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SIMULATION MODELLING AND ANALYSIS FOR SCHEDULING THE KANBAN CONTROLLED ASSEMBLY SYSTEM

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Supervisor
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SIMULATION MODELLING AND ANALYSIS FOR SCHEDULING THE KANBAN CONTROLLED ASSEMBLY SYSTEM

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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.

Abdaala Abdulmuhsen Habib AL-JEBUR

DEDICATION

We thank the Almighty Allah who helped us accomplish this humble work, which was our success between his hands and led us to this result.

I dedicate my success to:

Almighty Allah who was the only one that I return to when I have hard time and always I find the rights answer to let me continue my dream.

Our messenger, To the Prophet of mercy and the light of the worlds "Our master Mohammed and his family, peace be upon him".

The man of the struggle, to the mas who planted Islamic values and principles, who taught me tenderness without waiting to give him back .. To whom I bring his name with all pride, who gave me all his possessions until I achieve what he was hoping , to the man who was pushing me forward to achieve my goals, to the man who possessed humanity with all strength, to my father "ask Allah to be merciful on him and give him the place that he deserve in heaven" , I wish you were present right here today to see what I have achieved.

The meaning of love and to the meaning of tenderness and devotion .. To the smile of life and the secret of existence to which endowed with all its tenderness, she was my call to success, followed me step by step in my work, to The woman that kept praying for me until I achieved my dream, To my mother the most precious angel on earth, I am very grateful to have you beside me in tough and hard moments. Thank you Mom.

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The martyrs of Iraq, the righteous that defended for the sake of honor and religion, Allah has mercy on them.

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ABSTRACT

SIMULATION MODELLING AND ANALYSIS FOR SCHEDULING THE KANBAN CONTROLLED ASSEMBLY SYSTEM

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In today's industrial world, the scheduling for assembly systems is a significant issue, keeping industrial companies on a competitive edge. Flexibility indicates a manufacturing and assembly system's capability to act in response efficiently and rapidly to the trends of market, that have become more dynamic and unpredictable, up to now, the research efforts dealing with scheduling problems in assembly lines have been inadequate. There are two main problems with these studies: (1) all the studies of scheduling for assembly lines concentrated only on single-product assembly environments; (2) all these studies have neglected dynamic events and only concentrated on static situations. In light of those limitations, a new plan for tackling scheduling issues in assembly lines will be presented in this thesis. Due to the complexity of achieving this aim, there will be 3 stages to define the architecture of the developed strategy. The 1st stage focuses on the development of a novel method for scheduling assembly lines in a multi-product assembly environment under a pull control mechanism. The 2nd stage focuses on the development of an intelligent method for scheduling for assembly lines in dynamic situations by using kanban control. The 3rd stage focuses on extending the developed method for the purpose of optimizing dynamic scheduling of assembly lines for multi-objective problems. The 3 stages are implemented through using a grouping of advanced solution methods including Taguchi optimization approach, Kanban control system modelling and simulation. Two case studies are presented

in this thesis for demonstrating the robustness and effectiveness of the suggested scheduling strategy. The first case study is to prove that the developed methodology (first step) can concurrently assemble multi-products; the second case study is to verify and validate the proposed approach (second and third steps) for multi objective optimization regarding the tasks of dynamic scheduling. The results of the case studies show that the new method is effective and practical in assembly lines setting. Thus, the current study can be considered as a main factor in the direction of solving scheduling problems of kanban controlled assembly lines.

Keywords: Simulation Modelling ; Kanban Control; Assembly System.

ÖZET

KANBAN KONTROLLÜ MONTAJ SİSTEMİNİN ÇİZELGESİ İÇİN SİMÜLASYON MODELLEMESİ VE ANALİZİ

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Günümüzün endüstriyel dünyasında, montaj sistemlerinin programlanması önemli bir konudur. Esneklik, imalat ve montaj sisteminin, pazardaki eğilimlere daha hızlı ve dinamik uyum sağlama yeteneğini gösterir. Şimdiye kadar, montaj hatlarındaki zamanlama problemleriyle ilgili araştırma çabaları yetersiz kalmıştır. Bu çalışmalarla ilgili iki ana problem vardır: (1) sadece tek ürünlü montaj ortamlarına yoğunlaşmış montaj hatları için zamanlama çalışmalar vardır; (2) tüm bu çalışmalar dinamik olayları ihmal etmiş ve sadece statik durumlar üzerine yoğunlaşmıştır. Bu sınırlamaların ışığında, bu tezde montaj hatlarındaki çizelgeleme konularının ele alınması için yeni bir plan sunulacaktır. Bu amaca ulaşmanın karmaşıklığı nedeniyle, geliştirilen stratejinin mimarisini tanımlamak için 3 aşama olacaktır. Birinci aşama, çok ürünlü montaj ortamında montaj hatlarının programlanması için yeni yöntemin geliştirilmesine odaklanır. İkinci aşamada, kanban kontrolünü kullanarak dinamik durumlarda montaj hatlarının programlanması için akıllı bir yöntemin geliştirilmesine odaklanılmıştır. Üçüncü aşamada, çok amaçlı problemler için montaj hatlarının dinamik zamanlamasını optimize etmek amacıyla geliştirilen metodu genişletmeye odaklanılmaktadır. 3 aşama, Taguchi optimizasyon yaklaşımı, Kanban kontrol sistemi modellemesi ve simülasyonu içeren bir grup gelişmiş çözüm yöntemi kullanılarak gerçekleştirilir. Önerilen programlama stratejisinin sağlamlığını ve etkinliğini göstermek için bu tez çalışmasında iki vaka çalışması sunulmuştur. İlk vaka çalışması, geliştirilen metodolojinin (ilk adım) aynı anda çoklu ürünleri birleştirebileceğini kanıtlamaktadır; İkinci vaka çalışması, dinamik zamanlamanın görevleri ile ilgili çok amaçlı optimizasyon için önerilen yaklaşımı (ikinci ve üçüncü adımlar) doğrulamak ve doğrulamaktır. Örnek olay incelemelerinin sonuçları montaj hattının belirlenmesinde yeni yöntemin etkili ve pratik olduğunu göstermektedir. Bu nedenle, bu çalışma kanban kontrollü montaj hatlarının zamanlama problemlerini çözme yönünde onemli bir katki olarak düşünülebilir.

Anahtar Kelimeler: Simülasyon Modellemesi; Kanban Kontrolü; Montaj sistemi.

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LIST OF ABBREVIATIONS

KCAS : Kanban Controlled Assembly System

CAPP : Computer-Aided Process Planning

WIP : Work In Process

JIT : Just-In-Time

WIT : Weighted Idle Time

ORR : Order Review/Release

MOO : Multi-Objective Optimization

SA : Simulated Annealing

BOM : Bills Of Materials

ERP : Enterprise Requirements Planning

MES : Manufacturing Execution System

SQL : Structured Query Language

XML : Extensible Markup Language Schemas

CWT : Customer Waiting Time

1. INTRODUCTION AND RESEARCH OBJECTIVES

1.1 INTRODUCTION

In last years with economic growth most companies started to use Kanban Controlled Assembly Systems (KCAS) to deal with customer requirements [1].This is the reason to transition from traditional manufacturing to flexible distribution systems [2].The Scheduling represents a major issue in production research, The aim of scheduling is to improve performance by choosing the best resource to each operation and to determine the best sequencing for each resource [3].There are a lot of approaches used to solve the scheduling problem such as artificial intelligence, Hierarchical, Multi Criteria decision making, Petri Nets and Simulation approach [4].The objective of this paper is to suggest a mechanism for the scheduling in a dynamic environment [5]. Every manufacturing system have a multistage-job shop and each job has routing and processing requirements [6]. Usually, an assembly line can be dedicated for the purpose of producing a single product models or multiple product models, in which various items can be managed at the same time in batches or processed in lot sizes of single item for each model of a product [7].

The ability to introduce novel models quicker, and to offer additional alternatives for each model, is limited via the present technologies and equipment related to mass production operations, which does not have the ability to support variability of products. More complexity in automotive assembly, necessitates a complete view of the major attributes of manufacturing attributes which must be taken into account in the case when decisions of manufacturing, with regard to flexibility time, cost, and quality, are considered so that the assembly system can effectively manage such complexities,[8]. This thesis is composed of five chapters , The first chapter includes the objectives and the methodology composed of research, chapter two includes the explanation of assembly system simulation models and Kanban methods, chapter three includes models created by ARENA software for the analysis of a real assembly system, and discussion of the results by Taguchi technique chapter four contains the conclusions and recommendations. Figure 1.1 summarizes the methodology of the research.

1.2 RESEARCH METHODOLOGY

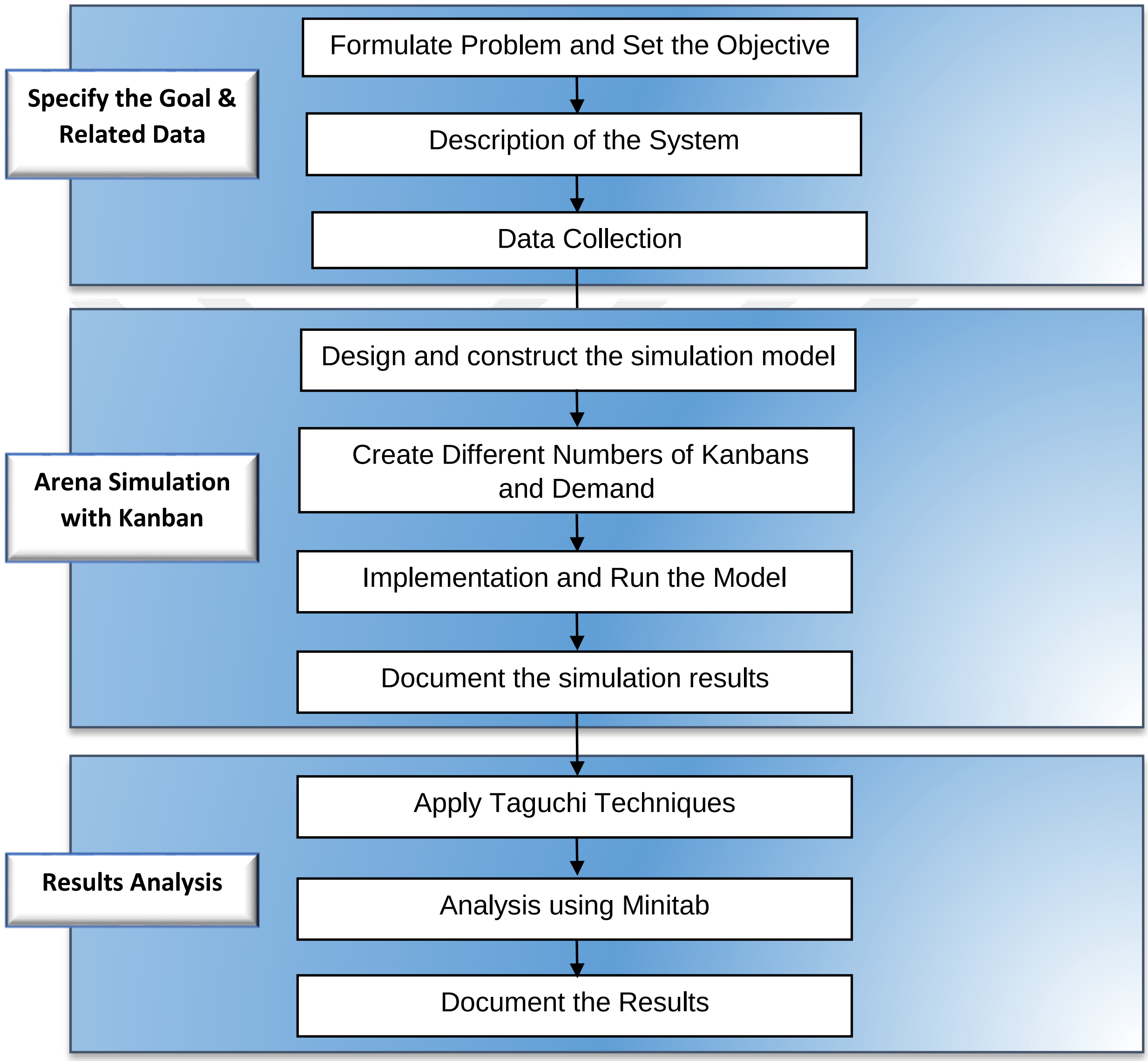


Figure 1.1: The methodology of the research.

1.3 CHARACTERISTICS OF SCHEDULING PROBLEMS

Certain elements are used to specify the properties related to scheduling problems in the assembly systems. The most important elements are decision variables, constraints, and objective. The paragraphs below will describe the elements in brief.

Decision variables: They one of the significant elements in scheduling problems are considered to be decision variables. Scheduling managers make use of decision variables for the purpose of matching resources and activities to complete jobs and at the same time optimizing the performance of the system. The general types of decision variable are:

* Sequencing;

* Routing;

* Timing/release; and

* Resource and activity reconfiguration.

Constraints: there are a lot of scheduling assembly system problems. Below are the most frequent constraints:

*Constraints of demand pattern and capacity;

*Constraints of handling material, resources and tooling;

* Constraints of routing and precedence; and

*Constraints of automation and industry type;

1.4 RESEARCH OBJECTIVES

The aim of this research are :

1. Analyzing the efficiency of Kanban Controlled Assembly System (KCAS) by using Arena simulation software.
2. Examining the goals of for meeting the deadline for orders made by customers and minimizing the time of completion under kanban control.

Analyzing the impact of kanbans on

* Inventory

* Waiting time of demand (customer)

* Waiting time of product

2. ASSEMBLY SYSTEM AND KANBAN CONTROL

2.1 INTRODUCTION

In last years the production system requirements became more complex and difficult thus the necessities of production systems have varied noticeably so the simulation models became very important to determine the sequencing for process and production planning. Initially, the assembly lines have been used for cost-effective manufacturing of single standardized product, in order that the products' manufacturers must manage a (theoretical) product variety that surpasses billions of models [9]. For the aim of enabling this a extremely varied product portfolio without risking the advantages of an effective flow-production, mixed-model assembly lines have been used. Automobile industry is not the only source for practical applications, it is also come from various parts of consumer goods industries, for example, clothing, white goods, consumer electronics, and furniture [10].

Concerning the mixed-model assembly line, using flexible machinery and workers lead to considerable decrease in cost and setup times, to facilitate the operation when different products might be manufactured together in intermixed product sequence (lot size of one) on the same line. Along with the availability of flexible resources, the lowest level or homogeneity are required by the production procedures of manufactured goods. Therefore, a common base product is typically existing, that is customizable through (selecting optional features from pre-determined selection of options [11].

The process plan defines the components and materials required for producing a product, and the needed operations and processes for transforming the raw materials to the ultimate product. Thus, process planning is considered as the function of relation between manufacturing and design. The information for the manufacturing procedures along with their parameters are the result of process planning, in addition to the recognition of fixtures, tools, and machines needed for the purpose of performing such procedures. Various process plans are produced in view of the existence of alternate machines and procedures for manufacturing the same part type [12].

Efficient production control, that translate to material flow's control which occur in the system of manufacturing in such a way which determines the trade-off between high service rate and low holding costs level have important role in the effectiveness of any system of manufacturing. Identifying the significance of efficient production control via research community produced a great deal of disparate production control methods. Nevertheless, a lot of production control methods for the flow-shop systems belong to two important types: pull type and push type. The systems of production control which use future demand forecasts for controlling the procedure of manufacturing are so-called push type production control systems. Alternatively, the plans of pull type control respond to definite incidence of demand only [13].

2.2 SCHEDULING FOR ASSEMBLY SYSTEM

One of the other functions of manufacturing system is scheduling, which tries to allocate the resources of manufacturing to operations specified in process plan in a way that certain related standards, including makespan and deadlines, are satisfied. Even though a solid association exists between scheduling and process planning, conventionally the two functions were examined separately. In the majority of present practice, the tasks of scheduling and process planning are achieved independently [14].

The process plan that should be fixed is assumed via the scheduling module, also this module tries to assign resources and sequence operations according to the followed plan. The majority of computer-aided process planning (CAPP) systems suppose that the shop floor is considered idle, also it assumes that the shop floor has limitless resources. So, the produced process plans are thought to be impractical and can not be executed readily on shop floor. Yet, the matters could be improved via solving the 2 problems at the same time. Integrating the 2 function scan present important enhancements to the effectiveness of manufacturing facilities via reducing the work-in-process, flow-time and scheduling conflicts, adaptation to irregular shop floor disturbances and increasing the usage of production resources [15].

The majority of researches in the area of scheduling take into consideration uncomplicated string-type and independent jobs, but then again in point of fact, the ultimate product might be more complex and have various assembly operations and components.

A lot of studies have considered the scheduling problems with various optimization standards. The next assumptions are considered by the majority of researches: there are parallel identical machines in all of the stages and they are presented via scheduling horizon, the stages have no buffer limit between them, no pre-emption is permitted, the number of machines at least on one stage is more than one. In this regard, complete surveys and solution approaches. Scheduling problems with assembly operations are the main focus of the presented thesis. Generally, there are two stages related to scheduling problems with assembly operations, assembly phase and machining (or fabrication) stage. Machining phase might be single flexible machine, (identical) parallel machines and at least two phase flow shop [13].

A major activity of humans is goods production. There are a lot of goods types, goods could be non-material(soft-ware) or material (computers, cars). Any of the goods is, actually, less or more complex system that should be created with material, energy and information flows synchronized extent feasible [16].

Production systems of high-volume were usually applied as flow lines for using economies of scale and productivity gains. Today, a company should provide a variety of products so as to compete in the global market. Regarding such case, a likely method is configuring the production system as multiple mixed-mode assembly-line system, in which all assembly lines have the capability to produce many variants which are related to common base product, whereas the base product is different between assembly lines. Such configuration may handle all assembly lines negligible set-up times and costs (one lot size) with high differentiation in the ultimate product.

An important problem in this framework is the parts feeding to productive units (assembly line stations). Flexible and consistent supply of parts is essential, since otherwise shortage of material will lead to line stoppage and many assembly workers being idle threaten. However, increased safety stocks near the line obstruct the assembly procedure in the scarce space of stations and raise the costs of inventory [17].

2.3 SIMULATION APPROACH TO ASSEMBLY SYSTEM AND KANBAN CONTROL

As the complexity of the modern assembly systems continues to increase, comprehensive models of simulation are required for reflecting complex control logic of interrelations amongst a variety of entities. Which is why, modeling and simulation of a process of production turns to be more challenging and requiring wider effort and expert knowledge. For the sake of enabling an industrial engineer that does not have enough simulation knowledge and experience for doing studies of simulation, data driven approach was developed for complicated systems of manufacturing. Usually, data analysis and simulation can be characterized as an approach allowing users to create and run simulation models with no need for coding. A data driven simulator is characterized as a model of simulation which may be entirely parameterized via providing data through a group of tables, spread sheets, data forms, or templates and is particularly designed to model a specified group of systems. The basic benefits of the data driven simulation are enabling the users, instead of the operation research experts, in preparing and running simulations, and achieving the capability of reconfiguring the models to assess varied or alternative situations [26].

In the process of simulation and data driven modeling, the information specifying the model needs to be represented such that it will be later utilized in a direct way by a model-building program for generating the suitable models. An information model for a machine shop has been presented by [25] for providing interfaces for the integration of software applications for the machine shop with simulation. The needed information, like the resource capacities, bills of materials (BOM), process time sand customer/supplier information may be gotten from available sources of data, like a manufacturing execution system (MES), and an enterprise requirements planning (ERP) system. The relational data bases like Extensible Markup Language (XML) and Structured Query Language (SQL), schemas [25].

Different dynamic factors influence the movement of materials in a manufacturing environment, continuously becoming complicated for plans of multi-product assembling because of the interconnectedness and multiplicity of those factors. The analysis of those factors may be similarly complicated, in that it requires tools of modelling and simulation [27].

In the presented study, ARENA is chosen as the target system of simulation. ARENA modeling structure is known for its flexibility in accommodating the complexity for any methodology and environment from a top down view.

2.3.1 Simulation Approach

Simulation means presenting expressive computer models related to a system and implementing these models for predicting the operational performance regarding the underlying system being modeled. Many books tackle simulation. Furthermore, a lot of books tackle the application, design, and using certain simulation packages and languages.

Thus, the approaches that depends on simulation are extensively applied for studying the impact of the number of resources on the performance of the system. Unluckily, an answer is not offered by such computerized test bed to the topic of what is the optimum configuration of the system with regard to objectives. More precisely, simulation permits modelling of the system to be designed and evaluating the performance of the system, however, selecting the optimum configurations is the role of the decision maker.

For the purpose of achieving this, logical scenario or systematic experimental design set must be created. The more commonly method for achieving this involve changing single factor at one time, and the remaining factors will be constant, and for monitoring the effect on tracked performance. Of course, this is impracticable when managing high dimensional problem.

In such simulation optimization problem, the outputs are referred to as performance measures, responses or criteria, while inputs are referred to as parameter settings, solutions, values, factors, or variables. In the majority of studies, certain outputs of the system are applied to create objective function and set of feasibility exists for factors, that generally express physical, operations or economic restrictions, like the highest number of machines of specific type. As concerns the simulation optimization, the main focus is always reducing global cost for design problem. At the same time, to invest in a lot of resources more than needed cause money waste [18].

2.3.2 Arena Software for Simulation

Arena implements a programming model combining visual and textual programming. The common Arena session includes the activities below:

1. Graphically connecting modules for indicating physical flow paths of transactions and/or logical flow control paths.
2. Choosing module/block icons from a template panel, then placing those icons on a canvas of graphical model (through drag and drop).
3. Writing fragments of code in modules with the use of a text editor. One of the characteristics of Arena code is that it is case-insensitive; which means that, upper case letters and lower case letters can be interchangeable.
4. Parameterizing elements or modules with the use of a text editor.

Constructing simulation models using Arena, includes the use of modeling shapes, referred to as modules, from the panel of Basic Process. Those modules are utilized as building blocks in the construction of a model of simulation. There are two module types on a panel:
Data modules: here, the user is capable of editing those modules in the interface of the spreadsheet. This type of modules isn't placed in the model window. The most popular modules of this type are: Resource, Variable, Queue, Set, and Schedule. Flowchart modules: A user places those modules in the window of the model and connects those models with the aim of forming a flowchart, describing the model's logic. The most widely used modules of this type are: Create, Decide, Dispose, Process, Separate, Batch, Record, and Assign. [25].

2.3.3 Kanban Control Technique

This system is considered as a novel viewpoint, that is of high importance in (Just In Time) production system. Kanban is essentially a plastic card that contains all the needed information for assembly and production of certain product at all phases and describe the completion path of the product. Kanban system is a multi-stage system for production scheduling and inventory control. The production flow and inventory are controlled via using these cards. Kanban eases high capacity utilization and high production volume with decreased work-in-process and production time [17].

The Kanban controlled production system gained a lot of consideration in the past due to the effortlessness where they have the ability to apply pull control policy through the use of make to stock production. There are several phases in the production system, all these phases correspond to sub-parts of the system, in which the production will be controlled via cards (referred to as Kanbans), serving as production orders.

The control system design consist in defining the how many Kanbans should be related with each phase. For the purpose of accomplishing this aim, the system performance should be evaluated, for specified values related to the number of Kanbans: after that, this is utilized as building block in an optimization process.

2.3.4 Arena Simulation Models of production action and Assembly Systems

Figure 2.1 displays a general production in which triangles and ellipses used for the purpose of representing the system buffers and the phases of production respectively. An assumption is made that the parts spend a specific time in each phase of production for the purpose of completing their procedure cycle; the time is not deterministic and mostly depend on the certain operations which is applied on the parts (for example, packaging, cheap removal and casting). A linear path is followed by the parts starting from first phase up until reaching the last one; after that, the final product will be waiting in the last buffer (buffer N in Figure 1) until the customers send a request for one part. At least one machine is included in each phase; for example, a phase could be a job shop composed of turning machines, grindings, drillings, and so on. where the parts are subjected to many cheap removal operations. The production stages are separated by buffers for the purpose of decreasing the interdependencies between various phases [19].

Part flow that enter each phase is controlled with the aim that the amount of system's work in process (WIP) is limited and the associated costs of inventory are decreased. Before entering each process phase, an authorization must be given to the parts. The arrival of permission to get into a system phase is modeled via Kanban's arrival, usually a card in the real shop floors.

Therefore, the number of Kanbans representing the authorization order will control the system's part flow.

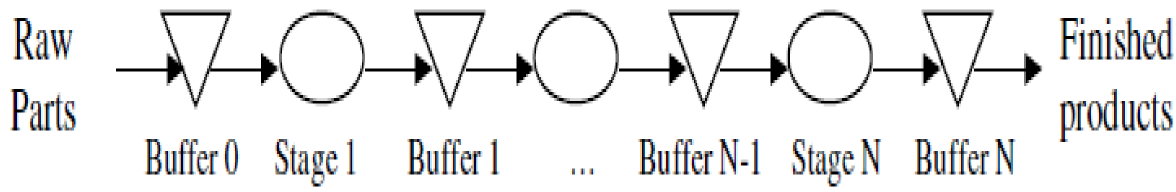


Figure 2.1: Production System with N stages. [19].

Let us denote by F P i the buffer containing products that stage i (where i= 1; . . . ; N) and by k i the number of kanbans at stage i (Fig. 2.1 shows the links between a stage i of a kanban system with stages i-1 and i +1, using queuing network modeling). Kanbans in buffer D i, which represent the production orders of stage i, wait for the arrival of (i_1)-stage finished parts while kanbans in buffer D i+1, which represent the production orders of stage i+1, wait for the arrival of i-stage finished parts [19].

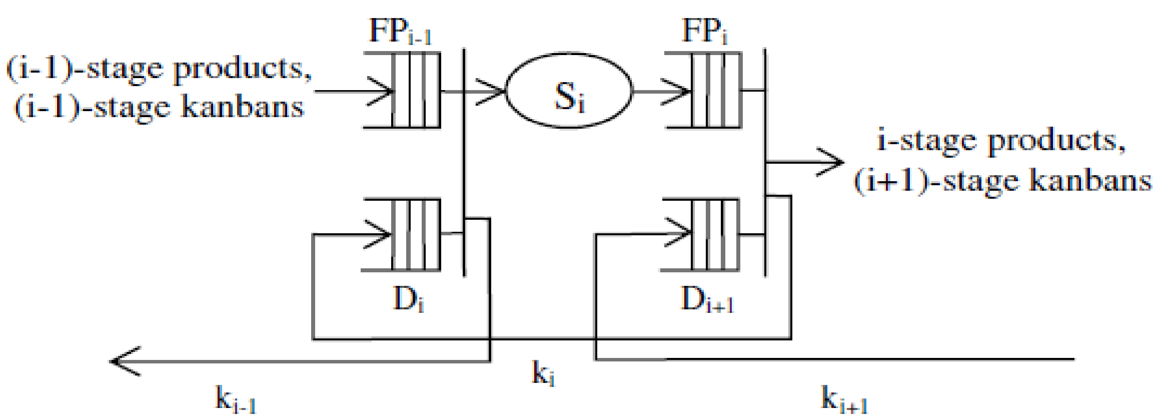


Figure 2.2 : Stage i of a kanban System [19].

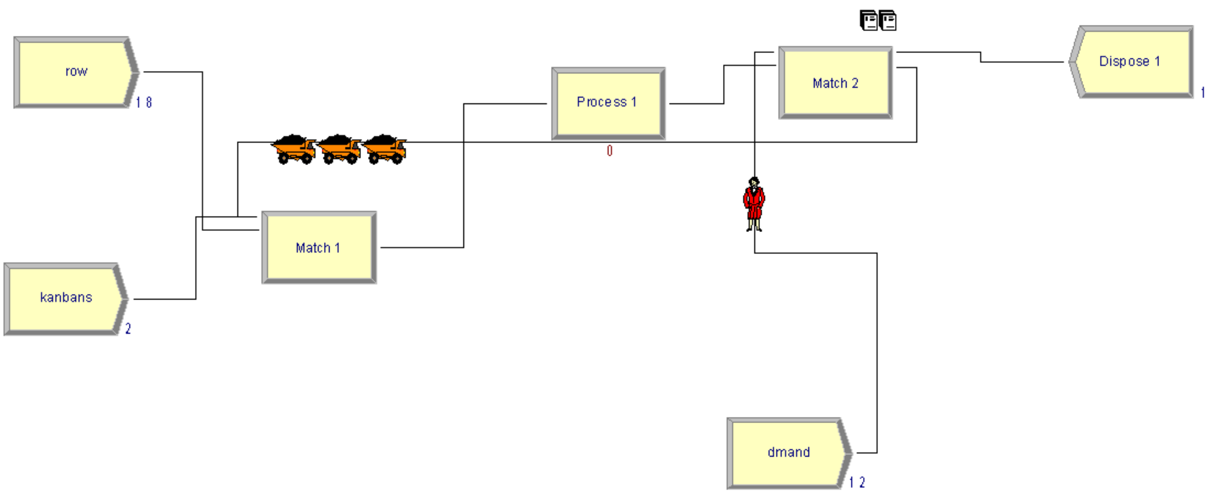


Figure 2.3 : Arena model of single stage production system controlled with kanbans.

Figure 2.3 demonstrates the ARENA simulation model of a single stage production system controlled with Kanbans. Figure 2.4 -2.11 show the details of the modules of the ARENA model.

Create - Basic Process

	Name	Entity Type	Type	Value	Units	Entities per Arrival	Max Arrivals	First Creation
1	Row materal	Entity 1	Random (Expo)	1 /0.8	Hours	1	20	0.0
2	dmand	demand	Random (Expo)	1/0.8	Minutes	1	20	0.0
3	kanbans	kanban	Random (Expo)	1	Hours	2	1	0.0

Figure 2.4 : Create-Basic process A single Stage production System.

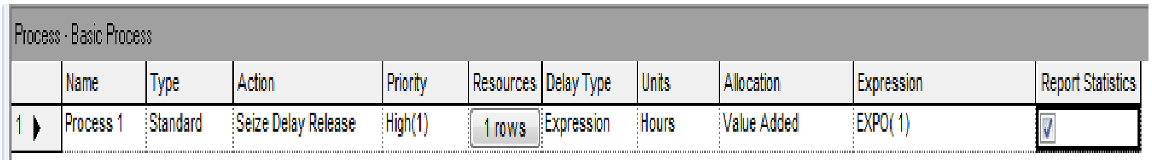


Figure 2.5 : Process-Basic process A single Stage production System.

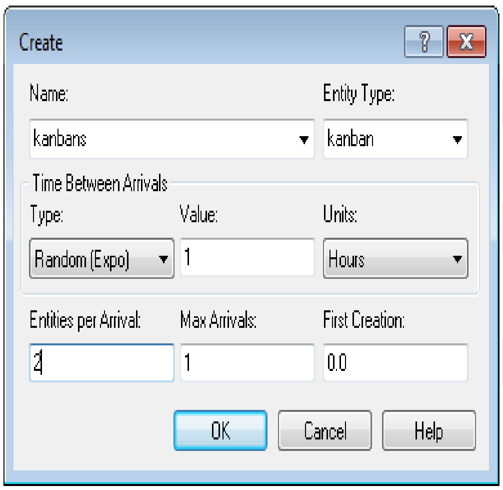


Figure 2.6 : Create a module for Kanban.

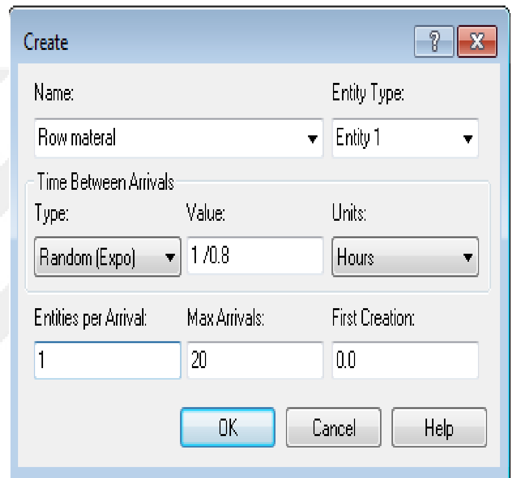


Figure 2.7 : Create a module for Raw material.

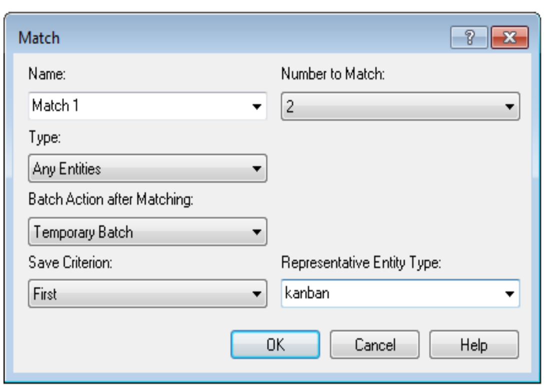


Figure 2.8 : Match 1 matching of raw materials and kanbans.

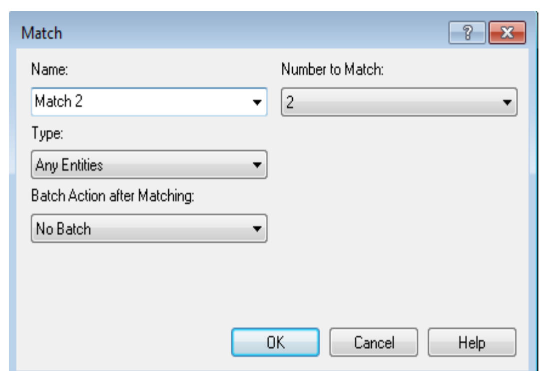


Figure 2.9 : Match 2 matching of finished products and customers.

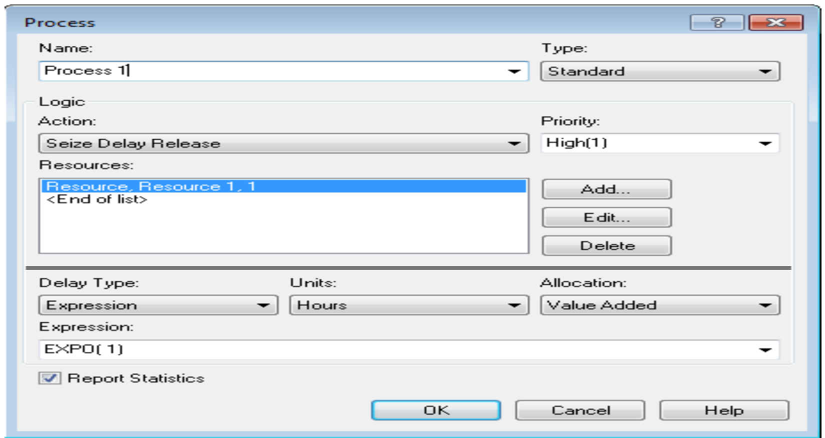


Figure 2.10 : (Process) module for the manufacturing stage.

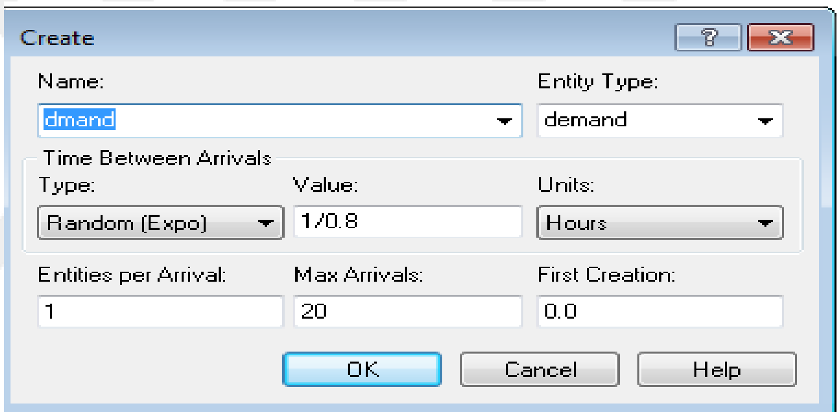


Figure 2.11 : Create a module for Demands.

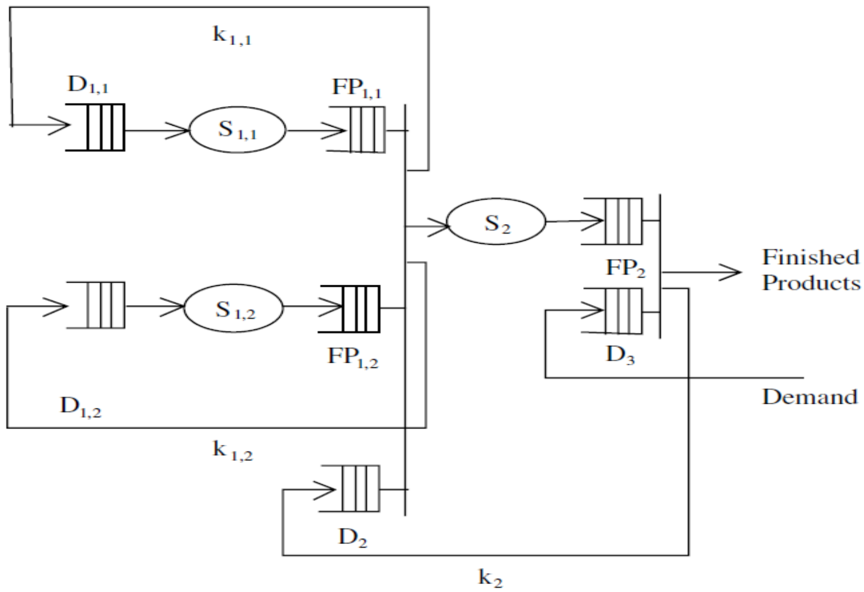


Figure 2.12 : : A two-stage assembly system with two components [19].

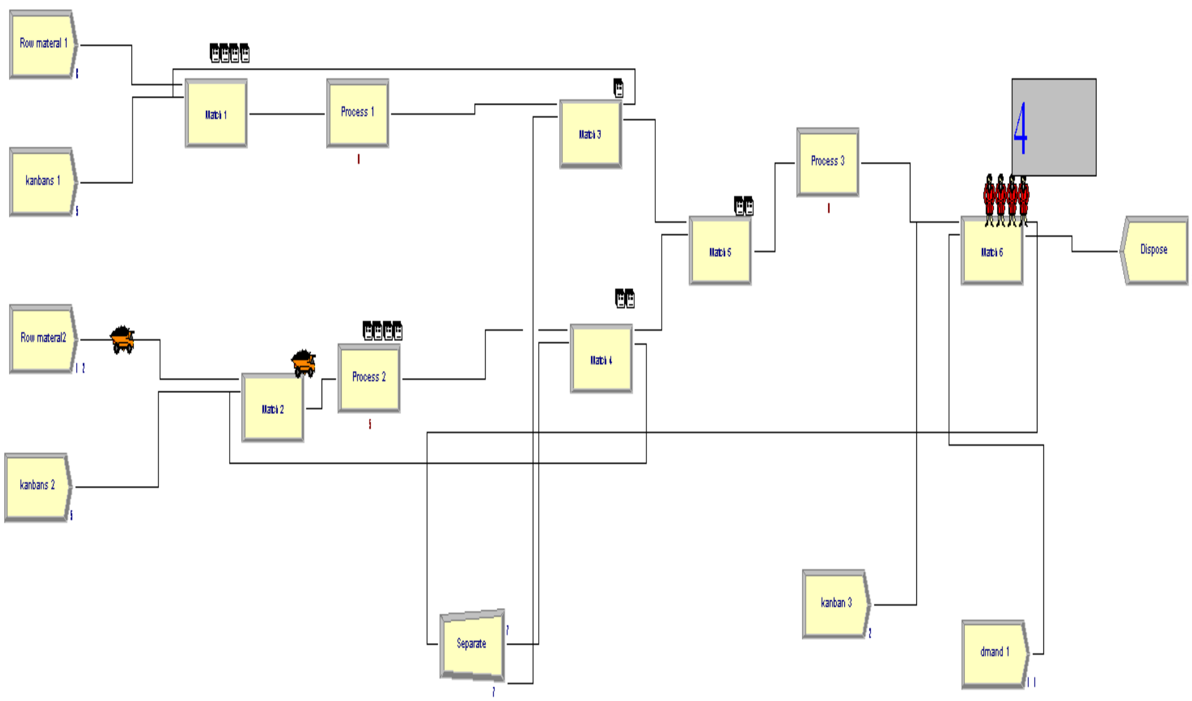


Figure 2.13 : Arena model of a Kanban controlled two-stage assembly system with two components.

Figure 2.13 depicts the ARENA simulation model of the two-stage assembly system with Kanban control, which is shown in Figure 2.12.

The details of the modules of the ARENA model are given in Figure 2.14 -2.16. In this model, we have three process

Modules:

Process 1 : Manufacturing of component 1.

Process 2 : Manufacturing of component 2.

Process 3 : Assembly of two components.

Create - Basic Process

	Name	Entity Type	Type	Value	Units	Entities per Arrival	Max Arrivals	First Creation
1	Row materal 1	part 1	Random (Expo)	1/0.5	Hours	1	20	0.0
2	kanbans 1	kanban	Random (Expo)	1	Hours	5	1	0.0
3	kanbans 2	kanban	Random (Expo)	1	Hours	5	1	0.0
4	dmand 1	dmand	Random (Expo)	1/0.5	Hours	1	20	0.0
5	Row materal2	part 2	Random (Expo)	1/0.5	Hours	1	20	0.0
6	kanban 3	kanban	Random (Expo)	1	Hours	2	1	0.0

Figure 2.14 : Create-Basic process two-stage assembly system with two components.

The arrivals of the entities (raw materials, demands, and Kanban) are shown in Figure 2.14. for three stages, there are three different kanban entities.

Process - Basic Process

	Name	Type	Action	Priority	Resources	Delay Type	Units	Allocation	Expression	Report Statistics
1	Process 1	Standard	Seize Delay Release	High(1)	1 rows	Expression	Hours	Value Added	EXPO(1)	☑
2	Process 2	Standard	Seize Delay Release	Medium(2)	1 rows	Expression	Hours	Value Added	EXPO(1)	☑
3	Process 3	Standard	Seize Delay Release	High(1)	1 rows	Expression	Hours	Value Added	EXPO(1)	☑

Figure 2.15 : Process-Basic process two-stage assembly system with two components.

Figure 2.16 explains the details of the process modules.

Match - Advanced Process

	Name	Number to Match	Type	Batch Action after Matching	Save Criterion	Representative Entity Type
1	Match 3	2	Any Entities	No Batch	Last	
2	Match 2	2	Any Entities	Temporary Batch	Last	
3	Match 4	2	Any Entities	No Batch	Last	
4	Match 5	2	Any Entities	Temporary Batch	Last	
5	Match 6	2	Any Entities	No Batch	Last	
6	Match 1	2	Any Entities	Temporary Batch	Last	

Figure 2.16 : Match-Advanced process two-stage assembly system with two components.

Moreover: there are six different (match) modules as shown in Figure 2.16

Match 1: matching of raw material 1 and Kanban 1.

Match 2: matching of raw material 2 and Kanban 2.

Match 3: matching of raw material 1 and Kanban 3.

Match 4: matching of raw material 2 and Kanban 3.

Match 5: matching of two components.

Match 6: matching of assembled product and demand.

2.4 LITERATURE REVIEW

The study of [18] highlights the simulation-based methods, that offer the ability to considering adequate details related to the system in the case of examining its dynamic behavior. Various randomness sources could be considered by simulation in the systems of manufacturing, including (1) arrival of raw materials, parts or orders, (2) inspection times, assembly, or processing, (3) machine time to failure, (4) unloading/loading time and (5) setup times. Furthermore, various dynamic behaviors could be identified, including machine blocking because of insufficient space of storage and vehicle collision because of ineffective design

The study of [20] deals with balancing mixed-model U-line in Just-In-Time (JIT) production system. The study aims for reducing the number of stations through maximizing weighted efficiency and workload balancing, that both are well-thought-out as the aims of this study. Reducing the number of stations is the main aim of this research. The main aim of lessening the number of stations is corresponding to lessening the idle time associated to the line. Each model's idle time is multiplied by the matching proportion, producing in total weighted idle time (WIT).

The aim of [21] is to define a procedure, supported by optimization via simulation, for determining the best number of Kanban for minimizing the costs of backlog, setup, inventory, and transportation in the initial phase of JIT execution. The "time periodic" approach of Kanban management and dual-card Kanban are utilized by this approach. The procedure was proved through evaluating it against a simulation model, with conventional standard of Kanban calculation (EPQ, multi-product EPQ, EPQ with overlapping, and so on) as well as against other models related to Kanban management, like "instantaneous" model and "Quantity Periodic" model.

The main aim of the study of [22] is to carry out a material flow analysis for maximizing productivity and for the purpose of offering technologies of simulation optimization to decision makers, including supervisors and production planners. This study presents production execution planning system for panel block operations through the use of simulated annealing and discrete-event simulation. Through using a real scenario of production, the simulation model has been authenticated and the assessment indicated a promising agreement between the simulation model and the actual panel shop. The suggested approach supports the production planners through optimization and general dispatching rules for making improved scheduling decisions on the shop floor. The method offers a complete schedule which is at the least as precise and clear as any schedule presently acquired.

The study of [23] deals with an assembly job shop scheduling issue taking into account two control stages: dispatching rules and order review/release (ORR). Previous job shop studies have utilized dispatching rules extensively. These rules control the processing sequence that is related to job waiting in queues of the equivalent machines. Recently, ORR has gained much focus and it has been considered as an extra option for job shop control. Releasing job to shop floor is determined by such control. Various ORR methods were invented and are stated to bring few benefits including shorter flow time for the orders, balanced and controlled levels of shop load and reduced cost for inventory. Previous researches on the topic of ORR presume basic job shop with no assembly operations, whereas this study apply ORR to assembly job shop. The main objective of the study of [23] is to evaluate the capability of various combinations of ORR-dispatching rules in enhancing flow time and deadline associated performance measures.

The study of [24] deals with multi-objective optimization (MOO) that is related to a single-model stochastic assembly line balancing problem with parallel stations. The aims are: (1) minimizing the smoothness index, (2) minimizing the cost for designing. For the purpose of obtaining a Pareto-optimal solutions for the problem, the paper suggests a novel solution algorithm, depending on simulated annealing (SA), which is referred to as m SAA. This solution algorithm (m SAA) implements a diversification approach, multinomial probability mass function method, repair algorithm and tabu list. The efficiency of m SAA has been examined through comparing the results of algorithms with the results of another SA (utilizing a weight-sum method) on a suite of twenty-four test problems. The computational results have indicated that m SAA with multinomial probability mass function method have more efficiency than SA with weight-sum method with regard to the excellence of Pareto-optimal solutions. Furthermore, [24] examines the impact of properties (i.e., diversification approach, repair algorithm and tabu list) on m SAA performance.

3. A CASE STUDY

3.1 SPECIFYING THE RELATED DATA

In this part of the thesis, a real assembly given in [28] is analyzed Figure 3.1 shows the seven manufacturing stages of the analyzer system.

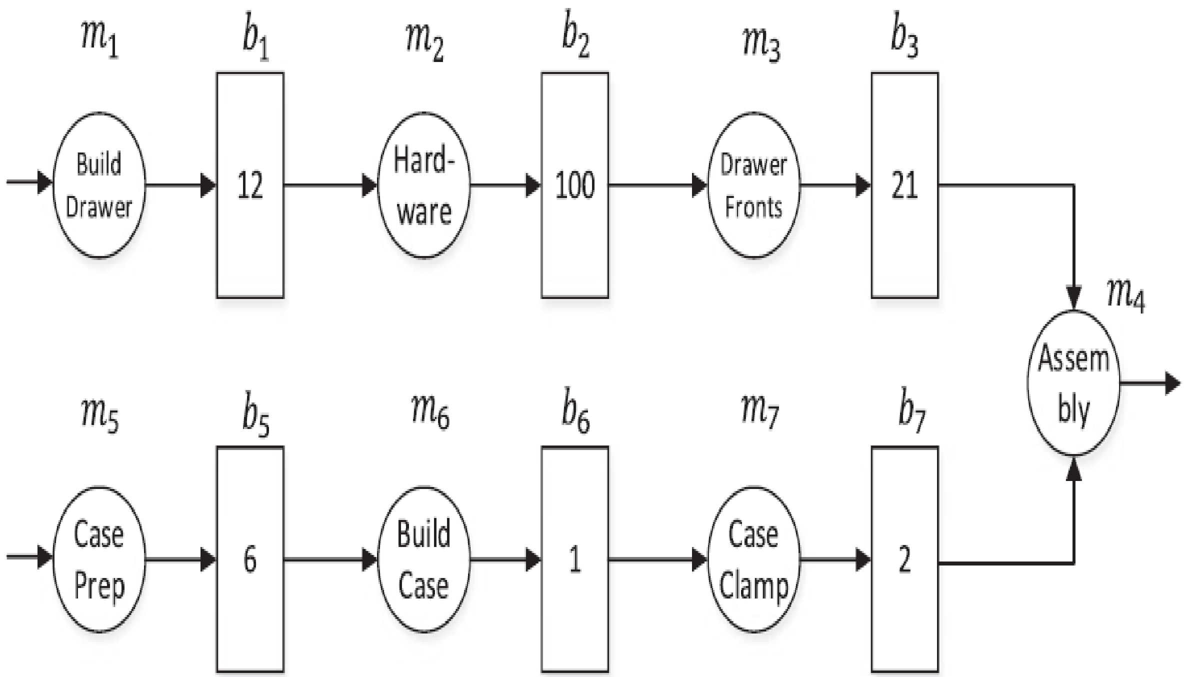


Figure 3.1 : Assembly line model[28].

The processing times of each production stage are given in Table 3.1.

Table 3.1 : Machine cycle time [28].

mi	Average processing time (min)	Average set-up time (min)	Average cycle time (min)
1	72	_	72
2	89	_	89
3	100	9.164	109.164
4	110	10.309	120.309
5	80	3.436	83.436
6	112	_	112
7	70	_	70

3.2 THE ARENA SIMULATION MODEL

Figure 3.2 shows the ARENA simulation model of the assembly system of [28].

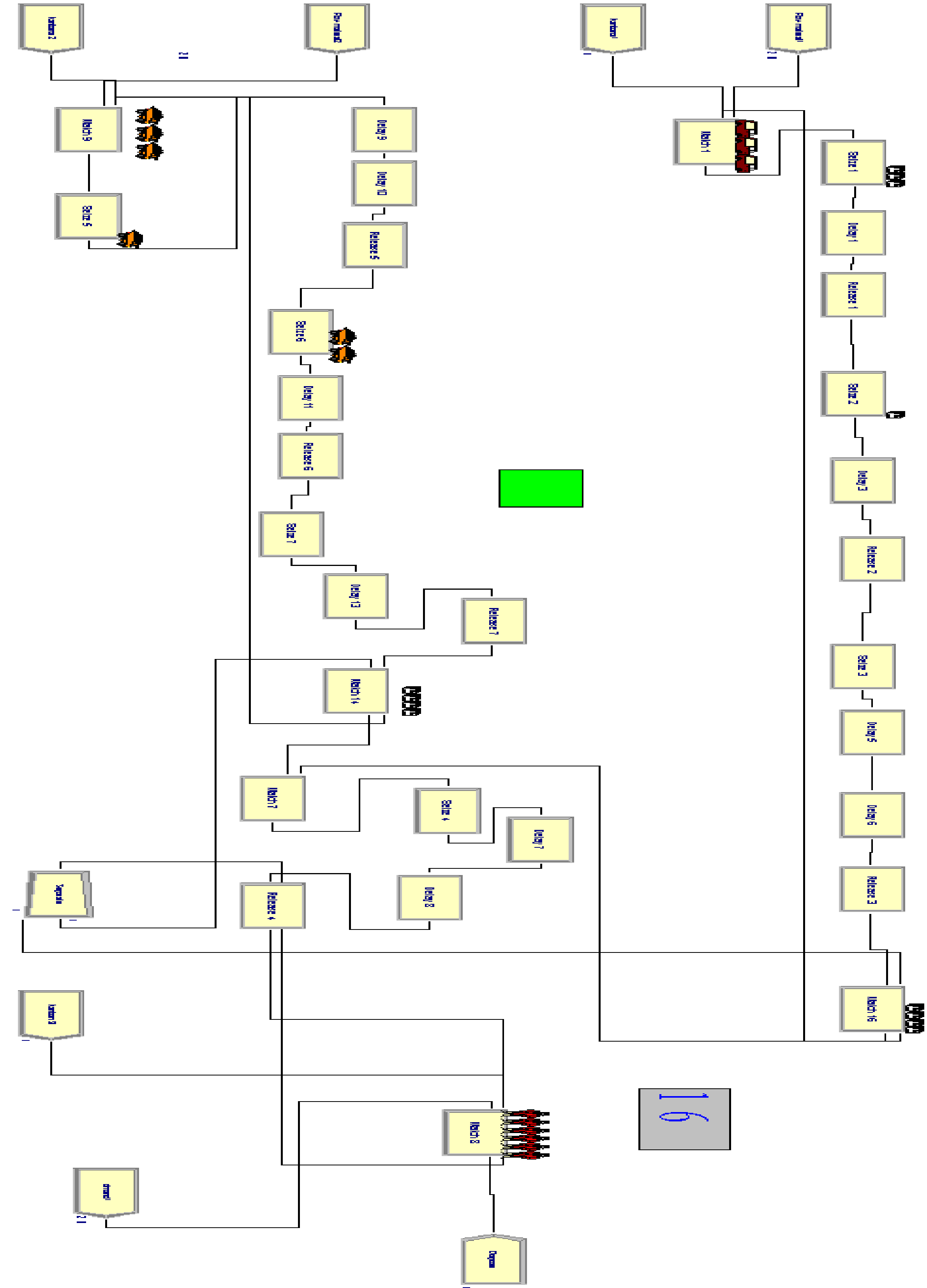


Figure 3.2 : Arena model of assembly line of [28].

The details of the modules given in Figures (3.3-3.45). The seven machines are grouped into three stages. There level, there three kanbans types devoted for three stages.

Create - Basic Process

	Name	Entity Type	Type	Value	Units	Entities per Arrival	Max Arrivals	First Creation
1	Row materal1	part 1	Random (Expo)	1	Minutes	1	20	0.0
2	kanbans1	kanban	Random (Expo)	1	Minutes	4	1	0.0
3	kanbans 2	kanban	Random (Expo)	1	Minutes	4	1	0.0
4	dmand1	dmand	Random (Expo)	1	Minutes	1	20	0.0
5	Row materal2	part 2	Random (Expo)	1	Minutes	1	20	0.0
6	kanban 3	kanban	Random (Expo)	1	Minutes	4	1	0.0

Figure 3.3 : Create-Basic process Arena model of assembly line**.**

Figure 3.3: shows the creation of three kanban types and also the creation of two raw material types and demands.

Match - Advanced Process

	Name	Number to Match	Type	Batch Action after Matching	Save Criterion	Representative Entity Type
1	Match 7	2	Any Entities	Temporary Batch	Last	
2	Match 14	2	Any Entities	No Batch	Last	
3	Match 8	2	Any Entities	No Batch	Last	
4	Match 1	2	Any Entities	Temporary Batch	Last	
5	Match 9	2	Any Entities	Temporary Batch	Last	
6	Match 16	2	Any Entities	No Batch	Last	

Figure 3.4 : Match-Advanced process Arena model of assembly line.

Release - Advanced Process

	Name	Resources
1	Release 3	1 rows
2	Release 7	1 rows
3	Release 4	1 rows
4	Release 1	1 rows
5	Release 2	1 rows
6	Release 5	1 rows
7	Release 6	1 rows

Figure 3.5 : Release-Advanced process Arena model of assembly line.

Seize - Advanced Process

	Name	Allocation	Priority	Resources	Queue Type	Queue Name
1	Seize 3	Other	Medium(2)	1 rows	Queue	Seize 3.Queue
2	Seize 7	Other	Medium(2)	1 rows	Queue	Seize 7.Queue
3	Seize 4	Other	Medium(2)	1 rows	Queue	Seize 4.Queue
4	Seize 1	Other	Medium(2)	1 rows	Queue	Seize 1.Queue
5	Seize 2	Other	Medium(2)	1 rows	Queue	Seize 2.Queue
6	Seize 5	Other	Medium(2)	1 rows	Queue	Seize 5.Queue
7	Seize 6	Other	Medium(2)	1 rows	Queue	Seize 6.Queue

Figure 3.6 : Seize-Advanced process Arena model of assembly line.

Delay - Advanced Process

	Name	Allocation	Delay Time	Units
1	Delay 5	Other	EXPO(100)	Minutes
2	Delay 6	Other	9.164	Minutes
3	Delay 13	Other	EXPO(70)	Minutes
4	Delay 7	Other	EXPO(110)	Minutes
5	Delay 8	Other	EXPO(10.309)	Minutes
6	Delay 1	Other	EXPO(72)	Minutes
7	Delay 3	Other	EXPO(89)	Minutes
8	Delay 9	Other	EXPO(80)	Minutes
9	Delay 10	Other	EXPO(3.436)	Minutes
10	Delay 11	Other	EXPO(112)	Minutes

Figure 3.7 : Delay-Advanced process Arena model of assembly line.

3.3 THE STUDY GOALS

There are two important goals of the case study

- Analyzing the efficiency of Kanban controlled Assembly System (kCAS) by using Arena simulation software.
- Minimizing the time of completion and meeting the deadline of customer orders.

3.4 IDENTIFYING INPUTS AND OUTPUTS VARIABLES

- The Inputs variables

The input variables, or the factors, of the Study, are shown (Table 3.2) with the levels of the factors.

Table 3.2 : The Inputs variables.

Kanban A	Kanban B	Kanban C	Demand D
4	4	4	1
4	4	8	0.5
4	8	4	0.5
4	8	8	1
8	4	4	0.5
8	4	8	1
8	8	4	1
8	8	8	0.5

The first three variables are the number of assembly system (kanban A , kanban B , kanban C). The last variable is the mean time between demand variables.

3.4.1 Kanban A : The stage of kanban A Includes the following components: create modules for kanbans and Raw material 1 Match 1 Seize 1 Delay 1 Release 1 Seize 2 Delay 3 Release 2 Seize 3 Delay 5 Delay 6 Release 3 Match 16. The details are shown below in Figure 3.8 - 3.21.

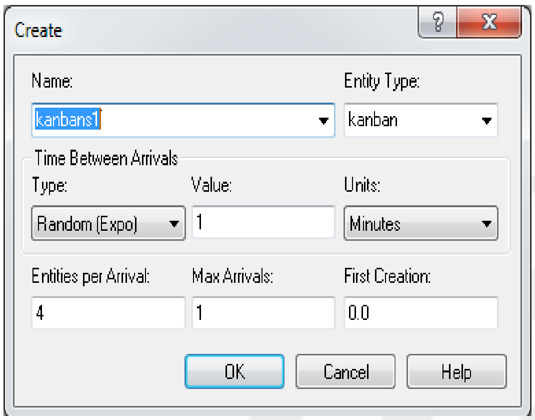


Figure 3.8 : Kanban 1 A Input variable.

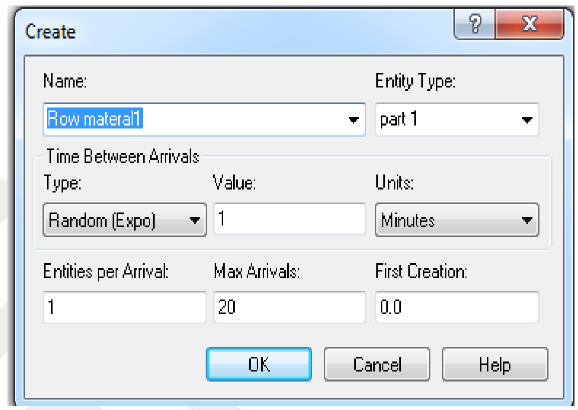


Figure 3.9 : Raw material 1 A Input variable.

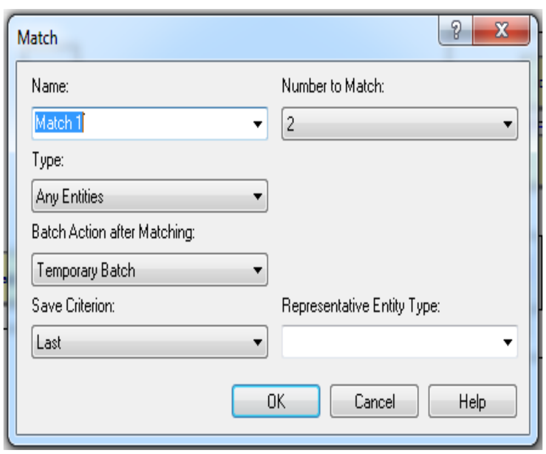


Figure 3.10 : Match 1 A Input variable.

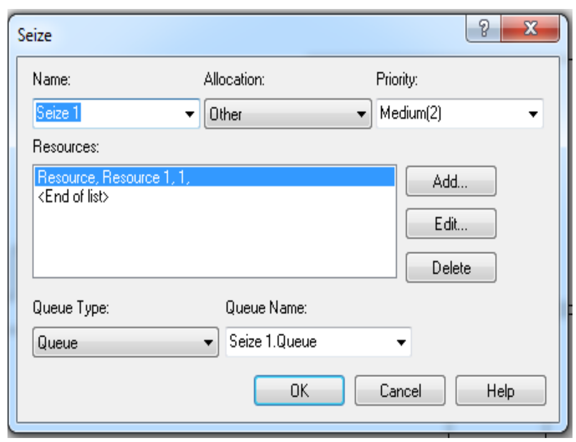


Figure 3.11 : Raw material Seize 1 A Input variable.

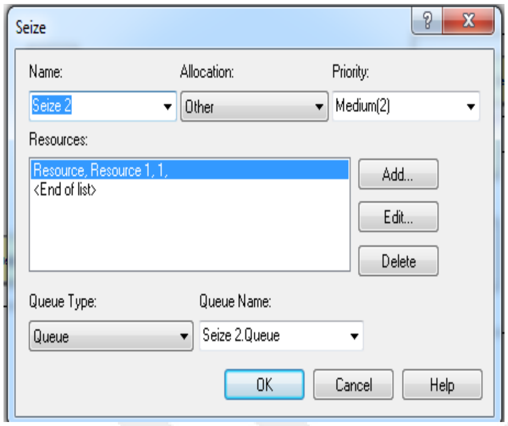


Figure 3.12 : Seize 2 A Input variable.

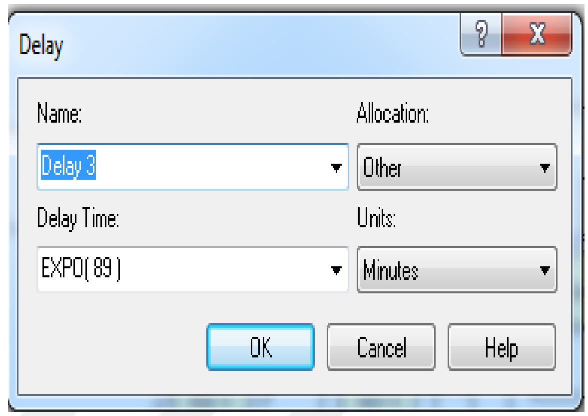


Figure 3.13 : Raw material Delay 3 A Input variable.

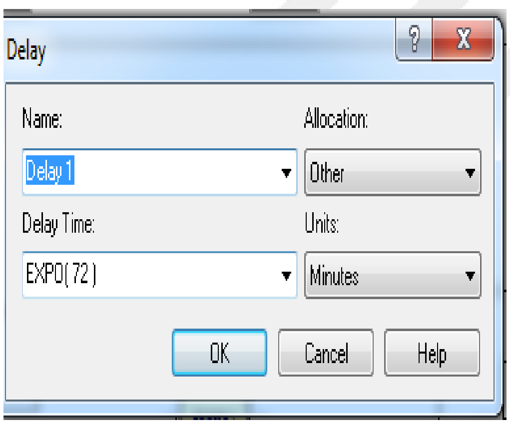


Figure 3.14 : Delay 1 A Input variable.

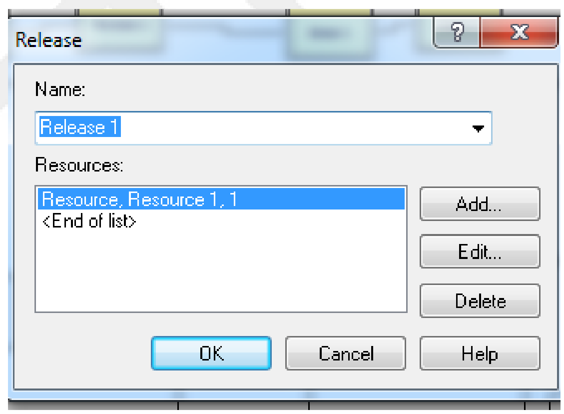


Figure 3.15 : Raw material Release 1 A Input variable.

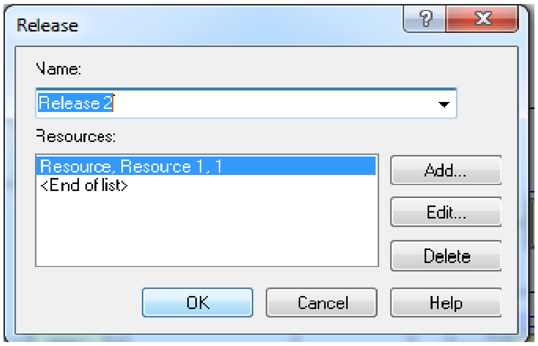


Figure 3.16 : Release 2 A Input variable.

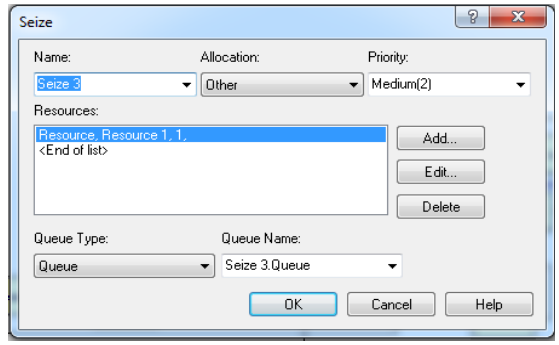


Figure 3.17 : Seize 3 A Input variable.

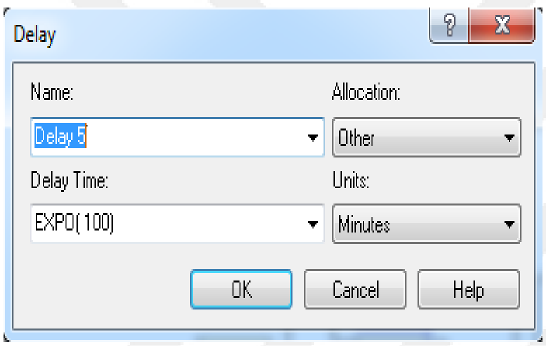


Figure 3.18 : Delay 5 A Input variable.

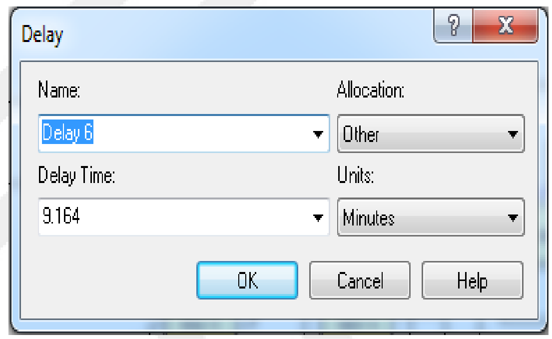


Figure 3.19 : Delay 6 A Input variable.

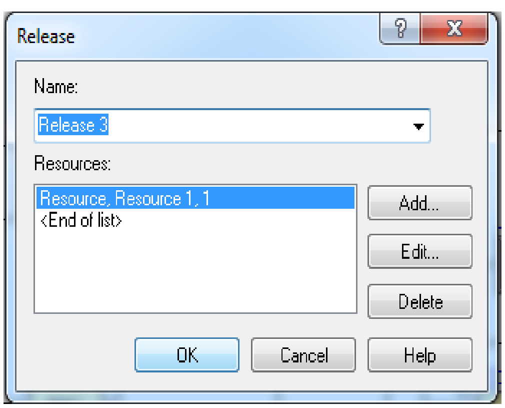


Figure 3.20 : Release 3 A Input variable.

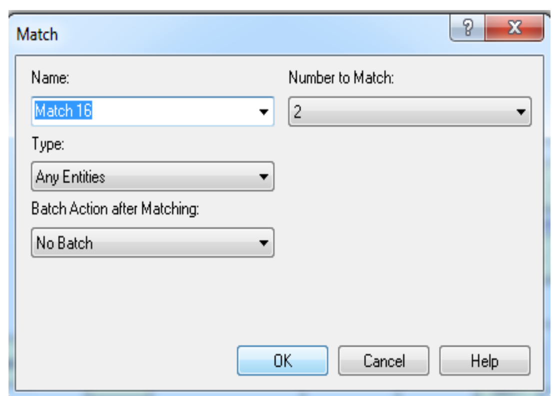


Figure 3.21 : Match 16 A Input variable.

3.4.2 Kanban B : The stage of kanban B Includes the following Includes these components: create modules for kanbans and Raw material 2 Match 9 Seize 5 Delay 9 Delay 10 Release 5 Seize 6 Delay 11 Release 6 Seize 7 Delay 13 Release 7 Match 14. The details are shown below in Figure 3.22 - 3.35.

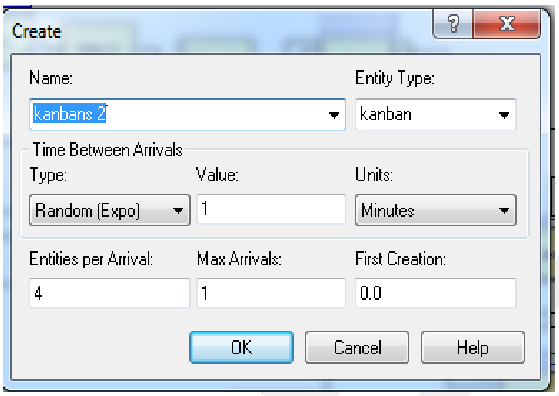


Figure 3.22 : Kanban 2 B Input variable.

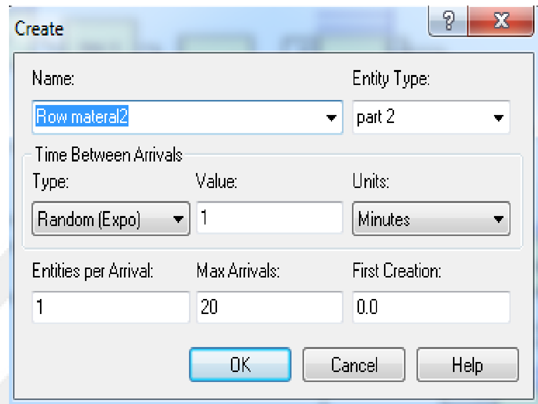


Figure 3.23 : Raw material 2 B Input. variable.

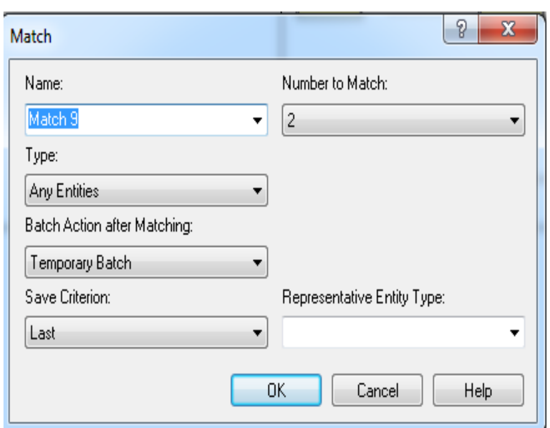


Figure 3.24 : Match 9 B Input variable.

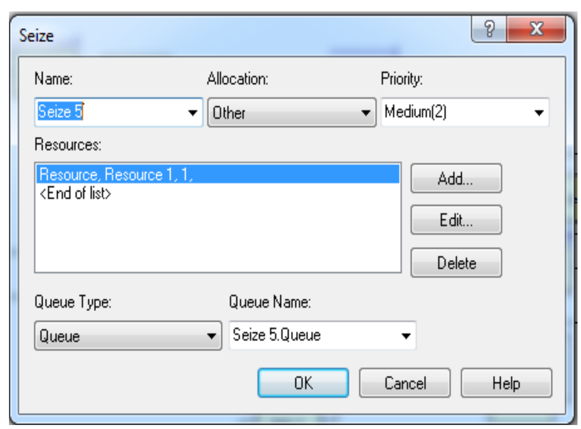


Figure 3.25 : Raw material Seize 5 B Input variable.

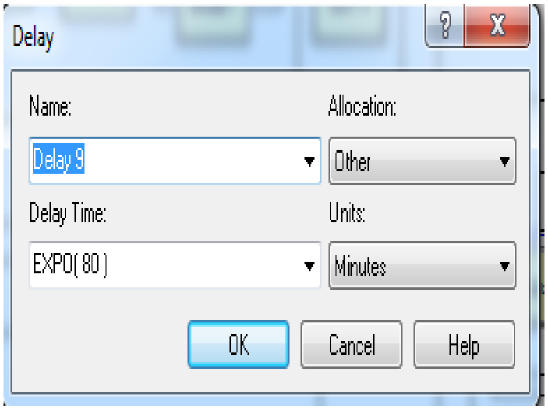


Figure 3.26 : Delay 9 B Input variable.

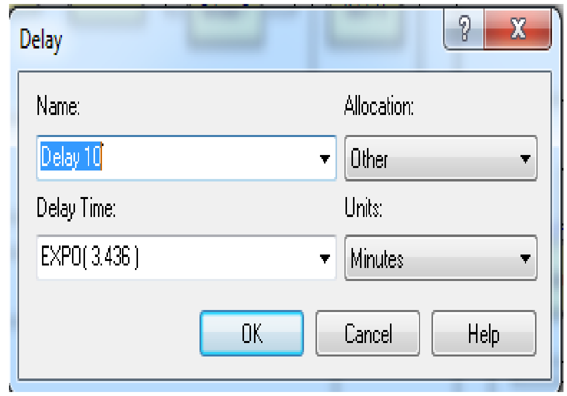


Figure 3.27 : Delay 10 B Input variable.

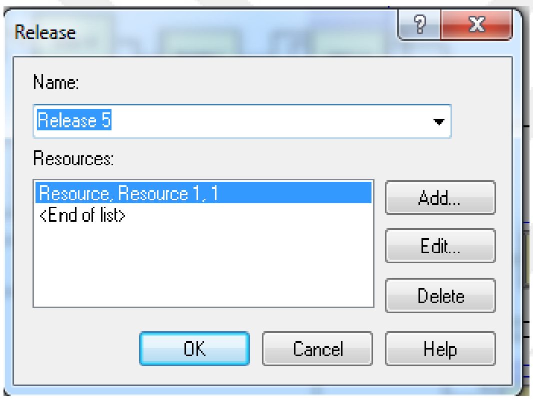


Figure 3.28 : Release 5 B Input variable.

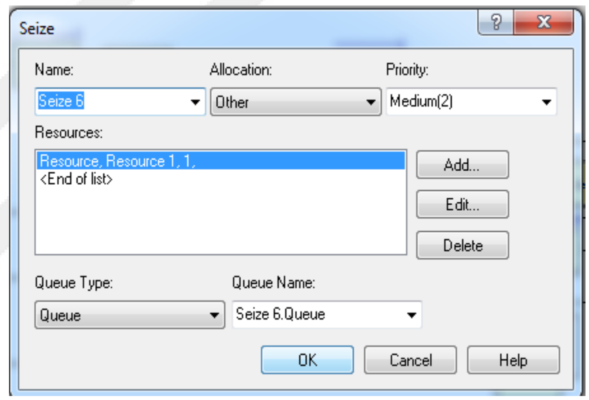


Figure 3.29 : Seize 6 B Input variable.

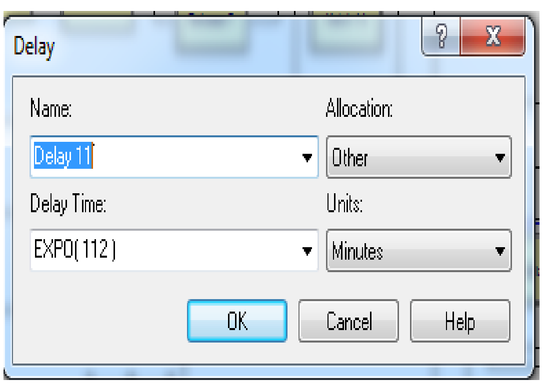


Figure 3.30 : Delay 11 B Input variable.

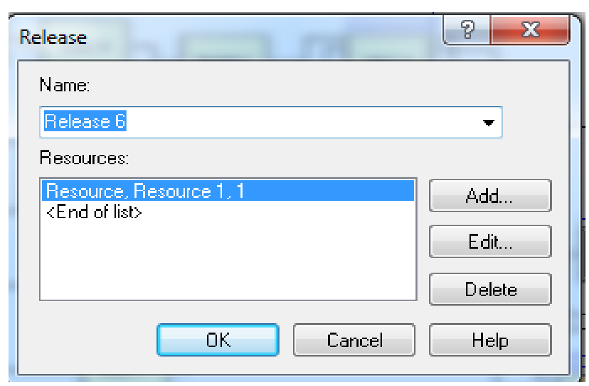


Figure 3.31 : Release 6 B Input variable.

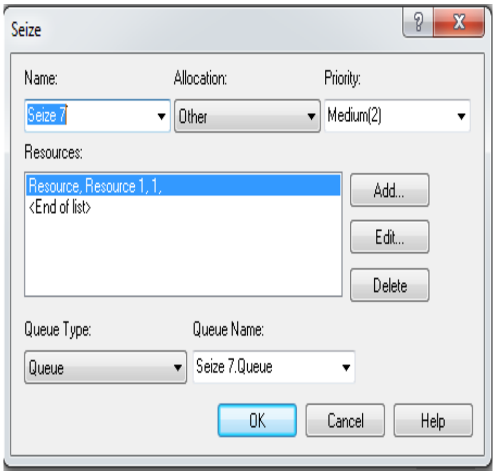


Figure 3.32 : Seize 7 B Input variable.

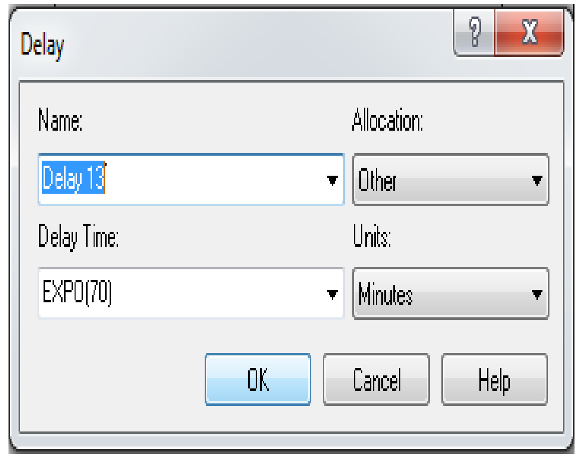


Figure 3.33 : Delay 13 B Input variable.

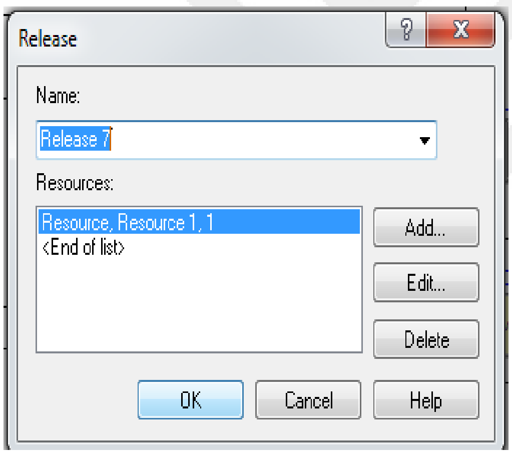


Figure 3.34 : Release 7 B Input variable.

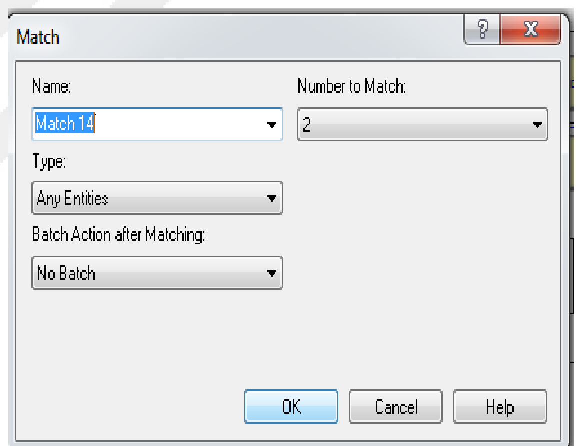


Figure 3.35 : Match 14 B Input variable.

3.4.3 Kanban C : The stage of kanban c Includes the following components: create modules of kanbans Match 7 and Seize 4 Delay 7 Delay 8 Release 4 Match 8 The details are shown below in Figure 3.36 - 3.42.

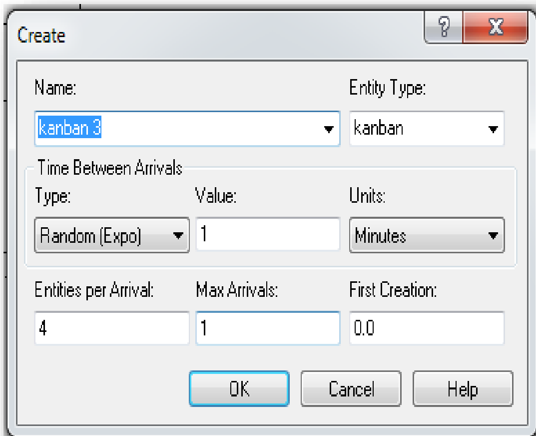


Figure 3.36 : Kanban 3 C Input variable.

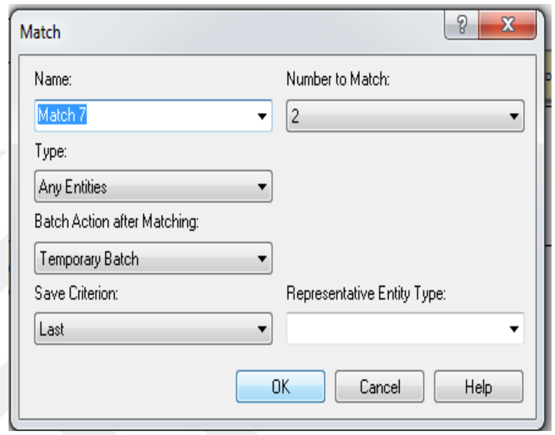


Figure 3.37 : Match 7 C Input variable.

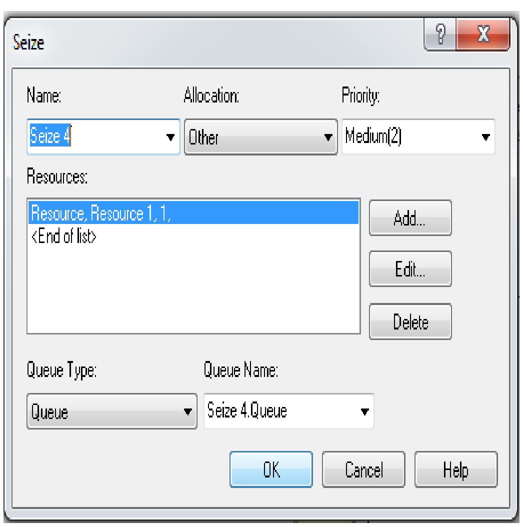


Figure 3.38 : Seize 4 C Input variable.

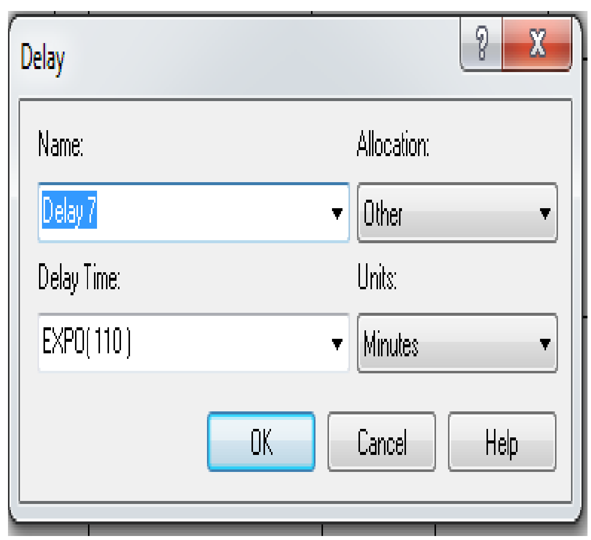
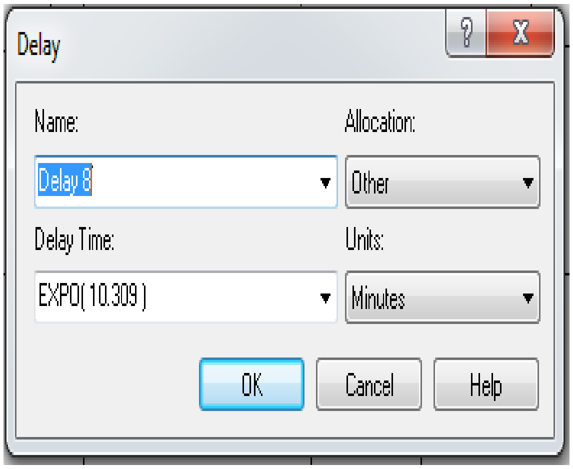


Figure 3.39 : Delay 7 C Input variable.



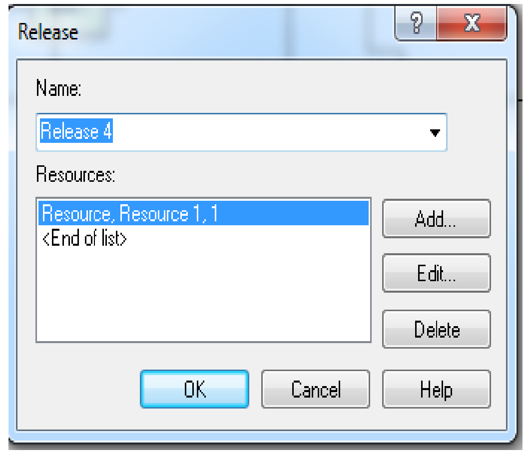


Figure 3.40 : Delay 8 C Input variable.

Figure 3.41 : Release 4 C Input variable.

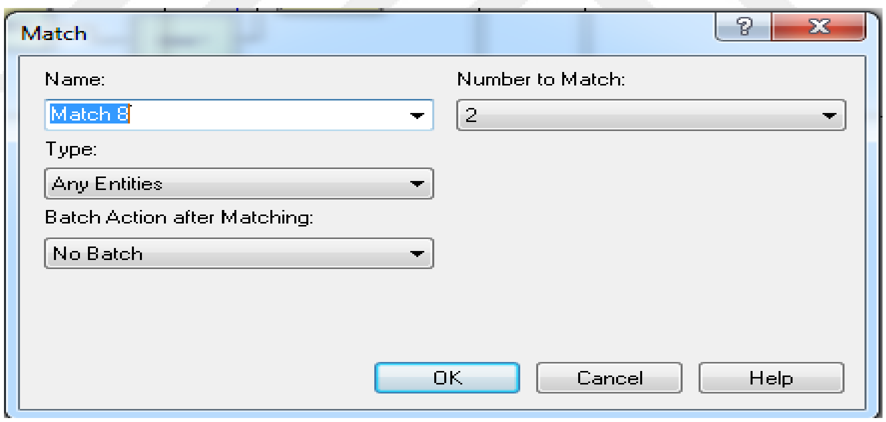


Figure 3.42 : Match 8 C Input variable.

3.4.4 Demand D : The create of demand and their matching with finished products one accomplished by using create and Match modules, whose details are shown below in Figure 3.43 and 3.44 respectively.

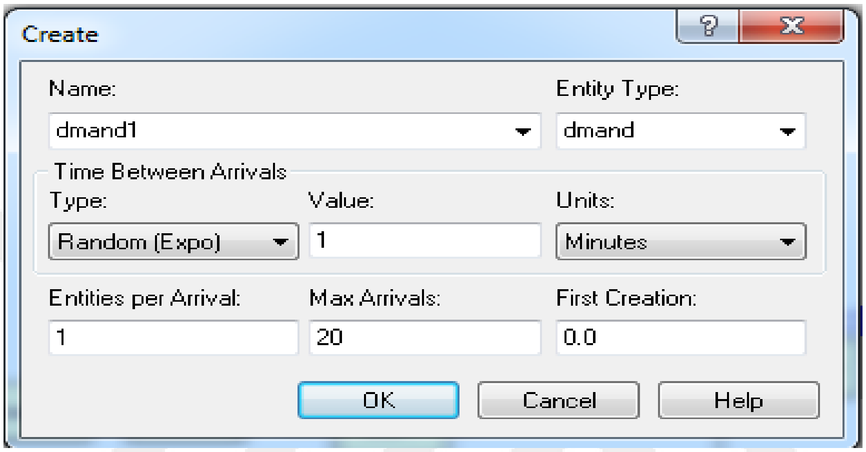


Figure 3.43 : Demand D Input variable.

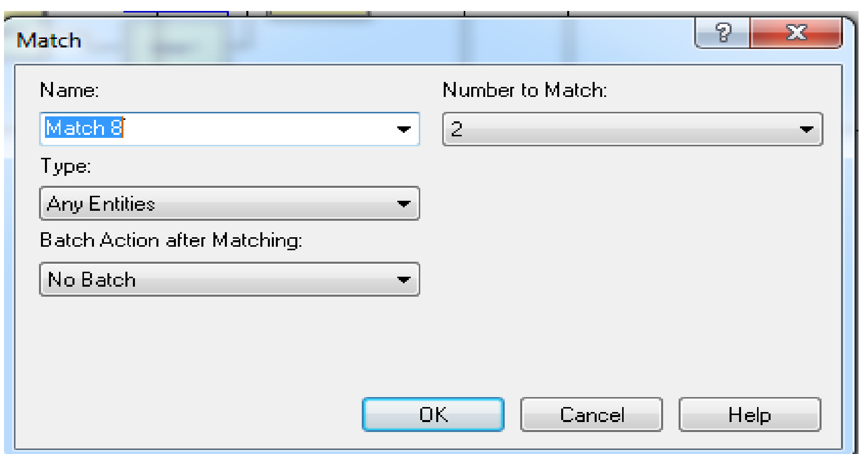


Figure 3.44 : Match 8 D Input variable.

3.4.5 The Outputs Variables

* Inventory:

Inventory can be represented by the input and output of the production system. Inventory includes some forms such as raw materials, semi-finished, and finished products.

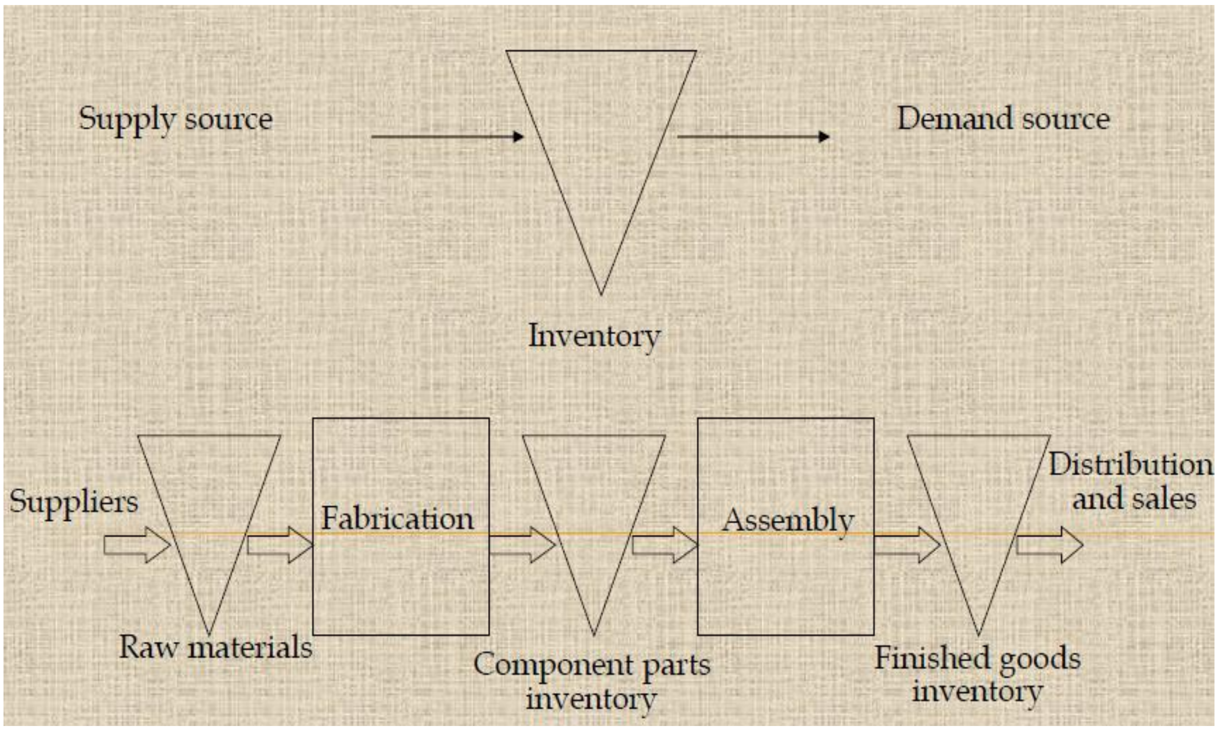


Figure 3.45 : Sketch of Inventory.

* Waiting time of demand (customer):

Can identify the elapsed time between the customer order and convincement of that order. Also can be named CWT.

* Waiting time of product:

Product waiting time can classify all waiting time a product (raw material, work-in-process, and finished goods) spends in all its different states. The waiting time represented the second most expensive waiting time of the three. When we see the cost of raw material storage and finished good storage (warehouses) you quickly observed the cost involved for all this. This cost or waste as can be seen by the lead engineer is the main objective for kaizen events.

3.5 NUMERICAL RESULTS

Table 3.3 and 3.4 show the waiting times of customer and products, respectively, which are obtained from 10 independent replications of the ARENA simulation model. The results are shown for 8 different cases given Table 3.1

Table 3.3 : The results of the Arena model for the time of a customer waiting (in minutes).

cases	Replication 1	Replication 2	Replication 3	Replication 4	Replication 5	Replication 6	Replication 7	Replication 8	Replication 9	Replication 10
1	121.91	109.58	105.63	107.89	109.67	112.32	113.93	114.66	116.05	118.67
2	75.315	71.901	66.332	66.97	65.792	55.571	71.435	71.916	71.053	75.822
3	124.25	130.83	145.15	137.16	125.07	140.19	162.69	130.05	135.45	125.83
4	83.859	88.589	90.530	88.550	82.820	78.272	101.34	95.328	84.268	80.977
5	143.95	123.95	127.91	126.35	107.66	122.49	142.36	131.43	120.85	139.06
6	93.462	94.021	87.849	90.894	68.869	84.670	95.847	81.818	92.466	84.458
7	137.92	138.6	127.68	143.26	127.93	131.65	159.14	148.02	130.13	133.98
8	97.596	91.906	90.994	92.701	78.366	92.776	94.491	88.870	91.750	76.168

Table 3.4 : The results for the Arena model for the time of products waiting. (in minutes).

cases	Replication 1	Replication 2	Replication 3	Replication 4	Replication 5	Replication 6	Replication 7	Replication 8	Replication 9	Replication 10
1	0.0036	0.0073	0.0081	0.0076	0.0038	0.0067	0.0138	0.0086	0.0019	0.0039
2	0.0125	0.0109	0.0098	0.0146	0.0132	0.0088	0.0181	0.0175	0.0093	0.0125
3	0.0018	0.0036	0.0038	0.0044	0.0027	0.0023	0.0081	0.0033	0.0009	0.0010
4	0.0354	0.0219	0.0214	0.0279	0.0228	0.0189	0.0478	0.0263	0.0124	0.0177
5	0.0018	0.0032	0.0027	0.0044	0.0027	0.0023	0.0058	0.0033	0.0009	0.0010
6	0.0182	0.0256	0.0346	0.0292	0.0220	0.0202	0.0410	0.0478	0.0136	0.0275
7	0.0036	0.0065	0.0059	0.0076	0.0038	0.0087	0.0137	0.0103	0.0019	0.0021
8	0.0125	0.0120	0.0150	0.0146	0.0130	0.0092	0.0207	0.0208	0.0098	0.0123

To analyze the impact of 4 factors on the result, the Taguchi method will be applied in the next section.

3.6 TAGUCHI METHOD

3.6.1 Introduction

In real industrial cases, the systems of manufacturing could encounter sudden events like cancelling of an order, changing of a deadline, arrival of urgent orders, and the shortage of materials or tools. Those cases could result in deviating from the plan of the schedule. Which is why, the significant cases have to be considered in the case of dealing with scheduling issues that might happen in real life. [29].

Generally, the process of scheduling in advanced systems of assembly is keeps increasing in complexity and dynamism, and one of the intelligent approaches is needed for assisting the decision makers. As it has been previously indicated, methods that are simulation-based are ones that have potential for addressing the issues of dynamic scheduling. In addition to that, the Taguchi approach is a sufficient tool for determining the minimum number of potential experiments for solving scheduling issues and for the analysis of the results of simulation.

Which is why, the aim of this part of the study is presenting the simulation-based method in combination with the Taguchi optimizing approach in a new dynamic scheduling problems application that takes under consideration the significance of scheduling factors that influence the job shop.

In the present section, the best combination of chosen factors of scheduling for obtaining the optimal results will be determined. The presented method includes four steps, which are: preparation, applying Taguchi approach, modelling of the simulation and statistical analysis.

3.6.2 Application of Taguchi Method

The possible advantage of the Taguchi approach is that it is capable of solving complicated tasks with performing considerably fewer experiments, thereby decreasing the cost of conducting those experiments [30]-[31]. Taguchi has designed special orthogonal arrays that were based on the number of factors and their levels. Those arrays specify the number of needed experiments. Taguchi has suggested a robust design criterion which is referred to as the signal-to-noise (S/N) ratio, which has been classified to three types: the larger the better, the smaller the better and the nominal the best [32]. There are two basic reasons to choose the Taguchi approach. Firstly, this approach was broadly utilized as an approach of optimizing for meeting the actual design and manufacturing issues [33]-[34]. Secondly, this approach was utilized with success for conducting experiments, analyzing the results of simulation and determining the important factors improving the performance of the system [35]-[38]. Here, three operations are carried out: first, selecting the suitable orthogonal array of Taguchi and assigning the scheduling factors to the orthogonal array; second, conducting experiments according to the arrangement of the array and measuring the values of the objective function; third, substituting the values of the objective function to a S/N ratio value.

3.6.3 Statistical Analysis

Here, two operations are carried out: firstly, the determination of the best level of every one of the scheduling factors, according to the results of S/N ratio; secondly, the determination of the most important factors of scheduling. The results of the S/N ratio may be analyzed with the use of statistical tools for the sake of the determination of the best conditions for the performance of the system. Based on the approach of Taguchi, analysis of variance (ANOVA) and analysis of mean (ANOM) may be carried out for the prediction of the optimum factor combinations and for the identification of the most important factors [39]-[41]. Analysis of mean is utilized for finding the optimum level of every factor. The impact of the level of a factor is the deviation it results in, from the entire mean response.

3.6.4 Analysis of Results

Table 3.5 : Analysis of the results of the Arena model for the time of customer. By using Minitab and Taguchi method.

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
	A	B	C	D	Replication 1	Replication 2	Replication 3	Replication 4	Replication 5	Replication 6	Replication 7	Replication 8	Replication 9	Replication 10	MEAN1
1	4	4	4	1	121.910	109.580	105.630	107.890	109.670	112.320	113.930	114.660	116.050	118.670	113.031
2	4	4	8	2	75.315	71.902	66.333	66.970	65.793	55.572	71.436	71.917	71.054	75.822	69.211
3	4	8	4	2	124.250	130.830	145.150	137.160	125.070	140.190	162.690	130.050	135.450	125.830	135.667
4	4	8	8	1	83.859	88.589	90.530	88.551	82.820	78.273	101.340	95.329	84.268	80.978	87.454
5	8	4	4	2	143.950	123.950	127.910	126.350	107.660	122.490	142.360	131.430	120.850	139.060	128.601
6	8	4	8	1	93.462	94.021	87.850	90.894	68.869	84.671	95.848	81.818	92.467	84.459	87.436
7	8	8	4	1	137.920	138.600	127.680	143.260	127.930	131.650	159.140	148.020	130.130	133.980	137.831
8	8	8	8	2	97.597	91.906	90.995	92.702	78.366	92.777	94.491	88.870	91.751	76.169	89.562

- In the following tables and figures, the impacts of four factors on the waiting time of customers are analyzed.

Table 3.6 : Scheduling factors and two levels.

Factor	Symbol	Factor level	Level ID
kanban size of stage A	A	low	4
		High	8
kanban size of stage B	B	low	4
		High	8
kanban size of stage C	C	low	4
		High	8
Demand Arrival Rate	D	low	1
		High	2

- *Taguchi Design*
- *Design Summary*

Taguchi Array L8(2^4)

Factors: 4

Runs: 8

Columns of L8(2^7) array: 1 2 4 7

- Taguchi Analysis: Replication 1; Replication 2; ... n 10 versus A; B; C; D

- Linear Model Analysis: Means versus A; B; C; D

Table 3.7 : Estimated Model Coefficients for Means.

Term	Coef	SE Coef	T	P
Constant	106.099	2.294	46.248	0.000
A 4	-4.758	2.294	-2.074	0.130
B 4	-6.529	2.294	-2.846	0.065
C 4	22.683	2.294	9.888	0.002
D 1	0.339	2.294	0.148	0.892

Model Summary

S	R-Sq	R-Sq(adj)
6.4888	97.35%	93.82%

Table 3.8 : Analysis of Variance for Means.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	1	181.14	181.14	181.14	4.30	0.130
B	1	341.06	341.06	341.06	8.10	0.065
C	1	4116.28	4116.28	4116.28	97.76	0.002
D	1	0.92	0.92	0.92	0.02	0.892
Residual Error	3	126.31	126.31	42.10		
Total	7	4765.71				

Table 3.9 : Response Table for Means.

Level	A	B	C	D
1	101.34	99.57	128.78	106.44
2	110.86	112.63	83.42	105.76
Delta	9.52	13.06	45.37	0.68
Rank	3	2	1	4

Main Effects Plot for Means

Main Effects Plot for SN ratios

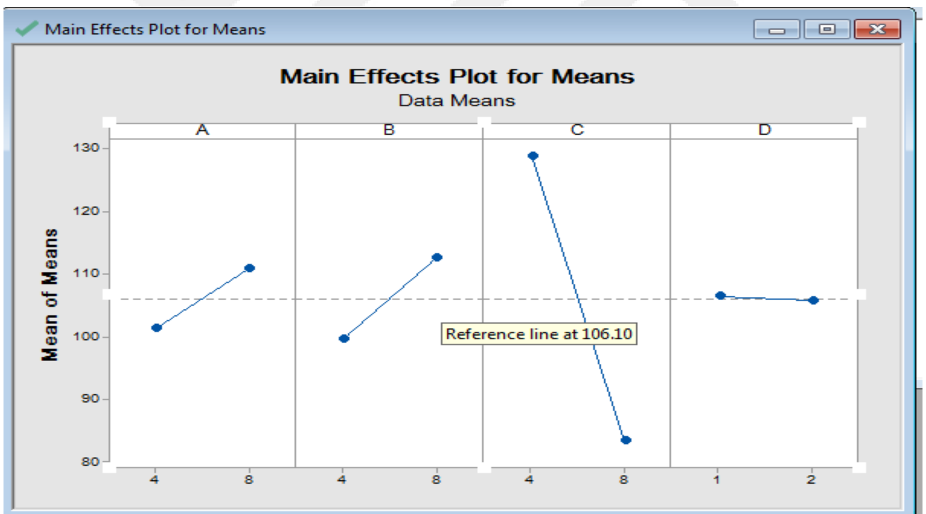


Figure 3.46 : Main Effects Plot for Means of waiting times of customer.

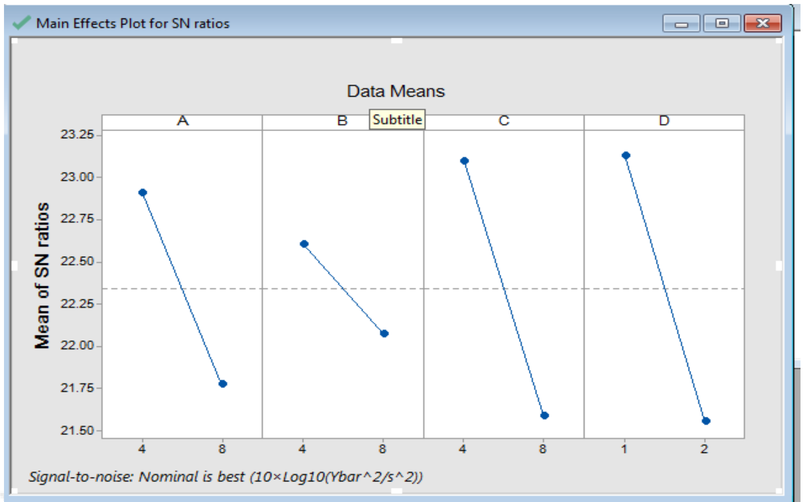


Figure 3.47 : Main Effects Plot for SN ratios.

From the reported results, it is observed that the most important factor to decrease the mean waiting times of customers is the number of kanbans of the last stage (kanban C). The demand arrival rate (factor D) has little impact on customer waiting time under the analyzed product setting.

In the following tables and figures, the impacts of four factors on the waiting time of products are analyzed.

Table 3.10 : Analysis of the results of Arena models for the waiting time of the products by us my Minitab and Taguchi method.

Worksheet 1 ***

↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14	C15
	A	B	C	D	Replication 1	Replication 2	Replication 3	Replication 4	Replication 5	Replication 6	Replication 7	Replication 8	Replication 9	Replication 10	MEAN1
1	4	4	4	1	0.0036290	0.0073664	0.0081061	0.0076571	0.0038886	0.0067426	0.0138815	0.0086573	0.0019148	0.0039564	0.0065800
2	4	4	8	2	0.0125772	0.0109966	0.0098301	0.0146737	0.0132712	0.0088433	0.0181604	0.0175067	0.0093470	0.0125173	0.0127723
3	4	8	4	2	0.0018145	0.0036643	0.0038200	0.0044095	0.0027516	0.0023104	0.0081994	0.0033077	0.0009574	0.0010608	0.0032296
4	4	8	8	1	0.0354293	0.0219932	0.0214555	0.0279320	0.0228917	0.0189858	0.0478042	0.0263935	0.0124359	0.0177201	0.0253041
5	8	4	4	2	0.0018145	0.0032545	0.0027321	0.0044095	0.0027516	0.0023104	0.0058246	0.0033077	0.0009574	0.0010608	0.0028423
6	8	4	8	1	0.0182844	0.0256193	0.0346460	0.0292476	0.0220297	0.0202781	0.0410653	0.0478937	0.0136910	0.0275217	0.0280277
7	8	8	4	1	0.0036290	0.0065089	0.0059079	0.0076571	0.0038886	0.0087407	0.0137811	0.0103674	0.0019148	0.0021217	0.0064517
8	8	8	8	2	0.0125605	0.0120808	0.0150730	0.0146737	0.0130369	0.0092074	0.0207953	0.0208436	0.0098918	0.0123224	0.0140485

- *Taguchi Design*
- *Design Summary*

Taguchi Array	L8(2^4)
Factors:	4
Runs:	8

Columns of L8(2^7) array: 1 2 4 7

- Taguchi Analysis: Replication 1; Replication 2; ... n 10 versus A; B; C; D

- Linear Model Analysis: Means versus A; B; C; D

Table 3.11 : Estimated Model Coefficients for Means.

Term	Coef	SE Coef	T	P
Constant	0.012407	0.001453	8.537	0.003
A 4	-0.000436	0.001453	-0.300	0.784
B 4	0.000149	0.001453	0.102	0.925
C 4	-0.007631	0.001453	-5.251	0.013
D 1	0.004184	0.001453	2.879	0.064

Model Summary

S	R-Sq	R-Sq(adj)
0.0041	92.30	82.03%

Table 3.12 : Analysis of Variance for Means.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	1	0.000002	0.000002	0.000002	0.09	0.784
B	1	0.000000	0.000000	0.000000	0.01	0.925
C	1	0.000466	0.000466	0.000466	27.57	0.013
D	1	0.000140	0.000140	0.000140	8.29	0.064
Residual Error	3	0.000051	0.000051	0.000017		
Total	7	0.000658				

Table 3.13 : Response Table for Means.

Level	A	B	C	D
1	0.011972	0.012556	0.004776	0.016591
2	0.012843	0.012258	0.020038	0.008223
Delta	0.000871	0.000297	0.015262	0.008368
Rank	3	4	1	2

- *Main Effects Plot for Means*
- *Main Effects Plot for SN ratios*

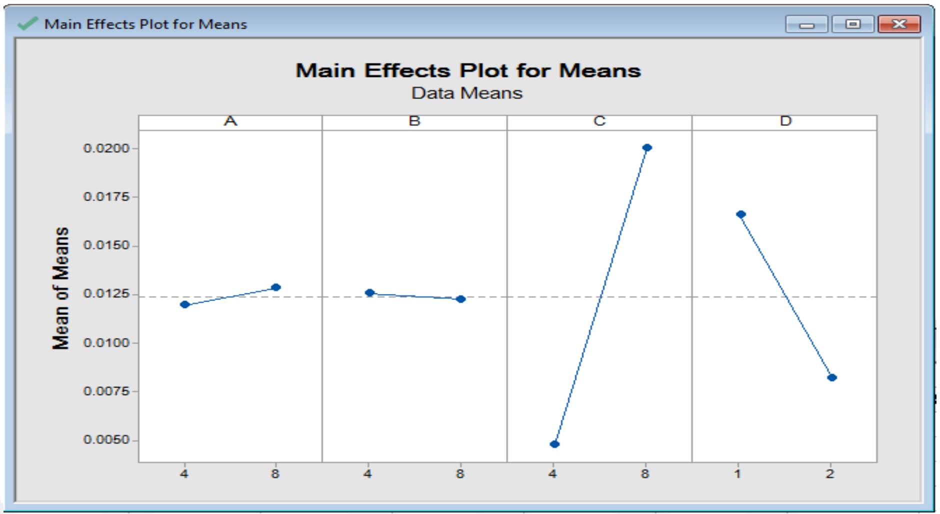


Figure 3.48 : Main Effects Plot for Means of waiting times of products**.**

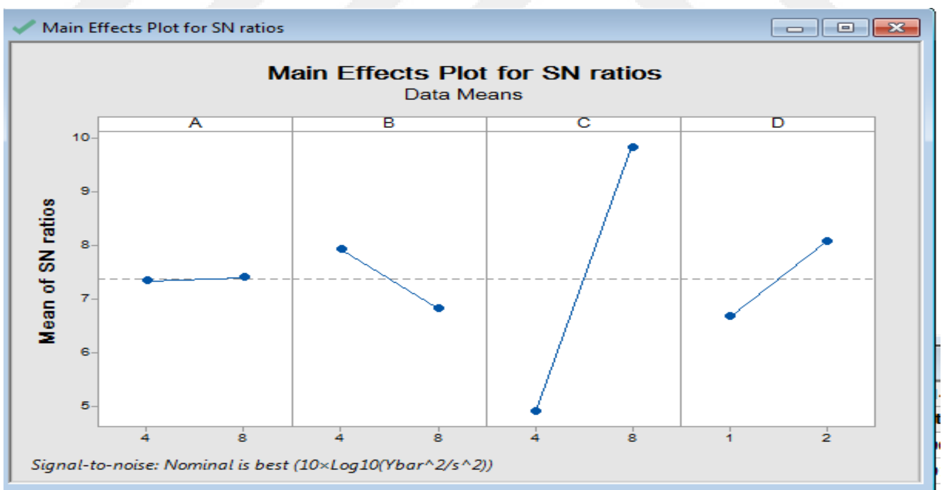


Figure 3.49 : Main Effects Plot for SN ratios.

From the reported results show that the most important factors to reduce the mean waiting time of finished products are the number of kanbans in the last stage (factor C) and the demand arrival rate (factor D), which is, in fact, an uncontrolled factor. The kanban sizes of the first stage (factor A and B) have little impact on the product waiting times.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

1. The basic aim of the presented thesis was to examine the scheduling tasks in kanban controlled assembly systems. In this thesis, three challenges have been encountered. The first one was the scheduling to an environment of multi-product assembly. The second one was the dynamic case scheduling. The third one was optimizing the dynamic scheduling for multi-objective tasks.

2. A level design method is followed for assembly systems in an environment of multi-product assembly. It includes features from earlier researches of scheduling assembly lines and manufacturing processes in that those researches had the emphasis on the assembly of only one product type at a time.

3. By using the proposed design method, the formulation and modelling of the scheduling problem in assembly lines can be accomplished by taking into account four objectives namely to reduce idle time, and waiting time, and to increase the productivity and increase the service customer.

4. A novel methodology is followed for the analysis of the simulation results of the kanban control system. In the established method, the experimental design approach of Taguchi is utilized to analyze the results and simulation models are utilized as tools. This approach can be useful in many respects, such as: (1) the fact that it can examine the behaviour of assembly lines under various factors of scheduling, (2) the fact that it can find the optimum or near-optimum combination of the chosen factors optimizing the objective functions, (3) the fact that it solves the scheduling tasks with the use of a significantly smaller number of experiments in comparison with the full factorial experimental approaches, and (4) the fact that it can predict the important factors affecting the performance of the system.

5. An advanced rule of scheduling, which is the kanban control system is demonstrated. It has been examined with the use of a simulation model. The kanban control was able to overcome the drawbacks in the available rules via taking under consideration all the significant input variables in the tasks of scheduling like the time of processing, size of the batch, the deadline, in addition to the number of needed stations.

4.2 RECOMMENDATIONS

In future, several issues need to be further explored.

1. The needed data of production needs to be automatically and directly collected from the company's IT system, and afterwards stored in a data base with the appropriate format. Manual collecting and entry of data could take much time and be a process prone to errors.

2. Other methods alternative to simulation and modelling can be used to improve the performance of assembly systems. Also, other programs can be used to generate models for simulation.

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