,18	1751.21	2103.88	1738.52	2125.10
Match.Queue3	1272.80	85,94	1089.96	1478.36	819.88	1742.80
Match.Queue4	1580.73	89,59	1396.21	1778.91	1166.87	2134.09
Match.Queue5	1473.81	87,33	1252.52	1684.07	1180.65	2180.78
Sending Coating.Queue	145.02	2,37	137.97	148.60	0.00	328.05
Worker Seize 3.Queue	251.20	7,54	235.08	269.37	0.00	580.09

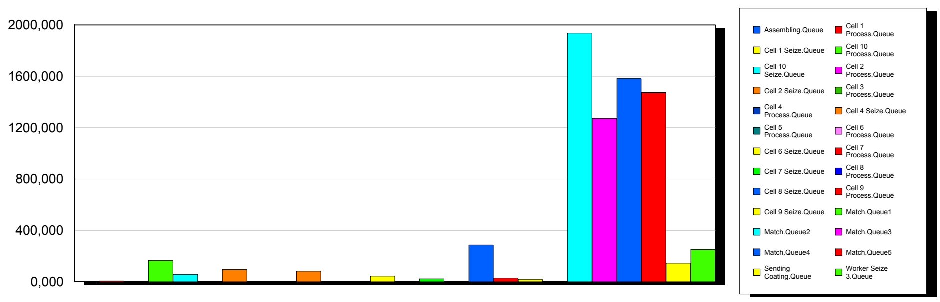


Figure C.58 Waiting Time in Queue

Resource

Usage

Number Busy	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Machine	0.04172454	0,00	0.03838039	0.04582410	0.00	1.0000
Cell 10 Machine	0.1922	0,01	0.1796	0.2076	0.00	1.0000
Cell 2 Machine	0.07647650	0,00	0.06962779	0.08585977	0.00	1.0000
Cell 3 New	0.2594	0,01	0.2427	0.2807	0.00	1.0000
Cell 3 Old 1	0.2821	0,02	0.2429	0.3082	0.00	1.0000
Cell 3 Old 2	0.2812	0,01	0.2620	0.3096	0.00	1.0000
Cell 3 Old 3	0.2807	0,02	0.2487	0.3103	0.00	1.0000
Cell 3 Old 4	0.2821	0,02	0.2422	0.3140	0.00	1.0000
Cell 4 Machine	0.1669	0,01	0.1547	0.1819	0.00	1.0000
Cell 5 Machine	0.2508	0,03	0.1842	0.3189	0.00	1.0000
Cell 6 Machine	0.06867437	0,00	0.06270093	0.07337133	0.00	1.0000
Cell 7 Machine	0.03919611	0,00	0.03451206	0.04203747	0.00	1.0000
Cell 8 Machine	0.3028	0,01	0.2801	0.3293	0.00	1.0000
Cell 9 Machine	0.3162	0,01	0.2934	0.3432	0.00	1.0000
Worker 1	0.4979	0,04	0.4043	0.5600	0.00	1.0000
Worker 2	0.4586	0,02	0.4196	0.5179	0.00	1.0000
Worker 3	0.4787	0,02	0.4321	0.5095	0.00	1.0000
Worker 4	0.4952	0,03	0.4512	0.5476	0.00	1.0000
Worker 5	0.4289	0,04	0.3772	0.5545	0.00	1.0000
Worker 6	0.5219	0,02	0.4640	0.5535	0.00	1.0000
Worker 7	0.5405	0,03	0.4892	0.6046	0.00	1.0000
Worker 8	0.2815	0,02	0.2345	0.3208	0.00	1.0000
Worker 9	0.2444	0,01	0.2312	0.2591	0.00	1.0000

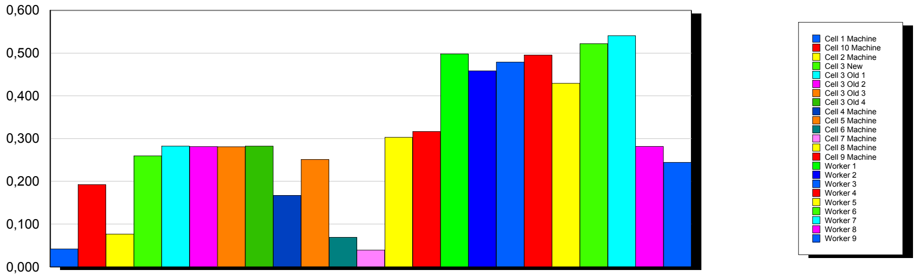


Figure C.59 Number of Busy Status

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Machine	12.0000	0,00	12.0000	12.0000
Cell 10 Machine	12.0000	0,00	12.0000	12.0000
Cell 2 Machine	17.0000	0,00	17.0000	17.0000
Cell 3 New	34.3000	2,50	28.0000	40.0000
Cell 3 Old 1	10.1000	1,56	7.0000	14.0000
Cell 3 Old 2	9.4000	0,97	7.0000	11.0000
Cell 3 Old 3	9.2000	1,16	8.0000	12.0000
Cell 3 Old 4	9.0000	1,26	6.0000	11.0000
Cell 4 Machine	17.0000	0,00	17.0000	17.0000
Cell 5 Machine	1.0000	0,00	1.0000	1.0000
Cell 6 Machine	12.0000	0,00	12.0000	12.0000
Cell 7 Machine	12.0000	0,00	12.0000	12.0000
Cell 8 Machine	12.0000	0,00	12.0000	12.0000
Cell 9 Machine	60.0000	0,00	60.0000	60.0000
Worker 1	28.7000	9,47	16.0000	50.0000
Worker 2	17.2000	6,13	12.0000	41.0000
Worker 3	15.6000	6,47	10.0000	41.0000
Worker 4	17.1000	6,68	11.0000	35.0000
Worker 5	18.4000	7,87	9.0000	41.0000
Worker 6	44.9000	1,19	42.0000	47.0000
Worker 7	25.4000	0,77	24.0000	27.0000
Worker 8	28.7000	1,01	26.0000	30.0000
Worker 9	30.0000	0,95	28.0000	32.0000

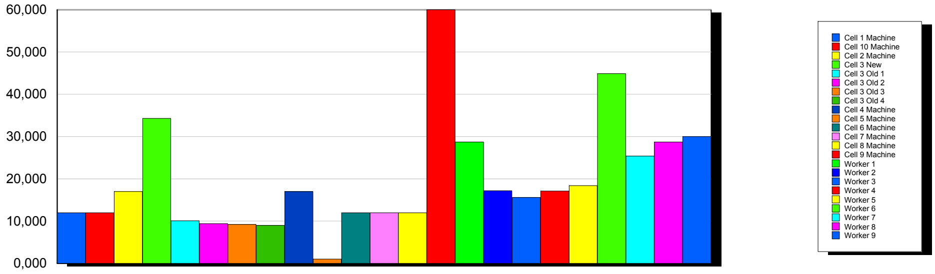


Figure C.60 Total Number Seized (Resources)

C.7 Statistical Results of Drive Shaft manufacturing under "Part Priority" Experiment (Time units: Minute)

Entity

Time

VA Time

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	818.19	97,25	640.21	1023.12	593.65	1064.21
Part 2	103.16	3,89	95.3357	111.75	64.5743	141.60
Part 3	242.94	10,68	212.33	270.70	171.35	312.56
Part 4	166.00	8,90	146.18	181.29	89.0949	230.17
Part 5	73.9340	1,72	69.0666	76.6503	49.0950	97.3219
Part 6	49.1808	1,47	45.8527	53.0108	41.7725	57.9887

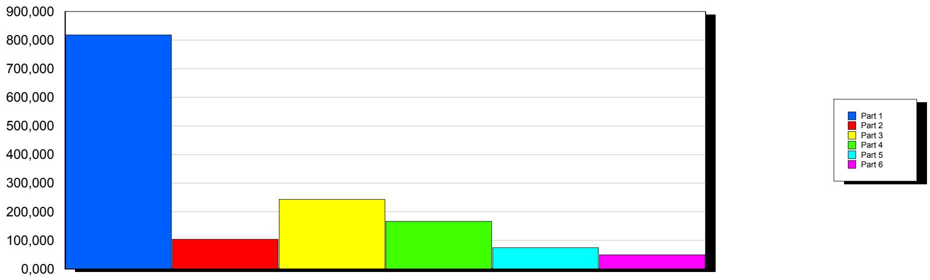


Figure C.61 Entity-Value Added Time

Wait Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	645.42	13,93	621.99	678.31	304.31	960.51
Part 2	1510.73	99,59	1314.48	1723.63	1107.16	1899.42
Part 3	1347.87	111,96	1144.79	1604.40	974.15	1803.29
Part 4	1443.30	98,03	1268.70	1668.84	1088.77	1808.29
Part 5	1532.00	96,01	1349.65	1749.49	1157.64	1927.07
Part 6	345.18	26,39	295.98	427.03	34.0900	480.19

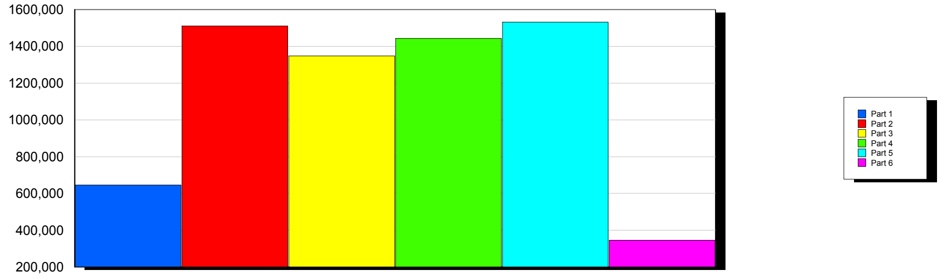


Figure C.62 Entity-Wait Time

Transfer Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	173.26	2,31	168.13	178.04	159.89	187.98
Part 2	27.1629	0,27	26.6798	28.0858	23.0749	29.9053
Part 3	47.1743	0,43	45.9738	48.3604	42.3989	52.2332
Part 4	27.1143	0,33	26.2741	27.7025	23.1248	30.1210
Part 5	27.0429	0,29	26.5011	27.6753	22.9567	30.5783
Part 6	11.7049	0,18	11.2842	12.1117	10.3652	13.9255

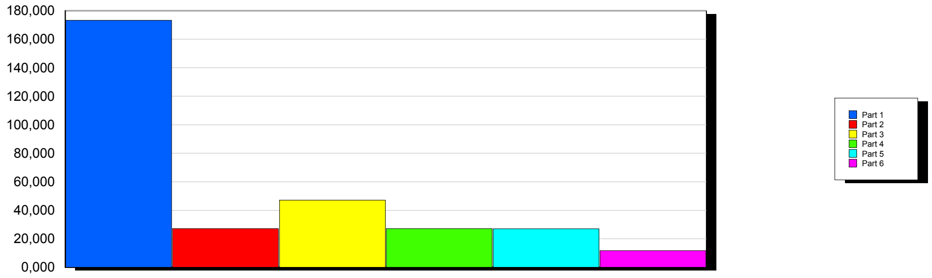


Figure C.63 Entity-Transfer Time

Total Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Part 1	1636.87	101,55	1453.38	1856.86	1222.42	2043.74
Part 2	1641.04	100,20	1447.11	1848.78	1272.55	2056.97
Part 3	1637.99	104,97	1442.34	1890.87	1271.18	2111.65
Part 4	1636.42	102,41	1443.22	1867.65	1271.16	2059.94
Part 5	1632.98	96,26	1449.90	1848.80	1272.53	2049.74
Part 6	406.07	26,54	357.92	488.54	98.8744	540.94

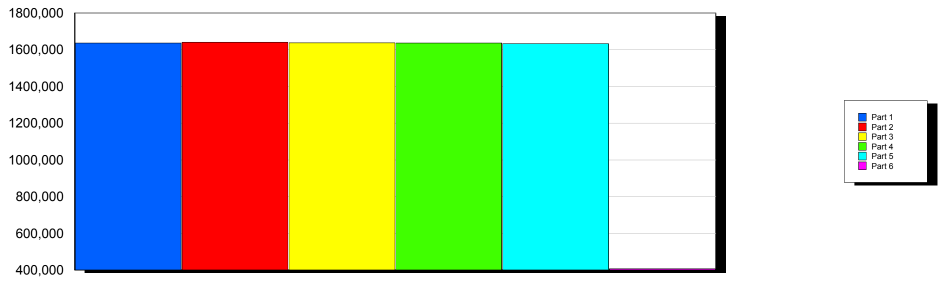


Figure C.64 Entity-Total Time

Process

Time per Entity

VA Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	9.8702	0,22	9.2783	10.3056	7.2477	11.8391
Cell 10 Process	44.3834	1,03	41.9160	46.4033	30.6150	59.0042
Cell 2 Process	12.6471	0,46	11.9146	13.5431	8.2134	25.3106
Cell 3 Process	54.2904	0,44	53.4434	55.6857	2.2375	163.50
Cell 4 Process	27.5425	0,31	27.0286	28.3320	22.4417	36.6263
Cell 5 Process	638.70	95,03	458.78	844.05	458.78	844.05
Cell 6 Process	16.1954	0,27	15.6698	16.8609	13.3607	20.6857
Cell 7 Process	9.1116	0,25	8.6472	9.8793	5.4811	11.8357
Cell 8 Process	71.7066	0,57	70.4669	72.8216	61.6712	78.4271
Cell 9 Process	14.9085	0,23	14.3817	15.3741	10.1337	19.5356

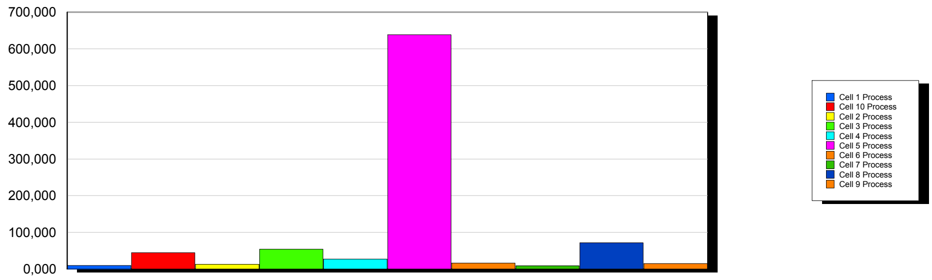


Figure C.65 Process-VA Time (Per Entity)

Total Time Per Entity	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Process	17.4123	3,32	12.7821	27.4544	7.2477	40.0744
Cell 10 Process	196.96	10,36	164.80	210.62	34.9146	336.89
Cell 2 Process	12.6471	0,46	11.9146	13.5431	8.2134	25.3106
Cell 3 Process	54.2904	0,44	53.4434	55.6857	2.2375	163.50
Cell 4 Process	27.5425	0,31	27.0286	28.3320	22.4417	36.6263
Cell 5 Process	638.70	95,03	458.78	844.05	458.78	844.05
Cell 6 Process	16.1954	0,27	15.6698	16.8609	13.3607	20.6857
Cell 7 Process	9.1174	0,25	8.6472	9.8793	5.4811	11.8357
Cell 8 Process	71.7066	0,57	70.4669	72.8216	61.6712	78.4271
Cell 9 Process	37.2899	1,95	33.2303	42.8416	10.6921	144.14

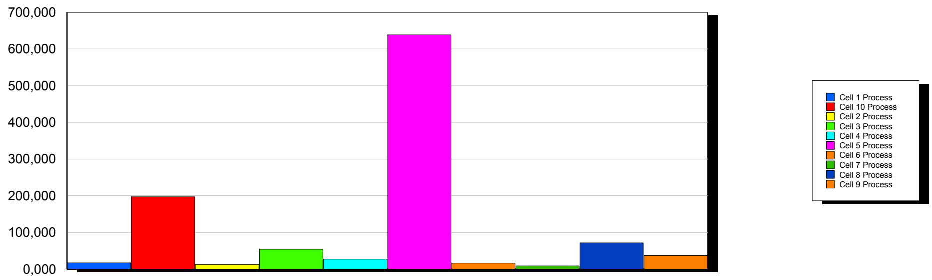


Figure C.66 Process-Total Time (Per Entity)

Accumulated Time

Accum VA Time	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Process	118.44	2,70	111.34	123.67
Cell 10 Process	532.60	12,39	502.99	556.84
Cell 2 Process	215.00	7,83	202.55	230.23
Cell 3 Process	3908.91	31,80	3847.92	4009.37
Cell 4 Process	468.22	5,29	459.49	481.64
Cell 5 Process	638.70	95,03	458.78	844.05
Cell 6 Process	194.35	3,23	188.04	202.33
Cell 7 Process	109.34	3,04	103.77	118.55
Cell 8 Process	860.48	6,84	845.60	873.86
Cell 9 Process	894.51	13,64	862.90	922.44

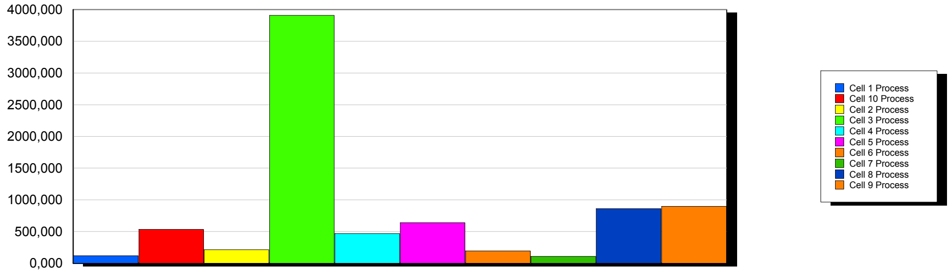


Figure C.67 Acc. Time-VA Time

Queue

Time

Waiting Time	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Assembling.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 1 Process.Queue	7.5421	3,40	2.8510	18.1761	0.00	29.6363
Cell 1 Seize.Queue	1.5637	1,57	0.06079119	7.3291	0.00	29.4176
Cell 10 Process.Queue	152.58	9,80	122.43	165.18	0.00	290.20
Cell 10 Seize.Queue	51.1057	7,97	29.8664	61.8049	0.00	135.07
Cell 2 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 2 Seize.Queue	13.4934	4,13	4.8011	23.6011	0.00	74.0556
Cell 3 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 4 Seize.Queue	126.58	10,40	104.22	149.98	0.00	408.47
Cell 5 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 6 Seize.Queue	41.5254	14,61	8.8189	72.0444	0.00	124.64
Cell 7 Process.Queue	0.00584856	0,01	0.00	0.05848565	0.00	0.7018
Cell 7 Seize.Queue	20.0966	3,99	13.4984	30.3979	0.00	135.69
Cell 8 Process.Queue	0.00	0,00	0.00	0.00	0.00	0.00
Cell 8 Seize.Queue	148.42	39,23	86.2426	249.06	0.00	490.88
Cell 9 Process.Queue	22.3813	1,76	18.8485	27.4676	0.00	129.66
Cell 9 Seize.Queue	5.7547	1,53	2.6809	11.1501	0.00	66.3911
Match.Queue1	5.5094	4,78	0.00	15.0182	0.00	89.3489
Match.Queue2	994.67	87,67	846.71	1195.74	562.06	1453.70
Match.Queue3	464.31	144,40	252.65	740.66	0.00	1213.18
Match.Queue4	914.33	97,24	736.37	1142.92	498.52	1422.43
Match.Queue5	965.68	91,91	762.79	1150.92	633.96	1468.86
Sending Coating.Queue	151.00	4,04	142.43	161.50	0.00	404.95
Worker Seize 3.Queue	223.78	12,00	194.99	251.85	0.00	619.69

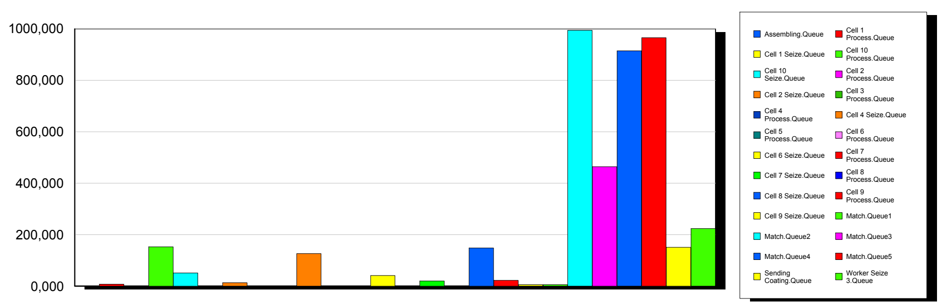


Figure C.68 Waiting Time in Queue

Resource

Usage

Number Busy

	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
Cell 1 Machine	0.05737095	0,00	0.04639153	0.06598660	0.00	1.0000
Cell 10 Machine	0.2579	0,02	0.2194	0.3094	0.00	1.0000
Cell 2 Machine	0.1040	0,01	0.08466348	0.1144	0.00	1.0000
Cell 3 New	0.3537	0,02	0.2961	0.4078	0.00	1.0000
Cell 3 Old 1	0.3871	0,04	0.3070	0.4625	0.00	1.0000
Cell 3 Old 2	0.3721	0,02	0.3120	0.4115	0.00	1.0000
Cell 3 Old 3	0.3849	0,03	0.3300	0.4637	0.00	1.0000
Cell 3 Old 4	0.3952	0,03	0.3236	0.4710	0.00	1.0000
Cell 4 Machine	0.2268	0,02	0.1943	0.2638	0.00	1.0000
Cell 5 Machine	0.3043	0,03	0.2549	0.3517	0.00	1.0000
Cell 6 Machine	0.0941	0,01	0.08142024	0.1124	0.00	1.0000
Cell 7 Machine	0.05298870	0,00	0.04342342	0.06145381	0.00	1.0000
Cell 8 Machine	0.4169	0,03	0.3523	0.4811	0.00	1.0000
Cell 9 Machine	0.4329	0,03	0.3723	0.4960	0.00	1.0000
Worker 1	0.6294	0,03	0.5670	0.7102	0.00	1.0000
Worker 2	0.6153	0,04	0.5078	0.6765	0.00	1.0000
Worker 3	0.6264	0,04	0.5653	0.6846	0.00	1.0000
Worker 4	0.6304	0,04	0.5465	0.7337	0.00	1.0000
Worker 5	0.5869	0,05	0.4638	0.6716	0.00	1.0000
Worker 6	0.6260	0,06	0.5197	0.7634	0.00	1.0000
Worker 7	0.7019	0,05	0.6016	0.8372	0.00	1.0000
Worker 8	0.3714	0,02	0.3385	0.4103	0.00	1.0000
Worker 9	0.3226	0,04	0.2526	0.4075	0.00	1.0000

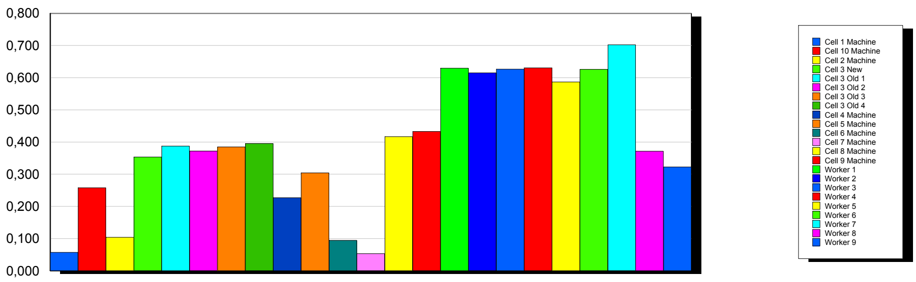


Figure C.69 Number of Busy Status

Total Number Seized	Average	Half Width	Minimum Average	Maximum Average
Cell 1 Machine	12.0000	0,00	12.0000	12.0000
Cell 10 Machine	12.0000	0,00	12.0000	12.0000
Cell 2 Machine	17.0000	0,00	17.0000	17.0000
Cell 3 New	30.8000	3,05	25.0000	38.0000
Cell 3 Old 1	10.8000	1,71	7.0000	15.0000
Cell 3 Old 2	10.2000	2,26	6.0000	16.0000
Cell 3 Old 3	10.2000	1,87	7.0000	14.0000
Cell 3 Old 4	10.0000	1,22	8.0000	14.0000
Cell 4 Machine	17.0000	0,00	17.0000	17.0000
Cell 5 Machine	1.0000	0,00	1.0000	1.0000
Cell 6 Machine	12.0000	0,00	12.0000	12.0000
Cell 7 Machine	12.0000	0,00	12.0000	12.0000
Cell 8 Machine	12.0000	0,00	12.0000	12.0000
Cell 9 Machine	60.0000	0,00	60.0000	60.0000
Worker 1	21.1000	6,46	13.0000	39.0000
Worker 2	17.5000	3,82	11.0000	29.0000
Worker 3	17.9000	5,34	10.0000	31.0000
Worker 4	14.8000	3,12	11.0000	26.0000
Worker 5	21.1000	5,99	11.0000	38.0000
Worker 6	44.0000	1,26	41.0000	47.0000
Worker 7	28.5000	2,03	25.0000	34.0000
Worker 8	30.2000	1,81	26.0000	34.0000
Worker 9	30.9000	0,92	29.0000	33.0000

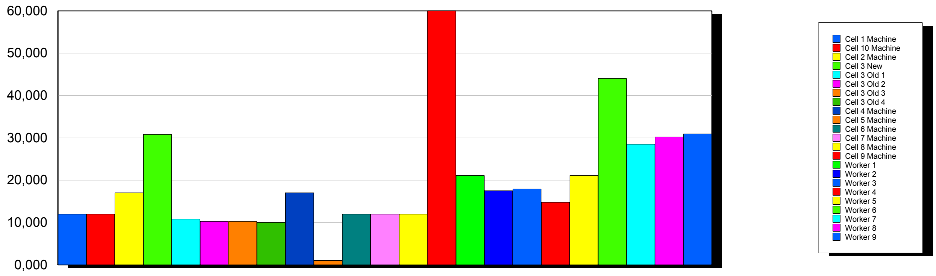


Figure C.70 Total Number Seized (Resources)