DEVELOPMENT AND ANALYSIS OF PULL CONTROL SYSTEMS FOR EFFECTIVE MANAGEMENT OF PRODUCTION SYSTEMS

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DECLARATION

I hereby declare that that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material which has been accepted for the award of any other degree or diploma of the university or any other institute of higher learning, except where due acknowledgement has been made in the text.

Date : 8/6/2015

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CERTIFICATE

This is to certify that the thesis entitled **"Development and Analysis of Pull Control Systems for Effective Management of Production Systems"** submitted by G. Gouripati Sastry, to University of Petroleum and Energy Studies, for the award of the degree of Doctor of Philosophy is a bonafide record of the research work carried out by him under our joint supervision and guidance. The content of the thesis, in full or parts have not been submitted to any other institute or university for the award of any other degree or diploma.

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G.GOURIPATI SASTRY

CONTENTS

ABSTRACT

The manufacturing industries for the past few decades are looking for the optimization of the parameters, like work in process and manufacturing lead time. The pull control systems result in reduction of lead time, work-in-process and cost. These control systems also improve quality, production volumes and eliminates waste. The blends of the existing pull control systems translate as a new approach to satisfy the manufacturing requirements.

The thesis addresses the modeling and simulation analysis of CONWIP, KCS and EKCS for single flow line multi-stage; multi flow line multi-stage; and single flow line multi-stage multi-product systems. The thesis is classified into four stages; literature review, research objectives, model configuration and simulation, simulation results for performance analysis along with a case study of the industry.

The literature review discusses the manufacturing trends in an industrial enterprise and significant differences between push and pull control manufacturing systems. The concepts and working of CONWIP, KCS, GKCS and EKCS for flow line manufacturing systems are reported. Also, the blocking mechanism, analytical algorithms and the hybrid system with possible combinations for the flow line manufacturing systems are being reviewed. The concepts of multi-product manufacturing using dedicated and shared kanban systems are present in the literature. The performance of single flow line multi stage pull control systems by modeling and simulation are discussed in the literature. Also, the performance analysis of EKCS and GKCS for multi-line assembly manufacturing systems for number of kanbans per stage is discussed in the literature. The performance due to variation in

processing time, machine breakdown, demand rate and number of kanban per stage for single line, multi-line and multi-product systems is the research gap found in literature. The focus of the present research is to address the above said issues in finding the performance behavior of the manufacturing system. In practice, most of the manufacturing systems are dynamic and stochastic and the real time data can be derived from computers and other related systems. The simulation tool has been opted to analyze the complex real conditions due to the dynamic practical approach of manufacturing systems which doesn't fit with other approach.

The following objectives are being planned for the research study to investigate and analyze the performance of pull control manufacturing systems; CONWIP, KCS and EKCS in terms of production, average waiting time, work in process and machine utilization by modeling and simulation. The pull control manufacturing systems have been modeled and simulated by using the software MATLAB/SIMULINK R 2011b.

1. Single flow line multi stage manufacturing systems.
    i. Validation: The simulation results have been validated with the results obtained by the code developed in programming language 'C'.
    ii. Number of kanbans per stage: With the objective of optimizing the number of kanbans for three workstations, and thereby optimizing the performance parameters.
    iii. Effect due to imbalance in processing mean time: With the objective to analyze the performance of the system due to imbalance in processing time for different configurations (i.e. LMH, HML and HLM).

iv. Breakdown per stage: Breakdown is the common problem at shop floor during manufacturing processes. The studies are carried out to analyze the performance of system due to breakdowns.

2. Two flow line multi stage manufacturing system.

   i. Validation: The simulation results have been validated with the results obtained by the code developed in programming language 'C'.

   ii. Performance comparison: The studies are carried out to compare and analyze the performance of the pull control systems.

3. Single flow line multi stage multi-product manufacturing systems

   i. Number of kanbans per stage: With the objective of optimizing the number of kanbans per stage for three workstations, fixed batch size, and optimizing the performance parameters.

   ii. Effect due to imbalance in processing mean time: With the objective to analyze the performance of the pull control system with respect to the processing mean time imbalance configurations (i.e. LMH, HML, HLM, MLH, LHM and MHL).

   iii. Performance: To analyze the performance of the pull control systems by varying the demand rate (with and without breakdown).

   iv. Case study: A small scale industry manufacturing multi products was considered for the study. Subsequently, the pull control system is implemented considering the real time conditions. The actual results are compared with simulation results for validation.

The model developed for single flow line three stages pull control manufacturing systems are validated by the results obtained from software simulation and analytical method. The system is analyzed for number of kanbans per stage. For optimum performance, the number of kanbans per stage should be equal to or greater than number of stages. Thus, the performance of the system depends upon demand rate and number of kanbans per stage. The performance of single flow line three stage pull control manufacturing systems are analyzed by varying the demand mean time. The performance of CONWIP system is relatively low compared to KCS and EKCS with and without considering the effect of breakdown. The production and average waiting time for KCS and EKCS has similar value; however, the average work in process for KCS has low value. The KCS has optimum average waiting time and work in process. The effect due to imbalance in processing mean time has marginal influence on the performance of CONWIP system as compared to KCS and EKCS. There is no effect of imbalance on production, WIP and machine utilization in KCS and EKCS. However, it functionally depends upon the number of kanbans per stage.

The model developed for two flow lines with three stages in each flow line pull control manufacturing systems are validated from the results of software simulation and analytical method. The performance of the pull control systems are analyzed by varying the demand rate. The EKCS has superior performance i.e. higher production, higher machine utilization, lower WIP and lower AWT, as compared to KCS and CONWIP system. The performance of multi-line production system depends on optimum demand mean time and number of kanbans per stage.

The model developed for single flow line multi stage multi-product pull control manufacturing systems are validated from the results of software simulation and case study. The performance of the pull control manufacturing system is analyzed for number of kanbans by varying the demand rate. At $K_i = S_i$ and $D_i = t_i$ where K_i is number of kanbans per stage , S_i is number of stages, D_i is demand mean time and t_i is processing mean time, the demand rate is optimum, and the performance of the systems shows low variability. The effect of imbalance on the sequence of processing mean time of different stages has the effect on the performance of the systems. The effect of performance on CONWIP system is least as compared to KCS and EKCS. The single flow line with low processing mean time at the first stage and medium processing mean time at the last stage has the best characteristics and the performance of EKCS was better as compared to KCS. The performance of the pull control systems are analyzed by varying the demand rate. At optimum demand rate, the performance of the pull control systems has low variability, and EKCS has better performance as compared to KCS and CONWIP system. The performance of the system depends upon demand, batch size and number of kanbans per stage.

A case study with single flow line three stage pull control manufacturing system for two types of product has been investigated. The performance of the pull control systems were analyzed, with and without the effect of breakdown, using simulation. The KCS and EKCS showed superior performance as compared to CONWIP system. The KCS and EKCS are implemented on experimental basis. The simulation and actual results obtained are validated, compared and analyzed. The production, average waiting time and utilization is optimum for EKCS. Finally, the EKCS was implemented on the shop floor for one month and simultaneously simulated for the same time period. The production of the industry has enhanced substantially compared to earlier production statistics.

LIST OF ABBREVIATIONS

JIT: Just in time

CONWIP: Constant Work in Process

KCS: Kanban Control System

GKCS: Generalized kanban control system

EKCS: Extended Kanban Control System

BSCS: Base stock control system

WIP: Work in process

AWT: Average Waiting Time

MTBF: Mean time between failure

MTTR: Mean time to repair.

MRP: Material requirement planning

LIST OF SYMBOLS

K_i = Number of kanbans per stage.

S_i = Number of manufacturing stages in a flow line

D_i = Demand mean time of stage i.

t_i = Processing Mean time of stage i.

PA_i = Queue of finished parts and kanban of stage i.

DA_i = Queue of demand and kanban of stage i.

P_0 = Queue of raw parts.

λ = Arrival rate

μ = Service rate.

W = Mean Waiting time.

L_i = Queue length of stage i.

d. = Imbalance factor

D = Queue for demands

A_i = Queue of free kanbans for stage i.

R_p = Production rate.

n = Number of kanbans.

LIST OF FIGURES

Page Nos.

LIST OF TABLES

Page Nos

CHAPTER 1

INTRODUCTION

1.1 PREAMBLE

The competitiveness in the manufacturing sector is a key requirement for the country's growth and better employment opportunities [1]. The manufacturing sectors are focusing on the analysis of production control systems to minimize the work in process and manufacturing lead time for the past few decades. The decade of 1990 became popular for lean manufacturing techniques and JIT systems. The lean manufacturing techniques are a typical mix of push manufacturing and pull manufacturing. The philosophy of JIT and other pull control systems is to eliminate waste, reduce work in process and maintain high quality. They are highly effective for minor process variations depending on user demand. The blending of the existing methods is a challenge for the manufacturing of highly integrated, complex and time sensitive products. Thus, the performance of pull control systems for single and multi-flow lines are investigated for different conditions by simulation studies.

1.2 RESEARCH MOTIVATION

The advancement of engineering methods and manufacturing processes are becoming highly integrated, complex, knowledge intensive and globally distributed. The manufacturing industries are striving for higher productivity to meet the competitive global markets. Thus, there is a need for the industries to improve the processes and production systems. Therefore, it becomes essential to study, evaluate and analyze the existing systems and identify the thrust areas for the improvement of production systems. The analytical approach is never easy for the modeling of production systems due to the complexity. The discrete event simulation tool can be used for the analysis and evaluation of the complex production systems. The best solution for the optimum manufacturing process may be time consuming. The multi objectives of production systems may conflict with each other i.e. maximizing production rate, minimizing the cycle time and work in process, may lead to complex situation. The Toyota production system implemented the pull control mechanism for achieving better performance with optimum resource utilization. So far, many researchers have worked to determine the production flow line settings for the configuration of optimum buffer capacity.

The interesting growth area is the application and development of standard methodologies for its implementation and the case studies related to success and failure.

1.3 RESEARCH QUESTIONS

The following are the research question which arises for the initial study of the pull control systems i.e., CONWIP, KCS and EKCS.

i. What is the variation in the performance between single parameter per stage and two parameters per stage?
ii. What are the basic comparing parameters for the pull control systems?
iii. Which tools can be used for the modeling analysis of the pull production control systems?

iv. What is the significant effect of number of kanbans per stage on the performance of CONWIP, KCS and EKCS?

v. Do the pull control systems give the same performance with simulation results and real time results of manufacturing industry? What are the probable reasons for any variation?

1.4 PULL CONTROL SYSTEMS

The material flow and the production in pull control systems depend on the customer demand at the downstream station instead of demand forecast. The upstream workstation produces "just in time" to meet the demand needed by the downstream work station [2]. This improves the product quality and minimizes the work-in-process and overall lead time.

The popular pull control mechanism [3] are Base Stock control system (BSCS), Kanban Control system(KCS), Generalized Kanban control system (GKCS),Extended Kanban Control system (EKCS) and Constant work in process (CONWIP) as a special case of KCS [4]. The philosophy and working of CONWIP system, KCS and EKCS are as follows:-

1.4.1 Constant Work in Process (CONWIP)

The CONWIP system [5] is improved form of KCS. Figure 1.1 shows the network diagram of CONWIP system. The system has only one production kanban to control the complete flow line. The raw part in the queue P_o synchronizes with production kanban - demand combination in the queue DA_i. The raw part with kanban is released to manufacturing stage for processing. After processing of the part, the finished part along with production kanban in the queue PA_i, synchronizes with the customer demand D_{i+1}, the finished part gets separated from the kanban and is delivered to the customer. Simultaneously, the production kanban with demand goes to the upstream station queue DA_i to synchronize with the new raw part for next cycle.

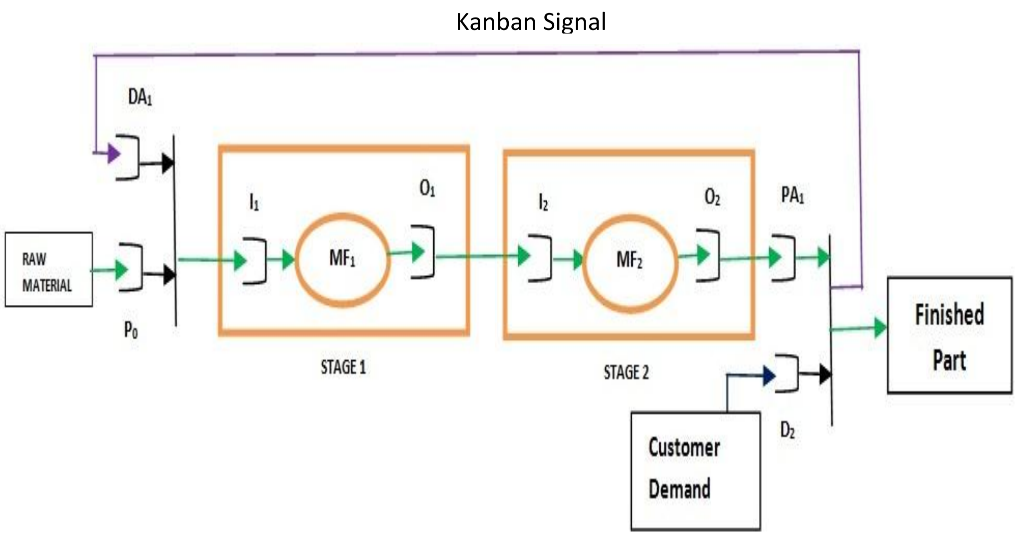

Figure.1.1: Network of CONWIP System with two stages in Series

1.4.2 Kanban Control System (KCS)

The KCS was first implemented in the Toyota Production line. The Figure 1.2 shows the network diagram of KCS. The word kanban means a card refers as production authorization attached to a part authorizing its release into a stage.

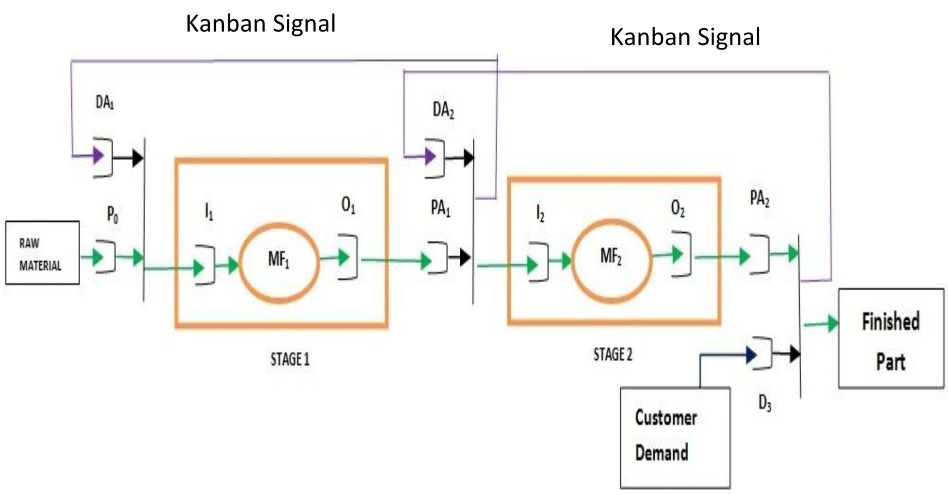

Figure.1.2: Network of KCS with Two Stages in Series

The philosophy of the KCS is that a customer demand D_{i+1} and kanban K_i is transmitted to the upstream stage i only when the finished part in the output queue $PA_i + K_i$ of stage i synchronizes with demand D_{i+1}. The KCS provides a tighter coordination of kanban and the part between stages and authorizes a new part only after it has released the finished part to the downstream stage

1.4.3 Extended Kanban Control System (EKCS)

EKCS is the combination of BSCS and KCS. Figure 1.3 shows the network diagram of EKCS with two stages in series.

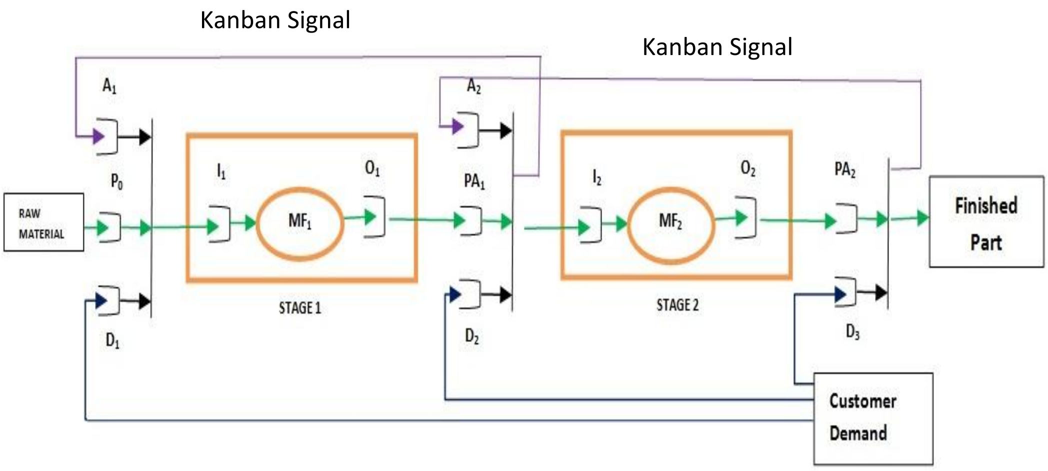

Figure.1.3: Network of EKCS with two stages in Series.

The philosophy of the EKCS depends on the arrival of customer demand D_i to all the stages simultaneously. The part is authorized to release from the stage of queue PA_i to downstream input buffer I_{i+1} after synchronizing with demand queue D_{i+1} and kanban queue A_{i+1}. The kanban A_i is detached from the part and kanban A_{i+1} is attached to the part and moves to the stage S_{i+1}.

1.4.4 Multi-Product pull Control System

The multi-product pull control system handles more than one type of product in the flow line. The production kanban based control system proposed is of two types, dedicated and shared. In dedicated kanban system, each kanban is assumed for each product type independently as shown in Figure 1.4

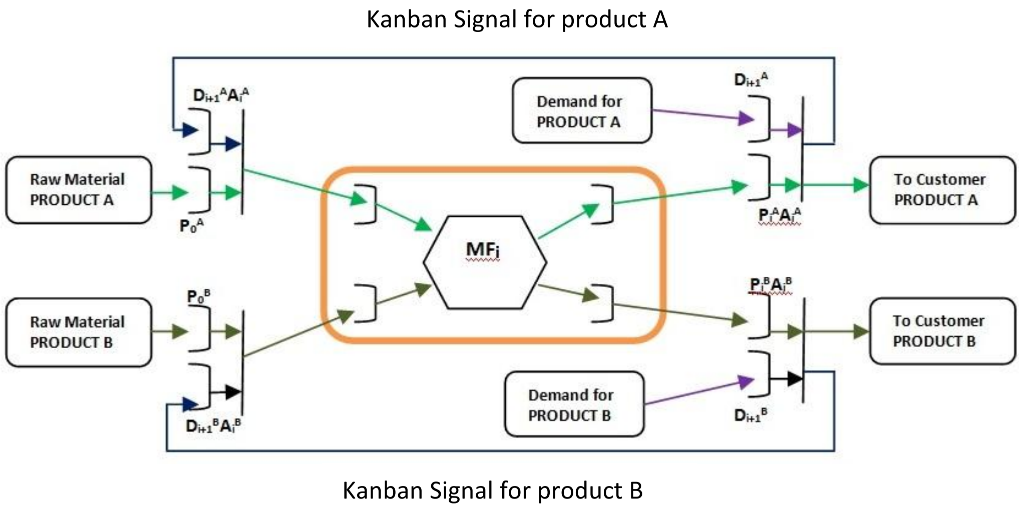

Figure.1.4: Network diagram of multi-product dedicated kanban system

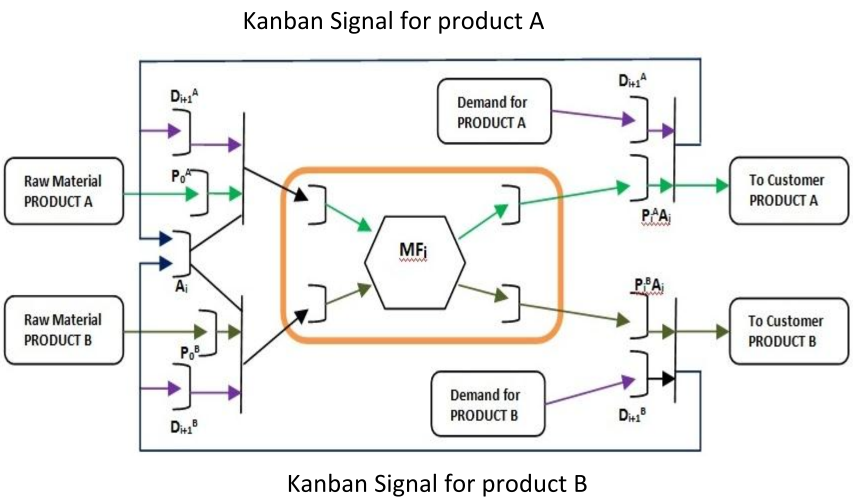

Figure.1.5: Network diagram of multi-product shared kanban system.

In shared kanban system, the kanban is shared between the product types manufactured in the flow line manufacturing systems as shown in figure 1.5 [6]. The flow line manufacturing system with stages in series is a composition of workstation, input buffer and output buffer.

1.5 PERFORMANCE MODELING TOOLS

The performance evaluation methods for production systems are categorized into two classes: performance modeling and performance measurement. The performance of the manufacturing system is configured by modeling and simulation using MATLAB/SIMULINK R2011b that supports powerful graphic animation. The analytical model is developed by using the programming language ‘C’ considering Markovian chains and closed form queuing techniques for validation. The performance of the system is analyzed and evaluated.

1.6 ORGANIZATION OF THESIS

The first chapter contains the background analysis of pull control manufacturing systems, research motivation and research questions. Chapter 2 covers the literature review of manufacturing evolution and developments, JIT system and pull control systems applied to single line, multi-line, multi-product systems and queuing networks along with the definitions of important terms used in the forthcoming chapters of the thesis. Chapter 3 covers the research objectives and the methodology. Chapter 4 presents the modeling, simulation and analytical configurations applied to CONWIP, KCS and EKCS for the performance measurement and enhancement. Chapter 5 presents the results and discussions that analyses the performance of various configurations considering the factors like machine breakdown, number of kanbans per stage, imbalance in processing time, demand variation etc. Chapter 6 discusses the industry case study of multi product flow line system. Chapter 7 presents conclusions derived from the work and significant contributions that arise from the investigation. A brief scope for further research has been identified to provide direction and possible extensions to the work. The reference presents the details of the technical papers referred in this thesis work. Lastly, the appendices include the code generated in programming language ‘C’ and the details of the software MATLAB/SIMULINK.

1.7 SUMMARY

This introduction chapter presents the overview of the dissertation in terms of its research area, motivation and preliminary research questions. This chapter presents a brief introduction, working and characteristics of pull control manufacturing systems, CONWIP, KCS, EKCS and classical theory of multi-product pull control system. The modeling and simulation tools for the analysis of complex system have been briefly introduced.

CHAPTER 2

LITERATURE REVIEW

A manufacturing system is a combination of human, machinery and equipment bounded by material and instruction. A detailed literature review is carried out in the areas of manufacturing evolution and development, JIT systems, pull control systems for single flow line, multi flow line, single flow line multi-product manufacturing systems and analytical queuing network with different configurations is presented. A number of analytical and simulation based approaches have been reported in the literature for the performance measurement of manufacturing systems.

2.1 INTRODUCTION

In recent years, manufacturing management interests are directed towards better resource utilization, high quality and low work in process. The manufacturing systems are divided into production cells. The self-managed production cell is a composition of an input buffer, manufacturing facility and an output buffer to coordinate production between self-managed cells by creating an integrated system. In pull control system, the time and quantity of parts to be released into each cell is based on the arrival of the customer demand. JIT manufacturing, the application of KCS invented in Toyota in the year 1970 has since been used widely in industry [7].

2.2 DEFINITIONS

The following elements are used in the body of the thesis that are defined and described.

i. Manufacturing Systems: A manufacturing system is an objective-oriented network of processes through which the entities flow. The objective is to transform the entity or part from one form to another [8].

ii. Entity: The entity means both the physical parts manufactured and the information passed through the system [9].

iii. Process: A process is a machine or a set of machines that performs the activity on the semi-finished components like mechanical removal of material, painting, assembly, inspection etc.

iv. Processing Time: The processing time is the number of time units the manufacturing equipment works on the part [8]. The component is held in the process which includes working time, setup time or preparation time. The breakdown time and other time consuming activities are modeled separately.

v. Flow Line Manufacturing Systems: The systems with processes in tandem and buffer in between the workstations for the components or parts to flow in a line. The flow line manufacturing systems is adjusted depending on the type of product.

vi. Working state: The process performs a work on the part or waits to move out of the process. The process is stopped or waits for the repair after a failure, or setup a process for new type of component.

vii. Work in Process (WIP): It is the number of parts between a start state and an end state in the flow line system.

viii. <u>Throughput</u>: Throughput or production rate (parts per time units) normally measured at the last station of the flow line. For certain conditions, it is necessary to measure the throughput at the first station or intermediate station.

ix. <u>Cycle time</u>: It is measured as the time elapsed (time units) for each component from the first station to the last station of the flow line system.

x. <u>Inventory/buffer</u>: Inventory is the storage for all types of parts in a system. The inventory is classified into four main categories: raw material, work in process, finished goods and spare parts [8].

2.3 MANUFACTURING –EVOLUTION AND DEVELOPMENT

Manufacturing enterprises are leaning forward for the integration of technology and manpower with planning, production, simulation, inspection, algorithm etc. The development of coordinated and automated concept is the revolution in the field of manufacturing [10]. The objective is to achieve high quality, optimum batch size and less cost. The future of manufacturing concentrates on issues like non-productive time, lean manufacturing and integration of processes.

Adaptive manufacturing is the latest evolution of long term trends in discrete manufacturing [11]. The pre-requisite for adaptive manufacturing is network friendly processes. The software implements adaptive manufacturing and integrates all the elements of product life cycle.

The manufacturing systems are reviewed [12] for the rapid systems by incorporating the principle of modularity, integration, scalability, adaptability, quality, reliability, system capability, flexibility and cost effectiveness. The important characteristic of the system is to reconfigure by making hardware and software design modular.

The turbulence and uncertainty in manufacturing system and environments are due to economic globalization and higher production capability [13]. The needs of manufacturing systems are shorter lead time, variability, customization and production fluctuations, low price structure, high quality and durability. The future manufacturing objectives is to devise the methods to coordinate modular components and to minimize the idle resources wastage.

Flexibility and changeability in manufacturing paradigm are the challenging parameters of production planning and control for evaluation and economic justification [14]. The human resource, technology and other new methods are adaptable parameters of manufacturing and production for sustainable competitiveness whereas markets, social factors and environment influence economical factor. The objective of changeability in manufacturing systems depends upon product flexibility, operation flexibility, capacity flexibility, changeover ability, re-configurability, transformability and agility.

The advancement of manufacturing with information technologies lead to strategic approach for the design of manufacturing information system [15]. This helps the industries to respond quickly to market fluctuations and manage the product and process flexibility.

A comprehensive review of production control systems based on the design for repetitive and flow shop environment are categorized as stock leveled control, flow scheduled, order controlled and hybrid systems [16]. The stock leveled controlled system is like a periodic review system. The CONWIP system, KCS and hybrid systems are the field of research for the practical application. The flow scheduled systems like base stock, material requirement planning (MRP) systems are more adequate to non-repetitive environment. The hybrid systems like hybrid- Kanban, hybrid push/pull system and hybrid decentralized work in process are suitable for job shop and non-repetitive environments. The hybrid systems constitute a promising field of research for the practical applications. The comprehensive review of manufacturing domains in industries is presented [17] and is focused on manufacturing design and knowledge modeling. The industry functions include planning, design, manufacturing, scheduling and control, execution, supporting structures and database systems. The collaboration of manufacturing domain with industry is largely application driven to improve the manufacturing information system extensively and to identify the future research issues.

2.3.1 Summary

Manufacturing Industries are focused towards the integration of resources for the optimum utilization and effective system [10]. The manufacturing issues are related to non-productive time by integrating the process for quality, reliability [12], adaptability, flexibility and agility [14]. This makes the system more adaptive, network friendly [11] and responsive to market variations. The manufacturing domain is application and industry driven to improve the information database and knowledge structures effectively [17]. The modular components in manufacturing minimizes the wastage of idle resources [13]. The pull control systems constitute low WIP for the flow shop and repetitive environment. Hybrid system [16] is the promising area of research for the practical application of job shop, repetitive and non-repetitive environment.

2.4 JUST IN TIME (JIT) SYSTEM

JIT, an application of KCS was invented in 1970 and implemented in Toyota to accomplish production [2]. The philosophy of KCS is based on the demand moved to the upstream stage of the flow line for the release of part to the downstream stage for processing.

JIT system manages the required products in required quantity at required time to every manufacturing stage in a flow line. The principle of kanban based JIT system for a three stage transfer line is analyzed [18] for the parameters like number of kanbans, bottlenecks, variation in demand mean time etc. for the defined model using simulation. The performance results of these simulations are more latent than real and points out some of the marginal tradeoff for optimization in JIT. The paper demands for more work on complex transfer line, flexibility etc. as the direction for future study.

A JIT system is a composition of production centers, inventory area, batches, production kanban, withdrawal kanban and containers [19]. JIT is an alternative to other manufacturing environments which includes constant work in process, reorder point, hierarchical production planning, and MRP. The JIT consideration is constant production rate and smooth flow of information to the adjacent levels. The worker’s idle time may increase in the case of machine breakdown.

A review addressing JIT production and inventory system is presented [20]. The demonstration of JIT system includes concepts, components and mechanics. It is compared with other production and inventory control applications.

The formulation of two novel tractable and optimal regenerative kanban control policies are introduced [21]. One is minimizing weighted starvation penalty and the other is maximizing weighted throughputs per unit time. This reduces the effect of processing time variations on the system performance. The optimal policy is vital to the design; analysis and control of complex type pull control systems. The performance and reliability may affect the dynamic changes in number of kanbans, machine failures and repair.

The thrust areas i.e. flow line problem, flow line loading and operational control exist in designing and implementing the JIT system are revealed [22]. The operational control problem is considered for single line multi stage system and modeled in a discrete time markovian process. The performance of JIT system is measured considering the effect of number of kanbans, machine reliability and the demand variability. The performance of the system achieved incremental improvement by reducing inventory level which results improvement of machine reliability. The book [23] is an excellent treatise for practical application of JIT. It covers control of production, reduction of waste, performance criteria and measurement.

The simulation of JIT system presents the behavior of manufacturing system to implement in the industry. The JIT system was modeled using the software SLAM and the comparison of results for pull and push systems are reported [24]. The study revealed that for modeling and simulation, the initial capacity of the input queue at each workstation is assumed as one for steady state behavior.

Ideally, the flow line manufacturing system has no inventory in the buffer. This is feasible only, when the processing time and worker performance are same. In real situation, the distribution related to worker and processing time deviates affecting the performance of push and pull type manufacturing systems [25]. The other parameters can be investigated to evaluate the performance for future research.

The review of JIT, MRP and its implementation for the productivity improvement are reported [26]. The investigation analyzes critical variables for waste elimination and employee involvement in decision making, supplier participation, total quality control etc. for implementing JIT.

The project management technique to adapt JIT in a small scale industry are presented [27] by analyzing the key elements like material shortage, manpower planning and shortage of vendors. The project management techniques are used for productivity improvement and lead time reduction.

JIT and MRP are iterative. They are the important characteristics for the material flow and are crucial to rate the success and failure of a manufacturing industry. The primary overview of manufacturing planning and control associated with MRP and JIT in manufacturing industry is presented [28] and is the prospective scope for future research.

A rule is defined to compute number of kanbans by considering critical factors [29]. In case of JIT, the classification and regression tree technique (CART) is defined for automatic computation of number of kanbans and the condition for its application in shop floor management. It is a useful direction of future research.

A new kanban system i.e. flexible kanban system (FKS) is designed to compute the number of kanbans because of breakdown and to measure the performance by simulation [30]. The performance of the FKS is superior as compared to the traditional kanban system. Single station breakdown was considered for the seven station flow line. The performance parameters are compared for average production time; order completion time, production rate and resource utilization for the same demand mean time.

The review, philosophy and the concept of push and pull systems are discussed [31]. The measure of the system performance depends on throughput, production lead time, utilization, work in process etc. The suggested future scope can be analyzed by met heuristic algorithm, genetic algorithm and simulated annealing (GASA) and ant colony approach. The minimum number of kanbans and performance comparison for relative improvement are determined. The various approaches like mathematical model, queuing model, simulation and markovian models, cost minimization model, constant WIP, supply chain management and its significances are discussed.

The performance study and measures of multiple parameters for JIT and total quality management (TQM) using the data obtained from few manufacturing companies are discussed and reported [32]. Manufacturing and competition are the important characteristic variables for the performance measurement system. The study analyses the techniques i.e. JIT and TQM, through the data collected from 122 manufacturing companies. The results reveal that the firms using JIT and TQM have high market position and multi-dimensional performance compared with others. It also becomes necessary to examine the variables like CAM, business structure, business size and culture.

The key to the growth in the trade share is the adoption of JIT manufacturing [33]. A numerical simulation of the trade share model is capable of capturing nearly half of the growth. JIT increases trade by developing a theory based on the logistics and supply chain technology. Technological parameters to implement JIT increases trade through the flexibility, price, and switching effects.

The author [34] presented the review focused on elimination of waste and productivity improvement. The performance behavior of manufacturing system by JIT, kanban system, CONWIP system and Kanban-CONWIP hybrid system are discussed. The performance parameters of JIT control techniques are broadly analyzed with issues related to JIT concepts.

Thirty two variations of the kanban systems classified into six categories are studied and investigated [35]. The operational difference between each variation and the original kanban systems were tested by using classification method which provides useful insights. After investigation, it was found that there is a great different between the theoretical and practical aspects of kanban systems.

Taiichi Ohno is credited for creating the JIT system to reduce the lead time, absolute elimination of waste, lower inventory, continuous improvement, cost reductions and high profit margins of TPS [36]. Optimal lot sizes are computed for higher efficiency and the workers were forced to become multi skilled. For mass production, the production efficiency increases by 2 to 3 times over one worker for one process.

The methodology of TPS and their practices are concentrated to increase from low to high targets [7]. It explains the basic logic and methodologies of TPS. It covers new information about Toyota practices in relation to humanistic management intensively. The methodology explores the latest developments of the TPS framework with updates like e-Kanban, mini-profit centers, computer-based information systems, cellular manufacturing, conveyor lines and innovative solutions to common obstacles [2]. It highlights the relative link between kaizen method and calculation method in TPS.

2.4.1 Summary and Research Gaps

The JIT accomplished by Toyota is an application of KCS [36]. It has been used in industry and confined to single line multi stage system. The JIT philosophy is based on the customer demand, which moves from downstream to upstream, whereas the part is processed from upstream to downstream. The literature presents the review of JIT and Kanban system with the concepts to reduce the work in process and increase in throughput [31]. The performance behavior of the system was presented for varying the number of kanbans per stage [24]. The modeling of three stage flow line is done using simulation software and results are analyzed for the number of kanbans and demand. The mathematical modeling was developed for single stage flow line and the input-output variables are defined for the performance measurement. Manufacturing enterprises adopting JIT and TQM techniques possess good position in market [32]. The performance of JIT depends on the variables like CAM, business structure, business size and culture for the industry growth [7].

The following are the research issues that are derived from the literature analysis:

i. Performance analysis of JIT systems may need a normative approach for the future study and analysis taking into consideration the complex transfer lines, mixed product and flexibility. It may be linked with other parameters like inventory control, inspection, vendor and total quality management (TQM) for the performance measurement.
ii. The effect of performance of JIT system (which includes minimum work in process and maximum production) due to dynamic variations in number of kanbans, machine failures and repairs, demand variability, reliability and inventory.
iii. The JIT systems are modeled and simulated for defined queue capacity. The performance can be investigated by considering more queuing factors at each workstation in the flow line.
iv. Performance analysis of JIT system using mathematical modeling, simulation, and cost minimization is presented [33]. The performance investigation of JIT system by using heuristic algorithm, GASA and ant approach etc. is the direction of future research.
v. Need for implementing the elements of project management like material shortage, manpower, and effect of productivity and reduction of lead time for the performance measurement of JIT system.

2.5 PULL CONTROL MANUFACTURING SYSTEM

Manufacturing system is the process of converting raw material into a physical product. The complex manufacturing systems are analyzed by modeling and simulation [37]. There are numerous cases to analyze the performance and behavior of typical systems like semi-conductor factories, chemical plants, automobile assembly lines, factories for lithographic equipment, wafer furnaces, chemical clinical analyzer etc. [37]. The different analysis methods suggested are rough estimate, simple queuing equations, advanced queuing theory, stochastic process theory and discrete-event simulation.

The theoretical concepts of asynchronous, synchronous and continuous flow line models are discussed [38]. The performance features of the flow line include blocking processing times, failures, repairs; idle times and their relationship with different models are discussed. Approximation methods are developed based on decomposition for large flow line systems. They are developed for quantitative measurement by small system approximations.

The review of traditional re-order point and economic lot size in Toyota replacing kanban method is presented [39]. The optimization model of kanban based systems covering serial production lines, bottleneck workstations and production of job-shop assembly is reviewed. The developed models are helpful for the production planners to choose number of kanbans and lot size for performance measurement.

The approximation method was developed for the steady state performance of a multi-stage system with assumed processing times in series with inventory in the intermediate buffer [40]. The production at each stage builds till the inventory reaches the limit. Once the inventory drops down to its re-ordering point, the system undergoes set up and the production is resumed. An approximation method is developed for the steady state performance of the system.

The production control systems i.e., KCS and CONWIP system for single product flow line with exponential service time distribution and unlimited demand are analyzed for the production rate and work in process [41]. The performance of KCS is more flexible than CONWIP system due to low work in process. It depends upon inter stage buffer and distribution of kanban cards which follows bowl phenomenon. The study of flow line performance for the variation of processing time is the direction for future research analysis.

The review and performance of pull control systems viz. KCS, BSCS and CONWIP system for repetitive manufacturing is discussed [42]. The information pattern for all the systems is combined and new hybrid policy is generated. The simulation results are compared and the performance of hybrid system out performs the individual KCS. The higher variation in the input parameters also benefits hybrid systems compared to KCS. The hybrid system combining with CONWIP system shows better performance.

The analytical method for the performance evaluation of multi stage kanban control production systems decomposed into stages is presented [43]. Each manufacturing stage modeled as queuing network is a composition of input buffer, output buffer and kanbans per stage. The performance of the system is analyzed in isolation using product form approximation technique. Results obtained by approximation technique are compared with simulation results and the difference is found to be marginal.

The performance of four stage tandem production line manufacturing the parts of an automotive assembly line is analyzed [44]. The KCS, BSCS, CONWIP system and KCS–CONWIP hybrid system are evaluated with minimal blocking. The performance is analyzed for constant demand rate and varying demand rates by simulation. Analyzing the results, the inventories of hybrid system are reduced by 10% to 15% compared with other kanban systems for the same input. The inventory increases with increase in the demand mean time and other inputs. Thus, the CONWIP system and hybrid system respond significantly for the change in demand rate.

A mechanism for production coordination and control of a multi stage make-to-stock system is devised [45]. The performance of the mechanism was analyzed for BSCS and KCS for the change in demand. The single stage and multi-stage model were evaluated and analyzed using numerical values. The mechanism worked remarkably for single stage system compared to multi stage system. The waiting time is reduced by 15% and production is increased by 10%.

The practical rules are defined for KCS, BSCS and GKCS for make to stock [46] to provide quantitative and qualitative comparisons to implement the production control systems. The cost is same for the three systems. However, for the order delay, the GKCS and BSCS have lower cost compared to KCS for the similar conditions of quality.

Simulation studies are performed for semi-continuous manufacturing cold rolling plant. The production control of the plant is by Material resource planning, CONWIP system and KCS [47]. CONWIP system was more effective based on simulation analysis. The WIP, inventory and inventory carrying cost are decreased whereas the throughput rate and resource utilization are increased.

An analytical approximation technique was developed for the performance evaluation of production lines for asynchronous and synchronous models [48] based on the decomposition [49]. The features of analytical method developed for continuous flow line model includes random yield, split and synchronizing mechanisms, and multi-product assembly systems. The efficient analytical approximation techniques developed are based on the decomposition extended to other configurations like closed-loop production lines, assembly and disassembly systems. Developing analytical methods with different configurations for real time applications is the direction for future work.

An optimization algorithm, Finite Perturbation Analysis (FPA), for single line multi-stage manufacturing systems was developed and analyzed to maximize throughput [50]. The number of kanbans and constant work in process is adjusted depending on the arrival and service time distributions. The algorithm is driven by the throughput sensitivities and can be estimated along the sample path of the system. The algorithm converges to optimal probability kanban allocation. The FPA algorithm derives an optimal kanban allocation for the smoothness condition. The alternative techniques like concurrent estimates for estimating the finite differences in kanban allocation and system generalization with multiple products is the direction for future research.

The material movement on the shop floor is administered by kanban system and the model is developed by object orientation technique [51] for property definition. The kanban system is simulated for the material requirement. The system increases the extend ability, flexibility, reusability of the model and directs towards enterprise integration.

The container sequencing for the kanban system is presented [52, 53]. The container movement between the stages is classified into kanban lot, production Kanban and withdrawl Kanban. The heuristic recursive equations are developed for sequencing and scheduling the containers, production kanban and withdrawal kanban for reducing the weighted flow time and tardiness of the container. The performance and bench mark is evaluated for the determination of container for various sizes and capacity.

The three stations tandem flow line for CONWIP system was analyzed [54]. An analytical method evaluates the system performance of three work stages to show how the optimal CONWIP system can be designed for chosen design criterion by considering saturated and non-saturated conditions. The supply of demand is infinite for saturated condition. In non-saturated condition, the demands arrive according to a Poisson process. This analytical method can be extended to more number of work stages and other types of pull control systems.

The analysis of the best pull control mechanism is very difficult to quantify [55]. A two stage model and an optimal control framework are used to measure the performance of a typical pull control mechanism following the stochastic principles. The pull control systems react rapidly to actual occurrences of demand to gain importance. The performance of pull control system was analyzed for the tradeoff between single stage and multi stage. Under certain conditions and for low demand rates, the performance of pull control mechanisms was very poor.

The routing flexibility leads to the production of the parts by alternate routes. The alternate routes are created by the use of different machines, different operations and different sequences [56]. The system with flexible routing was simulated by using simulation language SLAM (pritsker 1986). The routing flexibility has good effect on performance factors like backorder demand and work in process which is equal to number of workstations. The performance is good for higher flexibility. The performance of the pull control system can be evaluated using different scheduling rules as a scope of future study.

The basic framework of pull control system and its coordination for movement and release of parts for a multi stage manufacturing systems is presented [3]. The four basic pull production control mechanisms are: BSCS, KCS, GKCS, and EKCS. Few blocking mechanisms with restrictive cases of a multi-stage manufacturing system are CONWIP system and hybrid systems to control the work in process within each stage. The performance of each mechanism may be evaluated using numerical values for future research.

EKCS depends upon KCS and BSCS [57]. The property of EKCS depends on number of kanbans per stage. The optimization of kanban and base stock are done by simulation. Developing an algorithm for the EKCS property is a direction for future research.

The KCS and CONWIP system are reviewed for modeling and simulation by simulation software SIMAN [58]. The WIP for KCS is less compared to CONWIP system. In CONWIP system, one Kanban manages the entire flow line system.

An adaptive pull control system determines the release of parts based on customer demand [59]. An adaptive kanban system is superior compared to traditional kanban system after its implementation. The objective of adaptive system is to reduce work in process and limits the number of kanbans per stage. The kanban mechanism was investigated for the optimal design of multi stage system [60] by genetic algorithm (GA). The parameters optimized are number of kanbans, size of container, raw material, and inventory at each stage of manufacturing system. The future research direction is the performance of the pull control systems for the demand, transportation and other economical parameters.

The performance of CONWIP system was reviewed in the areas of operation and application for card setting and job sequencing [61]. The performance comparison of CONWIP system with other pull control systems is the relevant area for future research.

Echelon kanban system and hybrid system combines and synchronizes with reorder point and kanban policies of manufacturing systems [62]. The combination can be done in a synchronized or an independent way, leading to synchronized and independent hybrid policies, respectively. The production-inventory control system for non-serial systems in the hybrid models is the direction for future research.

The classical stock, echelon stock policy with advanced demand information was discussed [63]. The modeling framework was explored to include the production inventory control policies for non-serial systems.

The production systems with rework loops was implemented in manufacturing plants to improve the design and performance [64]. The production system are decomposed into four serial production lines, with the relationship of machines and buffer to accommodate the system with rework loops. The performance of the system was evaluated numerically and the results are validated analytically.

The scheduling of JIT manufacturing systems in shop floor environment is the complex task in operations management [65]. The manufacturing systems are designed and scheduled for 100 per cent machine reliability, without considering random interruptions. The JIT driven flexible manufacturing system was devised as a model to investigate the machine breakdown and material handling system. The changes in JIT system are characterized case by case based on the operating parameters for the optimum performance.

The pull and lean manufacturing techniques has significance in modern manufacturing technologies and can be implemented at strategic and tactile levels [8]. The pull control systems and lean manufacturing system is an important technological approach to reduce work in process and to minimize the inventory cost. The pull control systems can be monitored easily with less system congestion, better control and minimum work in process. The practical approach and its implementation in real areas is the challenging aspect towards future research.

The KCS has shortcomings in non-repetitive manufacturing environments [66]. The first approach is to develop a new system by combining the existing pull control systems. The other approach is the integration of JIT and MRP philosophies. The review and comparison of pull control systems addresses the service level and WIP tradeoff at low demand rate variability.

The tradeoff for multi stage system for optimal base stock levels, lead times and number of kanbans in base stock, kanban system and hybrid base stock/kanban policies are investigated using numerical values [67]. Advance demand information is used for the control of multi stage production inventory systems. The simulation-based computational method for tradeoff and control is analyzed for single-stage and two-stage production inventory systems. The optimal production capacity of the system depends on number of kanbans and is independent of advanced demand information.

Two alternate kanban control policies, simultaneous and independent release of kanbans are designed for the assembly systems [68]. The control system are evaluated by simulation for the performance parameters i.e. throughput and work in process. The results are validated by analytical approximation. The selection of appropriate control policy depends on the design phase.

The framework of JIT and MRP systems is analyzed for the vertically integrated hybrid system (VIHS) and horizontally integrated hybrid system (HIHS) [69]. The survey confirms that the JIT has more popularity compared to MRP system. The adoption of JIT and MRP with hybrid systems is low and the firms are unsure to adopt it.

The KCS is more flexible than CONWIP system for single product assembly systems with continuous demand at the end of the flow line. The number of kanbans is an optimum design consideration of the flow line system [5]. The KCS is superior to CONWIP system for the average WIP and the same throughput.

An analytical product approximation method is designed for the performance evaluation of a multi-stage, serial, echelon KCS [67]. The system is decomposed into a set of nested sub system using echelon technique. The system was fairly accurate with numerical results.

A case study of kanban system applied to a leading Australian lawn-care products manufacturing company was presented [70]. The KCS was implemented and analyzed to measure the overall benefits. The WIP, labor costs, assembly lead time, number of workers in the system are reduced and the production has increased significantly. The focus of future research to reduce number of kanbans, improve productivity and cost effectiveness.

The way to implement the multi kanban model in disassembly line was analyzed. The multi direction routing of kanbans in disassembly line depending on the real time conditions was analyzed [71]. The objective of the system was to minimize the work in process for varying demand levels considering blockage, starve and breakdown. The simulation results of multi kanban system used in the disassembly line was compared with traditional push system. Multi kanban system was superior compared to the traditional push system considering inventory level, demand and waiting time.

The hybrid pull type production system for manufacturing and remanufacturing activities satisfying the incoming demand was reviewed [72]. KCS, BSCS, GKCS and EKCS are compared for single-stage hybrid production system for a stochastic model developed by using approximation techniques. The comparison was done on the basis of cost function. EKCS was considered the best in terms of cost. The future research is the determination the unique characteristics of remanufacturing system compared to manufacturing.

Hybrid extended kanban control system (HEKCS) which is a combination of EKCS and CONWIP system, was proposed for single line multi stage manufacturing system with and without breakdown [73]. The performance of the system was analyzed by varying the demand rates using simulation. HEKCS has superior performance compared to EKCS and CONWIP system at higher demand rates.

The optimum number of kanbans are determined for generalized single flow line multi stage EKCS for different demand rates [74]. The optimum number of kanbans is determined by simulation software PROMODEL for lower work in process, higher production and higher utilization. A new algorithm was proposed [75] to determine the optimal WIP which depends on number of jobs and machines. The performance of the system was very good found to be without any significant error.

The determination of optimum number of kanbans for EKCS for different demand rates are analyzed and presented [74]. Simulations studies are performed for the single line three-stage EKCS with and without breakdown. The selection of optimum number of kanbans depends on maximum throughput, low work in process and high machine utilization. The number of kanbans with breakdown is more compared to without breakdown.

The performance of pull type kanban automated production system was analyzed using simulation techniques[76]. Three workstations including bottleneck station are considered. Sensors are introduced and positioned to control the speed of flow line, operational variations and performance. The accurate performance measures such as throughput, work in process and queue length depend upon the sensor position of the automated systems.

The modified kanban systems are studied for characteristics, operational differences, advantages, disadvantages with reference to the original kanban systems [35]. The objective was to improve the kanban system by adjusting it to the necessities of the production systems. The analysis presents the performance difference between ideal kanban and real kanban.

Simulation is an analysis tool for quantitative comparison of different system design effectively. The evaluation and comparison of performance of CONWIP system and pull system that limits WIP is carried out to explore the utilization and inventory control [77]. Simulation experiments were conducted to optimize inventory by maintaining throughput and cycle time of pull system as compared to push system. The impact of lean approach on the performance of the system using simulation could be the scope for future research.

A new approach of KCS has been proposed based on Petri nets [78]. Kanban is the important element of JIT and is suitable for stable demand. The Kanban can be adjusted by varying the demand for the efficient system. The Petri nets can be useful to model a kanban loop. The analytical relations of Petri net models are developed by using continuous approximation of a discrete petrinet model to control and improve the kanban system. The main advantages of the model are speed, stability and adaptability. The Petri net model results can be compared with concurrent methods of kanban system as future research work.

The kanban system was developed and implemented in a Malaysian manufacturing company. The study discussed the flow of implementation of manufacturing activities prior to kanban system. The implementation of kanban system optimizes lead time, minimizing shop floor and storage area [79]. The implementation of kanban system has optimized the manufacturing capability to satisfy the customer demand. Thus, the implementation of kanban system improves manufacturing systems and achieves JIT practices.

The order lead time for MRP system is determined for cost effectiveness. The system is modeled by markovian chain (Birth and death manufacturing process) and solved by geometric matrix techniques [80]. The system is tested by using numerical values for static and dynamic conditions to update the number of kanbans based on the lead time frequency and setting up the guidelines for the design parameters.

2.5.1 Summary and Gaps

The literature describes the review of synchronous, asynchronous and continuous serial flow line multistage system [38] which includes features like blocking of flow line, failure and repairs of workstation, reorder point for inventory and lot size for the performance measurement [39]. The evaluation of reorder point and kanban policy for non-serial systems is done by two proposed systems i.e. echelon and hybrid policy [81]. It is further extended to advance demand and MRP, by simulation and decomposition method. The analytical product form approximation method developed [43] for measuring the steady state performance of KCS produces high yield [48]. The analytical approximation technique proposed for BSCS was developed for production control, make to stock and lead time reduction for single stage and multi stage systems [45]. The single stage system was more effective than multistage system. Further, stochastic principles were used to define the performance measures of the pull control mechanisms. The performance was analyzed for the tradeoff [55] between single stage and multi stage systems which was ineffective for all the pull control systems.

The FPA algorithm [50] was developed for single line, multi stage kanban control system to maximize throughput, optimize number of kanbans and reduce work in process. Further, GA is used to compute the number of kanbans per stage, size, raw material and work in process per stage for the optimal design [60].

Heuristic equations are developed [52, 53] for container sequencing, kanban scheduling for optimizing container capacity. Analytical product form approximation methods are used for the performance analysis using inspection of each station for three stage CONWIP system [55]. The KCS uses two types of kanbans viz., simultaneous and Independent [68]. They are simulated and validated by analytical approximation for the performance evaluation. However, the system performance depends on the design phase of the system.

The complete frame work of pull control systems is defined in detail [3]. KCS, BSCS and CONWIP system for single product repetitive manufacturing with unlimited demand are analyzed for production and WIP [41]. The performance of KCS is highly flexible and WIP depends upon the buffer size in intermediate stages. The hybrid pull control system is defined with the combination of pull control mechanisms. The simulation results of hybrid systems with CONWIP system combination gives superior performance compared to KCS [42]. Further, the hybrid system for multi stage flow line was simulated for fixed and varying demands [44]. The work in process is reduced from 10% to 20% compared to other mechanisms.

The simulation studies for the production control of manufacturing rolling plant are done using CONWIP system and KCS [47]. The CONWIP system is effective for higher throughput and utilization and is less effective for work in process or shop floor inventory.

The material movement on shop floor is the integration of kanban and system automation [51]. This reduces the modeling and simulation time. The rule for KCS, GKCS and BSCS are defined for make to stock [46]. The KCS has higher cost compared to other mechanisms and the performance depends on number of kanbans. The performance of GKCS and EKCS for balanced line is reviewed and simulated for number of kanbans [73, 74]. The review states that the behavior of kanban system affects the manufacturing performance and depends upon the real kanbans [35].

Routing flexibility to manufacture parts by alternate routes is modeled and simulated by using software SLAM. The system performance is high with low WIP [56]. The performance of KCS and CONWIP system is reviewed by simulation using the software SIMAN [58]. KCS has lower WIP as compared to CONWIP system. Further, the operation and application for CONWIP system is reviewed [61] along with kanban setting and sequencing. The pull control systems are designed for maximum reliability without breakdown for the performance measurement [65]. Adaptive type KCS is flexible and reduces the WIP for varying demand [59]. The implementation of rework loop in pull control manufacturing systems [64] for the improvement of design and performance by serial flow line yields the relationship between machine and buffer.

The following are the research issues that are analyzed from the literature review.

i. Performance analysis of pull control mechanisms for flow line manufacturing systems considering numerical values for balanced and unbalanced processing times, varying demand, machine breakdown, material handling breakdown and number of kanbans.
ii. Performance of pull control mechanisms on cost effectiveness, productivity and safety.
iii. Pull control hybrid combinations with CONWIP system and inventory control policy for serial and non-serial flow systems.
iv. Analytical methods of pull control mechanism for real time applications and hybrid combinations for single product and multi-product.
v. Performance of pull control systems with routing flexibility for different scheduling rules.
vi. Performance of pull control systems and hybrid systems for optimizing number of kanbans and base stock using simulation and analytical approaches.
vii. Performance of flow line due to rework loop and its effect on production.

2.6 PULL PRODUCTION CONTROL SYSTEMS – MULTILINE

The EKCS is used for the assembly manufacturing systems [4]. The variants of EKCS developed are simultaneous extended kanban control system (SEKCS) which considers the simultaneous release of kanbans when all components are available. Independent extended Kanban control system (IEKCS) considers the independent release of kanbans when the each component or part is available. The objective of EKCS is to reduce the work in process. The performance of the EKCS for assembly systems can be analyzed by using simulation or analytical approximations.

A hybrid push and pull production control algorithm was developed [82] for multi-line multi stage assembly type repetitive manufacturing system primarily based on JIT approach. The results obtained by simulation and algorithm are compared for the performance parameters like production, lead time and WIP. The developed algorithm was effective for lower work in process. The future research is to develop an algorithm to optimize production, waiting time etc.

The variants of EKCS, i.e. SEKCS and IEKCS are analyzed by using simulation software SLAM [83]. At lower demand rates, the performance of SEKCS and IEKCS are similar for number of kanbans equal to number of manufacturing stages. At higher demand rates, the IEKCS has better performance compared to SEKCS. The direction for future research is the performance analysis of EKCS variants for increased number of kanbans per stage, workstations and number of flow lines.

The Performance of IEKCS, SEKCS, CONWIP, Hybrid IEKCS-CONWIP (HIEKCS) and Hybrid SEKCS-CONWIP (HSEKCS) for multi-line multi stage assembly manufacturing systems are investigated using simulation [84]. The performance factors i.e. production rate, AWT and WIP are analyzed by varying the demand rate. The performance of hybrid system is more superior compared to other systems.

A kanban control hybrid manufacturing system for two discrete production flow lines with exponential distribution of demand and service rate was reviewed [85]. The throughput of the system depends on three parameters; demand mean time, processing time and number of kanbans. The performance of adaptive KCS is compared with that of ordinary KCS by using numerical values. The adaptive KCS has better performance than ordinary KCS. A single stage pull type control system with adaptive kanbans and state independent routing of the production information is the direction of future research.

The manufacturing systems with assembly stations that produces a single type products are investigated [86]. The system contains an assembly station where two or more parts from lower hierarchically manufacturing stations merge in order to produce a single part of the subsequent stage. The application of assembly systems to produce single product type is modeled as queuing network for BSCS, KCS, CONWIP, CONWIP/Kanban Hybrid and EKCS. The performance of two line assembly systems and the optimum kanban systems is analyzed by discrete event simulation. The GA approach was proposed for controlling the parameter selection is that of a genetic algorithm with resampling. Resampling is a technique used for the optimization of stochastic objective functions. A synchronization station to comprehend modeling framework with number of input queues and number of outgoing customers is prospective future research.

2.6.1 Summary and Gaps

The variants of EKCS i.e. SEKCS and IEKCS are presented for assembly manufacturing systems [4]. The hybrid push/pull production control algorithm is developed based on JIT and MRP approach [82]. The results obtained by production control algorithm and the simulation are compared. The performance of EKCS variants is analyzed by using simulation software SLAM [83]. The pull systems are more responsive at higher demand rates. The performance of IEKCS is better and consistent compared to SEKCS. In addition to EKCS variants, CONWIP system and hybrid systems are analyzed by using simulation software SLAM [84]. The hybrid system has superior performance compared to other pull control systems. Adaptive manufacturing was introduced with hybrid system to analyze the multi-line systems having varying demand [85]. The throughput depends on three parameters, demand mean time, processing time and number of kanbans. The adaptive kanban system has better performance than traditional kanban system. The other pull control mechanisms [86] i.e. BSCS, CONWIP system and EKCS along with hybrid system, are investigated for performance measurement. The system was simulated to determine the optimum pull control system for multi-line assembly systems.

The following are the research gaps that are analyzed from the literature review.

i. An algorithm for the performance measurement of EKCS variants for multi-line multi stage assembly systems.

ii. Optimization of production lead time, utilization, number of kanbans, number of flow lines, number of workstations in each flow line for performance enhancement.

iii. Investigation on the multi-line manufacturing system by GA for the input queue size and production output.

2.7 PULL PRODUCTION CONTROL SYSTEMS - MULTI-PRODUCT

The performance of multi stage multi-product pull control systems is reviewed [87]. The upstream stage has raw material of infinite capacity and the downstream stage has finished product of finite-capacity. A continuous review inventory system monitors the work in process at each stage. The performance comparison is based on the parameters like average WIP, average backorder demand and the average number of set-ups. The optimum pull system is selected based on better customer service level.

KCS is normally used for single product manufacturing. The performance of KCS, GKCS and EKCS for multi-product is analyzed using two kanban types; dedicated kanban and shared kanban [6]. The working mechanism is exclusively discussed for the release of parts into different production stages. The performance analysis of shared kanban and dedicated kanban for pull control systems is the direction for future research.

The determination of lot size and set up time for each product is an important parameter. The optimum condition for the selection of shared and dedicated kanban is the prospective direction for future research [6].

The KCS with two or more products are processed on single manufacturing facility [88]. The setup time, processing time and demand mean time follows poisons distribution. The setup time and setup changes between productions take significant time. The inventory of finished parts doesn’t depend on customer demand; rather depends upon number of kanbans. A decomposition based approximation method is proposed for computing the steady-state performance of single stage multi product system.

The hybrid system is a combination of push/pull system [89]. The performance of hybrid system is superior compared to the individual systems. The performance of multi-product flexible manufacturing systems is validated for different material control strategies. The throughput and WIP is compared for pure pull and pure push system. The pure push strategy is significant for higher production and WIP compared to pure pull strategy.

The kanban systems as classified into two research levels; design and operational, are reviewed [90]. The analytical methods are designed for measuring the performance of both levels with a significant relationship between them. The analytical methods for multistage multi-product system are proposed to compute number of kanbans and size of kanbans for first in first out (FIFO) queuing discipline. The analytical approach can be used for other sequencing rules for the performance measurement.

The research review is focused on single flow line multi stage single product KCS [91]. The multi-product system is analyzed for dedicated kanban system. The performance is compared considering dedicated kanban and shared kanban for KCS, GKCS and EKCS. The GKCS and EKCS with dedicated and shared kanbans show better performance than KCS. The pull control system with shared kanban shows superior performance compared to dedicated kanban.

Considering the transfer time and set up time for the performance analysis and optimum lot size determination for multi-product system is a step for future research. The dedicated kanban is considered for a single product and shared kanban for multi-product [91]. The model for machine breakdown follows exponential distribution for mean time between failures and for mean time to repair. The consideration of preventive maintenance policy helps in reducing the impact of breakdowns which can be a step for future research.

The performance of multi-product, multi kanban for disassembly flow line with multiple demands are reviewed [92]. The objective is to minimize the inventory by optimized routing of kanbans. The system is simulated and analyzed using numerical values. The multi-kanban system significantly reduces the average inventory. The multi-kanban mechanism ceases the inventory levels fluctuations to meet the customer demand with adjustment of kanban routing in real time.

Analytical methods [93] are developed for CONWIP systems using closed queuing network for multi-product systems. The performance is analyzed by approximation methods. A two moment parametric-decomposition-based approach is used to measure throughput and mean queue length at individual stations using stochastic transformation equations. The results of analytical method are compared with simulation results using numerical values that yield accurate result.

The kanban create excess inventory in multi-product system. When a product is manufactured from a multi kanban on demand, the workstation replaces it with another product or its component in an assembly [94]. Thus, the number of components increases to produce the finished product to the customer. Product rationalization is attributed to additional kanbans to provide an increasing variety of products to meet the high customer demand.

The optimal and meta-heuristic methods are developed to determine the quantity of production kanban, withdrawal kanban and lot sizes in a supply chain system [95]. The meta-heuristic methods, Integer Non-linear

Programming, a genetic algorithm (GA) and a hybrid of genetic algorithm and simulated annealing (GASA) are used. The performance results of GA and GASA show nearly optimal solution. Further, the results obtained by GASA heuristic method show superior performance as compared to GA heuristic method.

A mixed integer non-linear programming model (MINLP) is developed for the optimal sequence of jobs and WIP level in a CONWIP production line to minimize the overall completion time [96]. A novel heuristic, artificial bee colony algorithm is proposed to solve this model. In comparison to other algorithms, such as nonlinear programming and mixed integer programming, the artificial bee colony algorithm does not use a linearized or simplified model of the system. The algorithm is tested, compared by numerical simulation and the results are validated for the computational efficiency. The artificial bee colony algorithm can be used for the problems of real time involving large number of parts, machines, and production lines.

The performance of KCS, CONWIP system and BSCS for a multi-stage, multi-product manufacturing system are compared using simulation [97]. The customer demand mean time, set up time and holding cost rate follows exponential distribution. The Base stock system shows the optimal performance with reference to WIP and the Kanban and CONWIP system shows the same level of the inter-operational stock for the change in demand rate.

Gradient base heuristic method are applied to GA for the design of multi product kanban system [98]. Different case studies are analyzed based on the simulation results obtained by modified GA and classical GA. The kanban plays an important role in manufacturing system. The design of kanban addresses selection of two important parameters i.e. number of kanbans and lot size.

2.7.1 Summary and Gaps

The multi stage, multi-product kanban control system [87] is analyzed. The inventory review system is used to control WIP. The performance factors like WIP, backorder demand are being analyzed to improve customer satisfaction level. The performance of KCS for multi-product was presented and two types of kanbans are introduced [6], shared Kanban are for multi products and dedicated Kanban are for individual product [91] . The performance of KCS, GKCS and EKCS for multi stage, multi-product is analyzed by simulation. GKCS and EKCS showed better performance compared to KCS. Shared kanbans are more versatile and better compared to dedicated kanban system [97]. The KCS and CONWIP system have high throughput and WIP is less for BSCS. The processing of three or more products on single workstation for KCS that follows stochastic distribution is analyzed [88]. Also, the KCS is reviewed and categorized for design level and shop floor level [90]. The production rate and WIP depends on number of kanbans and type of kanban. The hybrid system and flexible manufacturing system was introduced in push-pull systems for multi-product and is validated by different material strategies [89]. The throughput is high for the push system and work in process is low for the pull system. The analytical approximation method was developed for CONWIP system and the results are compared with the simulation results [93]. For multi products, rationalization of number of kanbans is needed to satisfy product variety and customer demand. In addition, meta heuristic, integer programming, GA, GASA techniques are used to determine the performance of multi product system [95]. GA and GASA shows optimum performance compared with the simulation results. The GA was analyzed with the case study values and compared with simulation results [98]. The artificial bee colony algorithm measures the performance parameters related to large number of parts, machines and production lines [96].

The following are the research gaps that are found from the literature review.

i. Performance of pull control systems for multi-product and multi-line systems along with multi kanban by considering the breakdown, setup time, transfer time, lot size and maintenance policies.

ii. Optimal conditions for the use of shared Kanban, dedicated Kanban and queue scheduling.

iii. Analytical method for steady state performance of pull control system for multi stage multi-product system.

2.8 PULL PRODUCTION CONTROL SYSTEMS- QUEUING NETWORK

The performance analysis of queuing network models are cost effective tools using modern computer systems [99]. The performance factors like utilization, mean queue length are defined with their operational relationship. The concept of job flow balance is introduced to study asymptotic throughput and response time. The concept of state transition balance, one step behavior and homogeneity are used to relate the proportions of time to which each state is occupied. The principle and concept of decomposition is analyzed by replacing subsystems with equivalent devices and the performance is illustrated by numerical examples.

The book presents a unified and systematic treatment of various modelling methodologies and analysis techniques for performance evaluation of automated manufacturing systems [100]. It gives an overview of automated manufacturing systems, and gives a comprehensive discussion of Markov chains, queuing networks and petri nets.

The queuing networks of two separate classes; single chain and multi chain are analyzed for the performance measurement. The mean queue length is proportional to server load (proportional bound) instead of balanced network (balanced bounds) due to tight coordination of different products at individual workstation. The relation between server network and balanced network as well as the communication network for single chain and multi chain are presented [101]. Bonding techniques are exclusive for multi chain network because of high computation time. The communication network for multi chain has accurate performance measurement for the routing chains.

The review of queuing models for kanban systems are presented [102]. The discrete models are analyzed using markovian approach. The performance of KCS using analytical approach is presented [103]. The GKCS for single stage and multi stage are analyzed using product form approximation technique using the numerical values to determine the mean waiting time, WIP and production rate. The algorithm is effective since it completes the computation in single iteration. The performance evaluation of the systems having kanban systems with multiple consumers, multi-products and multi flow line is the direction for future research study.

The algorithm is developed for the computation of normalization constants (partition functions). Normalization constant is a moment of product-form steady-state distribution of closed queuing networks and related models. The algorithm is to numerically invert the generating function of the normalization constant appearing in expressions into a remarkably simple form [104]. The required computation grows exponentially in dimensions and can be minimized by conditional decomposition. The algorithm is efficient for computing large sums using Euler summation developed for single server multi chain queuing networks. The inversion of the algorithm is a self-contained accuracy check which can be verified in the absence of alternative algorithms. There is significant scope for the improvement of the algorithm in future applications and complex problems.

The product form approximation of higher order is presented for single server queues and tandem queues. The higher order approximation is computationally flexible as it considers higher moments of the inter arrival and service distribution in evaluating the performance of the queuing network [105]. Numerical analysis for single server queuing network and tandem queuing network is better than two moment based approximation method. The approximation for higher moments and correlation of inter arrival and service distribution process for the study of queuing network is the direction for future research.

Continuous-time Markov chains (CTMCs) determines and analyzes the performance of manufacturing system for the computation of steady-state and transient-state probabilities. CTMCs real-time probabilistic properties and approximate algorithms are compared for the system [106]. The verification of probabilistic timing properties is verified by efficient techniques for transient analysis such as uniformization for CTMC. The bi-simulation preserves the validity of all formulas in the logic for aggregating CTMCs.

Analytical methods [107] are proposed for the performance of KCS. The KCS is transformed as a multi-class queuing network and a single Kanban loop is represented for the customers. The multi-class queuing network are analyzed using product-form approximation methods [43] and each loop is represented by customers class. This method provides a general framework for the analysis of KCS and is simple and faster. This approach can be extended to handle multiple consumers and multiple suppliers for KCS and GKCS assembly systems. This algorithm emphasizes its applicability to other kanban systems which is the scope for future research.

Queuing networks and markov chains measure the performance of manufacturing systems [108]. The book covers a detailed explanation of queuing network, CTMC, DTMC for steady state and transient state. The numerical solutions, algorithm, applications etc. in detail are covered and discussed.

The kitting system is introduced for the performance measurement. The Kit system is defined for grouping multiple products before assembly and is modeled as a synchronization station under KCS. The performance of kitting system is evaluated based on input factors by forming computable bounds[109]. The performance parameters of interest i.e. mean queue length, mean waiting time are compared by closed form approximation. The accuracy of the kitting system is validated by numerical values, experimentation and simulation. The potential application of the product approximation is optimizing the production capacity and number of kanbans. The focus of future research is on generalization of results.

2.8.1 Summary and Gaps

Queuing network models are performance effective and cost effective when using computer systems [99]. The flow rate of part between the stages of queuing network should have balance with respect to time and performance. The queuing network are classified as single chain and multi chain network for the performance measurement [101]. Based on the network coordination, the queue length follows server load or balanced load. A simple and faster analytical methods is proposed [103] for performance measurement of KCS and GKCS to transform as a single kanban loop. A multiclass queuing network using product-form approximation methods depends on multiple consumers and multiple suppliers. The single kanban and multi kanban queuing network for KCS and GKCS are upgraded [107]. An algorithm is developed to compute normalization constant (i.e. a generating function for queuing network into simplified form) for closed queuing networks and its related models [104]. The algorithm can be applied for multi chain queuing networks for single server and steady state distribution of closed queuing network. Product form approximation method of higher order for the performance measurement of single level and multi-level queuing network has been developed [110]. A kitting system for the performance evaluation of KCS for multi-product is introduced [109]. The kit is a group of multi-products and synchronizing station. It is an application of product approximation method to optimize product capacity and number of kanbans.

Markovian chains and queuing networks for steady-state and transient-state with case studies are comprehensively analyzed [108]. CTMCs are used for the performance analysis of steady-state and transient-state probabilities of manufacturing systems [106]. The CTMCs real-time probabilistic properties are compared with analytical approximation method.

The following are the research gaps found from the literature review:

i. Developing an algorithm to measure the performance of kanban systems for multi consumers, multi-product and multi flow line with a significant scope for future applications and complex problems.

ii. Developing a queuing network using the approximation method for higher moments and correlation of inter arrival and service distribution process.

iii. Developing multi class queuing network using product approximation method for other kanban systems except KCS and optimizing the product capacity and number of kanbans.

CHAPTER 3

PROBLEM STATEMENT

During the literature review, it was observed that in pull control manufacturing systems and hybrid systems, there are uncertainties associated with the performance due to dynamic variations in number of kanbans, machine breakdown and repair, demand variability and inventory for serial and non-serial flow systems. With this background, the present work has been planned with the objective to study the performance comparison and enhancement of CONWIP system, KCS and EKCS along with a case study for the effective management of manufacturing systems.

1.1 RESEARCH OBJECTIVES AND DESCRIPTION

The following are the performance measures considered in the manufacturing system.

(a) Production or throughput.

(b) Average work in process.

(c) Average waiting time.

(d) Machine utilization.

The objective of the research is the investigation and performance analysis of the three pull production control systems. The pull production control mechanisms considered are CONWIP system, KCS and EKCS for:-

a) **Single flow line multi stages pull control manufacturing systems:** The model is developed in technical computing software MATLAB/ SIMULINK for single product single flow line three stage manufacturing systems and simulated. The simulation results obtained from the model are compared with the results obtained from the code generated in programming language 'C' for validation. The performance is analyzed considering the following parameters with an objective to achieve efficient solution.
   - Number of kanbans: with the objective of optimizing the number of kanbans in concurrence with number of stages for the best performance output.
   - Imbalance in processing mean time: With the objective of analyzing the effect for different configurations and its influence on the performance of the system
   - Breakdowns: The breakdown is a common phenomenon in any manufacturing system. The workstation breakdown and its impact on the performance of the flow line system.

b) **Two flow line multi stage pull control manufacturing systems:** The modeling of multi flow line multi stage system converging into assembly stage is developed in technical computing software MATLAB/SIMULINK R2011b and simulated. The output results obtained from the model are compared with the results obtained from the code generated in programming language ‘C’ for the validation of the model and the results. Further, the performance of the systems is compared and analyzed an objective of achieving efficient solutions.

c) **Single flow line multi stage multi-product pull control manufacturing systems:** The model for single flow line multi stage multi-product system is developed by using technical computing software MATLAB/SIMULINK R2011b and simulated. The performance is analyzed on the basis of the following parameters with an objective to achieve optimized output.

- Number of kanbans: With the objective of optimizing the number of kanbans per stage by correlating with optimum performance.
- Imbalance in processing mean time: With the objective of analyzing the processing mean time imbalance and its influence on the output performance of the system.
- Breakdowns: The effect of stage breakdown and its impact on the performance of the flow line system.

d) **Single flow line multi stage multi-product pull control systems - A case study:** As discussed in (c) above, the simulation results and case study results are compared for the validation of the model and system.

3.2 PARAMETERS OF THE SYSTEM

The following are the definitions of modeling parameters used in the formulation for CONWIP system, KCS and EKCS.

3.2.1 Demand Arrival

The demand rate varies from 4 parts per hour to 20 parts per hour for single flow line and multi flow line systems. The demand mean time is assumed to follow an exponential distribution. The standard deviation is equal to the mean, i.e. the coefficient of variation, is equal to one.

3.2.2 Processing Mean Time

The processing mean time of the part signifies the use of machine or workstation and it follows exponential distribution [24] It specifically meets the requirements for describing processing mean time in the kanban environment and is computationally efficient.

Unlike as reported in the literature, the processing mean time for each the three stages of a flow line are assumed same and varied in order to study the performance variations.

The number of kanban per stage is kept same.

3.2.3 Time between Failures and Time to Repair

The effect of failure-prone is considered on system performance due to machine breakdown. The mean time between failures (MTBF) and the mean time to repair (MTTR) are exponentially distributed. These values are determined based on the machine utilization at each stage such that it signifies varying frequency of failures.

3.2.4 Warm-up and Simulation Time

The parameters like warm-up period, run length and number of replications are important for the analysis of the simulation results. Since all the simulation begins with all stages idle and buffer in each queue is equal to the preset number of kanbans, the warm up period will diminish the statistic variation during the initial time period. Further, the simulation run for longer duration is enough to dilute the statistical data of initial time period.

After the warm-up period, it is assumed that the remaining period would be sufficient to get the statistical data and the performance in steady-state of the system. The numerical values of warm up time, simulation time, demand mean time, processing time, MTBF and MTTR are given in the Chapter Results and Discussions for the respective objectives.

3.3 SUMMARY

In this chapter, the statement of research problem, performance parameters and the modeling approach to solve it are discussed. The input factors and their level to design the model are defined.

CHAPTER 4

SYSTEM CONFIGURATION AND MODELING OF PULL CONTROL SYSTEMS

4.1 INTRODUCTION

In dynamic manufacturing environment, the job enters and leaves the production system continuously and the job completion is affected by factors related to job complexity and characteristics. As discussed in the literature review, there are number of modeling approaches for the research of pull control systems. The modeling and simulation reflects the characteristics and features of manufacturing system. It cannot include all the factors related to real system. The system may be expensive to do test in real time, thus modeling is aimed to explore the understanding, comparison and improvement. The modeling and simulation is necessary in current research to study the system characteristics.

This chapter describes the assumptions applied to modeling and analysis of pull control systems. It presents the network diagram and queuing network analysis of CONWIP system, KCS and EKCS. The modeling of the manufacturing systems is done by using the software MATLAB/SIMULINK R2011b. The features of the software are described in Appendix B. The network models are described in the subsequent sections of this chapter. A code is developed for modeling the manufacturing system in programming

Language ‘C’. Simulation studies are done to investigate and analyze the performance of the systems.

4.2 MODELING ASSUMPTIONS

The following are the assumptions considered for the modeling of the manufacturing systems:

i. The flow line has three manufacturing stages. Each stage is assumed as cell and the manufacturing process follows exponential distribution.

ii. The setup time at each manufacturing stage for each type of part is included in the processing mean time of the respective stage.

iii. The transportation time and material handling time between the manufacturing stages are negligible.

iv. The inter arrival customer demand mean time follows exponential distribution.

v. Each manufacturing stage consists of input buffer, output buffer and processing equipment.

vi. Raw material arriving to the input buffer of the first manufacturing stage is infinite.

vii. If the demand is not satisfied with the finished part, then it is backordered.

viii. The system is assumed to have dedicated type of kanban for multi-product system.

ix. The system is assumed to have two flow lines for multi-line multi stage manufacturing system.

4.3 ANALYSIS OF THE QUEUING NETWORK

Each manufacturing stage is associated with its synchronization stations constitutes a closed queuing network with respect to the stage kanbans. The closed queuing network of a single stage can be analyzed using the algorithm proposed by Dallery et al [48]. The use of the algorithm gives the analysis for each stations of the closed queuing network in isolation.

4.3.1 Constant Work in Process System (CONWIP)

A raw part is processed in the three manufacturing stages for producing the finished part. After the finished part departs from the system, the new part enters the production line. The CONWIP system which is modeled as a network diagram with synchronization mechanism based on the assumptions is shown in Figure 4.1.

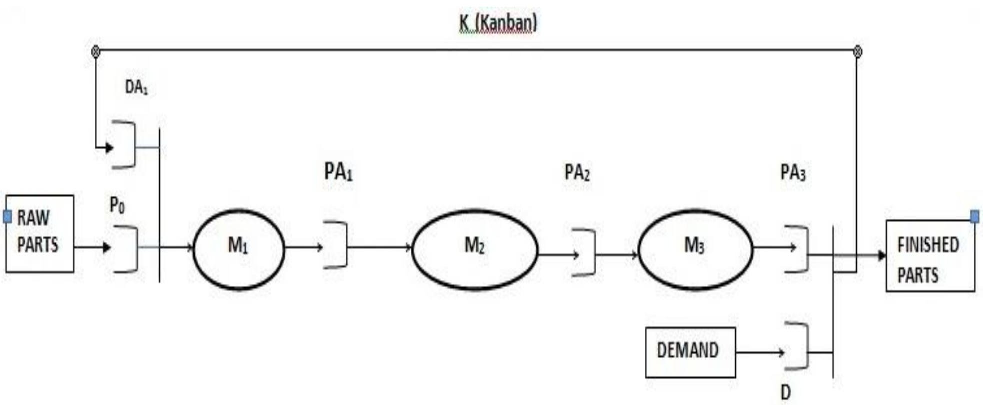

Figure 4.1: Queuing Network diagram for CONWIP system

The following are the invariants of CONWIP system consisting of kanban path.

$$M\ (D)\ M\ (PA_3) = 0$$

$$M\ (DA_1) + (M_1 + M_2 + M_3) + PA_3 = K$$

$$0 \leq DA_1 \leq K$$

$$0 \leq [(M_1 + M_2 + M_3) + PA_3] \leq K$$

The queuing network is closed with respect to the circulating kanbans. The number of kanbans associated with the system is fixed.

Notations

n = Number of kanbans.

PA_i = Queue of finished parts and kanban for stage i.

DA_i = Queue of demand and kanban for stage i.

P_0 = Queue of raw parts.

M_i = Workstation of stage i.

μ = Service rate of the stage.

λ = Arrival rate of demands.

4.3.1.1 Initial state of the system

Initially, the queues PA_i (i = 1, 2, 3) contains equal number of stage- i finished parts. The number of kanbans should be more for slower manufacturing facility due to higher imbalance. The Demand queue 'D' and the queue of free kanbans 'A' are empty. The queue P_0 contains more number of raw parts to synchronize with the Kanban at the starting stage.

4.3.1.2 Approximate analysis of the closed queuing network

The three manufacturing stages are grouped for satisfying the steady state condition. The throughput of the stage is equal to service rate. The service rate becomes the arrival rate of the finished parts at the synchronization station. From the behavior of the system, prior to the synchronization station, the system acts as a push system i.e. when a part is processed in a workstation, it immediately moves to the next workstation.

4.3.1.3 Analysis of the synchronization station for its throughput

The synchronization station at the end of the system is shown in figure 4.2.

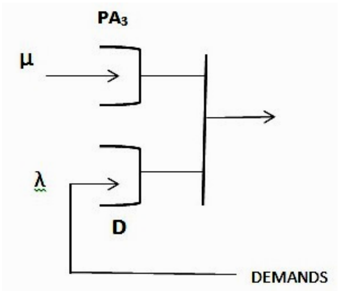

Figure 4.2: Synchronization Station of demand rate and service rate

The synchronization stage follows the birth and death manufacturing process as shown in figure 4.3. The transitions are between the neighboring states. It is a continuous time system and the results obtained are analogous for the discrete systems.

The transition rate $\boldsymbol{\lambda_i}$, where $i \geq 0$ are state dependent birth rates and μ_i, where $i > 0$ are state dependent death rates and are both independent of time. The steady state probability is obtained from the solution of the equation.

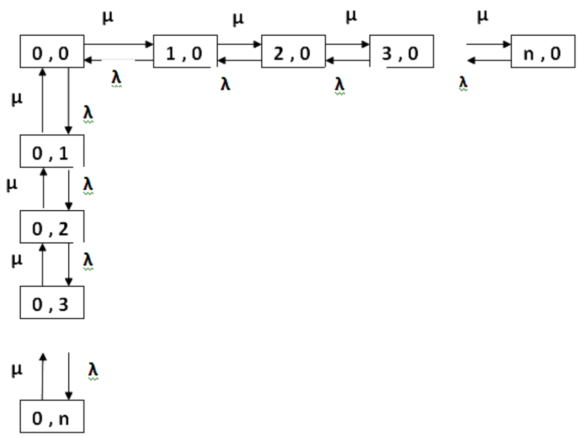

Figure 4.3: Birth and Death process of the synchronization of demand rate and part service rate

The rate balance equation for the horizontal component of the process is:

$$p\,(0, 0).\mu = p\,(1, 0).\,\lambda \qquad \text{Eqn. (4.1)}$$

$$p\ (1, 0)\ (\lambda + \mu) = p\ (0, 0)\ \mu + p\ (2, 0)\ \lambda \qquad \text{Eqn. (4.2)}$$

Substituting the value of P (1, 0) from equation (4.1) to equation (4.2), then

$$p\ (0, 0)\ \frac{\mu}{\lambda}.\ (\lambda + \mu) = p\ (0, 0)\ \mu + p\ (2, 0)\ \lambda$$

Solving the above equation for p (2, 0) yields,

$$p\ (2, 0) = \left[\frac{\mu^2}{\lambda^2}\right]\ .p\ (0, 0) \qquad \text{Eqn. (4.3)}$$

Equation (4.1) and (4.3) suggests a general solution of recursive relation in the following form.

$$P\ (x, 0) = \left[\frac{\mu^x}{\lambda^x}\right].\ P\ (0, 0) \qquad \text{Where } x = 1, 2, 3 \ldots n \qquad \text{Eqn. (4.4)}$$

Similarly, the rate balance equations for the vertical component of the process are

$$P\ (0, x) = \left[\frac{\lambda^x}{\mu^x}\right].\ P\ (0, 0) \qquad \text{Eqn. (4.5)}$$

The determination of steady state probabilities are organized as probability vector P. i.e. $\sum P = 1$.

$P = [p\ (0, \infty) + \ldots\ldots + p\ (0,1) + p\ (0,0) + p\ (1,0) + p\ (2,0) + \ldots\ldots + p\ (n,0)] = 1.$

Therefore,

$$\left[\frac{\lambda^\infty}{\mu^\infty}\right].\ p\ (0, 0) + \ldots\ldots + \left[\frac{\lambda^2}{\mu^2}\right].\ p\ (0, 0) + \left[\frac{\lambda}{\mu}\right].\ p\ (0, 0) + p\ (0, 0) + \left[\frac{\mu}{\lambda}\right].\ p\ (0, 0)$$

$$+\left[\frac{\mu^2}{\lambda^2}\right].\ p\ (0, 0) + \ldots\ldots\ldots + \left[\frac{\mu^n}{\lambda^n}\right].\ p\ (0, 0) = 1$$

Solving the above expression for geometric series,

$$P\ (0, 0)\left[\frac{1}{1-\frac{\lambda}{\mu}}\right] + p\ (0, 0)\left[\frac{\left(\frac{\mu}{\lambda}\right)^n - 1}{\left(\frac{\mu}{\lambda}\right) - 1}\right] = 1$$

Let $\frac{\lambda}{\mu} = r$ and $\frac{\mu}{\lambda} = r_1$. Substituting in the above expression,

$$p\,(0,0)\,.\,\left[\frac{1}{1-r} + \frac{r_1^n - 1}{r_1 - 1}\right] = 1$$

$$p\,(0,0) = \frac{1}{\left[\frac{1}{1-r} + \frac{r_1^n - 1}{r_1 - 1}\right]} \qquad \text{Eqn. (4.6)}$$

The marginal probabilities p(x), x = 0, 1, 2, 3….n of existing 'x' kanbans (attached with 'x' finished products) at the synchronization station can be calculated by using the equations (4.4), (4.5) and (4.6) as follows:

The probability of existing '0' kanbans is given by

$$P\,(0) = p\,(0,0) + \sum_{x=1}^{x=\infty} p(0,0)$$

The probability of existing 'n' kanbans is given by

$$P\,(x,0) = \left(\frac{\mu}{\lambda}\right)^{x} .\ P\,(0,0)$$

Throughput or Production rate (R_p)

The throughput of the synchronization station measures the rate at which the job leaves the station.

$$R_p = \sum_{x=1}^{x=n} p(x,0).\,\mu$$

Where μ = service rate of the station.

Mean Work in Process (WIP)

The WIP in the system is equal to number of kanbans in CONWIP system. The average number of semi-finished and finished parts waiting for dispatch is computed. It depends upon the arrival rate of demands.

The mean queue length (L_i) at the synchronization station is given by

$$L_i = \sum_{x=1}^{n} x.\,p(x,0)$$

Mean waiting time (W)

The mean waiting time of the finished products using Little's formula is

$$W = \frac{L}{\lambda}$$

The CONWIP system is developed as a network model to obtain the performance measures of the production system and is shown in figure 4.4. The network system coded using programming language 'C' is given in appendix A.

4.3.2 Kanban Control System (KCS)

The KCS is developed as a network model with three workstations M_1, M_2 and M_3 in series as shown in figure 4.5. The model has three stages S_1, S_2 and S_3. Each stage contains an input queue, workstation and output queue. The stage S_1 consists of input queue P_0, workstation M_1 and output queue PA_1. P_0 is the initial buffer of raw material. D_4 is the customer demand. The queue DA_1, DA_2 and DA_3 contain kanban and demand for the stages S_1, S_2 and S_3 respectively. The queue PA_1, PA_2 and PA_3 give the output of each stage respectively. The customer demand arrives to queue D_4, finished part is released from PA_3 to customer and Kanban k_3 gets detached and joins with demand and is transferred to upstream queue DA_3 for the release of finish part from stage S_2 to S_3. Thus, the coordination between the stages is by kanban only.

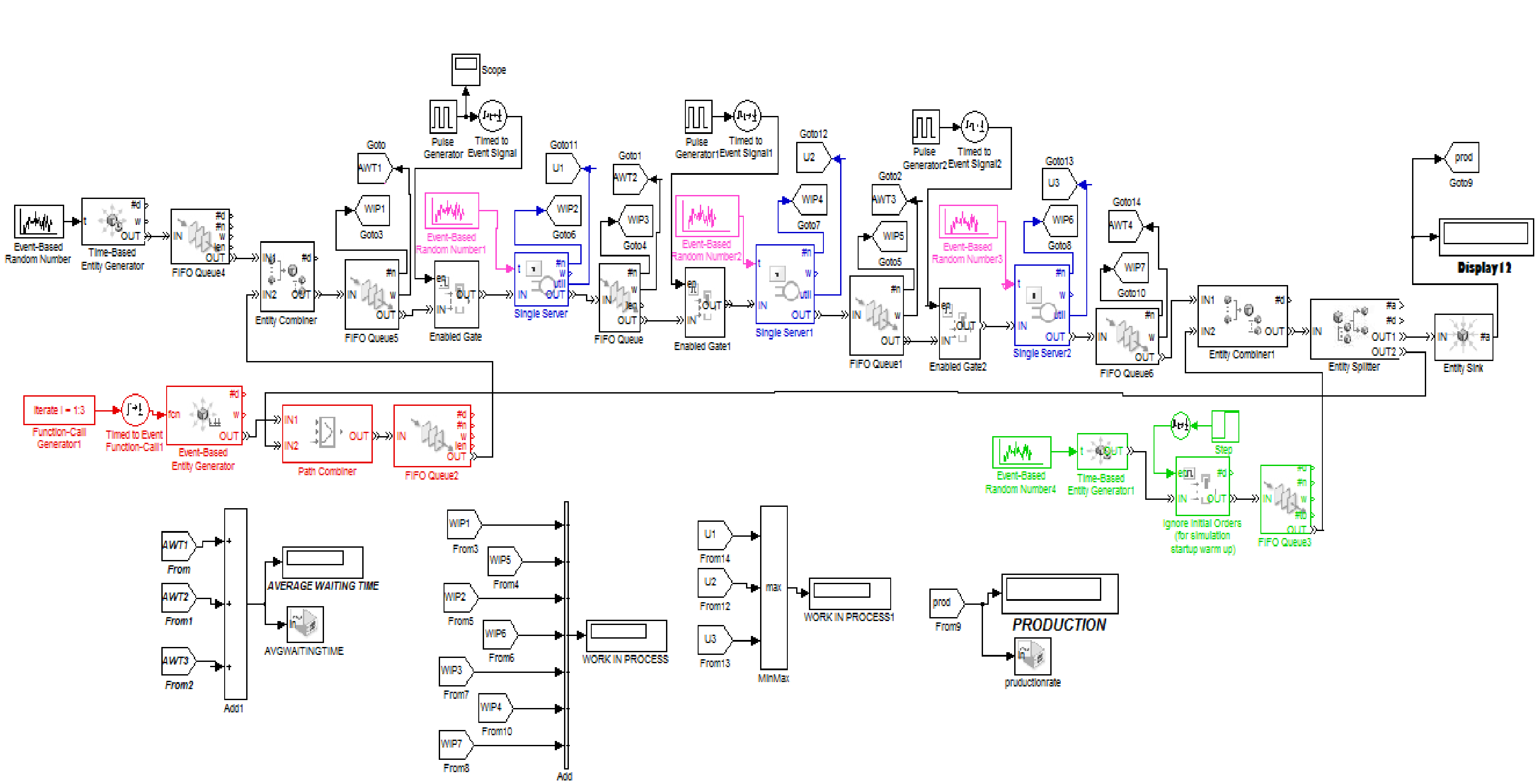

Figure 4.4: Network Model of CONWIP system for single line multi stage system

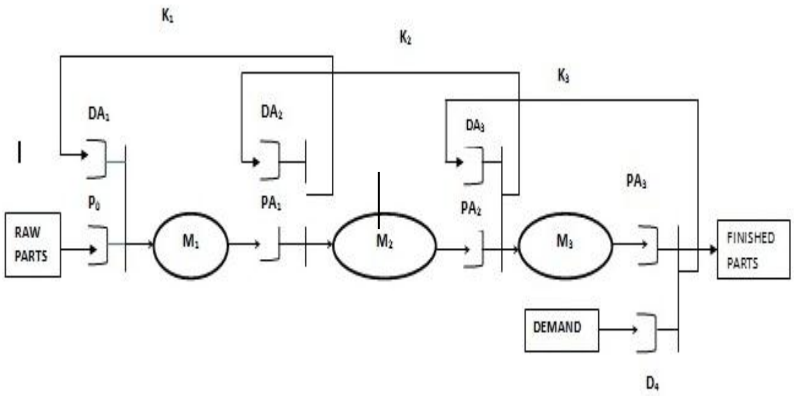

Figure 4.5: Queuing Network diagram for KCS

The KCS consisting of kanban in each stage imply the following invariants.

$$M\,(DA_{i+1})\;M\,(PA_i) = 0 \quad \text{where } i = 1, 2, 3...$$

$$M(DA_i) + M(M_i) + M(PA_i) = K_i \;, \quad \text{where } i = 1,2,3..$$

$$0 \le M_i \le K_i \,, \quad \text{where } i = 1,2,3...$$

$$0 \le (M_i + PA_i) \le K_i \,, \quad \text{where } i = 1, 2, 3\ldots$$

$$0 \le PA_i \le S_i, \quad \text{where } i = 1, 2, 3\ldots$$

Notations

n = Number of kanbans for each stage.

PA_i = Queue of finished parts with kanban for stage i.

DA_i = Queue of demand and kanban for stage i.

λ = Arrival rate of demand

P_0 = Queue for raw parts.

M_i = Workstation of stage i.

4.3.2.1 Initial State of the System

Initially, the queue PA_i of stage S_i contains the stage i finished parts. The queue DA_i contains n - S_i free kanbans. All other queues are empty.

4.3.2.2 Demand synchronization analysis

The demand queue synchronizes with the part and kanban as shown in figure 4.6.

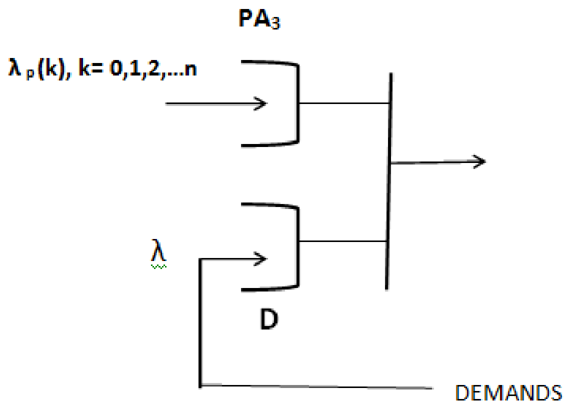

Figure 4.6: Demand synchronization with finished part-kanban

The birth and death process for the demand and finished part –kanban synchronization is shown in figure 4.7.

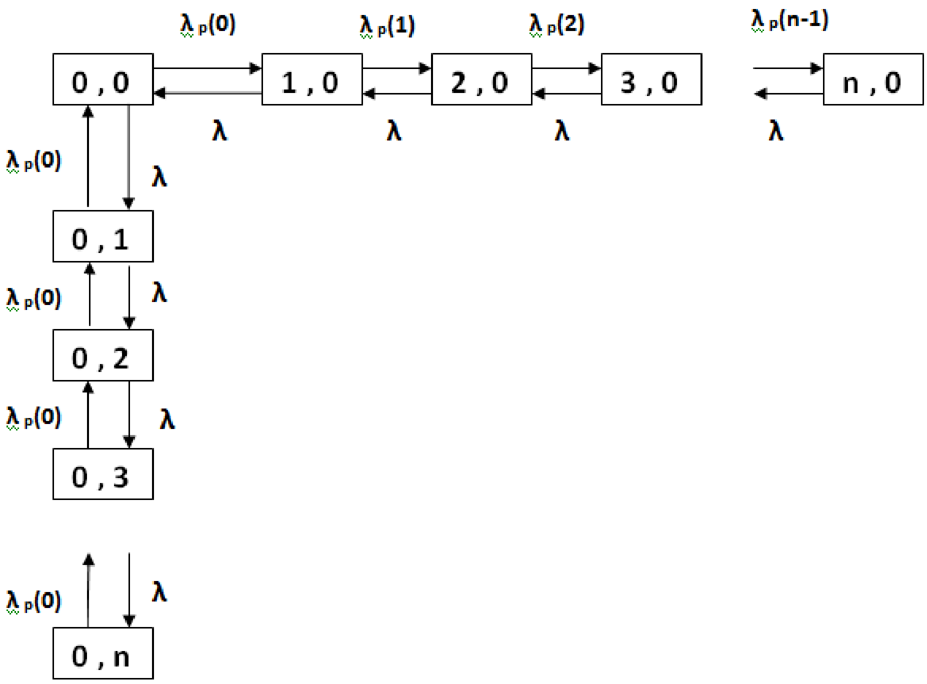

Figure 4.7: Birth and Death process for the Synchronization of demand and part-kanban

The transition rate i.e. arrival rate of parts λ_p (x), x $\geq$ 0 are birth rates and demand rate λ are referred to as death rates. The birth rate and death rate for state i is assumed to be independent of time.

The rate balance equations of demand and part synchronization for its horizontal component are

$$p\,(0, 0)\, \lambda_{p}(0) = \lambda \,.\, p\,(1, 0) \qquad \text{Eqn. (4.7)}$$

$$p\,(1, 0) = \frac{\lambda_{p(0)}}{\lambda} \,.\, p\,(0, 0) \qquad \text{Eqn. (4.8)}$$

$$p\,(1, 0)\,[\lambda + \lambda_p\,(1)] = p\,(0, 0)\, \lambda_p\,(0) + p\,(2, 0)\,.\lambda$$

Substituting the equation (4.8) in the above equation, the solution yields

$$p\,(2, 0) = \frac{\lambda_{p(0)}\, \lambda_{p\,(1)}}{\lambda^2} \,.\, p\,(0, 0)$$

$$P\,(x, 0) = \frac{\lambda_{p\,(x-1)}}{\lambda^x} \,.\, p\,(0, 0) \qquad \text{Eqn. (4.9)}$$

The equation (4.9) is a recursive relation and the general solution yields

$$p\,(x, 0) = \prod_{i=0}^{i=x-1} \frac{\lambda_{p\,(i)}}{\lambda^x}\; p\,(0, 0) \qquad \text{Eqn. (4.10)}$$

Similarly, the rate balance equation for the vertical components of the process is:

$$p\,(0, x) = \left[\frac{\lambda}{\lambda_{p(0)}}\right]^x \,.\, p\,(0, 0) \quad \text{Where } x = 1, 2, 3\ldots.\infty \qquad \text{Eqn. (4.11)}$$

The determination of steady state probabilities and probability vector P is $\sum$p = 1.

Therefore,

P = [p (0, ∞) + ………+ p (0,1) + p(0,0) + p(1,0) + p(2,0) + ……+ p (n,0)] =1

$$\left[\frac{\lambda}{\lambda_{p(0)}}\right]^\infty \,.\, p\,(0, 0) + \ldots\ldots\ldots + \left[\frac{\lambda}{\lambda_{p(0)}}\right] \,.\, p\,(0, 0) + p\,(0, 0) + \frac{\lambda_{p(0)}}{\lambda} \,.\, p\,(0, 0) +$$

$$\frac{\lambda_{p(0)}\, \lambda_{p\,(1)}}{\lambda^2} \,.\, p\,(0, 0) + \ldots\ldots\ldots + \frac{\lambda_{p(0)}\, \lambda_{p\,(1)}\, \lambda_{p\,(2)} \ldots.\lambda_{p\,(n-1)}}{\lambda^n} \,.\, p\,(0, 0) = 1$$

Solving the expressions for the geometric series,

$$p\,(0,0)\left[\frac{1}{1-\frac{\lambda}{\lambda_{p\,(0)}}}\right] + \frac{\lambda_{p(0)}}{\lambda}\,.\,p\,(0,0) + \frac{\lambda_{p(0)}\,\lambda_{p\,(1)}}{\lambda^2}\,.\,p\,(0,0) + \ldots\ldots\ldots +$$

$$\frac{\lambda_{p(0)}\,\lambda_{p\,(1)}\,\lambda_{p\,(2)}\ldots\lambda_{p\,(n-1)}}{\lambda^n}\,.\,p\,(0,0) \;= 1$$

$$p\,(0,0) = \frac{1}{\left[1-\frac{\lambda}{\lambda_{p\,(0)}}+\frac{\lambda_{p(0)}}{\lambda}+\frac{\lambda_{p(0)}\,\lambda_{p\,(1)}}{\lambda^2}+\ldots+\frac{\lambda_{p(0)}\,\lambda_{p\,(1)}\,\lambda_{p\,(2)}\ldots\lambda_{p\,(n-1)}}{\lambda^n}\right]} \qquad \text{Eqn. (4.12)}$$

The marginal probabilities p(x), x = 0, 1, 2, 3….n of existing 'x' demands (attached with 'x' finished products) at the synchronization station can be calculated by using the equations (4.10), (4.11) and (4.12) as detailed below.

$$p(0,x) \;= p\,(0,0) + \sum_{x=1}^{\infty}\left[\frac{\lambda}{\lambda_{p(0)}}\right]^x p\,(0,0) \qquad \text{Eqn. (4.13)}$$

$$p(x,0) = \prod_{i=0}^{i=x-1}\frac{\lambda_{p\,(i)}}{\lambda^x}\;p\,(0,0) \qquad \text{Eqn. (4.14)}$$

4.3.2.3 Part synchronization analysis

The part synchronization is a station where the queues of kanban and parts are synchronized and is shown in figure 4.8.

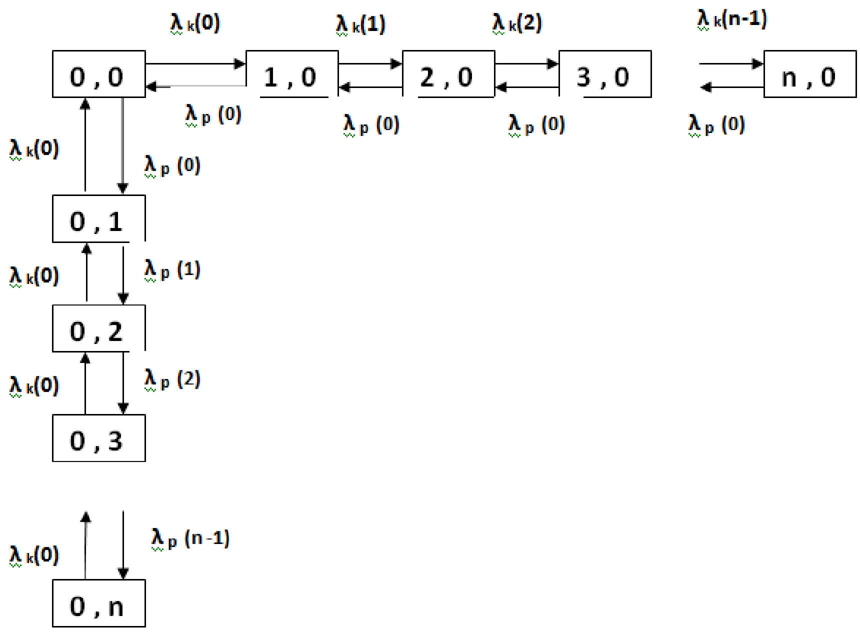

Figure 4.8: Birth and Death process of the Synchronization with part and kanban

The transition rates i.e. arrival rate of kanban λ_k (x), x ≥ 0 is state dependent birth rates and arrival rate of part λ_p (x) is state dependent death rates.

The general solution of the recursive relation for the kanban and part synchronization for horizontal equation yields

$$P(x, 0) = \prod_{i=0}^{x-1} \frac{\lambda_{k\,(i)}}{\lambda_{p\,(0)}}\ p(0, 0) \qquad \text{Eqn. (4.15)}$$

Similarly, the vertical stage general solution of the recursive relation yields:

$$P(0, x) = \frac{\prod_{i=0}^{x-1} \lambda_{p\,(i)}}{\left[\lambda_{k\,(0)}\right]^{x}} \,.\, P(0, 0) \text{ Where } x = 1, 2, 3\ldots.\infty \qquad \text{Eqn. (4.16)}$$

The determination of steady state probabilities is

$$P(0, 0) = \frac{1}{1+\left\{\frac{\lambda_{p\,(o)}}{\lambda_{k\,(0)}}+\cdots.+\frac{\lambda_{p\,(n-1)}\ldots\ldots\lambda_{p\,(0)}}{\left[\lambda_{k\,(0)}\right]^{n}}\right\}+\left\{\frac{\lambda_{k\,(0)}}{\lambda_{p\,(0)}}+\cdots\ +\frac{\lambda_{k\,(n-1)}\ldots\ldots\lambda_{k\ (0)}}{\left[\lambda_{p\,(0)}\right]^{n}}\right\}} \qquad \text{Eqn. (4.17)}$$

The marginal probabilities p(x), x = 0, 1, 2, 3….n of existing ‘x’ kanbans (attached with ‘x’ finished products) at the synchronization station and can be calculated by using the equations (4.15), (4.16) and (4.17) as detailed below

$$p(x, 0) = \sum_{x=1}^{n} \prod_{i=0}^{x-1} \frac{\lambda_{k\,(i)}}{\left[\lambda_{p\,(0)}\right]^{x}} \,.\, P(0, 0) \qquad \text{Eqn. (4.18)}$$

$$p(0, x) = \frac{\prod_{i=0}^{x-1} \lambda_{p\,(i)}}{\left[\lambda_{k\,(0)}\right]^{x}} \,.\, P(0, 0) \text{ Where } x = 1, 2, 3\ldots.n \qquad \text{Eqn. (4.19)}$$

Throughput (Production rate)

The throughput of KCS is the output of the last synchronization station in the system. The throughput is given by:

$$R_p = \sum_{x=1}^{n} p(x, 0).\,\mu(x)$$

Mean Work in process

The WIP in process can be calculated by summing the queue lengths of the output buffers of each stage i.e. $\sum_{i=1}^{n}(PA_i)$. The queue length of a station is given by:

$$L_i = \sum_{x=1}^{n} x \,.\, p(x,0)$$

Mean waiting time

The mean waiting time of a part in the system can be calculated using little's formula.

$$W = \frac{L}{\lambda} \quad \text{where } \lambda = \text{arrival rate of demands.}$$

The network model of KCS is developed by using MATLAB/SIMULINK R2011b and is shown in figure 4.9. The code is developed analytically in using programming language 'C' and given in appendix A for validation.

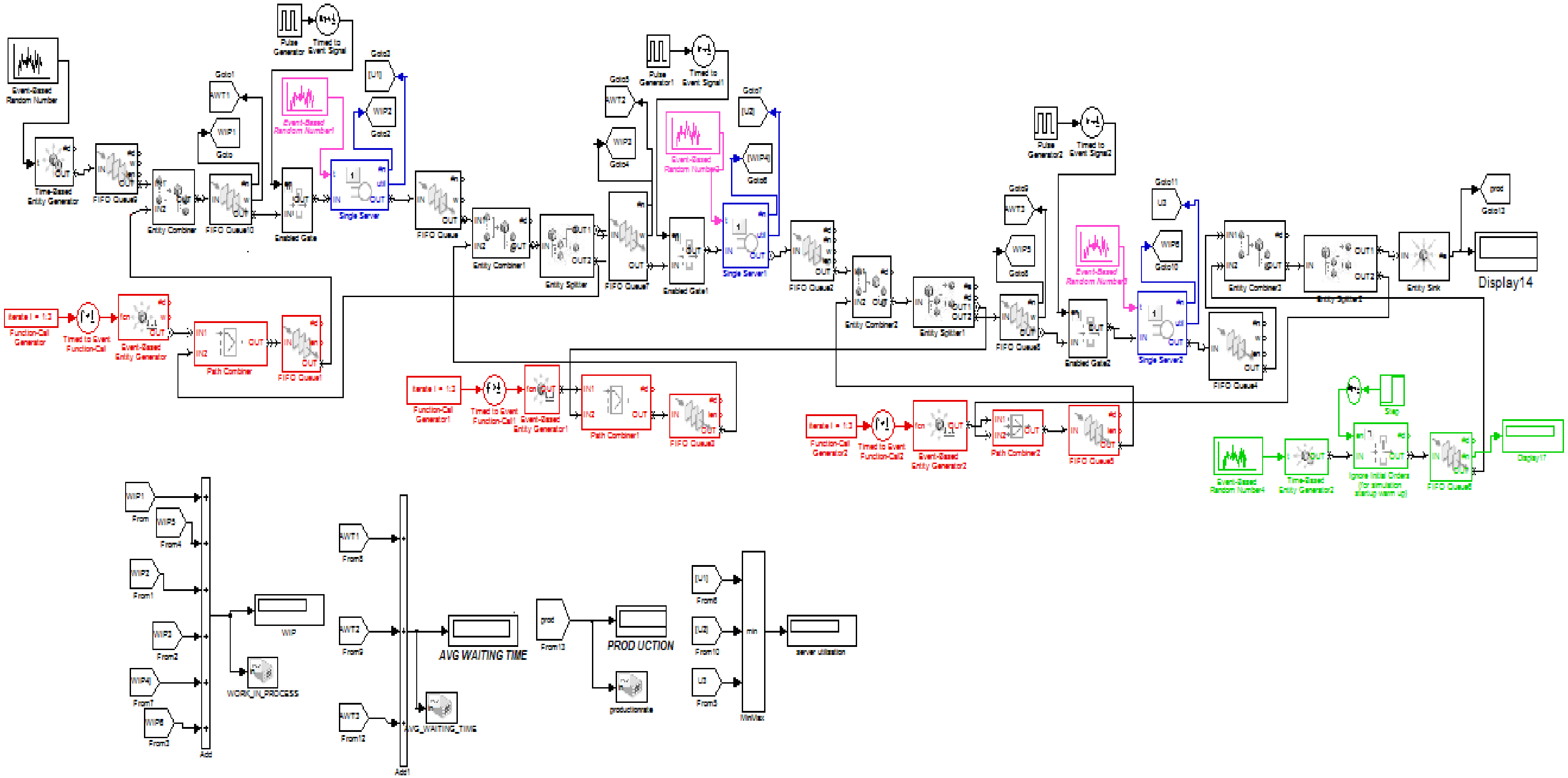

Figure: 4.9: Network diagram of KCS for single line multi stage system

4.3.3 Extended Kanban Control System (EKCS)

The figure 4.10 shows the network diagram of EKCS with three stages S_1, S_2 and S_3 in series. The PA_i is a queue of finished part and kanban at each stage. The queue A_1, A_2 and A_3 contain free kanbans i.e. n - S_i. The EKCS is similar to KCS when $K_i = S_i$. The customer demand D_i is instantly generated at all stages, (where i = 1, 2, 3….).

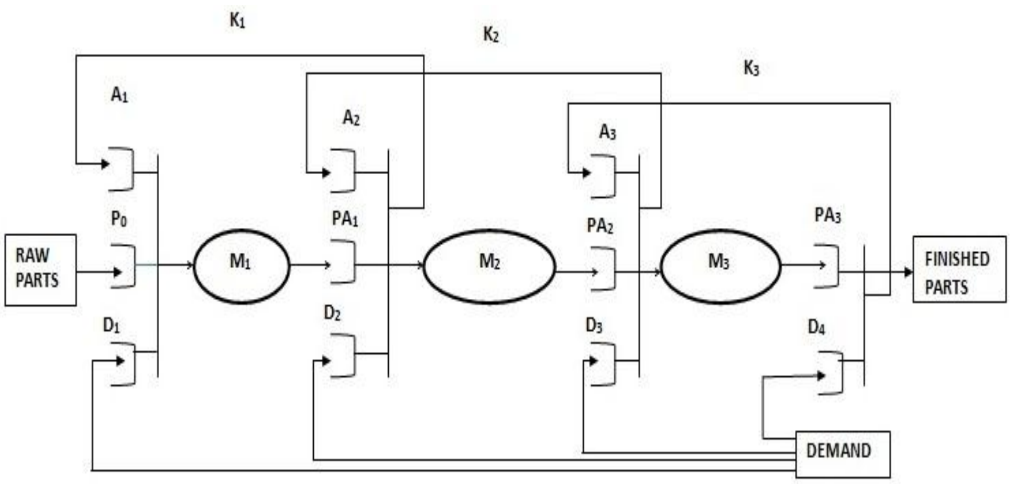

Figure.4.10: Queuing Network diagram for EKCS

The following are the invariants and characteristics of the system.

$$M(A_{i+1})\ M(PA_i)\ M(D_{i+1}) = 0 \text{ where } i = 1,2,3,4... \quad K_i \geq S_i$$

$$M(A_i) + M(PA_i) + M(M_i) = K_i \quad \text{where } i = 1, 2, 3, 4….$$

$$M(A_i) + M(D_{i+1}) - M(D_i) = K_i - S_i, \text{ where } i = 1,2,3,4 \ldots$$

$$0 \leq M(A_i) \leq K_i, \text{ where } i = 1,2,3,4 \ldots$$

$$0 \leq M_i \leq K_i, \text{ where } i = 1,2,3,4 \ldots$$

$$0 \leq (M_i + PA_i) \leq K_{i,} \text{ where } i = 1,2,3,4 \ldots$$

$$M(PA_i) - D_i \leq Si, \text{ where } i = 1,2,3,4 \ldots$$

Notations

n = Number of kanbans associated with each stage.

A_i = Queue of free kanbans for stage i.

PA_i = Queue of finished parts with kanban for stage i.

D_i = Queue of customer demand for stage i.

λ = Arrival rate of demands

P_0 = Queue for raw parts.

4.3.3.1 Initial State of the System

Initially, the queues PA_i contain finished parts of stage S_i. The queue A_i contains n - S_i free kanbans. All other queues are empty.

4.3.3.2 Analysis of Stations in Isolation

Case I: synchronization of Three Queues

The markovian analysis of synchronization with three queues is typical due to 3-dimensional state problem. Thus, it is proposed to synchronize the queues in two steps as shown in figure 4.11.

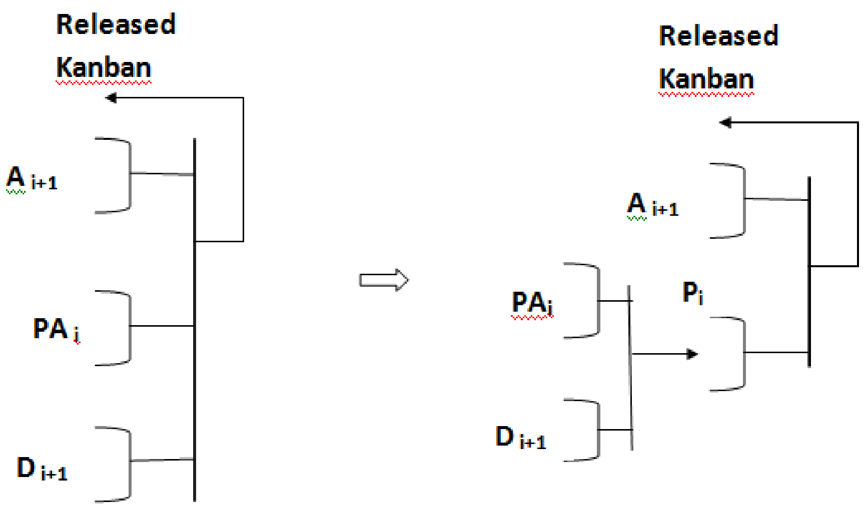

Figure 4.11: Synchronization of part, kanban and demand

The finished parts of stage i synchronize with demand of stage i+1, and the part is released to the queue P_i. Subsequently the queue P_i synchronizes with kanban of stage i+1. This step wise synchronizing method is an approximation to the analysis of three queue synchronization station.

Case II: Demand synchronization analysis

The queue of demand synchronizes with the queue of parts and kanban at the synchronization station. The demand synchronization station is shown in figure 4.12.

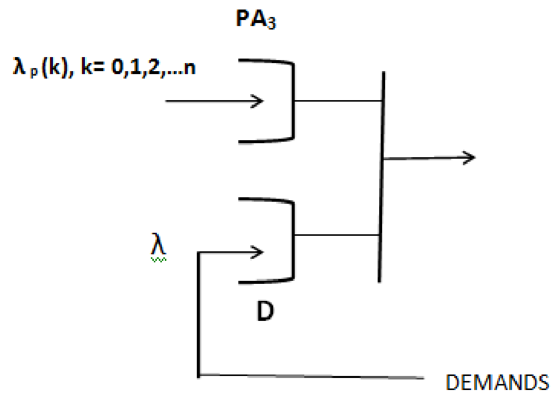

Figure 4.12: Synchronization of demand rate and part-kanban

The birth and death process of the demand synchronization station is shown in figure 4.13 below.

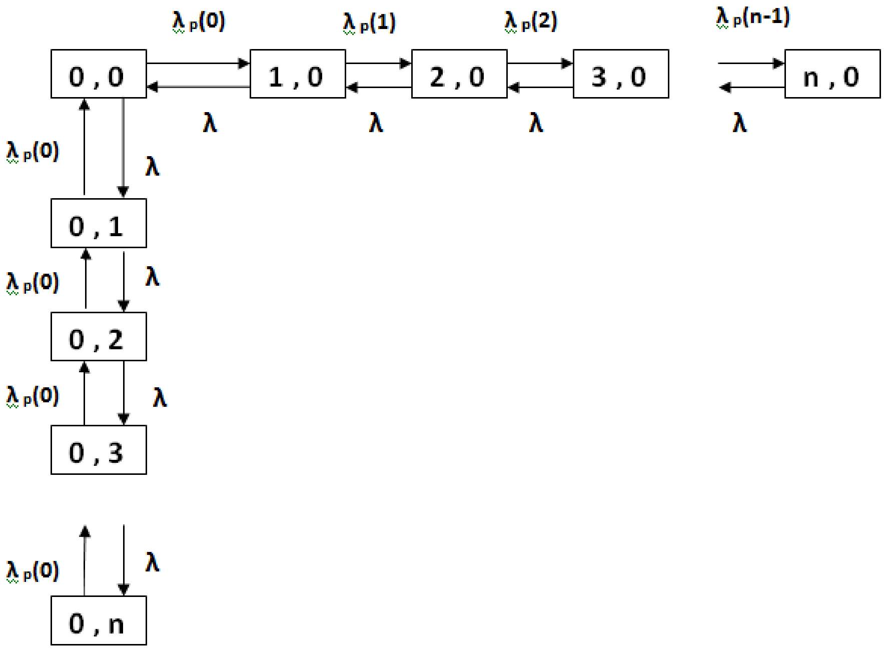

Figure 4.13: Birth and Death process of the Synchronization with demand and part kanban

The transition rate of part λ_p (x), $x \geq 0$ is the state dependent birth rate and demand rate λ is the state dependent death rate.

The rate balance equations of the demand and part synchronization for its horizontal component are

$$p(0, 0)\, \lambda_p(0) = \lambda \,.\, p(1, 0) \qquad \text{Eqn. (4.20)}$$

$$p(1, 0) = \frac{\lambda_{p(0)}}{\lambda} \,.\, p(0, 0) \qquad \text{Eqn. (4.21)}$$

$$p(1, 0)\, [\lambda + \lambda_p(1)] = p(0, 0)\, \lambda_p(0) + p(2, 0)\, .\lambda$$

Substituting the equation (4.20) in the above equation the solution yields

$$p(2, 0) = \frac{\lambda_{p(0)}\, \lambda_{p\,(1)}}{\lambda^2} \,.\, p(0, 0)$$

$$p(x, 0) = \frac{\lambda_{p\,(x-1)}}{\lambda^x} \,.\, p(0, 0) \qquad \text{Eqn. (4.22)}$$

The equation (4.22) is a recursive relation and the general solution yields.

$$p(x, 0) = \prod_{i=0}^{x-1} \frac{\lambda_{p\,(i)}}{\lambda^x}\; p(0, 0) \qquad \text{Eqn. (4.23)}$$

Similarly, the rate balance equation for the vertical components of the process is:

$$p(0, x) = \left[\frac{\lambda}{\lambda_{p(0)}}\right]^x \,.\, p(0, 0) \quad \text{Where } x = 1, 2, 3\ldots\infty \qquad \text{Eqn. (4.24)}$$

The determination of steady state probabilities are organized as probability vector P. i.e. $\sum p = 1$. Therefore,

$$P = [\, p(0, \infty) + \ldots\ldots\ldots + p(0,1) + p(0,0) + p(1,0) + p(2,0) + \ldots\ldots + p(n,0)\,] = 1$$

$$\left[\frac{\lambda}{\lambda_{p(0)}}\right]^\infty . \, p(0, 0) + \ldots\ldots\ldots + \left[\frac{\lambda}{\lambda_{p(0)}}\right] . \, p(0, 0) + p(0, 0) + \frac{\lambda_{p(0)}}{\lambda} . \, p(0, 0) +$$

$$\frac{\lambda_{p(0)}\, \lambda_{p\,(1)}}{\lambda^2} . \, p(0, 0) + \ldots\ldots\ldots + \frac{\lambda_{p(0)}\, \lambda_{p\,(1)}\, \lambda_{p\,(2)} \ldots \lambda_{p\,(n-1)}}{\lambda^n} . \, p(0, 0) = 1$$

Solving the expressions for the geometric series,

$$\mathrm{p}\,(0,0)\left[\frac{1}{1-\frac{\lambda}{\lambda_{p\,(0)}}}\right] + \frac{\lambda_{p(0)}}{\lambda}\ .\ \mathrm{p}\,(0,0) + \frac{\lambda_{p(0)}\,\lambda_{p\,(1)}}{\lambda^2}\ .\ \mathrm{p}\,(0,0) + \ldots\ldots\ldots +$$

$$\frac{\lambda_{p(0)}\,\lambda_{p\,(1)}\,\lambda_{p\,(2)}\ldots\lambda_{p\,(n-1)}}{\lambda^n}\ .\ \mathrm{p}\,(0,0) = 1$$

$$\mathrm{p}\,(0,0) = \frac{1}{\left[1-\frac{\lambda}{\lambda_{p\,(0)}}+\frac{\lambda_{p(0)}}{\lambda}+\frac{\lambda_{p(0)}\,\lambda_{p\,(1)}}{\lambda^2}+\ldots+\frac{\lambda_{p(0)}\,\lambda_{p\,(1)}\,\lambda_{p\,(2)}\ldots\lambda_{p\,(n-1)}}{\lambda^n}\right]} \quad \text{Eqn. (4.25)}$$

The marginal probabilities p(x), x = 0, 1, 2, 3….n of existing ‘x’ demands (attached with ‘x’ finished products) at the synchronization station can be calculated by using the equations (4.23), (4.24) and (4.25) as detailed below.

$$p(0,x) = \mathrm{p}\,(0,0) + \sum_{x=1}^{\infty}\left[\frac{\lambda}{\lambda_{p(0)}}\right]^x \mathrm{p}\,(0,0) \quad \text{Eqn. (4.26)}$$

$$p(x,0) = \prod_{i=0}^{x-1} \frac{\lambda_{p\,(i)}}{\lambda^x}\ \mathrm{p}\,(0,0) \quad \text{Eqn. (4.27)}$$

Case III: part synchronization Analysis

The kanban queue synchronized with the parts queue for the part synchronization is shown in figure 4.14. The birth death process as well as rate balance equation of the upstream station is the same as that for the downstream synchronization station.

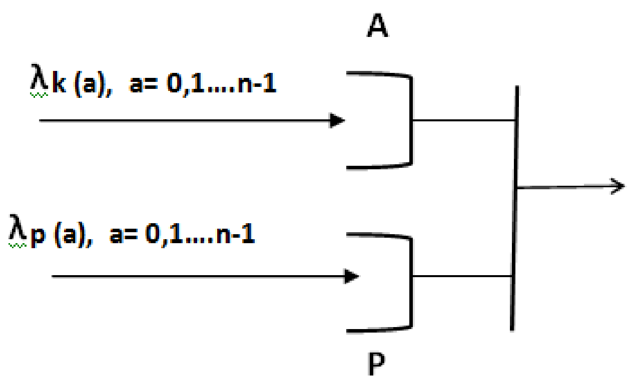

Figure 4.14: Synchronization of part and kanban

The birth and death process of the part synchronization is shown in figure 4.15.

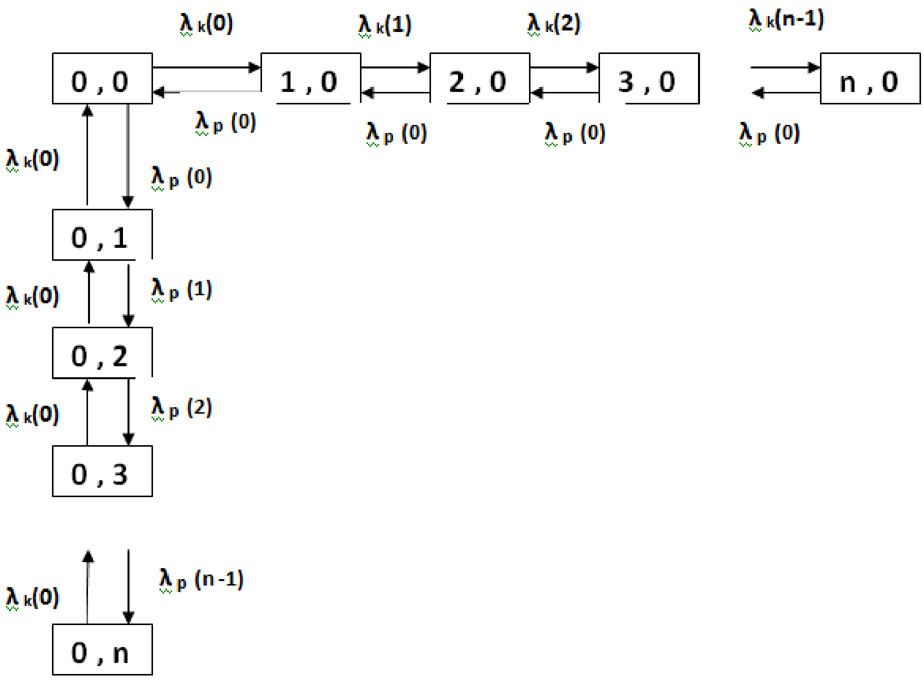

Figure 4.15: Birth and Death process of the Synchronization with part

The transition rates, arrival rate of Kanban λ_k (x), x ≥ 0 are state dependent birth rates and arrival rate of part λ_p (x) are referred to as state dependent death rates.

The general solution of the recursive relation for the Kanban and part synchronization for horizontal stage is

$$p\,(x, 0) = \prod_{i=0}^{x-1} \frac{\lambda_{k\,(i)}}{\lambda_{p\,(0)}}\ p\,(0, 0) \qquad \text{Eqn. (4.28)}$$

Similarly, the vertical stage general solution of the recursive relation yields:

$$p\,(0, x) = \frac{\prod_{i=0}^{x-1} \lambda_{p\,(i)}}{\left[\lambda_{k\,(0)}\right]^{x}}\ .\ p\,(0, 0) \quad \text{Where } x = 1, 2, 3,\ldots\infty \qquad \text{Eqn.(4.29)}$$

The determination of steady state probabilities is

$$p\,(0,0) = \frac{1}{1+\left\{\frac{\lambda_{p\,(0)}}{\lambda_{k\,(0)}}+\cdots+\frac{\lambda_{p\,(n-1)}\ldots\ldots\lambda_{p\,(0)}}{\left[\lambda_{k\,(0)}\right]^{n}}\right\}+\left\{\frac{\lambda_{k\,(0)}}{\lambda_{p\,(0)}}+\cdots+\frac{\lambda_{k\,(n-1)}\ldots\ldots\lambda_{k\,(0)}}{\left[\lambda_{p\,(0)}\right]^{n}}\right\}} \qquad \text{Eqn.(4.30)}$$

The marginal probabilities p(x), x = 0, 1, 2, 3….n of existing 'x' kanbans (attached with 'x' finished products) at the synchronization station can be computed by using the equations (4.28), (4.29) and (4.30) as detailed below

$$p(x,0) = \sum_{x=1}^{n} \prod_{i=0}^{x-1} \frac{\lambda_{k\,(i)}}{\left[\lambda_{p\,(0)}\right]^{x}} \,.p(0,0) \qquad \text{Eqn.(4.31)}$$

$$p(0,x) = \frac{\prod_{i=0}^{x-1} \lambda_{p\,(i)}}{\left[\lambda_{k\,(0)}\right]^{x}} \,.\, p\,(0,0) \quad \text{Where } x = 1,2,3,\ldots.n \qquad \text{Eqn.(4.32)}$$

Throughput (Production rate)

The throughput of EKCS is the last synchronization station in the system. The throughput of this station is given by:

$$R_p = \sum_{x=1}^{n} p(x,0)\,.\,\mu(x)$$

Mean work in process

The work in process can be calculated by summing the queue lengths of the output buffers of each stage i.e. $\sum_{x=1}^{n}(PA_i + P_i)$. The queue length of a station is given by:

$$L_i = \sum_{x=1}^{n} x\,.\,p(x,0)$$

Mean waiting time

The mean waiting time of a part in the system can be calculated by using Little's formula.

$$W = \frac{L}{\lambda} \quad \text{where } \lambda = \text{arrival rate of demands.}$$

The network model of EKCS is developed by using the software MATLAB/SIMULINK R2011b and is shown in figure 4.16. A code is developed analytically by using programming language 'C' and is given in Appendix A for the validation.

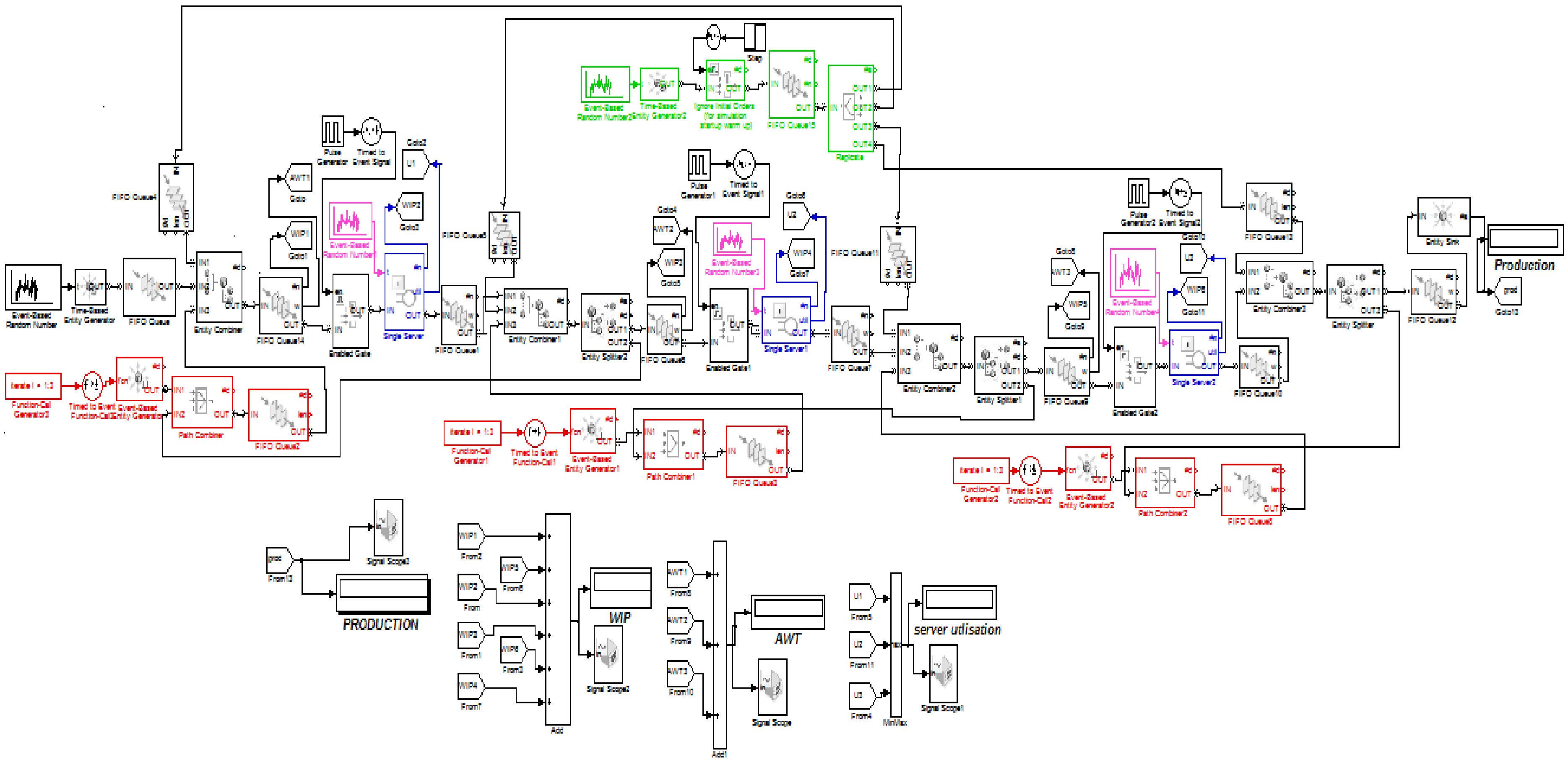

Figure 4.16: Network Model of EKCS of single line Multi stage system

4.4 SUMMARY

This chapter describes the requirements related to manufacturing system and its operating parameters. The need of modeling and simulation is presented in this chapter followed by the assumptions needed for the system configuration, modeling and simulation. This chapter presents the details of queuing network analysis such as synchronization mechanism, computation of performance parameters for CONWIP system, KCS and EKCS along with network diagrams. The network model for CONWIP system, KCS and EKCS are developed as discussed and coded in programming language ‘C’.

CHAPTER 5

RESULTS AND DISCUSSIONS

In the previous chapters, the problem statement, modeling assumptions are defined to meet the objectives, generate system configurations and queuing network analysis for model development. The simulation is an appropriate tool for the measurement and analysis of the manufacturing systems. The network model of CONWIP system, KCS and EKCS are developed in the software as discussed and their results are analyzed. A code is developed by using programming language 'C' for validation. In this chapter, the simulation results are validated and analyzed for various configurations. The performance variation between CONWIP system, KCS and EKCS are measured for throughput, AWT, WIP and machine utilization.

5.1 VALIDATION OF SIMULATION MODEL

The simulation models need verification, since they are based on hypothetical manufacturing systems i.e. whether the model performs as intended [111]. The simulated results of the model ensure that it truly replicate the hypothetical manufacturing system. The validation of the model is to verify the accurate representation of the real system chosen for the study. The verification involves debugging of simulation model, checking internal logic, comparing model output with manually simulated output for the same input.

5.2 ANALYSIS OF SINGLE FLOW LINE MULTI STAGE MANUFACTURING SYSTEM.

The performance output of CONWIP system, KCS and EKCS are validated and compared. The performance variation of the manufacturing systems is investigated for number of kanbans per stage, workstation breakdown and sensitivity analysis.

5.2.1 Results Validation

The modeling of CONWIP system, KCS and EKCS is developed by using the software as discussed and is shown in figure 4.4, figure 4.9 and figure 4.16. The systems are coded mathematically by object oriented language C is given in Appendix A. The results are validated by comparing the performance output obtained from the above models. The number of kanbans per stage is assumed to be three. The processing mean time for each stage is 15 minutes. The demand mean time varies from 10 minutes to 55 minutes in the time step of 5 minutes. The manufacturing systems are simulated for 9600 minutes (i.e. 10 days @16 hours/day). The validation of simulation results obtained for production and work in process by network model and programming code 'C' are shown in figures 5.1 to 5.6.

For low demand mean time, the production obtained from software simulation is approximately 5% low for CONWIP; 7% low for KCS; and 6% low for EKCS; as compared to analytical method. The WIP obtained from software simulation is one part less for CONWIP and KCS; whereas for EKCS it is negligible as compared to analytical method. For high demand mean time, the production obtained from software simulation for CONWIP, KCS and EKCS is approximately 1% to 2% low as compared to analytical method. The WIP obtained by software simulation for CONWIP is one part high; for KCS is two parts less; for EKCS is one part less; as compared to analytical method. Thus, the simulation results obtained are compared and validated.

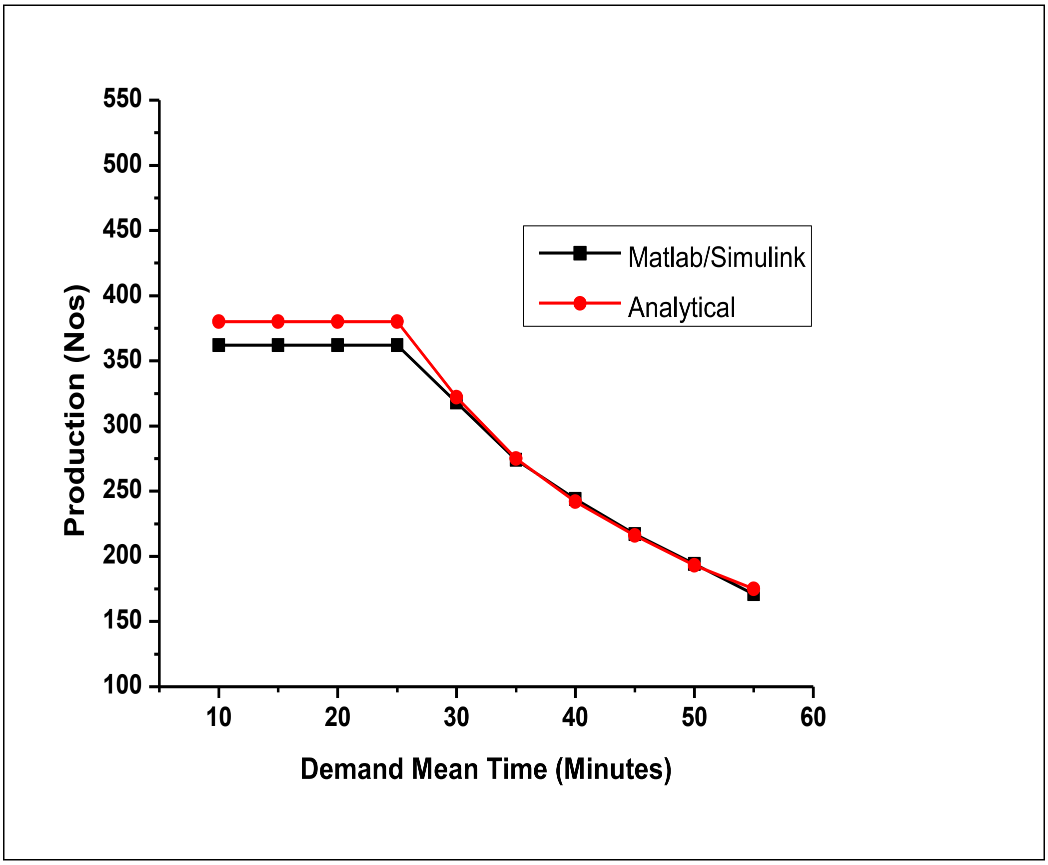

Figure 5.1: Validation of CONWIP for single flow line Multi stage system for production

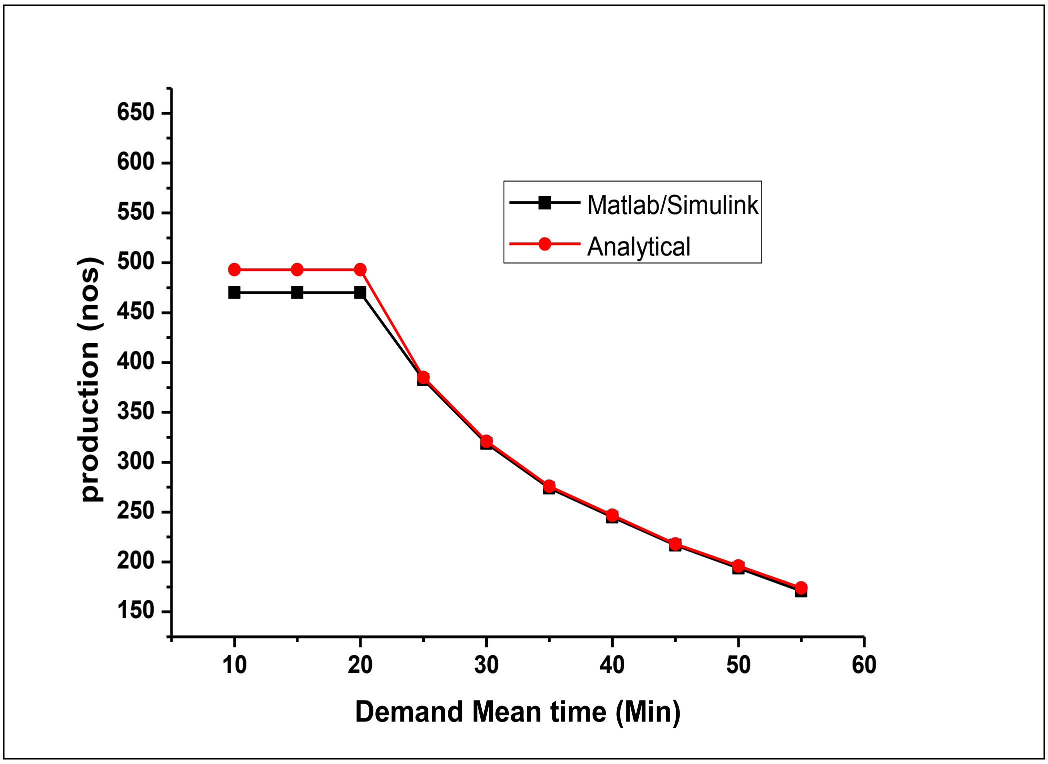

Figure 5.2: Validation of KCS for single flow line Multi stage system for Production

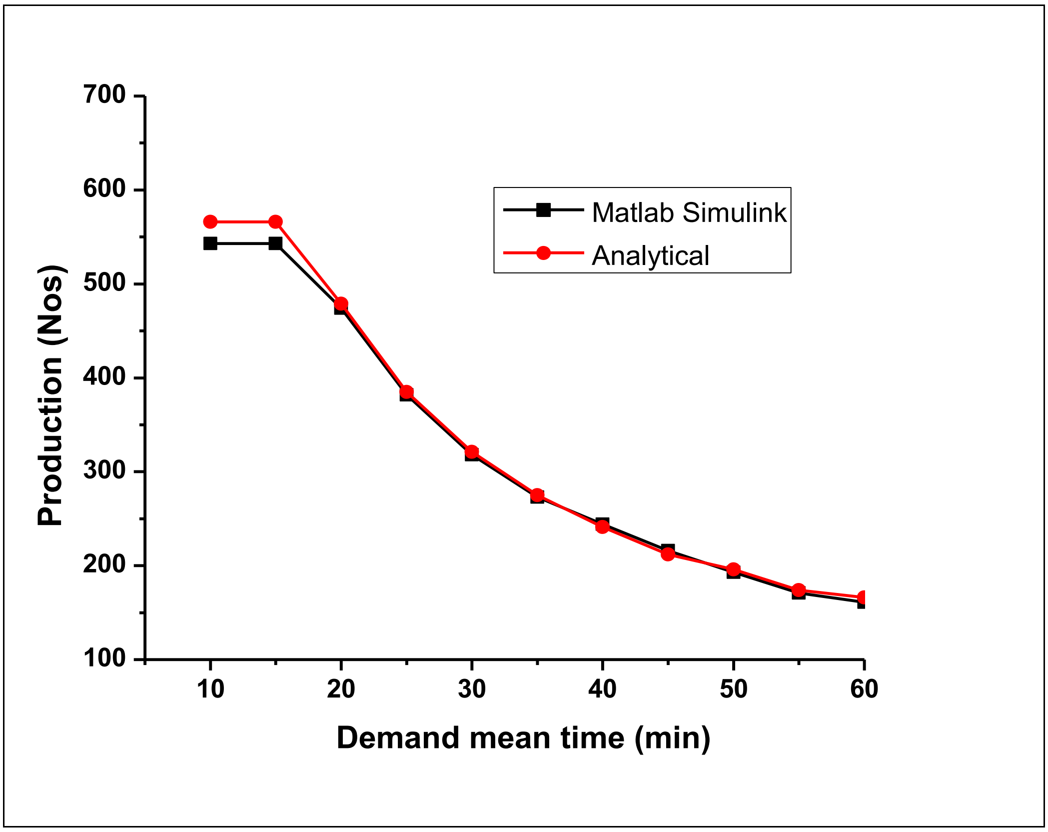

Figure 5.3: Validation of EKCS for single flow line Multi stage system for Production

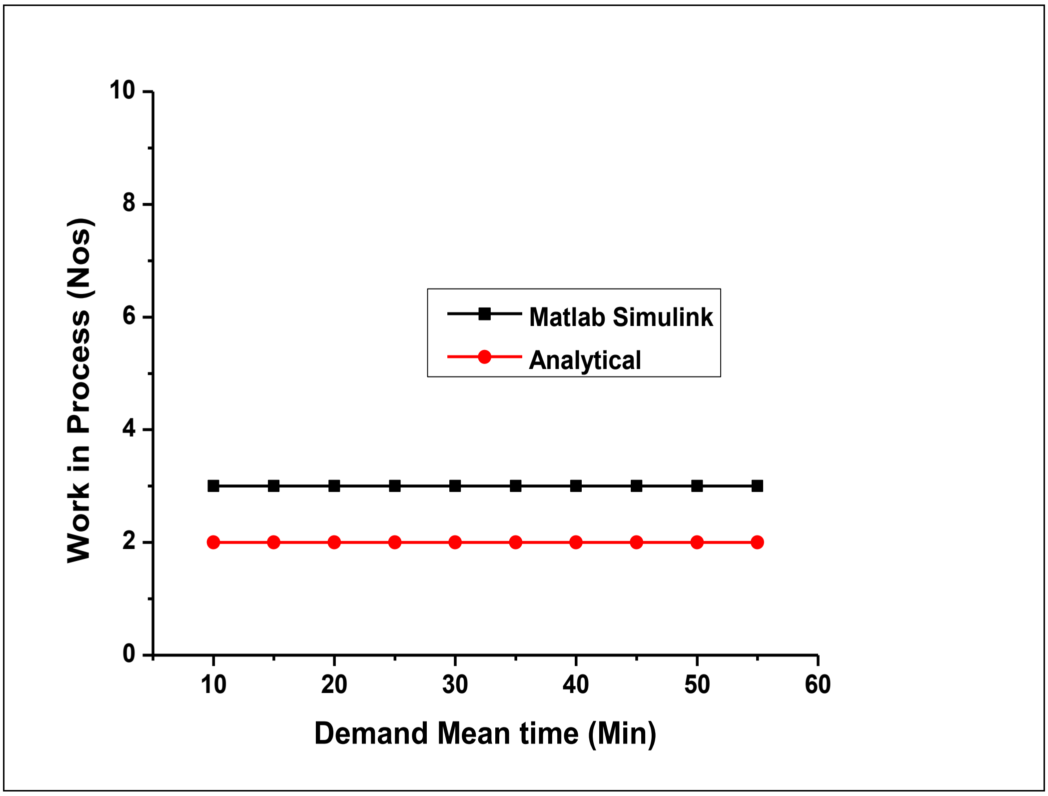

Figure 5.4: Validation of WIP for single flow line Multi stage system for CONWIP

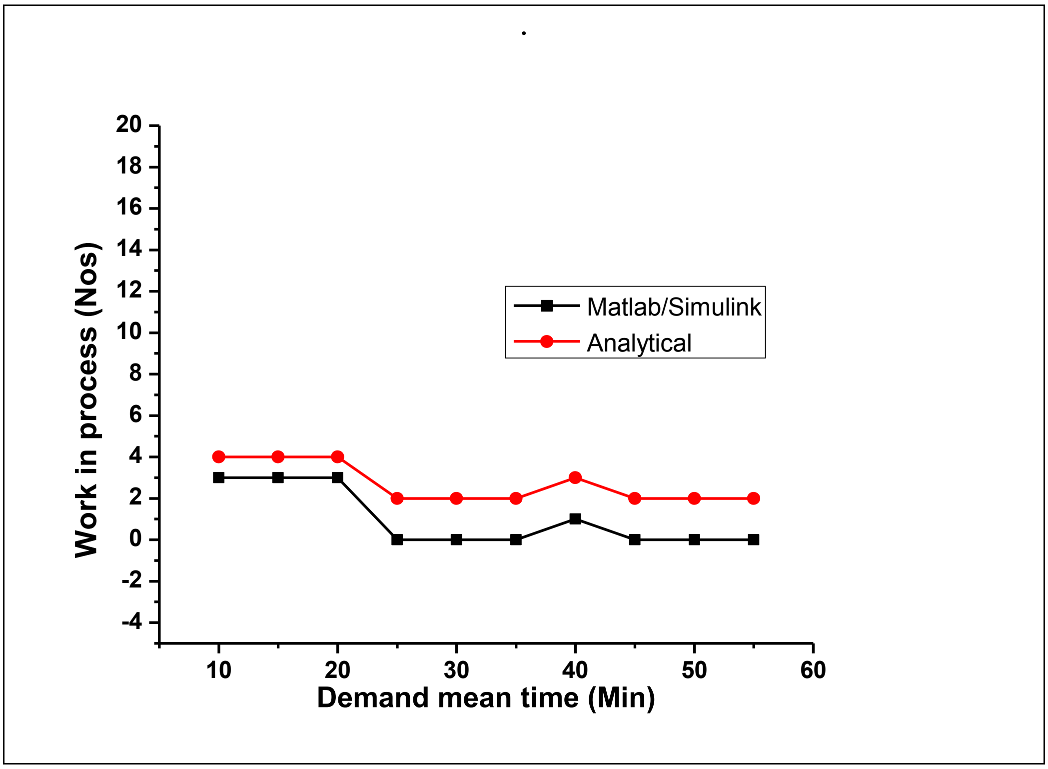

Figure 5.5: Validation of WIP for single flow line Multi stage system for KCS

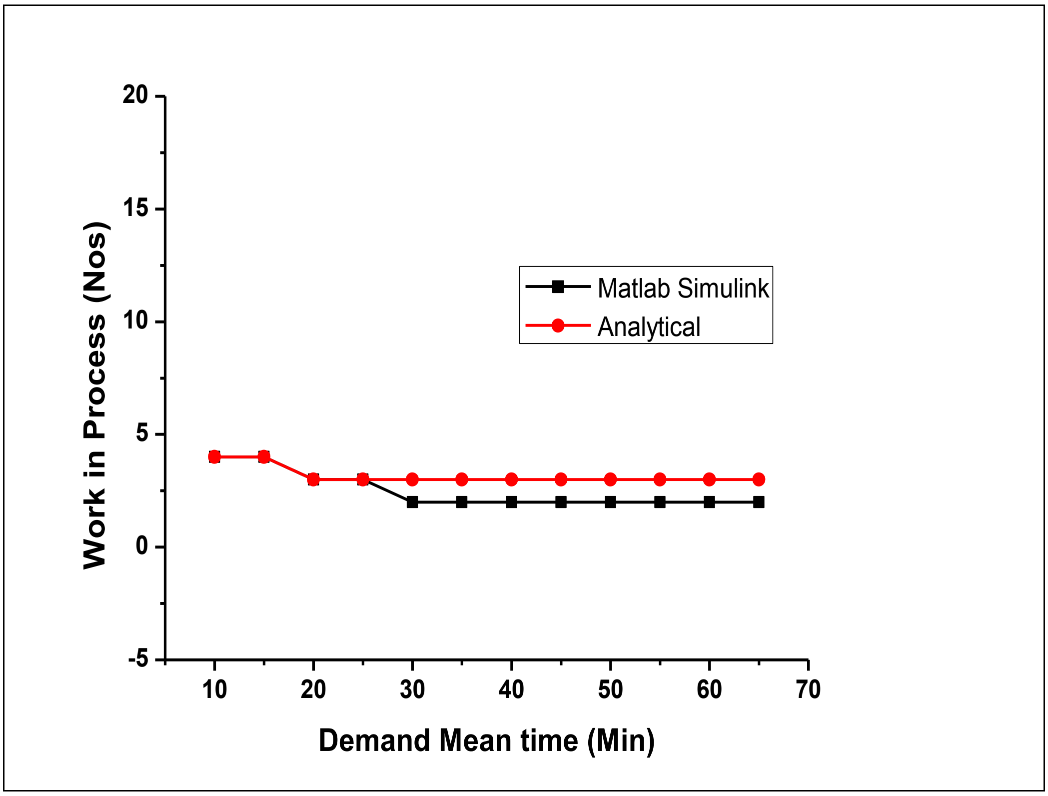

Figure 5.6: Validation of WIP for single flow line Multi stage EKCS

The model developed in the software and in programming language 'C' are also validated with the results of Selvaraj et al [73] . The input parameters are :- a). The workstation processing mean time is 15 minutes b) Demand rate is 1-3 parts/hour c) The number of kanbans per stage is three. d) The MTBF for the three stages are 3000 min, 4500 min, and 6000 min respectively. e) The MTTR is 120 min. f) The simulation time of the system is 400 hours that includes a warm up time of 6 hours. At high demand rate, the production obtained by software simulation is 3% less than analytical method; 8% less than the results from Selvaraj et al; for CONWIP. At low demand rate they are similar. For EKCS, at high demand rate the production obtained by software simulation is 5% less than analytical method; 9% less than the results of Selvaraj et al. The figures 5.7 to 5.12 show the comparison of results for the revalidation of CONWIP system and EKCS models.

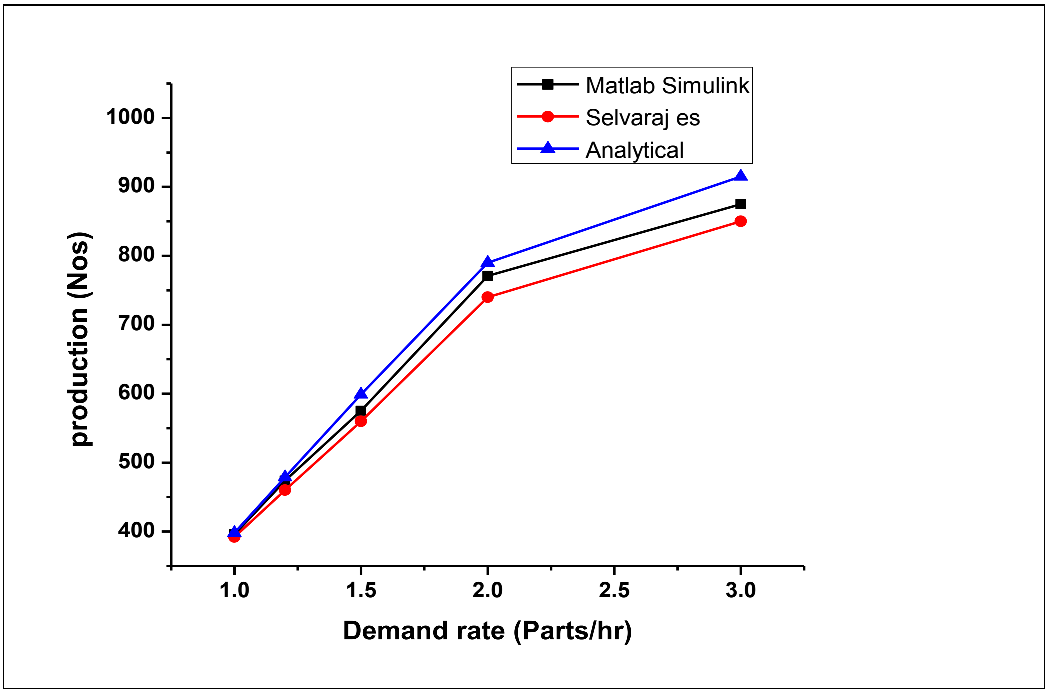

Figure 5.7: Revalidation of Production for single flow line Multi stage system for CONWIP after comparing with the results of Selvaraj et al [73]

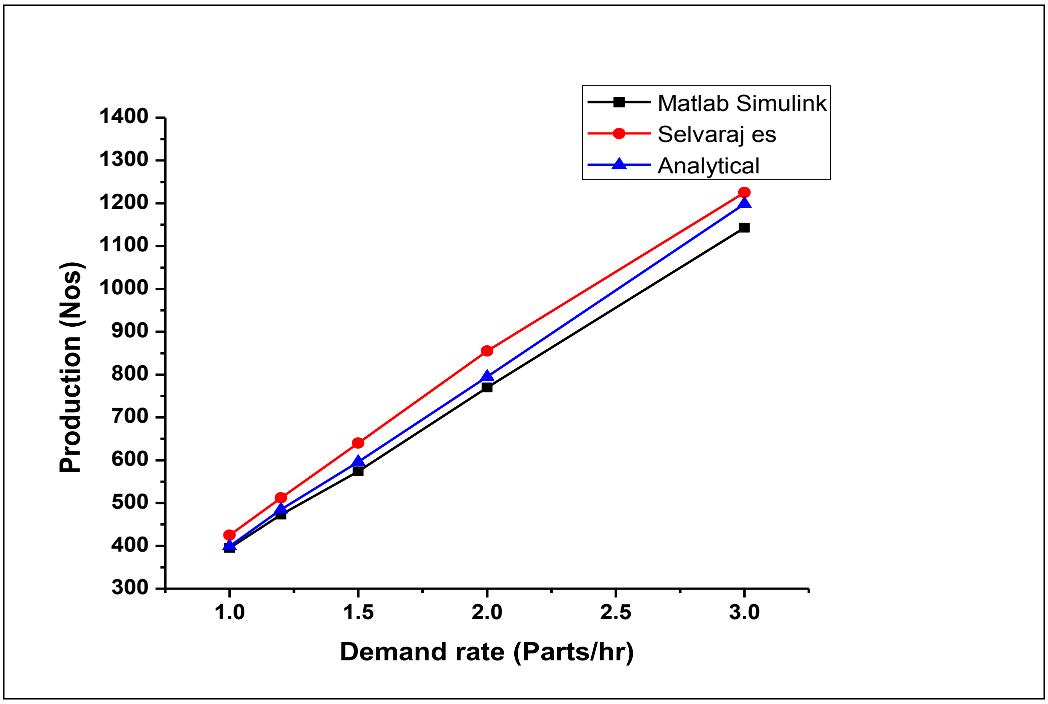

Figure 5.8: Revalidation of Production for single flow line Multi stage system for EKCS after comparing with the results of Selvaraj et al [73]

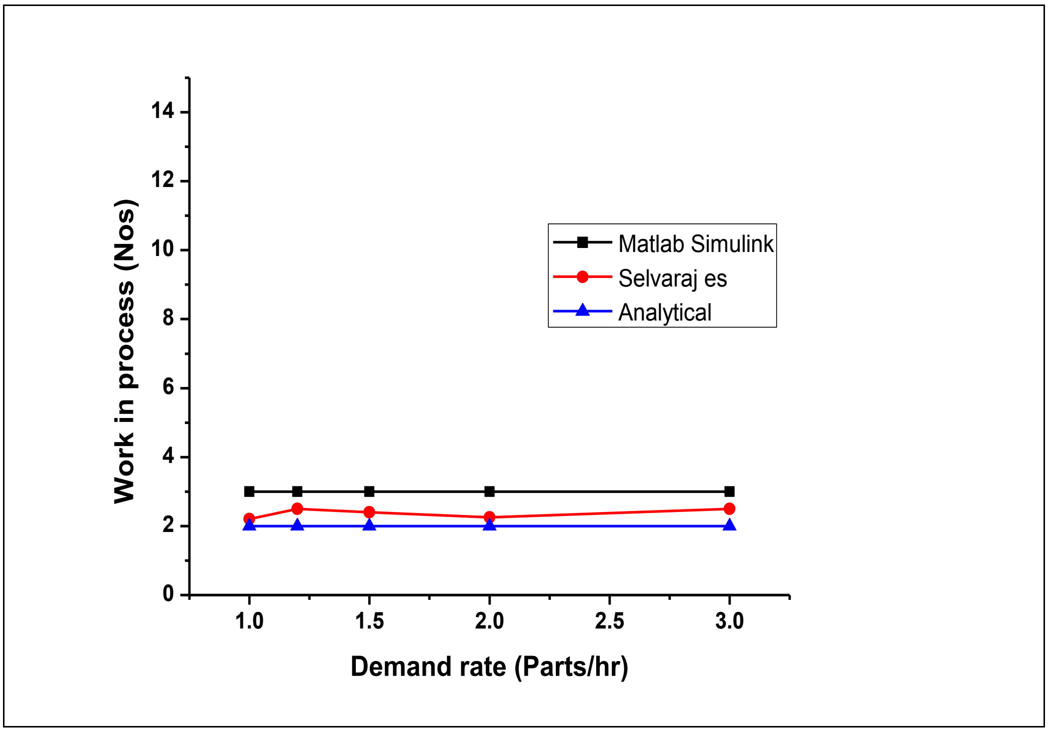

Figure 5.9: Revalidation of WIP for single flow line Multi stage system for CONWIP after comparing with the results of Selvaraj et al [73]

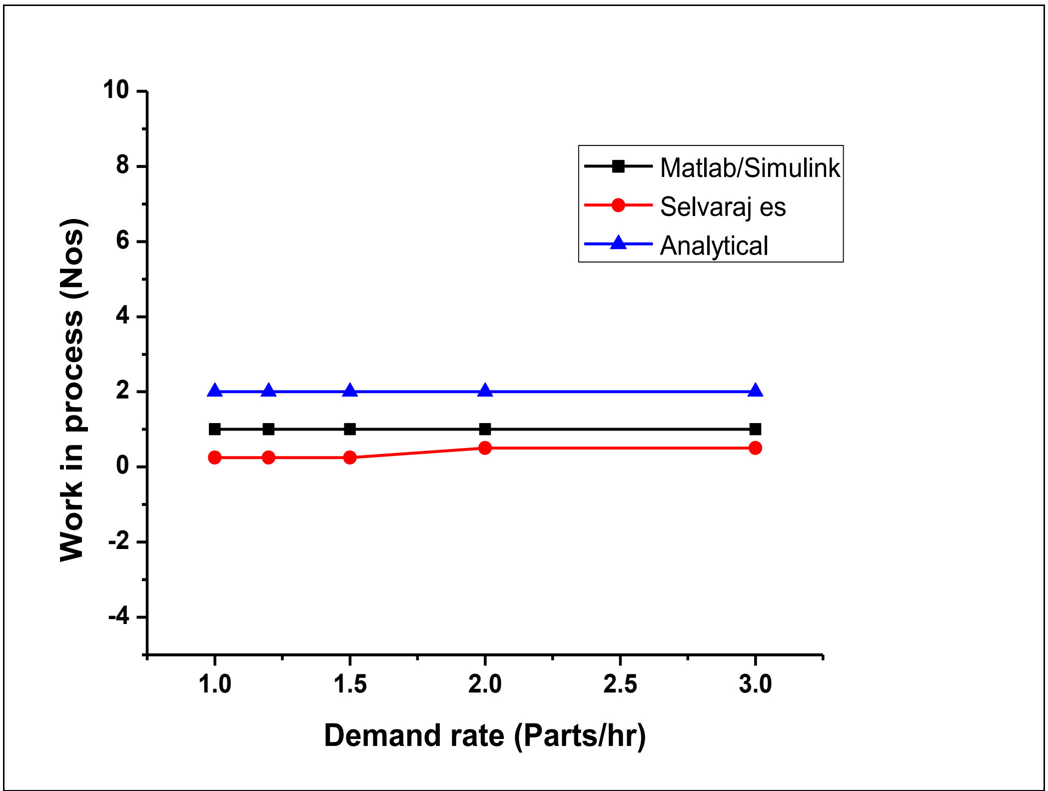

Figure 5.10: Revalidation of WIP for single flow line Multi stage system for EKCS after comparing with the results of Selvaraj et al [73]

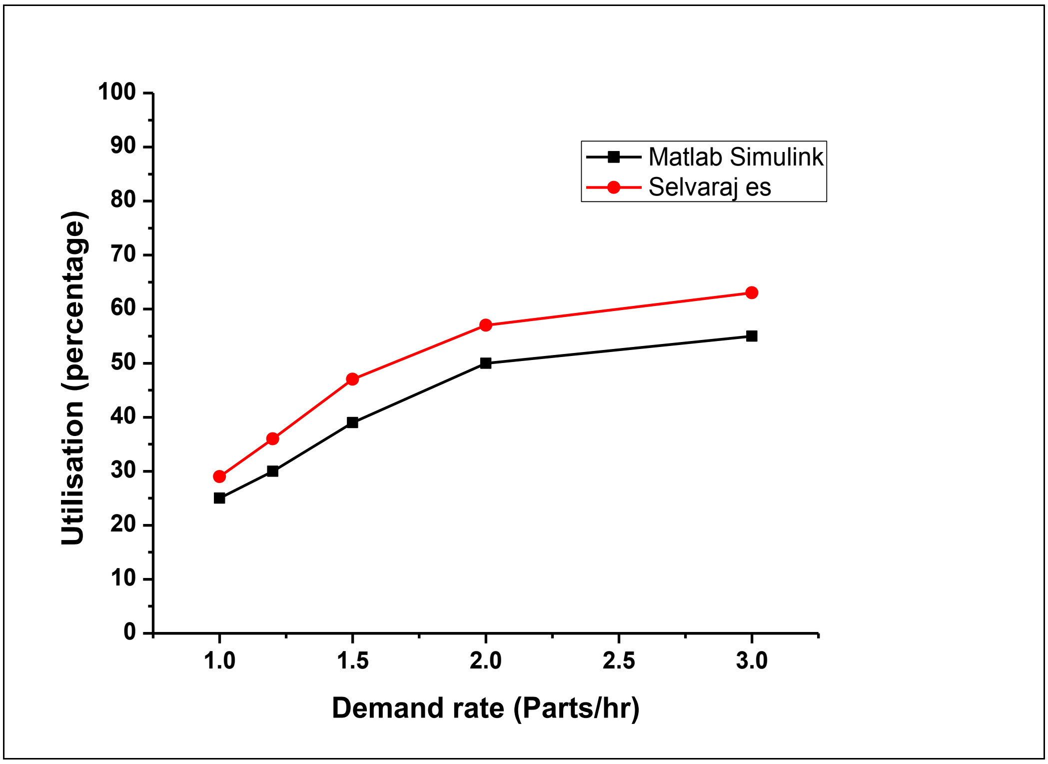

Figure 5.11: Revalidation of utilization for single flow line Multi stage system for CONWIP

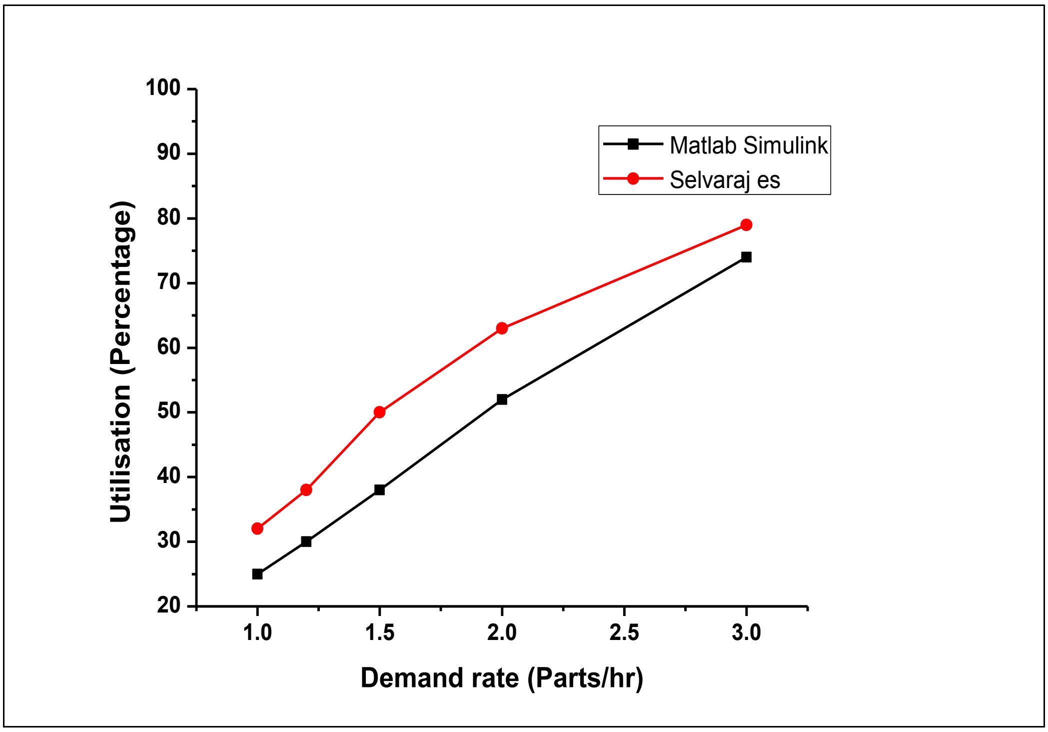

Figure 5.12: Revalidation of utilization for single flow line Multi stage system for EKCS

5.2.2 Performance Analysis of pull control systems

The performance comparison of CONWIP system, KCS and EKCS for single flow line, multi stage system is analyzed for the effect of number of kanbans per stage, with and without breakdowns, effect of imbalance in processing mean time using simulation results. The processing mean time for each workstation is assumed as 5 minutes. The manufacturing systems are simulated for a time period of 825 hours which includes the warm up time of 75 hours [97].

5.2.2.1 Effect of number of kanbans

Simulation experiments are conducted to evaluate the performance of single flow line three stage manufacturing systems for number of kanbans per stage. The mean demand time is assumed as 8 minutes. The detailed performance and comparative analysis of the results for the number of kanbans per stage are shown in figures 5.13 to 5.16.

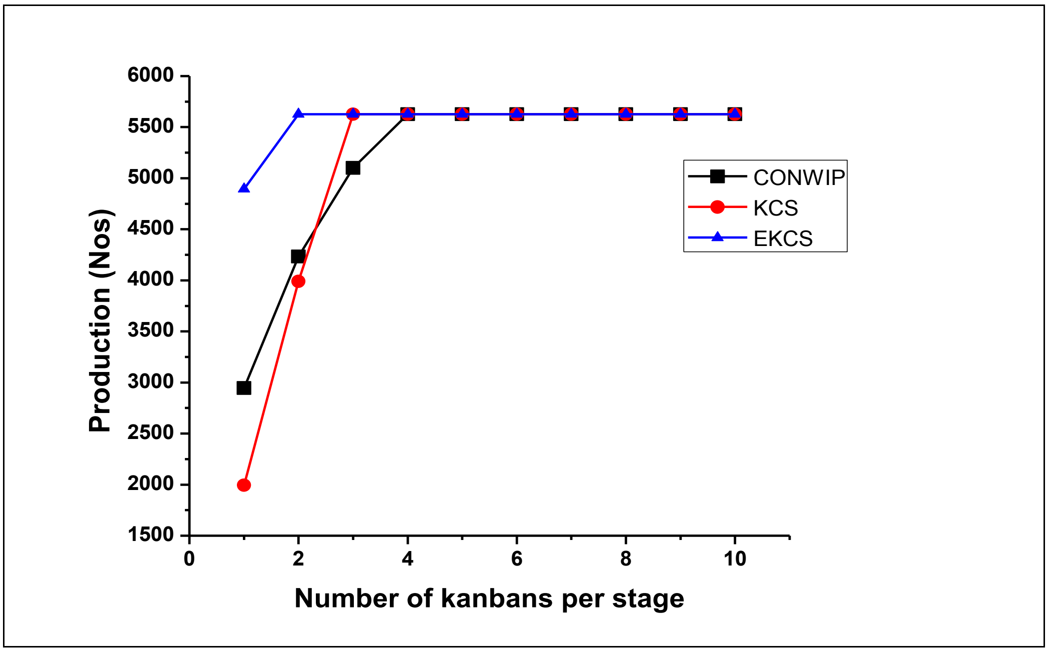

Figure 5.13: Effect of production on number of kanbans for CONWIP, KCS and EKCS

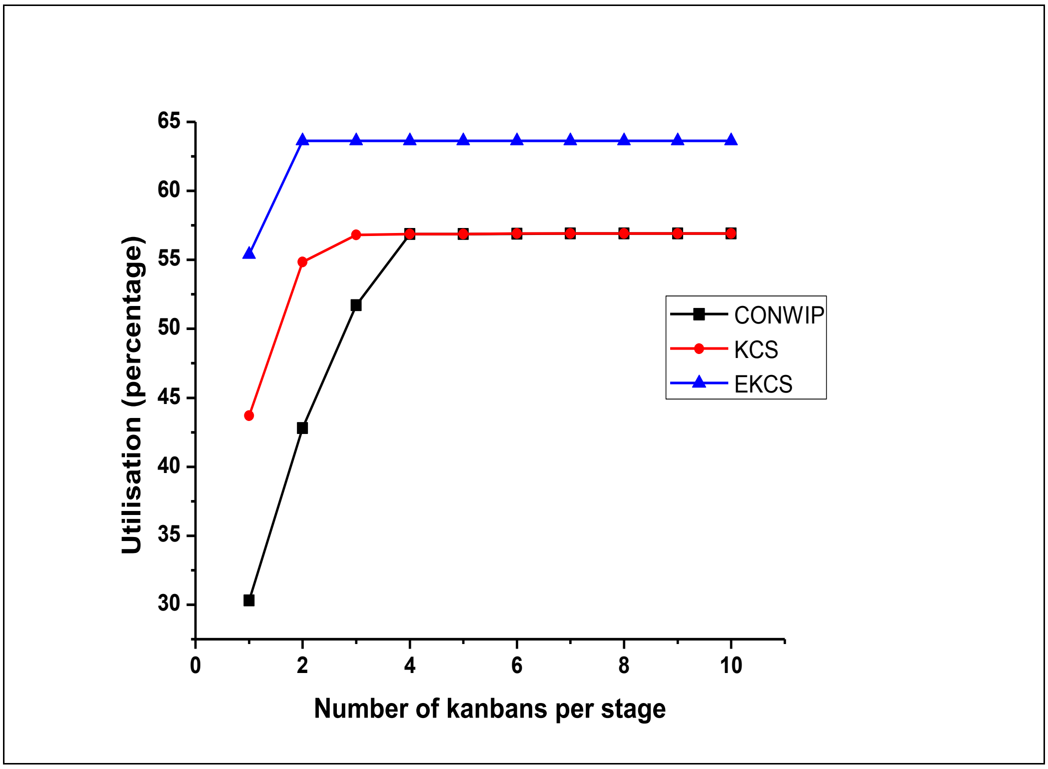

Figure 5.14: Effect of utilization on number of kanbans for CONWIP, KCS and EKCS

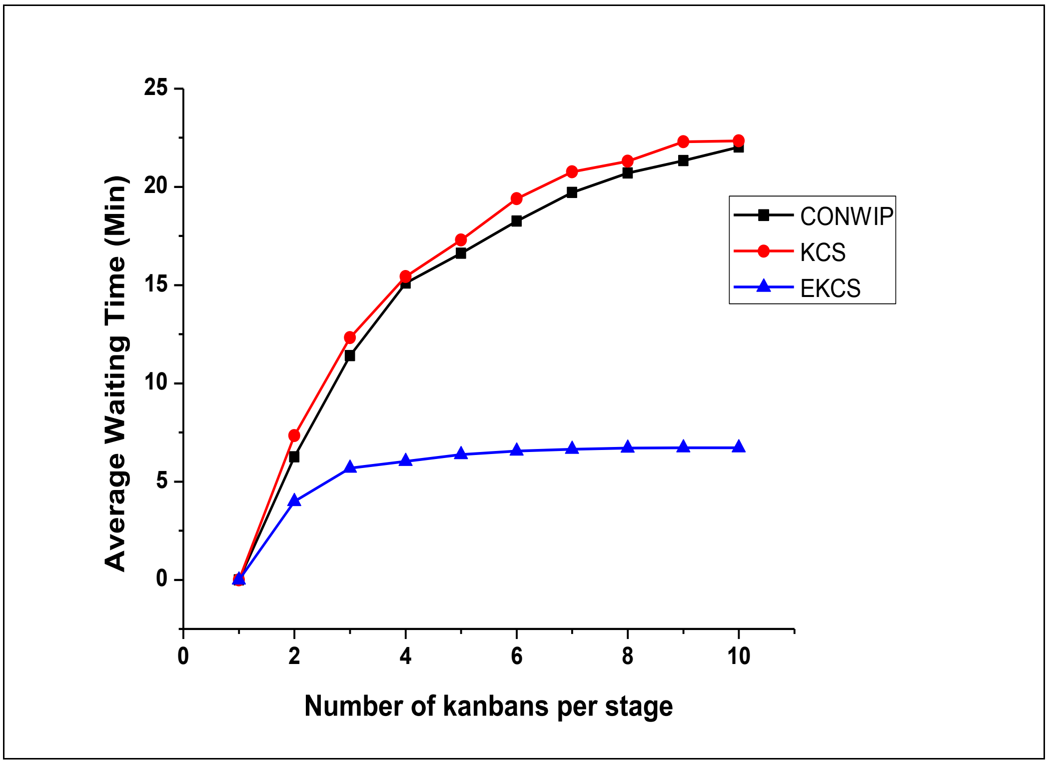

Figure 5.15: Effect of AWT on number of kanbans for CONWIP, KCS and EKCS

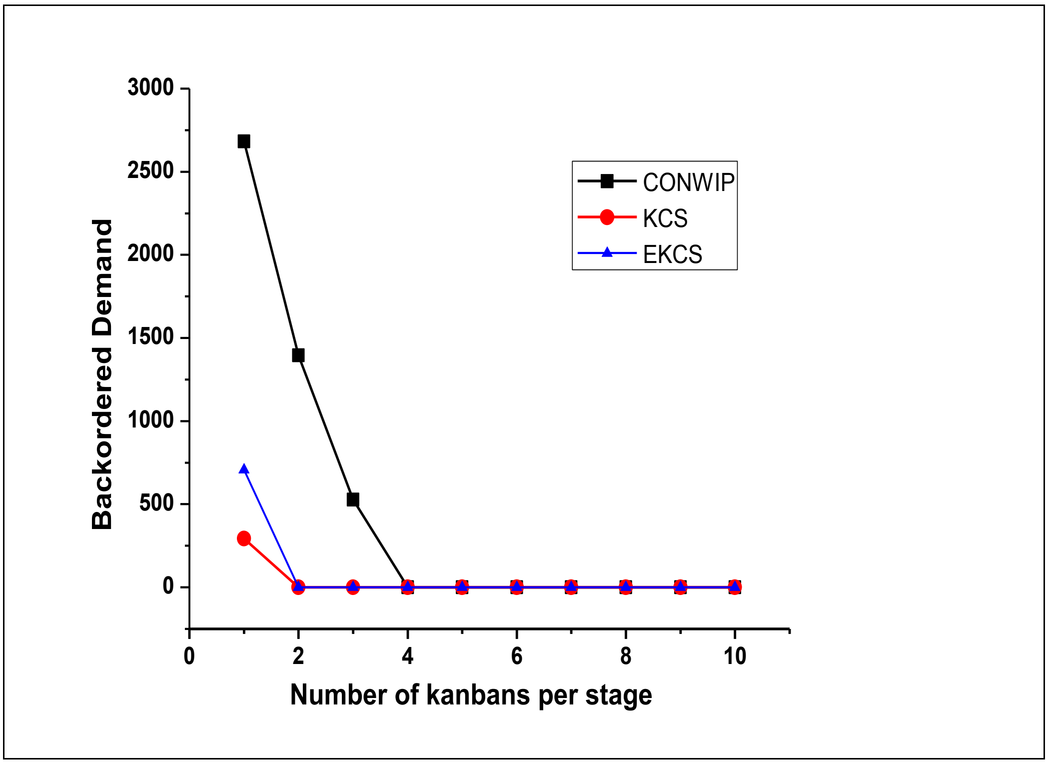

Figure 5.16: Effect of backordered demand on number of kanbans for CONWIP, KCS and EKCS

The system performance varies as the number of kanbans per stage increases from 0 to 3 kanbans per stage. Beyond 3 kanbans per stage, production, backorder demand and utilization for all the systems under investigation are similar and have negligible effect on their performance. However, the AWT increases with increase in number of kanbans, as more number of parts would be released and wait in the queues to get processed. The AWT for EKCS is comparatively less, since the part release and movement depends on the kanban and demand at each synchronization stage. In case of KCS and CONWIP system, the effect of demand is on the last downstream stage only before the finished part is released to the customer. The intermediate movement of part between the stages depends on kanban.

Initially for single kanban, the backordered demand is high since the demand has to wait for the part to synchronize to release the kanban. With increase in number of kanbans per stage, the part is available for every demand arrival. It depends on the processing mean time t_i and demand mean time D_i i.e. $t_i \leq D_i$. For 3 kanbans per stage, the performance comparison of the systems has less variability and the production, AWT, WIP, backordered demand and machine utilization are optimum.

5.2.2.2 Without breakdown

Figures 5.17 to 5.21 show the performance comparison and analysis of the CONWIP system, KCS and EKCS for production, AWT, utilization, WIP and backordered demands with demand rate of 4 to 12 parts per hour. The optimum number of kanbans per stage is three.

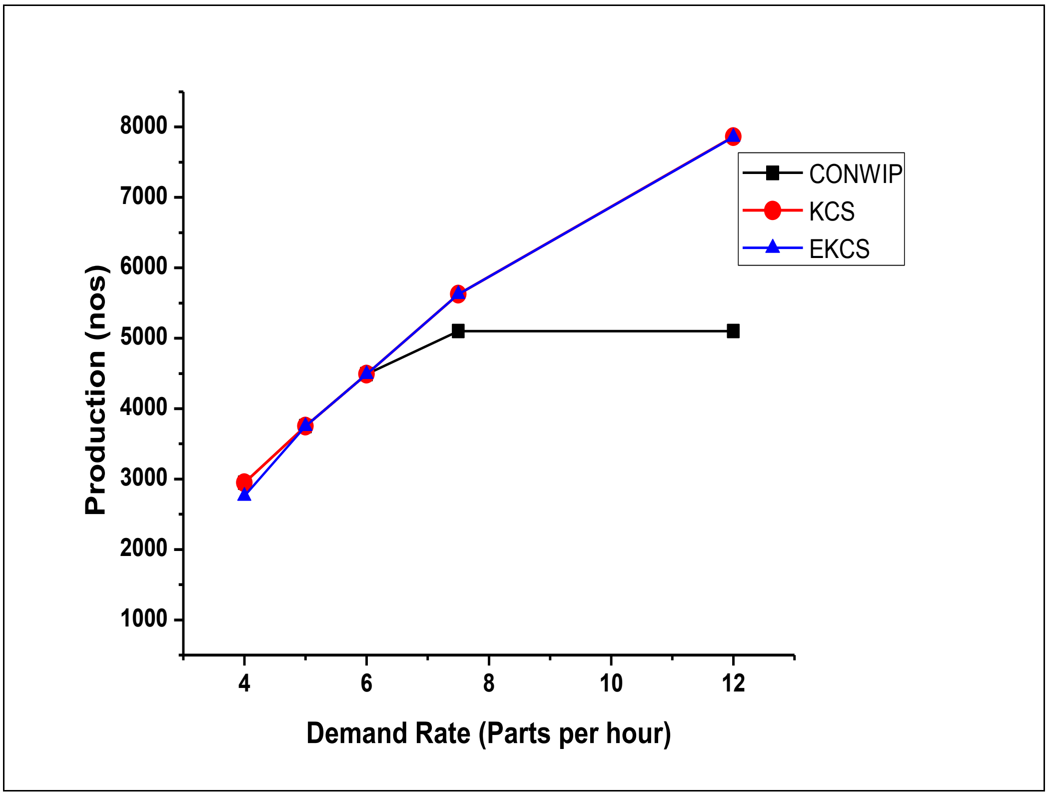

Figure 5.17: Performance of CONWIP, KCS and EKCS for single flow line multi stage system for production

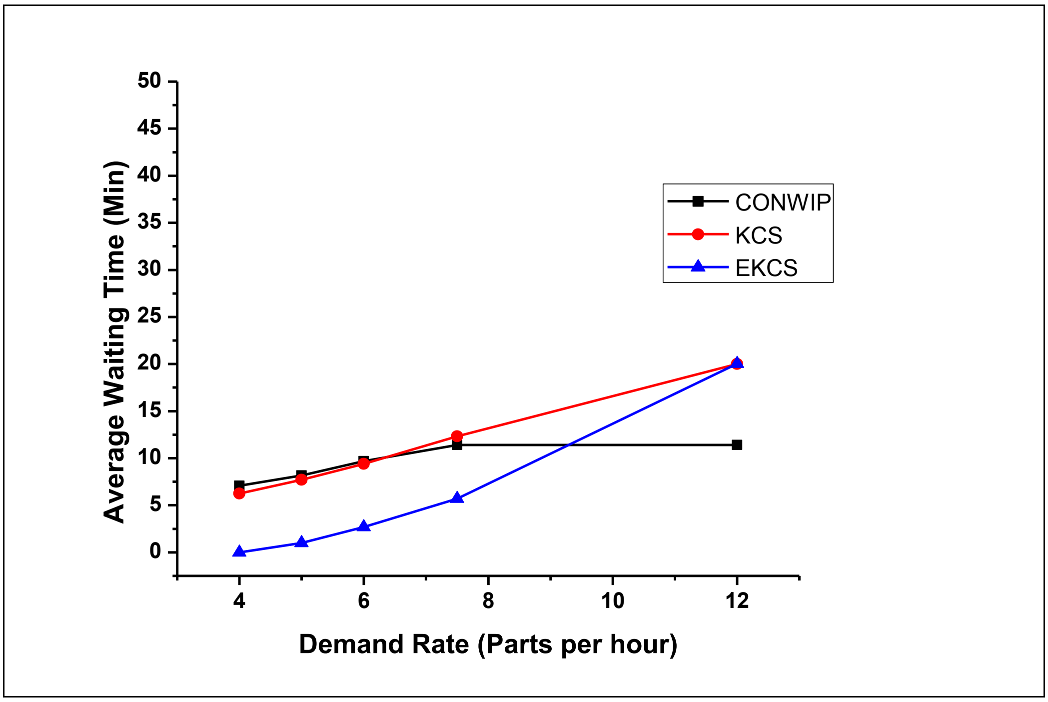

Figure 5.18: Performance of CONWIP, KCS and EKCS for single flow line multi stage system for AWT

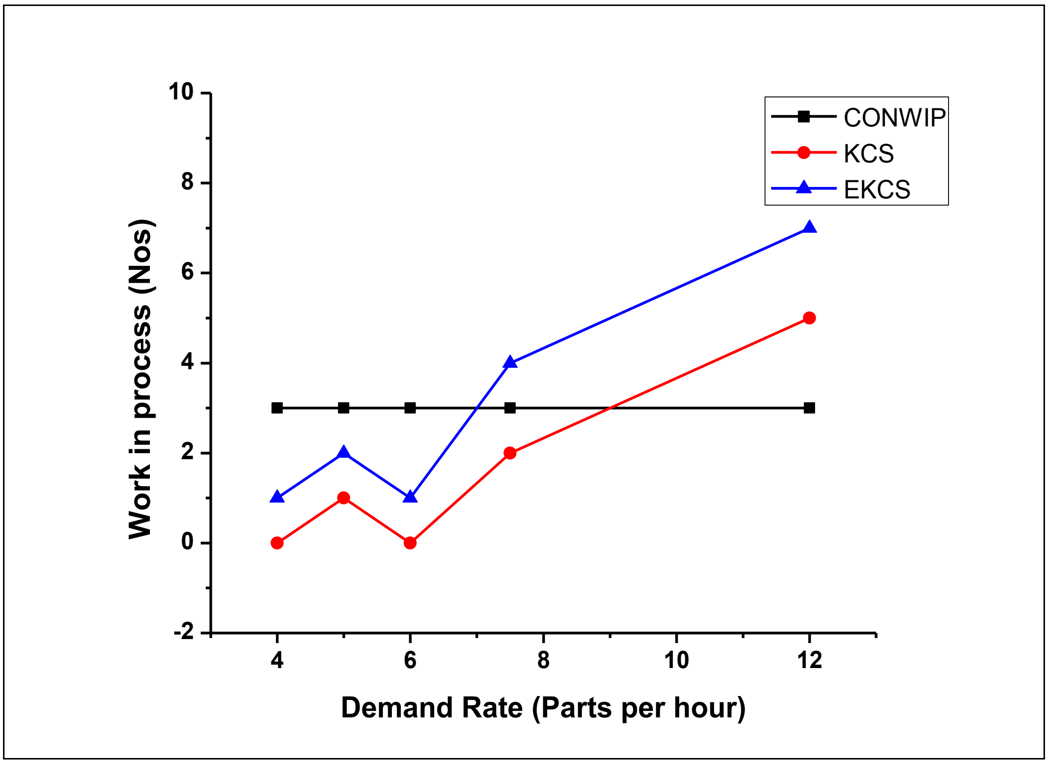

Figure 5.19: Performance of CONWIP, KCS and EKCS for single flow line multi stage system for WIP

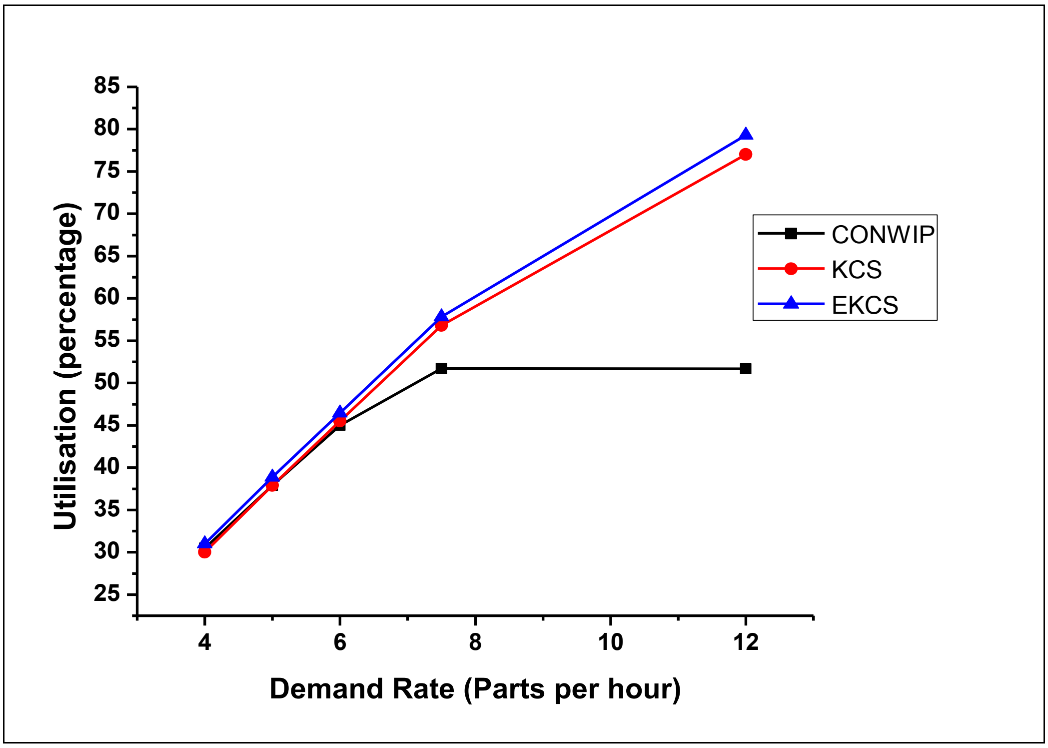

Figure 5.20: Performance of CONWIP, KCS and EKCS for single flow line multi stage system for WIP

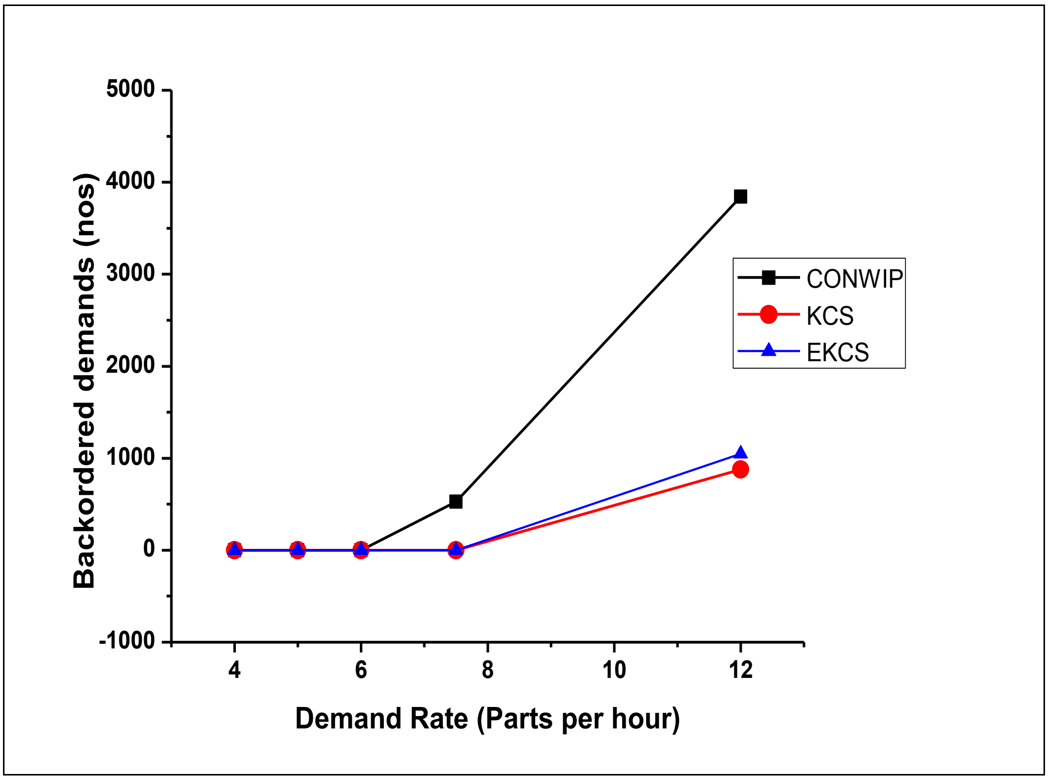

Figure 5.21: Performance of CONWIP, KCS and EKCS for single flow line multi stage system for backordered demand

The comparative performance of CONWIP system, KCS and EKCS is similar at low demand rate from 0 to 6 parts per hour. Since the processing time t_i of the stages combined together is less than the demand mean time D_i, i.e. (M_i +PA_i) > $K_{i.}$ For the demand rate greater than 6 parts per hour, CONWIP system has more number of backordered demands in queue than finished parts in queue PA_3. As the CONWIP system has only one synchronization station which controls the part movement of the complete flow line Further, the other performance parameters i.e. production, AWT and utilization have negligible variation as shown in figures 5.17 to 5.21.

The synchronization of part and kanban at each stage i.e. $K_i \geq S_i$ for all values of i, results free kanbans in the queue. This free kanbans and demand synchronizes for the release of new parts to the subsequent stage. This would increase the work in process and utilization. The movement of parts between the stages is due to the synchronization of kanban and finished part only. The pull control systems are more responsive to number of kanbans.

At low demand rates, the variation in production, utilization and backordered demand in the three systems is negligible.

At high demand rates, the production and machine utilization in CONWIP system is approximately 35% less; AWT in CONWIP system is 43% less; as compared to KCS and EKCS which have similar value. The WIP in CONWIP system is less and in EKCS is high as compared to KCS. At optimum demand rate, the production and utilization in KCS and EKCS are same and is 10% more than CONWIP system. There are more backordered demands for CONWIP system as compared to KCS and EKCS. The AWT and work in process for EKCS are low as compared to KCS. The AWT is 11.4% more for

KCS and 47% less for EKCS as compared to CONWIP system. The work in process is least for KCS and highest for EKCS. The performance of the systems has low variability at a demand rate of 7.5 to 8 parts per hour, hence it is considered as optimum. The performance of the systems at optimum demand rate of 7.5 to 8 parts per hour is given in Table 5.1. At optimum and higher demand rates, considering the production, machine utilization and work in process, KCS shows superior performance as compared to EKCS and CONWIP system.

Table 5.1: Performance Analysis for single line multi stage system (without breakdown)

	Optimum demand rate 7.5 to 8 parts/hr.			Low demand rate		
	CONWIP	**KCS**	**EKCS**	**CONWIP**	**KCS**	**EKCS**
Production	5100	5627	5626	3752	3752	3750
AWT	11.4	12.3	5.7	8.2	7.7	1
WIP	3	2	4	3	1	2
Utilization (% age)	51.72	56.8	58.8	37.9	37.9	37.8
Backordered demand	527	0	0	0	0	0

5.2.2.3 With breakdown

Manufacturing systems are prone to machine breakdown, operational delays and variable demands. The breakdown or failure signifies unavailability of the machine obstructing the work flow i.e. availability < 1. The performance of the pull control systems are analyzed for the effect of breakdown. The MTBF for the three stages is 3000 min, 4500 min and 6000 min respectively. The MTTR is 120 min for each stage [97]. The performance analysis due to effect of breakdown is presented in figures 5.22 to 5.26.

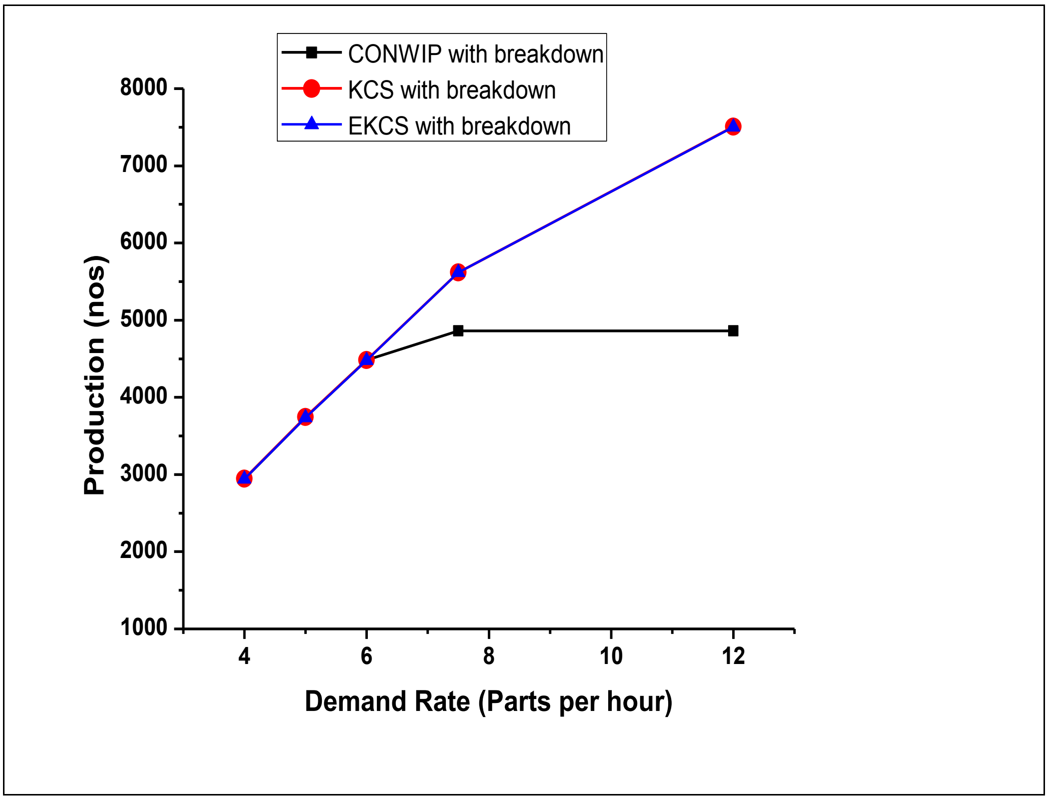

Figure 5.22: Performance of single flow line multi stage system for production considering breakdown

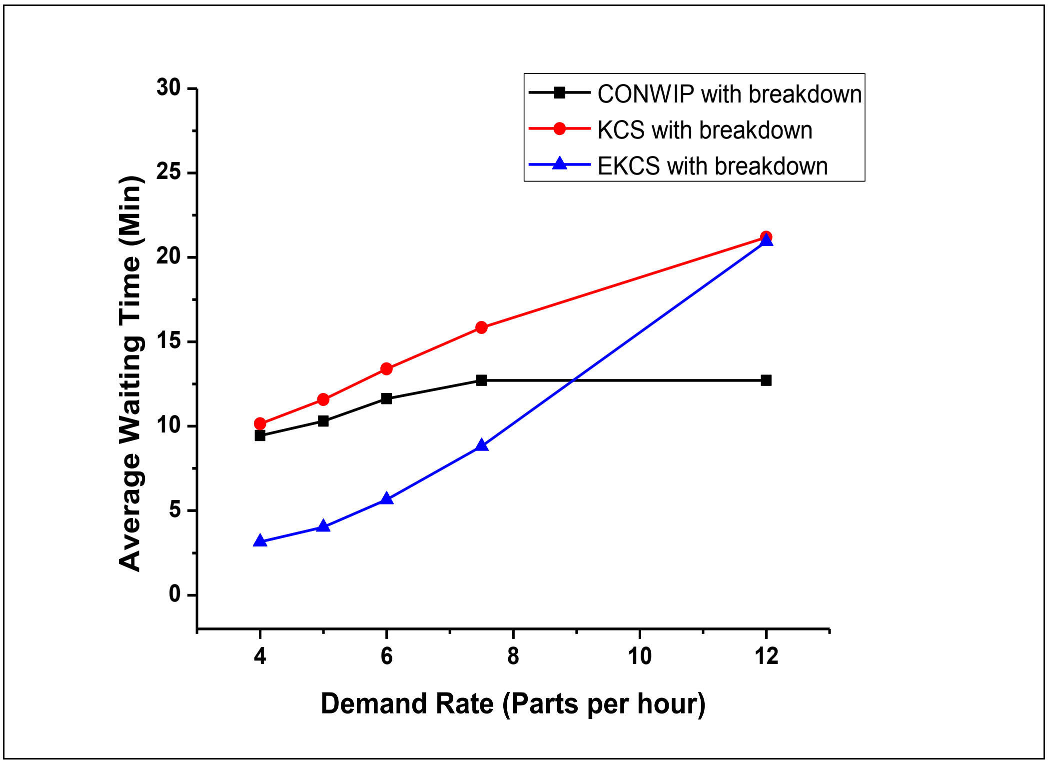

Figure 5.23: Performance of single flow line multi stage system for average waiting time considering breakdown

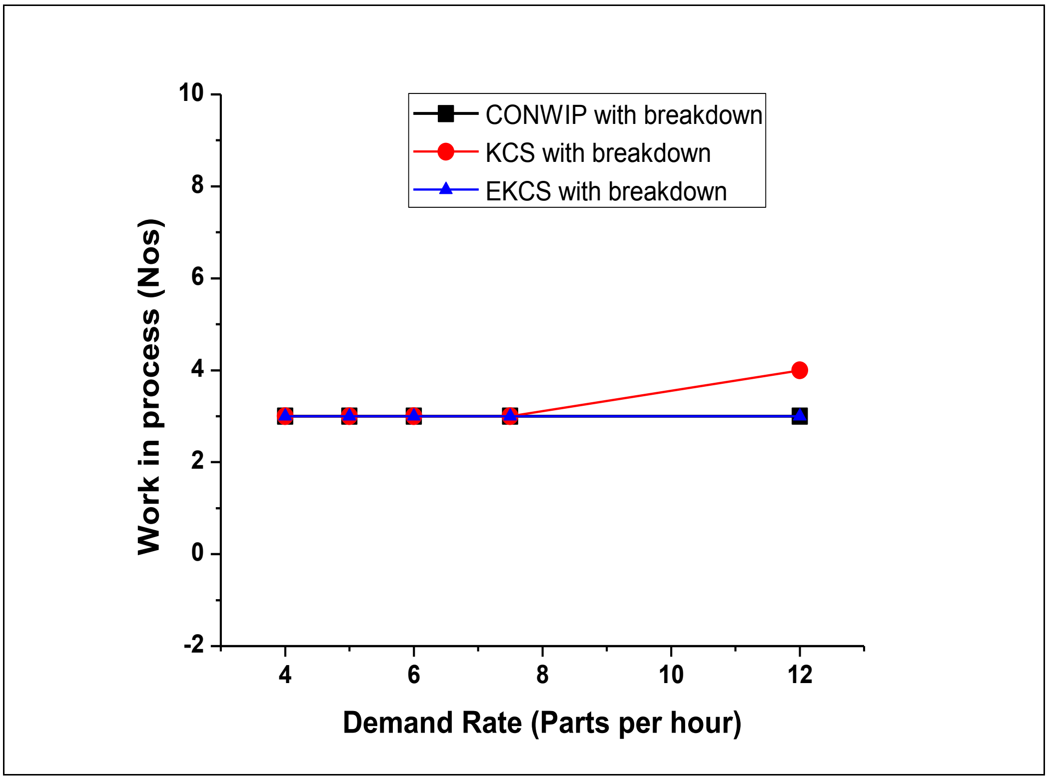

Figure 5.24: Performance of single flow line multi stage system for WIP considering breakdown

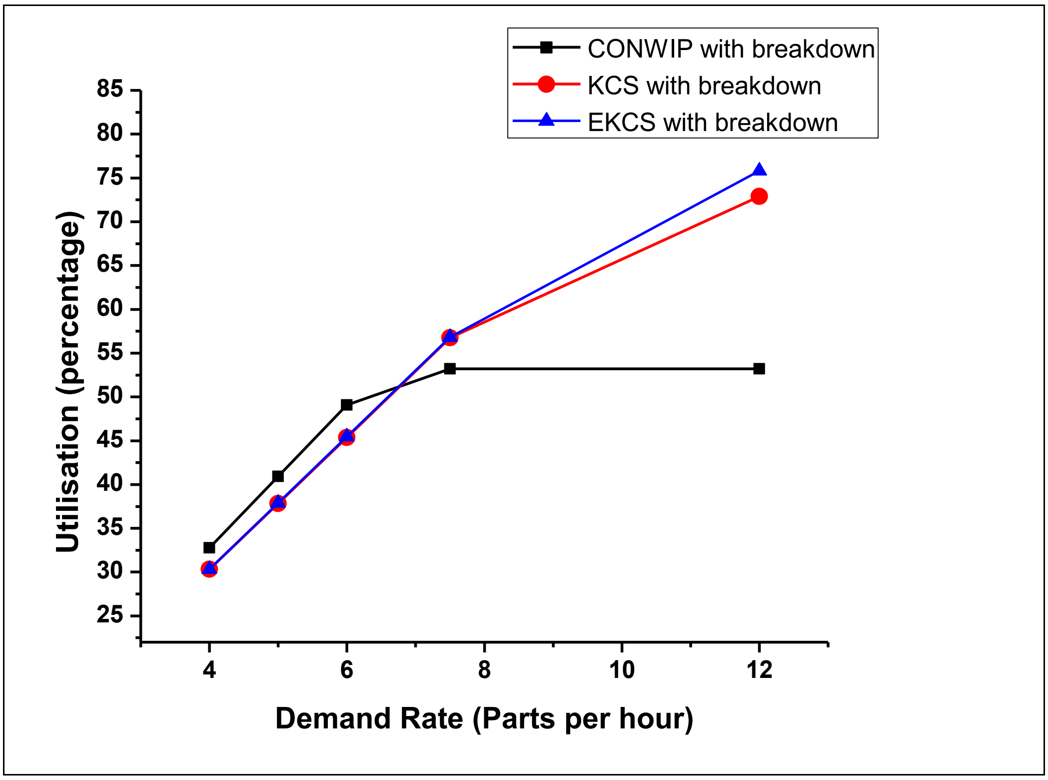

Figure 5.25: Performance of single flow line multi stage system for utilization considering breakdown

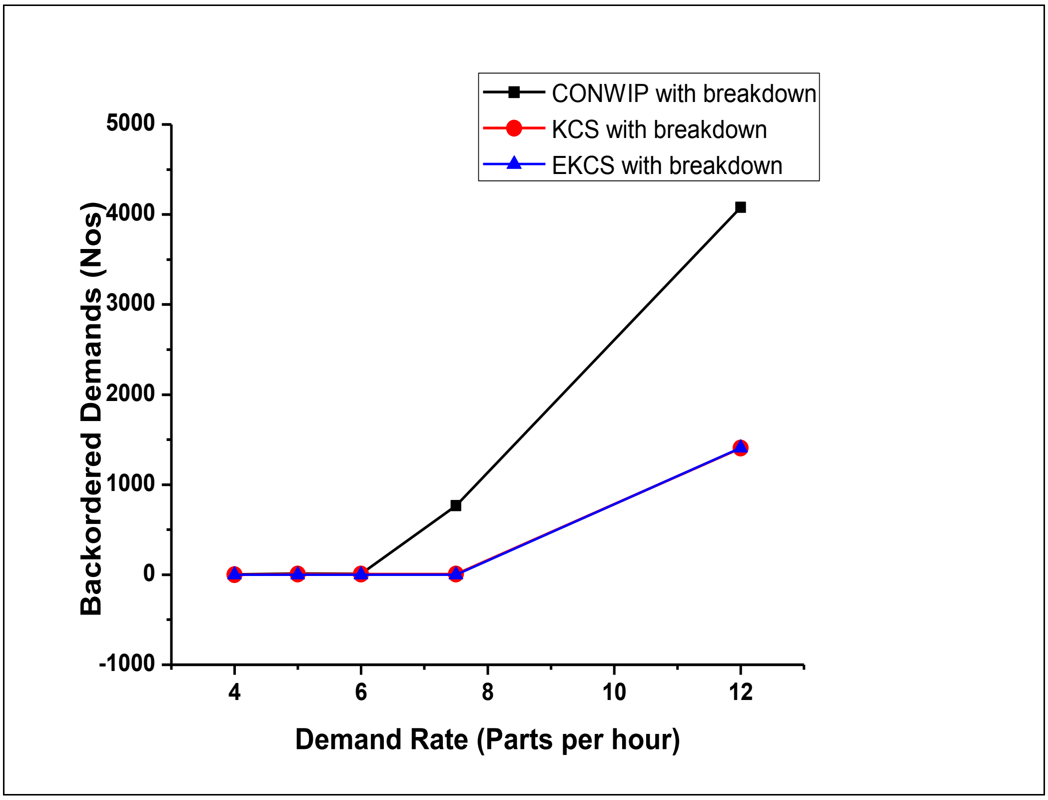

Figure 5.26: Performance of single flow line multi stage system for backordered demand considering breakdown

Simulation experiments are conducted with the defined MTBF and MTTR value for each control system. At low demand rates, the performance parameters i.e., production, machine utilization and WIP in CONWIP, KCS and EKCS are similar. The AWT for EKCS is less than CONWIP and KCS at low demand rates and at optimum demand rate. At optimum demand rate and low demand rate, WIP is same for all the three systems. At optimum demand rate, the production in KCS is 16% more than CONWIP and slightly higher than EKCS. The detailed performance analysis is given in Table 5.2. Thus, the WIP and AWT are the important performance parameters for considering the effect of breakdown at and above the optimum demand rate.

Table 5.2: Performance Analysis for single flow line multi stage system (with Breakdown)

	Optimum demand rate 7.5 to 8 parts/hr.			Low demand rate		
	CONWIP	**KCS**	**EKCS**	**CONWIP**	**KCS**	**EKCS**
Production	4862	5620	5617	3741	3745	3739
Average waiting time	12.7	15.9	8.8	10.31	11.58	4.03
WIP	3	3	3	3	3	3
Utilization (%age)	53.21	56.74	56.82	40.93	37.82	37.88
Backordered demand	765	7	0	11	7	0

5.2.2.4 Comparison of Performance (with and without breakdown)

The comparison of performance of single flow line multistage manufacturing system with and without breakdown is presented in figures 5.27 to 5.31.

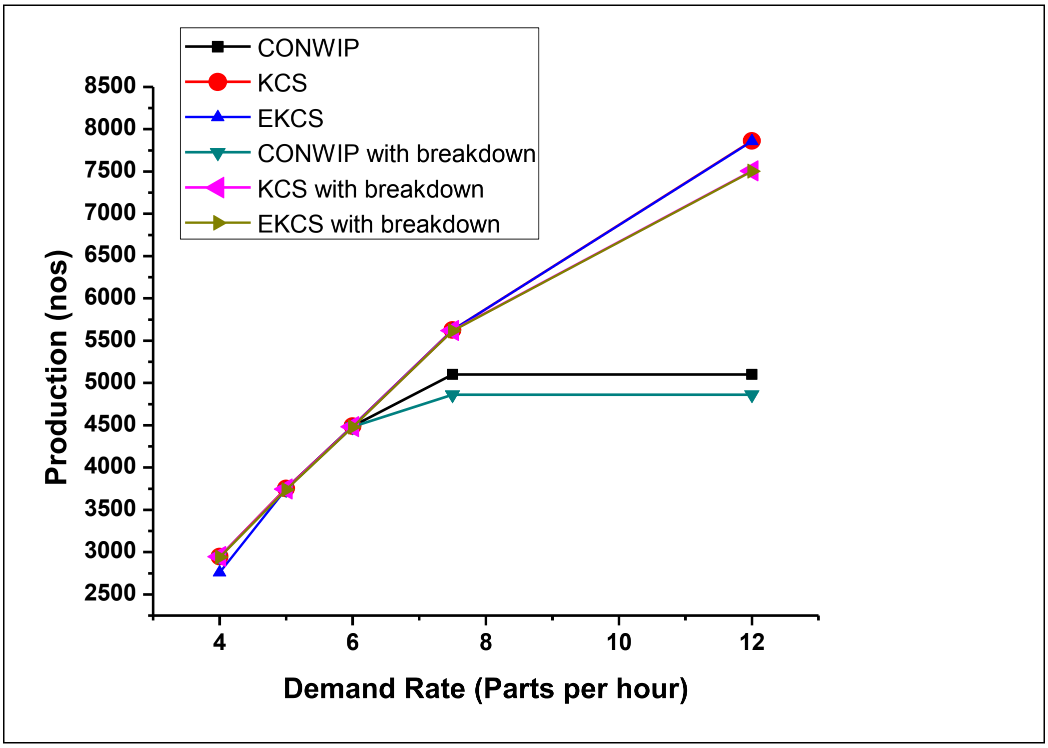

Figure 5.27: Performance Comparison of single flow line multi stage system for production with and without breakdown

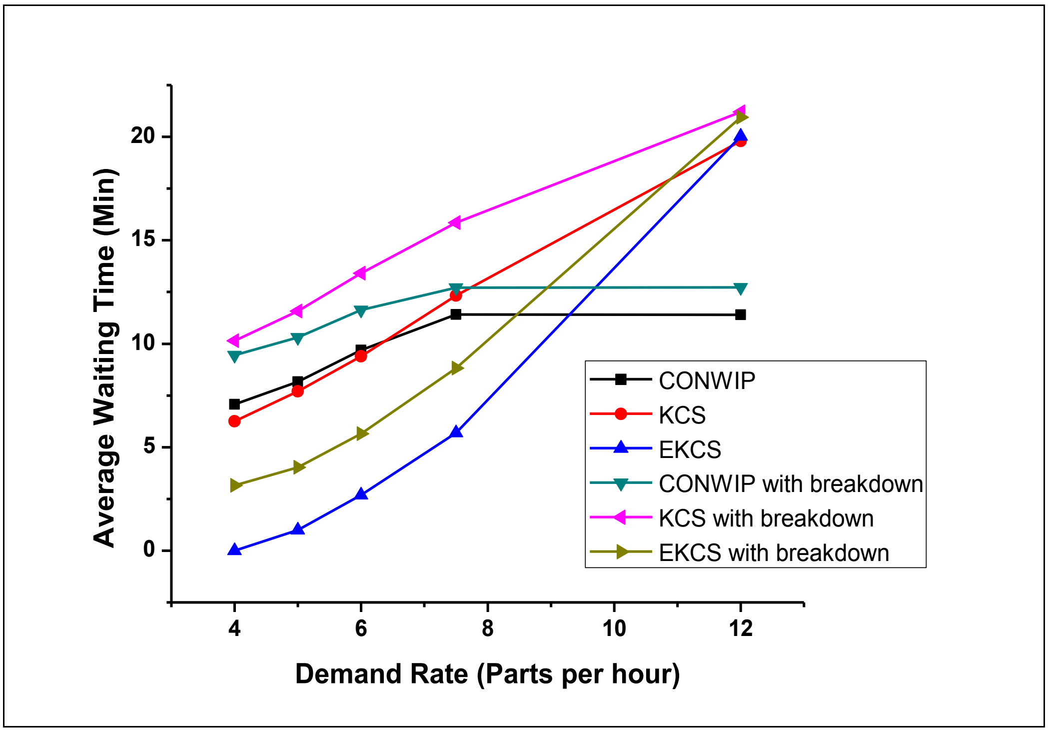

Figure 5.28: Performance Comparison of single flow line multi stage system for average waiting time (with and without breakdown).

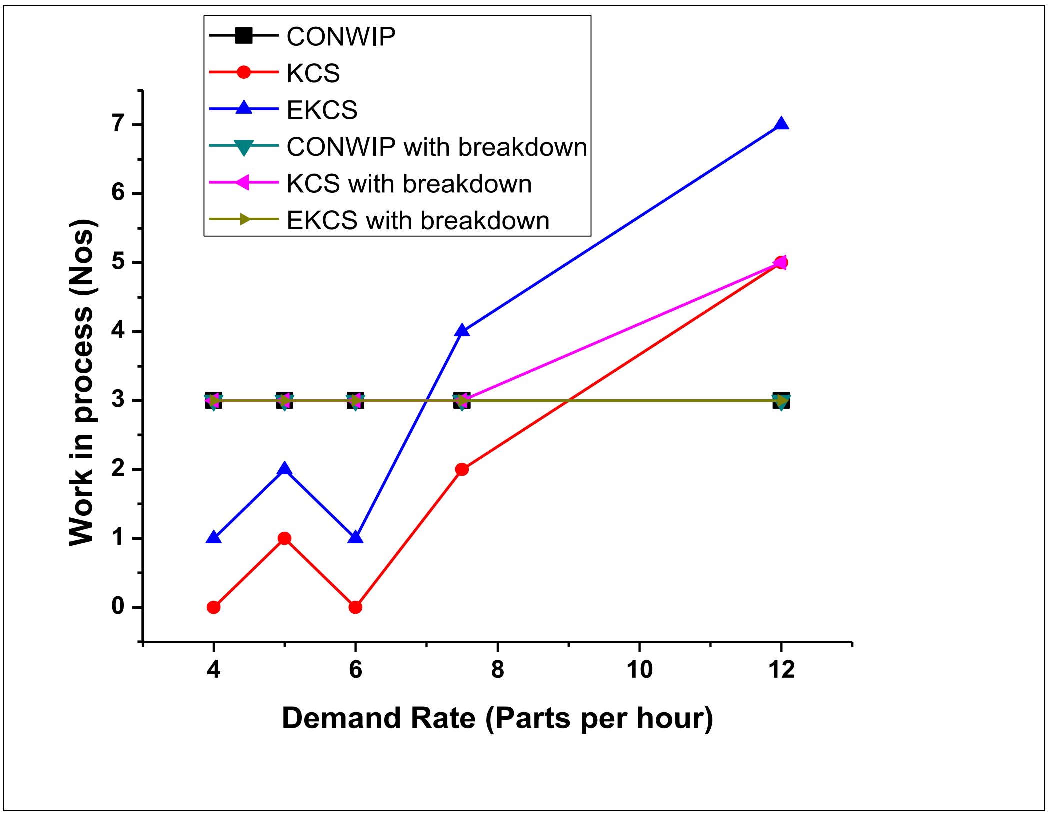

Figure 5.29: Performance Comparison of single flow line multi stage system for WIP with and without breakdown

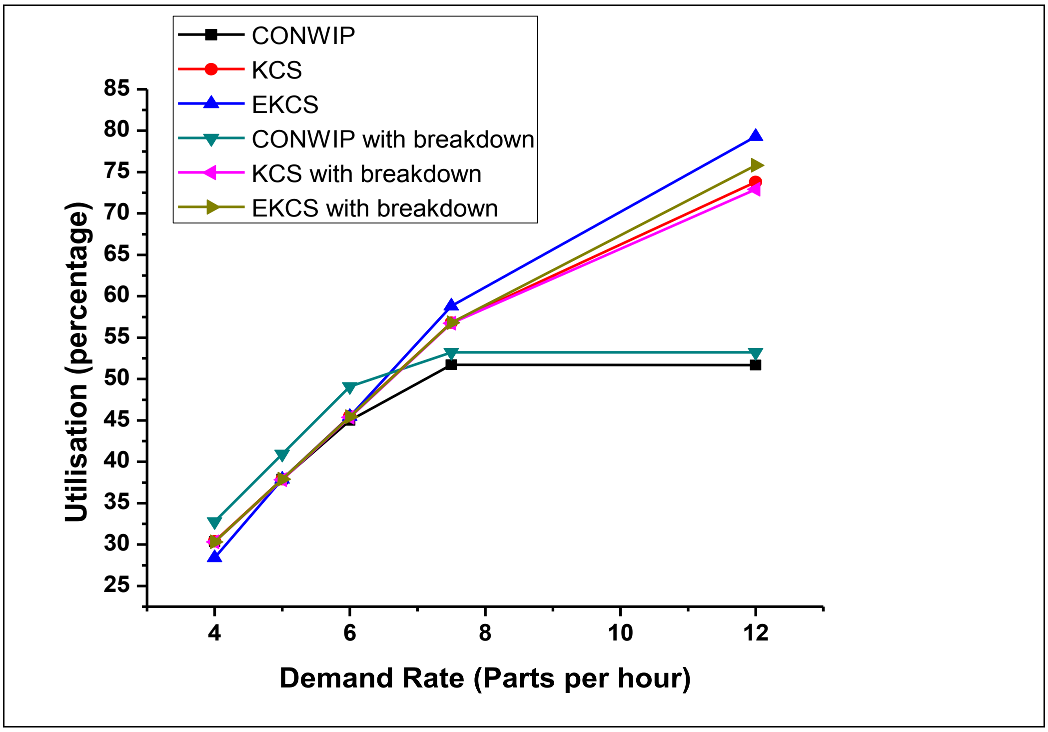

Figure 5.30: Performance Comparison of single flow line multi stage system for Utilization with and without breakdown

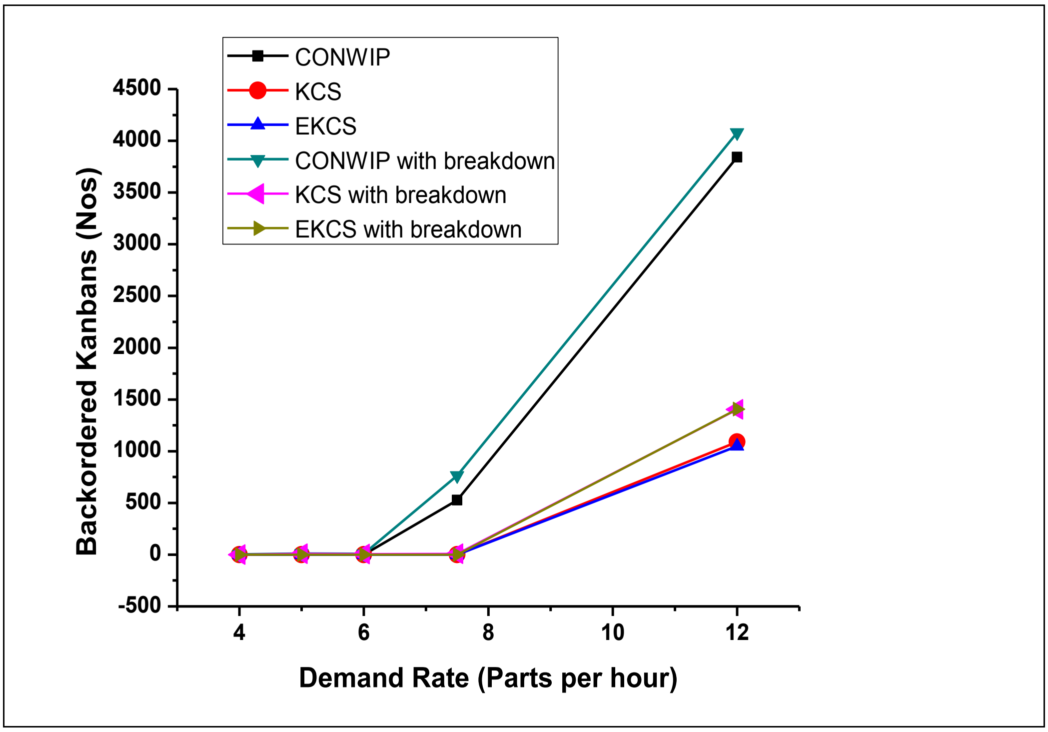

Figure 5.31: Performance Comparison of single line multi stage system for backordered demand with and without breakdown

Due to breakdown, the production and utilization decrease but the AWT and WIP increases with increase in demand rates. The production is reduced by 0.14% in KCS, 0.16% in EKCS and 4.6% in CONWIP system at the optimum demand rate of 7 - 8 parts per hour. As the demand rate decreases the effect of breakdown has negligible effect on production and utilization. However, the AWT is increased by 28% in KCS, 54% in EKCS and 13% in CONWIP system at a demand rate of 7 – 8 parts per hour. As the demand rate decreases, the AWT and WIP increase due to workstation breakdown because the parts are detained on the flow line due to high demand mean time. Further, at optimum demand rate, the backorder demand is increased by 45% in CONWIP system, whereas there is a slight increase in KCS and EKCS due to breakdown. The details of the performance analysis are given in Table 5.3. Therefore, KCS shows superior performance considering production, utilization and work in process.

Table 5.3: Performance Analysis for single line multi stage system (with breakdown and without breakdown)

Demand rate. parts/hr.		Production		Average waiting time (min)		WIP		utilization		Backordered demand	
		WBD	BD	WBD	BD	WBD	BD	WBD	BD	WBD	BD
7.5	CONWIP	5100	4862	11.4	12.7	3	3	51.7	53.2	527	765
	KCS	5627	5620	12.3	15.9	2	3	56.8	56.7	0	7
	EKCS	5626	5617	5.7	8.8	4	3	58.8	56.8	0	0
6	CONWIP	4490	4481	9.7	11.6	3	3	45	49.1	0	9
	KCS	4490	4484	9.4	13.4	0	3	45.5	45.4	0	6
	EKCS	4489	4478	2.7	5.7	1	3	45.4	45.5	0	0
5	CONWIP	3752	3741	8.2	10.3	3	3	37.9	40.9	0	11
	KCS	3752	3745	7.7	11.6	1	3	37.9	37.8	0	7
	EKCS	3750	3739	1	4	2	3	37.8	37.8	0	0
4	CONWIP	2945	2943	7.1	9.4	3	3	30.3	32.7	0	2
	KCS	2945	2945	6.2	10.1	0	3	30.4	30.3	0	0
	EKCS	2858	2941	0	3.2	1	3	28.4	30.3	0	0
		WBD: without breakdown				BD: With breakdown					

5.2.2.5 Sensitivity Analysis for imbalance 0.2min, 0.4min and 0.6 min.

The performance of CONWIP system, KCS and EKCS for single flow line three stage systems is analyzed by considering the processing time imbalance factor 'd' of 0.2min, 0.4min and 0.6min. The processing mean time 't_i' is 5 minutes. Considering imbalance factor of 0.2 min considering Low(L), Medium(M) and High(H) combination, the processing mean time for first stage is 4.8 min, second stage is 5min, and third stage is 5.2 min. Similarly, for H-M-L combination the processing time is 5.2 min, 5 min and 4.8 min respectively and for H-L-M combination, the processing time is 5.2 min, 4.8 min and 5min respectively. Similarly, the other imbalance factors 0.4 min and 0.6 min are considered for the above combinations. The performance of above three combinations is analyzed as these give higher variability as compared to other possible combinations. The performance due to effect of imbalance time is analyzed to identify the optimal system. The comparative performance in terms of the single flow line three stage systems with these combinations are shown in figures 5.32 to 5.76.

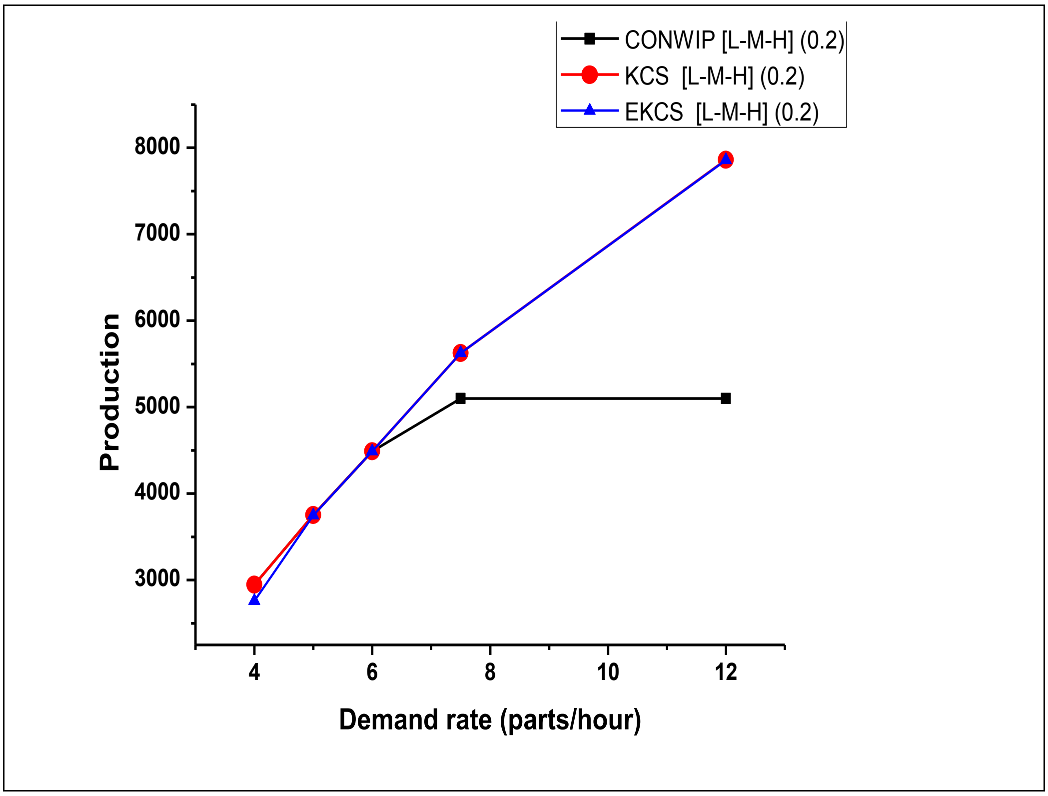

Figure 5.32: Sensitivity Analysis of production for imbalance 0.2min (L-M-H)

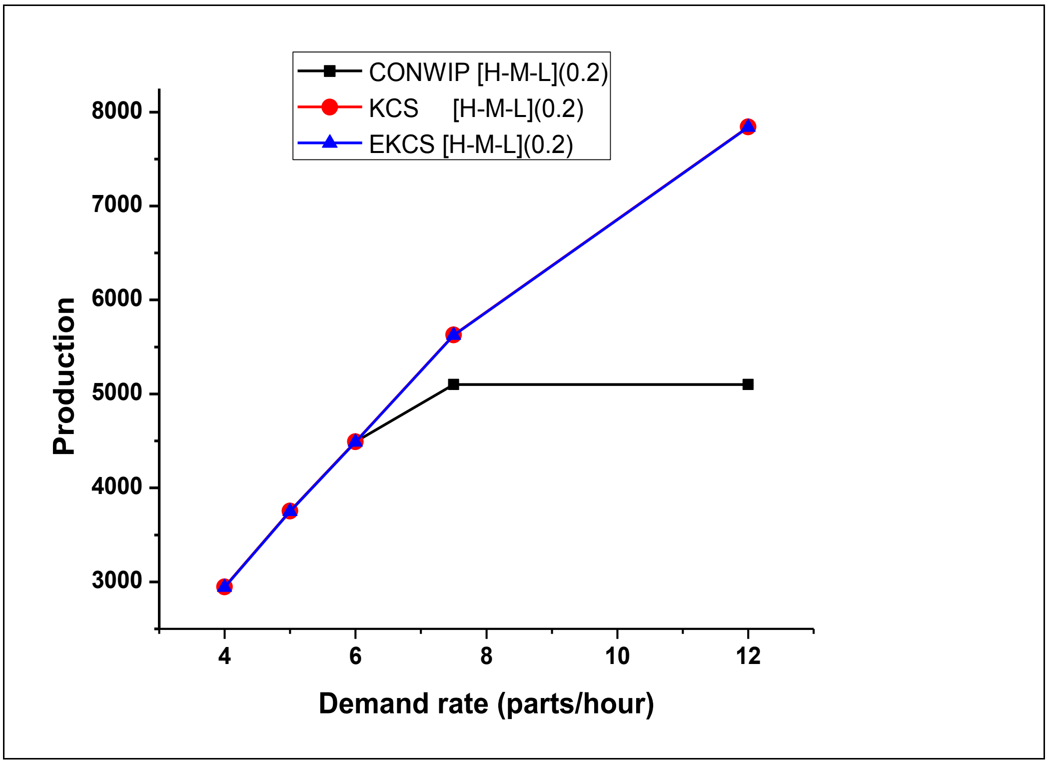

Figure 5.33: Sensitivity Analysis of production for imbalance 0.2 min (H-M-L)

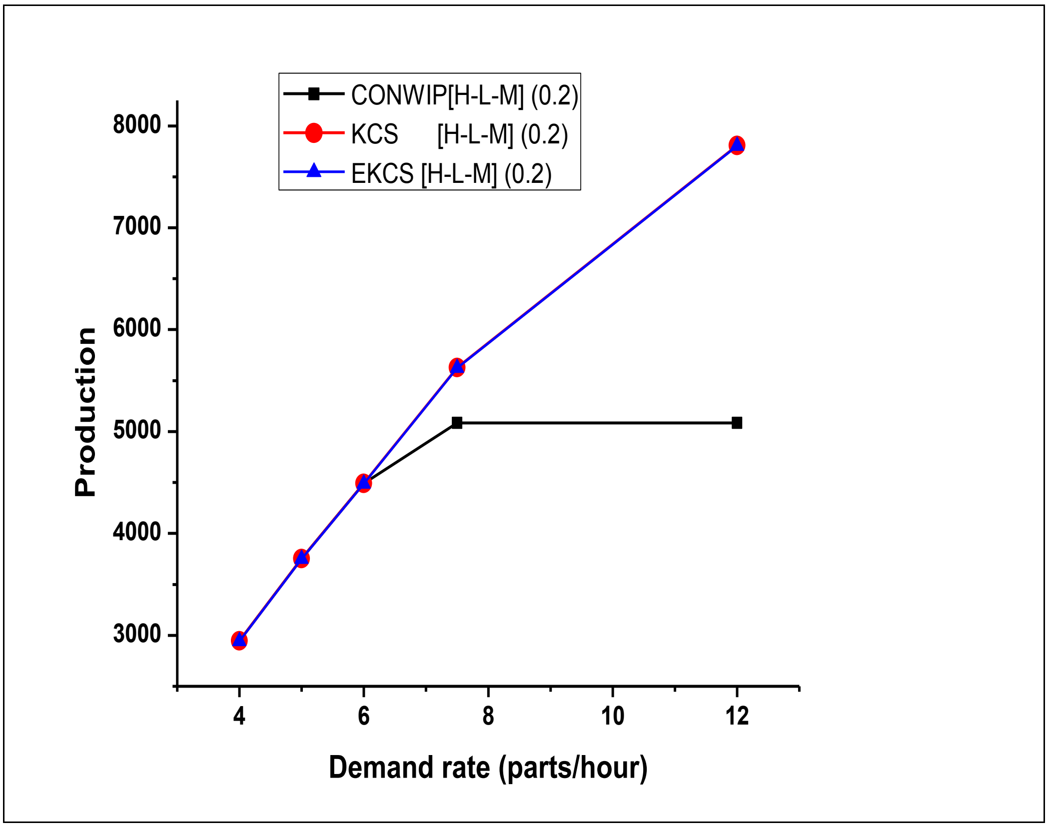

Figure 5.34: Sensitivity Analysis of production for imbalance 0.2min (H-L-M)

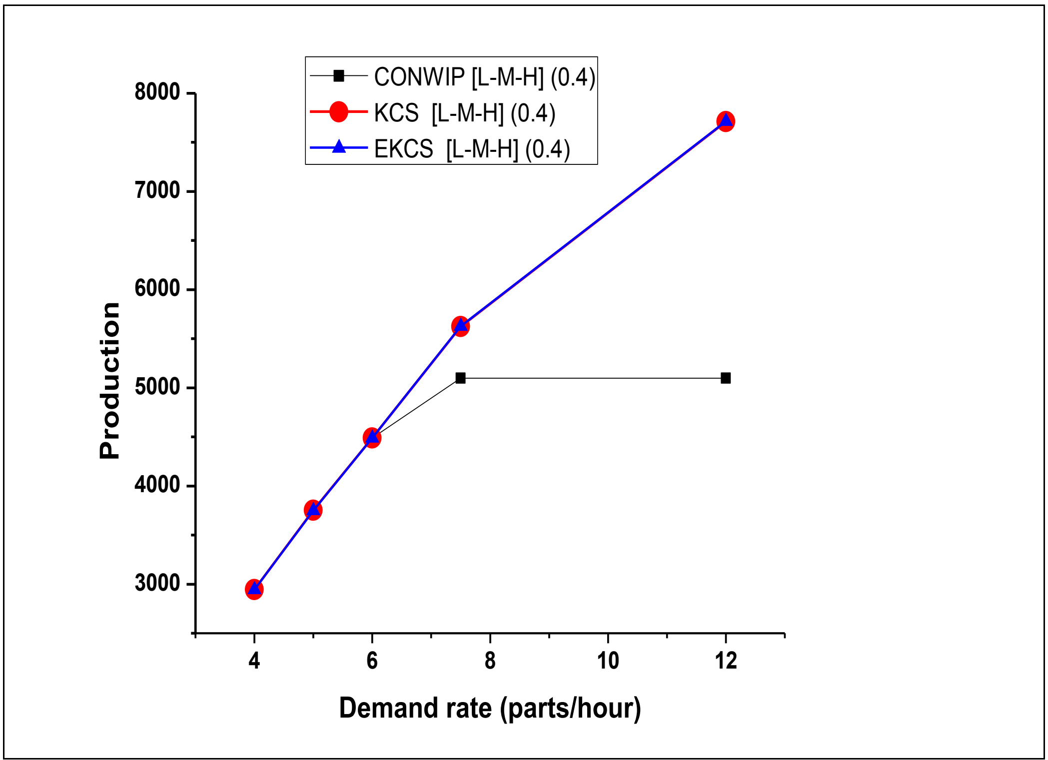

Figure 5.35: Sensitivity Analysis of production for imbalance 0.4 min (L-M-H)

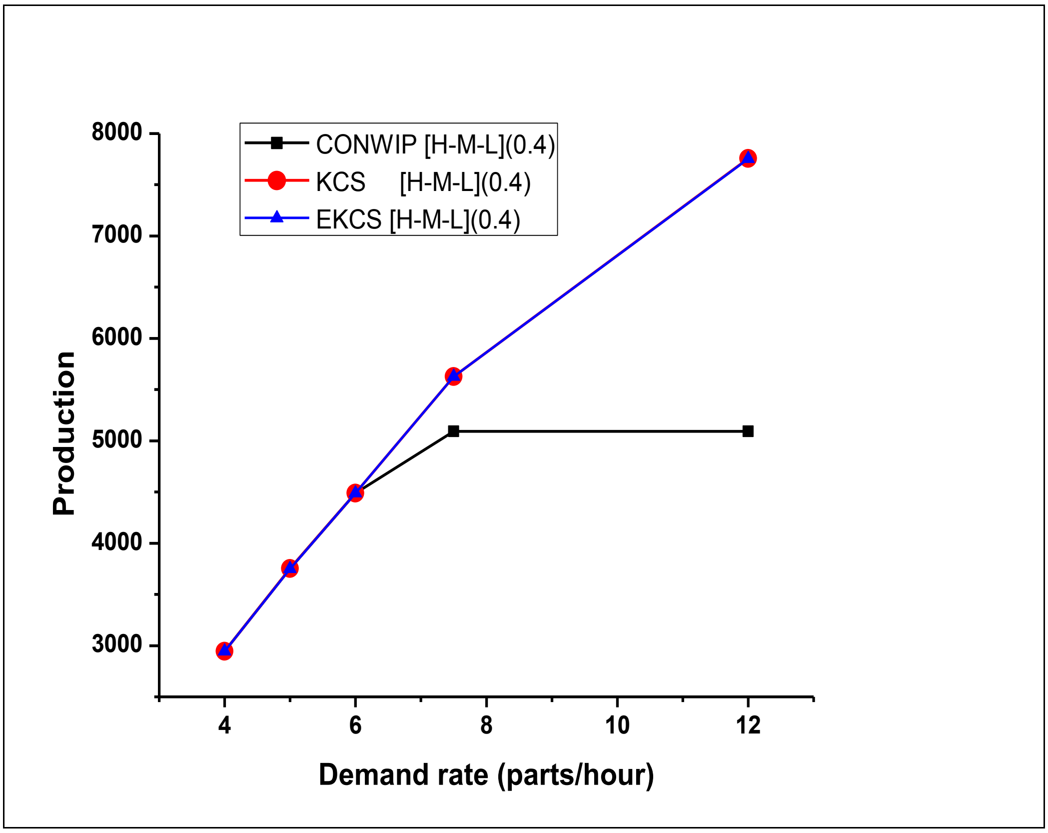

Figure 5.36: Sensitivity Analysis of production for imbalance 0.4min (H-M-L)

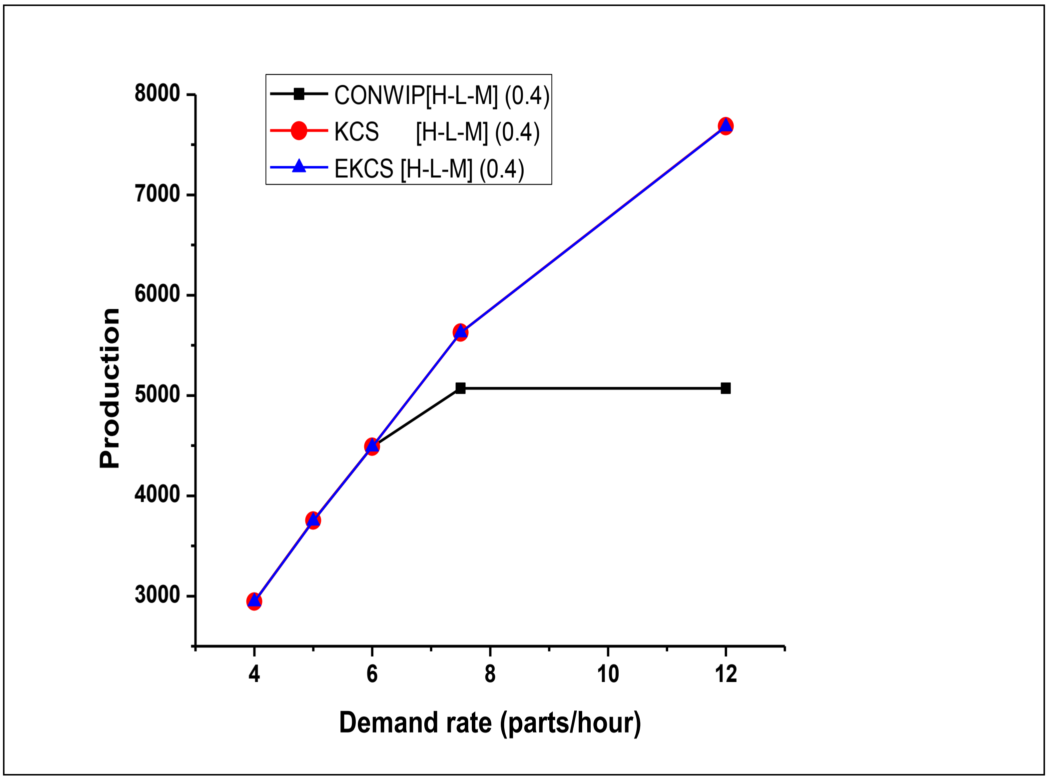

Figure 5.37: Sensitivity Analysis of production for imbalance 0.4 min (H-L-M)

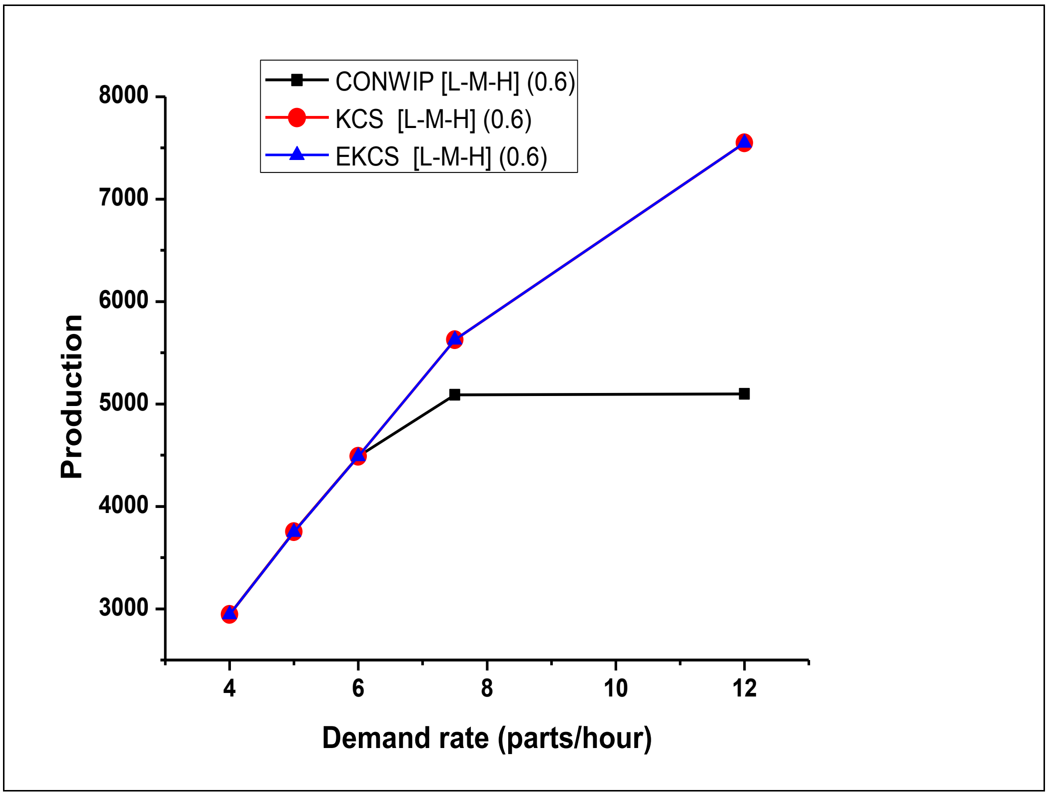

Figure 5.38: Sensitivity Analysis of production for imbalance 0.6min (L-M-H)

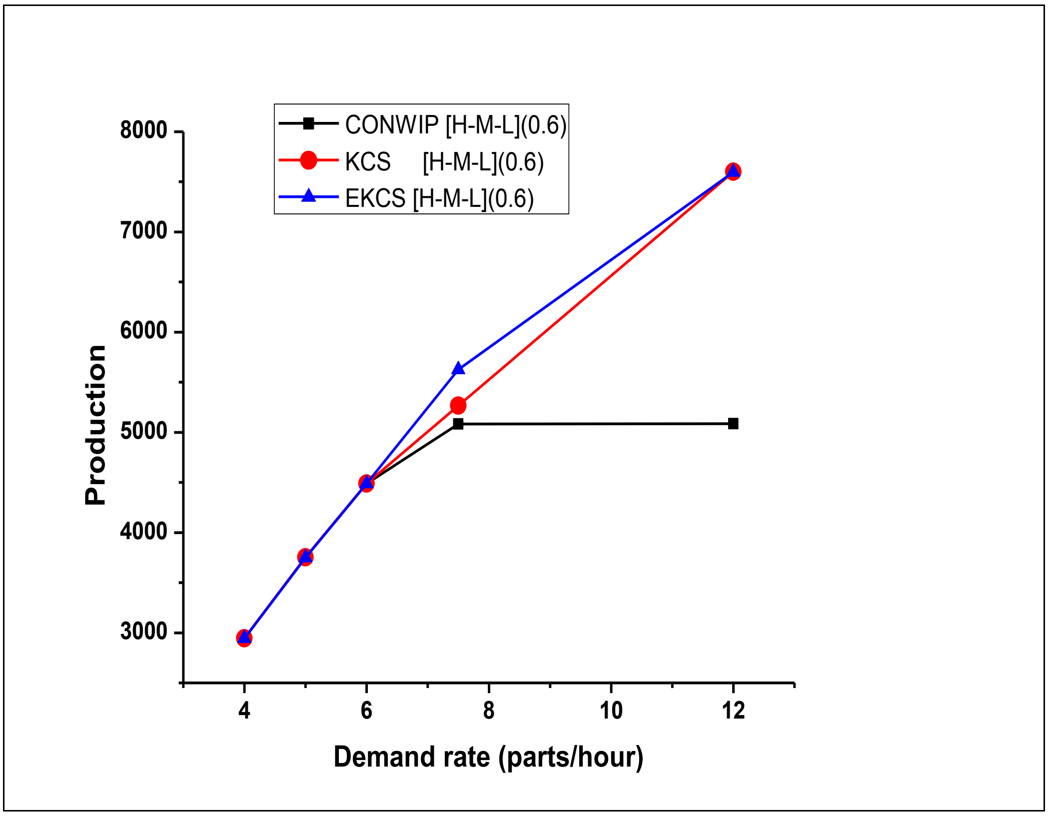

Figure 5.39: Sensitivity Analysis of production for imbalance 0.6 min (H-M-L)

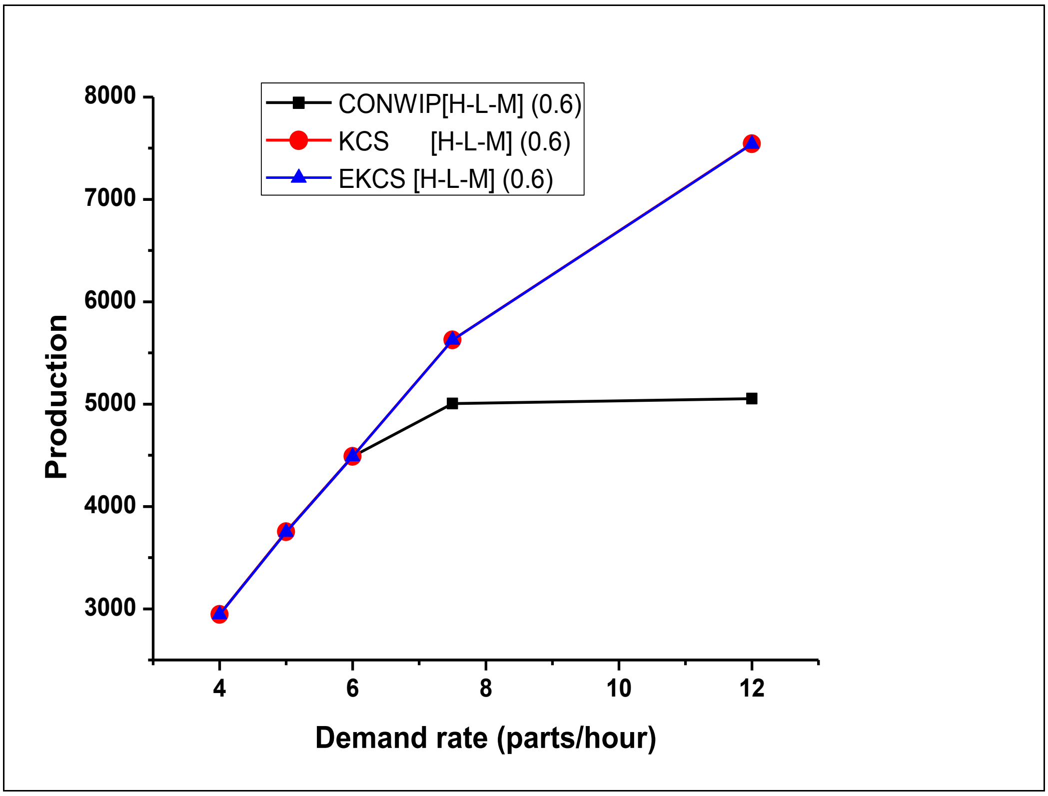

Figure 5.40: Sensitivity Analysis of production for imbalance 0.6 min (H-L-M)

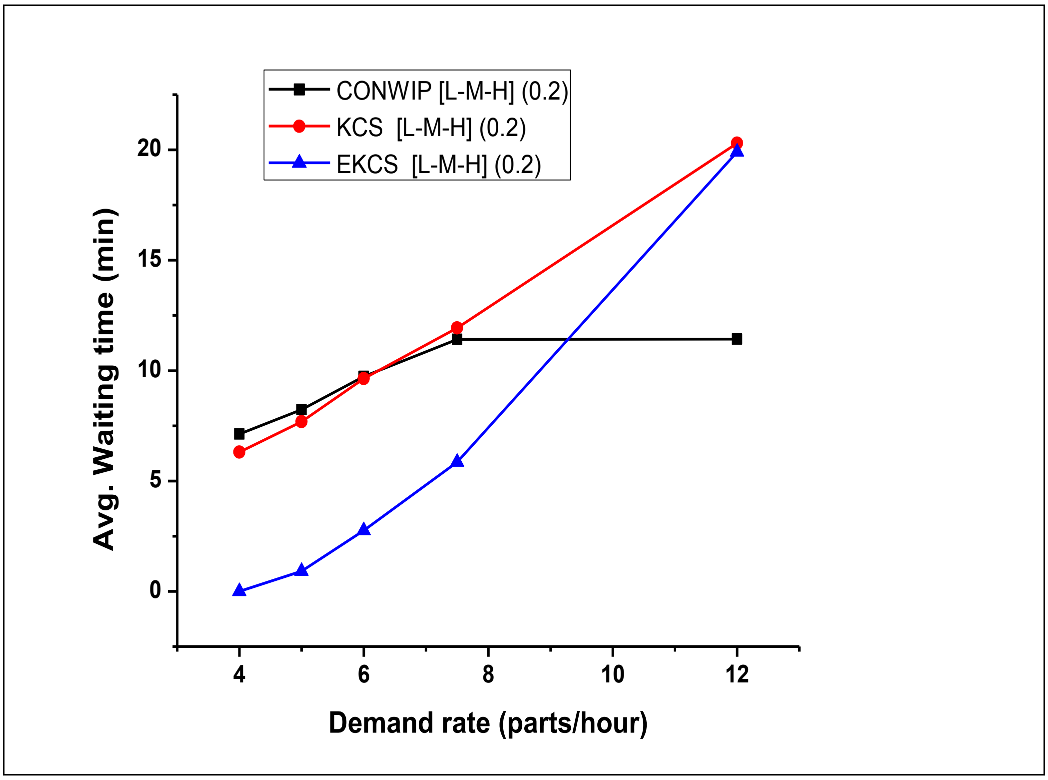

Figure 5.41: Sensitivity Analysis of AWT (Min) for Imbalance 0.2 min (L-M-H)

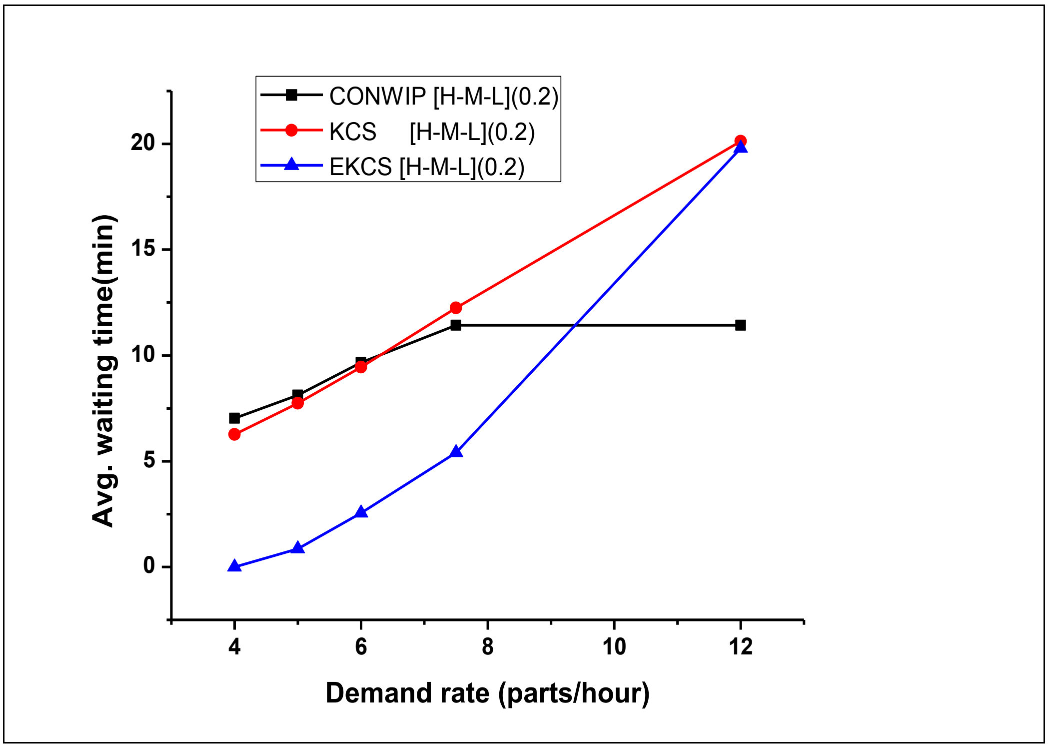

Figure 5.42: Sensitivity Analysis of AWT (Min) for Imbalance 0.2 min (H-M-L)

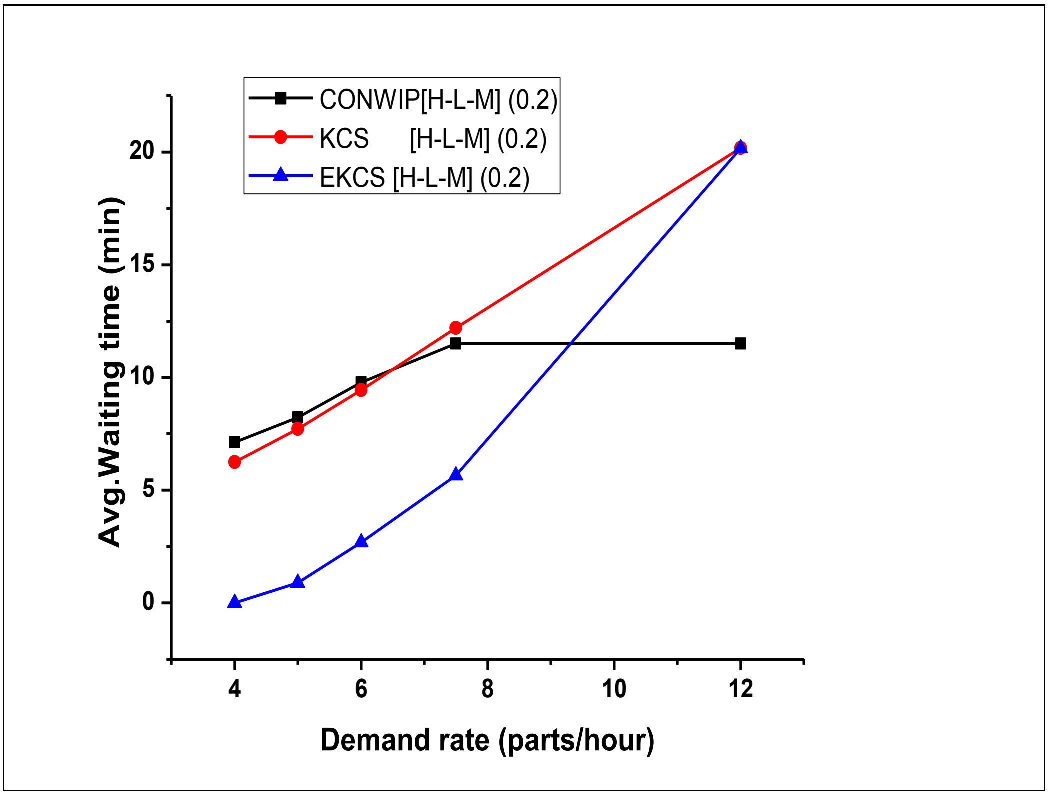

Figure 5.43: Sensitivity Analysis of AWT (Min) for Imbalance 0.2 min (H-L-M)

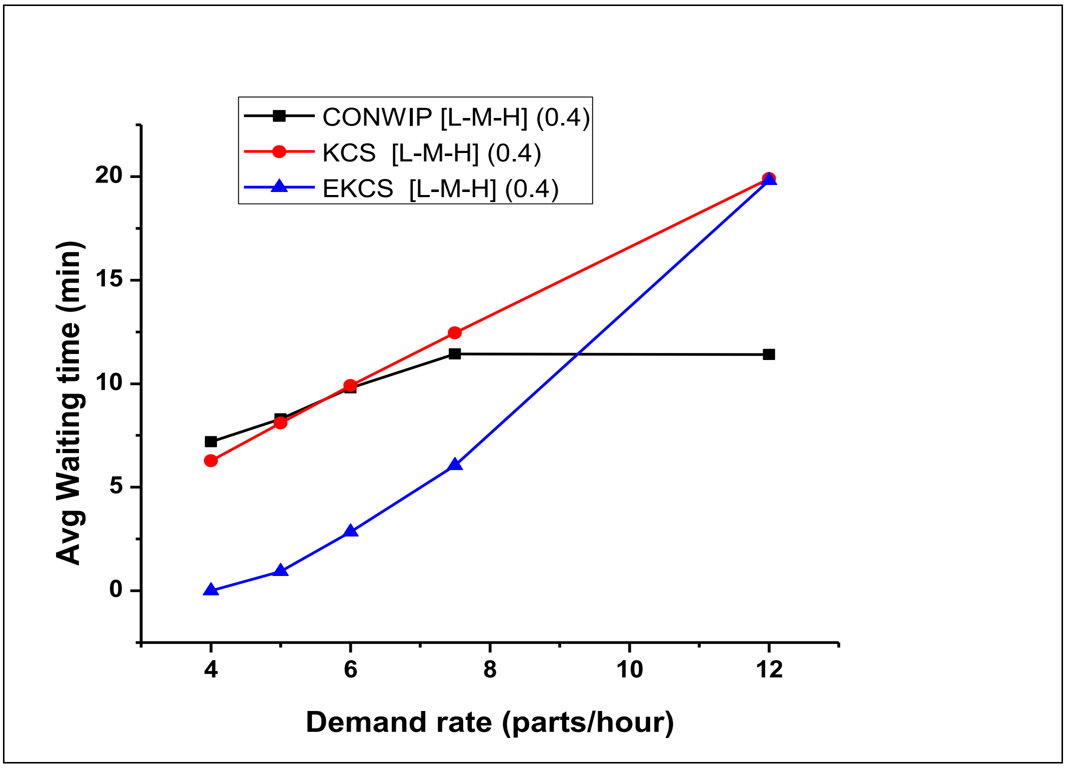

Figure 5.44: Sensitivity Analysis of AWT (Min) for Imbalance 0.4 min (L-M-H)

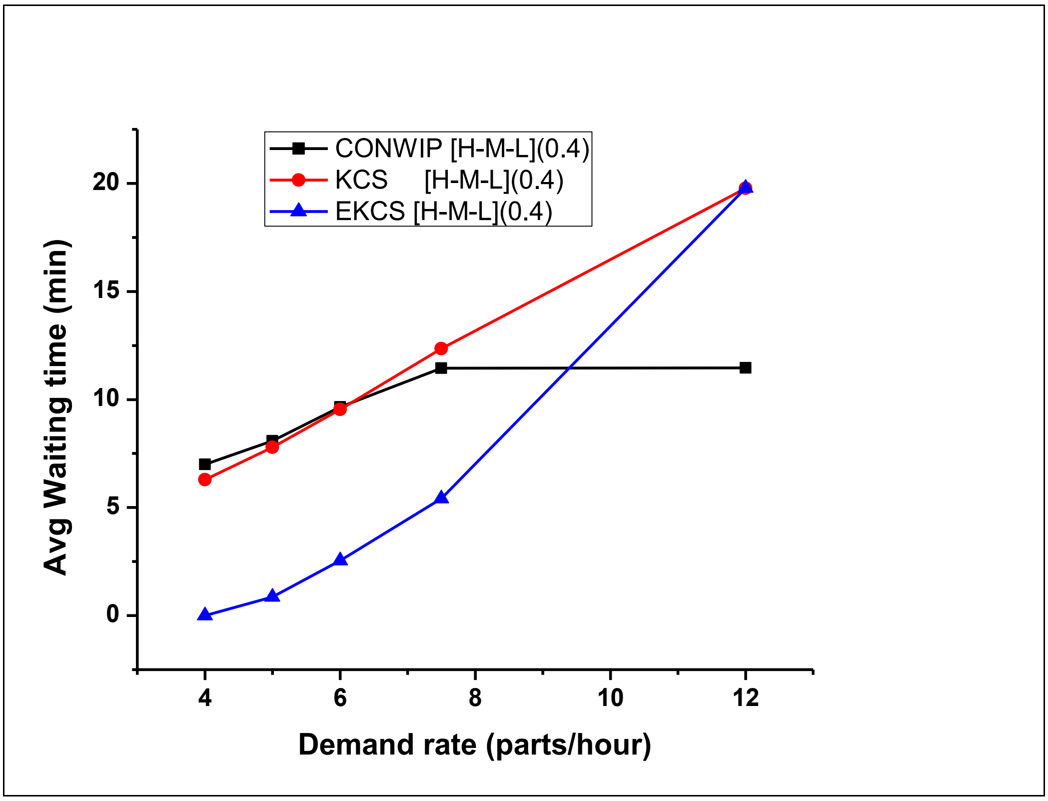

Figure 5.45: Sensitivity Analysis of AWT (Min) for Imbalance 0.4 min (H-M-L)

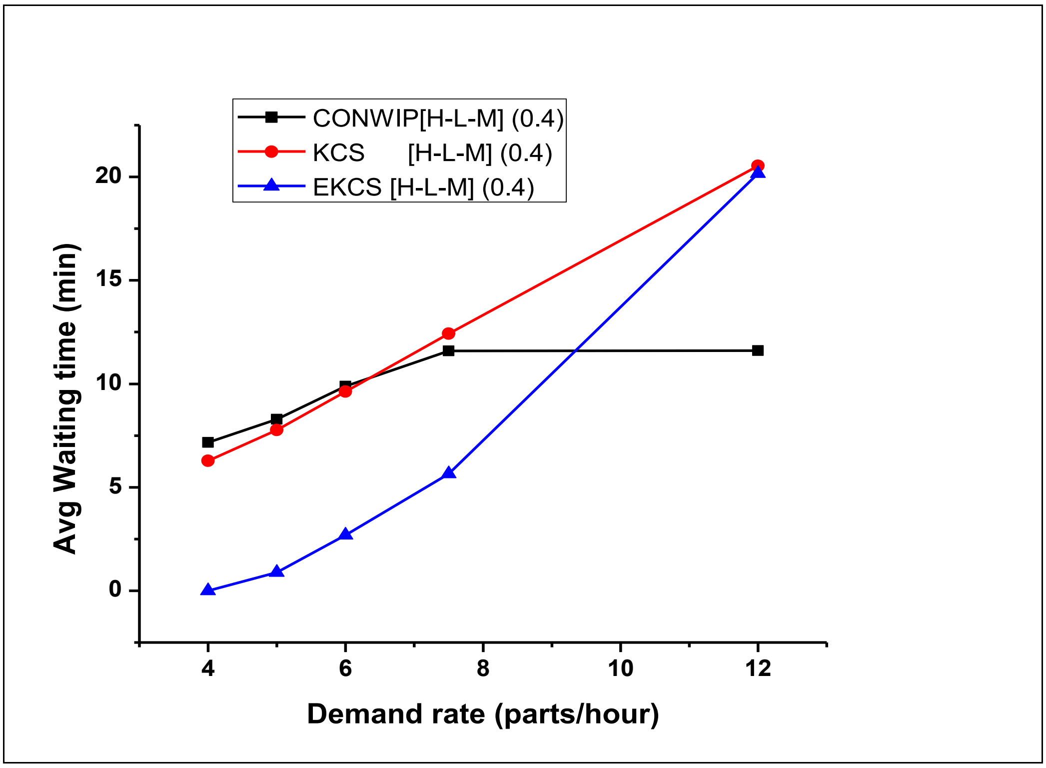

Figure 5.46: Sensitivity Analysis of AWT (Min) for Imbalance 0.4 min (H-L-M)

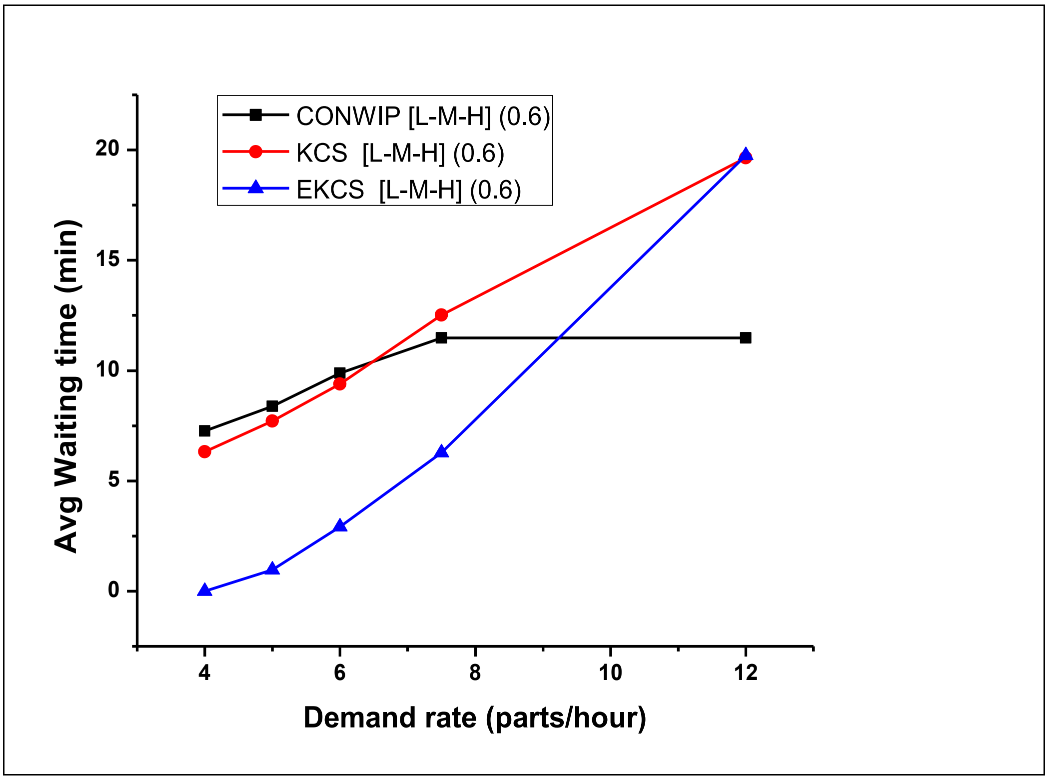

Figure 5.47: Sensitivity Analysis of AWT (Min) for Imbalance 0.6 min (L-M-H)

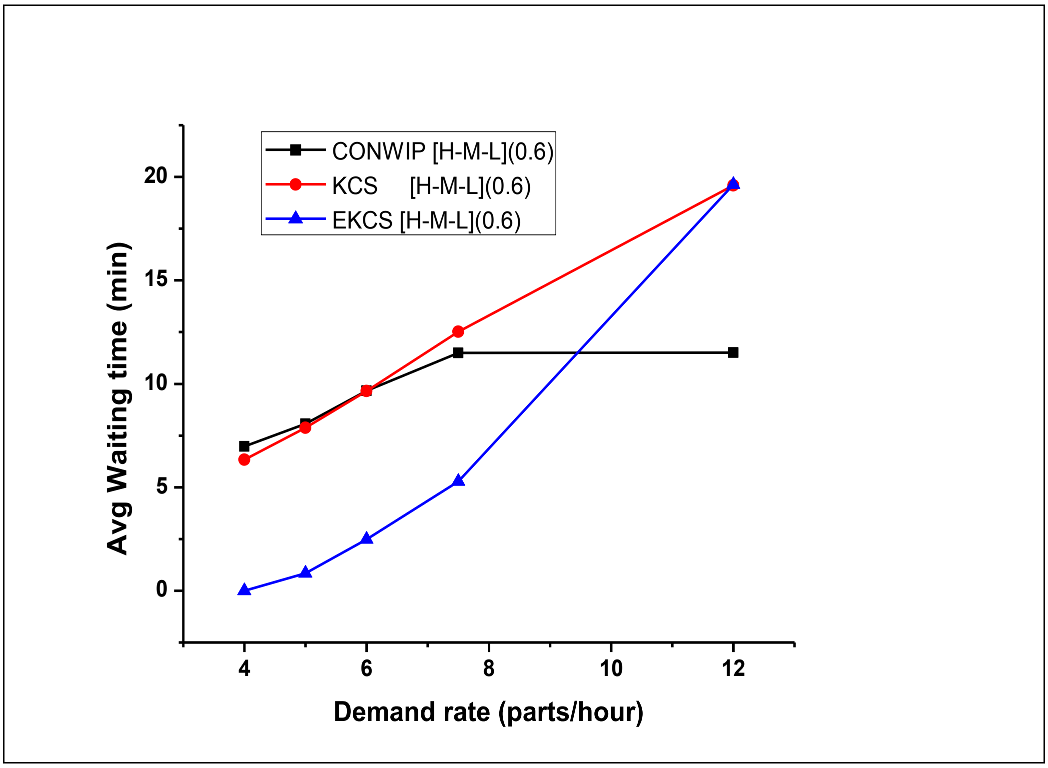

Figure 5.48: Sensitivity Analysis of AWT (Min) for Imbalance 0.6 min (H-M-L)

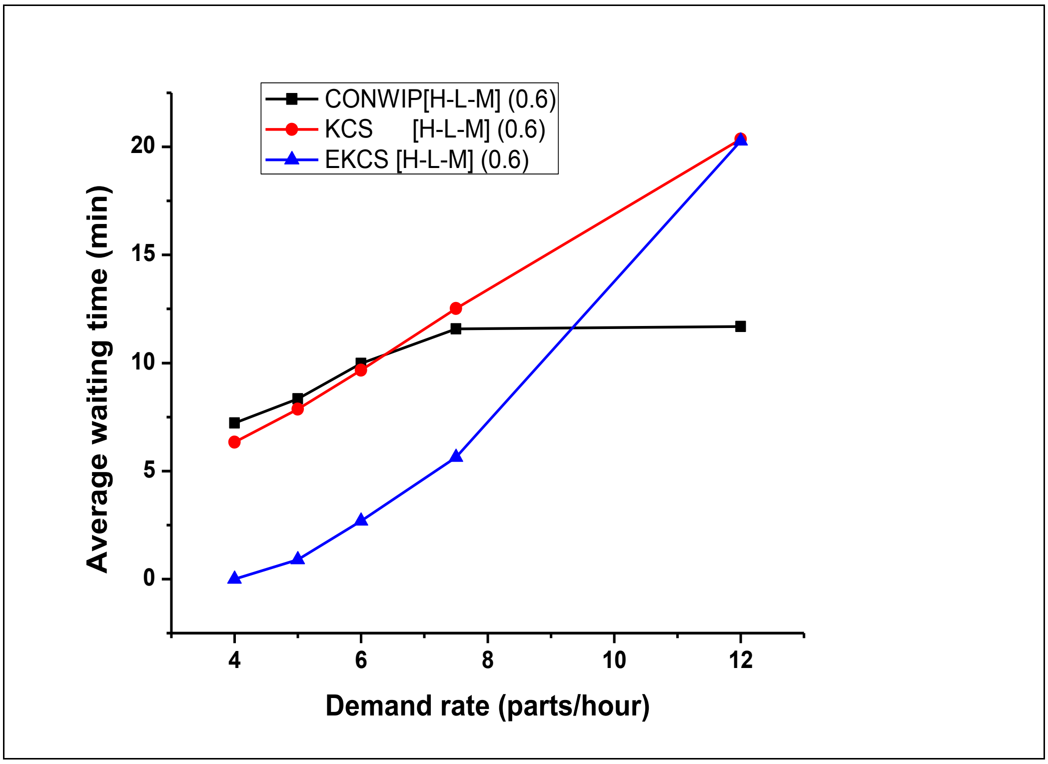

Figure 5.49: Sensitivity Analysis of AWT (Min) for Imbalance 0.6 min (H-L-M)

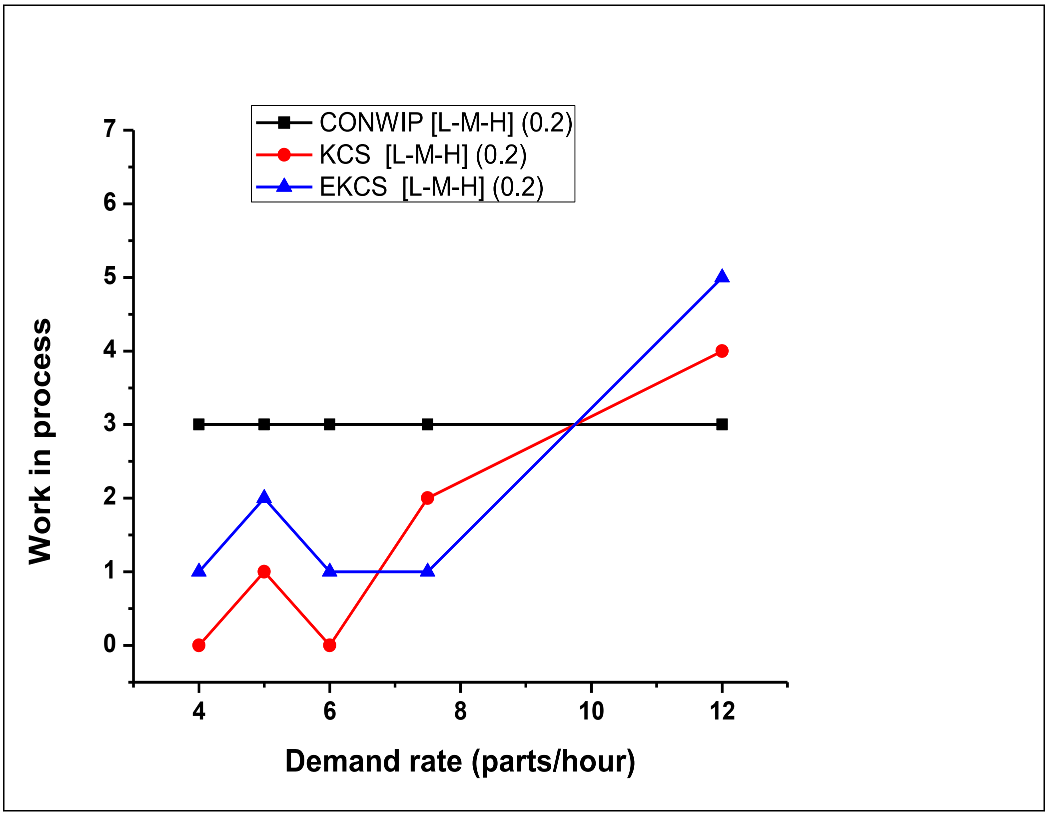

Figure 5.50: Sensitivity Analysis of WIP for Imbalance 0.2 min (L-M-H)

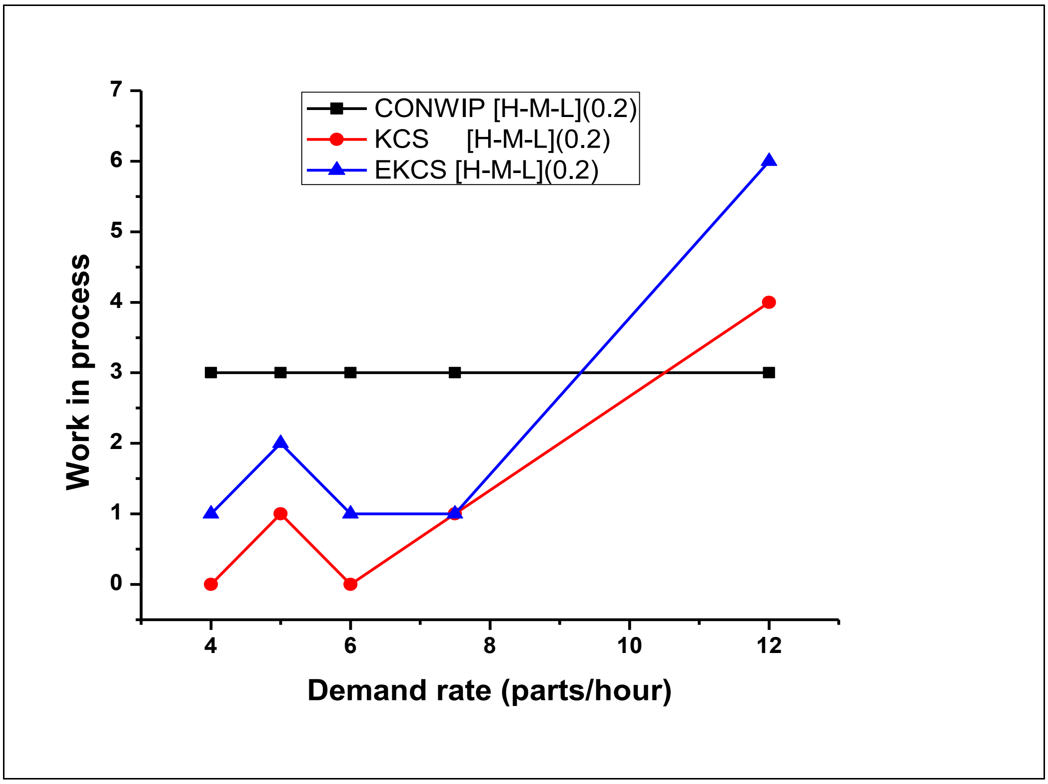

Figure 5.51: Sensitivity Analysis of WIP for Imbalance 0.2 min (H-M-L)

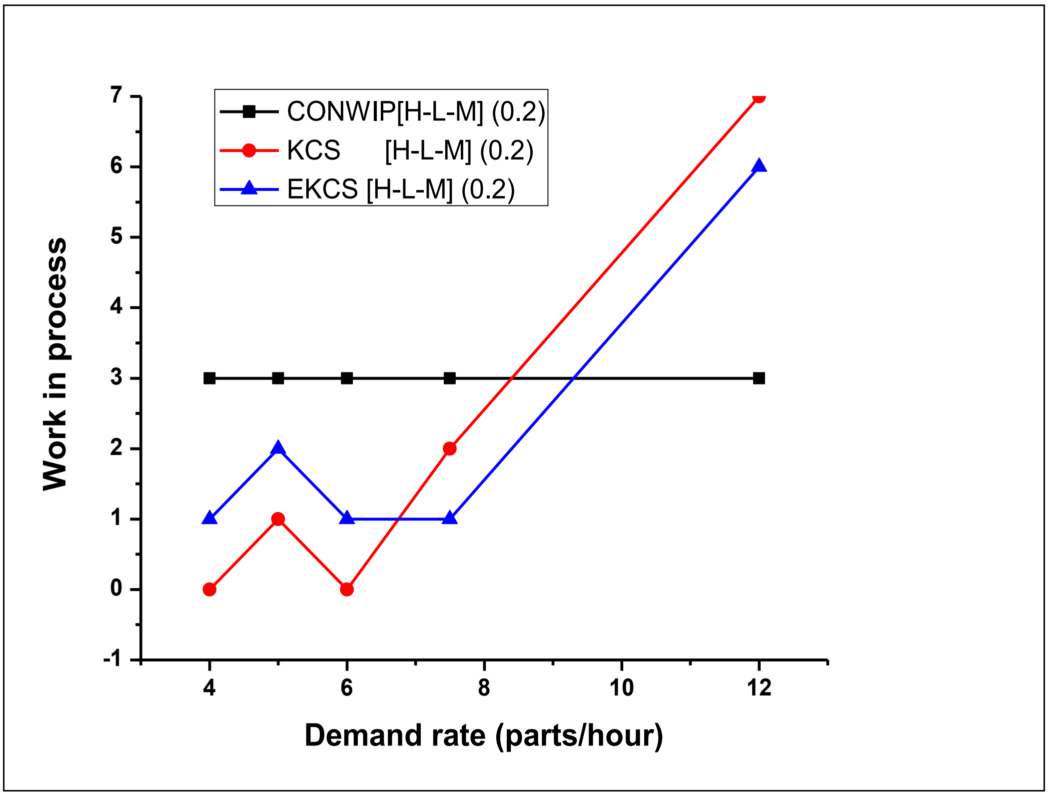

Figure 5.52: Sensitivity Analysis of WIP for Imbalance 0.2 min (H-L-M)

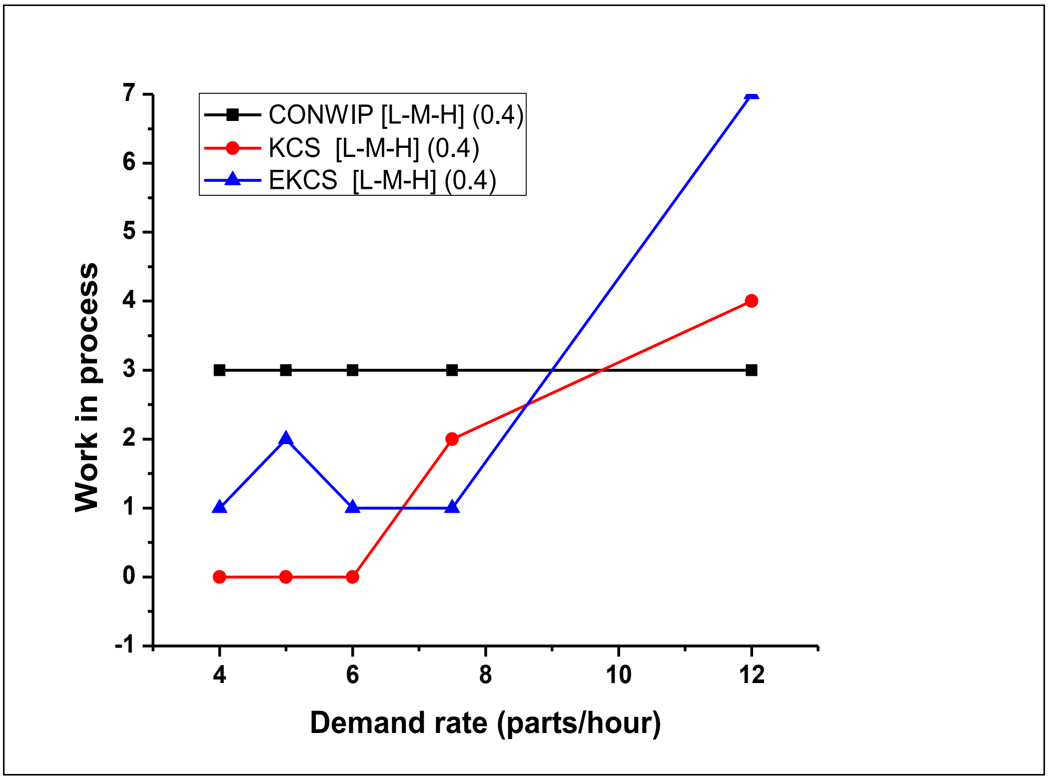

Figure 5.53: Sensitivity Analysis of WIP for Imbalance 0.4 min (L-M-H)

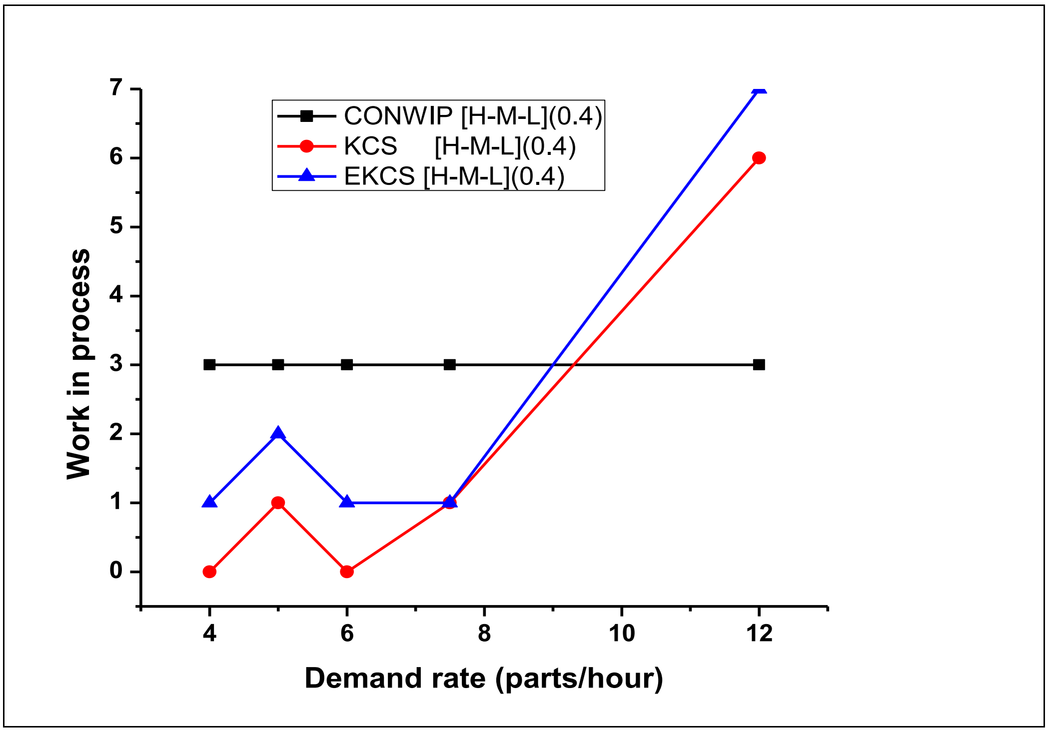

Figure 5.54: Sensitivity Analysis of WIP for Imbalance 0.4 min (H-M-L)

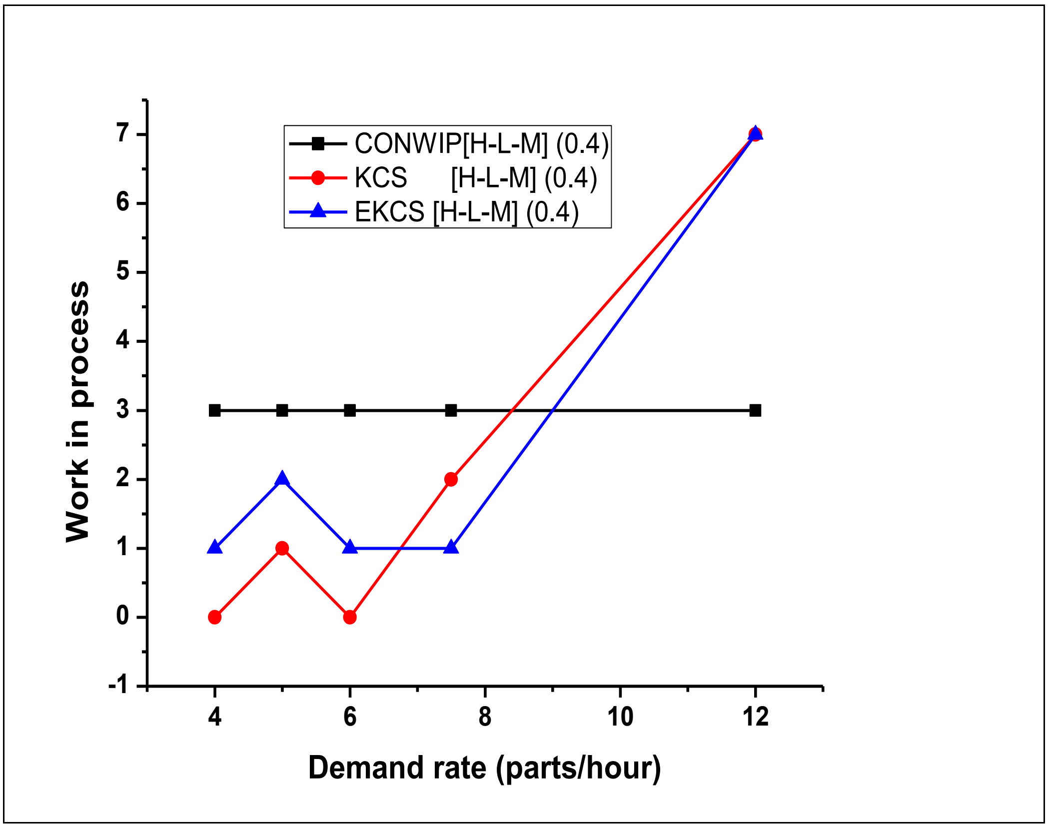

Figure 5.55: Sensitivity Analysis of WIP for Imbalance 0.4 min (H-L-M)

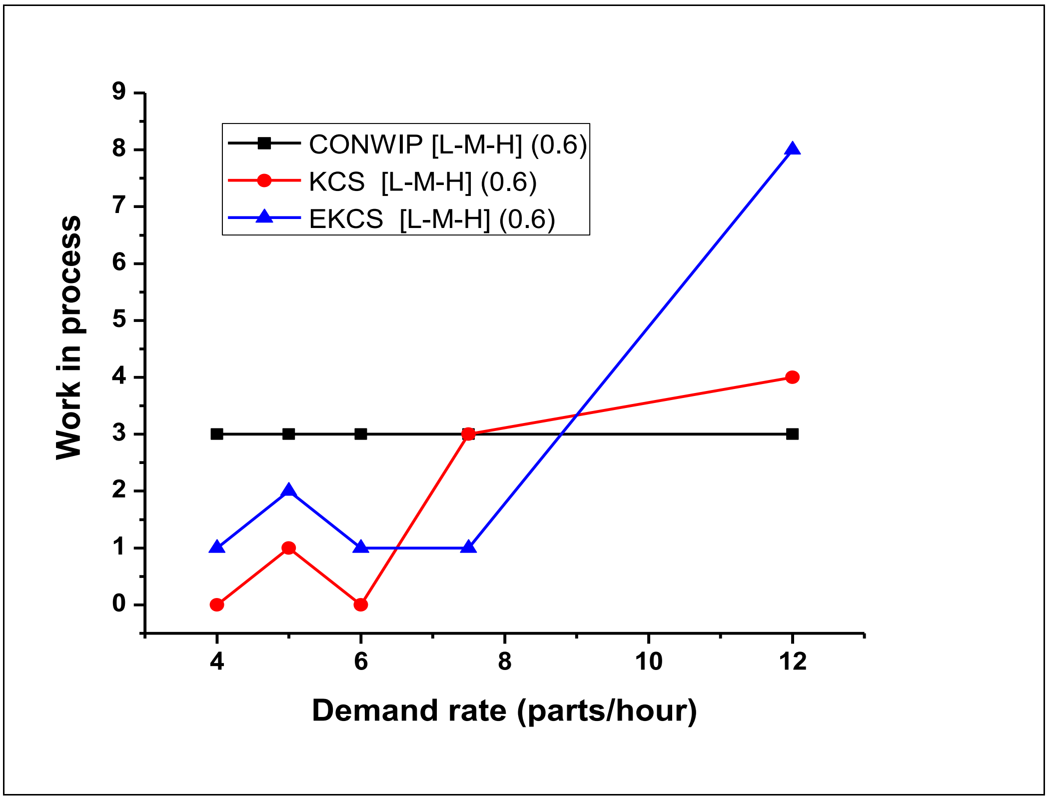

Figure 5.56: Sensitivity Analysis of WIP for Imbalance 0.6 min (L-M-H)

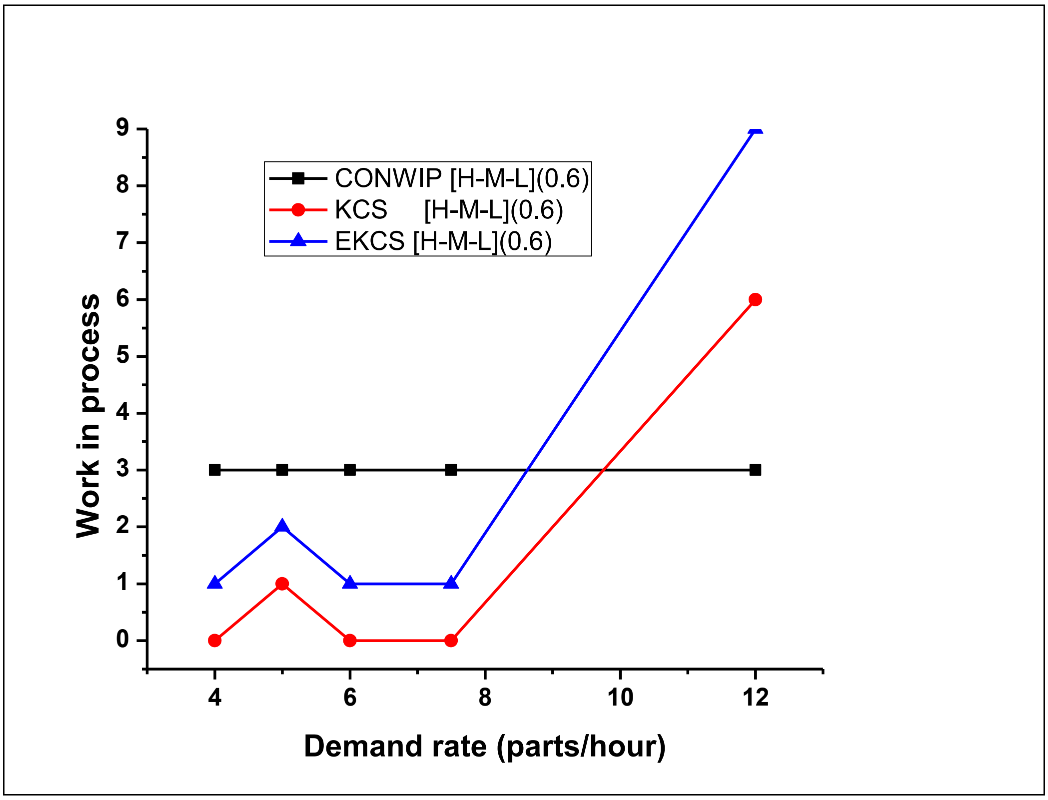

Figure 5.57: Sensitivity Analysis of WIP for Imbalance 0.6 min (H-M-L)

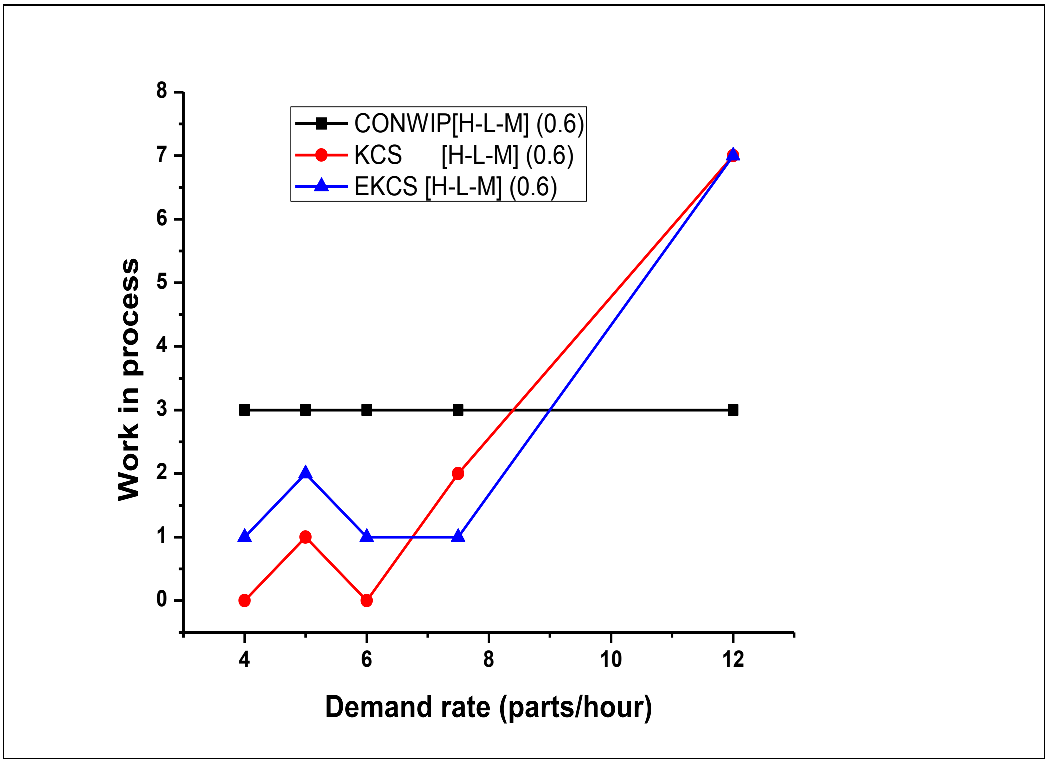

Figure 5.58: Sensitivity Analysis of WIP for Imbalance 0.6 min (H-L-M)

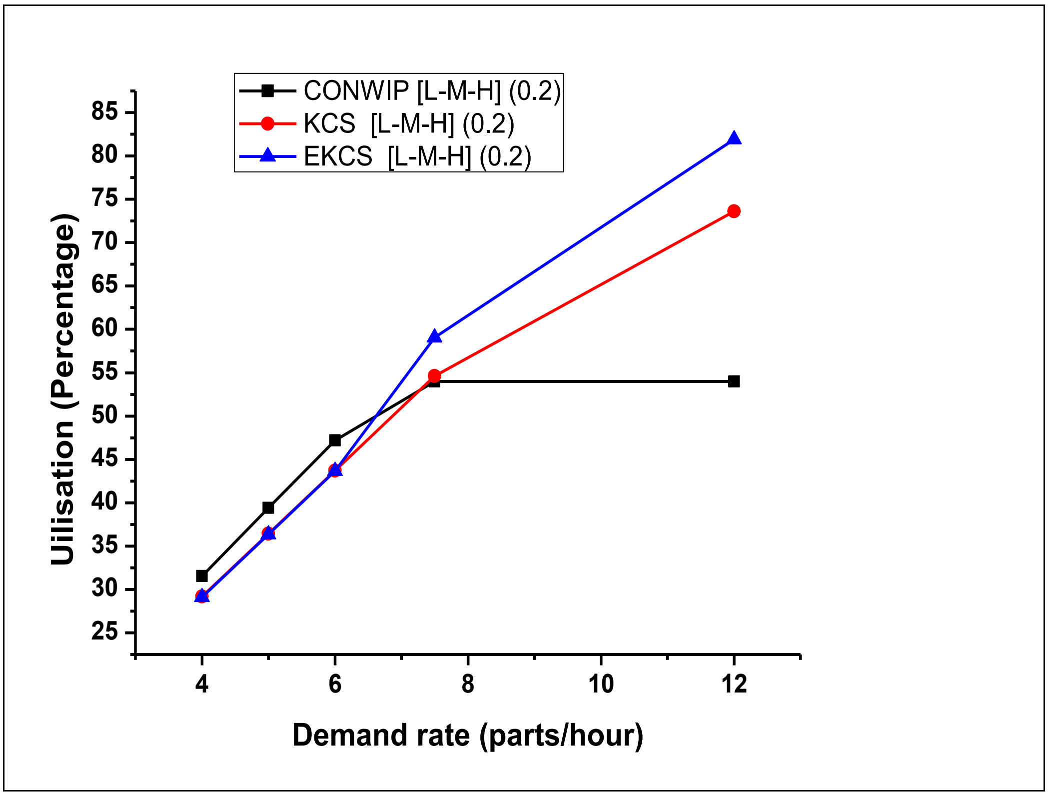

Figure 5.59: Sensitivity Analysis of utilization for Imbalance 0.2 min (L-M-H)

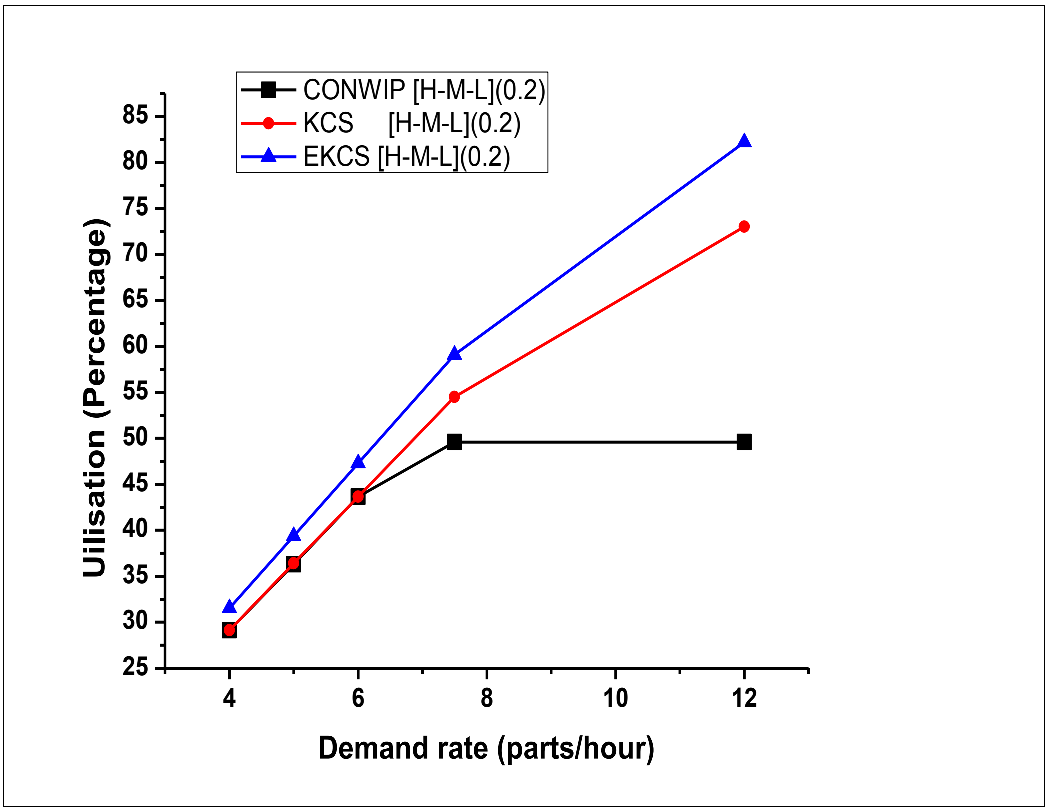

Figure 5.60: Sensitivity Analysis of utilization for Imbalance 0.2 min (H-M-L)

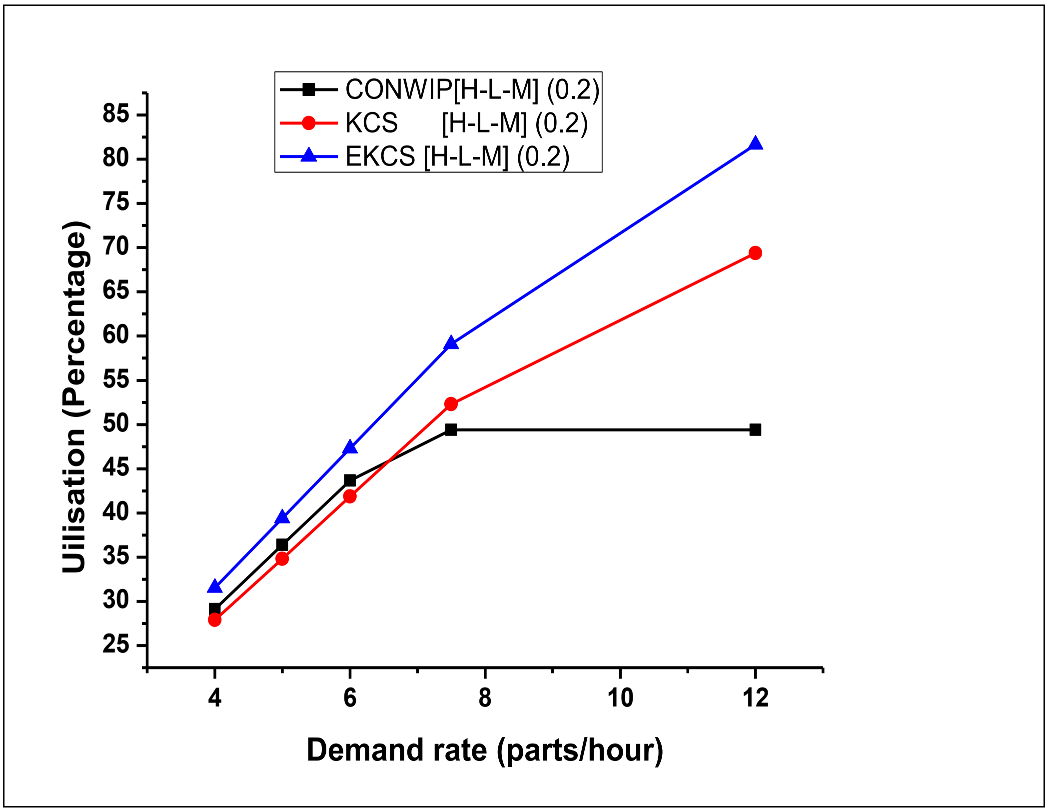

Figure 5.61: Sensitivity Analysis of utilization for Imbalance 0.2min (H_L-M)

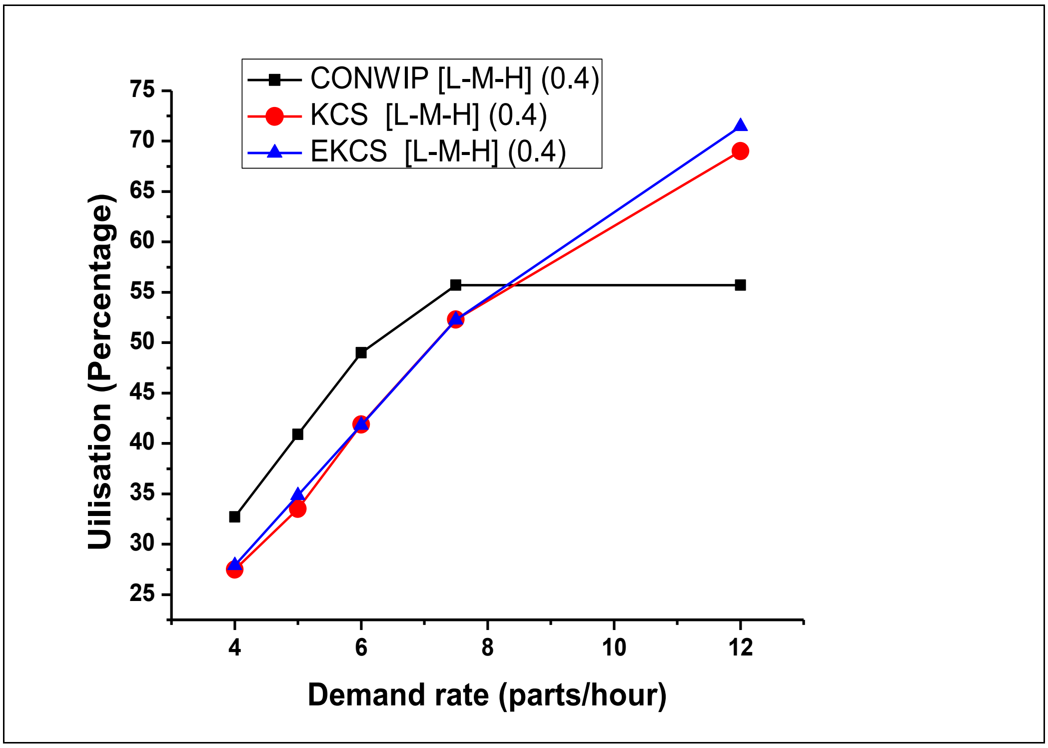

Figure 5.62: Sensitivity Analysis of utilization for Imbalance 0.4 min (L-M-H)

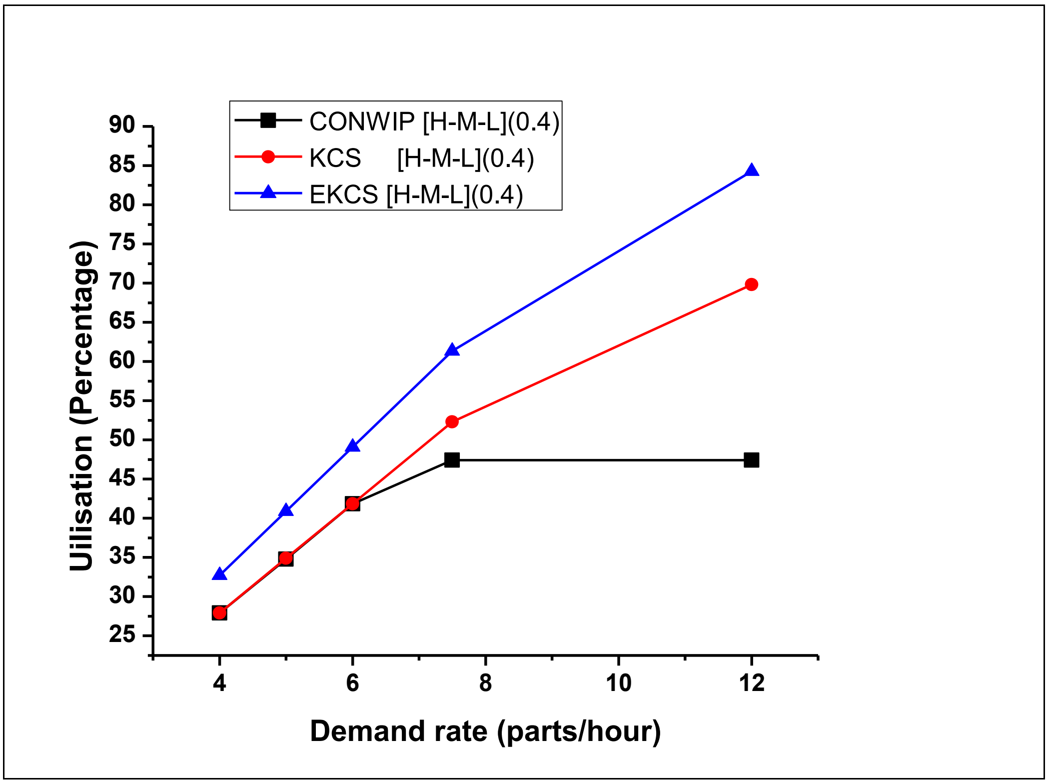

Figure 5.63: Sensitivity Analysis of utilization for Imbalance 0.4 min (H-M-L)

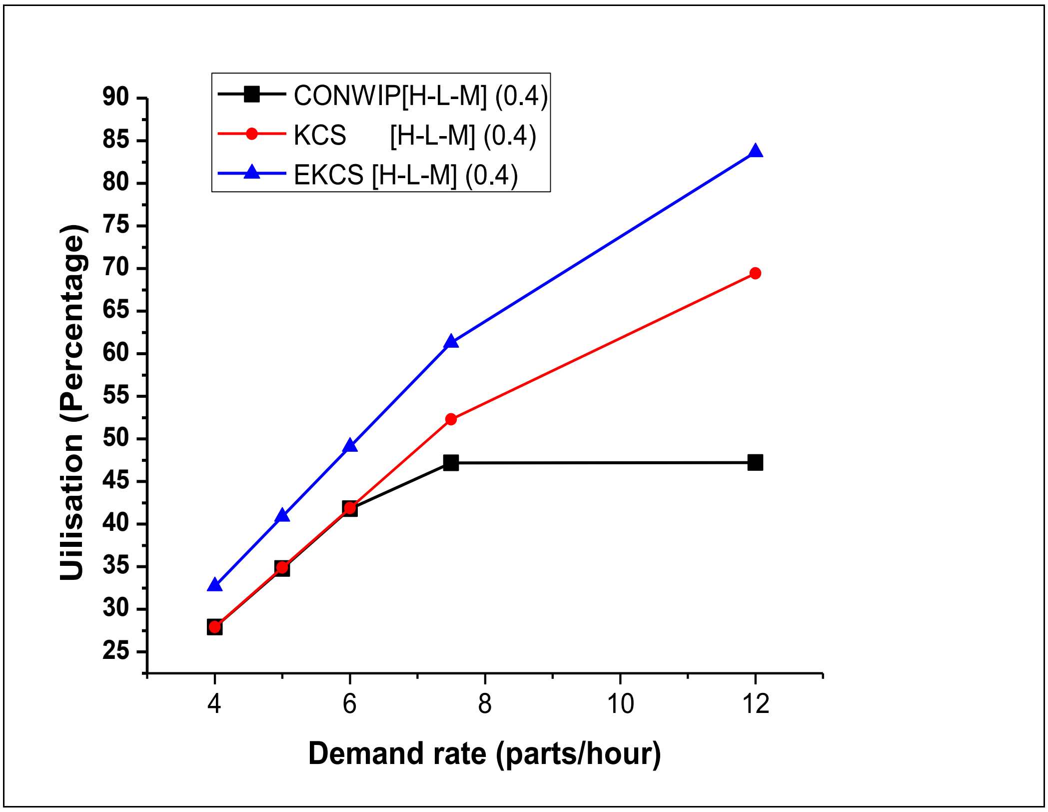

Figure 5.64: Sensitivity Analysis of utilization for Imbalance 0.4 min (H-L-M)

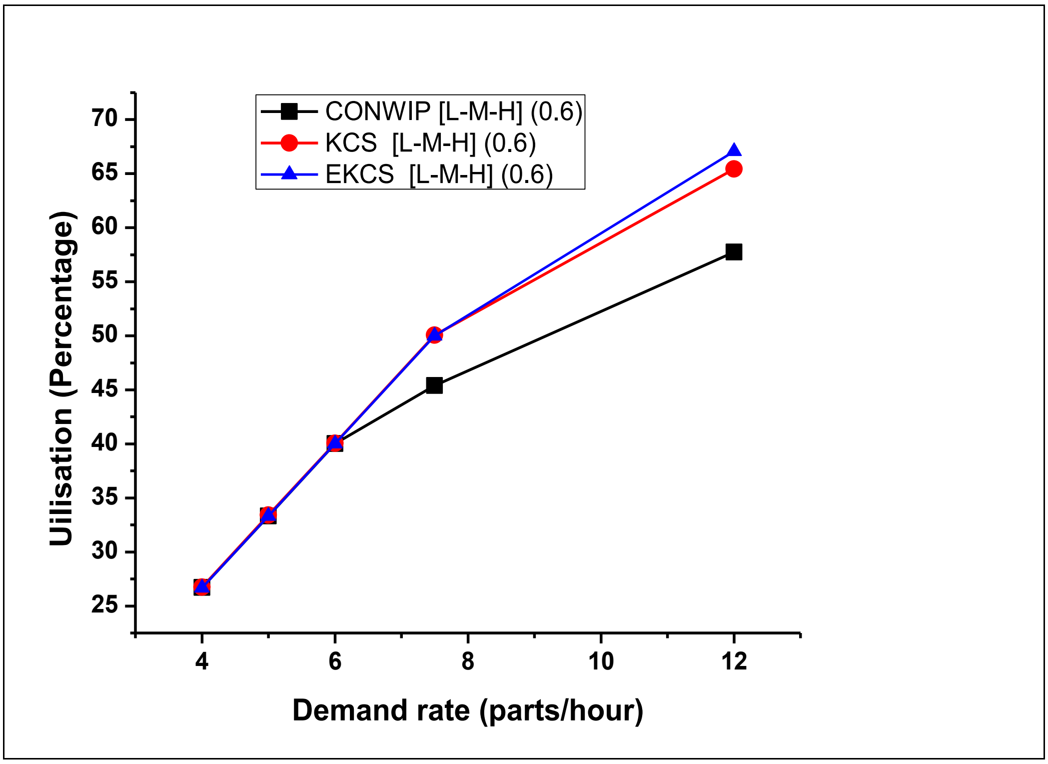

Figure 5.65: Sensitivity Analysis of utilization for Imbalance 0.6 min (L-M-H)

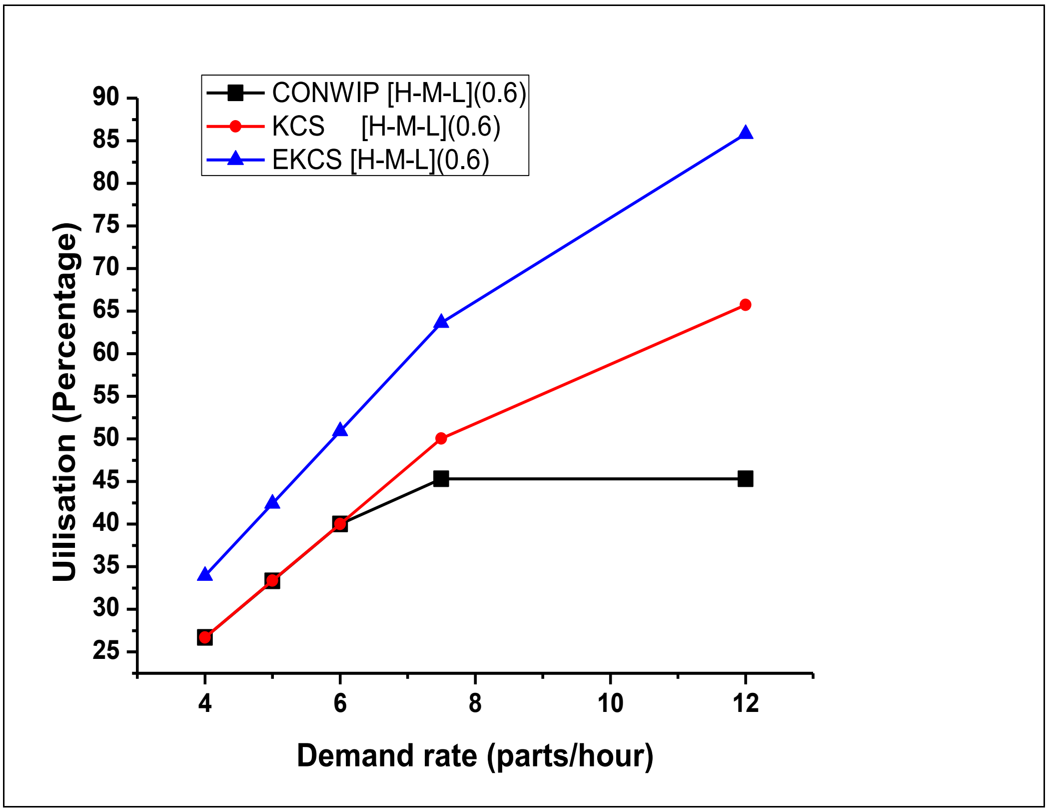

Figure 5.66: Sensitivity Analysis of utilization for Imbalance 0.6 min (H-M-L)

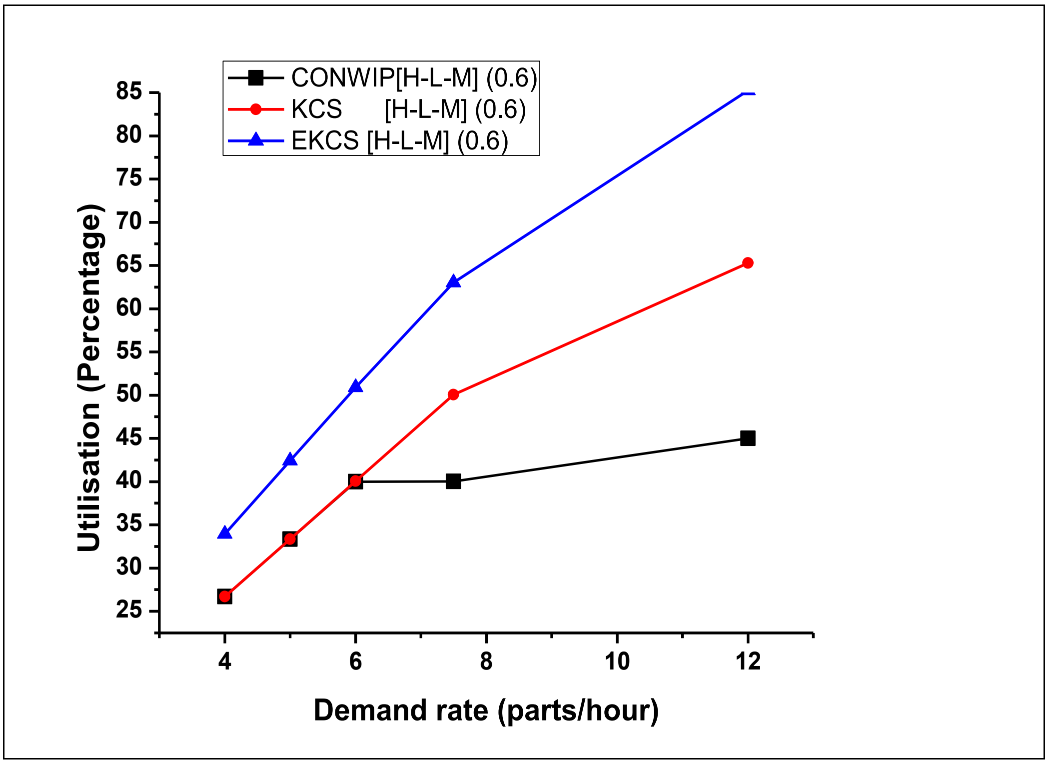

Figure 5.67: Sensitivity Analysis of utilization for Imbalance 0.6min (H-L-M)

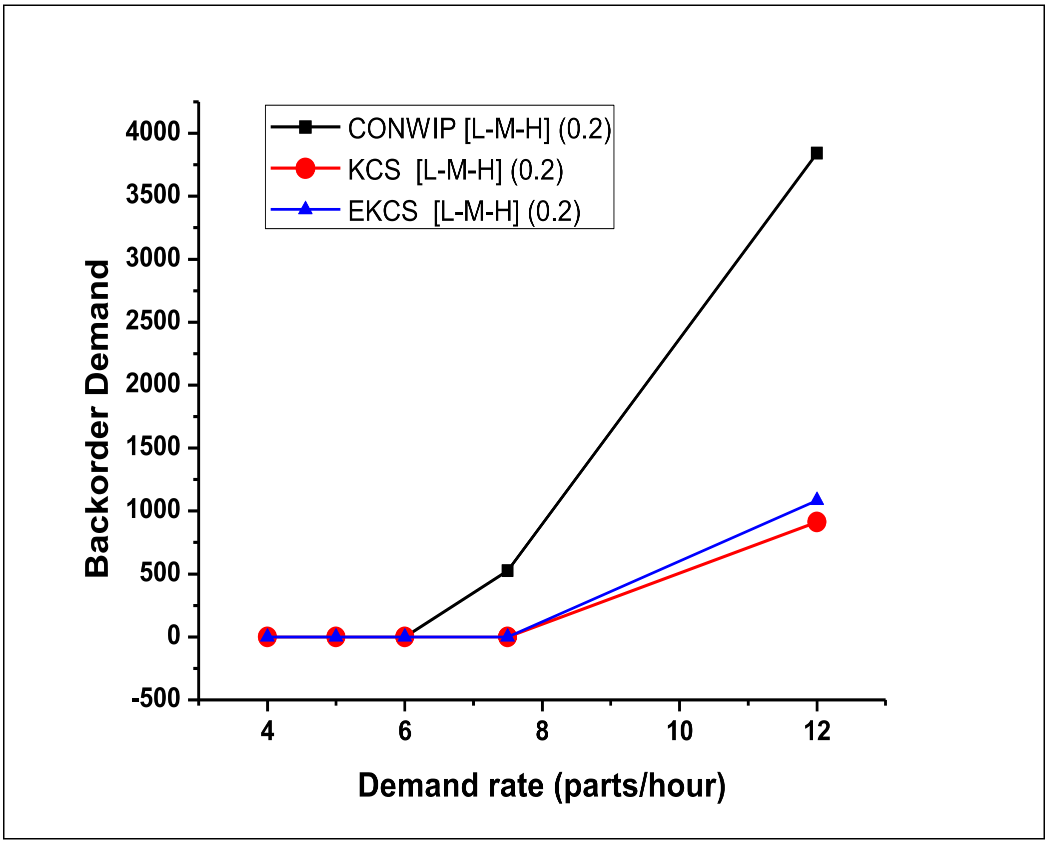

Figure 5.68: Sensitivity Analysis of backorder demand for Imbalance 0.2 min (L-M-H)

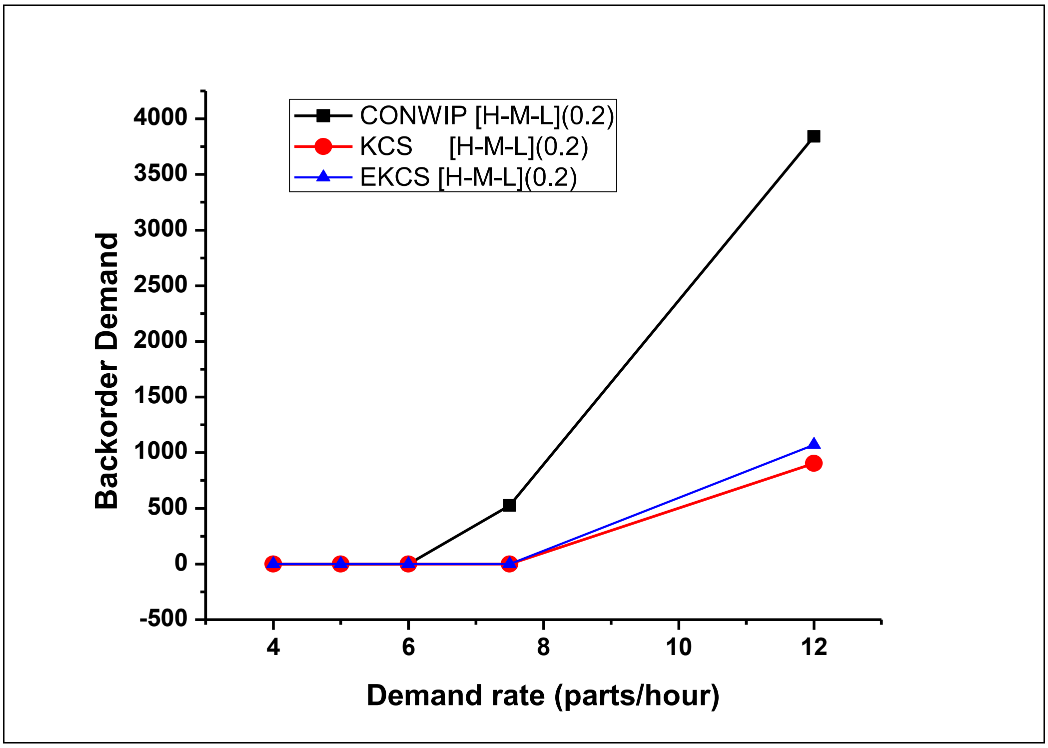

Figure 5.69: Sensitivity Analysis of backorder demand for Imbalance 0.2 min (H-M-L)

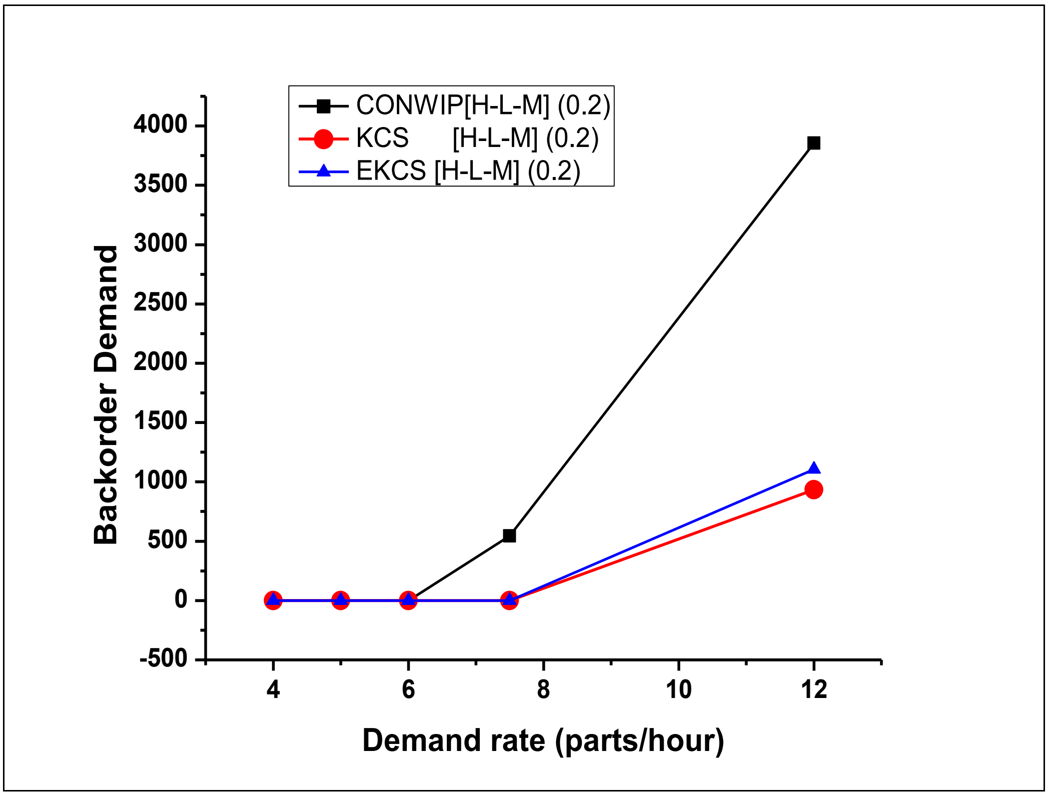

Figure 5.70: Sensitivity Analysis of backorder demand for Imbalance 0.2 min (H-L-M)

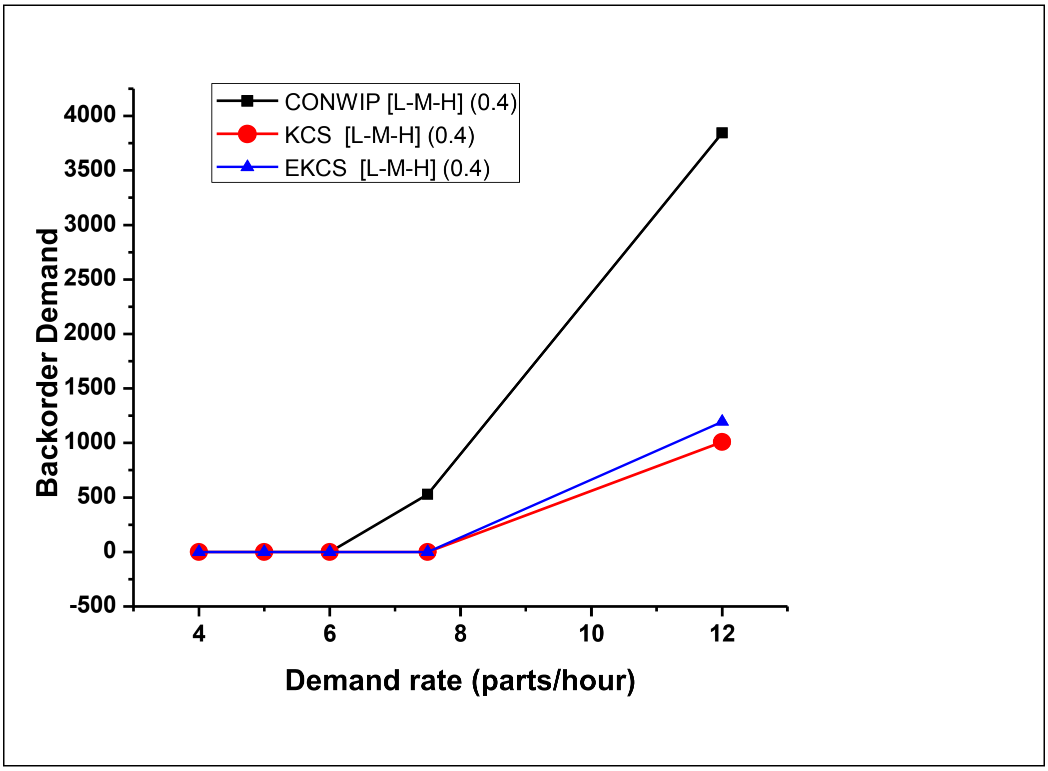

Figure 5.71: Sensitivity Analysis of backorder demand for Imbalance 0.4 min (L-M-H)

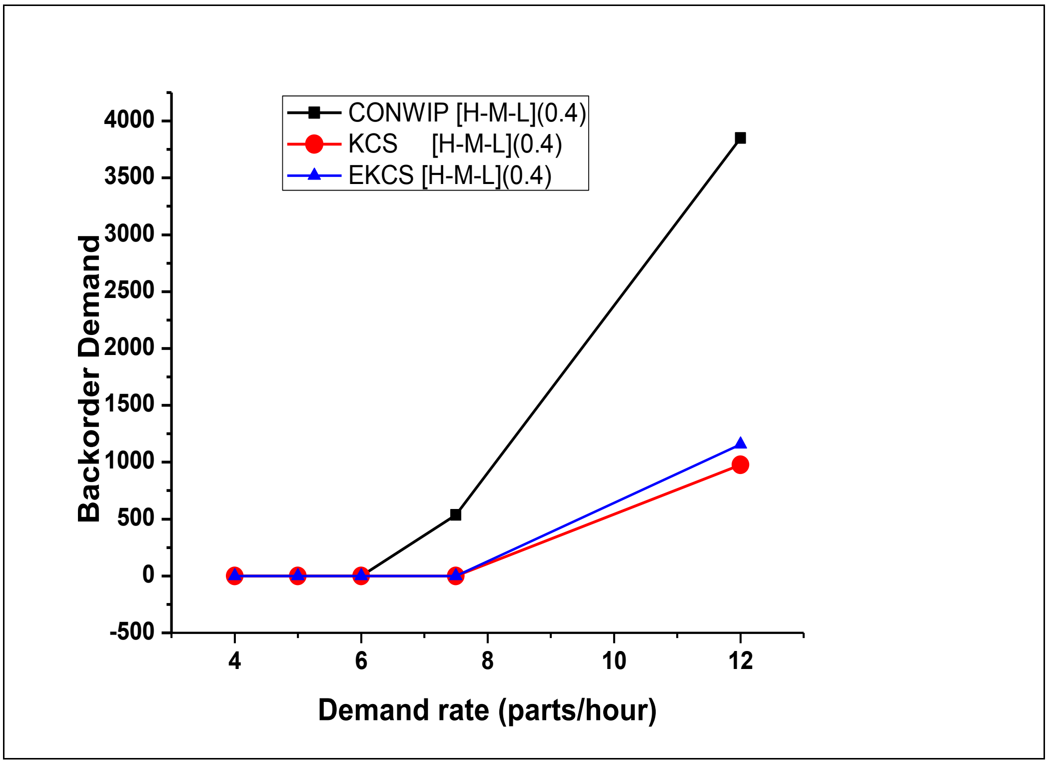

Figure 5.72: Sensitivity Analysis of backorder demand for Imbalance 0.4 min (H-M-L)

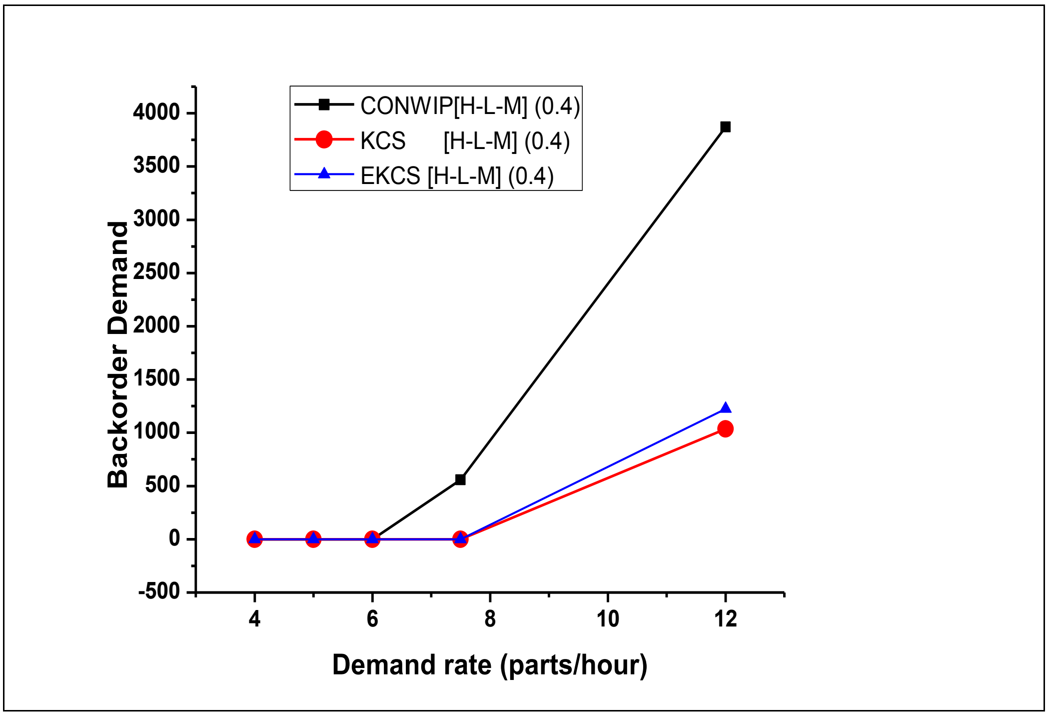

Figure 5.73: Sensitivity Analysis of backorder demand for Imbalance 0.4 min (H-L-M)

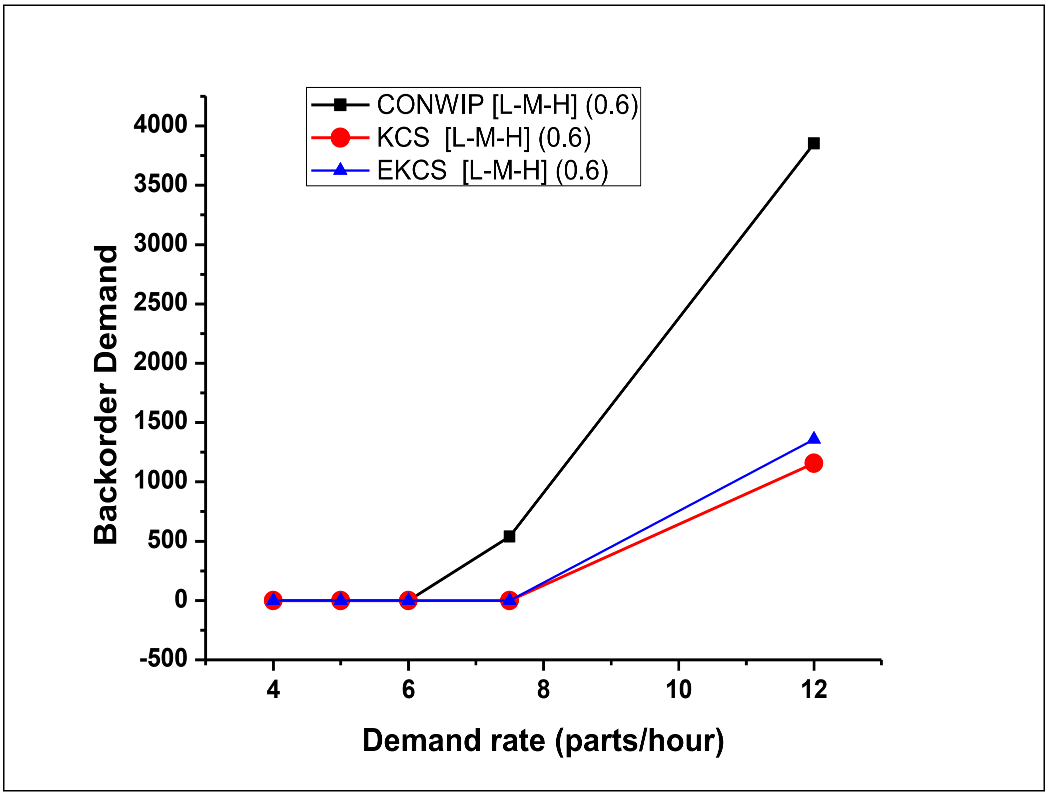

Figure 5.74: Sensitivity Analysis of backorder demand for Imbalance 0.6 min (L-M-H)

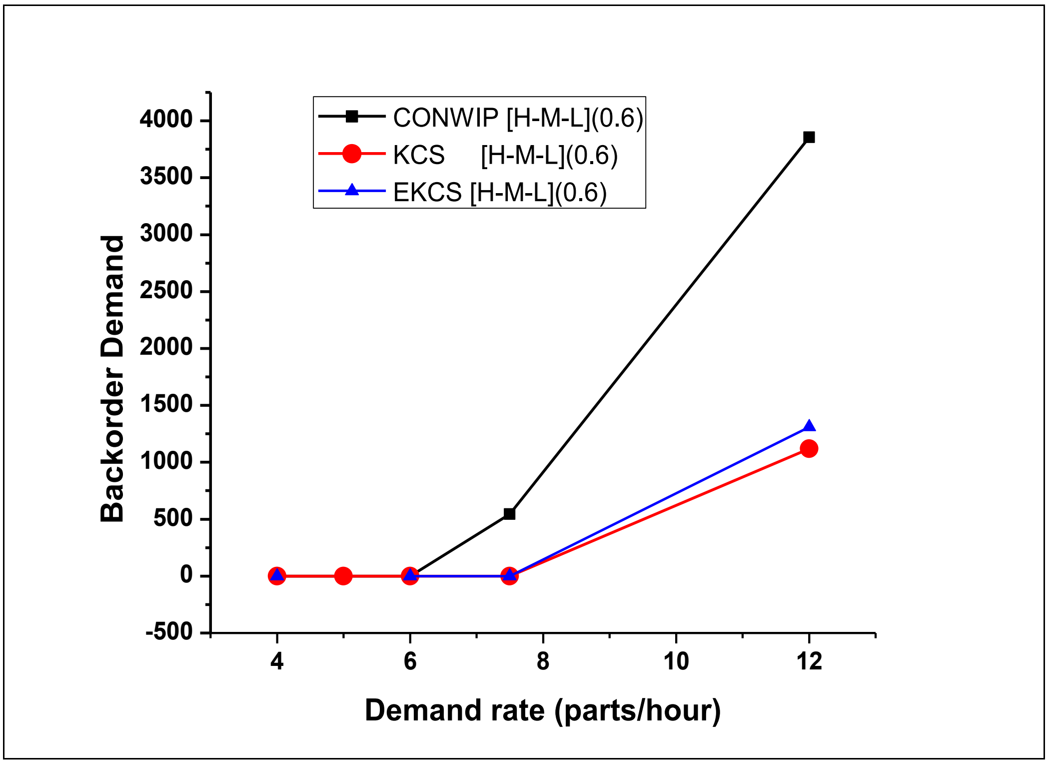

Figure 5.75: Sensitivity Analysis of backorder demand for Imbalance factor 0.6 (H-M-L)

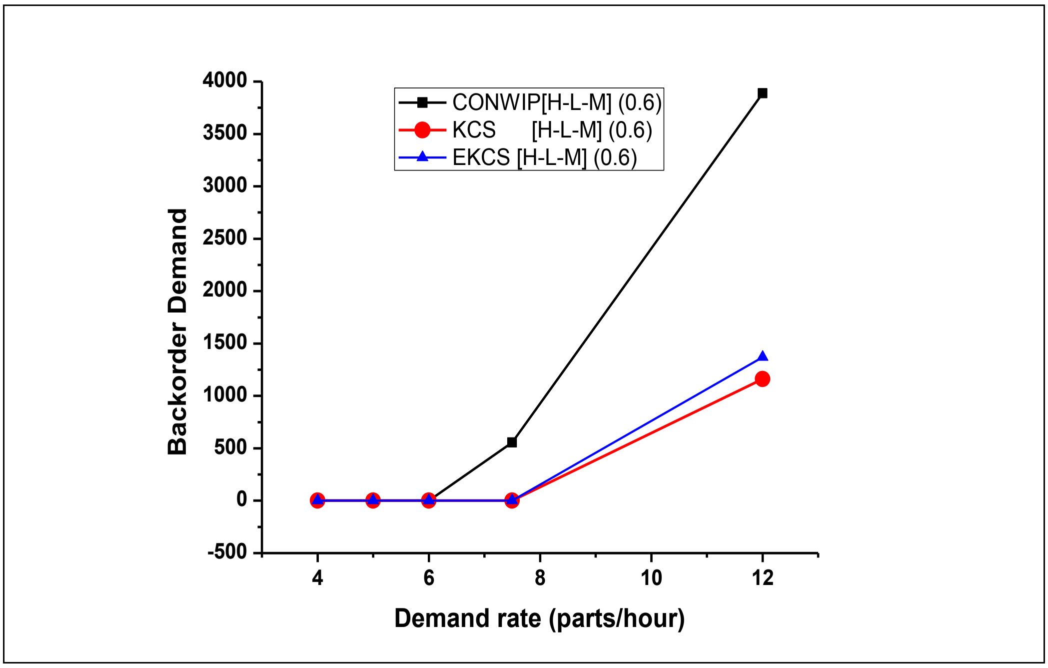

Figure 5.76: Sensitivity Analysis of backordered demand for Imbalance 0.6 min (H-L-M)

The effect of processing mean time imbalance on the performance of CONWIP system, KCS and EKCS for single line multi stage manufacturing system is very lean. There is no effect on the performance of the systems at low demand rates. There is a lean variation in the performance of the systems at a demand rate of 7 -8 parts per hour.

For CONWIP system, the low–medium-high (LMH) combination with degree of imbalance 0.2 min has highest production and high–low–medium (HLM) combination with degree of imbalance 0.6 min has lowest production. The maximum variation in production for LMH with imbalance 0.2 min is approximately 13.5% more as compared to HLM with imbalance 0.6 min. The utilization is also approximately 20.4% more for LMH with imbalance 0.2 min as compared to HLM with imbalance 0.6 min. The AWT and backordered demand for HLM combination with imbalance 0.6 min is 4% and 5% high as compared to those of LMH combination with imbalance 0.2 min respectively. The WIP is constant for all imbalance time factors and combinations. For HLM combination, the components processed in workstation M_1 takes more time resulting in starving situation for the workstations M_2 and M_3. Thus, the production is reduced and AWT of parts in queues increases because CONWIP system synchronizes part with kanban and demands at the end of the flow line. For LMH combination, the component processed in workstation M_3 takes more time resulting in blocking situation for the workstation M_1 and M_2. The performance details of CONWIP system for the three combinations are given in Table 5.4.

Table 5.4: Sensitivity Analysis of CONWIP for single line multi stage system for demand rate 7.5 parts/hour

	Imbalance (min)	L-M-H	H-M-L	H-L-M
Production	0.2	5100	5100	5083
	0.4	5098	5092	5070
	0.6	5089	5082	5004
Average Waiting time (Min)	0.2	11.41	11.42	11.5
	0.4	11.43	11.45	11.59
	0.6	11.48	11.5	11.88
WIP	0.2	3	3	3
	0.4	3	3	3
	0.6	3	3	3
Utilization (%age)	0.2	54	49.59	49.4
	0.4	55.7	47.4	47.2
	0.6	45.39	45.3	40.01
Backorder demand	0.2	527	527	544
	0.4	529	536	557
	0.6	538	545	555

For KCS, the effect of imbalance on the production for the three combinations is negligible. There is a marginal variation in the AWT for imbalance of 0.2 min, 0.4 min and 0.6 min for each combination. For imbalance of 0.6 min, there is negligible variation in AWT for the three combinations. The HML combination has the lowest WIP as compared to LMH and HLM combination considering the imbalance factor of 0.2min, 0.4min and 0.6min. There is marginal variation in machine utilization for imbalance factor of 0.2min, 0.4min and 0.6min for each combination. For imbalance factor of 0.6 min, the machine utilization has lowest value for the three combinations whereas it is high for imbalance factor of 0.2 min. The imbalance doesn't have any influence on backordered demand. The details of the performance of KCS for the three combinations are given in Table 5.5.

Table 5.5: Sensitivity Analysis of KCS for single line multi stage system for demand rate 7.5 parts/hour.

	Imbalance (min)	L-M-H	H-M-L	H-L-M
Production	0.2	5627	5627	5627
	0.4	5623	5627	5627
	0.6	5627	5627	5627
Average Waiting time (Min)	0.2	11.93	12.25	12.2
	0.4	12.45	12.35	12.42
	0.6	12.52	12.52	12.52
WIP	0.2	2	1	2
	0.4	2	1	2
	0.6	3	0	2
Utilization (%age)	0.2	54.6	54.5	52.3
	0.4	52.3	52.31	52.3
	0.6	50.07	50.04	50.06
Backorder demand	0.2	0	0	0
	0.4	0	0	0
	0.6	0	0	0

The sensitive effect is on AWT due to imbalance factor of 0.2 min, 0.4min and 0.6min. The combination with high processing mean time of first workstation as compared to other workstations has higher AWT. The part and kanban synchronizes at the end of each stage, whereas the demand synchronizes only at the end of the flow line. The part processed in the downstream workstation M_3 attached with kanban synchronizes with demand and is released. The kanban moves to the upstream station. The part is processed for longer time in workstation M_1 blocks the downstream stages of flow line resulting in retention of the parts in queues of stages S_2 and S_3. Further, the combination with workstation M_3 having high processing time as compared to other workstations has high WIP which vary with number of kanbans per stage.

The performance of EKCS and KCS are similar. The production in KCS and EKCS are similar for imbalance factor of 0.2min, 0.4min and 0.6min. The significant effect of imbalance factor of 0.2 min, 0.4min and 0.6min is on AWT. The combination with high processing mean time at workstation M_1 results in lower AWT than the combination having low processing mean time at M_1. For LMH combination, the AWT increases with increase in imbalance factor from 0.2 min to 0.6min whereas it decreases for HML and HLM combinations. In EKCS, the part, demand and kanban synchronize at every stage leading to a tight coordination. The dependence of part movement upon the availability of demand at each stage minimizes the WIP. The details of the performance are given in Table 5.6.

Table 5.6: Sensitivity Analysis of EKCS for single line multi stage system for demand rate 7.5 parts/hour

	Imbalance (min)	L-M-H	H-M-L	H-L-M
Production	0.2	5626	5626	5626
	0.4	5626	5626	5626
	0.6	5626	5626	5626
Average Waiting time (Min)	0.2	5.86	5.41	5.65
	0.4	6.05	5.41	5.65
	0.6	6.28	5.28	5.64
WIP	0.2	1	1	1
	0.4	1	1	1
	0.6	1	1	1
Utilisation (%age)	0.2	59.07	59.09	59.09
	0.4	52.27	61.36	61.3
	0.6	50	63.63	63.03
Backorder demand	0.2	0	0	0
	0.4	0	0	0
	0.6	0	0	0

5.3 ANALYSIS OF MULTI FLOW LINE MULTI STAGE MANUFACTURING SYSTEMS

The performance of CONWIP system, KCS and EKCS are analyzed for the multi flow line multi stage pull control manufacturing system. The manufacturing system is assumed to have two flow lines. The first flow line has three manufacturing stages M_1, M_2 and M_3. The second flow line also has three manufacturing stages M_4, M_5 and M_6. The processing mean time of each manufacturing stage is 15 minutes. The customer demand mean time varies from 10 minutes to 65 minutes in a time interval of 5 minutes. The simulation time is 9600 minutes (10 days @ 16 hours/day). These two flow lines converge to a single station M_7 for the assembly, as shown in figure 5.77.

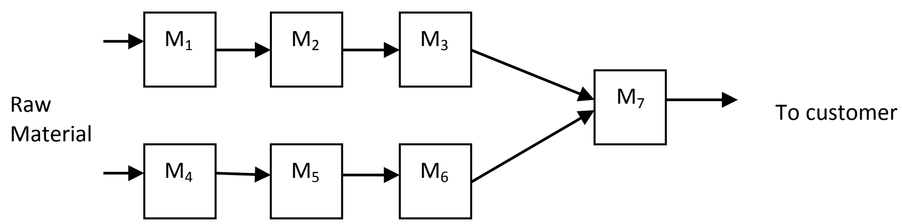

Figure 5.77: Multi flow line multi stage assembly system

The validation and simulation results analysis are presented as under:

5.3.1 Results Validation

The model for CONWIP system, KCS and EKCS is developed by using the computing software MATLAB/SIMULINK R2011b and is shown in Figures 5.78 to 5.80. A code is developed in object oriented programming language ‘C’ for validation and is included in Appendix A. Figures 5.81 to 5.89 shows the results obtained through simulation by network model and validated with the help of results obtained analytically by coded language ‘C’ for one, two and three kanbans per stage.

For low demand mean time, the production obtained by software simulation for CONWIP with single kanban per stage is approximately 1% less; with two kanbans per stage is 2% less; and with three kanbans per stage is 3.5%; as compared to analytical approach. Similarly, the production obtained by software simulation for KCS is approximately 7% less for single kanban per stage; 5% less for two kanbans per stage; 3% less for three kanbans per stage; as compared to analytical approach. For EKCS the production obtained from software simulation is approximately 5% less for single kanban per stage, 8% less for two kanbans per stage, 7% for three kanbans per stage as compared to the results obtained from analytical approach.

For high demand mean time, the production obtained from software simulation for CONWIP with single kanban per stage is approximately 2% less; with two kanban per stage is 3% less; and with three kanban per stage is 3% less. Similarly for KCS and EKCS, the production obtained from software simulation for single, two and three kanbans per stage is approximately 3% less as compared to analytical method.

The variations in results obtained through simulation and analytically coded language C are due to the fact that in network model the processing mean time, demand mean time etc. are defined using stochastic distribution whereas it is not considered in coded language language ‘C’. Therefore, the results obtained from network model are compared and validated.

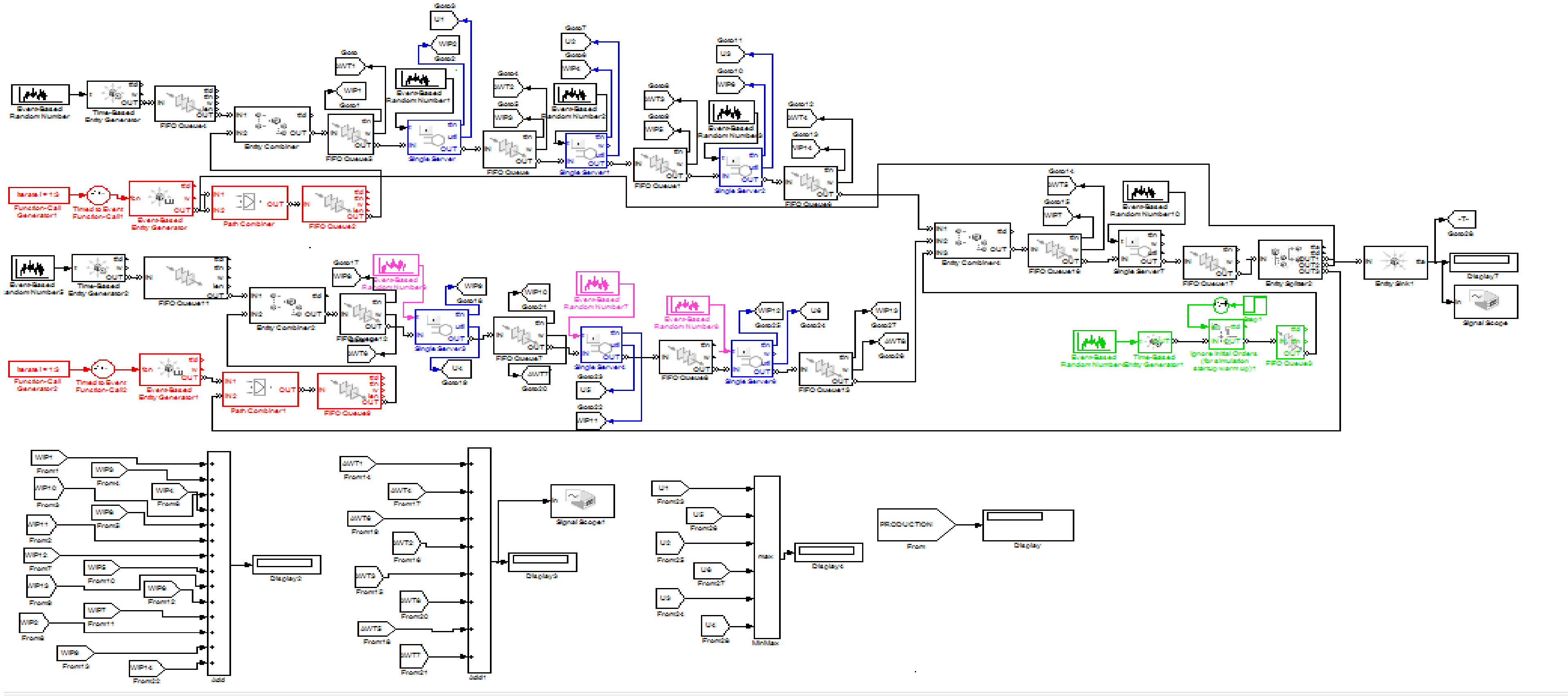

Figure 5.78: Network model of CONWIP system for multi-line multi stage system

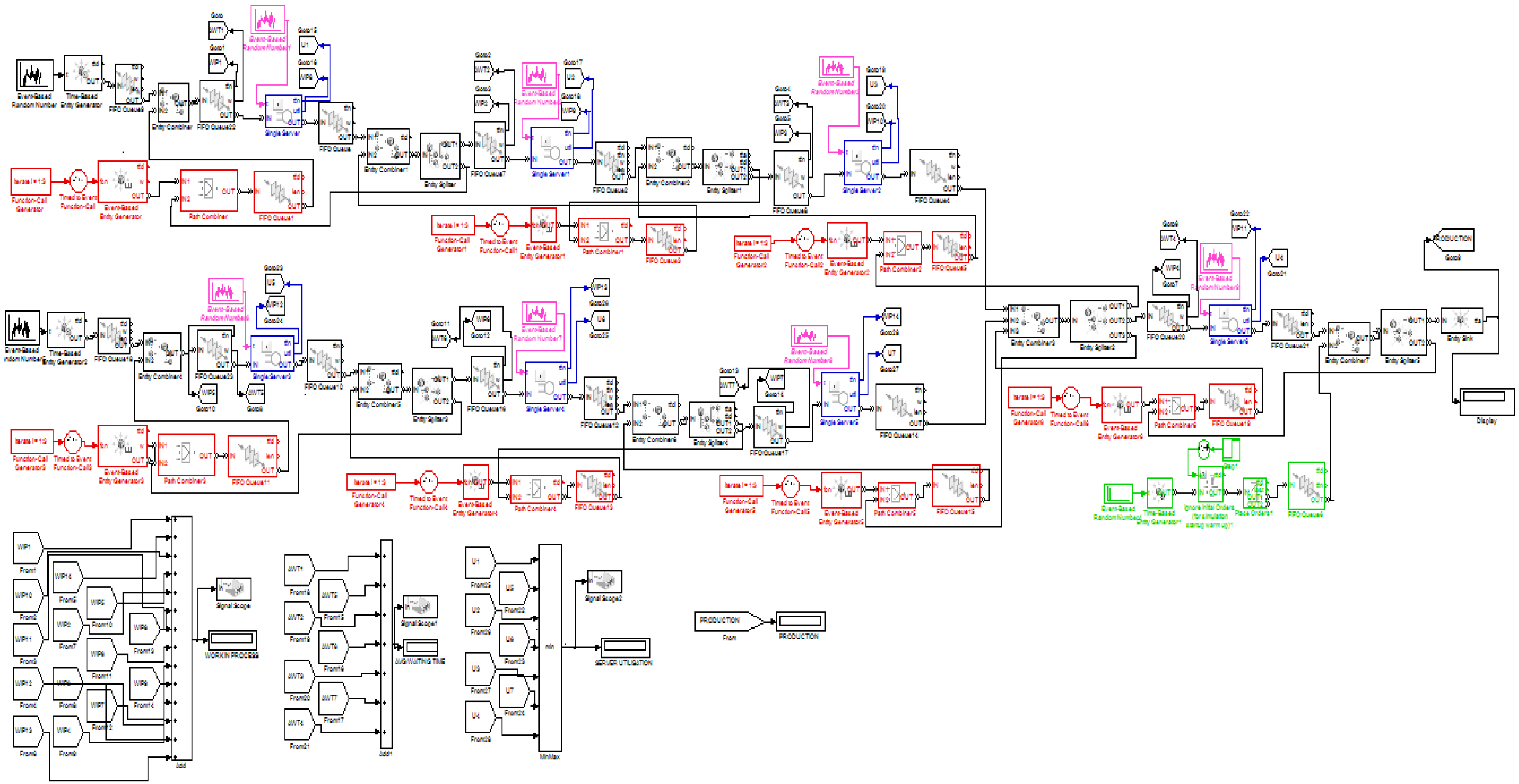

Figure 5.79: Network model of KCS for Multi line multi stage system

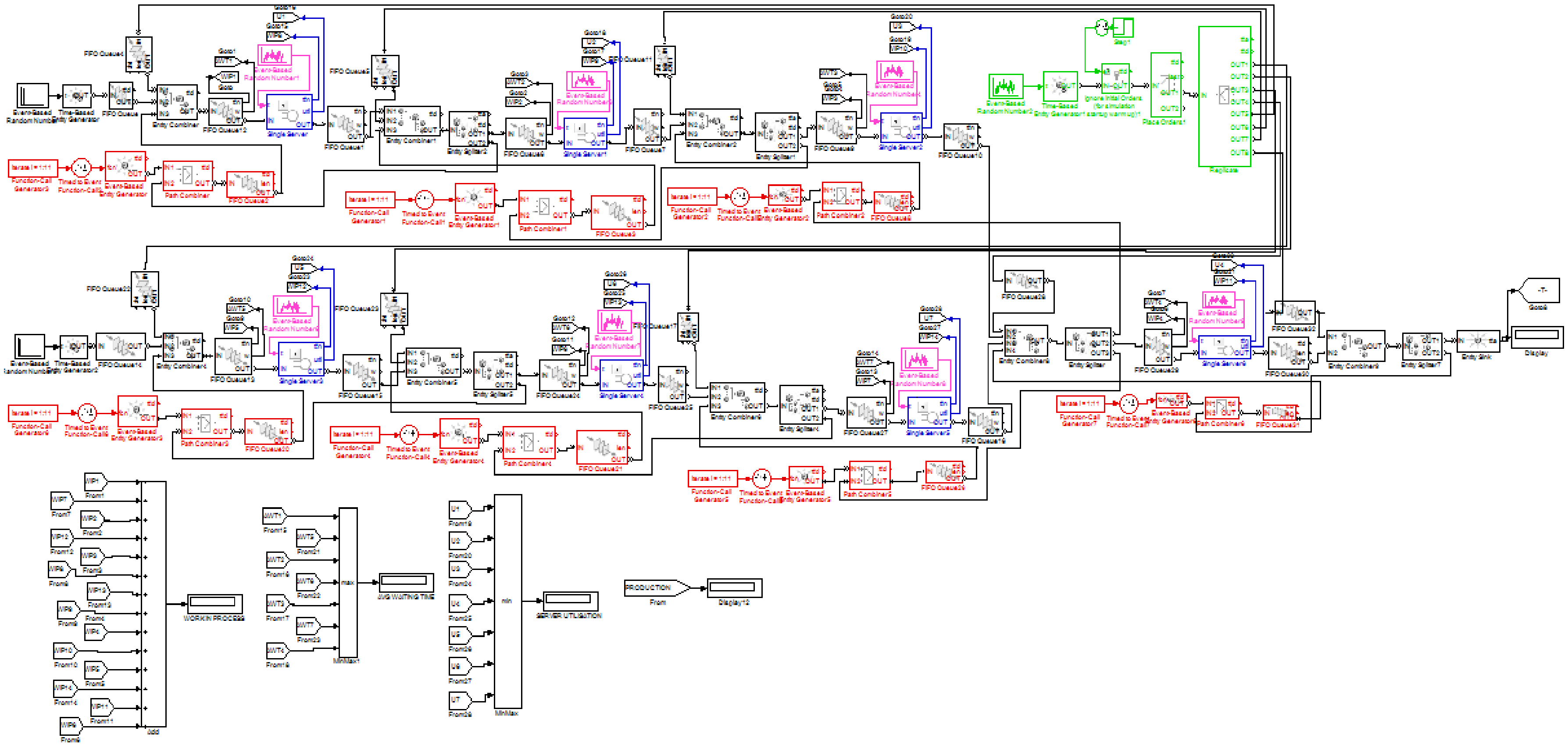

Figure 5.80: Network model of EKCS for multi-line multi stage system

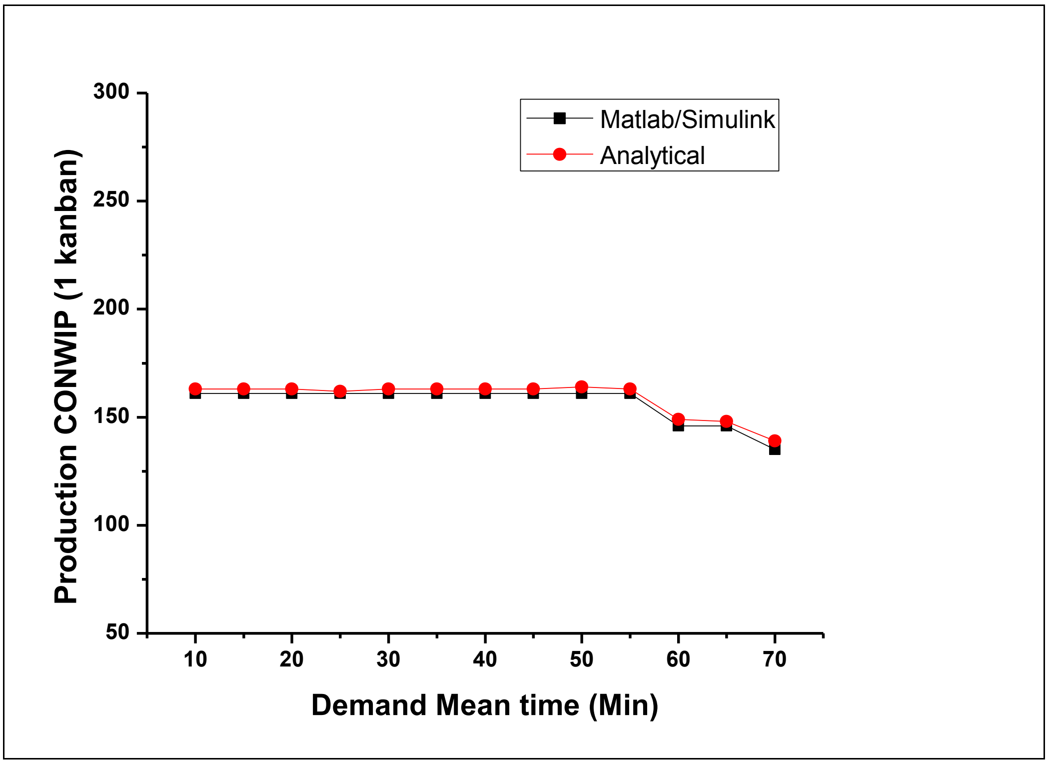

Figure 5.81: Validation of production for Multi flow line Multi stage system for CONWIP (Single Kanban per stage)

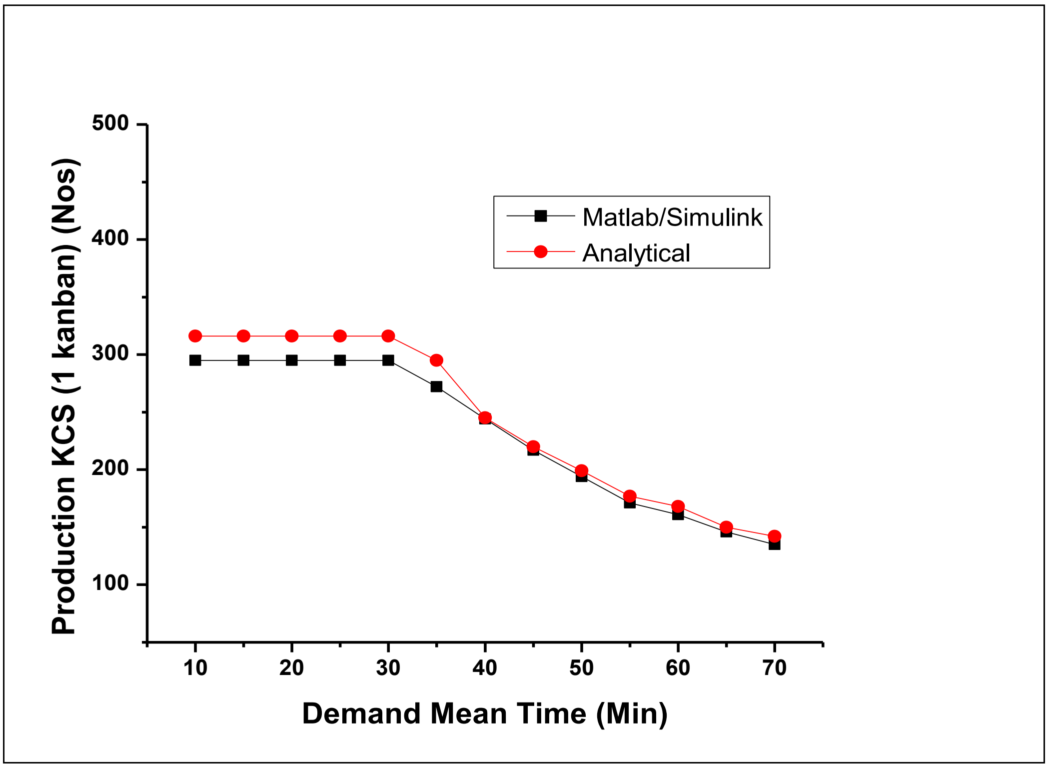

Figure 5.82: Validation of production for Multi flow line Multi stage system for KCS (Single kanban per stage)

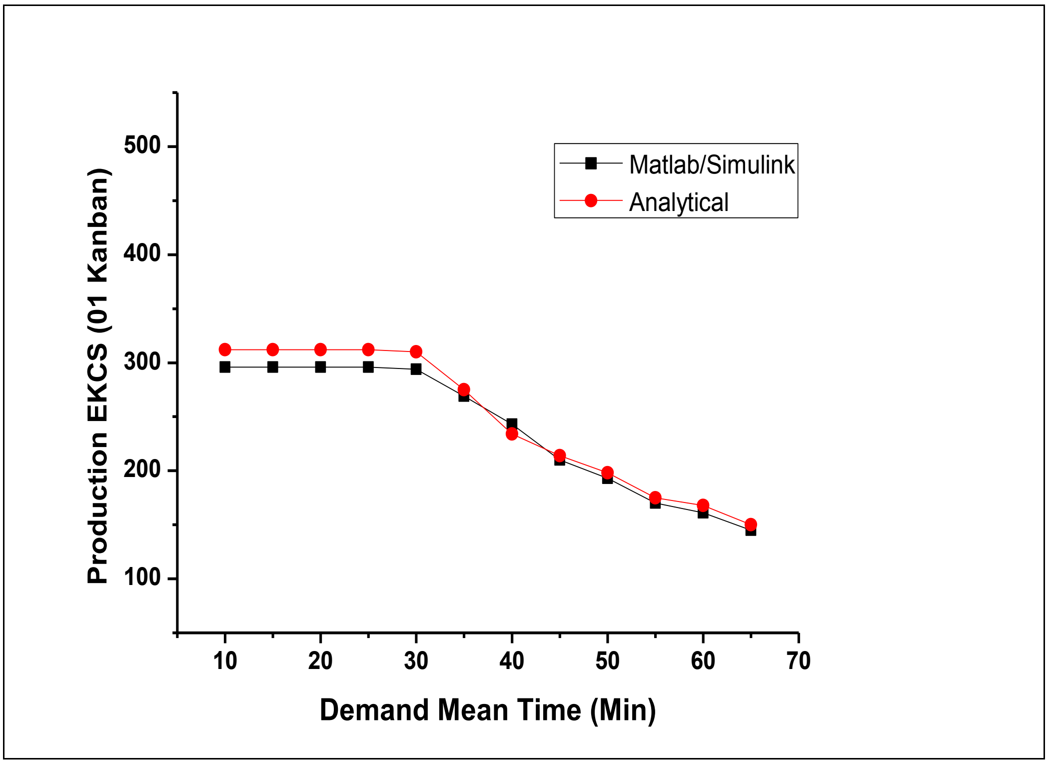

Figure 5.83: Validation of production for Multi flow line Multi stage system for EKCS (Single kanban per stage)

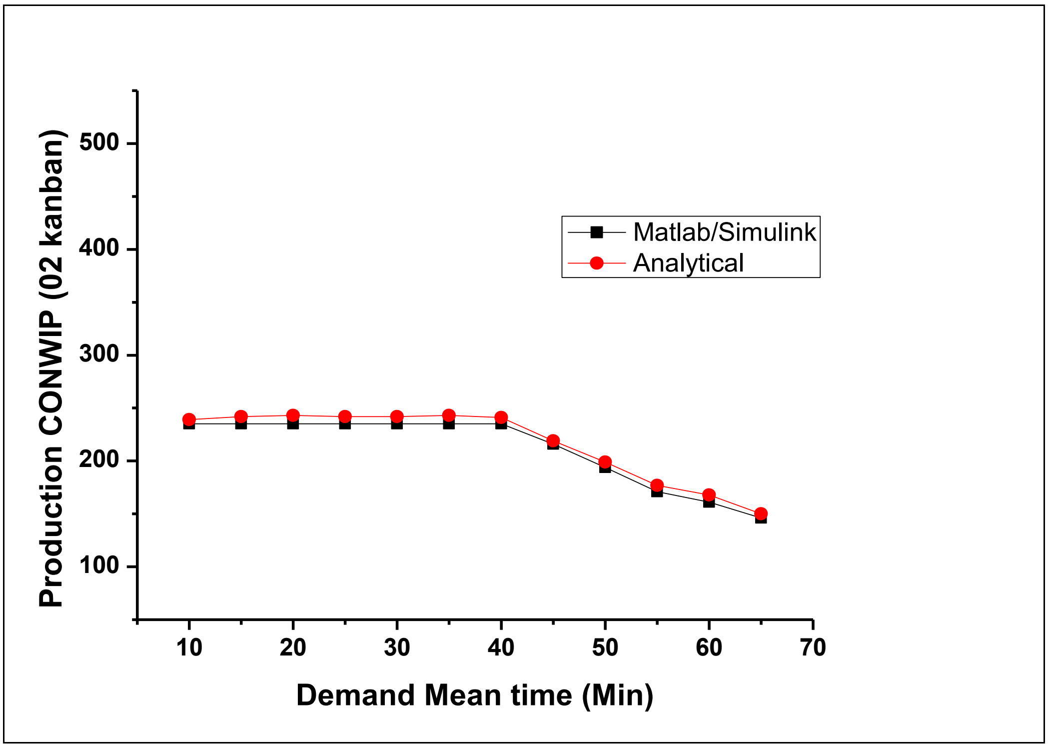

Figure 5.84: Validation of production for Multi flow line Multi stage system for CONWIP (Two kanban per stage)

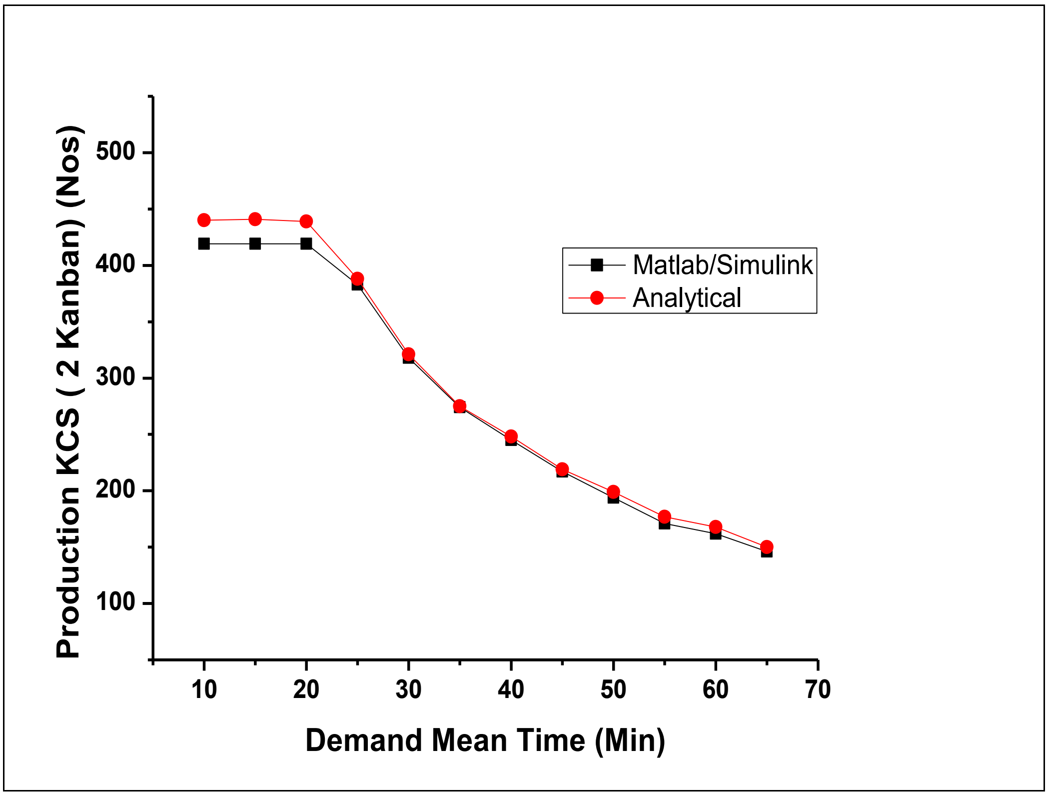

Figure 5.85: Validation of production for Multi flow line Multi stage system for KCS (Two kanbans per stage)

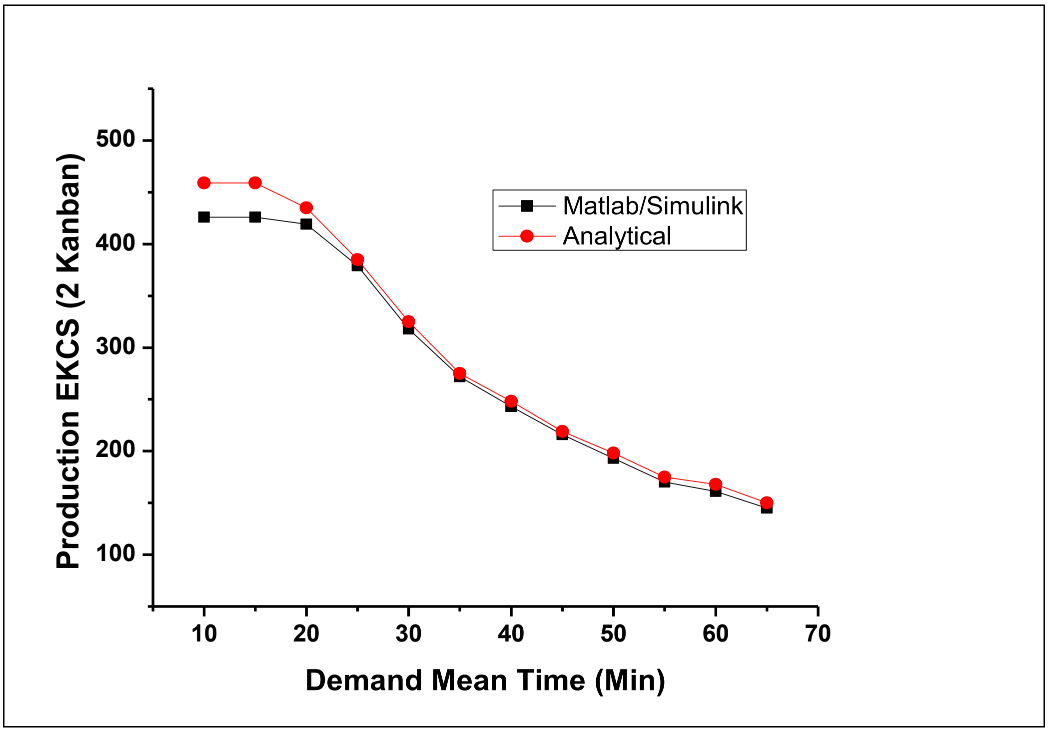

Figure 5.86: Validation of production for Multi line Multi stage system for EKCS (Two kanbans per stage)

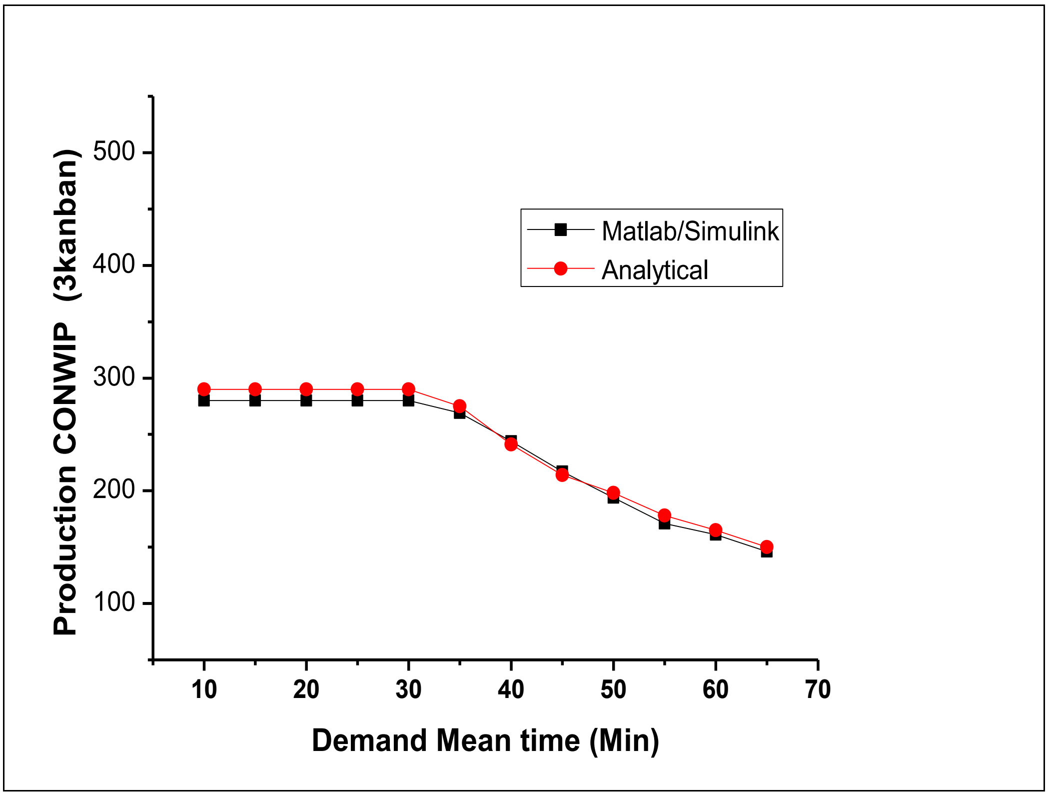

Figure 5.87: Validation of production for Multi flow line Multi stage system for CONWIP (Three kanbans per stage)

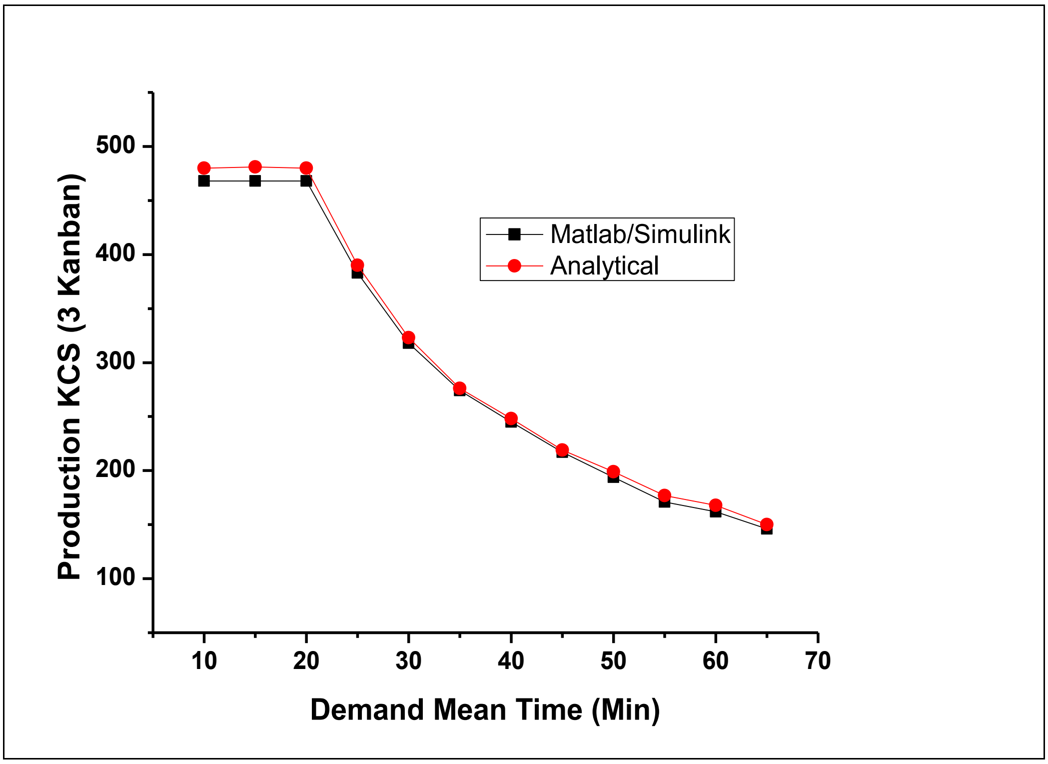

Figure 5.88: Validation of production for Multi line Multi stage system for KCS (Three kanbans per stage)

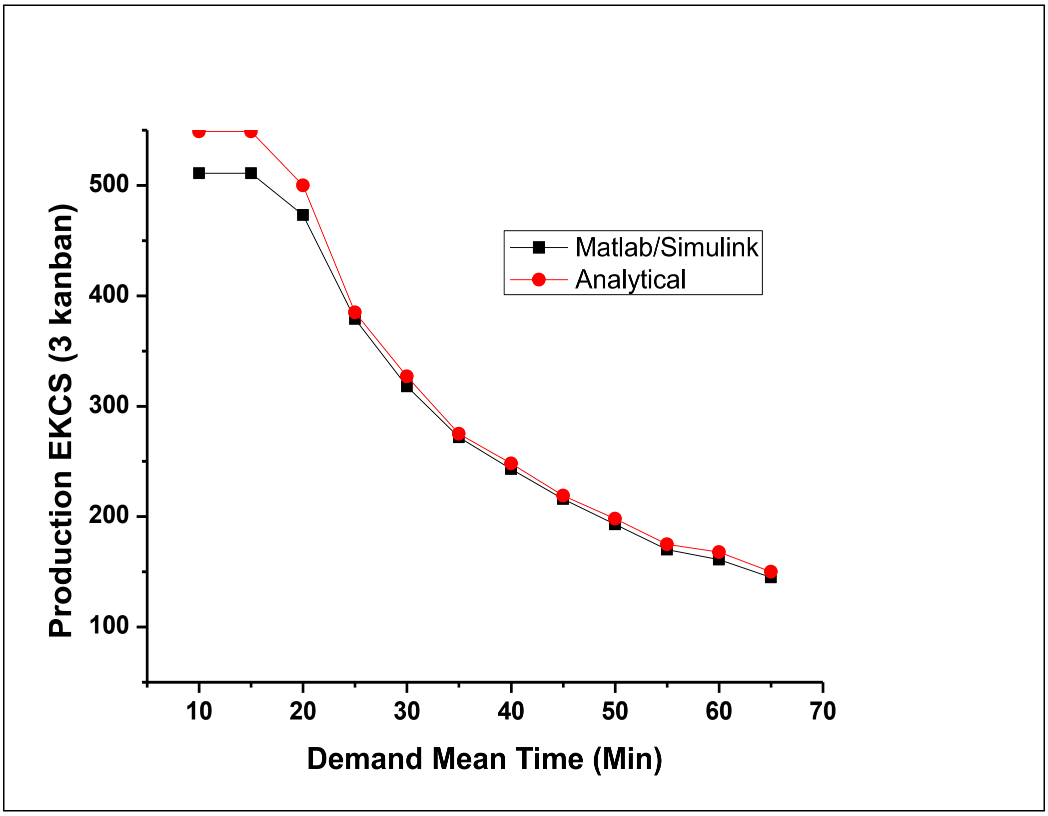

Figure 5.89: Validation of production for Multi flow line Multi stage system for EKCS (Three kanbans per stage)

5.3.2 Performance Analysis of Multi Flow Line Multi Stage System

The performance comparison of two flow line multi stage assembly system for CONWIP system, KCS and EKCS as analyzed by using the network model developed and discussed earlier is shown in the Figures 5.78 to 5.80 respectively. The processing mean time of each stage is assumed as 5 minutes. The flow line is considered to have 3 kanbans per stage. The systems are simulated for 825 hours with a warm up time of 75 hours. The performance factors like production, AWT, WIP, utilization and backordered demand are analyzed for the customer demand rate from 0 to 15 parts per hour as shown in figures 5.90 to 5.94.

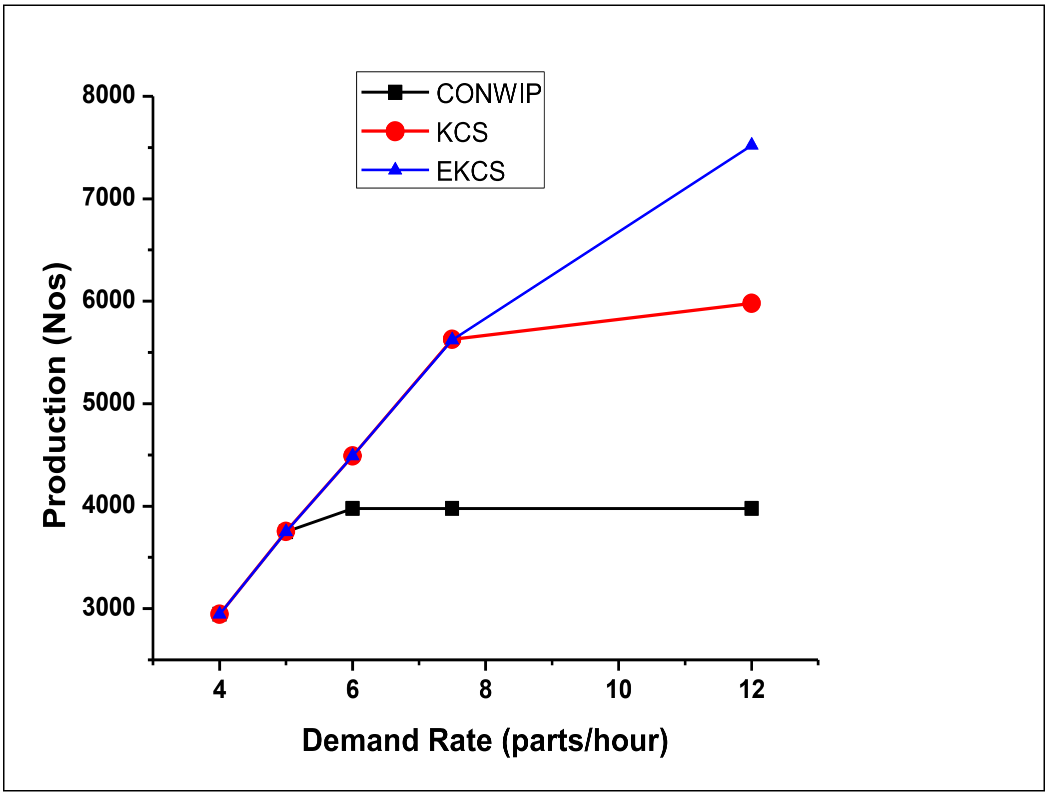

Figure 5.90: Performance of multi flow line multi stage system for production

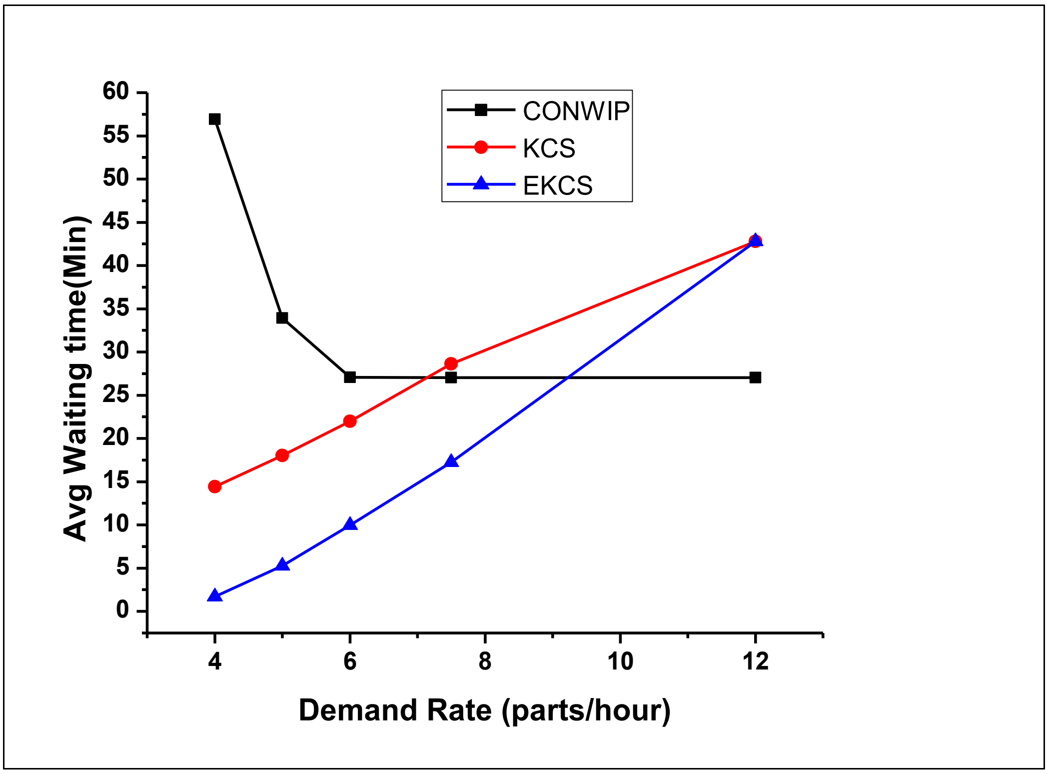

Figure 5.91: Performance of multi flow line multi stage system for AWT

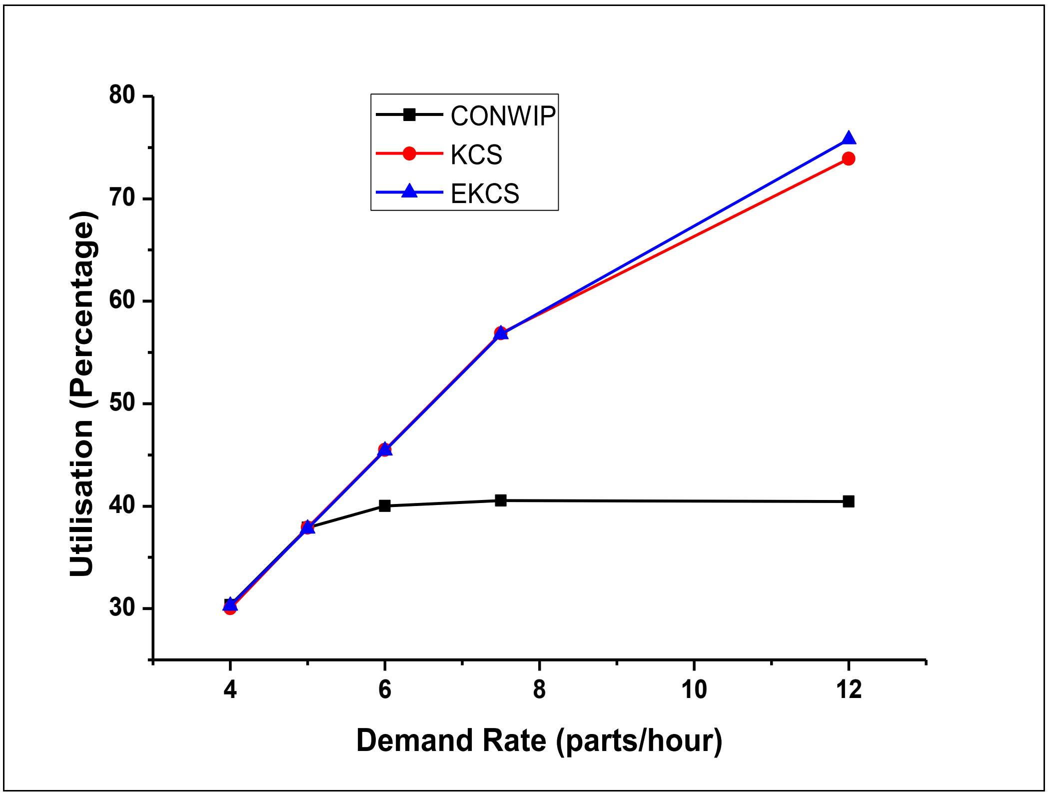

Figure 5.92: Performance of multi flow line multi stage system for utilization

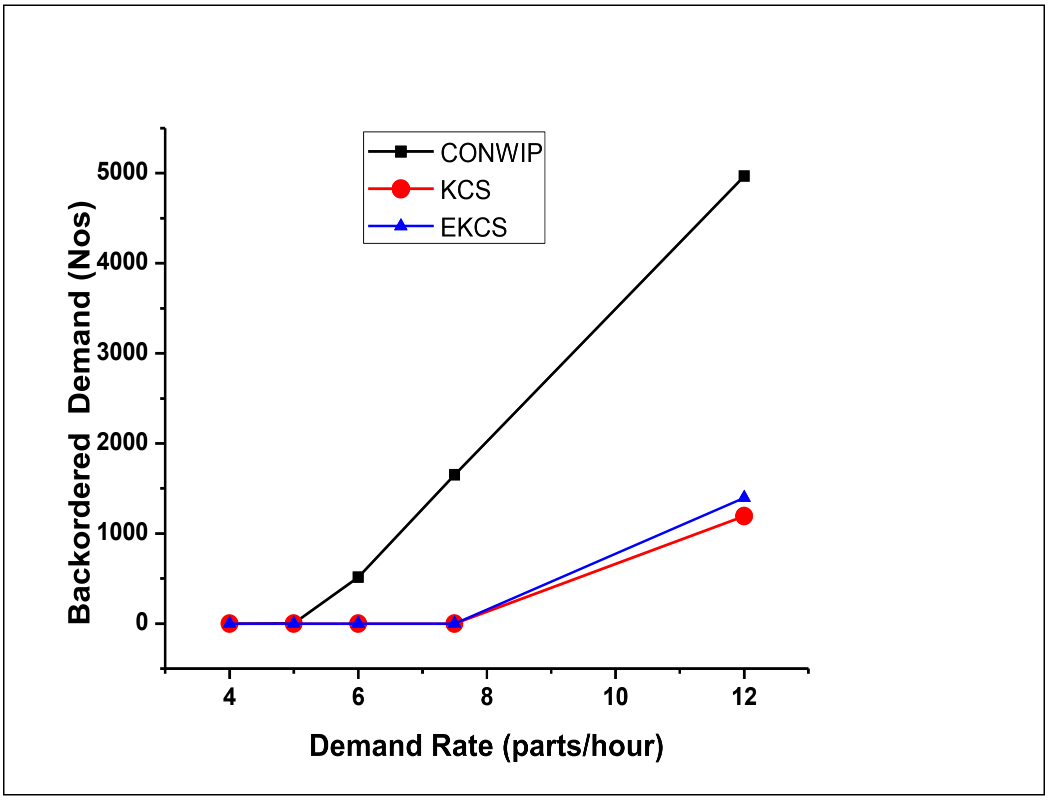

Figure 5.93: Performance of multi flow line multi stage system for backordered demand

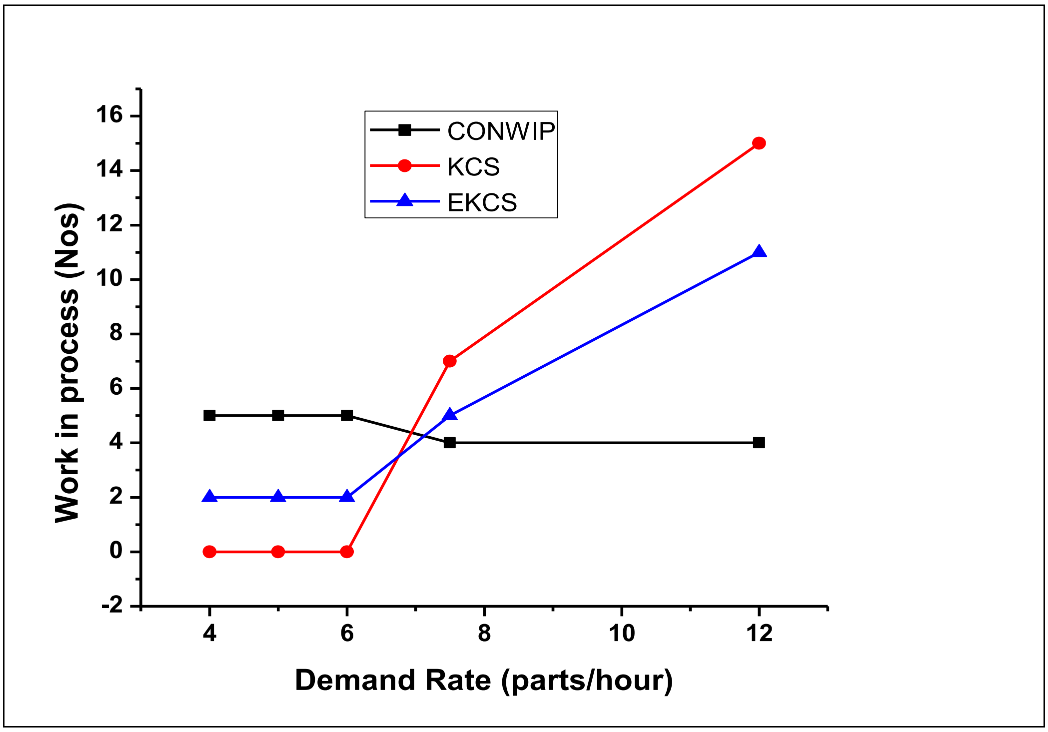

Figure 5.94: Performance of multi flow line multi stage system for WIP

The performance of multi-line multi stage pull control systems shows slight variation at a demand rate of 7 to 8 parts per hour. For low demand rate i.e. less than 7 parts per hour, the performance of pull control systems shows very less or negligible deviation whereas for high demand rate i.e. beyond 8 parts per hour, the performance of the system shows high deviation. Hence, it's interesting to compare and analyze the performance of pull control systems with reference to demand rate of 7.5 parts per hour considering it as optimum.

The production and utilization in CONWIP system, KCS and EKCS are same till the demand rate is 5 parts per hour. Beyond 5 parts per hour, the production and utilization for CONWIP system increases till 6 parts per hour and becomes constant. For KCS and EKCS, the production and utilization is same and both increases till 7.5 parts per hour before it deviates. At demand rate of 7.5 parts per hour, the production in KCS and EKCS is approximately

42% more than CONWIP system. The utilization in KCS and EKCS is 40% higher as compared to CONWIP system.

At low demand rate, the AWT in CONWIP system is high as compared to KCS and EKCS has the least value. With increase in demand rate, the AWT decreases in CONWIP system, whereas it increases for KCS and EKCS. At a demand rate of 7.5 parts per hour, the AWT in KCS is 6% high and in EKCS is 36% low as compared to CONWIP system.

At low demand rate, the WIP in CONWIP system has more parts compared to KCS and EKCS. The WIP is least in KCS. At a demand rate of 7.5 parts per hour, WIP in CONWIP system is low and KCS is high as compared to EKCS. The WIP in EKCS is approximately 28% lesser than KCS.

This is because in EKCS, the part and production kanban synchronizes with the demand at each manufacturing stage for its movement in the flow line. This results in increase of production and decrease of AWT and WIP. In KCS, the demand synchronizes with the finished part only at the last stage before release, whereas the movement of part is controlled by the kanbans at intermittent stages. The release of finished part from the flow line depends upon the availability of the demand at the last stage. Hence, this results in increase of AWT and work in process for KCS. In case of CONWIP system, the part movement in the flow lines depends on two synchronizations; one is raw part and kanban at the initial stage and other is finished part, kanban and the demand at the downstream stage only. This decreases the production, WIP and machine utilization; increases the AWT and backordered demand. The production control depends on number of kanbans per stage, demand and processing mean time. For demand mean time 'D_i' greater than processing mean time ‘t_i’, there is no effect on the system. When $D_i \leq t_i$, there is a considerable effect on the system performance. The performance of the pull control systems are optimum at a demand rate of 7-8 parts per hour. The performance of multi-line multi stage system at a demand rate of 7.5 parts per hour is given in Table 5.7.

Table 5.7: Performance Analysis of CONWIP, KCS and EKCS for multi flow line multi stage system for demand rate 7.5 parts/hour.

	CONWIP	**KCS**	**EKCS**
Production	3976	5627	5622
Average waiting time (min)	27.03	28.62	17.24
WIP	4	7	5
Utilization (%age)	40.53	56.86	56.78
Backordered Demand	1651	0	0

Therefore, considering production, utilization, AWT and WIP, the performance of EKCS is optimum for multi-line system as compared to KCS and CONWIP systems.

5.4 ANALYSIS OF SINGLE FLOW LINE MULTI STAGE MULTI-PRODUCT SYSTEM.

The performance of CONWIP system, KCS and EKCS for single flow line multi stage multi-product manufacturing system is analyzed by modeling and simulation. The single flow line has three manufacturing stages and processes two types of products.

5.4.1 Multi-product system – Model generation

Figure 5.95 illustrates the manufacturing system with two product types in three manufacturing stages $MP_{i,}$ where i=1, 2, 3….

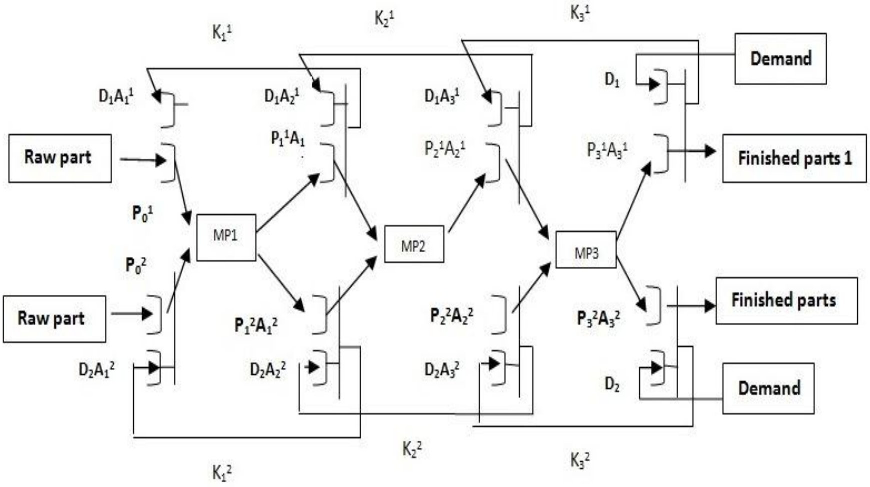

Figure 5.95: Queuing Network diagram of single flow line multi stage multi-product system

Queue p_i^r is the output buffers of product type r, of stage i where r=1, 2 and i=1, 2, 3. The finished product of each type is stored in the respective output queue. It synchronizes with the customer demand of the respective product type. The CONWIP system, KCS and EKCS has three dynamic elements i.e., product, demands and kanban (Product authorization). The product as a raw material or semi-finished product moves from upstream to downstream stage, being processed and wait at each buffer. The demand moves from downstream to input stages of upstream. Production authorization is a kanban fixed for each stage with a product type associated with it. The kanban goes with the part or demand or alone in each stage. The dedicated kanbans of stage i is synchronized with type 'r' product. The allocation of the product type to each manufacturing stage is by specific rules depending on the batch size and availability of products in the buffer. The processing mean time of manufacturing stages for product A are 1.5 minutes, 1.0 minutes and 1.2 minutes respectively and product B are 1.25 minutes, 0.75 minutes and 1.1 minutes respectively [97]. The product A and B are processed on the three manufacturing stages MP_1, MP_2 and MP_3. The network model developed for CONWIP system, KCS and EKCS by using the software MATLAB/SIMULINK R2011b are shown in Figure 5.96 to 5.98 respectively. The system is simulated for 5760 minutes (6 days @ 16 hours per day) includes warm up period of 360 minutes. The processing time for each product type is 480 minutes per batch.

5.4.2 Effect of number of kanbans per stage

At low demand rates, the production and utilization in EKCS, KCS and CONWIP system for two, three and four kanban's per stage are equal. However, the AWT increases with increase in number of kanbans per stage for all pull control systems. At low demand rates and with increase in number of kanbans per stage, the AWT for EKCS is less as compared to CONWIP and KCS because the release of part from each stage depends upon the availability of demand. The AWT is 60% to 67% less in CONWIP; 95% to 97% less in EKCS; as compared to KCS. Further, the WIP in EKCS is low and in KCS is high. The WIP in KCS is high because the kanban and part synchronizes at each stage whereas in EKCS demand synchronizes with kanban and part at each stage and in CONWIP, the part and kanban synchronizes only in the first stage of the flow line.

At high demand rates, the production in CONWIP is lowest and EKCS is highest for two, three and four kanbans per stage. With increase in number of kanbans per stage, the production in EKCS increases from 10% to 12%; in KCS increases from 4% to 5%; and in CONWIP increases from 18% to 20%, till $K_i \leq S_i$. For $K_i > S_i$, the increase in production is less than 5% for

CONWIP, KCS and EKCS. The machine utilization is highest in EKCS and lowest in KCS for two, three and four kanbans per stage. The WIP in KCS and EKCS is equal but less than CONWIP. The AWT in CONWIP is 8% to 10% higher than KCS; and is 25% to 35% higher than EKCS, till $K_i \leq S_i$. For $K_i > S_i$, the AWT in KCS is higher than CONWIP; and decreases in EKCS.

At demand rate of 30 parts per hour, the performance of the systems shows low variability for three kanbans per stage at $K_i = S_i$ and $D_i = t_i$, where D_i is demand mean time and t_i is processing mean time. The production in KCS is 2% high as compared to EKCS and 6% high as compared to CONWIP. The WIP and machine utilization are equal for KCS and EKCS and are slightly less than CONWIP. Thus, the performance of the system depends on the demand, number of kanbans per stage and processing mean time.

Therefore, the demand rate of 30 parts per hour for three kanbans per stage is consred as optimum for the performance analysis and comparison of CONWIP, KCS and EKCS.

The effect of number of kanbans per stage on the performance of the systems is given in Table 5.8.

Table 5.8: Effect of number of kanbans on the performance of single flow line multi stage multi-product system for varying demand rate

Demand rate (parts per hour)	**Production**																	
	CONWIP						**KCS**						**EKCS**					
	2 kanbans/stage		3 kanbans/stage		4 kanbans/stage		2 kanbans/stage		3 kanbans/stage		4 kanbans/stage		2 kanbans/stage		3 kanbans/stage		4 kanbans/stage	
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
15	718	716	718	717	718	717	718	717	718	717	718	718	717	692	717	692	717	692
20	950	949	951	950	951	950	951	950	951	950	951	950	950	916	950	916	950	916
30	1002	1163	1219	1410	1381	1410	1325	1388	1397	1410	1412	1411	1411	1364	1411	1364	1411	1364
60	1005	1192	1231	1433	1386	1432	1338	1381	1403	1410	1418	1411	1513	1752	1723	1982	1810	2067
	Average waiting time (Minutes)																	
15	11.4	12.3	25.1	26.1	24.1	27.2	39.7	39.6	61.7	61.8	83.7	84	1.85	2.06	1.66	1.93	1.6	1.87
20	7.15	8.2	18	19.7	16.1	18.9	24.2	24.3	42.2	42.7	59.2	59.7	1.44	1.34	1.16	1.15	1.07	1.08
30	6.35	5.59	11.3	13.4	8.72	10.3	5.67	4.9	6.97	6.83	15	16	1.063	1.04	0.87	0.72	0.58	0.59
60	6.17	5.28	7.53	6.78	8.59	7.34	5.47	4.85	6.79	6.56	8.52	8.39	4.91	4.19	5.72	4.94	6.58	5.7
	WIP																	
15	7		5		4		7		7		7		1		1		1	
20	6		4		4		4		7		7		2		2		2	
30	5		6		7		4		4		6		2		4		5	
60	4		6		8		4		4		5		4		4		5	
	Machine Utilization (% age)																	
15	34.6		34.65		34.75		29.14		29.22		29.4		28.96		28.55		28.6	
20	46.05		46.13		46.27		38.72		38.89		38.89		38.53		38		38.5	
30	52.34		64.07		68.28		56.9		57.8		58.02		57.85		57.85		57.85	
60	52.96		64.66		73.34		57.26		58.04		58.29		59		69.08		75.29	

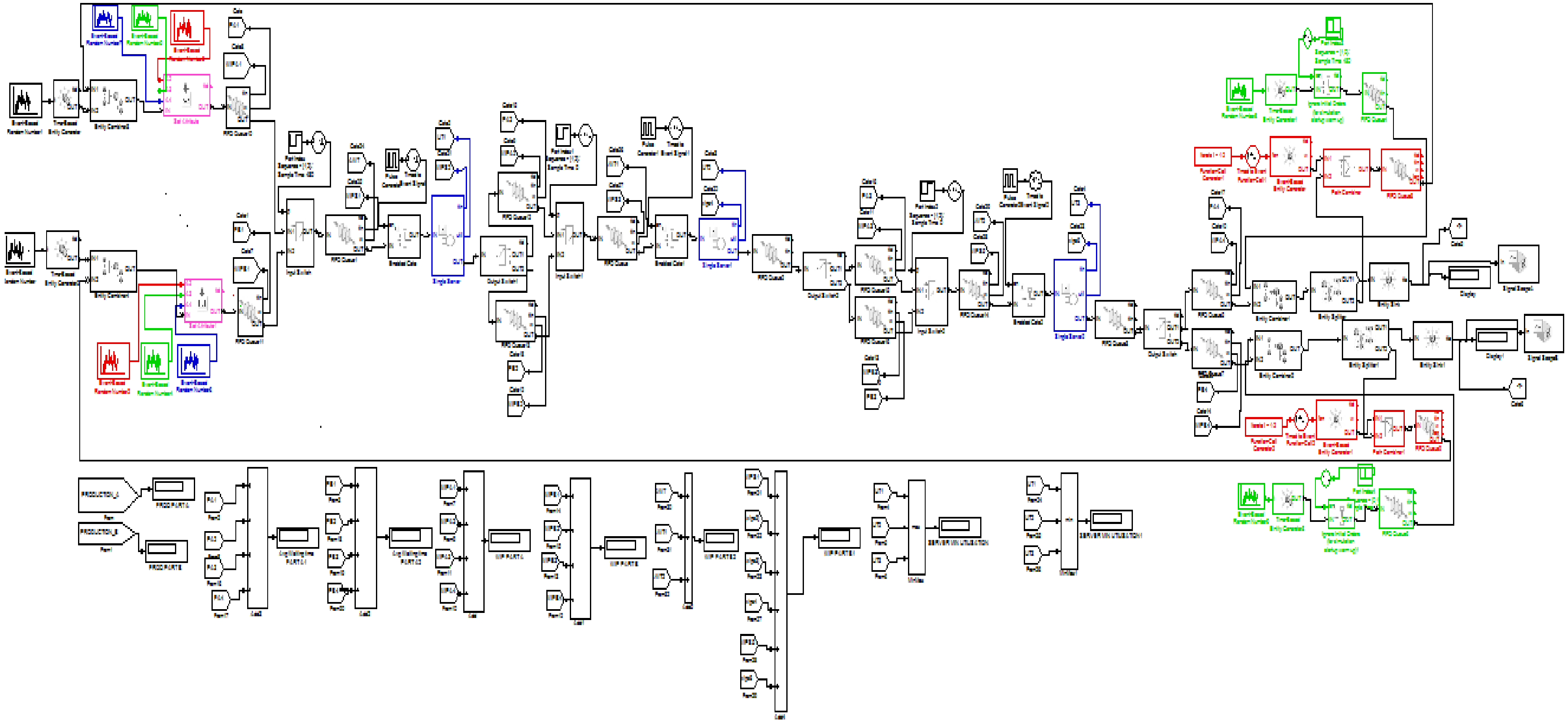

Figure 5.96: Network model of CONWIP for multi stage multi product system

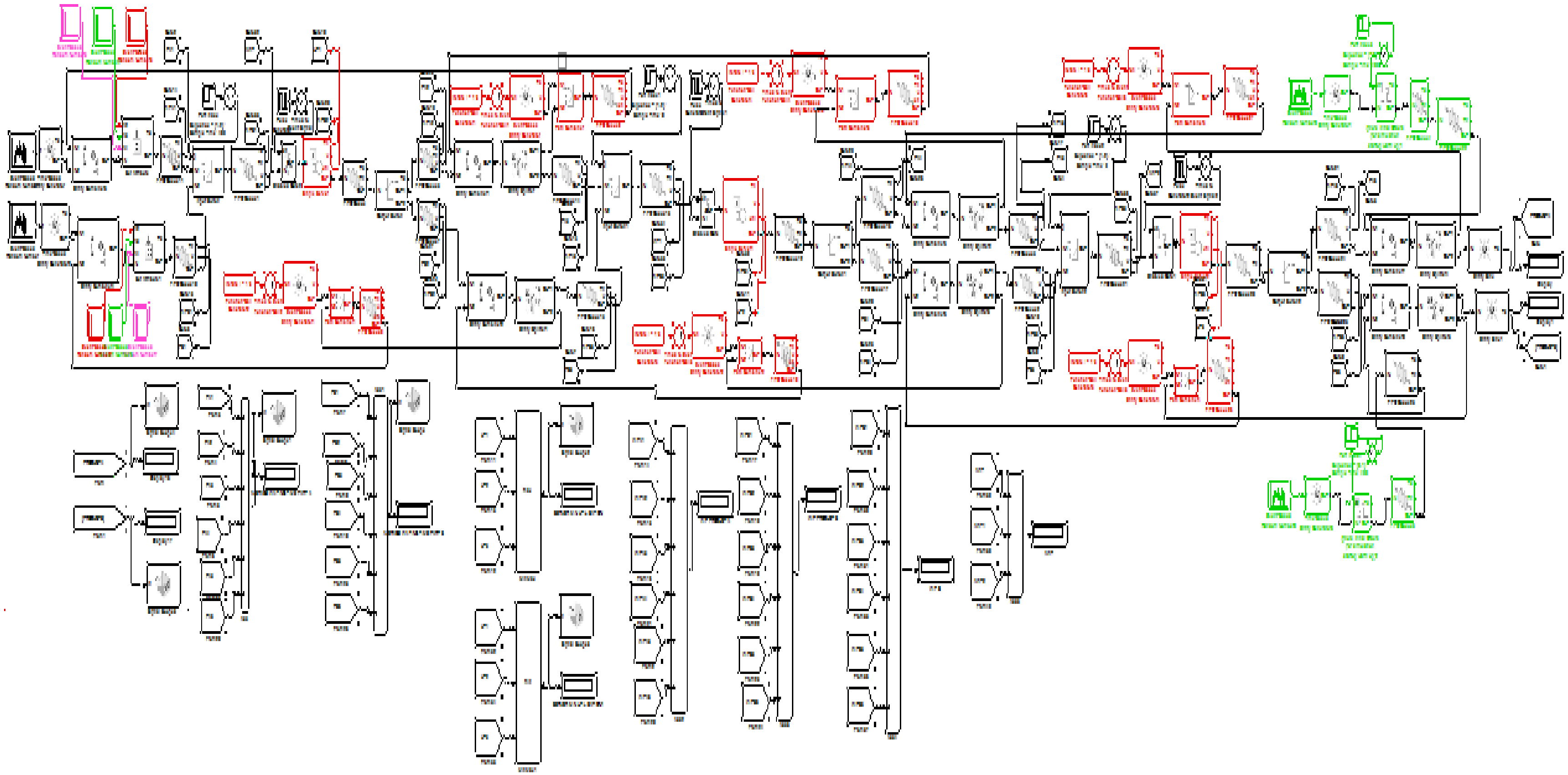

Figure 5.97: Network model of KCS for multi stage multi product system

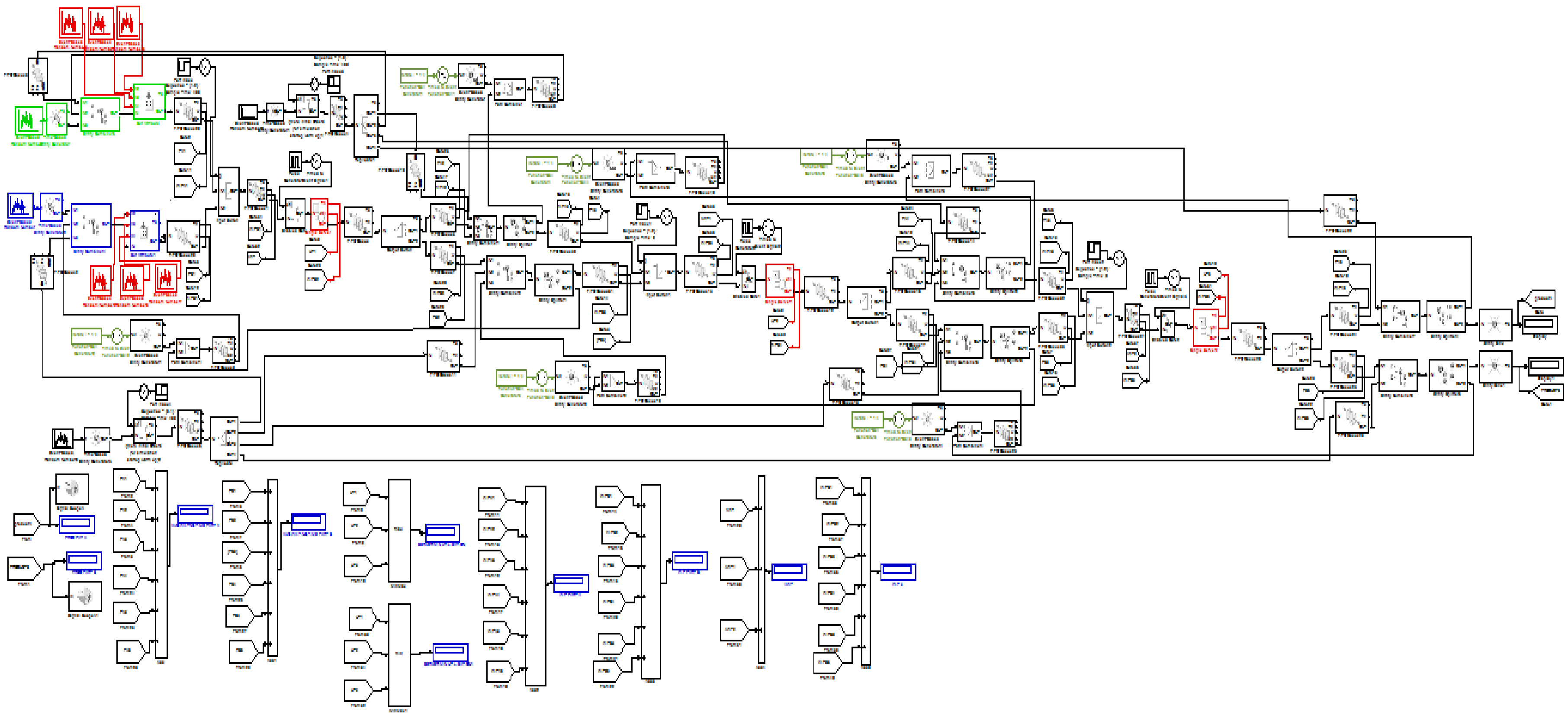

Figure 5.98: Network model of EKCS for multi stage multi product system

5.4.3 Sensitivity and Performance analysis

The performance of the single flow line multi stage multi-product pull control system is analyzed by sequencing the processing mean time in six combinations for the study and to identify the optimal combination. The order of workstation sequence is MP_1, MP_2 and MP_3. For high (H) – low (L) – medium (M) combination, the highest processing mean time (M) is assigned to MP_1, lowest processing mean time (L) is assigned to MP_2 and medium processing mean time (M) is assigned to MP_3. Similarly, the other defined combinations are M-L-H, L-M-H, H-M-L, L-H-M and M-H-L. Accordingly, the system is simulated and the performance is analyzed for two, three and four kanbans per stage.

5.4.3.1 High-Low-Medium (H-L-M)

The performance analysis of the pull control systems shows low variability for three kanbans per stage at optimum demand rate of 30 parts per hour. The performance analysis of HLM combination is given in Table 5.9.

Table 5.9: Performance analysis of single flow line multi stage multi-product system for demand rate 30 parts per hour (HLM combination)

Performance Parameters	CONWIP		KCS		EKCS	
	Product A	Product B	Product A	Product B	Product A	Product B
Production	1219	1410	1397	1410	1411	1364
Average waiting time(min)	7.55	6.71	6.97	6.83	0.87	0.72
WIP	6		4		4	
Utilization (%age)	64.07		57.8		57.85	

The production in CONWIP system is low as compared to KCS and EKCS. The production in KCS is 6% to 7% higher and in EKCS is 5% to 6% higher as compared to CONWIP. The CONWIP system has high AWT as compared to KCS and EKCS. The AWT in KCS is 3% less and in EKCS is 88% less than CONWIP. The WIP and machine utilization in KCS and EKCS are less as compared to CONWIP. The results obtained by simulation for CONWIP, KCS and EKCS for two, three and four kanbans per stage are presented in figures 5.99 to 5.110

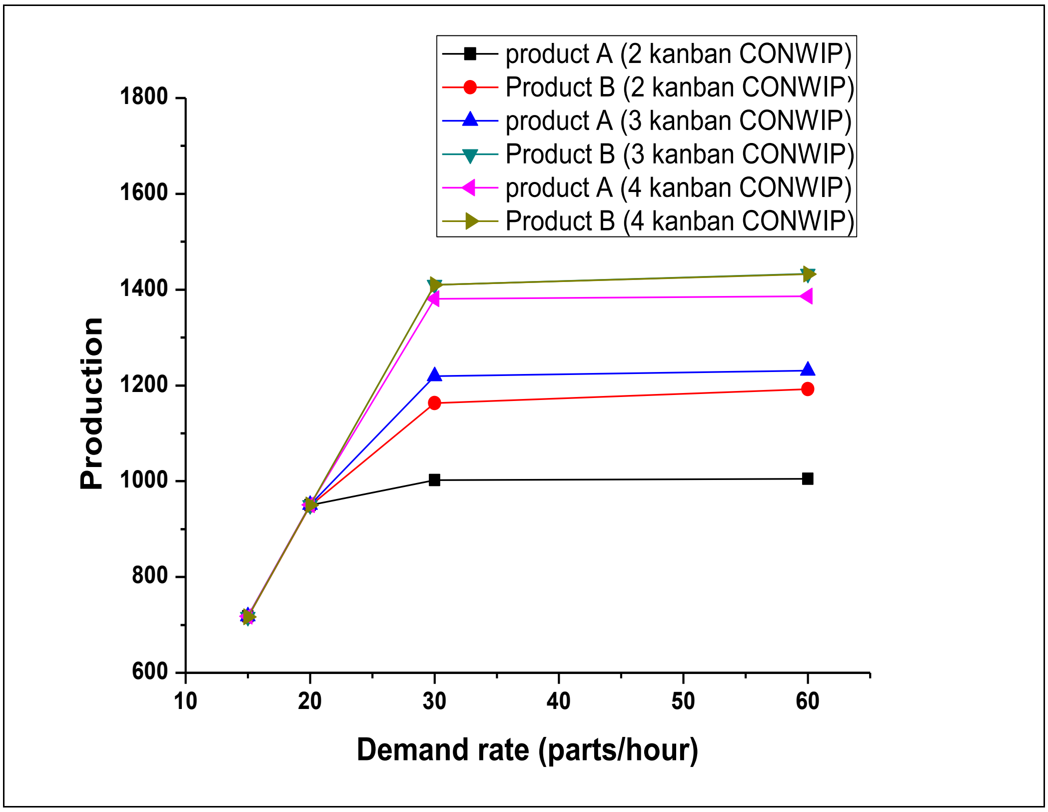

Figure 5.99: Performance Analysis of CONWIP for single flow line Multi stage Multi product system for production (H-L-M)

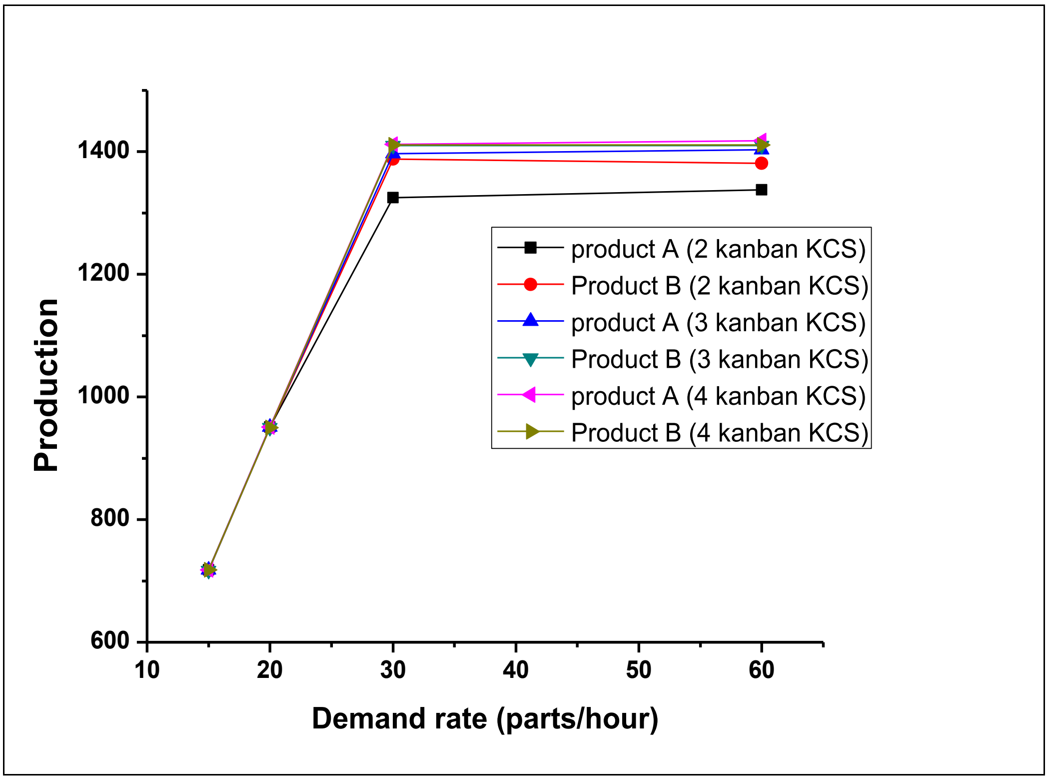

Figure 5.100: Performance Analysis of KCS for single flow line Multi stage Multi product system for Production (H-L-M)

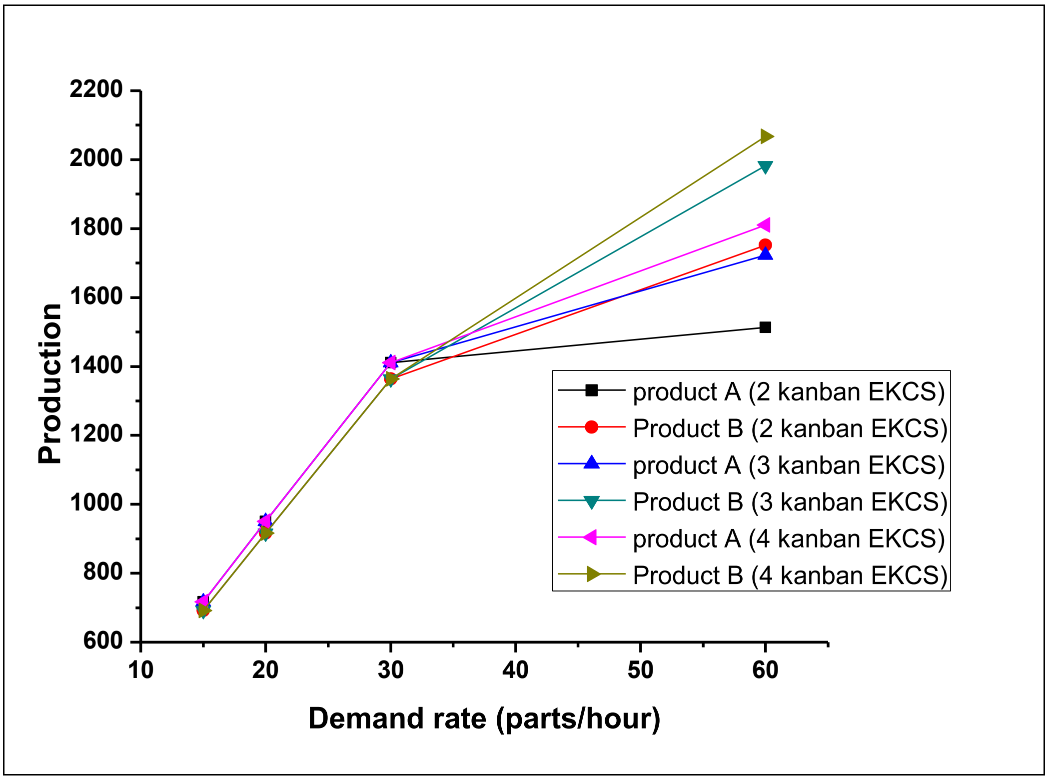

Figure 5.101: Performance Analysis of EKCS for single flow line Multi stage Multi product system for Production (H-L-M)

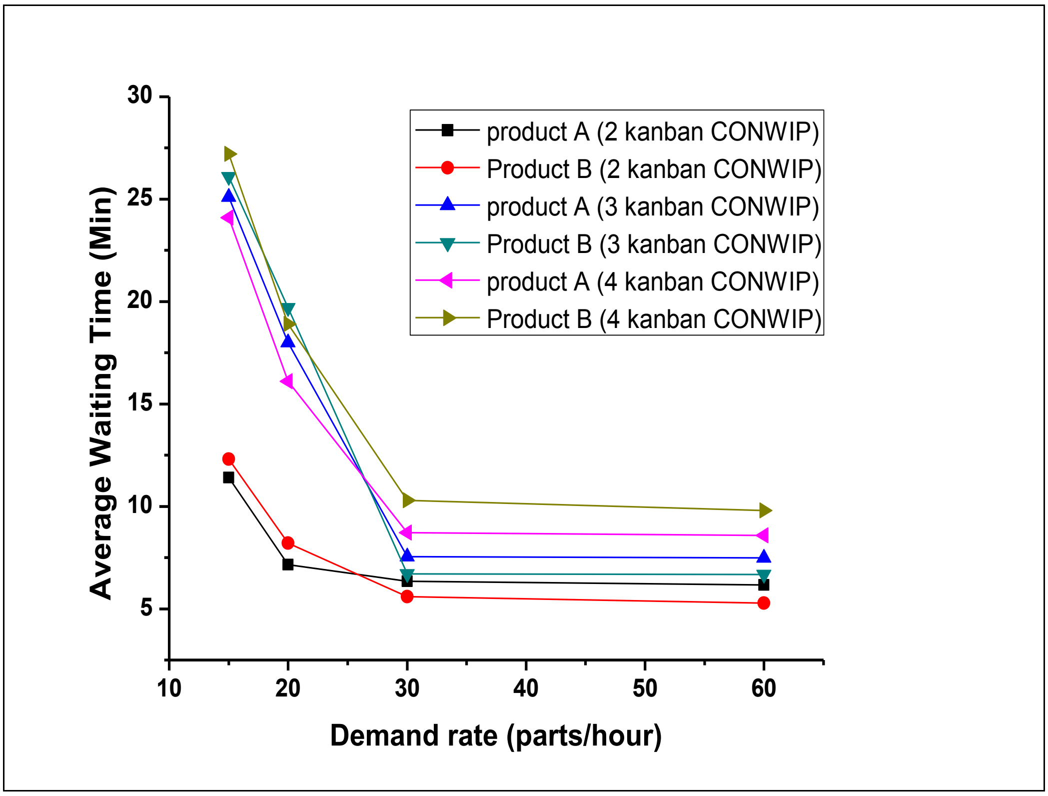

Figure 5.102: Performance Analysis of CONWIP for single flow line Multi stage Multi product system for AWT (H-L-M)

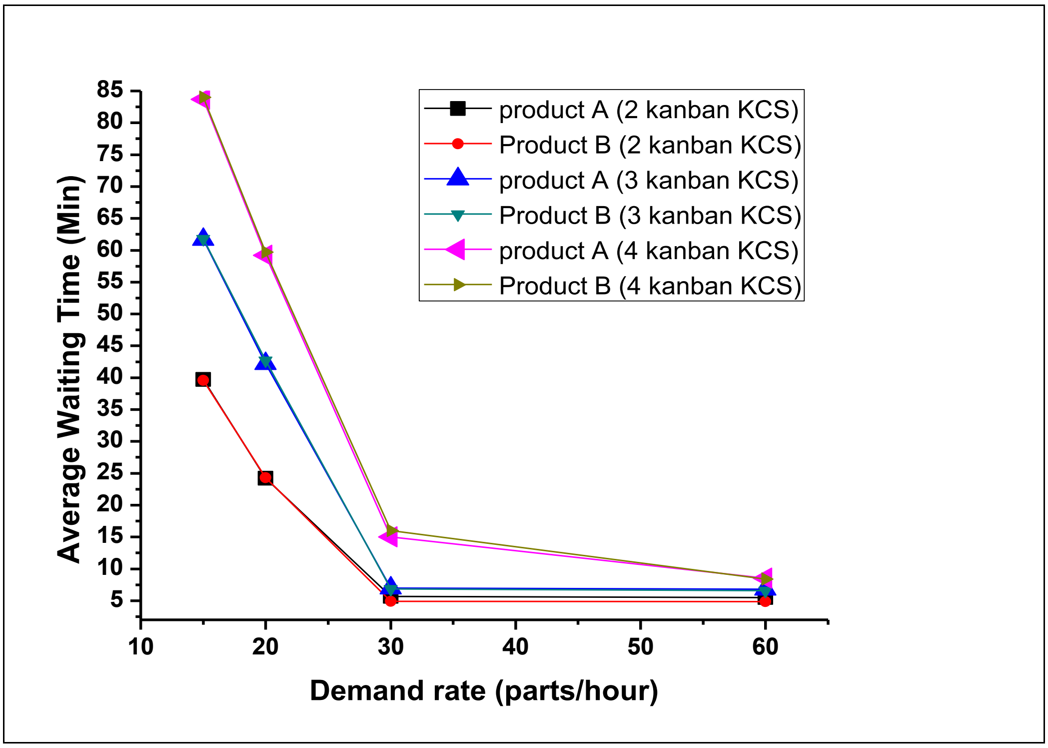

Figure 5.103: Performance Analysis of KCS for single flow line Multi stage Multi product system for AWT (H-L-M)

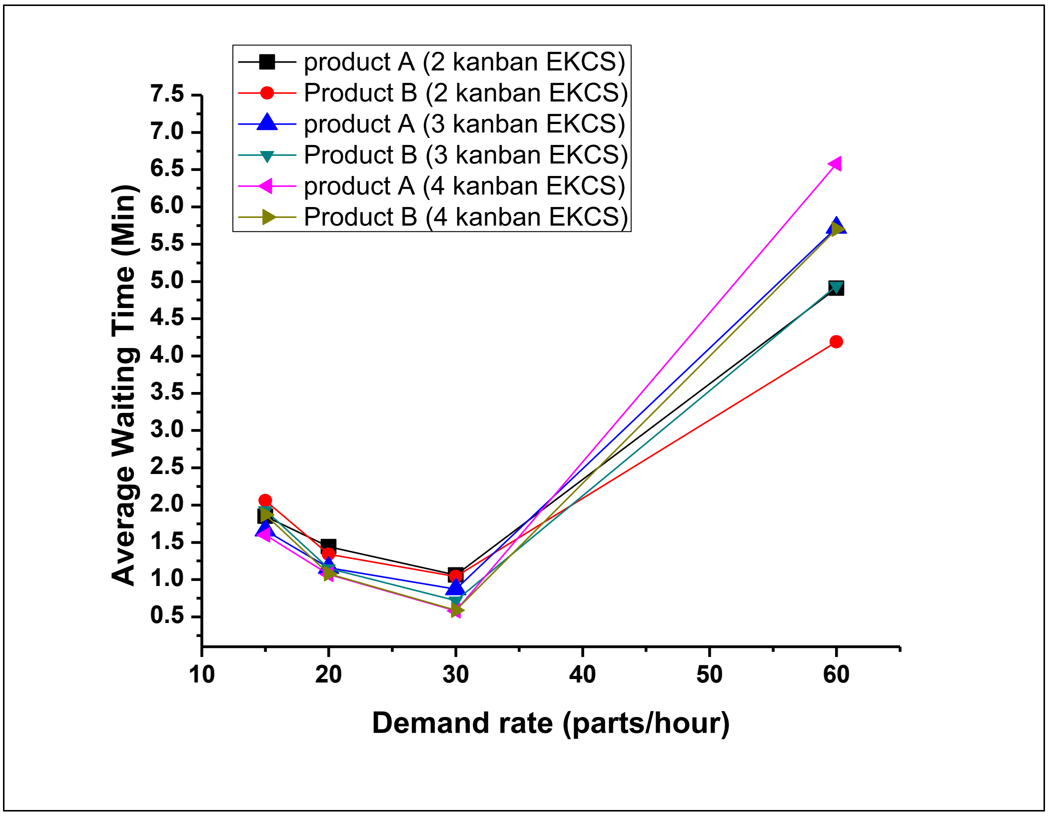

Figure 5.104: Performance Analysis of EKCS for single flow line Multi stage Multi product system for AWT. (H-L-M)

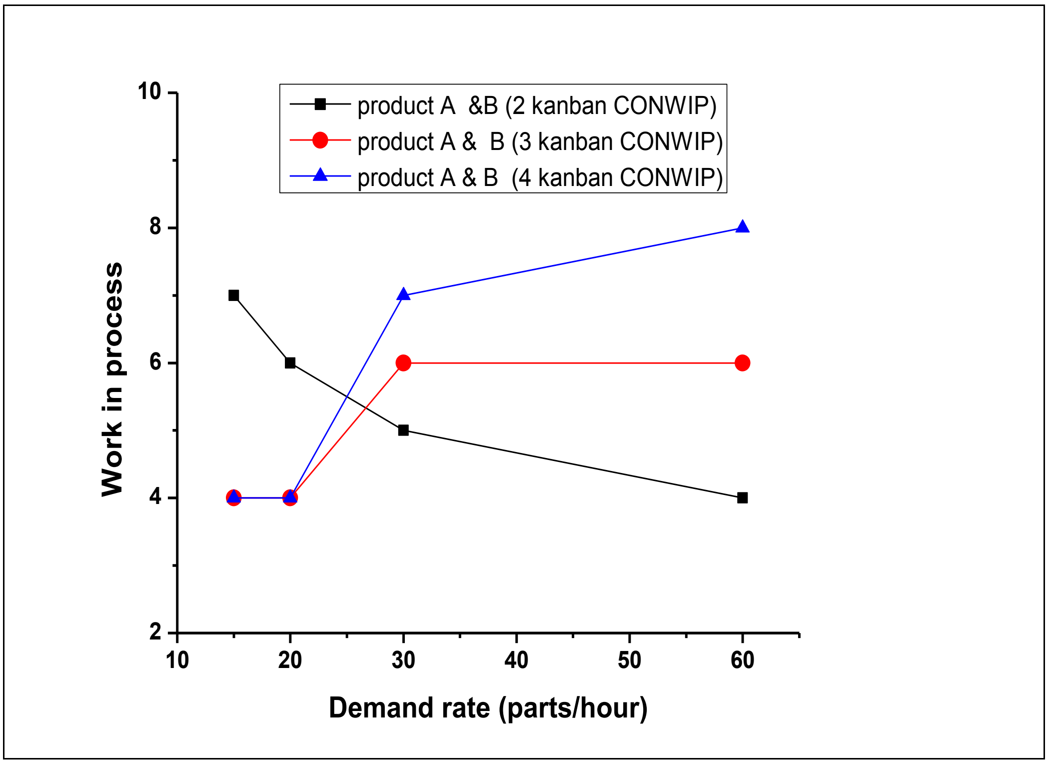

Figure 5.105: Performance Analysis of CONWIP for single flow line Multi stage Multi product system for WIP (H-L-M)

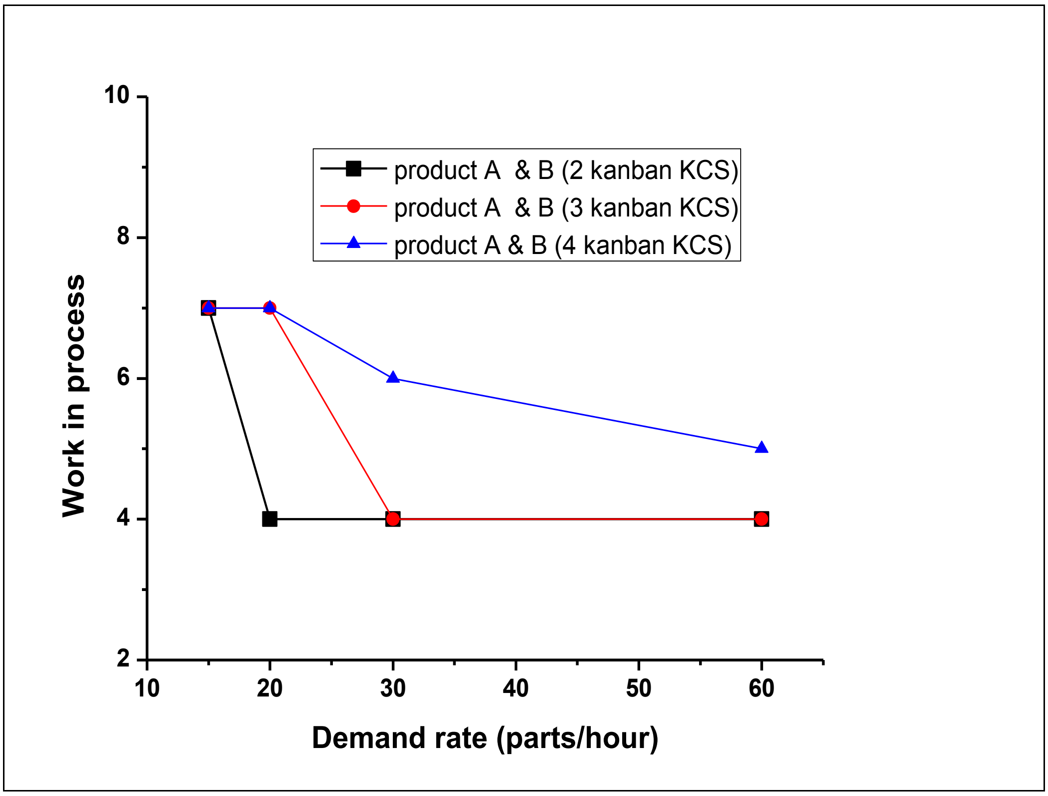

Figure 5.106: Performance Analysis of KCS for single flow line Multi stage Multi product system for WIP (H-L-M)

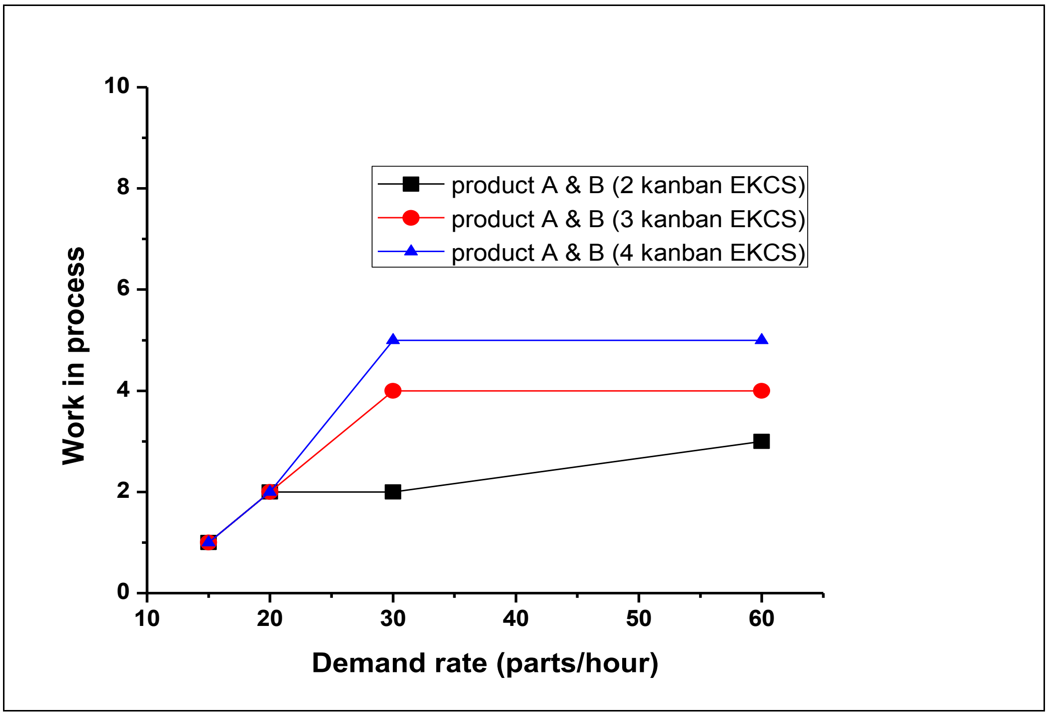

Figure 5.107: Performance Analysis of EKCS for single flow line Multi stage Multi product system for WIP (H-L-M)

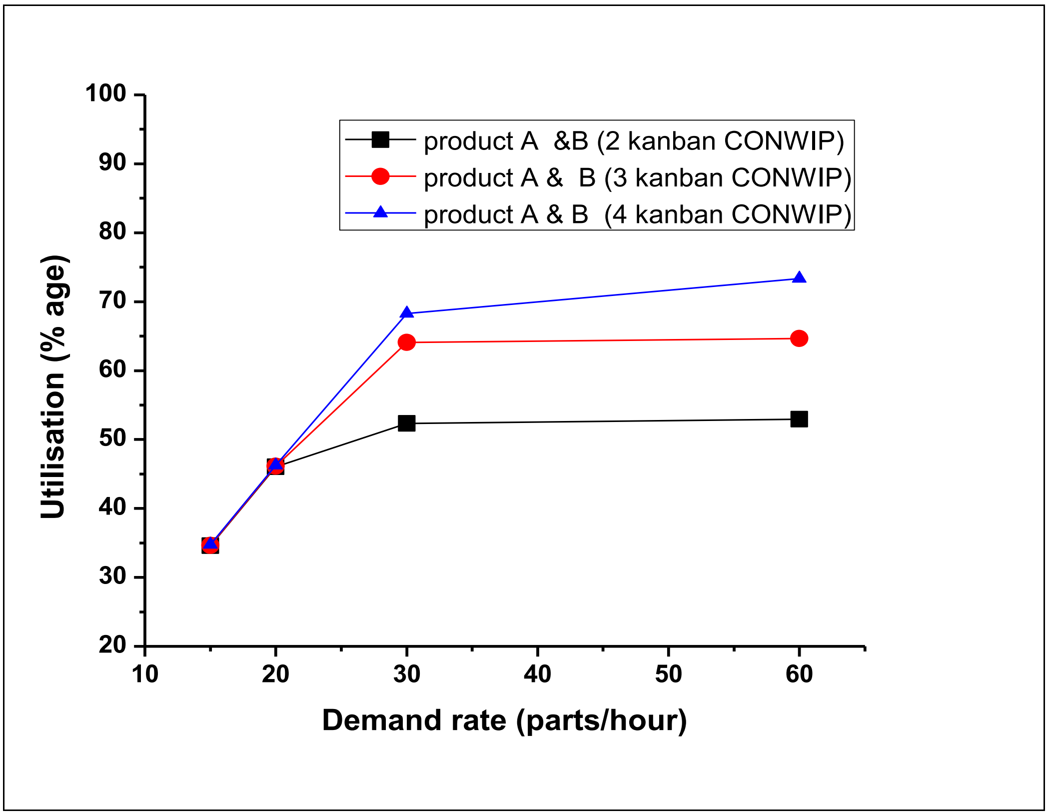

Figure 5.108: Performance Analysis of CONWIP for single flow line Multi stage Multi product system for utilization (H-L-M)

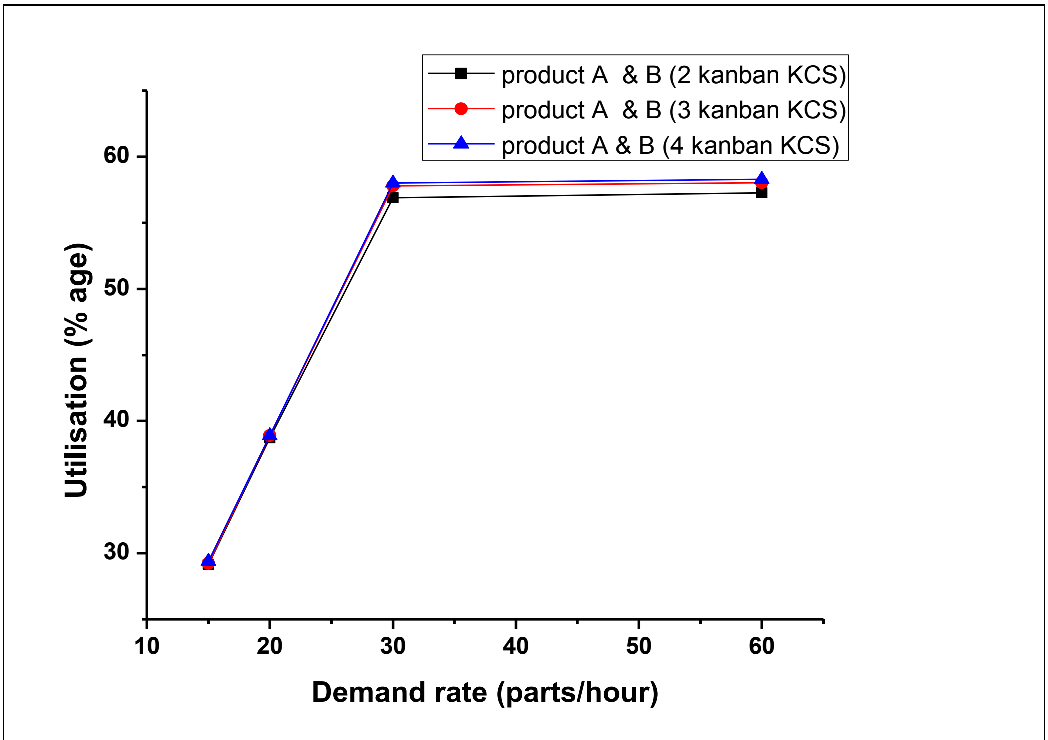

Figure 5.109: Performance Analysis of KCS for single flow line Multi stage Multi product system for utilization (H-L-M)

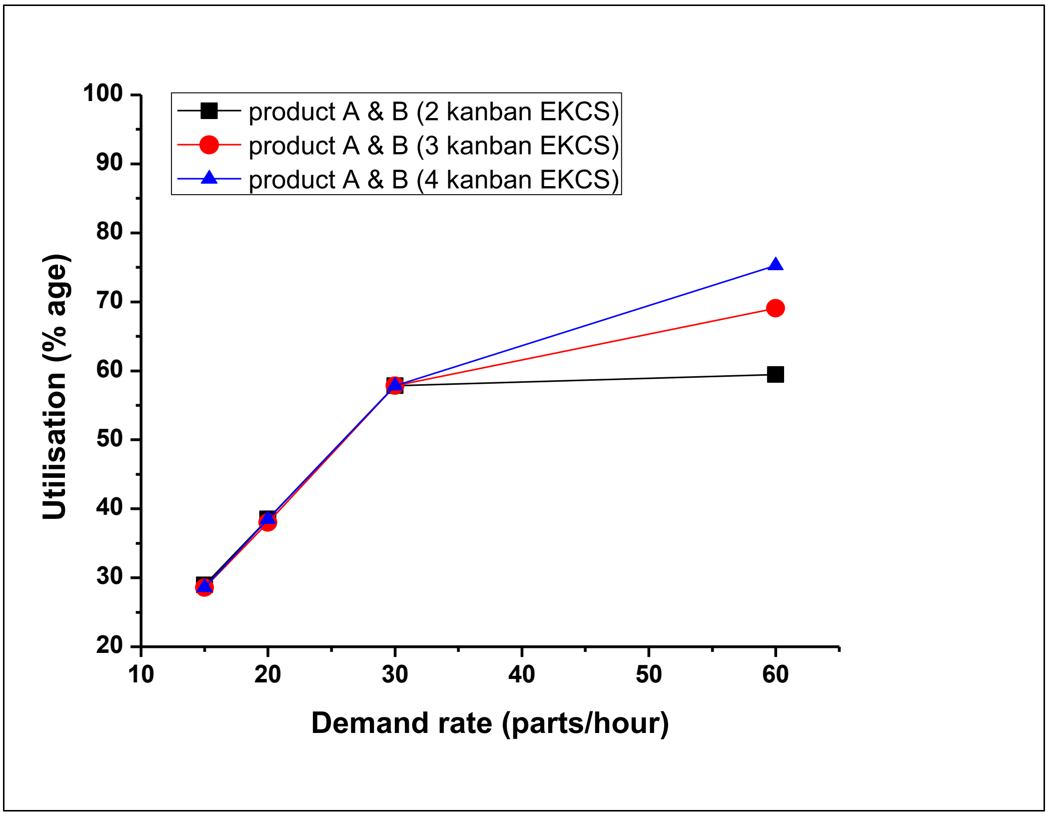

Figure 5.110: Performance Analysis of EKCS for single flow line Multi stage Multi-product system for utilization (H-L-M)

5.4.3.2 Medium- Low- High (M-L-H)

At a demand rate of 30 parts per hour, the performance analysis of the pull control systems for MLH combination shows less variation for three kanbans per stage. The performance MLH combination is given in Table 5.10.

Table 5.10: Performance analysis of single flow line multi stage multi-product system for demand rate 30 parts per hour (MLH combination)

Performance Parameters	CONWIP		KCS		EKCS	
	Product A	Product B	Product A	Product B	Product A	Product B
Production	1219	1410	1408	1411	1409	1400
Average waiting time(min)	7.61	6.75	11.8	11.1	0.83	0.77
WIP	6		5		4	
Utilization (%age)	56.19		68.9		68.27	

The production in CONWIP system is 7% to 7.5% less as compared to KCS and EKCS. The KCS has high AWT as compared to CONWIP and EKCS. The AWT in KCS is 55% high and in EKCS is 88% less as compared to CONWIP. The WIP in KCS and EKCS is less compared to CONWIP. The utilization in CONWIP system is less as compared to KCS and EKCS. The results obtained by simulation for CONWIP, KCS and EKCS for two, three and four kanbans per stage are presented in figures 5.111 to 5.122.

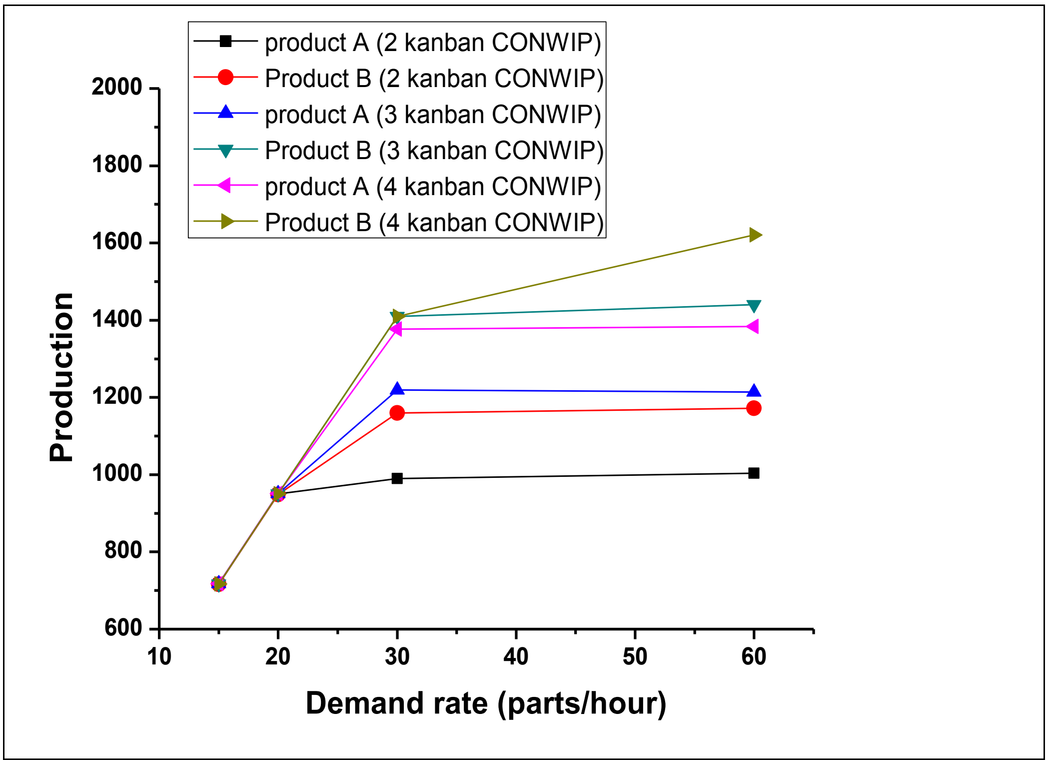

Figure 5.111: Performance Analysis of CONWIP for single flow line Multi stage Multi product system for production (M-L-H)

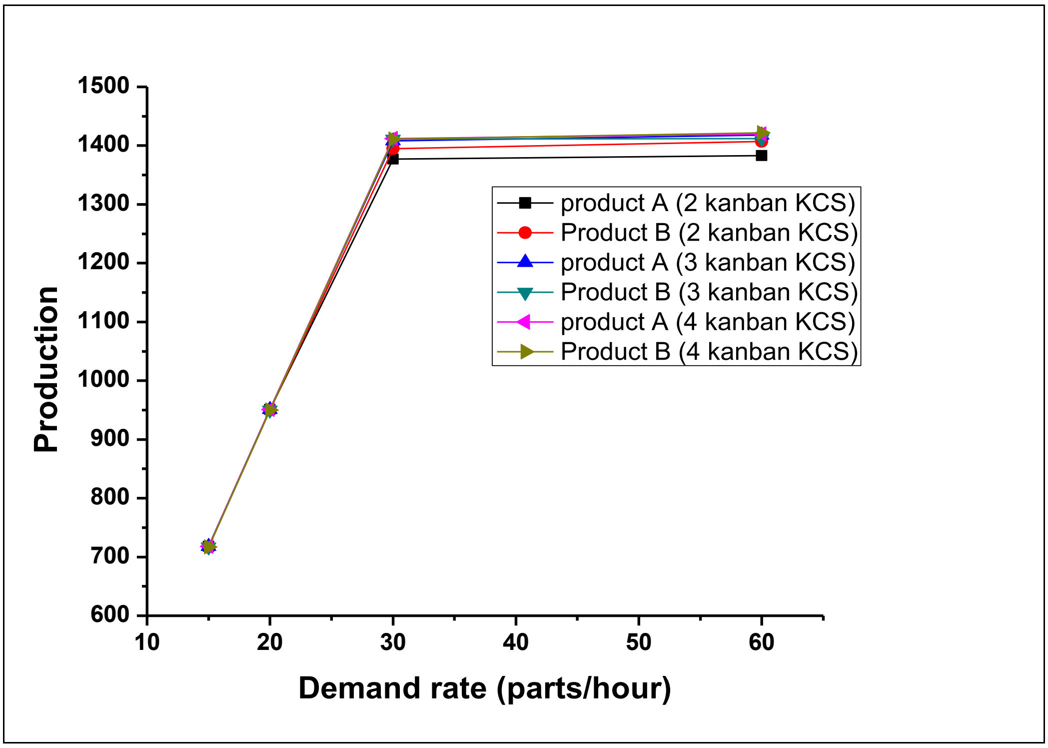

Figure 5.112: Performance Analysis of KCS for single flow line Multi stage Multi product system for production (M-L-H)

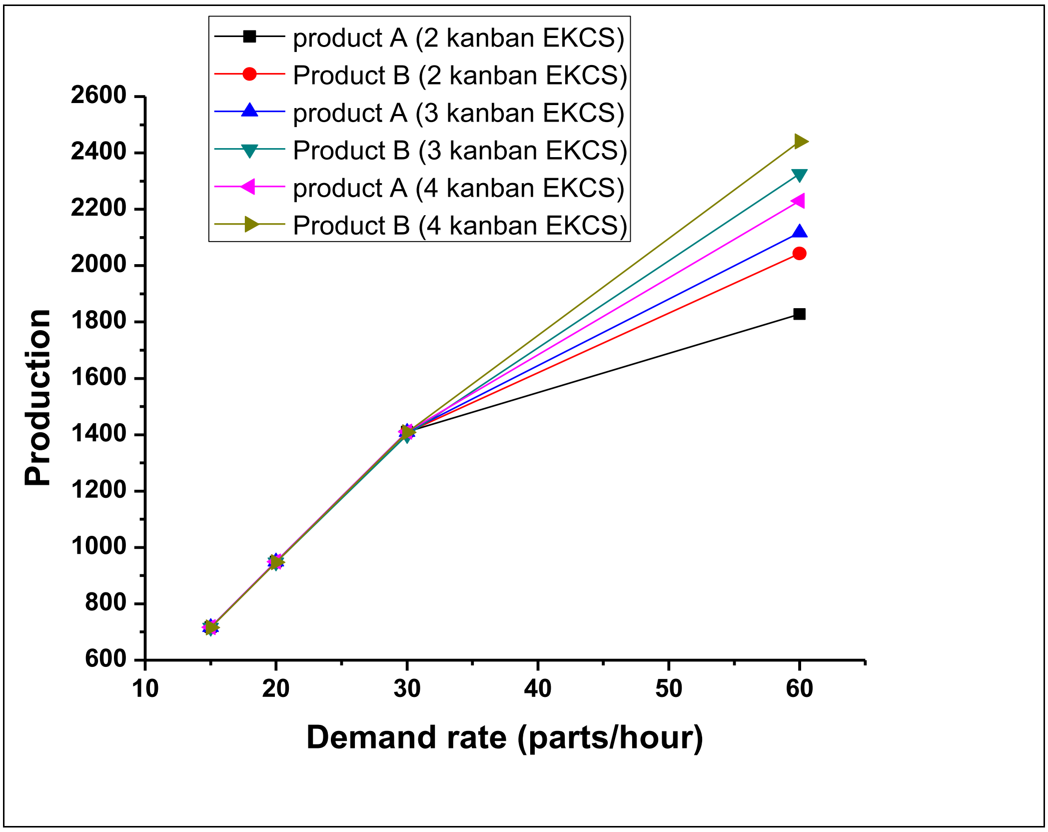

Figure 5.113: Performance Analysis of EKCS for single flow line Multi stage Multi product system for production (M-L-H)

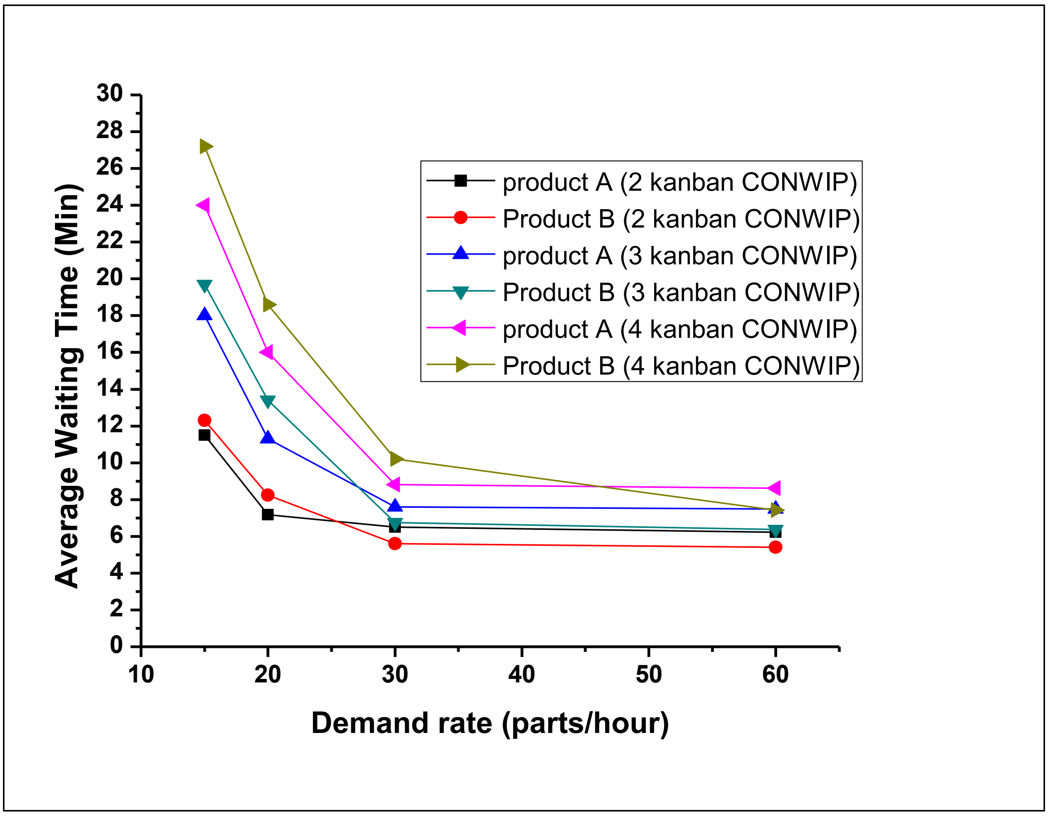

Figure 5.114: Performance Analysis of CONWIP for single flow line Multi stage Multi product system for AWT (M-L-H)

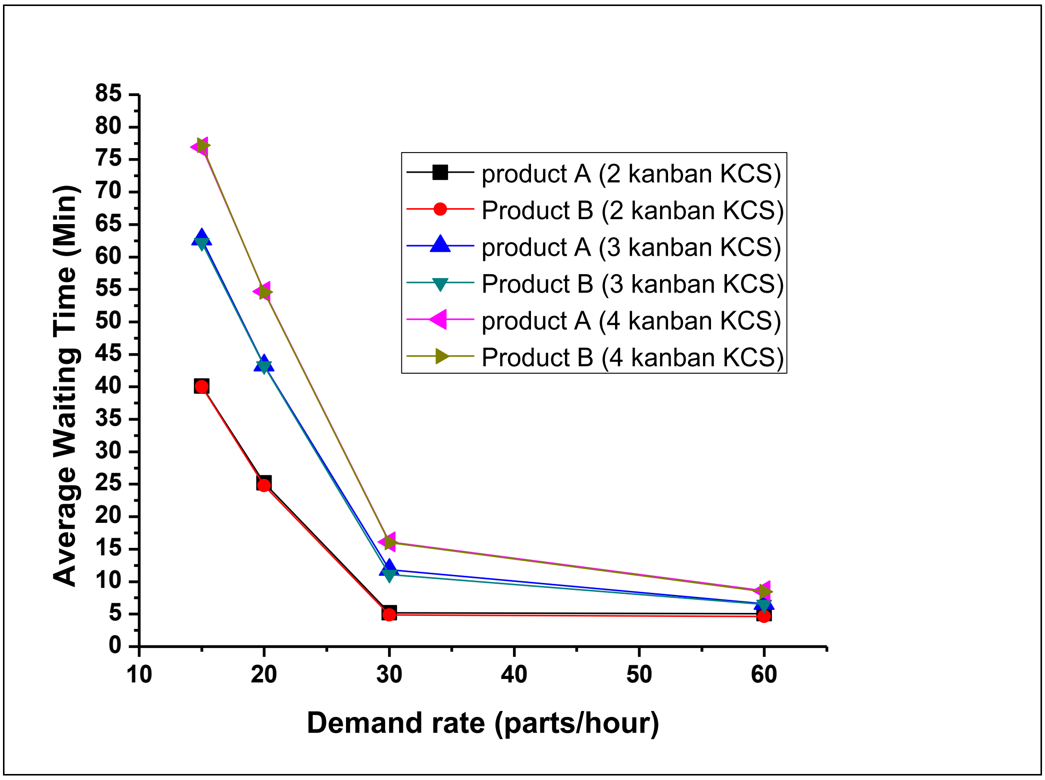

Figure 5.115: Performance Analysis of KCS for single flow line Multi stage Multi product system for AWT (M-L-H)

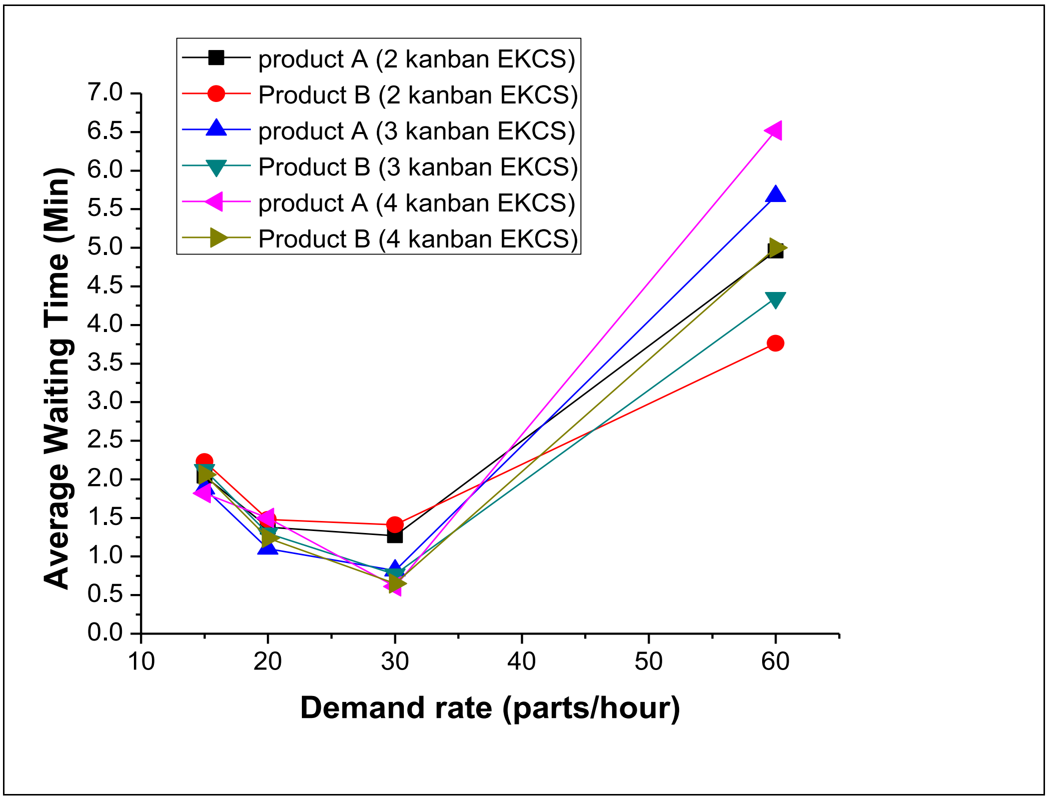

Figure 5.116: Performance Analysis of EKCS for single flow line Multi stage Multi product system for AWT (M-L-H)

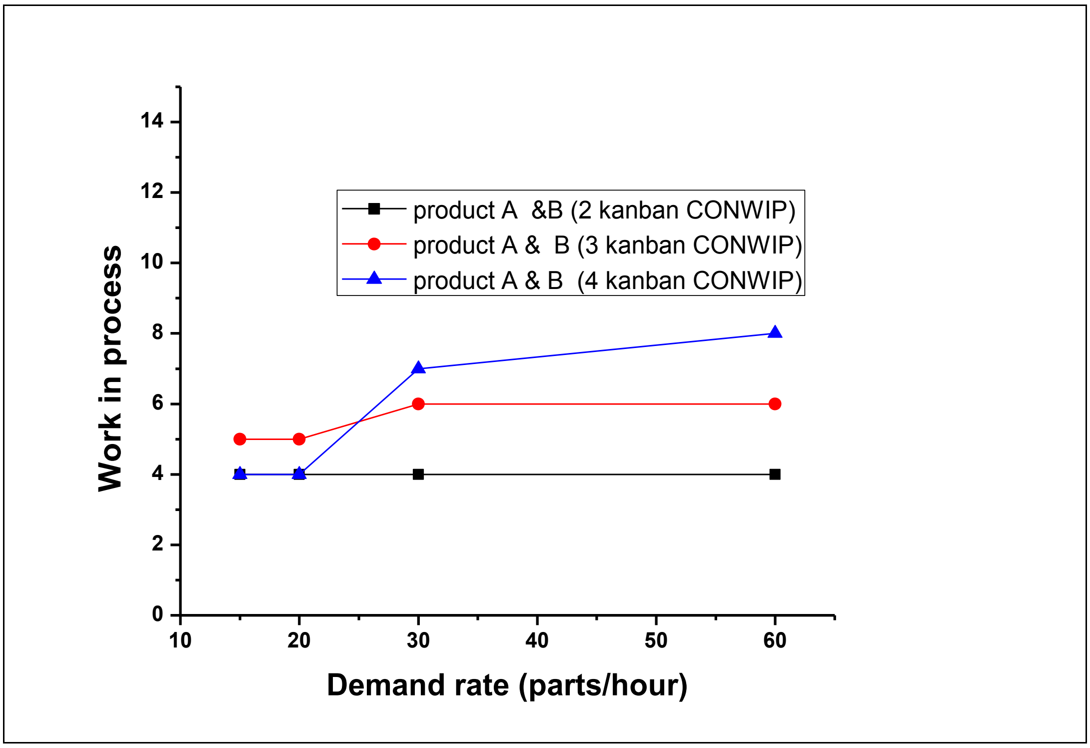

Figure 5.117: Performance Analysis of CONWIP for single flow line Multi stage Multi product system for WIP (M-L-H)

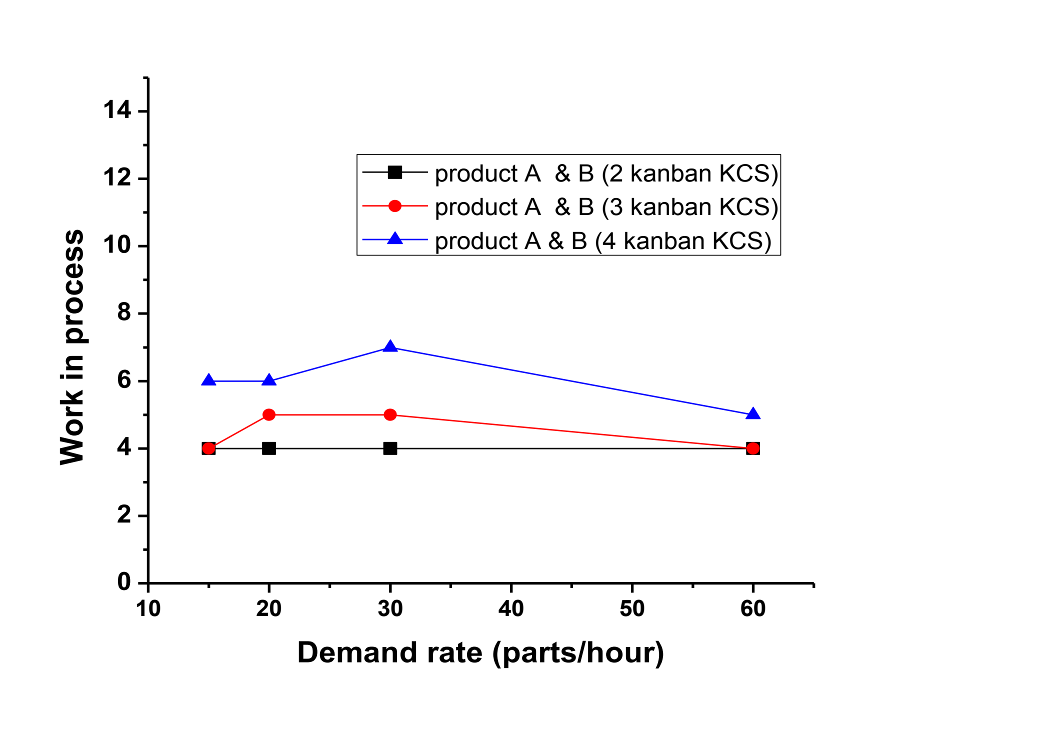

Figure 5.118: Performance Analysis of KCS for single flow line Multi stage Multi product system for WIP (M-L-H)

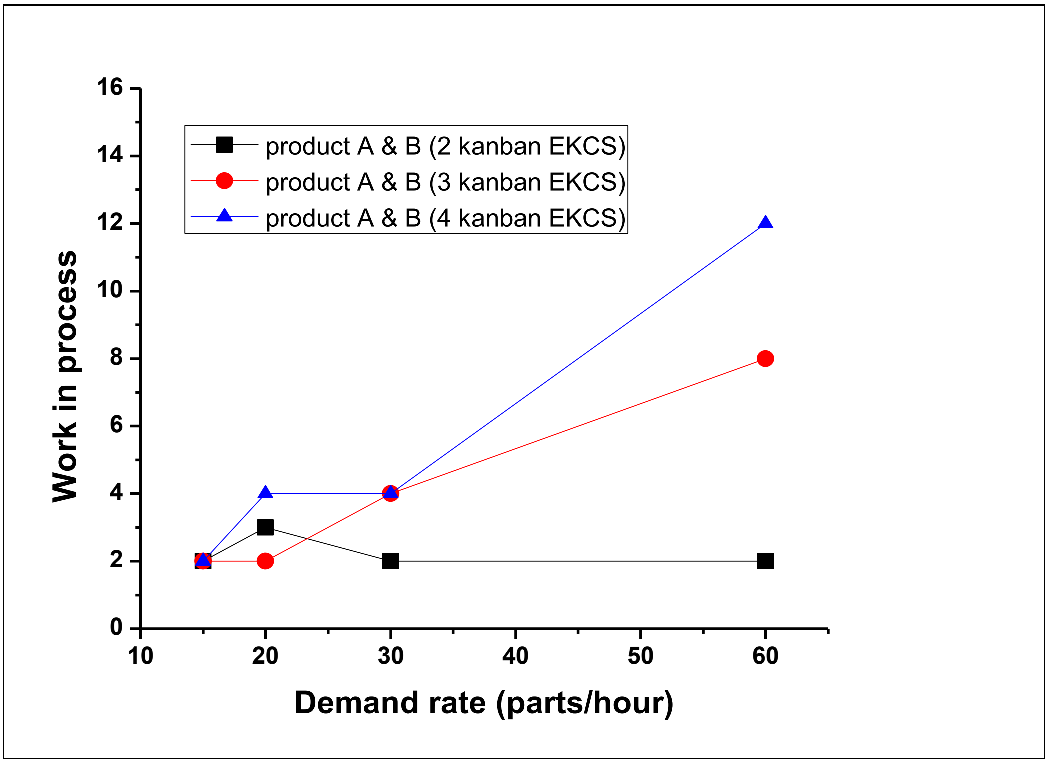

Figure 5.119: Performance Analysis of EKCS for single flow line Multi stage Multi product system for WIP (M-L-H)

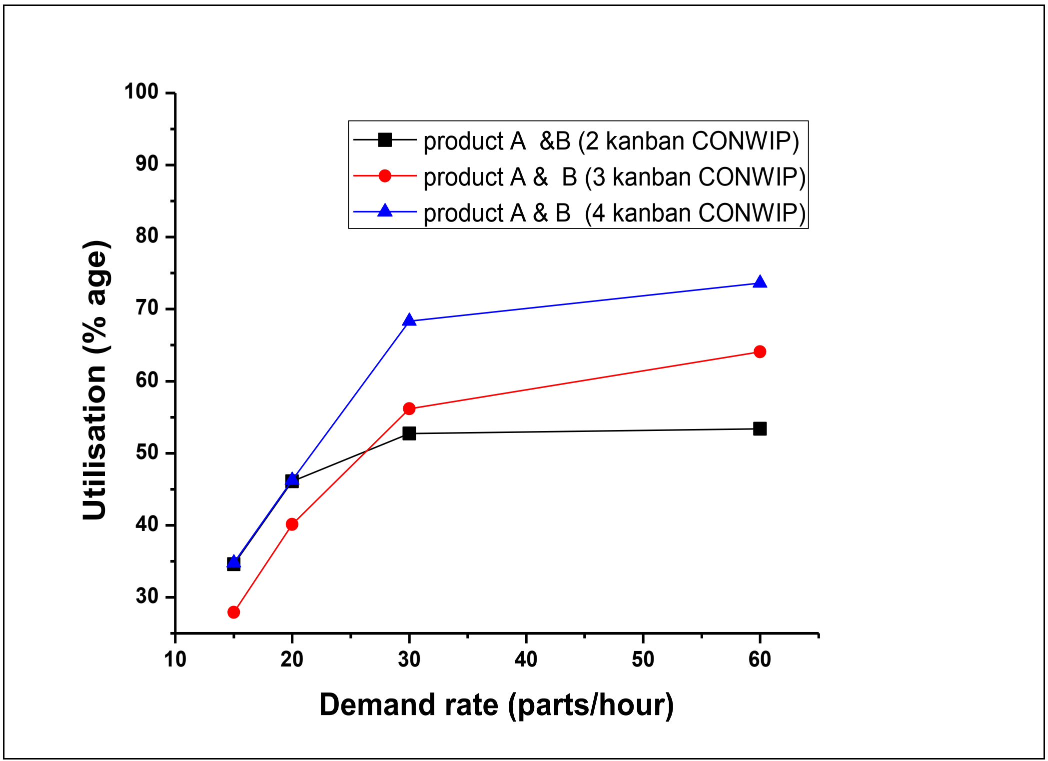

Figure 5.120: Performance Analysis of CONWIP for single flow line Multi stage Multi product system for utilization (M-L-H)

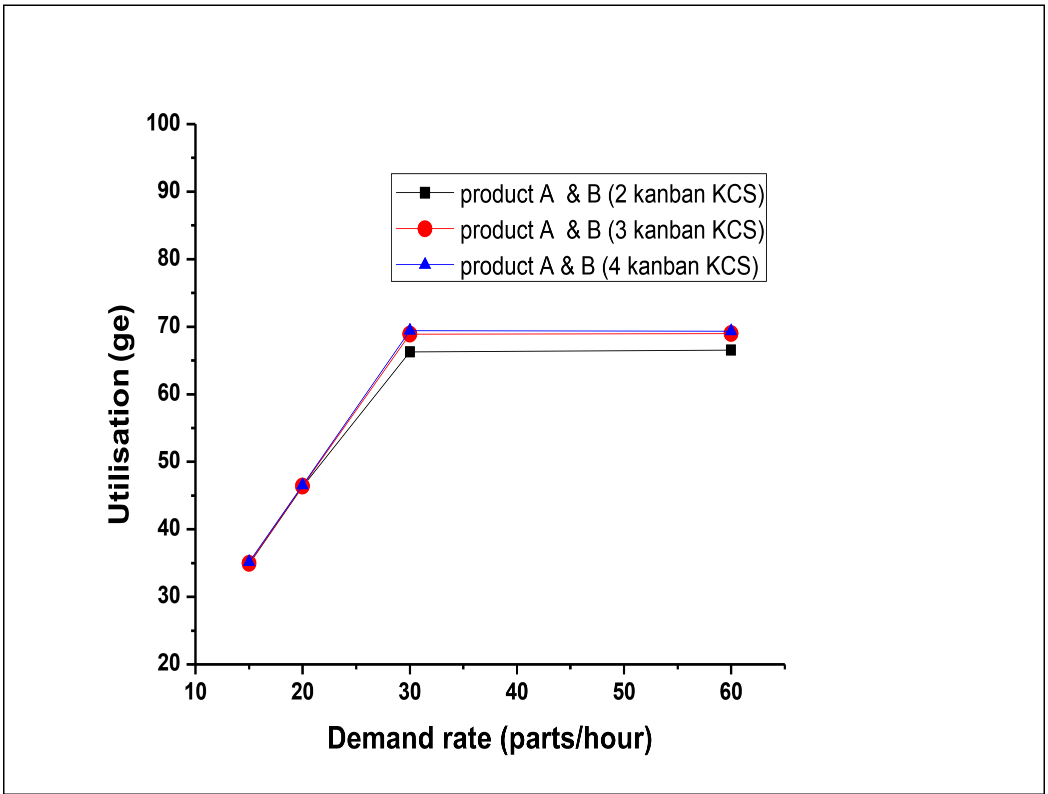

Figure 5.121: Performance Analysis of KCS for single flow line Multi stage Multi product system for utilization (M-L-H)

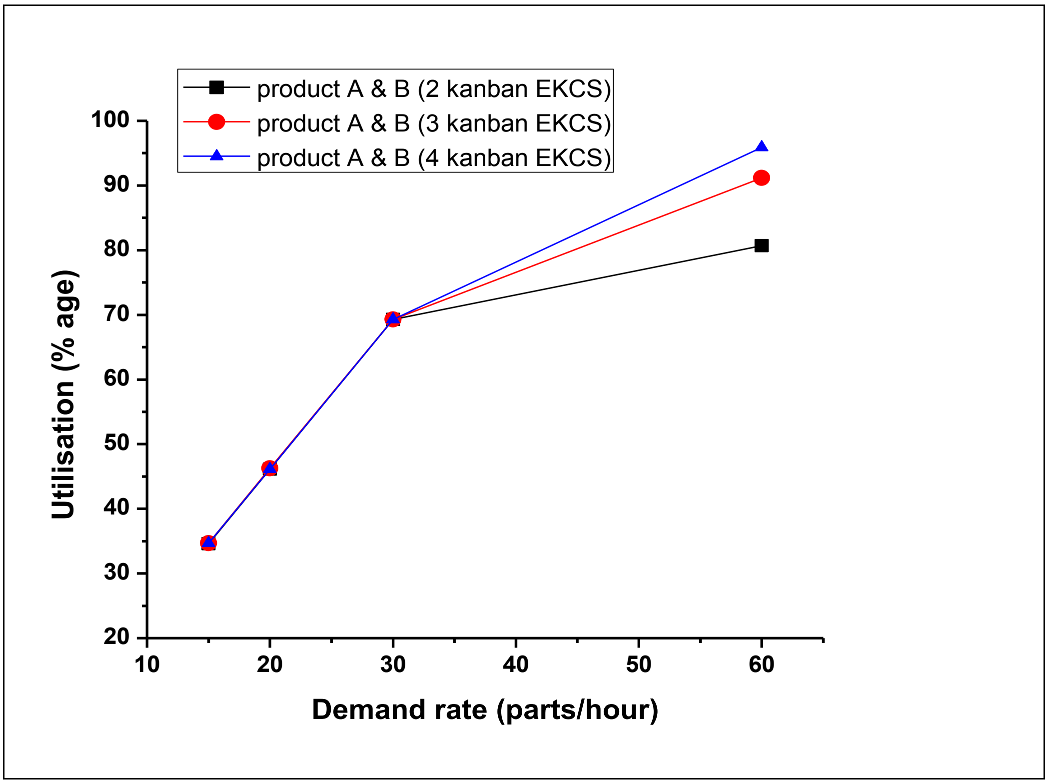

Figure 5.122: Performance Analysis of EKCS for single flow line Multi stage Multi product system for utilization (M-L-H)

5.4.3.3 Low –Medium- High (L-M-H)

The performance analysis of the pull control systems has low variability for three kanbans per stage at optimum demand rate of 30 parts per hour. The LMH combination is analyzed for performance given in Table 5.11.

Table 5.11: Performance analysis of single flow line multi stage multi-product system for demand rate 30 parts per hour (LMH combination)

Performance parameters	CONWIP		KCS		EKCS	
	Product A	Product B	Product A	Product B	Product A	Product B
Production	1210	1410	1408	1411	1411	1410
Average waiting time (min)	7.72	6.59	10.84	11.1	0.99	0.4
WIP	6		5		3	
Utilization (%age)	63.9		57.8		57.8	

The production in CONWIP system is less as compared to KCS and EKCS. The production in KCS and EKCS is 7.5% higher as compared to CONWIP. The AWT in KCS is high as compared to CONWIP and EKCS. The AWT in KCS is 53% high and EKCS is 90% less as compared to CONWIP. The WIP and utilization in KCS and EKCS is less as compared to CONWIP.

The results obtained by simulation for CONWIP, KCS and EKCS for two, three and four kanbans per stage are presented in figures 5.123 to 5.134.

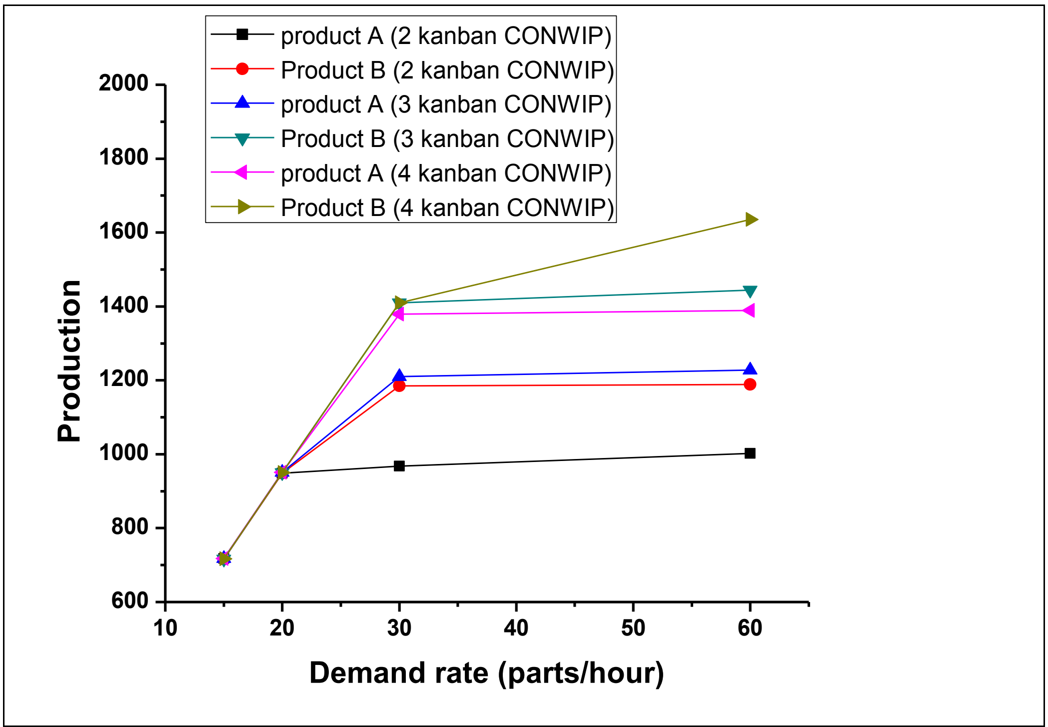

Figure 5.123: Performance Analysis of CONWIP for single flow line Multi stage Multi product system for production (L-M-H)

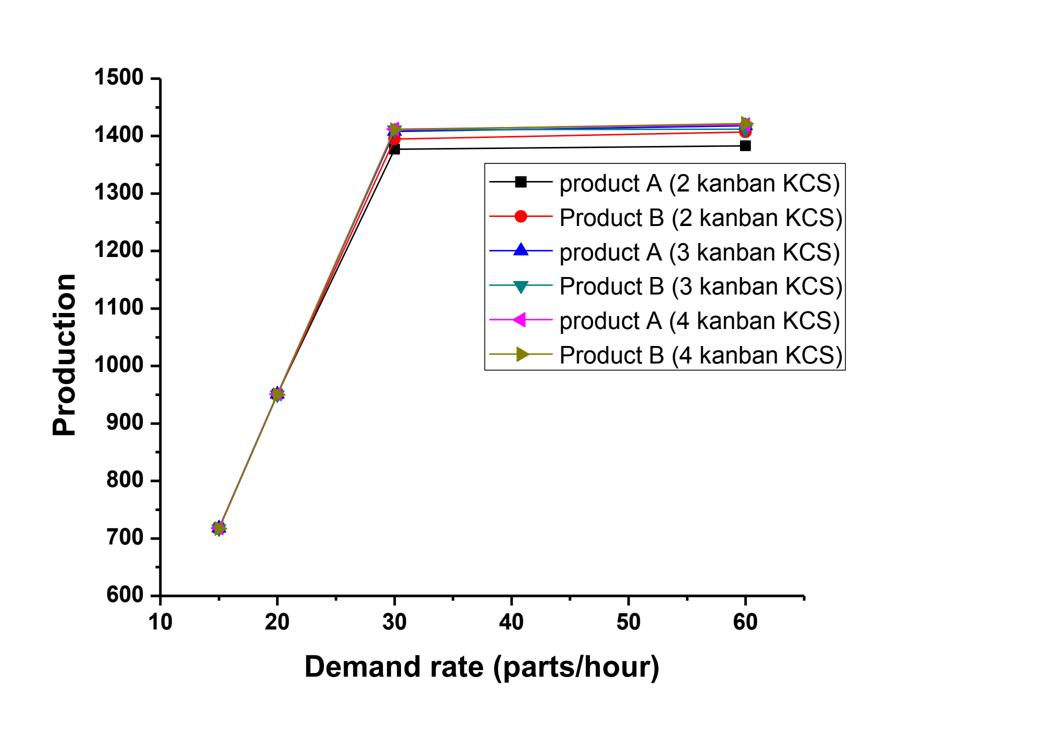

Figure 5.124: Performance Analysis of KCS for single flow line Multi stage Multi-product system for production (L-M-H)

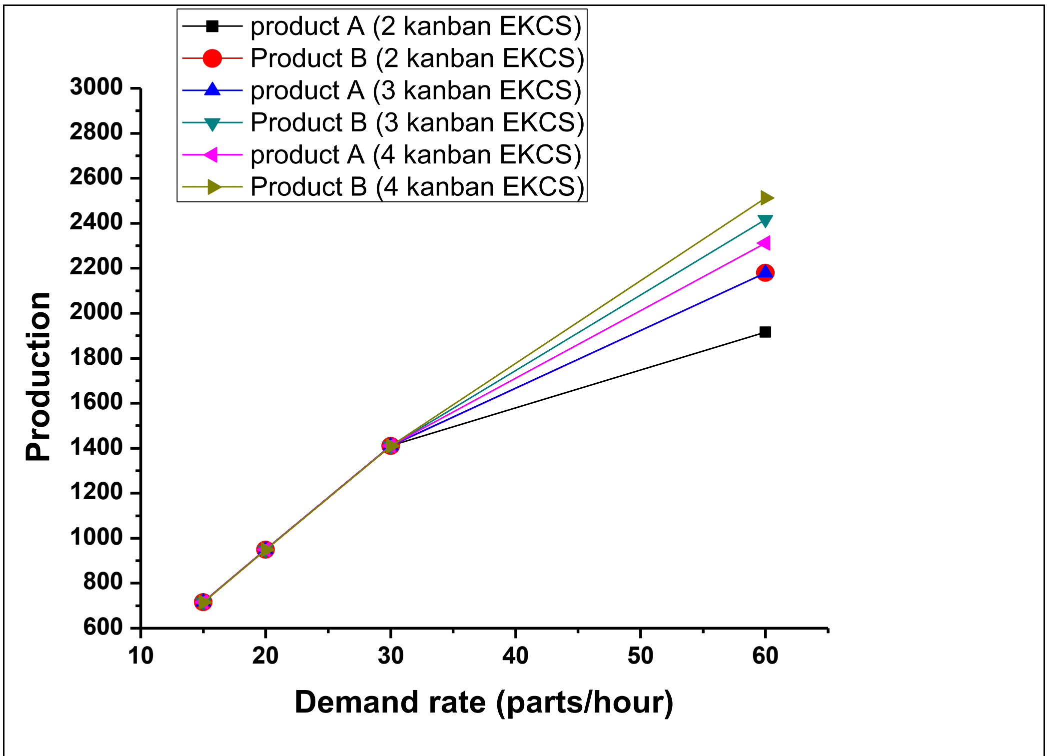

Figure 5.125: Performance Analysis of EKCS for single flow line Multi stage Multi-product system for production (L-M-H)

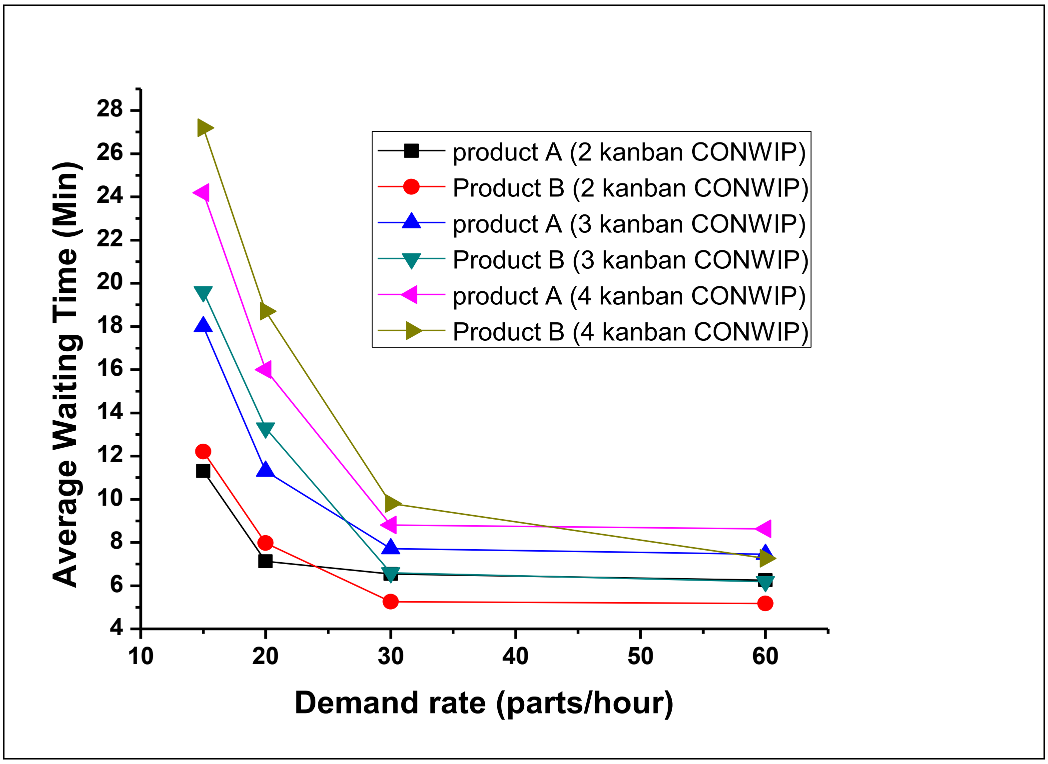

Figure 5.126: Performance Analysis of CONWIP for single flow line Multi stage Multi-product system for AWT (L-M-H)

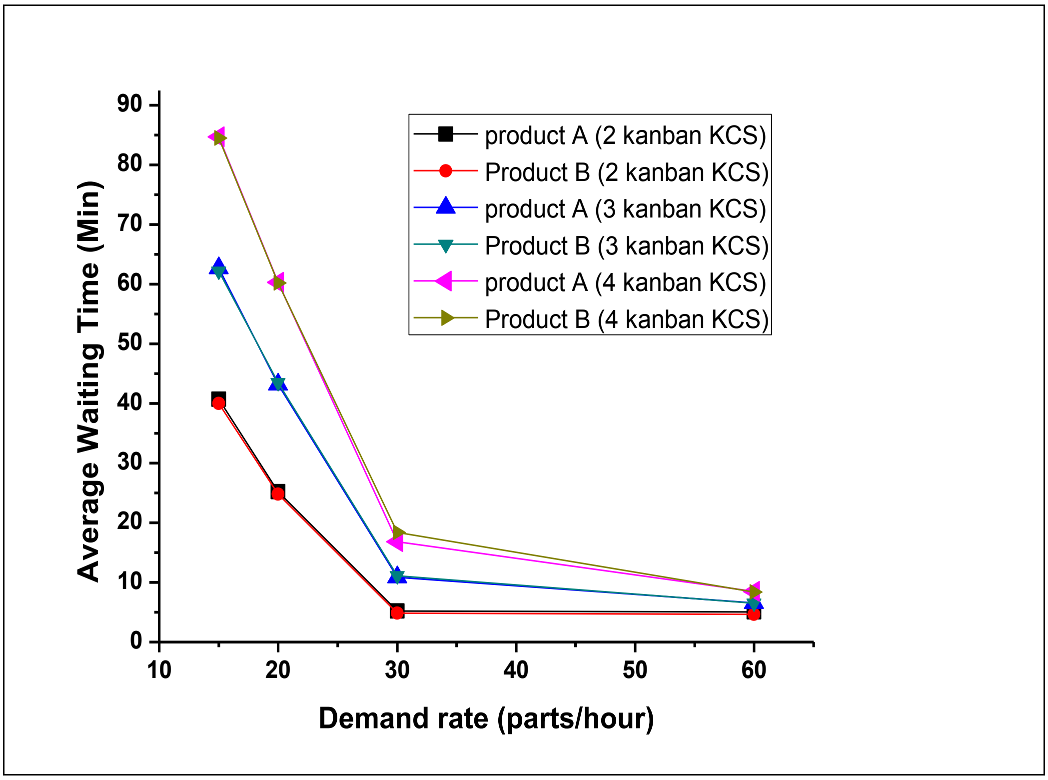

Figure 5.127: Performance Analysis of KCS for single flow line Multi stage Multi product system for AWT (L-M-H)

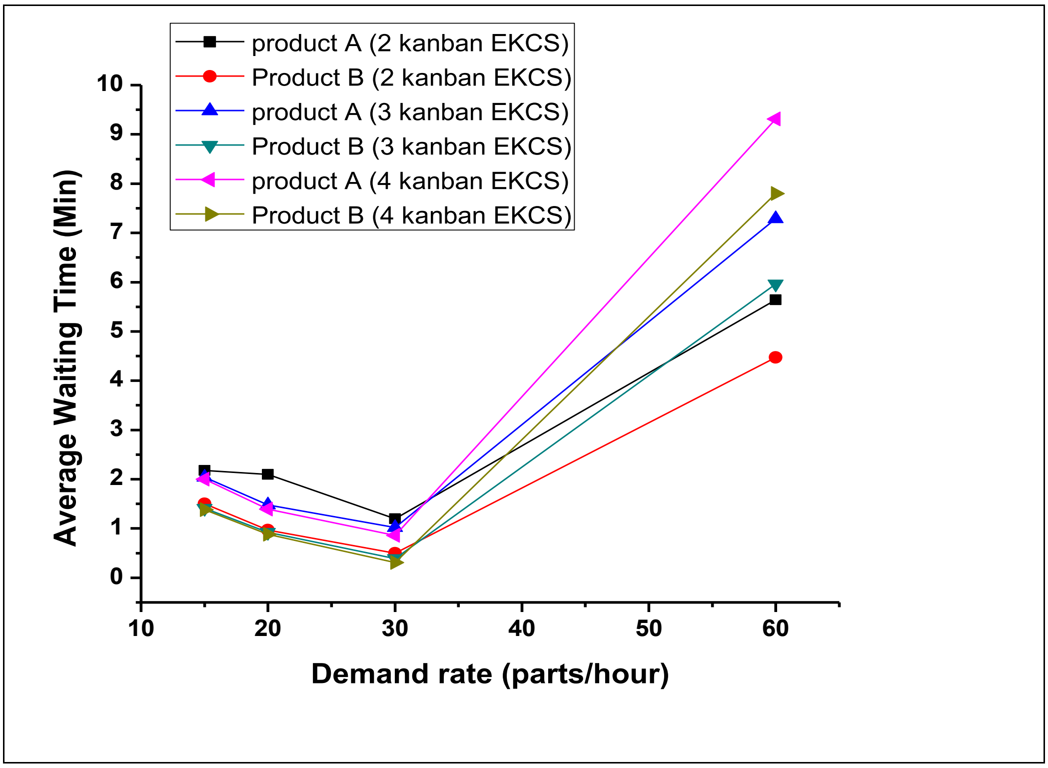

Figure 5.128: Performance Analysis of EKCS for single flow line Multi stage Multi product system for AWT (L-M-H)

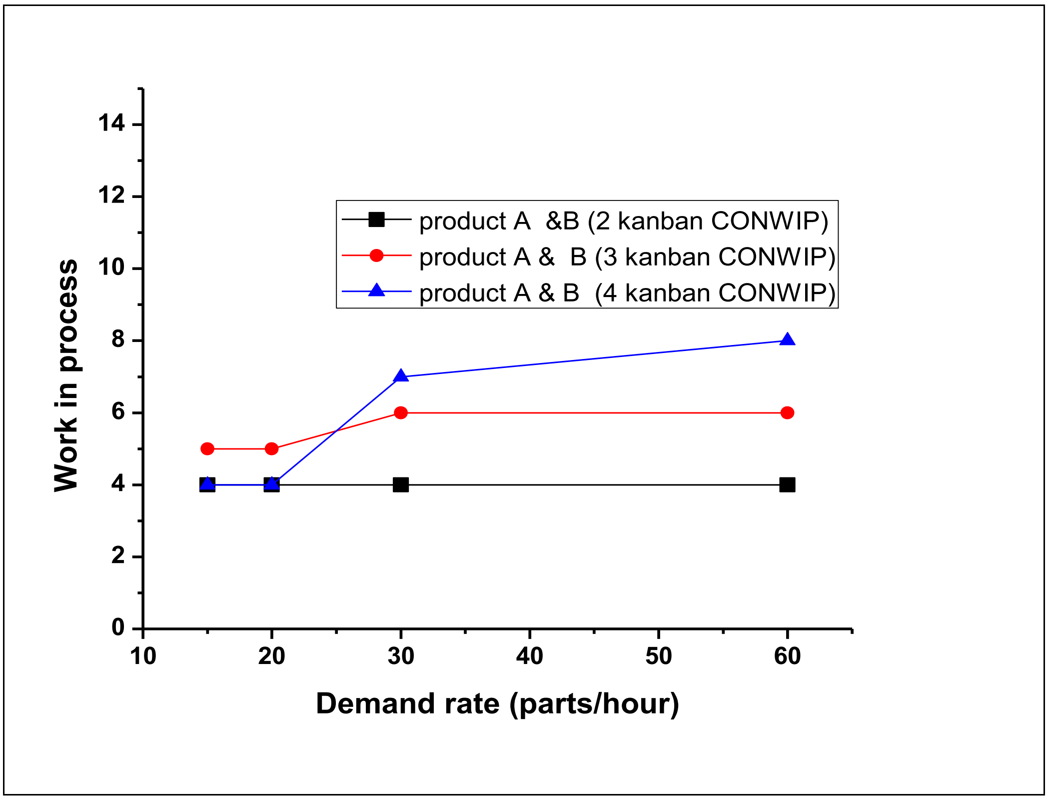

Figure 5.129: Performance Analysis of CONWIP for single flow line Multi stage Multi-product system for WIP (L-M-H)

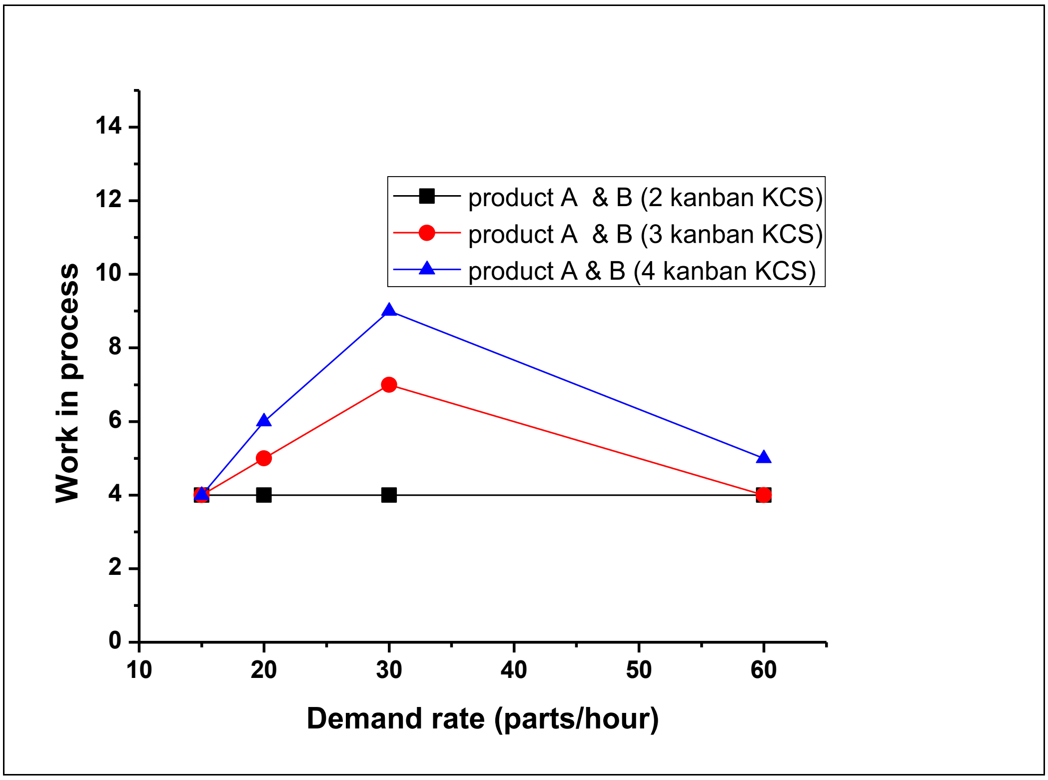

Figure 5.130: Performance Analysis of KCS for single flow line Multi stage Multi-product system for WIP (L-M-H)

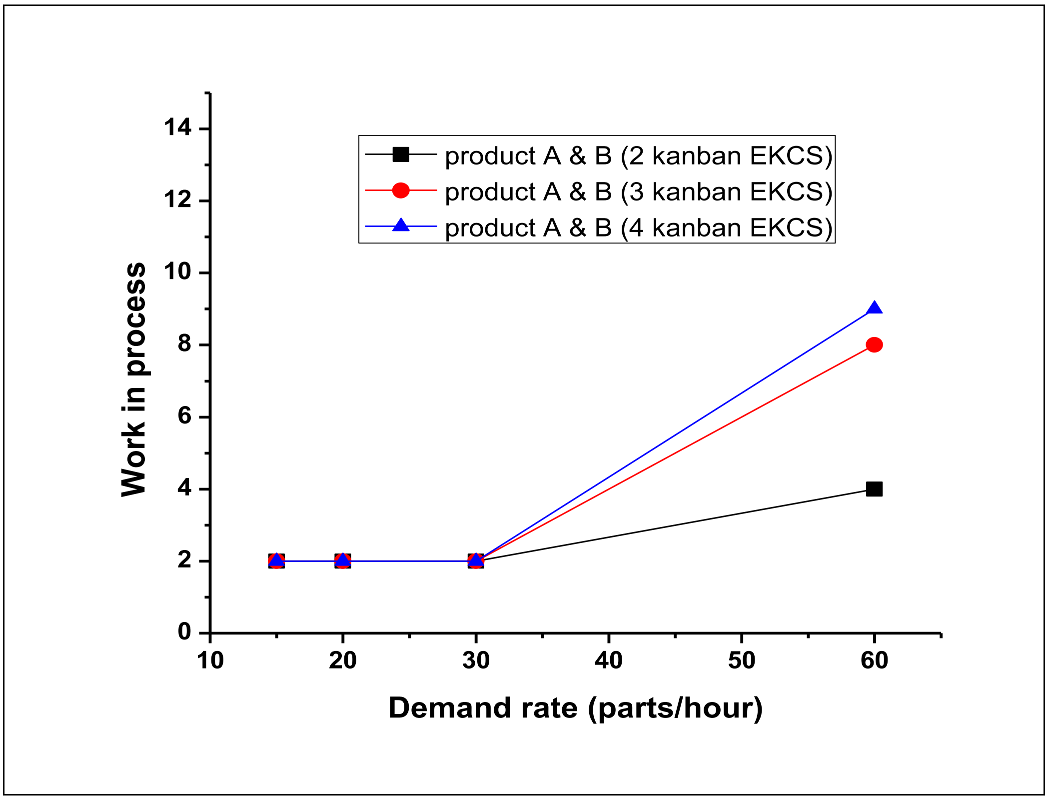

Figure 5.131: Performance Analysis of EKCS for single flow line Multi stage Multi-product system for WIP (L-M-H).

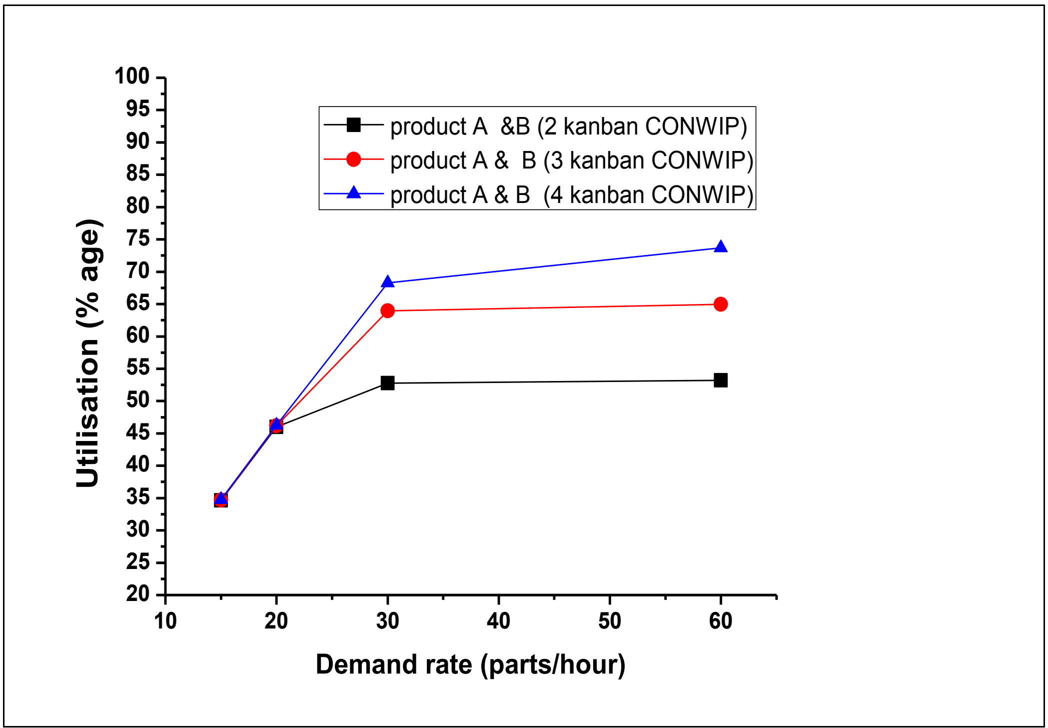

Figure 5.132: Performance Analysis of CONWIP for single flow line Multi stage multi- product system for utilization (L-M-H)

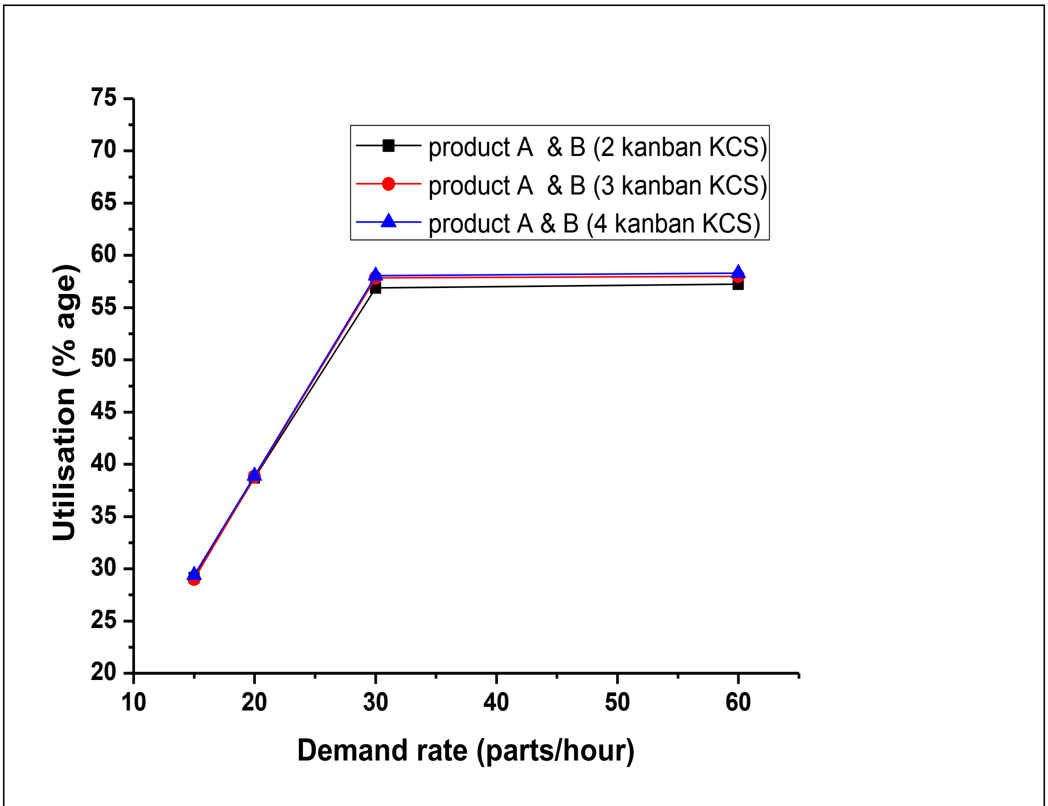

Figure 5.133: Performance Analysis of KCS for single flow line Multi stage Multi-product system for utilization (L-M-H)

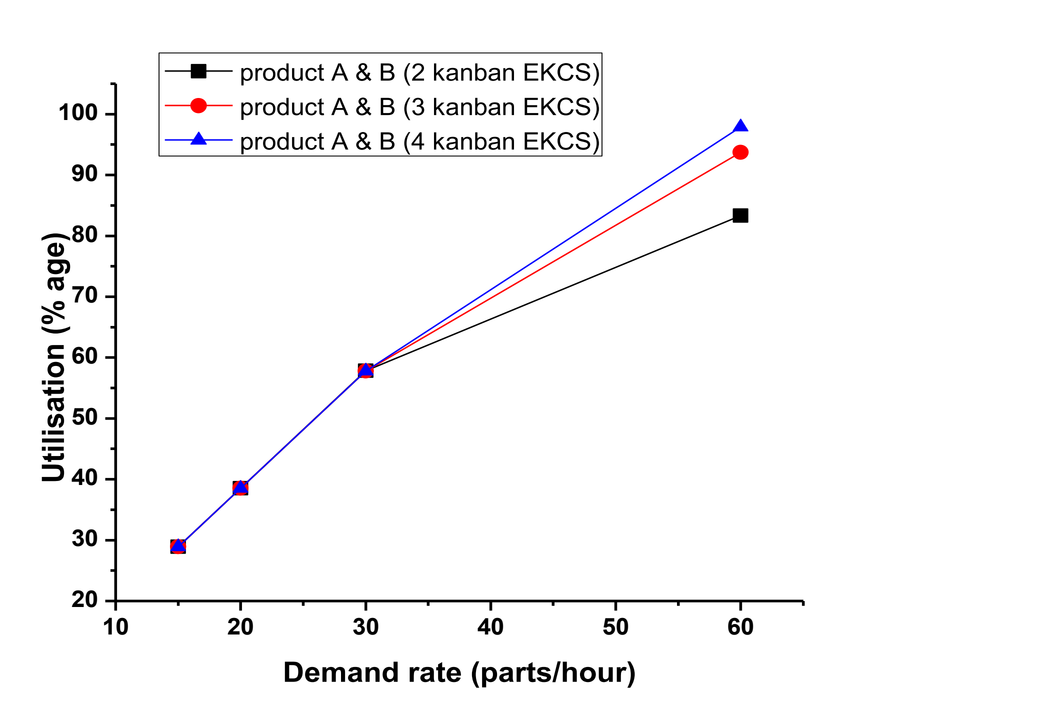

Figure 5.134: Performance Analysis of EKCS for single flow line Multi stage Multi-product system for utilization (L-M-H)

5.4.3.4 High-Medium-Low (H-M-L)

The performance analysis of the pull control systems has low variability for three kanbans per stage at optimum demand rate of 30 parts per hour. The HML combination is analyzed for performance as given in Table 5.12.

Table 5.12: Performance analysis of single flow line multi stage multi-product system for demand rate 30 parts per hour (HML combination)

Performance Parameters	CONWIP		KCS		EKCS	
	Product A	Product B	Product A	Product B	Product A	Product B
Production	1237	1410	1394	1406	1411	1407
Average waiting time(min)	7.42	6.77	7.18	7.32	1.5	1.04
WIP	6		5		5	
Utilization (%age)	64.46		68		69.14	

The production in CONWIP system is less as compared to KCS and EKCS. The production in KCS is 5.8% higher and EKCS is 6.4% higher as compared to CONWIP. The KCS system has high AWT as compared to CONWIP and EKCS. The AWT in KCS is 2% high and in EKCS is 82% less as compared to CONWIP. The WIP in KCS and EKCS is less as compared to CONWIP. The utilization in CONWIP is less as compared to KCS and EKCS.

The results obtained by simulation for CONWIP, KCS and EKCS for two, three and four kanbans per stage are presented in figures 5.135 to 5.146

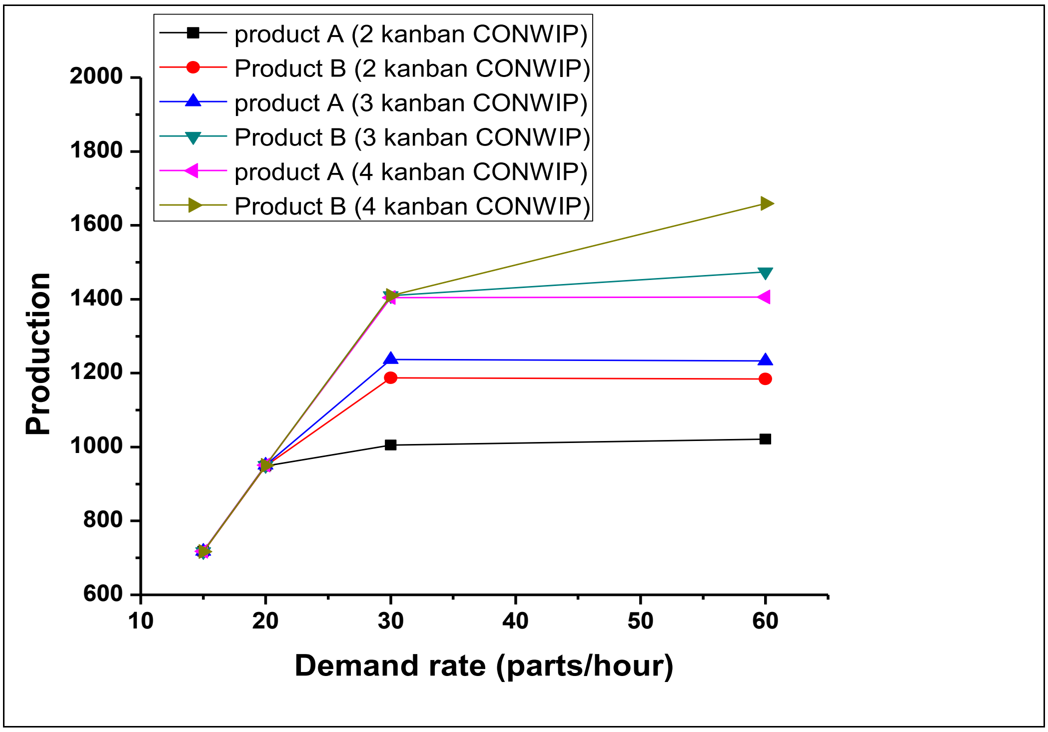

Figure 5.135: Performance Analysis of CONWIP for single flow line Multi stage Multi- product system for production (H-M-L)

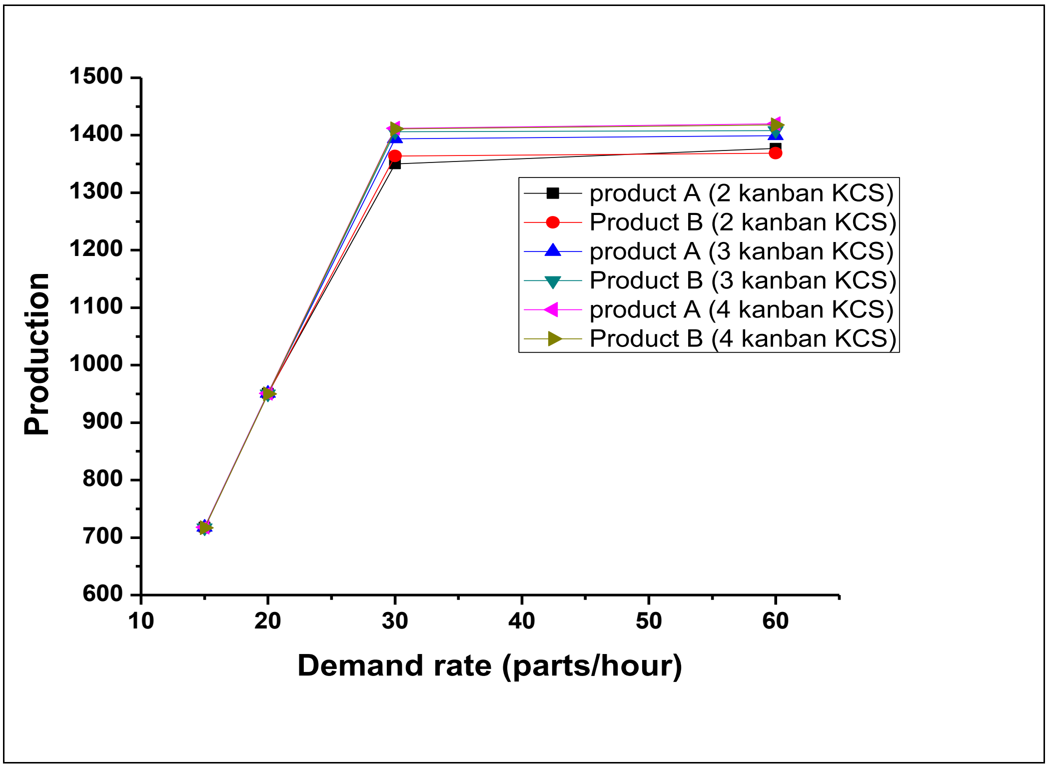

Figure 5.136: Performance Analysis of KCS for single flow line Multi stage Multi-product system for production (H-M-L)

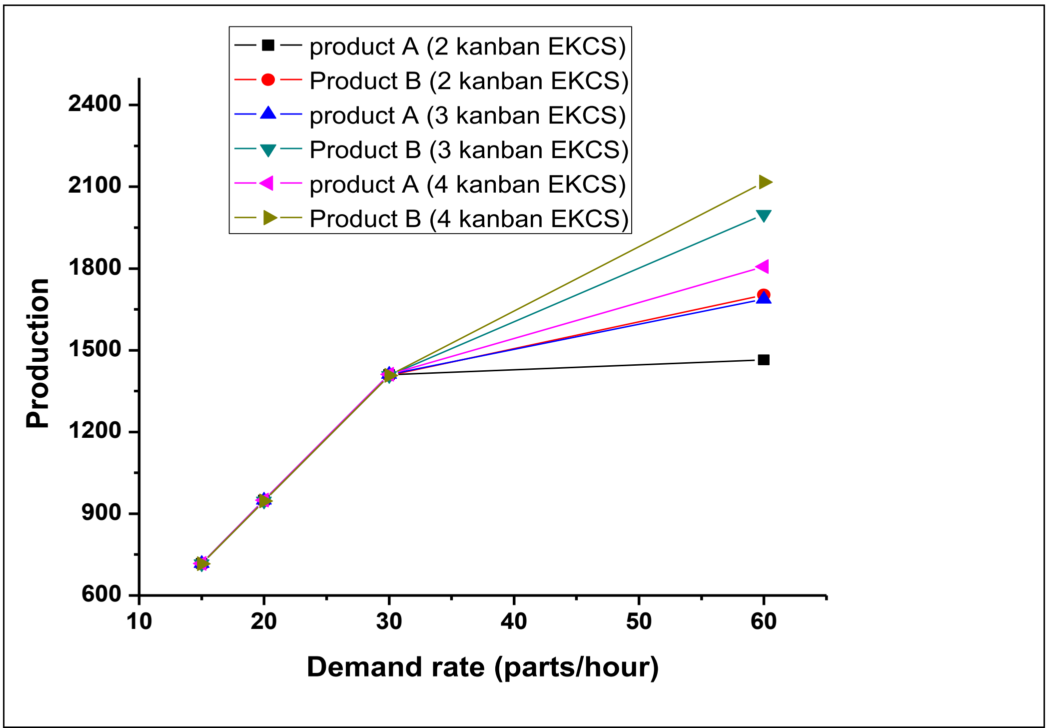

Figure 5.137: Performance Analysis of EKCS for single flow line Multi stage Multi-product system for production (H-M-L)

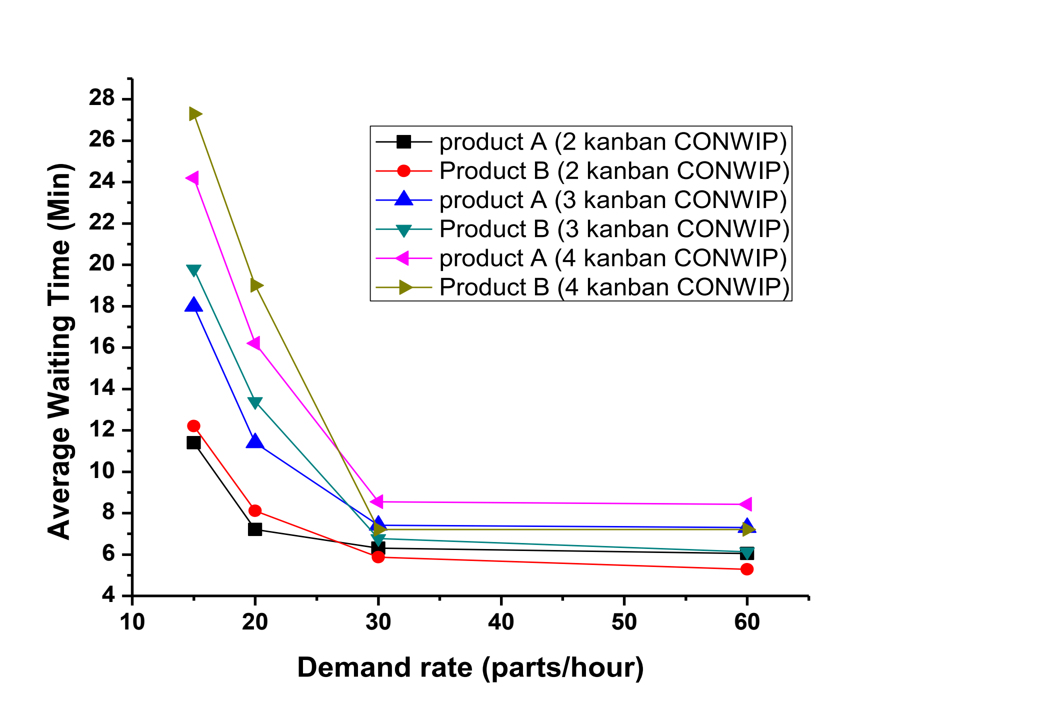

Figure 5.138: Performance Analysis of CONWIP for single flow line Multi stage Multi-product system for AWT (H-M-L).

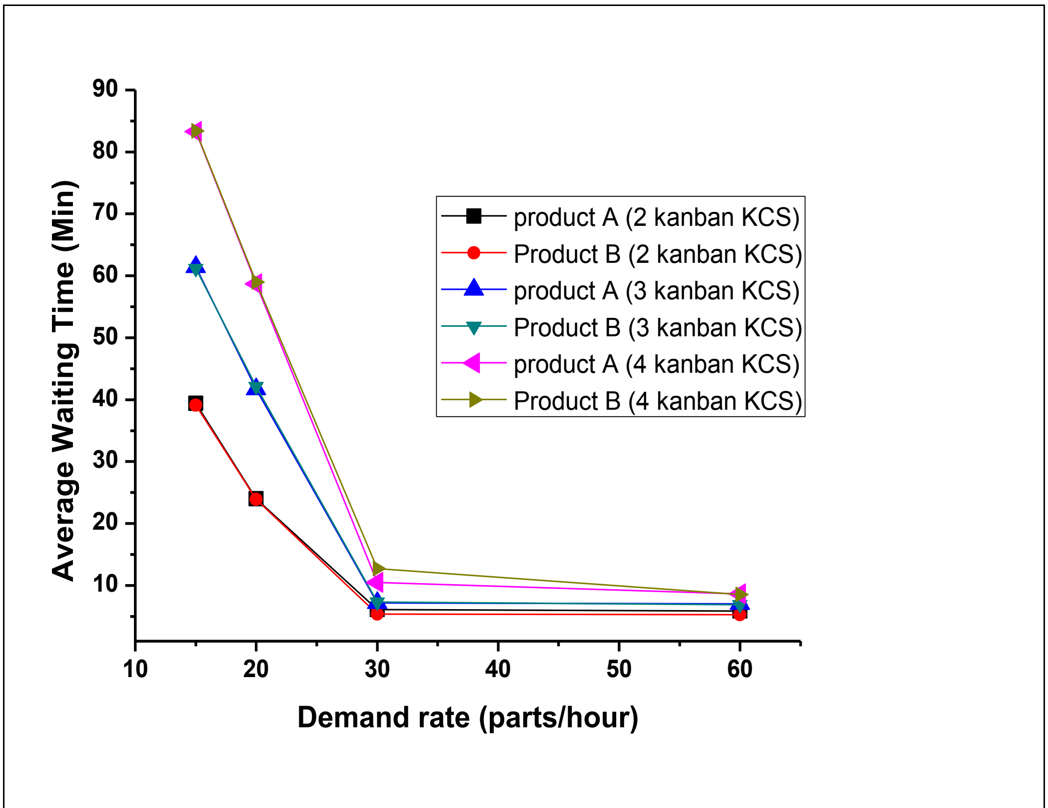

Figure 5.139: Performance Analysis of KCS for single flow line Multi stage Multi-product system for AWT (H-M-L)

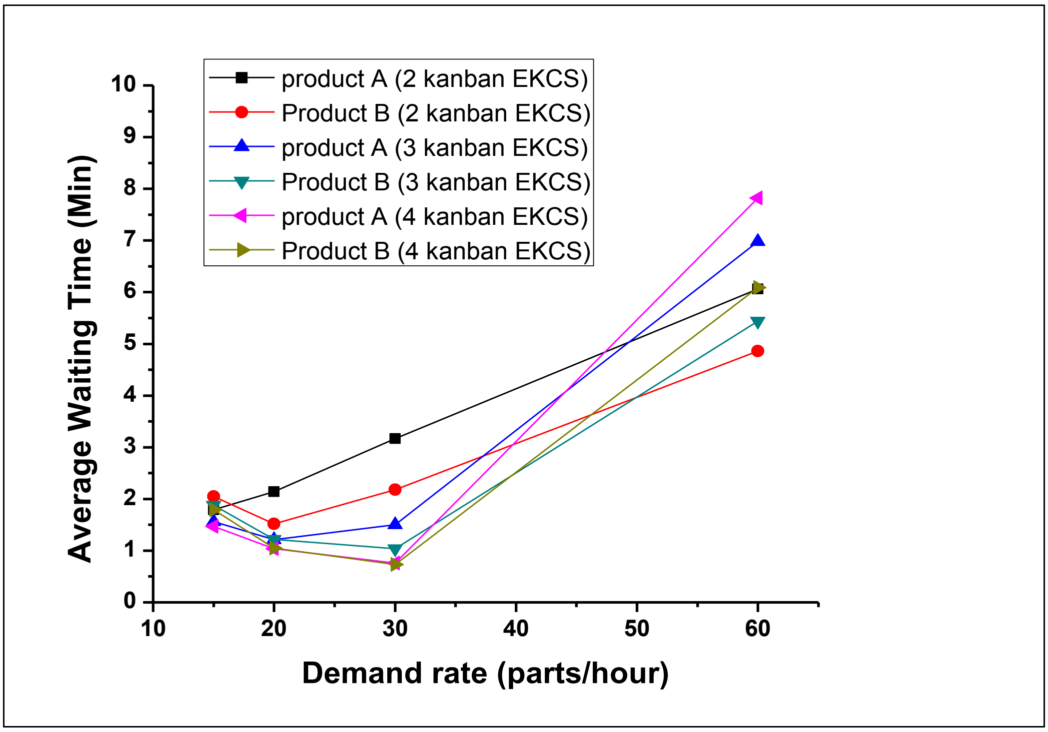

Figure 5.140: Performance Analysis of EKCS for single flow line Multi stage Multi-product system for AWT (H-M-L)

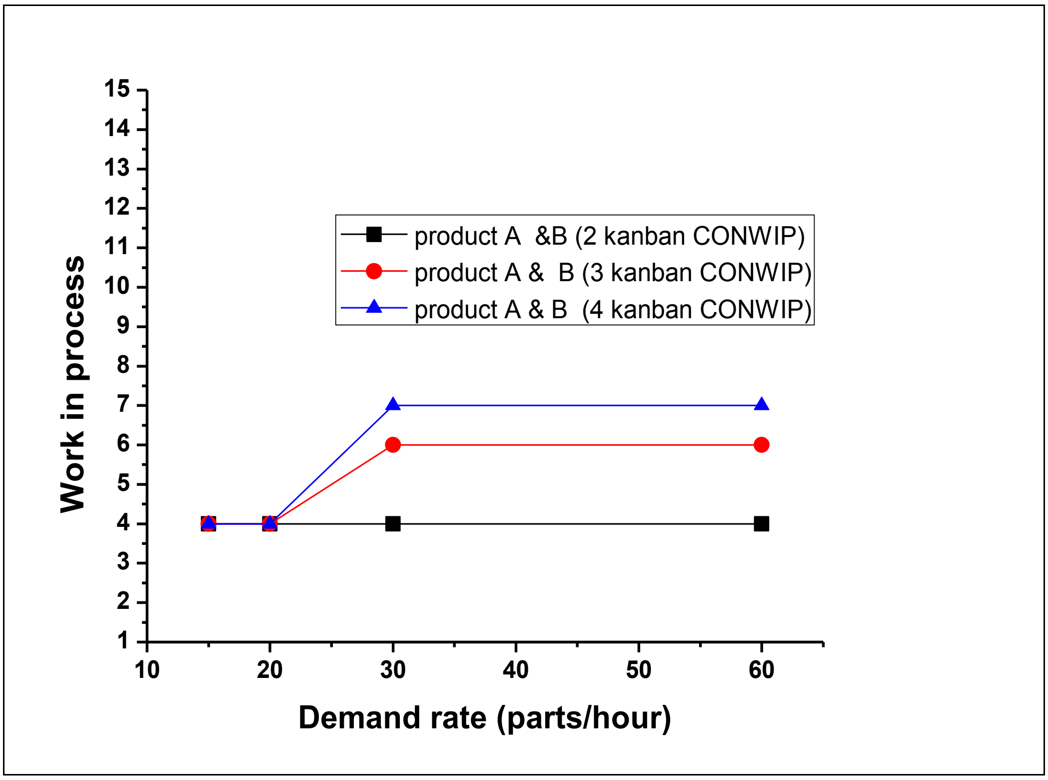

Figure 5.141: Performance Analysis of CONWIP for single flow line Multi stage Multi-product system for WIP (H-M-L)

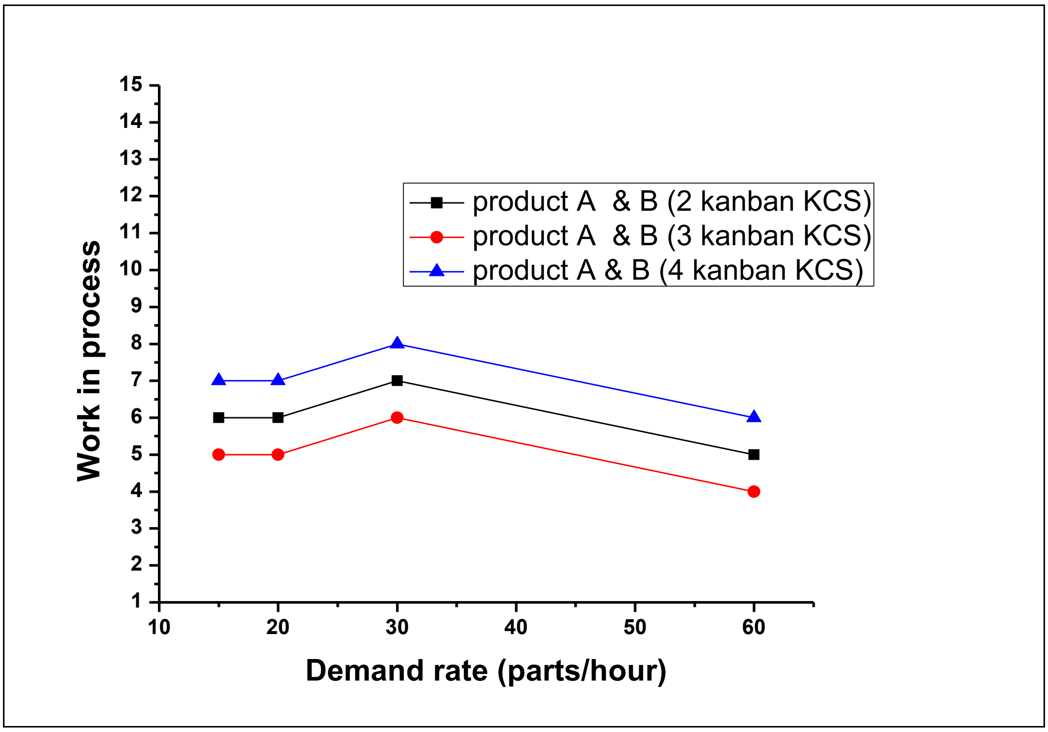

Figure 5.142: Performance Analysis of KCS for single flow line Multi stage Multi-product system for WIP (H-M-L)

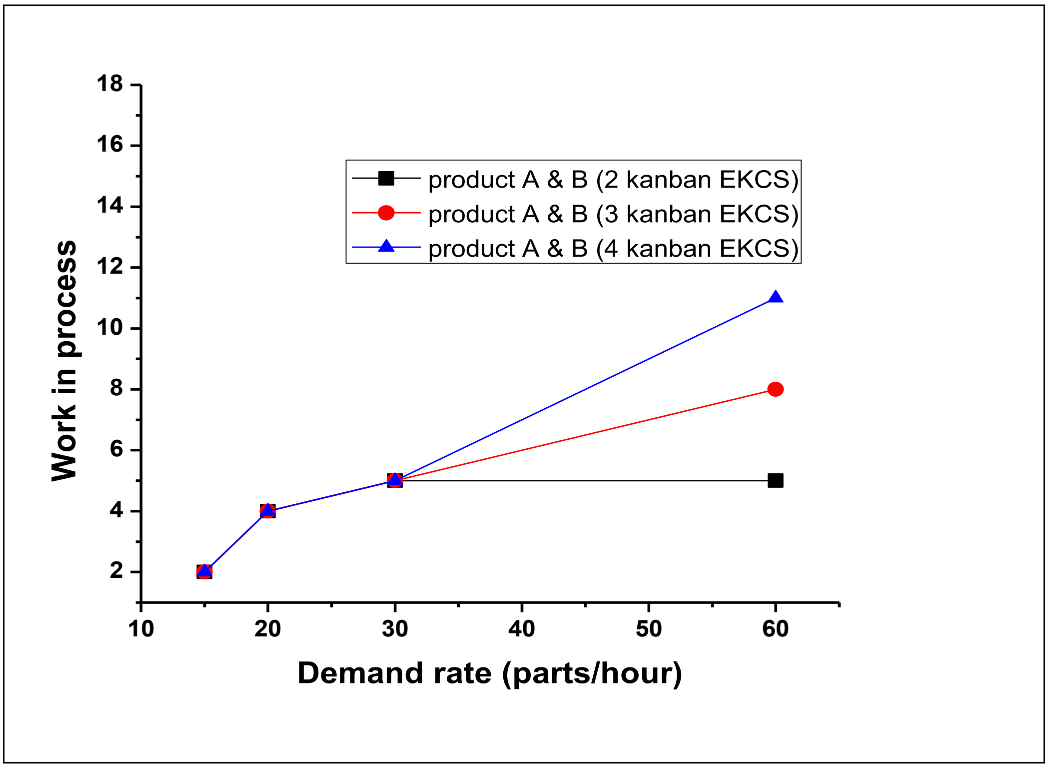

Figure 5.143: Performance Analysis of EKCS for single flow line Multi stage Multi-product system for WIP (H-M-L)

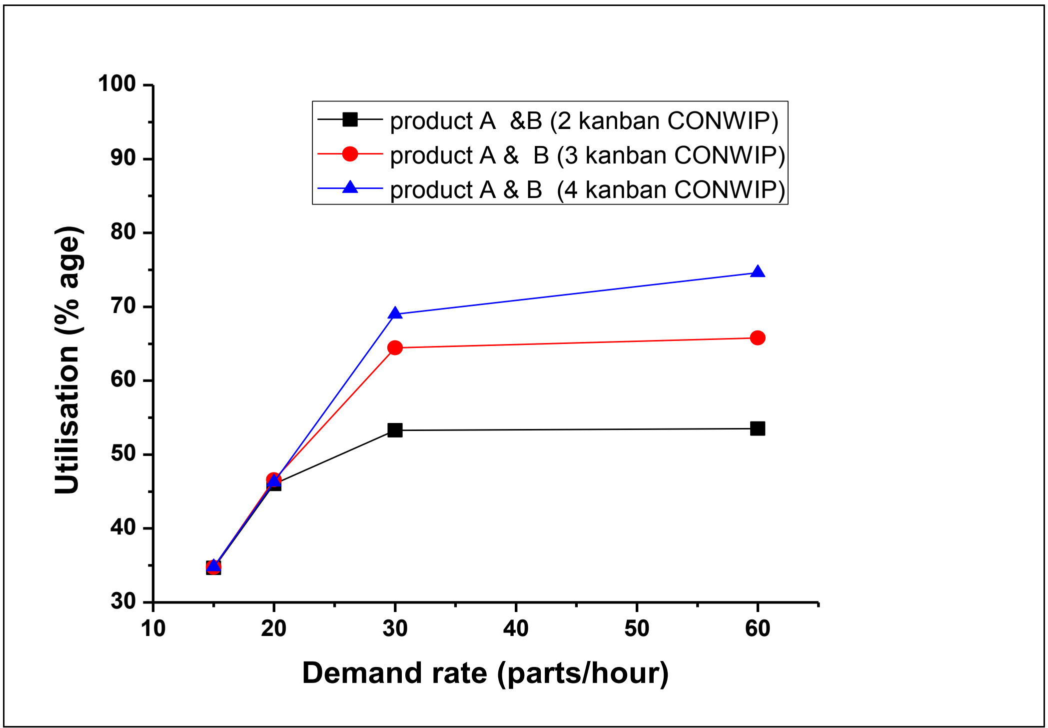

Figure 5.144: Performance Analysis of CONWIP for single flow line Multi stage Multi-product system for utilization (H-M-L)

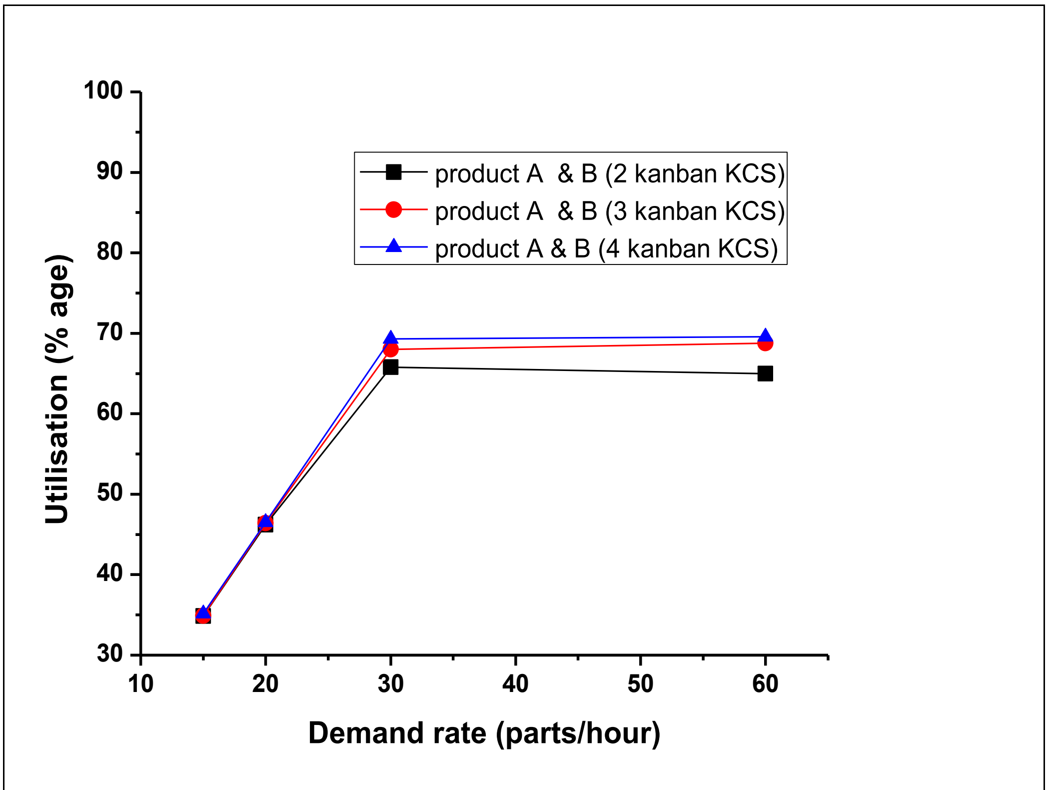

Figure 5.145: Performance Analysis of KCS for single flow line Multi stage Multi-product system for utilization (H-M-L)

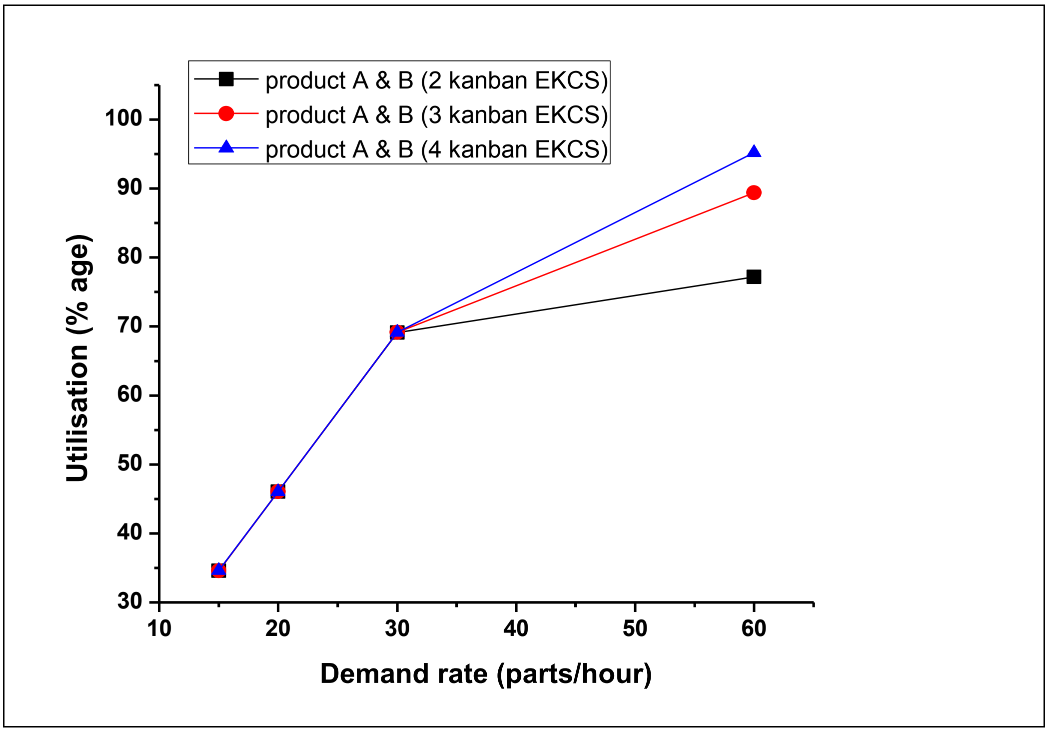

Figure 5.146: Performance Analysis of EKCS for single flow line Multi stage Multi-product system for utilization (H-M-L)

5.4.3.5 Low-High-Medium (L-H-M)

At optimum demand rate of 30 parts per hour, the performance analysis of the pull control systems has low variability for three kanbans per stage. The LHM combination is analyzed for performance is given in Table 5.13.

Table 5.13: Performance analysis of single flow line multi stage multi-product system for demand rate 30 parts per hour (LHM combination)

Performance parameters	CONWIP		KCS		EKCS	
	Product A	Product B	Product A	Product B	Product A	Product B
Production	1230	1410	1412	1410	1411	1408
Average waiting time(min)	7.55	6.68	9.58	10.5	1.42	0.46
WIP	6		7		4	
Utilization (%age)	64.3		69.26		69.45	

The production in CONWIP system is less as compared to KCS and EKCS. The production in KCS and EKCS is approximately 6% high as compared to CONWIP. The KCS system has high AWT as compared to CONWIP and EKCS. The AWT in KCS is 41% high and in EKCS is 87% less as compared to CONWIP. The WIP in EKCS is less as compared to KCS and CONWIP. The CONWIP has low machine utilization as compared to KCS and EKCS.

The results obtained by simulation for CONWIP, KCS and EKCS for two, three and four kanbans per stage are presented in figures 5.147 to 5.158.

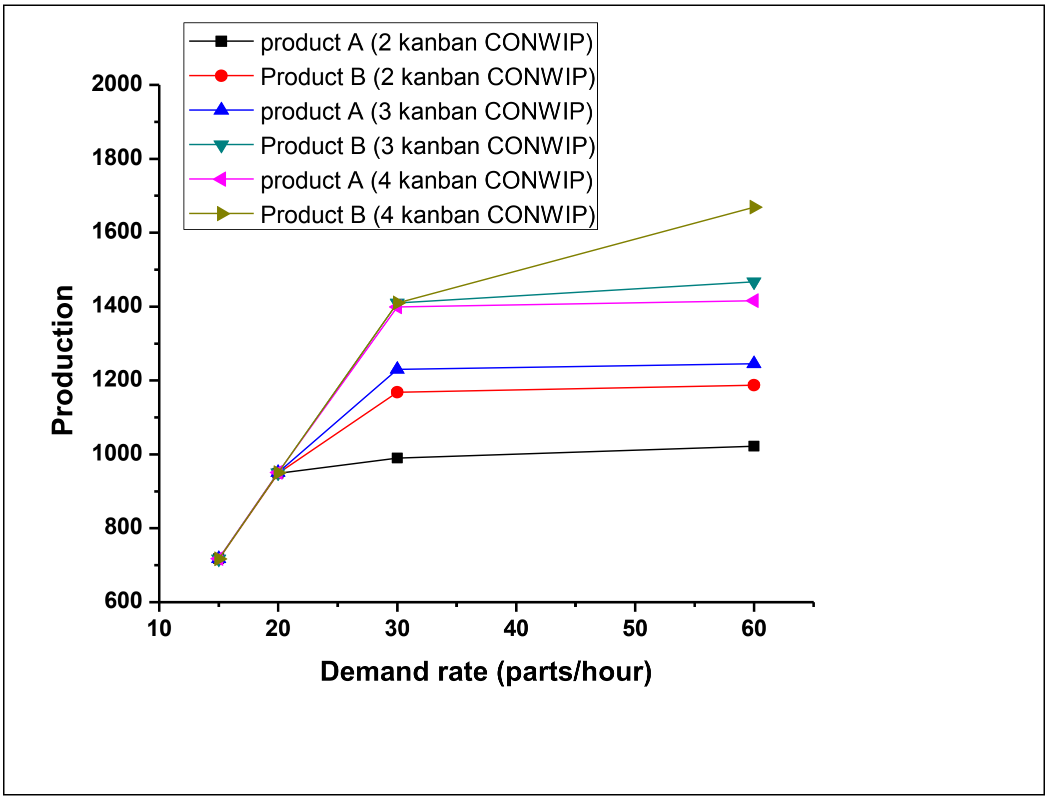

Figure 5.147: Performance Analysis of CONWIP for single flow line Multi stage Multi-product system for production (L-H-M)

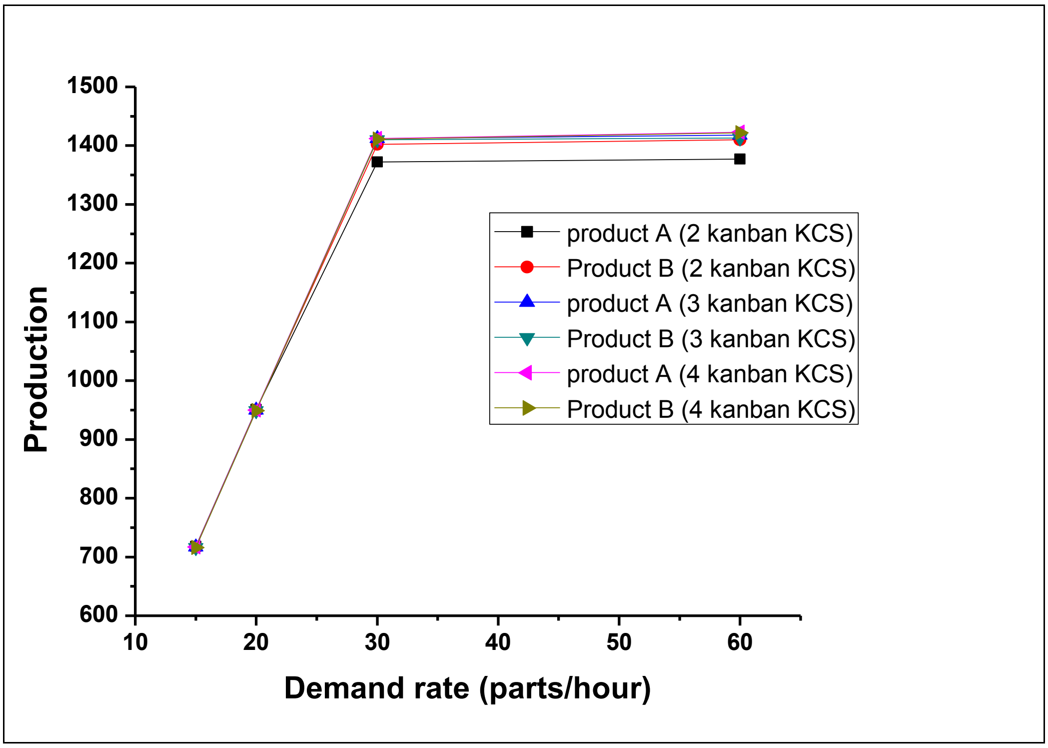

Figure 5.148: Performance Analysis of KCS for single flow line Multi stage Multi-product system for production (L-H-M)

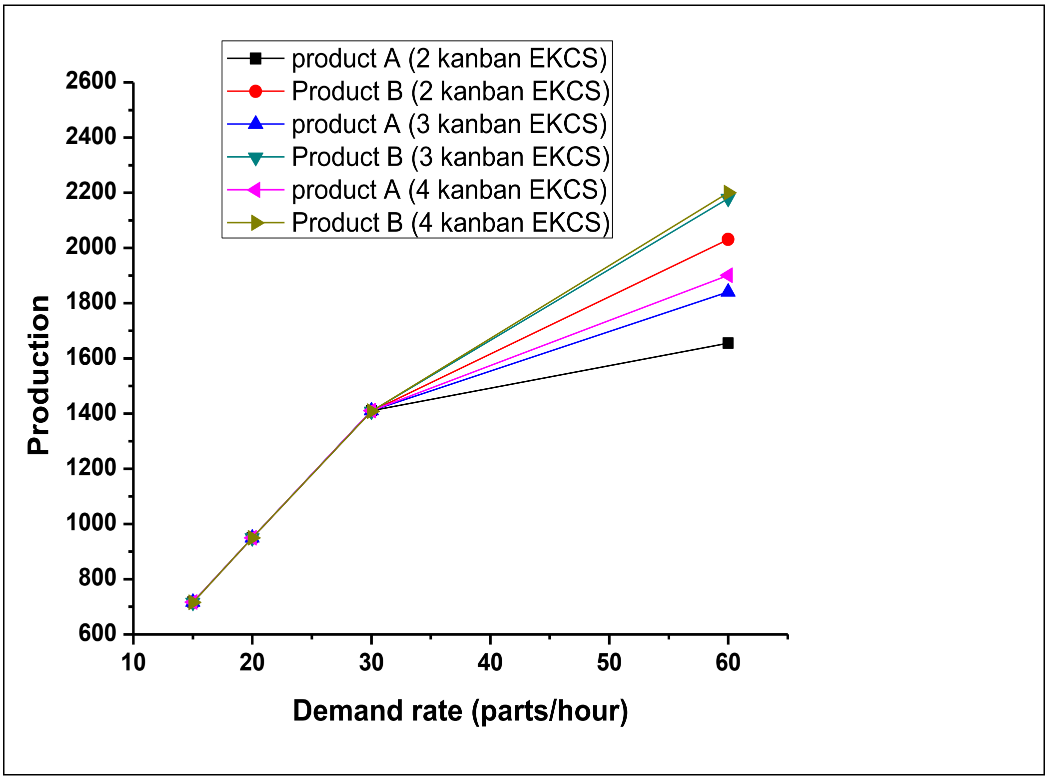

Figure 5.149: Performance Analysis of EKCS for single flow line Multi stage Multi-product system for production (L-H-M)

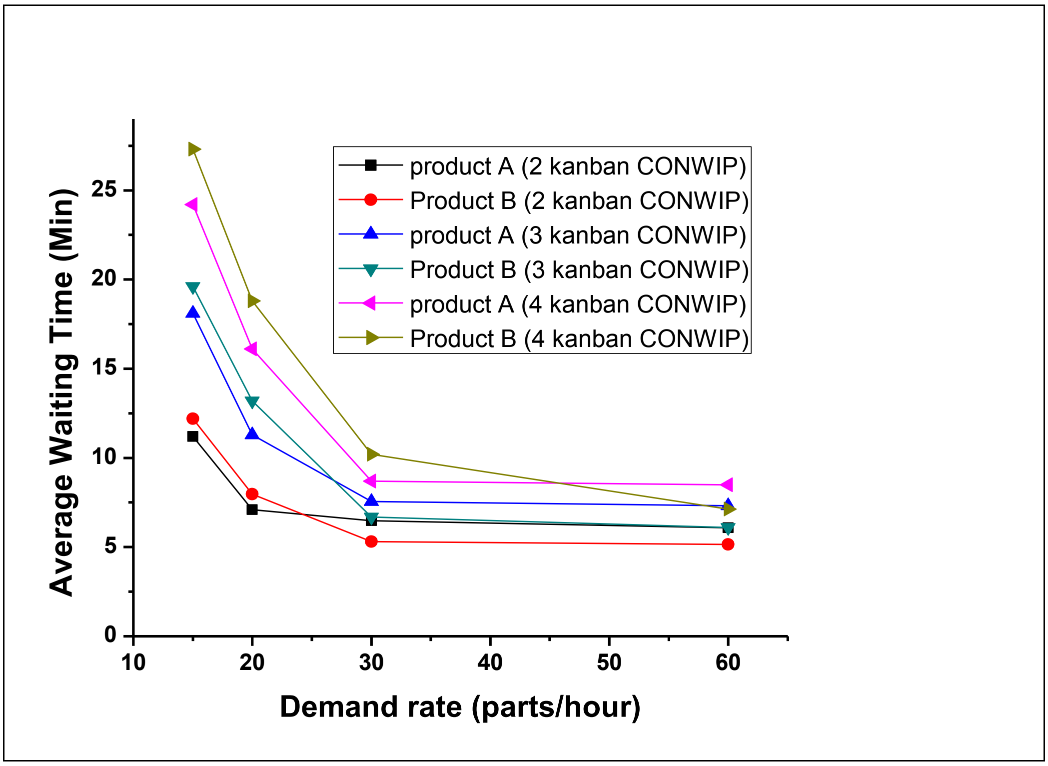

Figure 5.150: Performance Analysis of CONWIP for single flow line Multi stage Multi-product system for AWT (L-H-M)

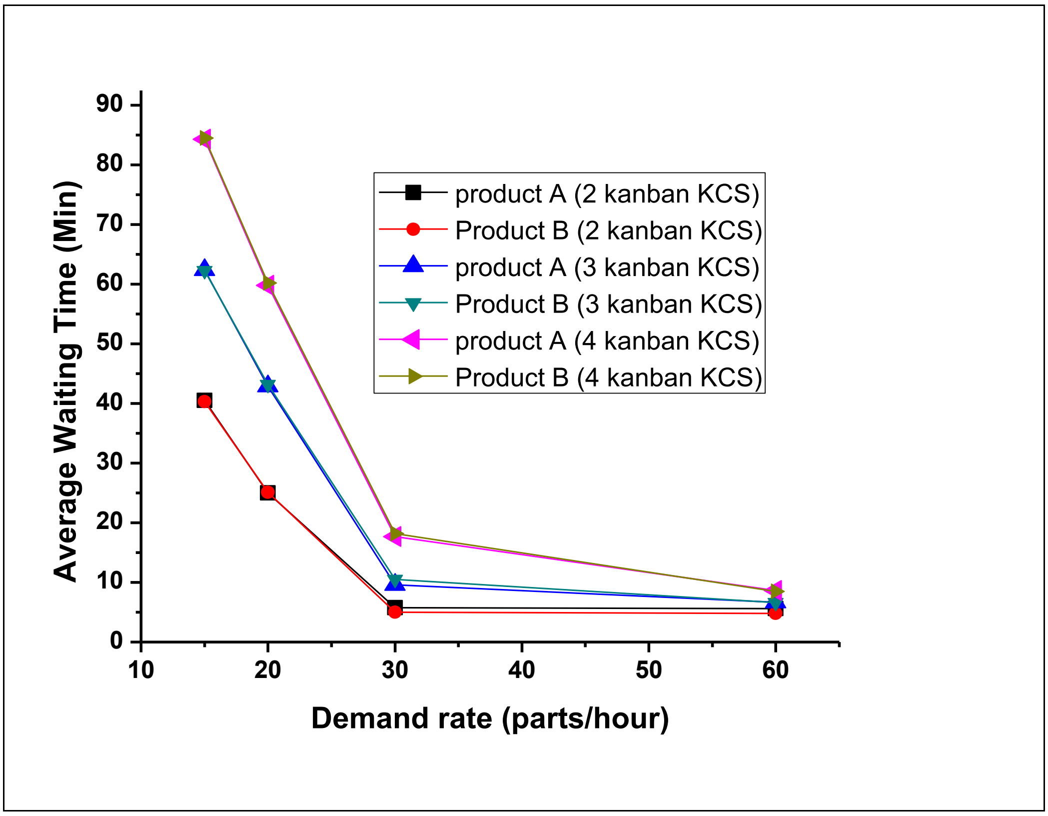

Figure 5.151: Performance Analysis of KCS for single flow line Multi stage Multi-product system for AWT (L-H-M)

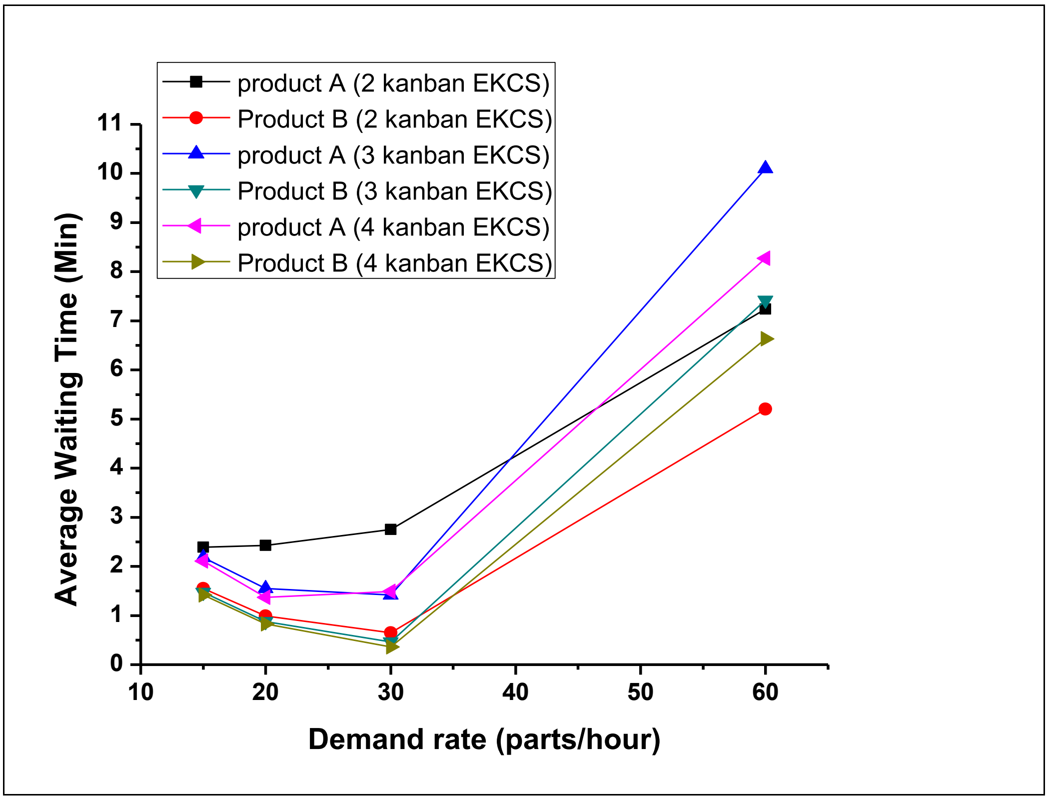

Figure 5.152: Performance Analysis of EKCS for single flow line Multi stage Multi product system for AWT (L-H-M)

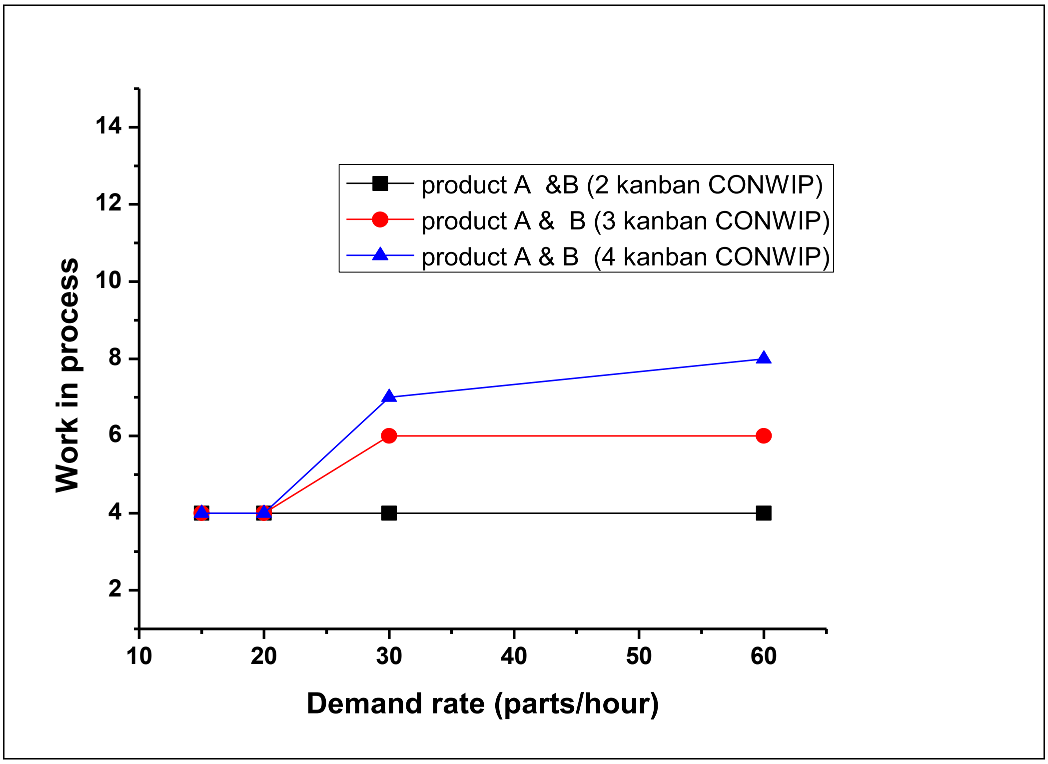

Figure 5.153: Performance Analysis of CONWIP for single flow line Multi stage Multi product system for WIP (L-H-M)

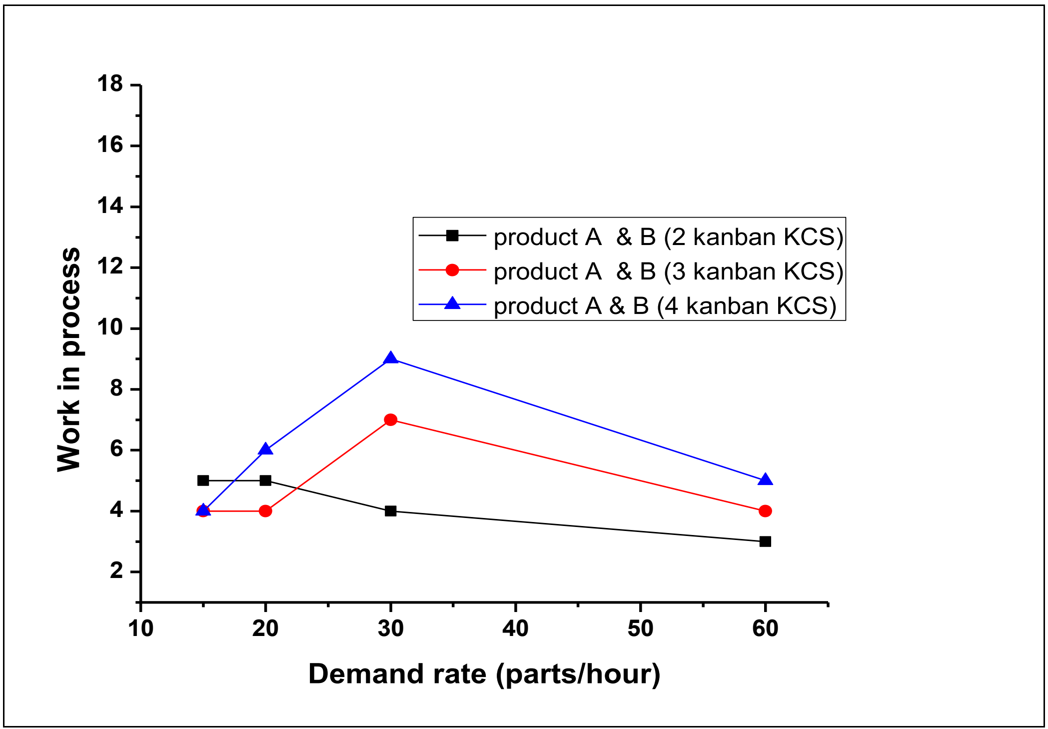

Figure 5.154: Performance Analysis of KCS for single flow line Multi stage Multi-product system for WIP (L-H-M)

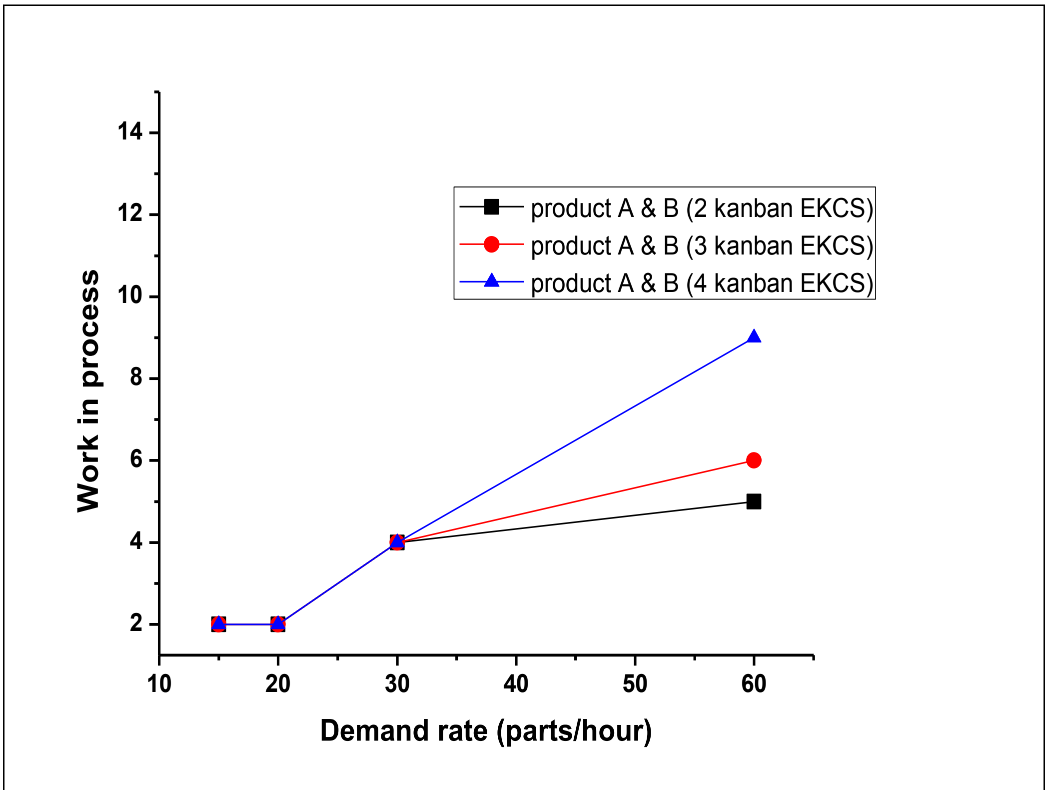

Figure 5.155: Performance Analysis of EKCS for single flow line Multi stage Multi product system for WIP (L-H-M)

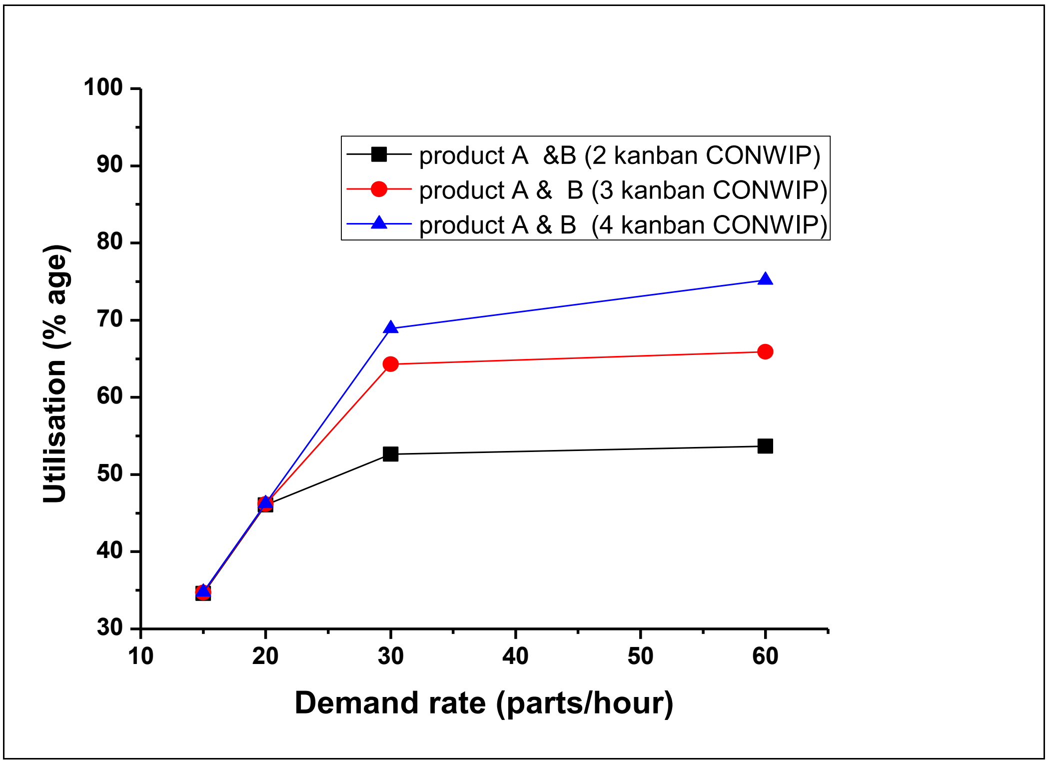

Figure 5.156: Performance Analysis of CONWIP for single flow line Multi stage Multi-product system for utilization (L-H-M)

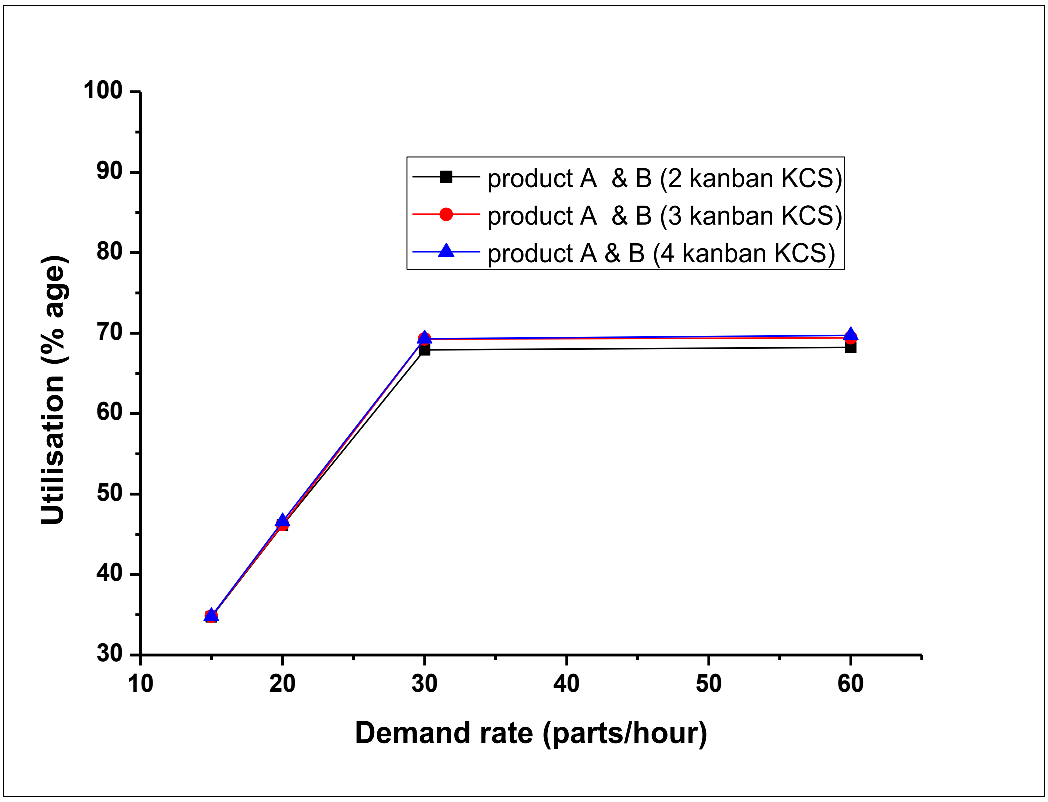

Figure 5.157: Performance Analysis of KCS for single flow line Multi stage Multi-product system for utilization (L-H-M)

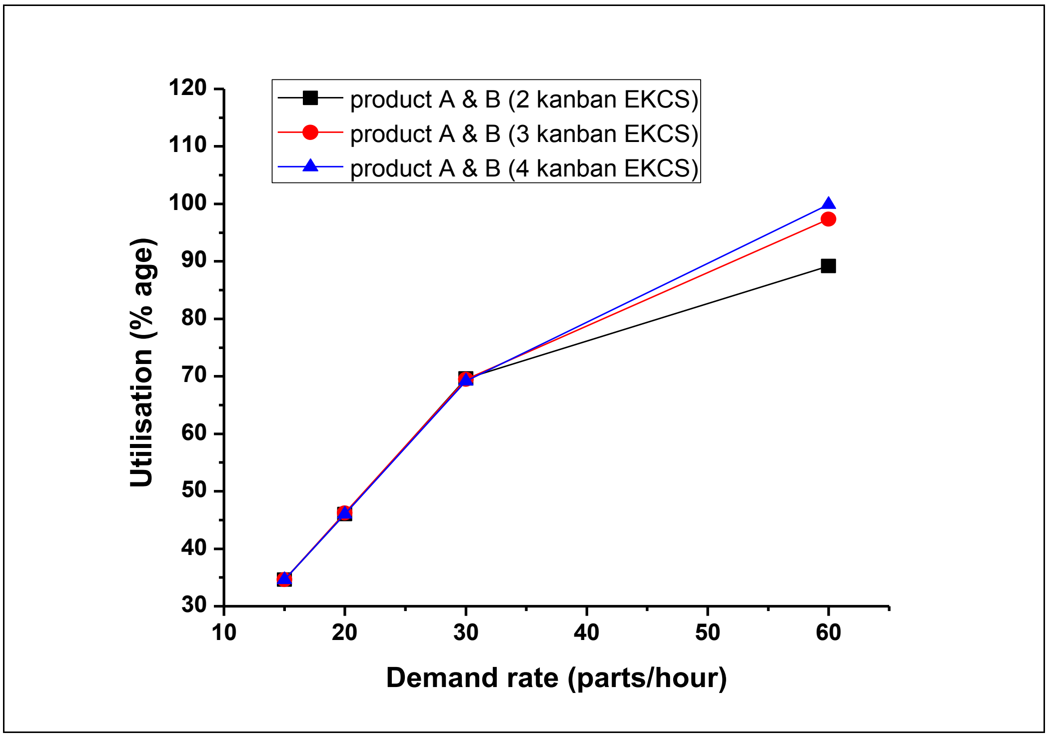

Figure 5.158: Performance Analysis of EKCS for single flow line Multi stage Multi-product system for utilization (L-H-M)

5.4.3.6 Medium-High-Low (M-H-L)

The performance analysis of the pull control systems has low variability for three kanbans per stage at optimum demand rate of 30 parts per hour. The MHL combination is analyzed for performance is given in Table 5.14.

Table 5.14: Performance analysis of single flow line multi stage multi-product system for demand rate 30 parts per hour (MHL combination)

Performance parameters	CONWIP		KCS		EKCS	
	Product A	Product B	Product A	Product B	Product A	Product B
Production	1237	1410	1396	1410	1411	1407
Average waiting time(min)	7.43	6.78	7.53	9.12	1.59	1.14
WIP	6		4		5	
Utilization (%age)	64.43		68.85		69.14	

The production in CONWIP system is less as compared to KCS and EKCS. The production in KCS is 6% higher and EKCS is 10% higher as compared to CONWIP. The KCS system has high AWT as compared to CONWIP and EKCS. The AWT in KCS is 17% high and EKCS is 80% less as compared to CONWIP. The WIP in KCS and EKCS is less as compared to CONWIP. The utilization is less in CONWIP as compared to KCS and EKCS.

The results obtained by simulation in CONWIP, KCS and EKCS for two, three and four kanbans per stage are presented in figures 5.159 to 5.170

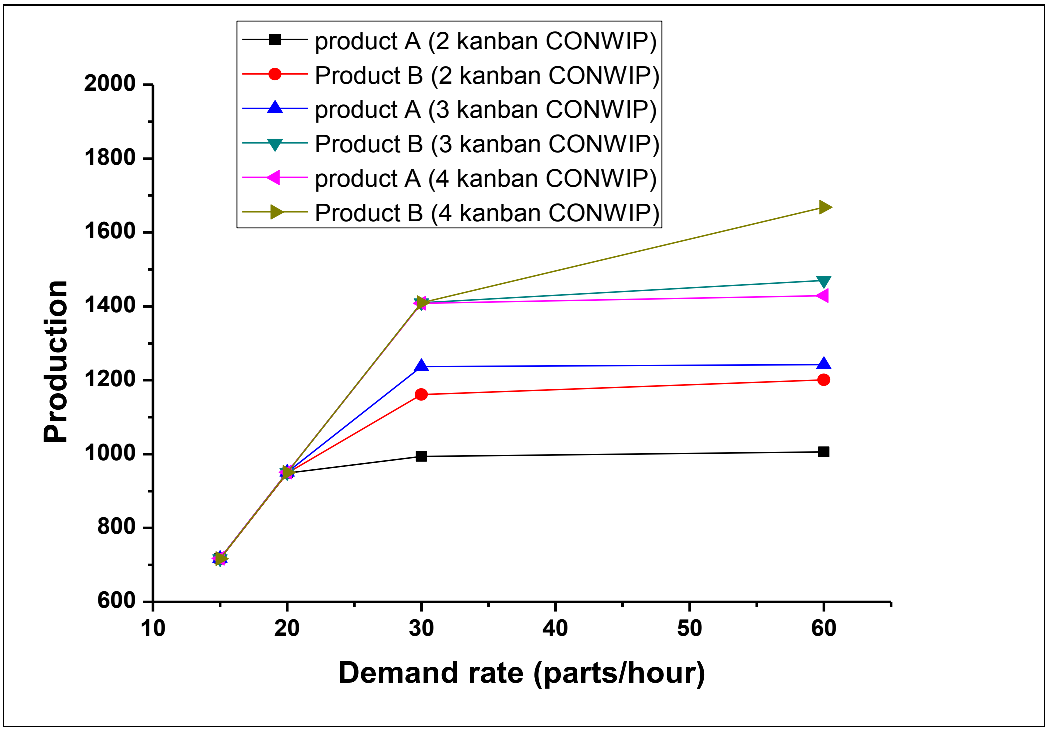

Figure 5.159: Performance Analysis of CONWIP for single flow line Multi stage Multi product system for production (M-H-L)

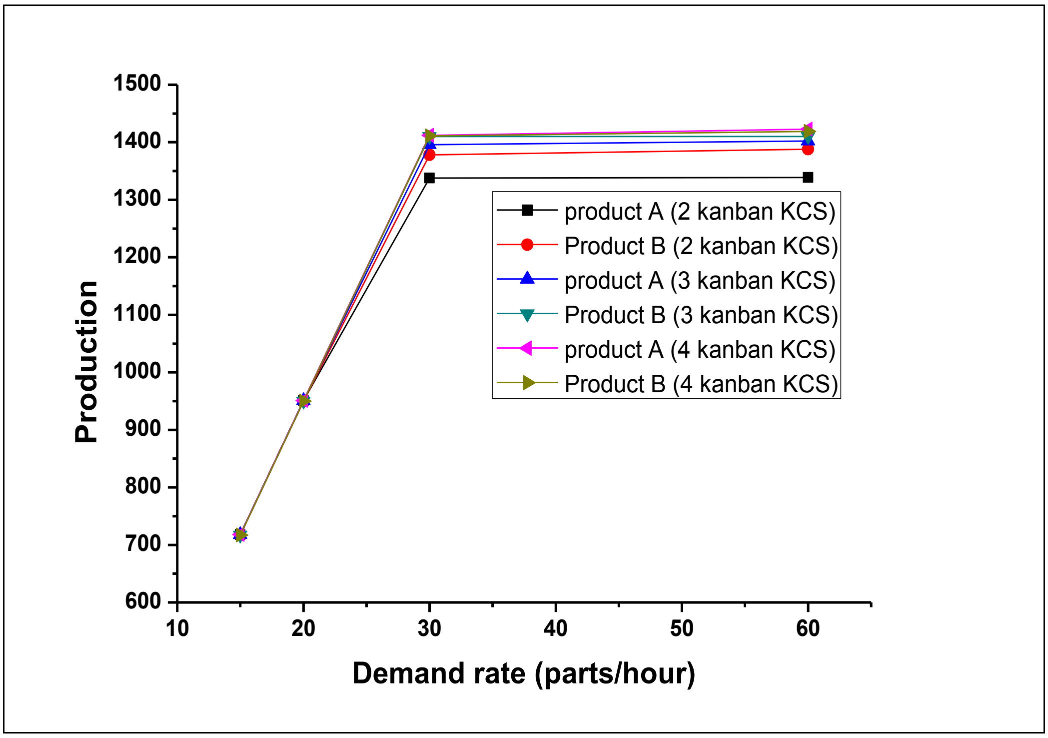

Figure 5.160: Performance Analysis of KCS for single flow line Multi stage Multi product system for production (M-H-L)

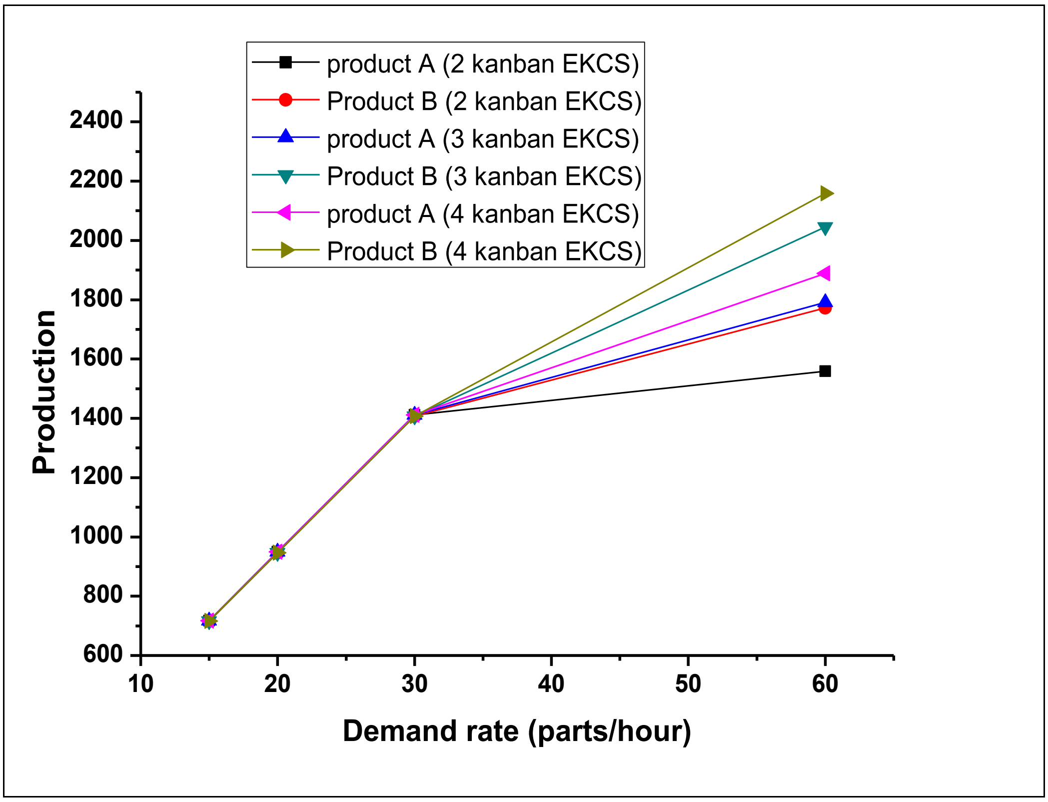

Figure 5.161: Performance Analysis of EKCS for single flow line Multi stage Multi-product system for production (M-H-L)

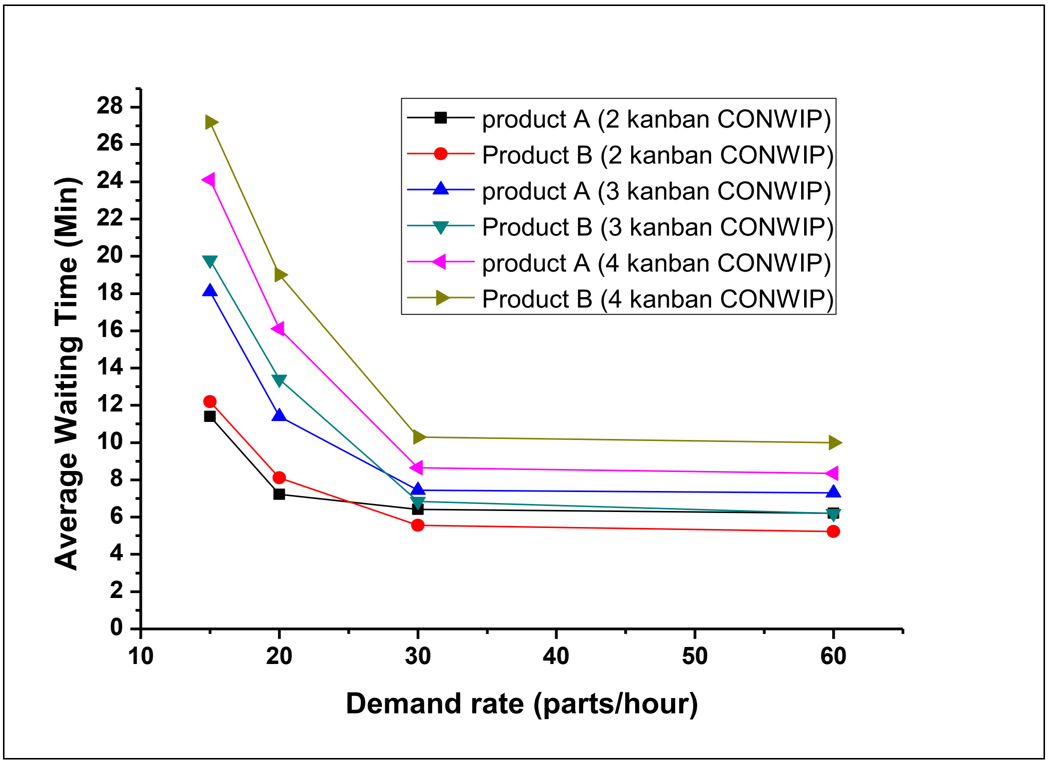

Figure 5.162: Performance Analysis of CONWIP for single flow line Multi stage Multi- product system for AWT (M-H-L)

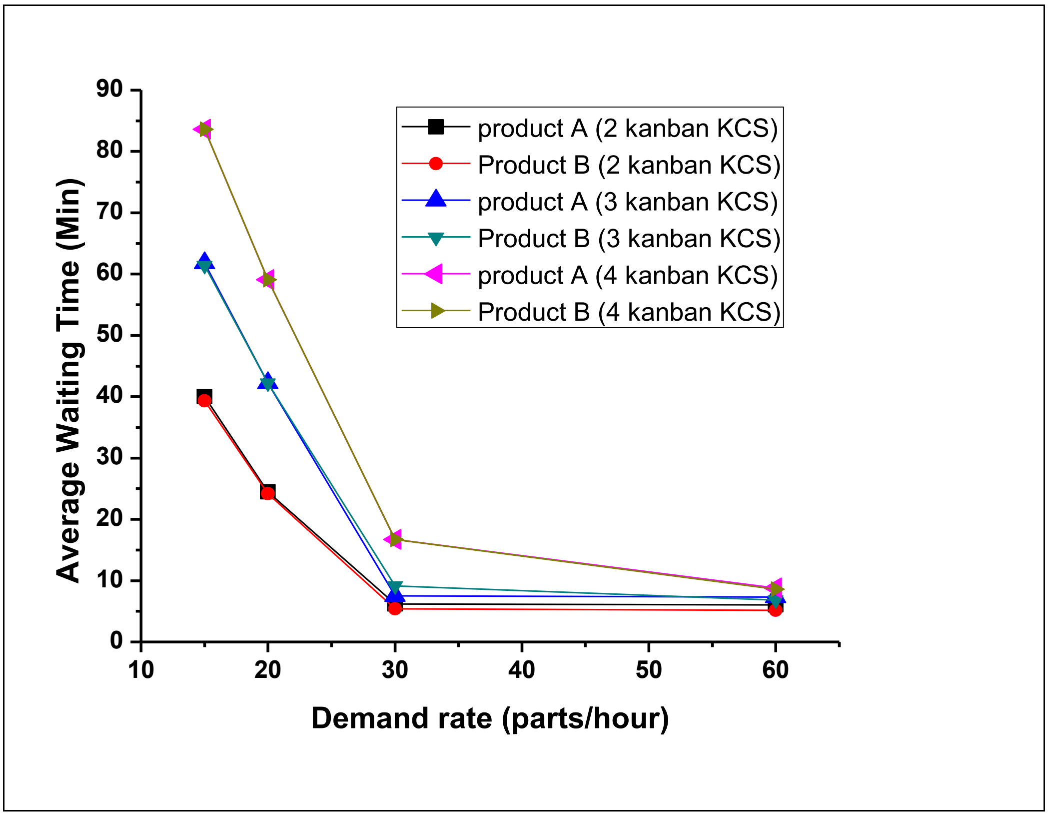

Figure 5.163: Performance Analysis of KCS for single flow line Multi stage Multi product system for AWT (M-H-L)

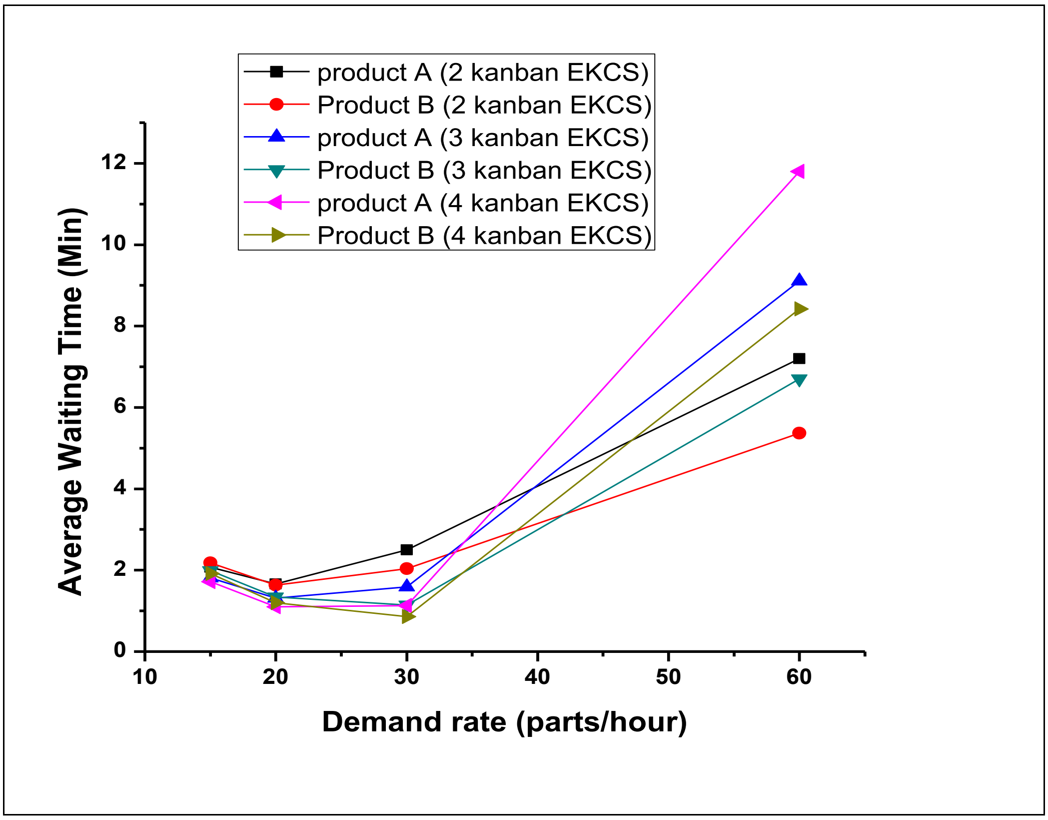

Figure 5.164: Performance Analysis of EKCS for single flow line Multi stage Multi product system for AWT (M-H-L)

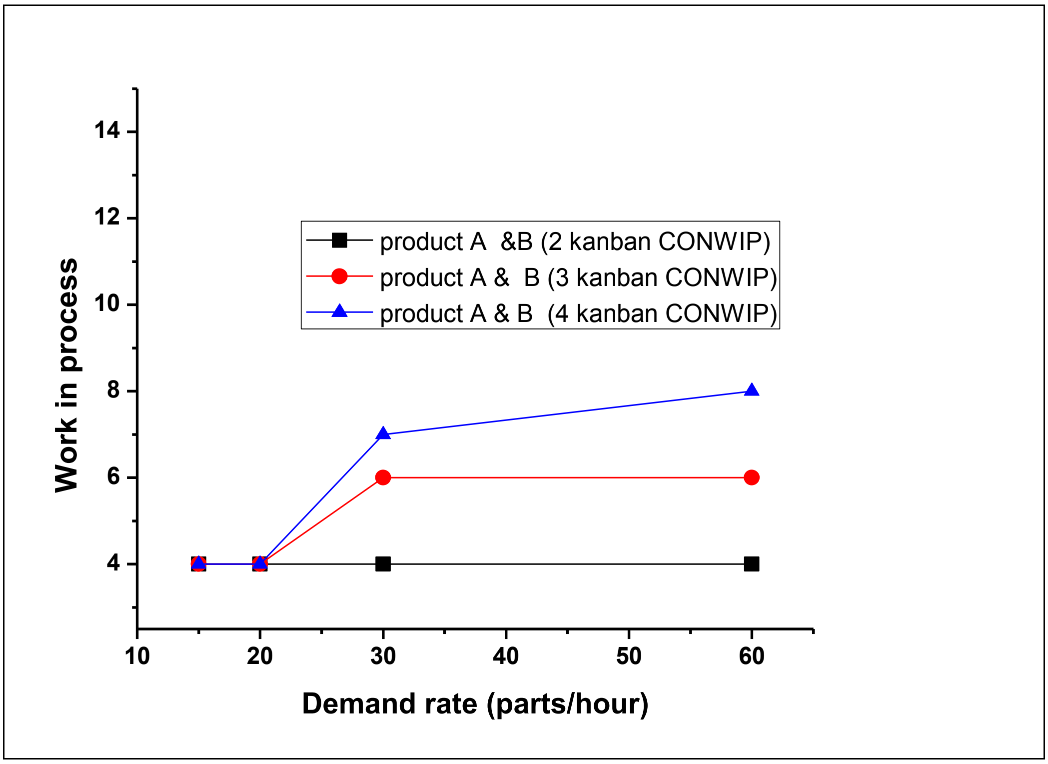

Figure 5.165: Performance Analysis of CONWIP for single flow line Multi stage Multi-product system for WIP (M-H-L)

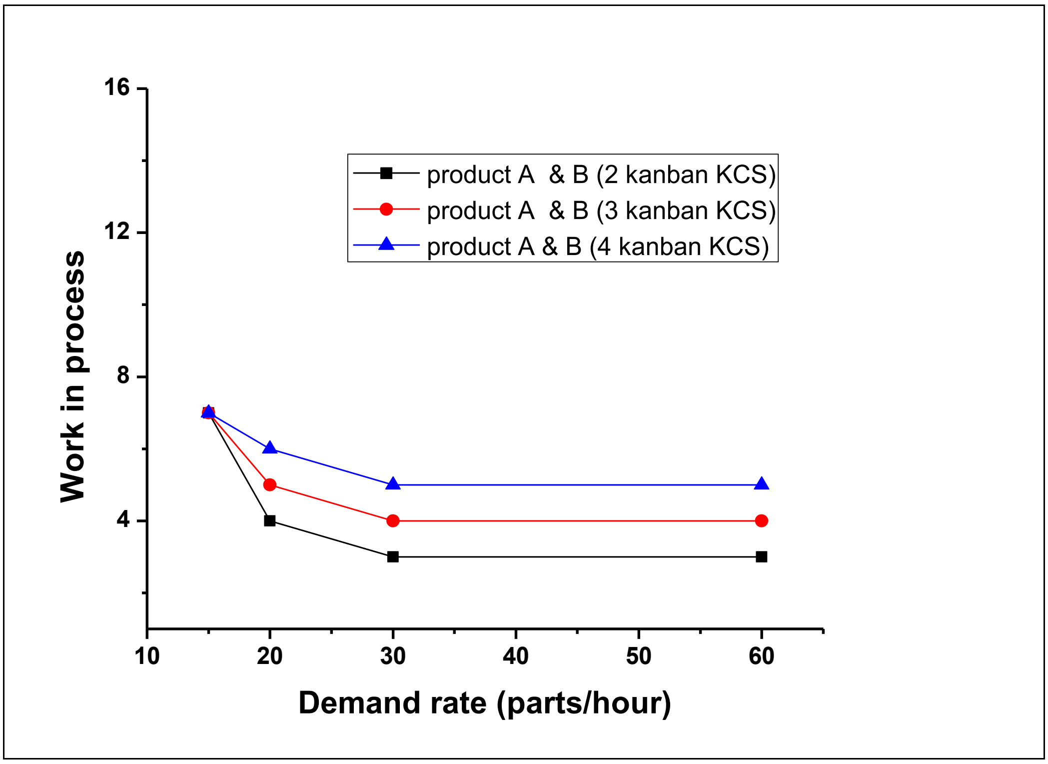

Figure 5.166: Performance Analysis of KCS for single flow line Multi stage Multi-product system for WIP (M-H-L)

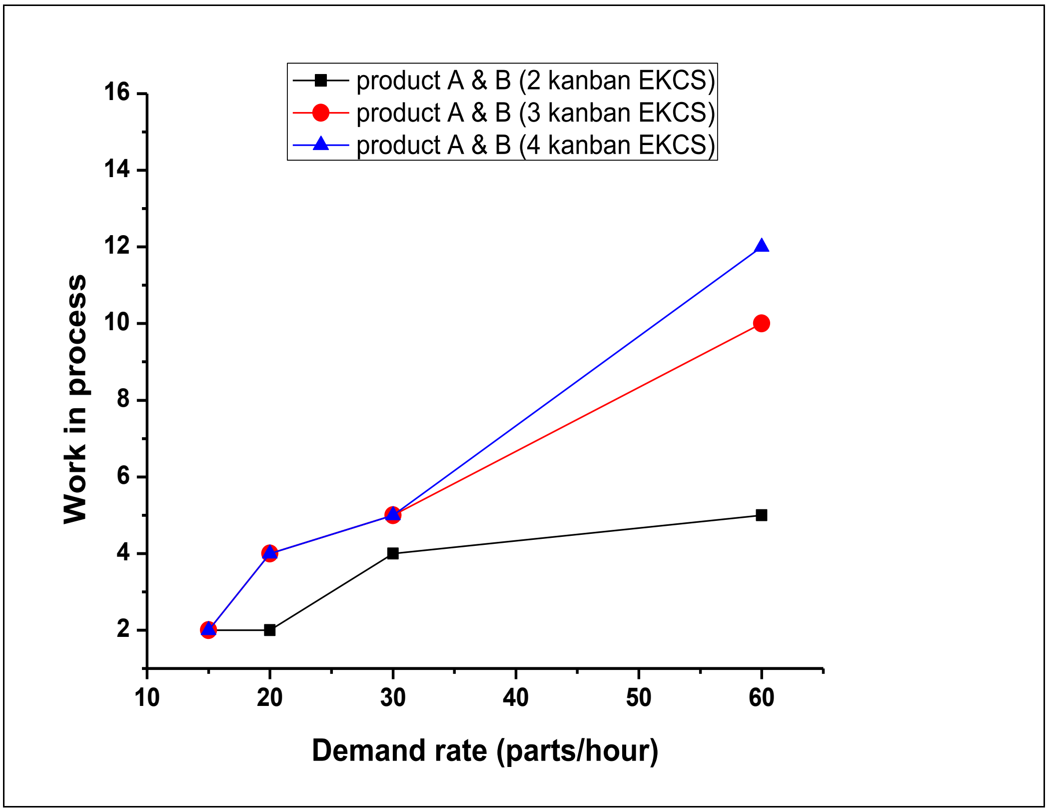

Figure 5.167: Performance Analysis of EKCS for single flow line Multi stage Multi product system for WIP (M-H-L)

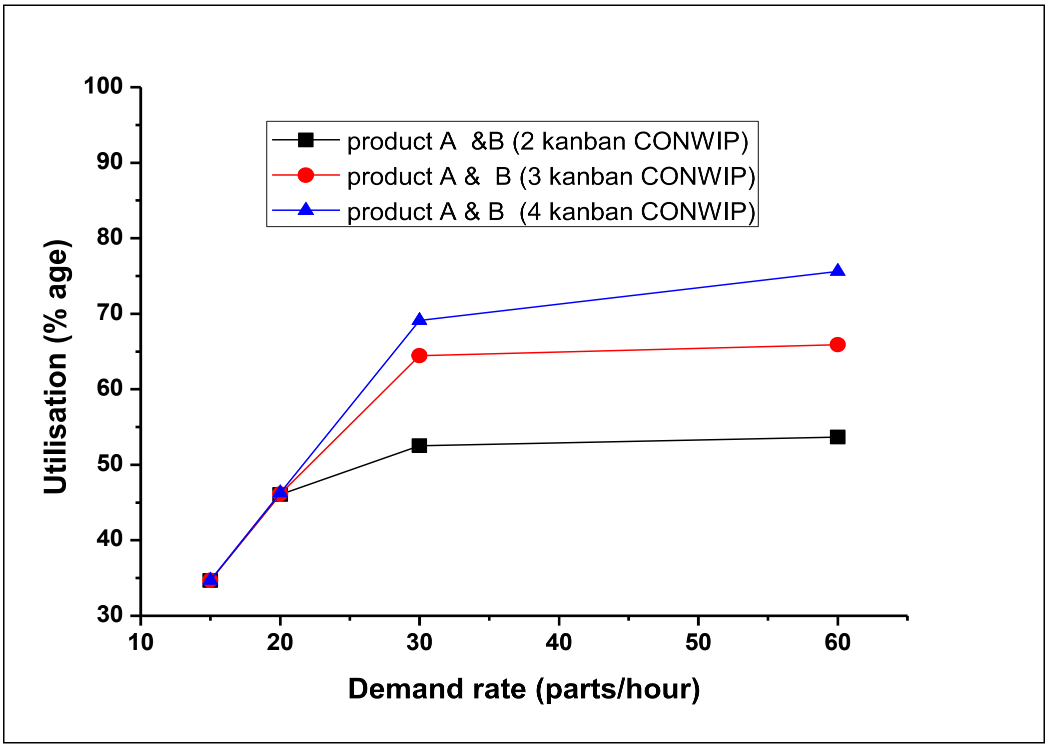

Figure 5.168: Performance Analysis of CONWIP for single flow line Multi stage Multi-product system for utilization (M-H-L)

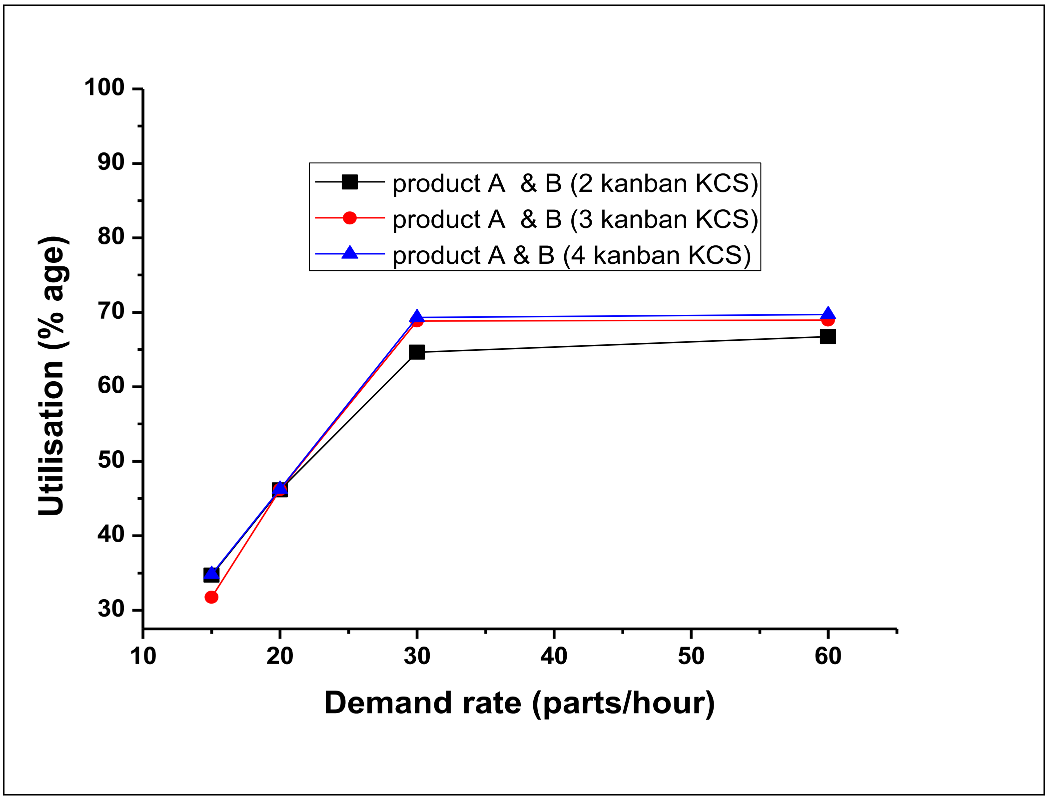

Figure 5.169: Performance Analysis of KCS for single flow line Multi stage Multi product system for utilization (M-H-L)

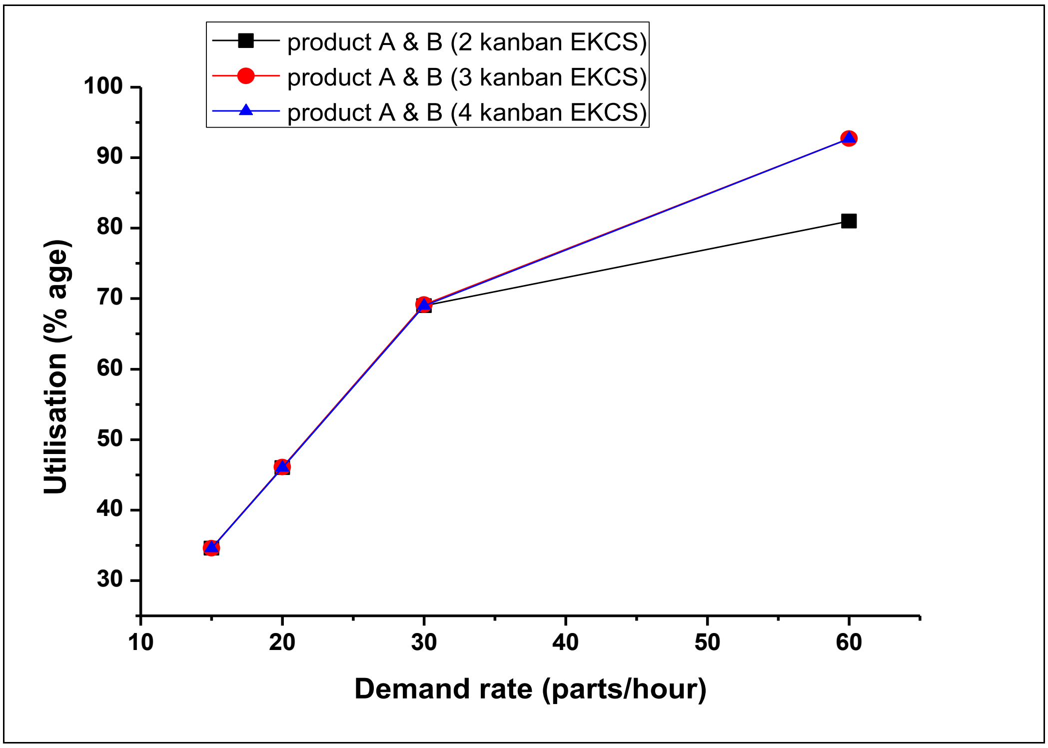

Figure 5.170: Performance Analysis of EKCS for single flow line Multi stage Multi-product system for Utilization (M-H-L)

The performance of the single flow line multi stage multi-product pull control manufacturing systems depends upon the demand mean time D_i, processing mean time t_i, number of kanbans per stage k_i and number of stages S_i. The performance of the pull control systems has minimum variability for three kanbans per stage and at optimum demand rate of 30 parts per hour.

The processing mean time and their combinations for the three stage single flow line have considerable effect on the performance of CONWIP, KCS and EKCS and are described as follows :-

<u>Constant work in process (CONWIP)</u>: The performance of the CONWIP system for different combinations at an optimum demand rate of 30 parts per hour for three kanbans per stage is given in Table 5.15.

Table 5.15: Performance of CONWIP system for single flow line multi stage multi-product system for demand rate 30 parts per hour (all combinations)

Combination	Product Type	Production	Average waiting time (min)	WIP	Utilization (%age)
HLM	A	1219	7.55	6	64.07
	B	1410	6.71		
MLH	A	1219	7.61	6	56.19
	B	1410	6.75		
LMH	A	1210	7.72	6	53.54
	B	1410	6.59		
HML	A	1237	7.42	6	64.46
	B	1410	6.77		
LHM	A	1230	7.55	6	64.33
	B	1410	6.68		
MHL	A	1237	7.43	6	64.33
	B	1410	6.78		

The combinations are divided into three groups; each group consists of two combinations, on the basis of similarity in their performance. When the processing mean time of the third stage i.e. LMH and MLH combinations, is high as compared to other stages, the production and utilization is lower and AWT is higher as compared to other combinations. Further, comparing LMH and MLH combinations, the production and machine utilization in LMH is lower as compared to MLH. Hence LMH stands last among all combinations.

When the processing mean time of the third stage is low i.e. HML and MHL combinations, as compared to other stages, the production and machine utilization is higher and AWT is lower as compared to other combinations. Further, comparing HML and MHL combinations, the production and machine utilization is higher; AWT is lower in HML. Thus, HML combination stands best among all the combinations. When the processing mean time of the third stage is medium i.e. HLM and LHM combinations, as compared to other stages, the production, AWT and machine utilization has intermediate values as compared to other combinations.

Kanban control system (KCS): The performance analysis of KCS for different combinations of processing mean time at optimum demand rate of 30 parts per hour for three kanbans per stage is given in Table 5.16.

Table 5.16: Performance of KCS for single flow line multi stage multi-product system for demand rate 30 parts per hour (all combinations)

Combination	Product type	Production	Average waiting time (min)	WIP	Utilization (%age)
HLM	A	1397	6.97	4	57.8
	B	1410	6.83		
MLH	A	1408	11.84	5	68.9
	B	1411	11.1		
LMH	A	1408	10.84	5	57.86
	B	1411	11.1		
HML	A	1394	7.18	6	68
	B	1406	7.32		
LHM	A	1412	9.58	7	69.26
	B	1410	10.5		
MHL	A	1396	7.53	5	68.85
	B	1410	9.12		

The combinations due to change in sequence of processing mean time has effect on the performance parameters i.e. production, AWT, utilization and WIP. The combinations are divided into two groups for analysis; each group consists of three combinations, on the basis of similarity in their performance. The first group with HLM, HML and MHL combinations has low production and low AWT as compared to other combinations. Comparing these combinations, HML has lowest production as compared to HLM and MHL combinations. The MHL has the higher AWT and machine utilization, whereas WIP is slightly less than other two combinations. Considering production, utilization and WIP, HML stands last of all combinations. Considering AWT, MHL combination stands last of all combinations where production is increased by 0.25%; WIP and machine utilization being slightly more as compared to HML combination.

The other group i.e. MLH, LMH and LHM combinations, has higher production, AWT and WIP as compared to other combinations. Comparing these combinations, the production, and machine utilization is higher; AWT is lower; in LHM combination as compared to MLH and LMH combinations. The WIP in LHM is slightly high than other two combinations. Considering the production and AWT, LHM stands as the best combination. Considering machine utilization and WIP, LMH stands as best combination where the production is decreased by 0.1%; AWT increased by 9.3% as compared to LHM combination.

Considering production, HML is last of all combinations whereas LHM stands as best of all combinations.

Extended Kanban Control system (EKCS): The performance of EKCS is analyzed for various combinations of processing mean time. The performance of EKCS for different combinations at optimum demand rate of 30 parts per stage for three kanban per stage is given in Table 5.17. The combinations are divided into two groups for analysis; each group consists of three combinations, on the basis of similarity in their performance. The first group includes HLM, MLH and LMH; whereas the other group has HML, LHM and MHL combinations. The first group i.e. HLM, MLH and LMH combinations, has lower production, lower machine utilization, lower AWT and lower WIP as compared to other combinations

Table 5.17: Performance of EKCS for multi stage multi-product system for demand rate 30 parts per hour (all combination)

Combination	Product type	Production	Average waiting time (min)	WIP	Utilization (%age)
HLM	A	1411	0.87	4	57.8
	B	1364	0.72		
MLH	A	1409	0.83	4	68.27
	B	1400	0.77		
LMH	A	1409	1	3	57.85
	B	1402	0.69		
HML	A	1411	1.5	5	69.14
	B	1407	1.04		
LHM	A	1411	1.42	5	69.45
	B	1408	0.6		
MHL	A	1411	1.59	5	69.14
	B	1407	1.14		

Among these three combinations, the production, AWT and machine utilization in HLM combination is lowest. Thus, HLM stands last among all the combinations.

The other group i.e. HML, LHM and MHL combinations, has higher production, higher AWT, higher machine utilization and higher WIP as compared to other combinations. Comparing these three combinations, the production and machine utilization is higher and AWT is less in LHM as compared to other combinations. Therefore, LHM stands as the best among all the combinations.

<u>Performance Analysis</u>

The performance of single flow line multi stage multi-product pull control manufacturing systems is analyzed for three kanbans per stage for low demand rate, high demand rate and optimum demand rate and is given in Table 5.18

The production and utilization in KCS, EKCS and CONWIP system is similar at low demand rate from 0 to 20 parts per hour because the processing mean time t_i of each stage is less than the demand mean time D_i. The AWT is lowest in EKCS and in KCS is highest. The AWT for KCS is 58% higher than CONWIP system and 97% higher than EKCS. The WIP in KCS is high; EKCS is low as compared to CONWIP system. For increase in demand rate, the AWT increases and WIP decreases for the pull control manufacturing systems. Thus, at low demand rate, EKCS is the best as compared to KCS and CONWIP.

For high demand rate, the production in CONWIP system is lowest and EKCS is highest. The production in KCS is approximately 8.5% more and in EKCS is approximately 39% more as compared to CONWIP system. The AWT is approximately 6.7% less in KCS and 25% less in EKCS as compared to CONWIP system. The WIP in KCS and EKCS is equal and is less as compared to CONWIP system. The machine utilization is lowest in KCS and highest in EKCS. In EKCS, the kanban and demand synchronizes with the part at each stage for its movement. This result in increase of production; decrease of AWT and WIP. In KCS, the finished part synchronizes with the demand at the end of flow line for its release. The movement of parts is controlled by the kanbans at the intermittent stages. Thus, AWT and WIP increases depending upon kanban availability. In CONWIP system, the kanban and part synchronizes at the start, but the finished part and demand synchronizes at the end of the flow line. This decreases production; increases the AWT and WIP. Thus, at high demand rate, EKCS is the best as compared to KCS and CONWIP system.

For $D_i \leq t_i$ i.e. at a demand rate of 30 parts per hour, the performance of the pull control systems has minimum variability in production, machine utilization and WIP. The production in EKCS is approximately 5.5% higher; and in KCS is approximately 6% higher; as compared to CONWIP system. The AWT is higher for CONWIP system and minimum for EKCS. Comparing with CONWIP, the AWT is 2.8% less in KCS and 88% less in EKCS. The WIP for KCS and EKCS is similar but less than CONWIP system. The machine utilization in KCS and EKCS are approximately same and is low as compared to CONWIP system. Hence the least variation in performance at a demand rate of 30 parts per hour.

The performance of CONWIP, KCS and EKCS is analyzed for different combinations of processing mean time sequence at an optimum demand rate of 30 parts per hour are given in Table 5.19. Considering all the combinations, the performance of CONWIP system is least as compared to KCS and EKCS, hence not considered for further analysis. The single flow line with low processing mean time at first stage and medium processing mean time at third stage i.e. LHM, is the best combination for KCS and EKCS having similar production and machine utilization. However, the AWT and WIP respectively in EKCS is approximately 83% less and 28% less as compared to KCS. The flow line with high processing mean time at first stage and medium processing mean time at third stage i.e. HLM, stands last among all combinations for KCS and EKCS considering production and machine utilization. The production is approximately 0.53% less in KCS and 1.5% less in EKCS; AWT is 31% less in KCS and 21% less in EKCS; machine utilization is 42% less in KCS and 20% in EKCS; 42% less in KCS and 20% less in EKCS, as compared to the best combination i.e. LHM combination.

Table 5.18: Performance of CONWIP, KCS and EKCS for single flow line multi stage multi-product system for three kanban per stage

Demand Rate hour	Production						Average Waiting time (Min)						WIP			Machine Utilization %age		
	CONWIP		KCS		EKCS		CONWIP		KCS		EKCS		CONWIP	KCS	EKCS	CONWIP	KCS	EKCS
	A	B	A	B	A	B	A	B	A	B	A	B	A&B	A&B	A&B	A&B	A&B	A&B
15	718	717	718	717	717	692	25.1	26.1	61.7	61.8	1.66	1.93	5	7	1	34.65	29.22	28.55
20	951	950	951	950	950	916	18	19.7	42.2	42.7	1.16	1.15	4	7	2	46.13	38.89	38
30	1219	1410	1397	1410	1411	1364	7.5	6.7	6.97	6.83	0.87	0.72	6	4	4	64.07	57.8	57.85
60	1231	1433	1403	1410	1723	1982	7.48	6.6	6.79	6.56	5.72	4.94	6	4	4	64.66	58.04	90.08

Table 5.19: Performance analysis of CONWIP, KCS and EKCS for multi stage multi-product system for demand rate 30 parts per hour (all combinations)

Combination	Product type	Production			Average Waiting time (Min)			WIP			Machine Utilization (%age)		
		CONWIP	KCS	EKCS	CONWIP	KCS	EKCS	CONWIP	KCS	EKCS	CONWIP	KCS	EKCS
HLM	A	1219	1397	1411	7.55	6.97	0.87	6	4	4	64.07	57.8	57.85
	B	1410	1410	1364	6.71	6.83	0.72						
MLH	A	1219	1408	1409	7.61	11.84	0.83	6	5	4	56.19	68.9	68.27
	B	1410	1411	1400	6.75	11.1	0.77						
LMH	A	1210	1408	1409	7.72	10.84	1	6	5	3	63.54	57.86	57.85
	B	1410	1411	1402	6.59	11.1	0.69						
HML	A	1237	1394	1411	7.42	7.18	1.5	6	6	5	64.46	68	69.14
	B	1410	1406	1407	6.77	7.32	1.04						
LHM	A	1230	1412	1411	7.55	9.58	1.42	6	7	5	64.33	69.26	69.45
	B	1410	1410	1408	6.68	10.5	0.6						
MHL	A	1237	1396	1411	7.43	7.53	1.59	6	5	5	64.33	68.85	69.14
	B	1410	1410	1407	6.78	9.12	1.14						

5.5 SUMMARY

The network models of KCS, EKCS and CONWIP system are developed in the software MATLAB/SIMULINK R2011b for single flow line multi stage system; multi-line multi stage system; and single flow line multi stage multi-product system. A code is developed as a model in programming language C for single line multi stage system; multi-line multi stage system for validation. The single line multi stage multi-product system is validated through a case study.

The performances of KCS, EKCS and CONWIP system are analyzed for single flow line multi stage manufacturing system for number of kanbans, workstation breakdown and imbalance in processing mean time. The simulation results are validated as shown in figures 5.1 to 5.12. The results obtained analytically are approximately 5% to 7% high as compared to simulation. The performance of the systems has qualitative effect on number of kanbans and depends on it. The performance is optimum and effective, when number of kanbans per stage is less than number of manufacturing stages. The performance of the manufacturing system is optimum for $D_i \leq t_i$ and $K_i \geq S_{i.}$ The effect of imbalance in processing time has effect on the performance of pull system. The performance of KCS and EKCS is good as compared to CONWIP system. The workstation breakdown has considerable effect on the performance parameters i.e., work in process and AWT as given in Tables 5.1 to 5.3. The effect of breakdown on KCS and EKCS is less as compared to CONWIP system.

The performances of the single flow line multi stage multi-product pull control systems are summarized. The production and machine utilization for EKCS is higher as compared to KCS and CONWIP for all the combinations as given in Tables 5.15 to 5.17. Comparatively, the CONWIP has the least production. The EKCS has least AWT among all the systems. The backordered demands are more in CONWIP system as compared to KCS and EKCS because in CONWIP system, the raw part and kanban synchronizes at the start whereas the demand and finished part synchronizes at the end of the flow line. The performance of EKCS and KCS is optimum for the combination with high processing mean time at intermediate stage which leads to high production, high machine utilization and low AWT. Thus, the processing mean time combination is an important constraint for the performance of the systems.

The performances of multi flow line multi stage pull control manufacturing systems have high effect on the coordination of kanban, part and demand. The CONWIP system has least effect as compared to KCS and EKCS. On comparing the production, AWT and work in process, EKCS shows better performance as compared to KCS for variation in demand rate as given in Table 5.7. The performance depends on the optimum demand rate and number of kanbans and satisfying the conditions $Di \leq t_i$ and $K_i \geq S_i$.

After comparing the three pull control systems, EKCS shows best performance and CONWIP shows worst performance for single flow line multi stage multi-product system.

CHAPTER 6

CASE STUDY

6.1 INTRODUCTION

In the modernized manufacturing sector, the industries find a competitive environment to work exclusively for the products of distinguished quality, higher perish ability and demand fluctuation. It is very important to focus on the factors like product quality, on-time delivery, flexibility and cost. Many manufacturing Industries follow make-to-order approach[18]. The make-to-order approach applied to food industry has been discussed [112]. The Pull control manufacturing systems, like KCS have been successfully implemented in few industries. The push manufacturing systems are meant for make-to-stock approach based on the forecast whereas the pull manufacturing systems are meant for make-to-order approach based on the customer demand [25]. However, the make-to-stock approach policy yields high cost due to inventory. In this chapter, the application of single flow line multi stage multi-product pull control system is reviewed as a case study to compare the performance based on simulation results and actual results.

6.2 PROBLEM STATEMENT OF THE CASE STUDY

A small scale industry manufacturing multi products is selected to review as a case study for implementation of CONWIP system, KCS and EKCS. The small scale industry i.e. “Premier manufacturer’s private limited”, located in

Ghaziabad, UP, is manufacturing Gears for its supply to other industries located in and around Delhi. The work force of the industry is 15

The industry manufactures two Gears of different diameters, Gear A and Gear B, with the following operations in sequence and as shown in Figure 6.1.

a) Turning and Gear cutting

b) Gear Chamfering

c) Gear brushing/burnishing.

The processing mean time of above operations for Gear A is 17 minutes, 10 minutes and 22 minutes and for Gear B is 20 minutes, 13 minutes and 18 minutes respectively. The expected demand of each gear type is 20 pieces per day. The industry works 6 days per week (@ 16 hours per day).

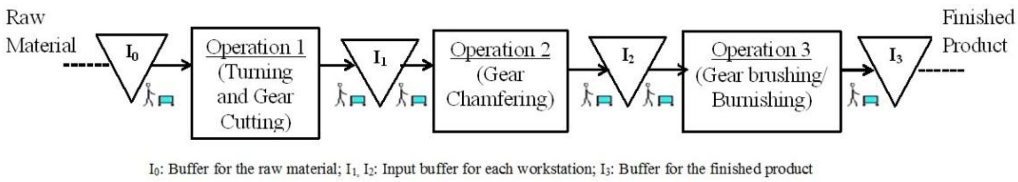

Figure 6.1: Block diagram for material flow on the shop floor

6.3 INITIAL ANALYSIS

Simulation studies are performed for demand rate of 2.5 to 3 parts per day (i.e. Demand mean time 20 minutes to 23 minutes). The models for CONWIP system, KCS and EKCS are developed in the software MATLAB/SIMULINK R2011b and are simulated for 5760 minutes (i.e. Six days @ 16 hours) this includes warm up period of 30 minutes. The performance of the system is analyzed for two, three and four kanbans per stage with and without considering the breakdown. The MTBF is 480 minutes and MTTR is 30 minutes. The simulation results are given in Tables 6.1 to 6.4.

Table 6.1: Simulation results of single flow line multi stage multi product for Production (with and without breakdown)

Demand Rate Parts/ Hour	PRODUCTION (Without Breakdown)																	
	Constant Work in process (CONWIP)						**Kanban Control System (KCS)**						**Extended Kanban Control system (EKCS)**					
	2 Kanban		3 Kanban		4 Kanban		2 Kanban		3 Kanban		4 Kanban		2 Kanban		3 Kanban		4 Kanban	
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
3	84	66	99	82	98	94	116	125	147	131	149	129	138	99	140	129	148	133
2.85	84	66	99	82	123	82	116	125	139	129	139	132	138	97	138	127	138	136
2.72	84	66	99	82	123	82	134	107	139	132	139	136	138	97	138	125	138	133
2.61	84	66	99	82	123	82	127	102	127	126	127	126	120	94	122	121	126	120
PRODUCTION (With Breakdown)																		
3	82	64	99	82	94	95	112	99	144	129	149	122	137	97	134	127	145	129
2.85	83	64	99	81	94	95	113	97	139	129	139	131	135	96	134	126	138	132
2.72	83	64	85	94	94	94	132	96	139	129	139	129	130	96	123	121	136	132
2.61	82	73	87	83	94	94	127	98	127	125	127	126	116	93	118	119	123	117

Table 6.2: Simulation results of single glow line multi stage multi product for AWT (with and without breakdown)

Demand Rate Parts/ Hour	AVERAGE WAITING TIME (Without Breakdown) in Minutes																	
	Constant Work in Process (CONWIP)						**Kanban Control System (KCS)**						**Extended Kanban Control System (EKCS)**					
	2 Kanban		3 Kanban		4 Kanban		2 Kanban		3 Kanban		4 Kanban		2 Kanban		3 Kanban		4 Kanban	
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
3	58	85	79	92.2	102	109	90.2	58.1	112	75	216	99	39.5	64.7	57	43	28	42.8
2.85	58	84	72	100	72.5	124	94	58.2	140	81	261	100	27.7	64.7	47.5	43.2	31.3	19
2.72	54	66	70	96.9	72.5	124	76	73	159	94	261	102	20.4	61	46.5	35.8	32.8	21.8
2.61	69	78	75.5	101	105	101	125	92	221	171	320	246	32.9	50.6	39.9	29.2	19.4	18.8
AVERAGE WAITING TIME (With Breakdown) in Minutes																		
3	68.4	79.2	74.5	100	103	105	68.9	75.4	104	76	188	104	43.9	68.8	60.8	51.5	62	53.1
2.85	62.1	89.7	74	103	105	108	73.9	76.3	121	79.5	190	102	42.7	68.2	60.7	43.8	60.9	29.2
2.72	59.3	85	90.8	79.2	104	106	82.3	77.9	133	83.9	207	107	40.8	61.7	59.1	55	53	29.1
2.61	67.5	78	92.7	95.8	107	101	135	84.9	182	164	292	218	34.5	48.5	40.3	31.1	43.9	32.9

Table 6.3: Simulation results of single flow line multi stage multi product for Work in process (with and without breakdown)

<table>
<tr><th rowspan="4">Demand Rate Parts/ hour</th><th colspan="18">WORK IN PROCESS (without Breakdown)</th></tr>
<tr><th colspan="6">Constant Work in Process (CONWIP)</th><th colspan="6">Kanban Control System (KCS)</th><th colspan="6">Extended Kanban Control System (EKCS)</th></tr>
<tr><td colspan="2">2 Kanban</td><td colspan="2">3 Kanban</td><td colspan="2">4 Kanban</td><td colspan="2">2 Kanban</td><td colspan="2">3 Kanban</td><td colspan="2">4 Kanban</td><td colspan="2">2 Kanban</td><td colspan="2">3 Kanban</td><td colspan="2">4 Kanban</td></tr>
<tr><th>A</th><th>B</th><th>A</th><th>B</th><th>A</th><th>B</th><th>A</th><th>B</th><th>A</th><th>B</th><th>A</th><th>B</th><th>A</th><th>B</th><th>A</th><th>B</th><th>A</th><th>B</th></tr>
<tr><td>3</td><td colspan="2">4</td><td colspan="2">6</td><td colspan="2">8</td><td colspan="2">6</td><td colspan="2">9</td><td colspan="2">12</td><td colspan="2">8</td><td colspan="2">11</td><td colspan="2">9</td></tr>
<tr><td>2.85</td><td colspan="2">4</td><td colspan="2">6</td><td colspan="2">8</td><td colspan="2">6</td><td colspan="2">8</td><td colspan="2">10</td><td colspan="2">6</td><td colspan="2">7</td><td colspan="2">5</td></tr>
<tr><td>2.72</td><td colspan="2">4</td><td colspan="2">6</td><td colspan="2">8</td><td colspan="2">5</td><td colspan="2">9</td><td colspan="2">8</td><td colspan="2">5</td><td colspan="2">8</td><td colspan="2">6</td></tr>
<tr><td>2.61</td><td colspan="2">4</td><td colspan="2">6</td><td colspan="2">8</td><td colspan="2">8</td><td colspan="2">9</td><td colspan="2">11</td><td colspan="2">7</td><td colspan="2">8</td><td colspan="2">7</td></tr>
<tr><th colspan="19">WORK IN PROCESS (With Breakdown)</th></tr>
<tr><td>3</td><td colspan="2">3</td><td colspan="2">5</td><td colspan="2">7</td><td colspan="2">4</td><td colspan="2">9</td><td colspan="2">10</td><td colspan="2">8</td><td colspan="2">9</td><td colspan="2">11</td></tr>
<tr><td>2.85</td><td colspan="2">3</td><td colspan="2">5</td><td colspan="2">7</td><td colspan="2">8</td><td colspan="2">9</td><td colspan="2">11</td><td colspan="2">5</td><td colspan="2">10</td><td colspan="2">7</td></tr>
<tr><td>2.72</td><td colspan="2">3</td><td colspan="2">5</td><td colspan="2">7</td><td colspan="2">6</td><td colspan="2">9</td><td colspan="2">10</td><td colspan="2">5</td><td colspan="2">8</td><td colspan="2">9</td></tr>
<tr><td>2.61</td><td colspan="2">3</td><td colspan="2">5</td><td colspan="2">7</td><td colspan="2">6</td><td colspan="2">11</td><td colspan="2">12</td><td colspan="2">7</td><td colspan="2">9</td><td colspan="2">13</td></tr>
</table>

Table 6.4: Simulation results of single flow line multi stage multi product for Utilization (with and without Breakdown)

Demand Rate Parts/ Hour	UTILISATION (without Breakdown) in percentage																	
	Constant Work in Process (CONWIP)						Kanban Control System (KCS)						Extended Kanban Control system (EKCS)					
	2 Kanban		3 Kanban		4 Kanban		2 Kanban		3 Kanban		4 Kanban		2 Kanban		3 Kanban		4 Kanban	
	A	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**	**A**	**B**
3	54		67.8		71.4		82		91.67		94.25		81		89.4		92.3	
2.85	53.9		66.7		73.6		82.4		91		92.5		80.47		88.47		91.3	
2.72	53.4		68.4		76.38		80.9		91.25		93.65		80.33		87.99		90.2	
2.61	52.4		68.65		70.35		79		87.2		89.68		77.05		83.78		84.4	
UTILIZATION (With Breakdown) in percentage																		
3	52.75		67.08		68.94		78.8		89.6		92.07		80.35		86.67		90.4	
2.85	53.01		66.05		69		80.35		89.6		92.52		79.57		86.67		90.4	
2.72	53.01		64.7		68.5		80.23		89.6		91.69		78.47		84.18		88.58	
2.61	52.88		62.4		69.65		78.47		86.9		89.26		75.17		82.32		83.61	

The simulation results are analyzed for Gear A and Gear B. For the same input parameters, the production and utilization in KCS and EKCS are similar for a demand rate of 2.72 parts per hour (i.e. demand mean time 22 min) with four kanbans per stage whereas the WIP in EKCS is equal to or less than that of KCS. The AWT in EKCS is less than KCS. For the same input parameters, the production in CONWIP is less as compared to KCS and EKCS. Thus, it was not considered for further analysis. Hence, for the same input parameters and customer demand, the performance of EKCS is optimal as compared to KCS considering production, AWT, work in process and utilization.

6.4 KCS AND EKCS IN INDUSTRY - IMPLEMENTATION

The KCS and EKCS each were implemented on the shop floor for two days on experimental basis. Initially, the workers were imparted training about the working mechanism of KCS and EKCS. The KCS was implemented for the first two days @ 16 hours per day, and the EKCS for the last two days @16 hours per day. The same sets of workers were involved during these four days. A log sheet was maintained to record the machine usage time for computing the utilization. The data was recorded in real time considering the warm up time and breakdown. The same input data was used in the network model developed as discussed earlier and simulated for 1920 minutes for each system. Tables 6.5 to 6.7 shows the comparative performance based on the results obtained from simulation and shop floor.

Table 6.5: Comparative Results of KCS and EKCS for production

Demand mean time 22 min. 4 Kanban/stage	PRODUCTION							
	KCS Simulation		KCS Actual		EKCS Simulation		EKCS Actual	
	A	B	A	B	A	B	A	B
	44	40	36	34	43	43	36	36

Table 6.6: Comparative Results of KCS and EKCS for work in process

Demand mean time 22 minutes 4 Kanban/stage	WORK IN PROCESS			
	KCS Simulation	KCS Actual	EKCS Simulation	EKCS Actual
	8	10	6	8

Table 6.7: Comparative Results of KCS and EKCS for utilization

Demand mean time 22 minutes 4 Kanban/stage	UTILISATION percentage			
	KCS Simulation	KCS Actual	EKCS Simulation	EKCS Actual
	94.48	88	89.5	84.5

The production in EKCS was found relatively more than that of KCS whereas KCS has higher machine utilization than EKCS. The work in process in KCS and EKCS has shown similar variation between simulated and actual results. Thus, considering the production, WIP and machine utilization, the EKCS was found to have optimum performance. Therefore, EKCS was implemented for long time duration to analyze the performance.

6.5 PERFORMANCE REVIEW OF EKCS IN INDUSTRY – A CASE STUDY.

The performance of EKCS implemented in industry was analyzed for one month and the results were recorded on weekly basis. The optimum demand mean time was found to be 22 min i.e. 2.72 parts/hour. The batch size for each type gear was 21. Simultaneously, with the same input data, the system was simulated for one month i.e. four weeks (24 days @16 hours =23040 minutes).

The simulation results and the real time output obtained after four weeks are given in Table 6.8. The Figure 6.2 to 6.4 show the performance comparison of production, utilization and work in process respectively obtained by simulation, actuals before implementing the pull control system and actuals after implementation of EKCS.

Table 6.8: Simulation and actual Results of EKCS

4 Weeks @ 6 days per week	**Production**				**Work in Process**		**Utilization (%age)**	
	Simulation		Actual		Simulation	Actual	Simulation	Actual
	A	B	A	B	A & B		A & B	
	544	543	524	520	4	7	88.2	80 – 83

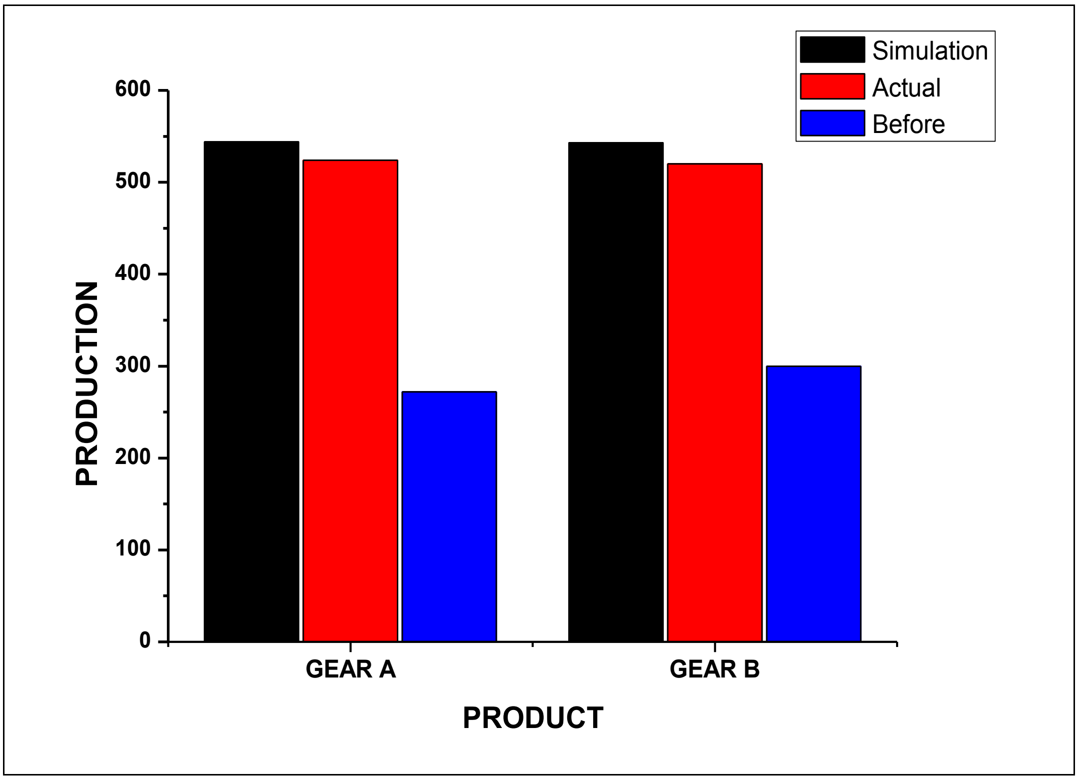

Figure 6.2: Performance comparison of EKCS in Industry for production

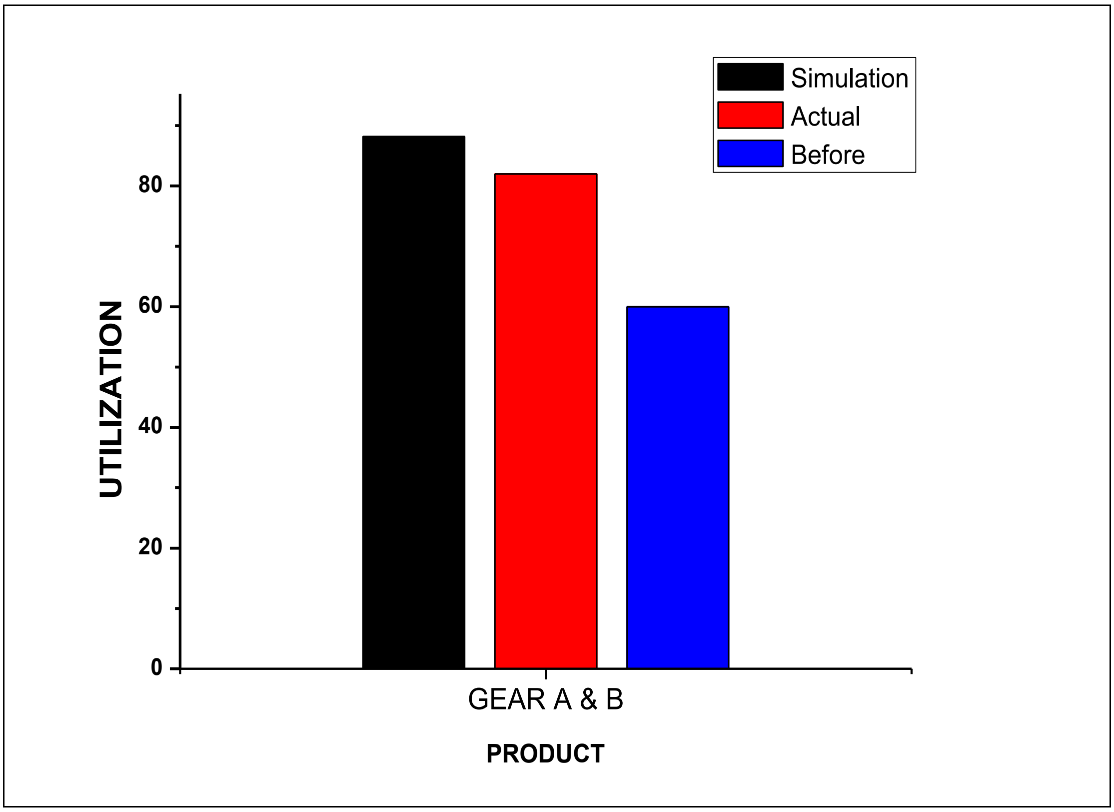

Figure 6.3: Performance Comparison and Analysis of EKCS in Industry for Utilization

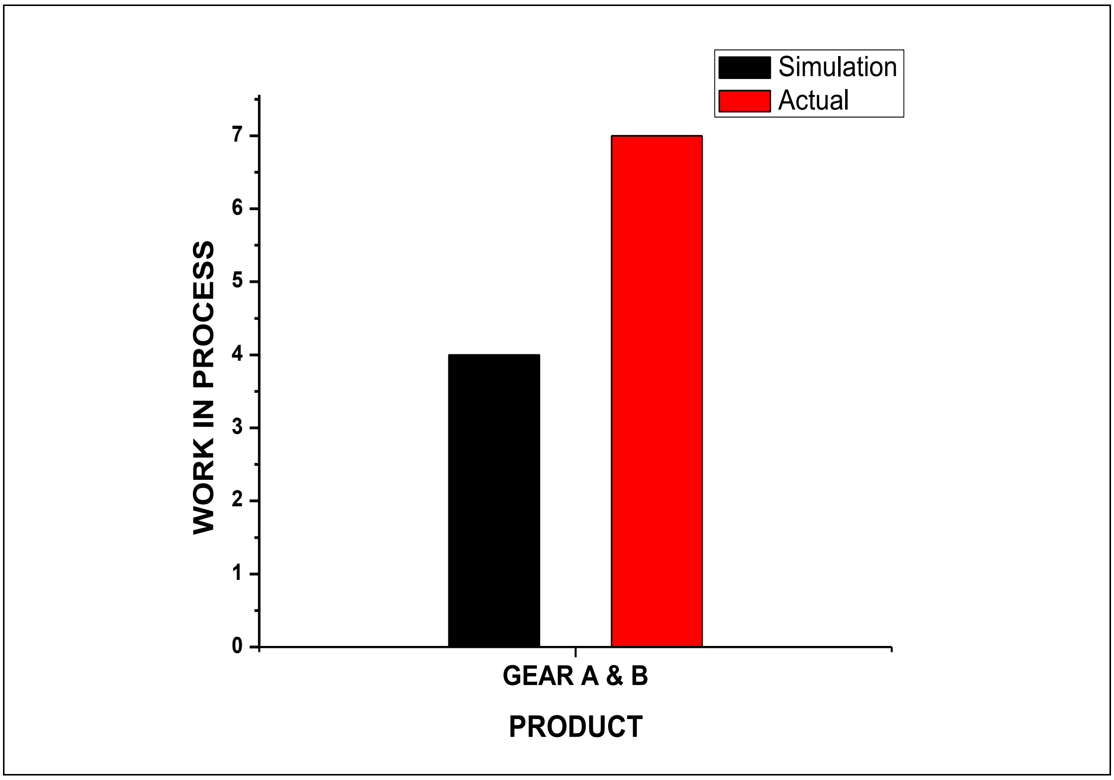

Figure 6.4: Performance comparison of EKCS in Industry for WIP

6.6 SUMMARY

In this chapter, the performance of CONWIP system, KCS and EKCS for single flow line multi stage multi-product system have been analyzed under different levels of system operating parameters and system configurations. Initially, the system is analyzed on the basis of simulation results. Initially, the simulation study indicates that the performance of KCS and EKCS is sensitive to part complexity, breakdown level, AWT and WIP. Hence, it is concluded to implement KCS and EKCS on shop floor to evaluate the relative performance of these pull control systems. After analysis, EKCS emerges relatively better than KCS on the basis of production, work in process and utilization. The performance analysis is given in Tables 6.5 to 6.7. The EKCS is implemented on the shop floor for longer time duration. The performance comparison based on the simulation results and actual results is given in Table 6.8. The comparison of simulation and actual results reveals that the variation between simulation and actual results for production is 4% to 6%. Earlier the industry was producing 12-13 gears of each type per day. After implementing EKCS, the production of the industry has improved to 20 to 21 gears of each type per day. The production has increased by approximately 54 %. The performance improvement is shown in Figures 6.2 to 6.4. The semi-finished component has decreased and machine utilization has improved.

CHAPTER 7

CONCLUSIONS AND SCOPE FOR FUTURE

The main focus of present research is the performance analysis of CONWIP system, KCS and EKCS for single flow line and multi flow line manufacturing system by modeling and simulation. The performance analysis covers various issues like, workstation breakdown, imbalance in processing mean time, multi-product manufacturing and a real time case study. The complete work is categorized into three groups.

1. **Single flow line multi stage system**

   The performance of CONWIP system, KCS and EKCS are analyzed for single flow line multi-stage systems. The performance is investigated using the following environment.

   i) A network model developed by using the software MATLAB/SIMULINK R2011b.

   ii) Validation of the network model by developing a code in object oriented programming language C and data from published papers

   iii) Number of kanbans per stage for optimum demand

   iv) Varying the demand rate with constant system input parameter i.e. processing mean time and number of kanbans per stage.

   v) Workstation breakdown on system configuration parameters.

   vi) Processing mean time imbalance on system performance.

2. Multi flow line multi stage system

The performance of CONWIP system, KCS and EKCS are analyzed for multi flow line multi stage system and is investigated using the following environment.

i) A network model developed by using the software MATLAB/SIMULINK R2011b

ii) Validation of the network model by developing a code in object oriented programming language C and data from published papers.

iii) Varying the demand rate with constant system input parameter i.e. processing mean time and number of kanbans per stage.

3. Single flow line multi stage multi-product system

i) Developing a network model by using the software MATLAB/SIMULINK R2011b.

ii) Validation of the model with the results of case study.

iii) Varying the demand rate with constant system input parameters i.e. processing mean time, number of kanbans per stage.

iv) Processing mean time imbalance on system configuration and performance.

v) Workstation breakdown on system configuration and performance.

vi) Case study

The conclusions drawn from the present study and the scope for future research work in the area are summarized in the following sections.

7.1 CONCLUSIONS

The following are the conclusions derived from this research work.

1. **Based on single flow line multi stage pull control manufacturing systems**

   i) Validation

   - At lower demand rates, the production obtained from software simulation is approximately 2% to 3% low as compared to the production attained by analytical method.
   - At higher demand rates the production obtained from software simulation is approximately 5% to 7% low as compared to the production attained by analytical method.

   ii) Number of kanbans per stage,

   - The performance of the pull control systems depends upon number of kanbans per stage and demand rate. The system requires that number of kanbans k_i should be equal to or greater than number of stages S_i i.e. ($K_i \geq S_i$), for optimum performance.
   - The number of kanbans per stage is three and optimum demand rate is 8 parts per hour.

   iii) Performance (without machine breakdown)

   - At low demand rate, the production and machine utilization are same for CONWIP system, KCS and EKCS.
   - The AWT and WIP in CONWIP are higher than KCS, whereas it is low in EKCS at low demand rates.

- At high demand rates, the production, machine utilization and AWT in KCS and EKCS are similar but higher than CONWIP system.
- The WIP in EKCS is more than KCS and is least for CONWIP system. The backordered demand is least in KCS and most in CONWIP system at high demand rates.
- At optimum demand rate of 8 parts per hour the KCS and EKCS have same production and is 10% more than the production in CONWIP system.
- The AWT in CONWIP system and EKCS respectively is 7.2% less and 51% less than KCS.
- The WIP in CONWIP system is highest and in KCS is lowest.
- KCS gives better performance characteristics as compared to EKCS and CONWIP system.

iv) Performance (With machine breakdown)

Comparison of the performance of system without machine breakdown with the performance of the system with machine breakdown for three kanbans per stage at optimum demand rate is as under:-

- The production and machine utilization are decreased whereas the AWT and work in process are increased.
- The production is decreased by 10% for CONWIP system 1% for both KCS and EKCS.

- The AWT in CONWIP system, KCS and EKCS are increased by 11%, 7% and 4% respectively.
- The variation in WIP and machine utilization is very less.
- KCS shows optimum performance considering the machine breakdown.

v) Imbalance of 0.2min, 0.4min and 0.6min in processing mean time

- In CONWIP system, the production in LMH combination (i.e. processing mean time of first stage is low, second stage is medium and third stage is high) is high as compared to HLM combination. The imbalance of 0.2 min. has high production as compared to 0.6min.The production in LMH is 0.3% more for 0.2 min, 0.5% more for 0.4 min, 1.9% more for 0.6 min as compared to HLM combination.
- There is no effect of imbalance on production in KCS and EKCS for the three combinations.
- The AWT is less for LMH and high for HLM in CONWIP, whereas it is reverse for KCS and EKCS. In CONWIP system, the AWT in LMH is 0.7% more for 0.2 min, 1.3% more for 0.4 min and 3.4% more for 0.6 min as compared to HLM combination. In KCS, the AWT in HLM combination is 2.2% more for 0.2 min and no effect for 0.4 min and 0.6 min as compared to LHM combination. In EKCS, the AWT in HLM is 8.1% more for 0.2 min, 11.3% more for 0.4min and 18% more for 0.6min as compared to LHM combination.

- There is no effect of imbalance on work in process in CONWIP system, KCS and EKCS.
- The backordered demands in LMH combination are more than HLM combination for CONWIP system. There is no effect of imbalance on backordered demands in KCS and EKCS.

2. **Based on multi flow line multi stage manufacturing systems.**

   i) Validation

   - The production obtained from software simulation for CONWIP is 2% to 3% low; for KCS is 3%to 4% low; and for EKCS is 6% low as compared to analytical method for low demand mean time.
   - The production obtained from software simulation for CONWIP, KCS and EKCS is 3% lower than the production determined by analytical approach for high demand mean time.

   ii) Performance Comparison and analysis

   - At low demand rates, the production and utilization in CONWIP system, KCS and EKCS are similar.
   - The AWT in CONWIP system is highest and EKCS is lowest at low demand rates.
   - At high demand rates, the production in EKCS is 20% more than KCS and 47% more than CONWIP system. The AWT and utilization in KCS and EKCS are similar and is approximately 36% more than CONWIP system. The WIP in KCS is highest and CONWIP is lowest.

- The production in EKCS is 2.6% higher than KCS and 29% higher than CONWIP system at optimum demand rate of 8 parts per hour. Production is unaffected in CONWIP system at high demand rates.
- The AWT in EKCS is approximately 40% less and in CONWIP is approximately 6% less as compared to KCS at optimum demand rate. The machine utilization is same in KCS and EKCS whereas in CONWIP system it is approximately 28% less than EKCS and KCS.
- The WIP in KCS is higher as compared to EKCS and CONWIP system at optimum demand rate.
- EKCS shows better performance than KCS and CONWIP systems. for optimum demand rate and number of kanbans per stage.

3. Based on single line multi stage multi-product system

i) Performance

- The production and machine utilization are equal for CONWIP system, KCS and EKCS at low demand rates.
- The WIP and AWT in KCS are highest and in EKCS is lowest at low demand rates.
- The production in EKCS is highest and in CONWIP is lowest at high demand rates.
- The AWT and work in process in EKCS is less as compared to KCS and CONWIP system at high demand rates.
- The machine utilization is high in EKCS, low in KCS and is intermediate in CONWIP system at higher demand rates.

- At an optimum demand rate of 30 parts per hour i.e. $D_i \leq t_i$, the production and machine utilization in EKCS and KCS is higher as compared to CONWIP system.
- The AWT for EKCS is less as compared to CONWIP system and KCS at optimum demand rate.
- The WIP for EKCS and KCS are same but less than CONWIP system.

ii) Effect of Imbalance

- The effect of sequence of imbalance on processing mean time influences the performance of the system.
- The performance of CONWIP system is low as compared to KCS and EKCS for all combinations.
- The flow line with high processing mean time at first stage and medium at third stage i.e. HLM, stands last among all combinations for KCS and EKCS.
- The flow line with low processing mean time at first stage and medium at third stage i.e. LHM is the best combination for KCS and EKCS.
- EKCS is the best pull control system considering AWT , WIP and production as compared to KCS

iii) **case study**

- The variation in production is 4% between simulated results and actual results after validation.

- On the basis of simulation results, the production, AWT and utilization is optimum for EKCS as compared to KCS at an optimum demand rate of 2.72 parts per hour.
- The EKCS is implemented in industry for one month. The production is improved by approximately 54%.
- The machine utilization and work in process have shown significant improvement.

7.2 RESEARCH CONTRIBUTIONS

a. The CONWIP system, KCS and EKCS are more performance sensitive at high demand rates. The performance behavior of the system depends on demand mean time and processing mean time.

b. The optimum performance of pull control system depends upon effective coordination of number of kanbans and demand mean time. It should satisfy the condition $K_i \geq S_i$.

c. For balanced and unbalanced single flow line multi stage manufacturing system, with and without breakdown, KCS gives better performance irrespective of number of stages.

d. The part movement in a flow line depends on number of kanbans per stage, demand rate, processing mean time and number of synchronizations.

e. Multi flow line being complex may have more work in process. Thus, EKCS shows superior performance and is more effective for the conditions $Di \leq t_i$ and $K_i \geq S_i$.

f. The performance of single flow line multi stage multi-product manufacturing is more responsive to the conditions Di $\leq$ t_i. The performance of KCS and EKCS is superior when the processing mean time of downstream stage is higher than that of upstream stages.

g. In a single flow line system, EKCS shows better performance than other systems for multi-product manufacturing whereas KCS shows better performance than other systems for single product manufacturing.

h. Implementation of EKCS in industry showed remarkable improvement in the performance.

7.3 FUTURE SCOPES OF RESEARCH

A very exhaustive work has been already done before this investigation but still a lot can be done in future. The proposed future work in the relevant area may be as follows:

a. Developing new hybrid systems combinations with CONWIP and inventory systems for serial and non-serial flow systems.

b. Developing Serial and non-serial flow line hybrid systems for single and multi-product by using simulation and analytical approaches.

c. The performance analysis of pull control systems in the areas like inventory control, inspection, cost effectiveness, productivity, safety, total quality management etc.

d. Further, the system can be complete by using heuristic algorithm, genetic algorithm and simulated annealing methods.

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APPENDIX A

C- PROGRAMMES

A1: C Coded Programme – CONWIP: Single line multi stage system

```
#include<iostream.h>
#include<conio.h>
void main()
{
clrscr();
long int T,P,t1,t2,t3,d,z,Q;
cout<<"Enter the simulation time :-";
cin>>T;
z=T;
cout<<"\n Enter the number of Kanban :- ";
cin>>P;
Q=P;
cout<<"\n Enter the processing time of station 1 :- ";
cin>>t1;
cout<<"\n Enter the processing time of station 2 :- ";
cin>>t2;
cout<<"\n Enter the processing time of station 3 :- ";
cin>>t3;
cout<<"Enter the demand :- ";
cin>>d;
long int I3=0,I1=0,I2=0,I=1;
long int A=0,m=0,i=0,j=0,k=0;
I3--;
A++;
P++;
while(T>0)
{
if(P>0)
{
i++;
if(i%t1==0)
{
I1++;
I++;
P--;
}
}
```

```
if(I1>0)
{
j++;
if(j%t2==0)
{
I2++;
I1--;
}
}
if(I2>0)
{
k++;
if(k%t3==0)
{
I3++;
I2--;
}
}
m++;
if((I3>0) && (m%d==0))
{
I3--;
A++;
P++;
}
T--;
}
long int q=0,n=1,x;
float w=0;
x=t1+t2+t3;
P=Q+1;
T=z;
while(T>0)
{
if(Q==1)
{
if(n<P)
{
q=(n*d)-x;
x=x+5;
}
}
else
{
if(n<=P)
{
q=(n*d)-x;
x=x+5;
}
```

```
}
n++;
w=w+q;
T=T-d;
}
n++;
w=w/n;
cout<<"\n Total number of finished parts delivered :- ";
cout<<A;
A=A+I3;
cout<<"\n Total parts produced :- ";
cout<<A;
I=I-A;
cout<<"\n Work in progress :- ";
cout<<I;
cout<<"\n Average time :- ";
cout<<w;
getch();
}:
```

A2: C –Coded program – KCS : Single line multi stage system

```
#include<iostream.h>
#include<conio.h>
void main()
{
clrscr();
long int T,P,t1,t2,t3,d,t;
long int I1=0,I2=0,I3=0;
long int DA1,DA2,DA3;
int i=0,j=0,k=0,m=0,g=0;
int FP1=0,FP2=0,FP3=0,I,A=1;
cout<<"Enter the simulation time :-";
cin>>T;
cout<<"\n Enter the number of Kanban (enter in multiple of 3):- ";
cin>>P;
cout<<"\n Enter the processing time of station 1 :- ";
cin>>t1;
cout<<"\n Enter the processing time of station 2 :- ";
cin>>t2;
cout<<"\n Enter the processing time of station 3 :- ";
cin>>t3;
cout<<"\n Enter the demand :- ";
cin>>d;
I=1;
t=t1+t2+t3;
DA1=DA2=DA3=P/3;;
while(T>0)
{
if(DA1>0)
{
i++;
if(i%t1==0)
{
I1++;
I++;
}
if(i%t1==0)
{
I1--;
FP1++;
DA1--;
}
}
if((DA2>0) && (FP1>0))
{
j++;
if(j%t2==1)
{
```

```
I2++;
DA1++;
FP1--;
}
if(j%t2==0)
{
I2--;
FP2++;
DA2--;
}
}
if((DA3>0) && (FP2>0))
{
k++;
if(k%t3==1)
{
I3++;
DA2++;
FP2--;
}
if(k%t3==0)
{
I3--;
FP3++;
DA3--;
}
}
m++;
if(t>d)
{
if(m%d==0)
g++;
if((FP3>0) && (g>0))
{
FP3--;
A++;
DA3++;
g--;
}
}
else
{
if((FP3>0) && (m%d==0))
{
FP3--;
A++;
DA3++;
}
}
```

```
T--;
}
cout<<"\n Total number of finished parts delivered :- ";
cout<<A;
A=A+FP3;
cout<<"\n Total parts produced :- ";
cout<<A;
I=I-A;
cout<<"\n Work in progress :- ";
cout<<I;
getch();
}
```

A3: C - Coded Programme - EKCS: Single line multi stage system

```
#include<iostream.h>
#include<conio.h>
void main()
{
clrscr();
long int T,P,t1,t2,t3,d,t;
long int I1=1,I2=1,I3=1;
long int DA1,DA2,DA3;
long int i=0,j=0,k=0,m=0,g=0;
long int FP1=0,FP2=0,FP3=0,I,A=1;
long int o1=0,o2=0,o3=0;
cout<<"Enter the simulation time :-";
cin>>T;
cout<<"\n Enter the number of Kanban (enter in multiple of 3):- ";
cin>>P;
cout<<"\n Enter the processing time of station 1 :- ";
cin>>t1;
cout<<"\n Enter the processing time of station 2 :- ";
cin>>t2;
cout<<"\n Enter the processing time of station 3 :- ";
cin>>t3;
cout<<"\n Enter the demand :- ";
cin>>d;
I=1;
t=t1+t2+t3;
DA1=DA2=DA3=P/3;
while(T>0)
{
m++;
if(m%d==0)
{
o1++;
o2++;
o3++;
}
if((DA1>0) && (o1>0))
{
i++;
if(i%t1==0)
{
I1++;
I++;
}
if(i%t1==0)
{
I1--;
FP1++;
```

```
DA1--;
}
}
if((DA2>0) && (FP1>0) && (o2>0))
{
j++;
if(j%t2==1)
{
I2++;
DA1++;
FP1--;
}
if(j%t2==0)
{
I2--;
FP2++;
DA2--;
}
}
if((DA3>0) && (FP2>0) && (o3>0))
{
k++;
if(k%t3==1)
{
I3++;
DA2++;
FP2--;
}
if(k%t3==0)
{
I3--;
FP3++;
DA3--;
}
}
if(t>d)
{
if(m%d==0)
g++;
if((FP3>0) && (g>0))
{
FP3--;
A++;
DA3++;
g--;
}
}
else
{
```

```
if((FP3>0) && (m%d==0))
{
FP3--;
A++;
DA3++;
}
}
T--;
}
cout<<"\n Total number of finished parts delivered :- ";
cout<<A;
A=A+FP3;
cout<<"\n Total parts produced :- ";
cout<<A;
I=I-A;
cout<<"\n Work in progress :- ";
cout<<I;
getch();
}
```

A4: C Coded Programme –CONWIP Multi line multi stage system

```
#include<iostream.h>
#include<conio.h>
void main()
{
clrscr();
int T,P,ta1,ta2,ta3,tb1,tb2,tb3,t,d,z;
cout<<"Enter the simulation time :-";
cin>>T;
z=T;
cout<<"\n Enter the number of Kanban :- ";
cin>>P;
cout<<"\n Enter the processing time of station 1 of line A :- ";
cin>>ta1;
cout<<"\n Enter the processing time of station 2 of line A :- ";
cin>>ta2;
cout<<"\n Enter the processing time of station 3 of line A :- ";
cin>>ta3;
cout<<"\n Enter the processing time of station 1 of line B :- ";
cin>>tb1;
cout<<"\n Enter the processing time of station 2 of line B :- ";
cin>>tb2;
cout<<"\n Enter the processing time of station 3 of line B :- ";
cin>>tb3;
cout<<"\n Enter the processing time of last station :- ";
cin>>t;
cout<<"Enter the demand :- ";
cin>>d;
int Ia3=0,Ia1=0,Ia2=0,Ia=1,Ib3=0,Ib1=0,Ib2=0,Ib=1,I=0;
int A=1,m=0,i=0,j=0,k=0,u=0,v=0,y=0,q=0,q1=0;
int Pa,Pb;
int g=0;
Pa=Pb=P;
while(T>0)
{
if(Pa>0)
{
i++;
if(i%ta1==1)
{
Ia++;
}
if(i%ta1==0)
{
Ia1++;
Pa--;
}
}
```

```
if(Ia1>0)
{
j++;
if(j%ta2==0)
{
Ia2++;
Ia1--;
}
}
if(Ia2>0)
{
k++;
if(k%ta3==0)
{
Ia3++;
Ia2--;
}
}
if(Pb>0)
{
u++;
if(u%tb1==1)
{
Ib++;
}
if(u%tb1==0)
{
Ib1++;
Pb--;
}
}
if(Ib1>0)
{
v++;
if(v%tb2==0)
{
Ib2++;
Ib1--;
}
}
if(Ib2>0)
{
y++;
if(y%tb3==0)
{
Ib3++;
Ib2--;
}
}
```

```
if((Ia3>0) && (Ib3>0))
{
q++;
}
if(q>0)
{
q1++;
if(q1%t==0)
{
Ia3--;
Ib3--;
I++;
q--;
}
}
m++;
if(m%d==0)
g++;
if((I>0) && (g>0))
{
I--;
A++;
Pa++;
Pb++;
g--;
}
T--;
}
cout<<"\n Total number of finished parts delivered :- ";
cout<<A;
A=A+I;
cout<<"\n Total parts produced :- ";
cout<<A;
/* I=I-A;
cout<<"\n Work in progress :- ";
cout<<I;
*/
getch();
}
```

A5: C Coded Programme – KCS Multi line multi stage system

```
#include<iostream.h>
#include<conio.h>
void main()
{
clrscr();
int T,P,ta1,ta2,ta3,tb1,tb2,tb3,d,t;
int Ia1=0,Ia2=0,Ia3=0,Ib1=0,Ib2=0,Ib3=0;
int DAa1,DAa2,DAa3,DAb1,DAb2,DAb3;
int i=0,j=0,k=0,m=0,g=0,u=0,v=0,y=0,q=0,q1=0,I=0;
int FPa1=1,FPa2=1,FPa3=1,FPb1=1,FPb2=1,FPb3=1,Ia,Ib,A=1;
cout<<"Enter the simulation time :-";
cin>>T;
cout<<"\n Enter the number of Kanban (enter in multiple of 3):- ";
cin>>P;
cout<<"\n Enter the processing time of station 1 of line A :- ";
cin>>ta1;
cout<<"\n Enter the processing time of station 2 of line A :- ";
cin>>ta2;
cout<<"\n Enter the processing time of station 3 of line A :- ";
cin>>ta3;
cout<<"\n Enter the processing time of station 1 of line B :- ";
cin>>tb1;
cout<<"\n Enter the processing time of station 2 of line B :- ";
cin>>tb2;
cout<<"\n Enter the processing time of station 3 of line B :- ";
cin>>tb3;
cout<<"\n Enter the processing time of last station :- ";
cin>>t;
cout<<"Enter the demand :- ";
cin>>d;
Ia=3;
Ib=3;
DAa1=DAa2=DAa3=DAb1=DAb2=DAb3=P/3;;
while(T>0)
{
if(DAa1>0)
{
i++;
if(i%ta1==1)
{
Ia1++;
Ia++;
}
if(i%ta1==0)
{
Ia1--;
FPa1++;
```

```
DAa1--;
}
}
if((DAa2>0) && (FPa1>0))
{
j++;
if(j%ta2==1)
{
Ia2++;
DAa1++;
FPa1--;
}
if(j%ta2==0)
{
Ia2--;
FPa2++;
DAa2--;
}
}
if((DAa3>0) && (FPa2>0))
{
k++;
if(k%ta3==1)
{
Ia3++;
DAa2++;
FPa2--;
}
if(k%ta3==0)
{
Ia3--;
FPa3++;
DAa3--;
}
}
if(DAb1>0)
{
u++;
if(u%tb1==1)
{
Ib1++;
Ib++;
}
if(u%tb1==0)
{
Ib1--;
FPb1++;
DAb1--;
}
```

```
}
if((DAb2>0) && (FPb1>0))
{
v++;
if(j%tb2==1)
{
Ib2++;
DAb1++;
FPb1--;
}
if(v%tb2==0)
{
Ib2--;
FPb2++;
DAb2--;
}
}
if((DAb3>0) && (FPb2>0))
{
y++;
if(y%tb3==1)
{
Ib3++;
DAb2++;
FPb2--;
}
if(y%tb3==0)
{
Ib3--;
FPb3++;
DAb3--;
}
}
if((FPa3>0) && (FPb3>0))
{
q++;
}
if(q>0)
{
q1++;
if(q1%t==0)
{
FPa3--;
FPb3--;
I++;
q--;
}
}
m++;
```

```
if(m%d==0)
g++;
if((I>0) && (g>0))
{
I--;
A++;
DAa3++;
DAb3++;
g--;
}
T--;
}
cout<<"\n Total number of finished parts delivered :- ";
cout<<A;
A=A+I;
cout<<"\n Total parts produced :- ";
cout<<A;
getch();
}
```

A6: C Coded Programme – EKCS Multi line multi stage system

```
#include<iostream.h>
#include<conio.h>
void main()
{
clrscr();
int T,P,ta1,ta2,ta3,tb1,tb2,tb3,d,t;
int Ia1=0,Ia2=0,Ia3=0,Ib1=0,Ib2=0,Ib3=0;
int DAa1,DAa2,DAa3,DAb1,DAb2,DAb3;
int i=0,j=0,k=0,m=0,g=0,u=0,v=0,y=0,q=0,q1=0,I=0;
int FPa1=1,FPa2=1,FPa3=1,FPb1=1,FPb2=1,FPb3=1,Ia,Ib,A=1;
cout<<"Enter the simulation time :-";
cin>>T;
cout<<"\n Enter the number of Kanban (enter in multiple of 3):- ";
cin>>P;
cout<<"\n Enter the processing time of station 1 of line A :- ";
cin>>ta1;
cout<<"\n Enter the processing time of station 2 of line A :- ";
cin>>ta2;
cout<<"\n Enter the processing time of station 3 of line A :- ";
cin>>ta3;
cout<<"\n Enter the processing time of station 1 of line B :- ";
cin>>tb1;
cout<<"\n Enter the processing time of station 2 of line B :- ";
cin>>tb2;
cout<<"\n Enter the processing time of station 3 of line B :- ";
cin>>tb3;
cout<<"\n Enter the processing time of last station :- ";
cin>>t;
cout<<"Enter the demand :- ";
cin>>d;
Ia=3;
Ib=3;
DAa1=DAa2=DAa3=DAb1=DAb2=DAb3=P/3;;
while(T>0)
{
if(DAa1>0)
{
i++;
if(i%ta1==1)
{
Ia1++;
Ia++;
}
if(i%ta1==0)
{
Ia1--;
FPa1++;
```

```
DAa1--;
}
}
if((DAa2>0) && (FPa1>0))
{
j++;
if(j%ta2==1)
{
Ia2++;
DAa1++;
FPa1--;
}
if(j%ta2==0)
{
Ia2--;
FPa2++;
DAa2--;
}
}
if((DAa3>0) && (FPa2>0))
{
k++;
if(k%ta3==1)
{
Ia3++;
DAa2++;
FPa2--;
}
if(k%ta3==0)
{
Ia3--;
FPa3++;
DAa3--;
}
}

if(DAb1>0)
{
u++;
if(u%tb1==1)
{
Ib1++;
Ib++;
}
if(u%tb1==0)
{
Ib1--;
FPb1++;
DAb1--;
```

```
}
}
if((DAb2>0) && (FPb1>0))
{
v++;
if(j%tb2==1)
{
Ib2++;
DAb1++;
FPb1--;
}
if(v%tb2==0)
{
Ib2--;
FPb2++;
DAb2--;
}
}
if((DAb3>0) && (FPb2>0))
{
y++;
if(y%tb3==1)
{
Ib3++;
DAb2++;
FPb2--;
}
if(y%tb3==0)
{
Ib3--;
FPb3++;
DAb3--;
}
}
if((FPa3>0) && (FPb3>0))
{
q++;
}
if(q>0)
{
q1++;
if(q1%t==0)
{
FPa3--;
FPb3--;
I++;
q--;
}
}
```

```
m++;
if(m%d==0)
g++;
if((I>0) && (g>0))
{
I--;
A++;
DAa3++;
DAb3++;
g--;
}

T--;
}
cout<<"\n Total number of finished parts delivered :- ";
cout<<A;
A=A+I;
cout<<"\n Total parts produced :- ";
cout<<A;
getch();
}
```

APPENDIX B

THE MATLAB /SIMULINK SOFTWARE – A SIMULATION TOOL

This appendix contains a brief introduction to MATLAB/SIMULINK software used to carry out the various discrete event simulations in the present work. MATLAB and Simulink are registered trademarks of The MathWorks, Inc.An overview of the software, modeling elements, scenarios, graphics, outputs reporting etc are presented along with screenshots of simulation models.

B.1.1 Introduction

SimEvents® provides a discrete-event simulation engine and component library for Simulink®. It can model event-driven communication between components to analyze and optimize end-to-end latencies, throughput, packet loss, and other performance characteristics. Libraries of predefined blocks, such as queues, servers, and switches, enable you to accurately represent the system and customize routing, processing delays, prioritization, and other operations. With SimEvents the simulation of event-driven processes, such as the execution of a mission plan or the stages of a manufacturing process, to determine resource requirements and identify bottlenecks **.** The Key Features are:

1. Discrete-event simulation engine for multidomain modeling of complex systems in Simulink
2. Predefined block libraries, including queues, servers, generators, routing, and entity combiner/splitter blocks.

3. Entities with custom data attributes for flexible representation of packets, tasks, and parts
4. Built-in statistics aggregation for obtaining delay, throughput, average queue length, and other metrics
5. Library blocks for defining domain-specific constructs, such as communication channels, messaging protocols, and conveyor belts.
6. In-model animation for visualizing model operation and debugging.

Discrete-event simulations typically involve discrete items of interest. By definition, these items are called *entities* in SimEvents software. Entities can pass through a network of queues, servers, gates, and switches during a simulation. Entities can carry data, known in SimEvents software as *attributes*.

B 1.2. Modeling Elements

The main Simulink SimEvents library window appears. This window contains an icon for SimEvents library. The screenshot of the library is shown below :

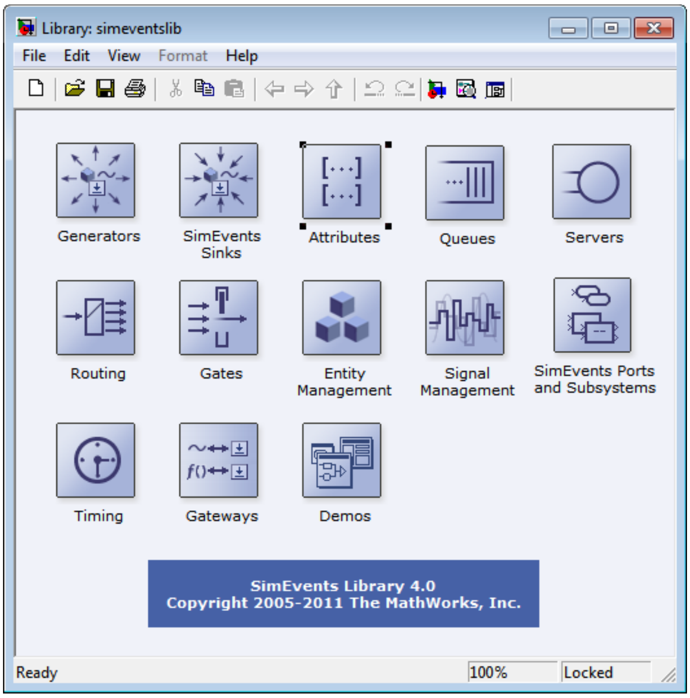
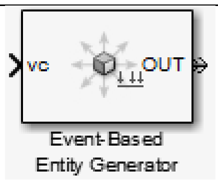
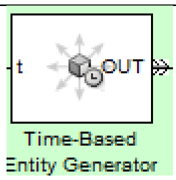
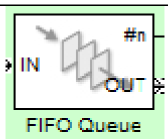
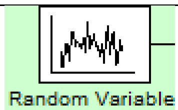
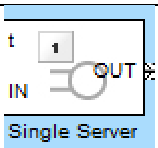
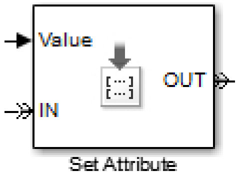
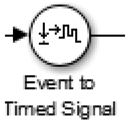
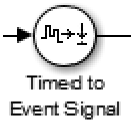
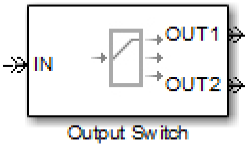
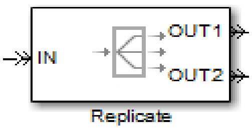
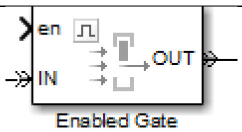


Figure B1: Simulink Simevent Library Browser

The various modeling elements used in this thesis for modeling are as follows:

S.No	Icon or Symbol	Description
1		Generate entity upon signal-based event or function call
2		This block is designed to generate entities using intergeneration times that satisfy criteria that you specify. The intergeneration time is the time interval between two successive generation events.
3		Store entities in sequence for undetermined length of time
4		Generate random numbers from specified distribution, parameters, and initial seed

5		This block serves one entity for a period of time, and then attempts to output the entity through the OUT port.
6		This block accepts an entity, assigns data to it, and then outputs it. Assigned data is stored in attributes of the entity, where each attribute has a name and a value.
7		Convert event-based signal to time-based signa
8		This block converts a time-based data signal into an event-based data signal
9		This block receives entities, which depart through one of multiple entities output ports. The selected port can change during the simulation
10		This block outputs a copy of the arriving entity through each entity output port that is not blocked the number of copies that the block makes, using the Number of entity output ports parameter.
11		Permit entity arrivals only when control signal is positive
12		Accept or block entities.

B 1.3 Elements used in modeling approaches

A new entity that enters into the system at any time is called an arrival and is defined by specifying information like frequency of arrivals, time of arrival etc. Deterministic, conditional or stochastic arrivals can be modeled by using the arrivals of the element. As a part of present work, the network model single line single stage kanban control system is shown in figurer B2.

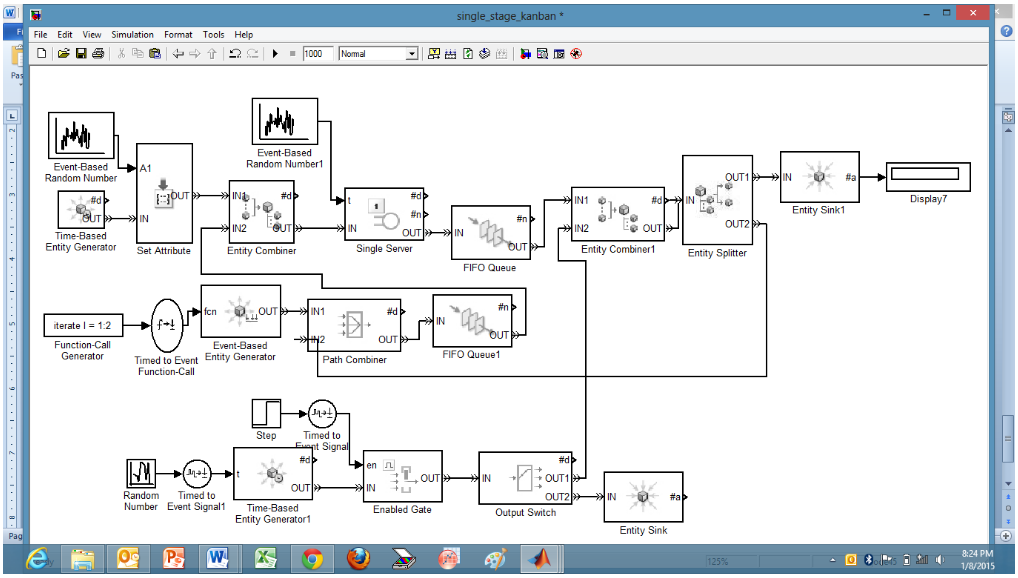


Figure B2: Network model of single line single stage Kanban control system

B 1.4 Graphics

Graphics in Simulink are realistic and easy to create. Visually realistic animation helps simulation to become an effective communication. Simulink includes an extensive library of graphics with provision to create and add graphics to the library. In addition to modeling tools with color spectrum, scaling, rotating, copying and other editing features are available.

B 1.5 Output Analysis

Users can customize their output as desired by the sinks shown in Figure B3. The result database can be saved as external spreadsheet or automatically converted to tables. The graphics of the outputs can be displayed, printed, plotted or pasted into other programmers. The output statistics can be saved as an excel spreadsheet.

B 1.6 Summary

This appendix provides an overview of MATLAB SIMULINK software along with sieving library and presents its modeling and analysis capabilities. For successful implementation of SIMULINK, the problem should be planned and understanding the requirements of each tasks involved in it. The modeling may require good analytical, statistical and understanding of industry. MATLABSIMULINK along with its regular features includes SIMEVENT, SIMSCAPE, STATEFLOW, and SIMMECHANICS as additional excellent tools towards optimization. The simulation makes a standard method in providing relevant and beneficial answers to Engineers, Managers and industrialists.

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