A CONWIP APPLICATION IN AN ELECTRONICS COMPANY

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

BY

ELİF GÜNGÖRER

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

FEBRUARY 2010

Approval of the thesis:

A CONWIP APPLICATION IN AN ELECTRONICS COMPANY

submitted by **ELİF GÜNGÖRER** in partial fulfillment of requirements for the degree of **Master of Science in Industrial Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen ________________
Dean, Graduate School of **Natural and Applied Sciences**

Prof. Dr. Nur Evin Özdemirel ________________
Head of Department, **Industrial Engineering**

Prof. Dr. Nur Evin Özdemirel ________________
Supervisor, **Industrial Engineering Dept., METU**

Examining Committee Members:

Prof. Dr. Ömer Kırca ________________
Industrial Engineering Dept, METU

Prof. Dr. Nur Evin Özdemirel ________________
Industrial Engineering Dept, METU

Prof. Dr. Meral Azizoğlu ________________
Industrial Engineering Dept, METU

Asst. Prof. Dr. Ferda Can Çetinkaya ________________
Industrial Engineering Dept, Çankaya University

Asst. Prof. Dr. Sedef Meral ________________
Industrial Engineering Dept, METU

Date: 04.02.2010

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

Name, Last name: Elif Güngörer

Signature :

ABSTRACT

A CONWIP APPLICATION IN AN ELECTRONICS COMPANY

Güngörer, Elif
Industrial Engineering Department
Supervisor: Prof. Dr. Nur Evin Özdemirel

February 2010, 159 pages

In this thesis, a real world application of the constant work in process (Conwip) system in an electronics company is realized. The aim of the application is to reduce the work in process (WIP) inventory while maintaining the same throughput level. A model is developed to determine the constant work in process level of the Conwip system for the production lines in this company. The approximated mean value analysis approach is used for the solution. Real system data are collected before and after the Conwip application. Hypothesis tests are used to compare the WIP and the throughput levels of the Conwip system with the existing push control system for a pilot production line. Results of the hypothesis tests show that the Conwip production control system can signinifcantly reduce the WIP while maintaining the same throughput rate.

Keywords: Conwip, Pull system, Work in process, Throughput, Electronics production

ÖZ

BİR ELEKTRONİK FİRMASINDA CONWIP UYGULAMASI

Güngörer, Elif
Endüstri Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Nur Evin Özdemirel

Şubat 2010, 159 sayfa

Bu tezde bir elektronik firmasında sabit üretim içi stok (Conwip) sisteminin uygulama çalışması gerçekleştirimiştir. Bu uygulamanın amacı, üretilen iş miktarını değiştirmeden üretim içi stok miktarını düşürmektir. Bu firmanın üretim hatları için Conwip sisteminin sabit üretim içi stok değerini belirlemek amacıyla bir model geliştirildi. Çözüm için tahmin edilen ortalama değer analizi kullanıldı. Conwip uygulamasından önce ve sonra gerçek sistem verileri toplandı. Conwip sisteminin ve var olan itme sisteminin üretim içi stok ve üretilen iş miktarı seviyeleri hipotez testleri kullanılarak karşılaştırıldı. Hipotez testlerinin sonuçları, Conwip üretim kontrol sisteminin üretilen iş miktarını değiştirmeden üretim içi stok miktarını önemli ölçüde düşürebileceğini gösterdi.

Anahtar Kelimeler: Conwip, Çekme sistemi, Üretim içi stok, Üretilen iş,
Elektronik üretim

ACKNOWLEDGMENTS

The author wishes to express his deepest gratitude to his supervisor Prof. Dr. Nur Evin Özdemirel for her guidance, advice and criticism throughout the research.

The author would also like to thank Nilgün Sertpoyraz, Nuray Demir and Gamze Büyükfidan for their collaboration and support.

TABLE OF CONTENTS

LIST OF TABLES

TABLES

LIST OF FIGURES

FIGURES

LIST OF ABBREVIATIONS

Conwip: Constant Work in Process

DBR: Drum-Buffer-Rope

ERP: Enterprise Resource Planning

JIT: Just in Time

MDS : Master Demand Schedule

MPS: Master Production Schedule

MRP: Material Requirements Planning

MVA: Mean Value Analysis

ROP: Reorder Point

ROQ: Reorder Quantity

SCV: Squared Coefficient of Variances

TPS: Toyota Production System

TQM: Total Quality Management

WIP: Work In Process

WIP cap: Work In Process Capacity

CHAPTER 1

INTRODUCTION

Over the past two decades two major trends shaped the production planning and inventory control practices: hierarchical planning systems and just in time (JIT) ideas and techniques.

Most hierarchical planning systems such as enterprise resource planning systems (ERP) are built around sophisticated databases and utilize detailed scheduling procedures. JIT techniques, on the other hand, are characterized by real time and autonomous control. Both systems have advantages and disadvantages.

A hierarchical planning system works in a wide variety of environments and does not require any drastic changes in the environment. However, JIT can work well in manufacturing environments having low demand variability, few product types, flow line or work-cell layout, and requires environmental changes such as reducing set-up times. Unfortunately, sometimes it is not possible to make the required changes in the manufacturing environment to make JIT work. On the other hand, when JIT can be applied, it is shown that it has several advantages in shop floor control when used together with hierarchical planning systems.

At first glance, these two systems seem mutually exclusive, but this is not true. Spearman et al. (1990) developed a modified Kanban system that works at operational level in more general manufacturing environments while providing most of the benefits of Kanban. They refer to this system as Conwip for “constant work in process”.

The multi-product, variable demand environments for which Kanban is not suitable require forecasting and demand management at strategic and tactical levels. Because of this, Conwip should be integrated with hierarchical planning systems in such environments.

Spearman et al. (1990) showed that such integrated hierarchical planning systems could co-exist with Conwip and made this system work in a semiconductor company.

Spearman's study encouraged us to integrate the existing hierarchical planning system (ERP) in an electronics company with a Conwip based shop-floor control system, in order to take the advantage of a pull system without making drastic changes in the existing manufacturing environment.

In this thesis, we firstly introduced the production environment of the company and described the existing production control system. Than, we gave a general description of the Conwip system.

We developed a Conwip model to calculate the minimum work in process level (WIP cap) providing the maximum throughput for telecommunication board production in the company. In the light of the studies in literature, we evaluated the proposed analytical approaches to solve our problem. We decided to use the approximated mean value analysis (AMVA) approach taking into consideration the ease of implementation, ease of integration to the existing hierarchical system and suitability to the production environment in the company. However, the production environment in the company did not fit exactly to the assumptions of the approximated MVA algorithm. For this reason, we made some adaptations to use this algorithm in the solution of the problem.

After determination of the Conwip parameters, we integrated this model to the existing hierarchical planning system and applied it to the real system. We chose telecommunication board production division for pilot application because of the following reasons.

a) This production division carries a large portion of the total work in process in the company.
b) Demand variation of the boards produced in this division is relatively low compared to demand variation in the other divisions.
c) The wide variety of boards produced in this division could be grouped into a few product families according to process times and similarity of components.
d) This division is the oldest division of the company and there are almost no changes in the environment (the number of machines, process times, and so on). This stability is important for a fair comparison of the proposed model results with those of the existing system.
e) The machine that supplies semi-finished boards as input to this division is an underutilized machine and there are few shortages of semi-finished boards used as input.

During the pilot application we retrieved data from the ERP system. We compared real data sets of the existing system and the proposed system using statistical hypothesis tests. Our aim was to reduce the work in process (WIP) inventory while maintaining the same throughput level in the telecommunication board production division. Results of the hypothesis tests showed that we could achieve our aim with the Conwip control system.

The rest of the thesis is organized as follows. Chapter 2 provides a description of the existing system. A brief history of the production planning systems, a general description of Conwip and literature survey about Conwip are given in Chapter 3. In Chapter 4, model parameters for Conwip are defined and their determination is explained. Chapter 5 describes the integration of the Conwip system to the existing hierarchical system and information flow in the new system. Comparison of real life data before and after the implementation and results of the hypothesis tests are presented in Chapter 6. The thesis concludes with Chapter 7.

CHAPTER 2

HIERARCHICAL PRODUCTION PLANNING SYSTEM IN THE COMPANY

2.1 Resource Management Tools in the Company

The company uses Oracle ERP Application Software as the resource management tool. Most of the operational transactions are realized on this system. The scope of the ERP system can be seen in Figure 2.1. Activities supported by the ERP system include:

- Purchasing
- Quality management
- Production control
- Production and materials planning
- Inventory management
- Engineering
- Sales order management

In addition to the standard ERP applications, there exist:

- An in-house developed application for service operations
- Rational portfolio management application for project management in research and development activities.
- Some procedures developed in the company and integrated to the ERP system for performance management, supplier evaluation, and detailed production planning

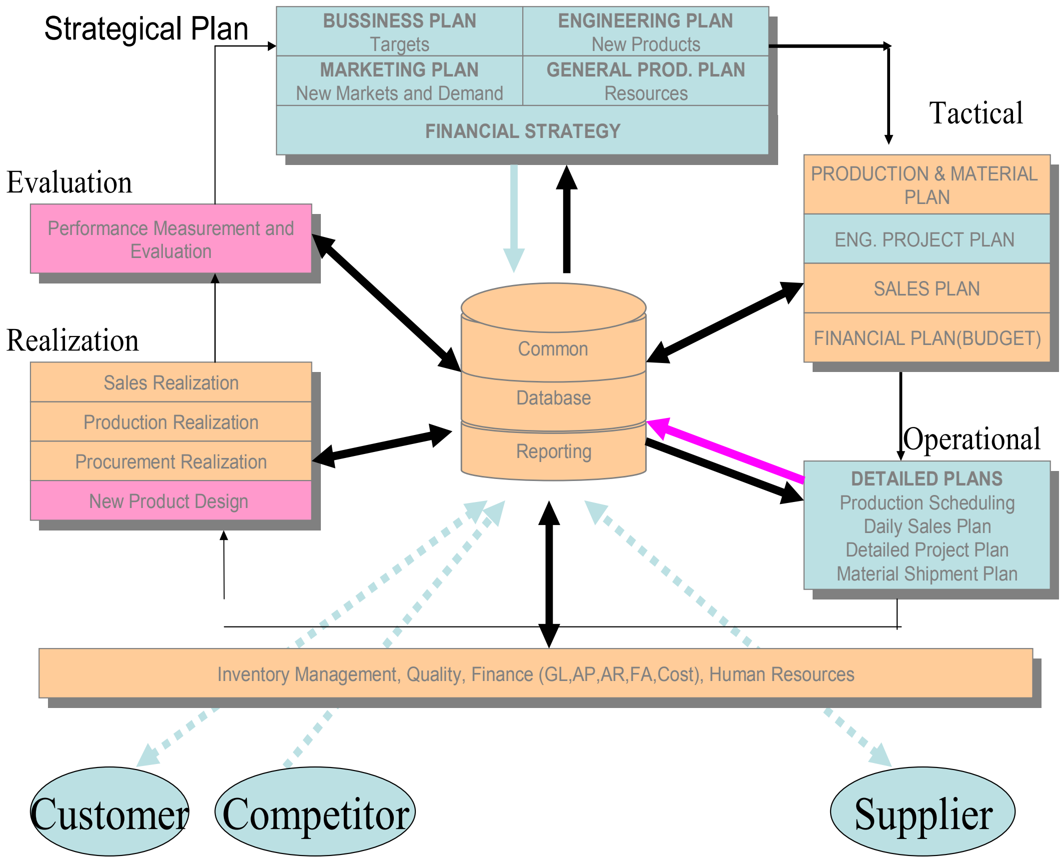

Figure 2.1 General Flow of Resource Planning in the company

2.2. Complexity of Production

There are three main production divisions and a common automated insertion machines group which serves these three divisions in the company. These are:

1) Production division for telecommunication products
2) Production division for white goods electronic boards

3) Production division for defence electronic boards
4) Automated insertion machines group

There are different types of products having different bill of material levels, different production types and different production planning methodologies used in these groups. A comparison of these lines can be seen in Table 2.1.

Table 2.1 Comparison of the Complexities of the Lines in the Company

	TELECOM				Electronic Production						Defence		
	PBX		Accessories & Consoles		White Goods					Water Heater	Defence1	Defence2	Defence3
	Small/ Medium Sized	Large Sized	Accessories	Consoles	Dish Washer	Washing Machine	Dryer	Oven	Refrigerator	Water Heater	Defence1	Defence2	Defence3
Demand Variability	M	H	H	H	M**	M**	L	H	L	M	M	M	H
Demand Volume	M	L	M	M	H	H	M	L	L	M	M	L	L
Type of Manuf.	MPL	MPL	MPL	MPL	L	L	L	MPL	MPL	MPL	JS	JS	JS
Type of Prod.	MTF	ATO	MTF	MTF	MTO *	MTO *	MTO *	MTO *	MTO *	MTO *	MTO	MTO	MTO
BOM Level (Max)	3	5	3	3	2	2	2	5	2	2	5	5	10

*:Customers release their sales orders according to their forecast. These can be accepted as make-to-forecast

**Finished goods are similar in their groups, and variability within groups is low

Demand Variability: L:Low, M: Medium, H: High

Demand Volume: L:Low, M: Medium, H: High

Type of Manufacturing: MPL: Multiple Production Lines, L: Line, JS: Job Shop

Type of Production: MTF: Make to Forecast, ATO: Assembly to Order, MTO: Make to Order

2.3. General Flow of Production and Material Requirements Planning

2.3.1. Demand Management

Forecasts and sales orders are collected from the marketing department for telecommunication products and from customers for electronics and Aselsan products. These monthly forecasts and sales orders are converted to a master demand schedule. For this purpose forecasts are equally divided into weekly demands. Sales orders are used as is in the master demand schedule. This converted master demand schedule is used for production planning purpose.

Material purchasing lead times are very long in electronic components market and it is very difficult to respond to instant demand changes in the environments having long lead times. Because of that, safety forecasts are determined for material requirements planning purposes. These are generally determined as 50% of the average monthly demand to 50% increase in monthly demand. The average material purchasing lead time is three months. This means that the company can respond up to 50% demand increase in a three months period. These safety forecasts are added to the master demand schedule and used for material requirement planning.

Demand management activities followed by production planning and material requirement planning activities are summarized in Figure 2.2.

2.3.2. Production Planning

Type of production is indicated in Table 2.1 for each of the product groups. For products having “assembly to order” type of production, semi-finished items are planned according to forecasts and end items (finished products) are planned according to sales orders. For “make to forecast” products, all levels of end items and semi-finished goods are planned according to forecasts. For products having “make to order” products, all levels of end items and semi-finished goods are planned according to sales orders.

Master Production Scheduling (MPS) procedure runs every week using appropriate master demand schedule, existing work orders, bill of materials, defined routes for items and defined order modifiers (number of supply days, minimum and maximum order quantities, lot sizes). This procedure gives “reschedule and quantity change messages” for existing work orders and “plan order” messages for new work orders. All messages are realized by planners.

Production planning activities are summarized by processes 4-9 in Figure 2.2.

2.3.3. Material Requirements Planning

Material Requirements Planning (MRP) procedure also runs every week using appropriate master demand schedule (includes safety forecasts), existing purchase orders, bills of materials, defined routes for items and defined order modifiers (number of supply days, minimum and maximum order quantities, package sizes, safety lead times). This procedure gives “reschedule messages” for existing purchase orders and “plan order” messages for new purchase orders. These messages are negotiated with suppliers, and according to the results of these negotiations, vendor promise dates on existing purchase orders are updated. For planning messages of new purchase orders, appropriate vendors are selected according to price, promise dates and quality grades. New purchase orders are then created with negotiated vendor promise dates.

Material requirements planning activities are given by processes 10-16 in Figure 2.2.

2.3.4. The Working of the Supply Chain

The supply-demand assignment procedure (written in the company) is run to connect all demands and supply of an item.

There exist three types of demand:

1) Independent demand that comes from the master demand schedule
2) Dependent demand that comes from work order requirements
3) Safety stocks

There exist four types of supply:

1) Quantity on hand
2) Quantity in receiving
3) Work orders for produced items
4) Purchase orders for purchased items

All supplies are sorted according to:

1) type of supply
2) priority (assigned to supplies and demands using priority assignment procedure)
3) status of work orders (components of work orders issued to production or not)
4) production due dates for work orders and vendor promise dates for purchase orders

All demands are sorted according to:

1) priority
2) status of source work order
3) due date of demand

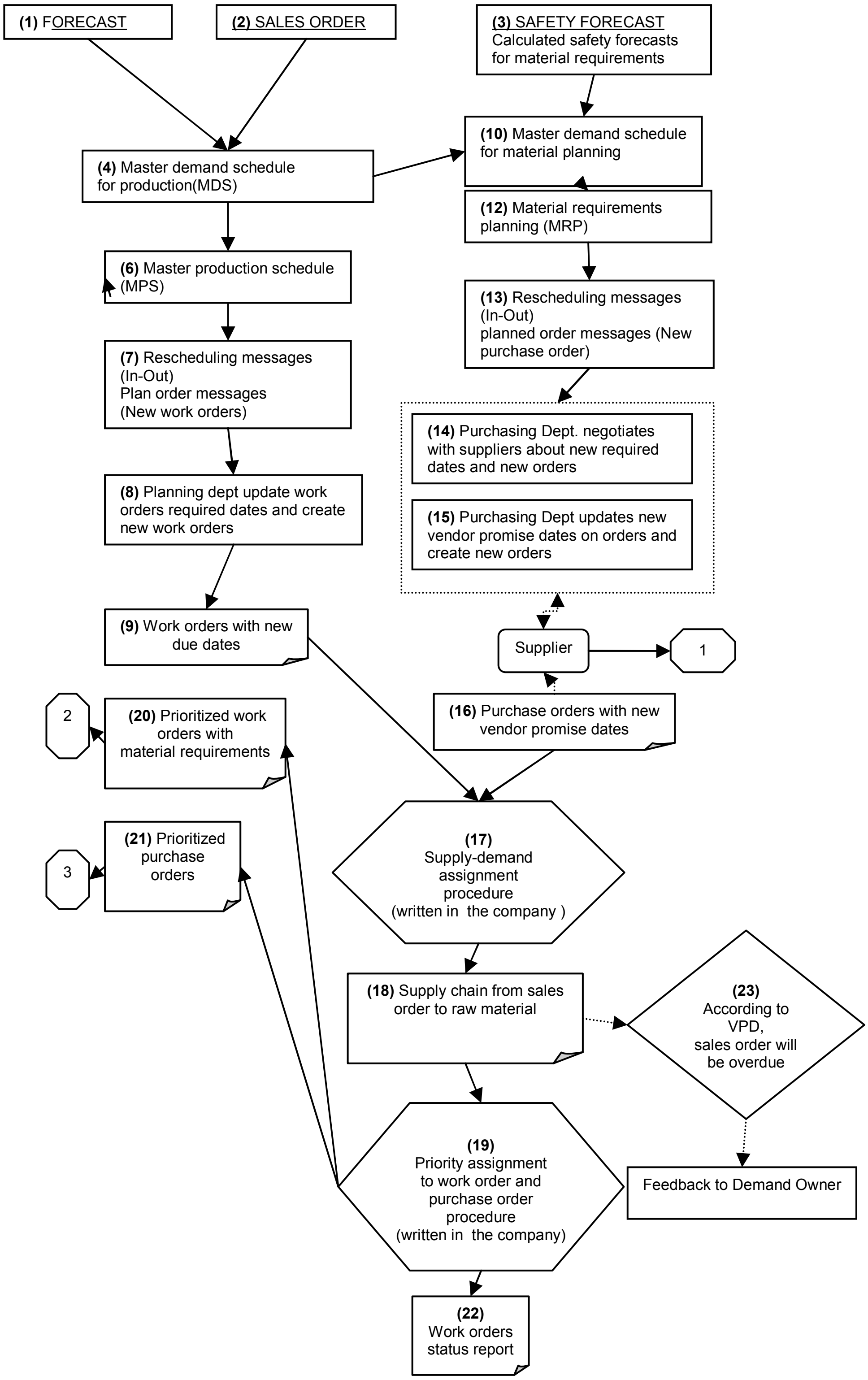

Figure 2.2 Flow of Production and Material Requirements Planning

All supplies of an item are assigned to demands of the item. These assigned supplies and demands are connected to other related items with dependent demand aids. A chain from master demand schedule to raw material is generated. By this way, it can be seen easily which sales order or forecast will be affected from a problem in a purchase order or work order.

Main supply chain activities are represented by processes 17 and 18 in Figure 2.2

2.3.5. Prioritizing Work Orders and Purchase Orders

A procedure written in the company is used for prioritizing the work orders and the purchase orders. Before the prioritizing procedure, all the existing priorities on work orders and purchase orders are cleared. Then the supply chain is created. Using this chain, the priorities of orders and forecasts given by sales department, are assigned to all supplies in the chain. Prioritizing work orders and purchase orders are represented by processes 19-21 in Figure 2.2.

2.3.6 Receiving Items to the Inventory

When the required materials are shipped by supplier, the Import Department of the company pulls the imported materials (70% of all materials) from the customs according to prioritized purchase orders. This prioritized list is important for cash management.

Materials pulled from the customs and materials shipped by internal suppliers arrive at the First Acceptance Department. These materials are inspected by eye, counted, tagged and transferred to Quality Inspection Department.

The materials are inspected according to the quality specifications of items. An item is accepted and transferred to the inventory if it fits these specifications. Otherwise, it is rejected and transferred to First Acceptance Department for return to the supplier.

The placement program is run for the items stored in the automated stocking machine. This program determines an appropriate place in the machine for these items. After transactions are entered in system, these items are placed in the determined place in the automated stocking machine. Other items are placed in the first available space on the shelves.

Receiving items to inventories can be seen in processes 24-29 in Figure 2.3.

2.3.7 Job Sequencing for Automated Insertion Machines

For the items that will be produced in automated insertion machines, the following inputs are used for job sequencing:

- Prioritized work orders
- Due dates of these work orders
- Material requirements of these work orders
- Vendor promise dates of the assigned purchase orders of these required materials (vendor promise dates that are used are determined by the supply chain)
- Set-up group of the item
- The machine assignment of the item

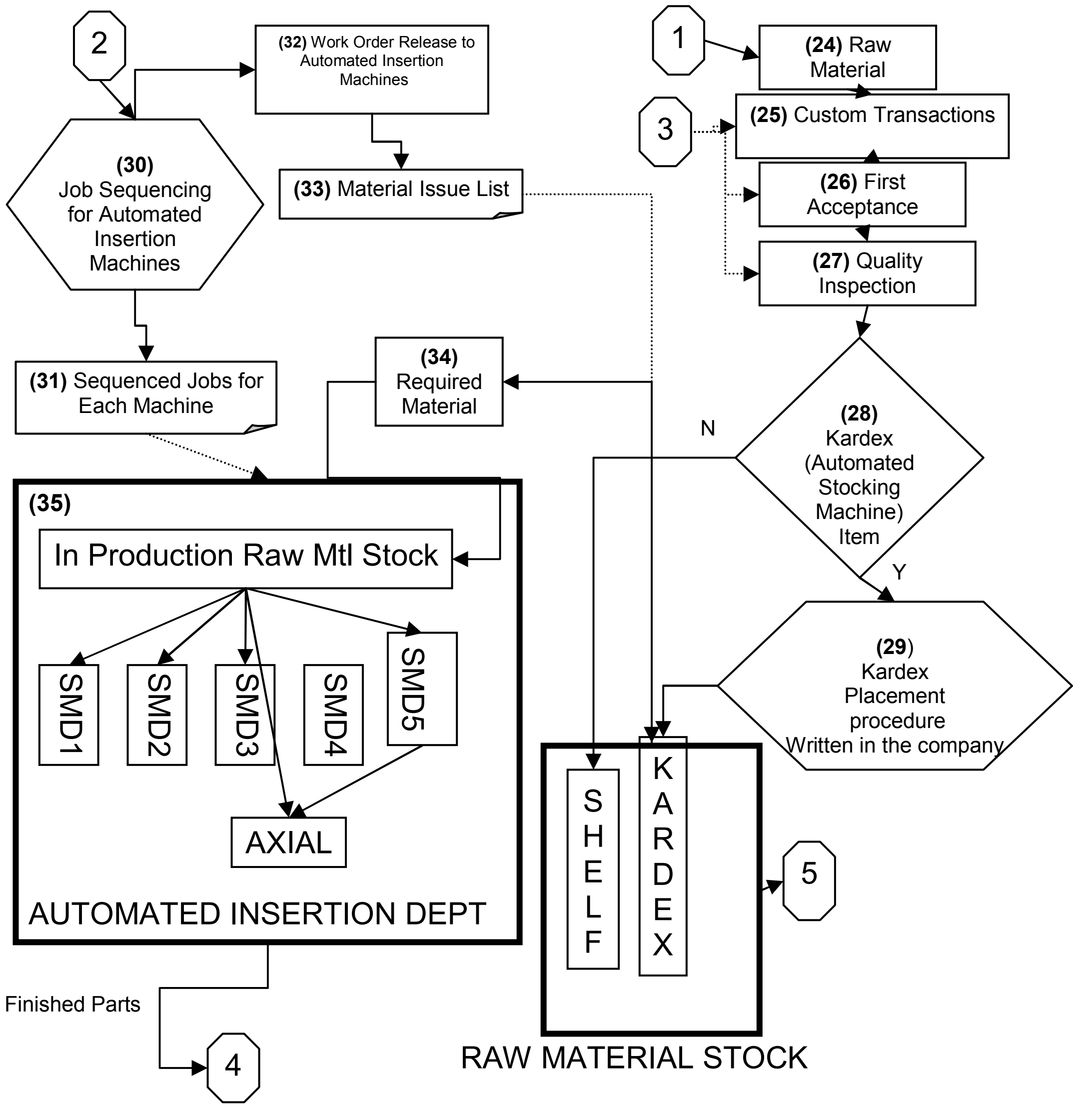

Figure 2.3 General Flow of Order Release and Automated Insertion

For all work orders, the latest vendor promise date of required materials is taken as “can begin date”.

For all set-up groups, the earliest due date of the work orders in a set-up group is taken as “first required date of set-up group” and highest priority of the work orders in a set-up group is taken as “priority of the set-up group”.

All work orders within a set-up group are sorted by priority and first required date. Using this sorted list, the processing times and minor and major set-up times of the items, the beginning dates of the work orders are calculated. If beginning dates of the work orders are earlier than the “can begin dates” (calculated using vendor promise dates) , the sequencing of work orders is changed iteratively until a feasible solution is achieved. This sequenced work order list is sent to the Automated Insertion Department for production.

The material requirements list of these work orders is received by the inventory staff from the system to prepare the required materials and send them to the in production raw material stock area.

After the automated insertion processes of the boards are completed, the semi-finished boards are transferred to automated insertion semi-finished products inventory for the further usage in the production.

Job sequencing activities are summarized by processes 30-34 in Figure 2.3.

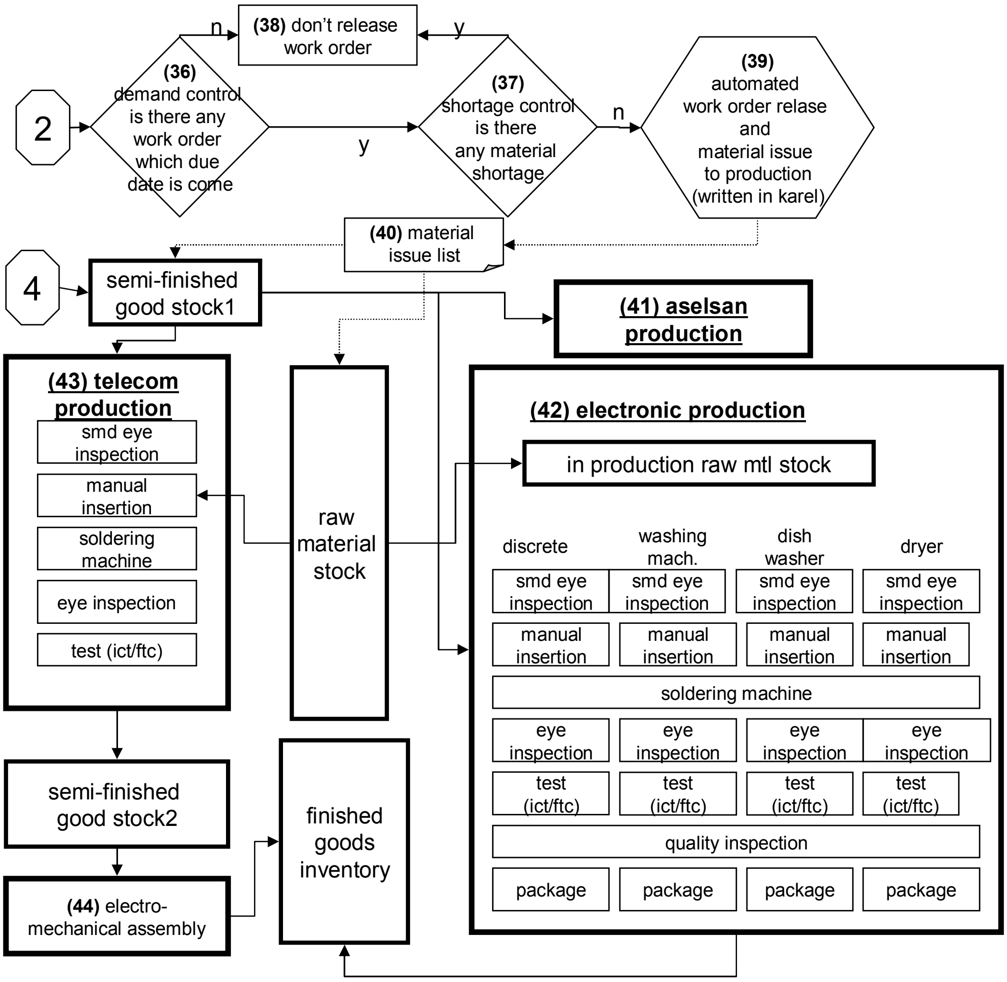

Figure 2.4 General Flow of Assembly and Quality Control

"Automated work order release" procedure creates material preparation lists and realizes "issue components to work order" transactions in the system automatically. Inventory staff prepare required components, group them by work orders and send them to the production area.

Work order release activities are given by processes 36-40 in Figure 2.4.

2.3.8 Production

Almost all the electronic boards are produced using the same basic route indicated below:

SMD eye inspection: Semi-finished boards produced in automated insertion machines are inspected, and missing or defective components are fixed in this operation.

Manual insertion: Some electronic and mechanical components cannot be assembled in automated insertion machine. The assemblies of these components are made manually in this operation.

Soldering machine: After components are assembled to the boards, they go through the soldering machine for fixing the components to the boards.

Eye inspection: The process in SMD eye inspection is repeated for manually inserted components.

Test: All produced boards are tested 100% electrically (in circuit test) and functionally. Failing boards are sent to the repairing work center which is off the line.

Electro-mechanical assembly: This process produces the electronic devices as the end product. In this stage, required boards, chassis and cables are assembled and the devices are functionally tested. Produced electronic devices are packaged, transferred to finished goods inventory and wait for shipment to the customer.

Some of the boards are produced for use in end products of other manufacturers. These boards are directly sent to packaging operation without going through the electro-mechanical assembly process.

Production activities are represented by processes 41-44 in Figure 2.4.

2.4 Telecommunication Board Production Line

There are five sub-lines in the telecommunication production line:
Subline1: Small and medium sized PABX
Subline2: Large sized PABX
Subline3: Consoles
Subline4: Accessories
Subline5: Other small and medium sized PABX, large sized PABX, consoles and accessories produced rarely in low volumes.

Figure 2.5 shows the production flow in these sub-lines. Production of boards in these sub-lines follow the same route described in Section 2.4.9. The first four of these sub-lines are suitable for Conwip application, and we intend to use one of these sub-lines for a pilot implementation within the scope of this thesis.

2.4.1 Environment Characteristics

Environment characteristics of telecommunication production sub-lines are listed below:

a) Deterministic process times for every product type

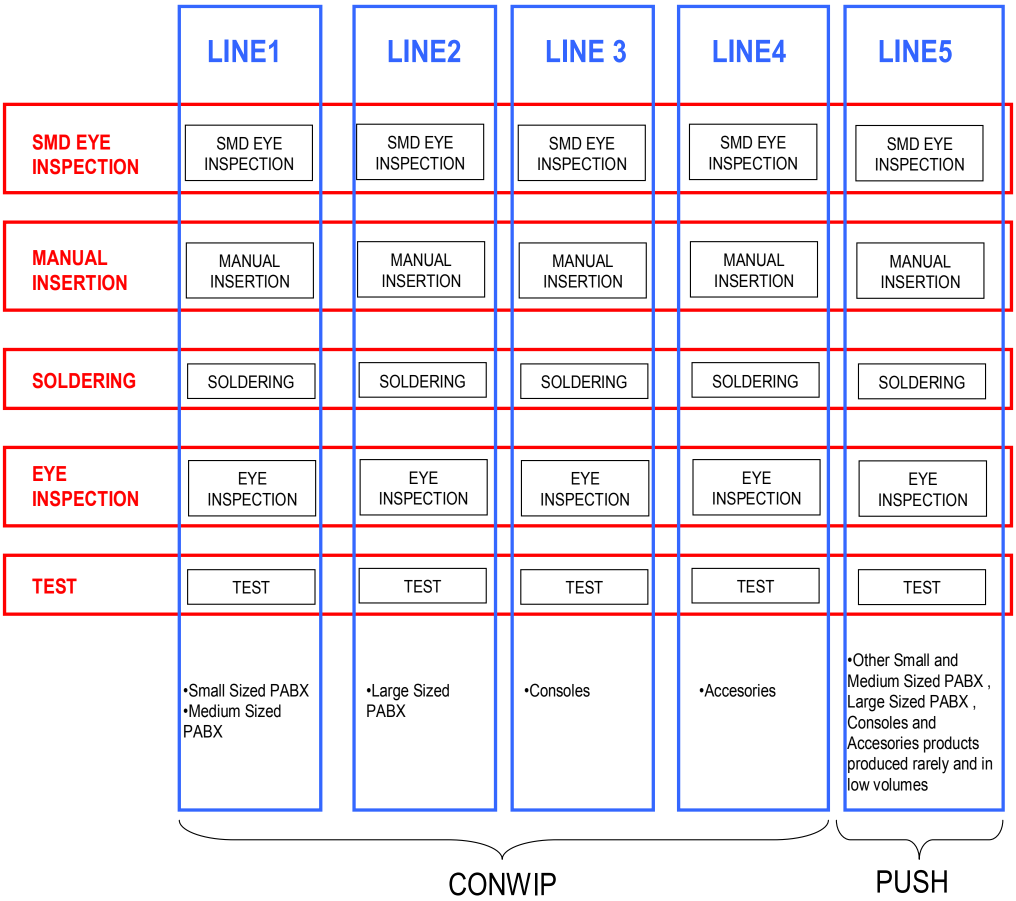

Figure 2.5 Telecommunication Production Sub-Lines

b) Product groups: Products are grouped according to their processing times and functionalities. Groups are assigned to sub-lines. In telecommunication board production line, there are numerous products but they can be assigned to a few groups.

c) Multiple parallel servers at stations: All of the sub-lines share the same resources (servers) that are managed centrally. At the beginning of the month, chiefs of the common resources distribute the resources to the sub-lines according to the demand and work load of the sub-lines. Once these resources are distributed for the month, each sub-line functions independently of the others until the next month.

d) Transfer batch sizes: Every sub-line has a constant transfer batch size. Products are transferred between stations with the fixed batch size of the sub-line.

e) Off-line rework: Repair center is off the lines. Defective products are not kept in the lines and are sent to the repair center immediately.

f) Negligible set-up times: Set-up times between product groups in the sub-lines can be ignored. Telecommunication boards production line is heavily dependent on manual workforce and changing from one product to the next is easy compared to the automated insertion machines.

g) Negligible machine breakdowns: There are very few machines in the telecommunication board production line. Solder machine did not break down in the last 10 years. There are spare ICT and FTC equipment for testing purposes. Because of these reasons, machine breakdowns can be ignored.

CHAPTER 3

LITERATURE SURVEY

In this chapter we first give a brief history of push and pull systems to understand the root of Conwip. A general description of Conwip is given in Section 3.2. Section 3.3 reviews Conwip literature including its applications.

3.1. Brief History of Push and Pull Systems

The historical information given in this section is a summary of the work by Hopp and Spearman (2004).

Prior to intensive use of computers in manufacturing, inventory was controlled using reorder-point or reorder-quantity (ROP/ROQ) type methods. During the 1960s, Joseph Orlicky, Oliver Wight, and George Plossl along with others developed a new system, which they termed Material Requirements Planning (MRP) (Orlicky, 1975).

In 1980s, MRP grew in scope and evolved to MRP-II, which combined MRP with master scheduling, rough cut capacity planning, capacity requirement planning, input-output controls and other modules. By 1989, MRP/MRP-II dominated western production control in manufacturing market.

While MRP/MRP-II dominated western manufacturing market, in Japan, Toyota improved conventional ROP/ROQ methods and developed the Toyota Production System (TPS). TPS had two main components: continuous improvement and just in time manufacturing (JIT).

According to Ohno (1988), JIT has two characteristics: Kanban and production leveling. Leveling production involves the changes that Ohno proposed in the environment such as set-up, lot size, and lead time reduction to make this system work.

By the early 1980s, western manufacturers realized that they had fallen behind in the manufacturing system and production efficiency. Although MRP continued its growth, some manufacturers began to think that MRP was not the best system. Western academicians visited Japan to study JIT, and quite a few books were published on JIT during this period.

During 1980s, western JIT implementations were faced with a simple philosophy and complicated techniques. Managers had to come up with some environmental innovations to make the system work. Depending on how creative they were doing this, JIT worked in certain cases and it did not in others.

By the end of 1980s, JIT began to lose its popularity with the introduction of the ERP systems. With the development of client-server information technology, it became feasible to integrate all business applications of a firm through a common database. ERP offered total integration and best practices of business functions. In spite of the high cost and unsuccessful implementation stories, ERP continued its growth. The “totally integrated firm” premise played an important role in this growth.

While ERP continued its growth, a case study conducted by MIT was published in “The Machine That Changed the World” by Womack et al. (1990). This study compared the western and Japanese automobile manufacturing techniques and concluded in no uncertain terms that the Japanese methods were superior. In this study, JIT was renamed as “lean manufacturing”. With a new name and new success stories, the system created by Ohno again became a hot topic in the world.

JIT movement also spawned a separate movement that became even larger than JIT: total quality management (TQM). TQM was institutionalized in the ISO 9000 certification process. In 1980s Motorola improved TQM by establishing a quality goal and developing a set of statistical techniques for measuring and achieving this quality goal. This approach was named as “Six Sigma”. Six Sigma carried the legacy of TQM, as “lean manufacturing” carried the legacy of JIT. Despite these two paths developed separately, in recent years Six Sigma and lean manufacturing techniques were merged as “lean Six Sigma”.

In 2000s ERP applications have been transformed into Supply Chain Management (SCM) systems with the integration of suppliers to the system.

3.1.1. Characteristic of Pull Systems

While manufacturing firms were confused in a sea of new terminology, researchers began to study and tried to find the answer of this question: What is so special about Kanban.

The well known water and rock analogy suggests that, the real benefits of Kanban come from environmental improvement (removing rocks or problems such as long lead times, long set-up times, large batch sizes). However, some researchers are not willing to ascribe the benefits of JIT only to environmental improvements. First of all, all the environmental changes are made by Ohno (1988) to make Kanban work. In other words Kanban is the essential part of JIT. Moreover, if the flow control method did not matter, the companies that used MRP could easily achieve all the benefits of JIT by improving environment without any change in their flow control system. However this did not happen.

Spearman et al. (1990) claim that while specific environmental changes are influential there are three primary logistical reasons for the improved performance of JIT:

1) Less congestion
   Comparison of an open queuing network with an equivalent closed one shows that the average WIP is lower in the closed network than in the open network given the same throughput. This is due to the fact that queue lengths have no correlation in the open network but are negatively correlated in the closed one.

2) Easier control
   a. WIP is easier to control than throughput, because it can be observed directly.
   b. Throughput is typically controlled with respect to capacity. Because it cannot be observed directly, capacity must be estimated by considering process time, set-up time, random failure, worker efficiency, rework, and other factors that affect the rate of production.
   c. Throughput is controlled by specifying an input rate. If input rate is less than the capacity, the throughput is equal to the input. If not, throughput is equal to capacity and WIP is built without bounds (or bounded only with physical space capacity).

3) WIP cap
   The benefits of pull environment are more a result of the fact that WIP is bounded than the practice of pulling everywhere. This was argued by observing that a simple overall bound on the WIP (as in a closed queuing network without blocking) will show the same benefits cited by Kanban. Moreover closed queuing network without blocking shows better throughput performance than Kanban.

Based on these findings, Spearman et al. (1990) proposed a hybrid push/pull system known as Conwip that shows the benefits of Kanban and that can be applied to more general manufacturing environments.

3.2. General Description of Conwip

Conwip is a system that possesses the benefits of a pull system and that can be used in a wide variety of manufacturing environments including push systems.

Spearman et al. (1990) describe the Conwip system as follows:

> It can be said that Conwip is a generalized form of Kanban. Like Kanban, it relies on signals from the shop-floor (Kanban card flow is given in Figure 3.1). In a Conwip system, cards traverse a circuit that includes the entire production line. A card is attached to a standard container of parts at the beginning of the line. When the container is used at the end of the line, the card is removed and sent back to the beginning where it waits in a card queue to be attached to another container of parts.
>
> The numbers are matched with the cards by referencing a "backlog list". When work is needed for the first work center in the production line, the card is removed from the queue and marked with the first part number in the backlog list as to which raw materials are present. The time of the part number match is also noted on the card as the system entry time. Card flow of Conwip line is given in Figure 3.2.
>
> Maintenance of the backlog list is the responsibility of production and inventory control staff. In many cases the backlog will be generated from a master production schedule. In other cases, firm orders may be added to the backlog as they are received. Expeditors are allowed to arrange and maintain backlog list but not allowed to force the start of work without a card present.

The queue discipline used at all process centers in the line is FIFO (First In First Out). In other words, work with the lowest entry time is started first. The only exception is rework, which is given the highest priority.

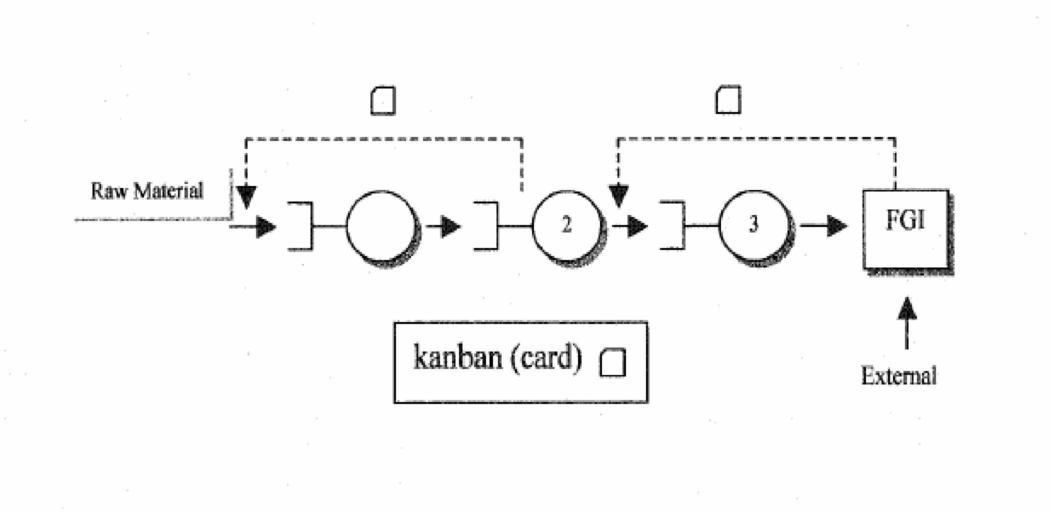

Figure 3.1 Flow of Kanban System (Spearman et al., 1990)

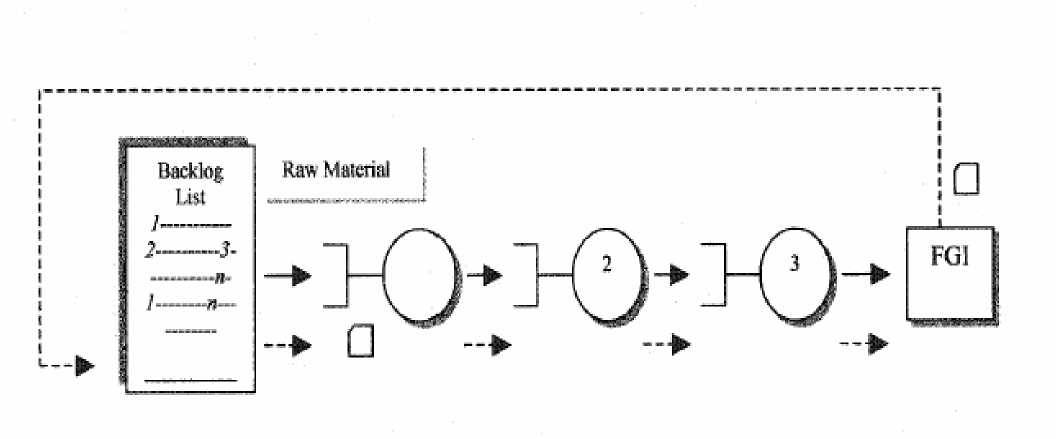

Figure 3.2 Flow of Conwip system (Spearman et al., 1990)

3.2.1 The Parameters To Be Established In a Conwip Line

According to Spearman et al. (1990), the following parameters need to be determined for Conwip application.

a) WIP setting (WIP cap): Maximum WIP amount allowed in the line.
b) Production quota: Target production quantity during a period.
c) Maximum work ahead amount: If during a period, the production quantity exceeds the production quota plus the maximum work ahead the line is stopped.
d) Capacity shortage trigger: If at the end of the production period, the produced quantity stays below the production quota minus the capacity shortage trigger, this trigger indicates that an additional capacity should be utilized, e.g. overtime must be scheduled.
e) Backlog list determination and maintenance rules.

There are many studies in literature for setting these parameters, which will be discussed in the next section.

3.2.2. Comparison of Conwip With Other Systems

The comparison of Conwip with other systems given below is a summary of the works by Spearman et al. (1990) and Hopp and Spearman (1996).

<u>Conwip is more general than Kanban</u>:
Some manufacturing environments are not well suited for Kanban. In particular, production lines that produce many different parts face practical problems. There may not be enough space to have a standard container for each part. Even if there is, WIP levels will be higher than necessary. Conwip solves this problem by

utilizing the backlog list. Conwip does not maintain WIP for every item. Backlog list determines which parts are to be produced and in which sequence. Cards are used to determine when to produce.

Production environments where it is not feasible to eliminate significant set-up times are not appropriate for Kanban. On the other hand, Conwip allows sequencing jobs to incorporate the set-up in the planning stage.

When jobs have priorities, sequences may need to be controlled. In Conwip system, sequencing jobs is allowable according to priorities, whereas in Kanban, job sequencing is made on shop-floor.

Conwip results in lower WIP levels than Kanban

A Conwip line will result in lower WIP levels than a Kanban system with the same throughput. In a Conwip system, the product flow is pushed through the production line, and WIP tends to accumulate at the bottleneck station. Hence, Conwip will provide higher utilization of bottleneck and greater throughput than Kanban.

Conwip is more effective than push

Conwip shows all the advantages of pull systems over push systems: less congestion, easier control and reduced WIP while keeping the throughput at the same level as a result of WIP cap.

Conwip versus Drum-Buffer-Rope (DBR)

There are many similarities between Conwip and DBR proposed by Goldratt and Fox (1986). DBR is more general than Conwip. However, in the environments where Conwip can be applied, DBR and Conwip show similar results.

In a DBR system, the whole system is synchronized with the bottleneck work center. All the non-bottleneck work centers are arranged so as not to allow starvation of the bottleneck. Job release to the system is adjusted according to the bottleneck requirement. Bottleneck requirement is calculated by adding a buffer time to the “bottleneck processing time” of the WIP in front of the bottleneck and the upstream work centers of the bottleneck. In other words, job release is made according to the bottleneck production rate to prevent the increase in inventory.

Under Conwip, excess WIP tends to accumulate in front of the bottleneck work center and the production rate of the bottleneck determines the job release to the shop-floor.

The main difference between DBR and Conwip is that under DBR, decisions must be made regarding the time of job releases, while under Conwip the releases occur at the bottleneck rate automatically.

Given the relative effectiveness of controlling WIP versus controlling release rates, it would appear that Conwip will be more robust to errors in capacity estimation. Because WIP will accumulate in front of the bottleneck, Conwip will be robust to the error in determining the bottleneck and changes in the product mix which may move the bottleneck.

When there is a distinct and stable bottleneck, it would be advisable to pull from the bottleneck by making the bottleneck the last machine in the Conwip loop and push work to the downstream work centers. This would prevent the cards from piling up in front of a failed machine that cause starvation of the bottleneck.

3.3 Review of Conwip Literature

Since its introduction, the Conwip system has attracted a lot of attention from practitioners and researchers. As a pull system it shows all the advantages of pull systems over push systems using WIP control. On the other hand, it is more robust, flexible, and easier to implement compared to other Kanban type pull systems.

These characteristics are very important for manufacturing companies. Conwip systems try to control inventories and at the same time run in the uncertain and dynamic environments where Kanban does not perform well.

According to today's viewpoint, Conwip is a manufacturing control tool based on production. However, recent research shows that Conwip control systems can be used not only in manufacturing stages but also in different echelons of a supply chain (Ovalle and Marquez, 2003).

The research about Conwip can be devoted to one or more of the following topics. (Framinan et al., 2003)

1) Determination of Conwip parameters: Decisions to be made in order to efficiently operate Conwip according to given performance measures.

2) Application of Conwip in different environments: Results of the Conwip application to various manufacturing scenarios. Results of the real implementation or computer simulation of the performance of Conwip application in these manufacturing scenarios.

3) Comparison of Conwip with other production control systems: Analysis of Conwip performance to see whether or not it is superior to other systems in terms of given performance measures.

It is clear that the above topics are closely related with each other. For instance, determination of Conwip parameters is closely related with the manufacturing scenario for which Conwip is applied. On the other hand, determination of the best operation parameters is essential for a fair comparison of different production planning systems. However, most of the studies in literature concentrate on one specific aspect of the Conwip system, and it is not easy to understand the system as a whole. A summary of these studies is provided in Table 3.1.

3.3.1 Determination of Conwip Parameters

When implementing a Conwip system, there are two main parameters:

1) The number of Conwip cards
2) Sequence of the jobs in the system

<u>The number of Conwip cards:</u> This number defines the maximum amount of WIP allowed in the system. All of the researches deal with the number of Conwip cards directly or indirectly. It is the most important parameter influencing the system's performance, but unfortunately there are no clear rules to determine it.

The procedures to determine the number of Conwip cards can be classified in two groups: analytical models and simulation models

Most of the analytical models are based on the approximation of throughput as a function of WIP. Such an expression allows us to estimate WIP for a throughput target or to minimize a cost function which includes WIP and throughput. For this purpose, the queuing theory is used, and the Conwip system is modeled as a closed network without blocking. (Kanban is defined by a closed network model with blocking.) On the other hand, simulation is used especially in complex environments or for determining the best parameter before comparison of different systems. However, using simulation may not be very practical in some real applications.

Most of the studies are about card setting, i.e., determining the number of cards that satisfy given performance criteria under certain manufacturing conditions. However, there exist a few studies about maintaining the number of cards, i.e. developing rules to change the number of cards according to changing conditions. Hopp and Roof (1998) apply statistical throughput control for card maintenance in a make to order environment. Their procedure increases or decreases the number of cards according to the discrepancy of the average and deviation of inter-output times from target throughput.

Sequence of the jobs in the system: For all types of Conwip systems except single product, make to stock systems, job sequencing is made in the backlog level. For the jobs waiting to enter the system, the production sequence is determined by prespecified queue discipline such as FIFO, LIFO, and earliest due date and so on. It should be noted that the jobs in the backlog list are only sequenced. Release dates of the jobs are not determined and these depend on the production status. In other words, sequenced jobs are released to the production when there exist available Conwip cards.

According to Table 3.1, we were able to find three studies that primarily deal with sequencing of jobs in the backlog list.

3.3.2 Applications of Conwip to Different Manufacturing Environments

There are a few studies that describe a real world application of Conwip and there are relatively more studies about application of Conwip to different hypothetical manufacturing environments. The types of production in these environments include the following.

1. Assembly lines
2. Independent lines sharing common machines
3. Job-shop
4. Alternate production routes

Table 3.1 also shows that some of these environments have the characteristics given below.

1. Machine failures
2. Set-up times
3. Rework

Table 3.1 Summary of Conwip Studies in Literature

		MAIN FOCUS OF THE STUDY			CONWIP APPLICATION ENVIRONMENT					COMPARISON WITH							
year	Reference	Analytical card setting	Simulation based card setting	Backlog sequencing	Real world application	Type of production	Machine failure	Set-Up times	Rework	Kanban	Push system	Hybrid system	DBR	New job release	Base stock	Base stock with WIP cap	Pull from bottleneck
1989	Spearman Hopp and Woodruff (1989)				y												
1990	Spearman Hopp and Woodruff (1990)		y								y						
1991	Hopp and Spearman (1991)	y					y										
1993	Duenyas, Hopp and Spearman (1993)	y					y										
1993	Duenyas and Keblis (1993)	y				1				y							
1996	Bonvik and Gerhwin (1996)		y				y			y		y					
1996	Gstettner and Kuhn (1996)									y							
1997	Graves and Milne (1997)		y				y						y	y			
1997	Herer and Masin (1997)	y		y				y									
1998	Duenyas and Patananake (1998)		y												y	y	
1998	Hopp and Roof (1998)																
1998	Huang, Wang and Ip (1998)	y			y	2					y						
1998	Ryan, Baynat and Choobineh (1998)	y				3											
1999	Ayhan and Wortman (1999)			y		1											
1999	Golany, Dar-El and Zeev (1999)	y		y		4		y		y							
2000	Duri, Frein and Lee (2000)	y							y								
2000	Gaury, Pierreval and Kleihnen (2000)		y							y		y					
2000	Luh, Zhou and Tomastik (2000)			y		3											
2001	Framinan, Usano and Leisten (2001)		y														
2002	Gillard (2002)				y						y		y				y

1: Assembly Line

2:Independent Lines Sharing Common Machines

3:Job-Shop

4:Alternate Production Route

These articles are indicated in the last column of Table 3.1.

3.3.3. Comparison of Conwip With Other Systems

There are many articles in literature about comparison of the Conwip system with other systems listed below.

a) Kanban
b) Push systems
c) Hybrid systems
d) DBR
e) New job release (a new methodology proposed by author)
f) Base stock
g) Base stock with WIP cap
h) Pull from bottleneck

3.3.4 Review of Individual Studies

Brief descriptions of the studies included in Table 3.1 are given below in chronological order.

Spearman, Hopp and Woodruff (1989) described a hierarchical planning framework for a production control mechanism known as Conwip. A specific implementation of this system was realized for a large computer manufacturer. They focused on the interactions between the planning modules at different levels in the hierarchy and on the architecture linking them. The modules included demand planning, WIP and quota setting, sequencing and batching, real time simulation for hot jobs, online feedback (statistical throughput control and maintenance of WIP according to this feedback), and long range production tracking (for input quota estimation).

Spearman, Woodruff and Hopp (1990) gave general description of Conwip and practical advantages of Conwip over push and other pull systems. Simulation was used to compare Conwip with push systems and results showed that Conwip was superior to push systems.

Hopp and Spearman (1991) developed an analytical approximation of throughput as a function of WIP under the assumption of deterministic process times and exponential failure and repair times. They compared their approximation with mean value analysis (MVA) approximation of throughput as a function of WIP under the exponential process time assumption. They showed that the proposed approximation is better than MVA under deterministic process time and exponential failure and repair assumption.

Duenyas, Hopp and Spearman (1993) developed an approximation for throughput, similar to Hopp and Spearman's (1991) approximation, under the assumption of deterministic process times and exponential failure and repair times. Using this approximation, they developed a mathematical model to minimize a cost function which is an expression of throughput and WIP, and solved this mathematical model for setting card counts and production quotas.

Duenyas and Keblis (1993) proposed an analytical model for throughput of Kanban as an expression of WIP under general distribution process time and assembly line assumption. For this purpose, they firstly defined a relationship between Kanban and Conwip throughput for the same WIP level. Then, they used the Shantikumar and Gocmen's (1983) approximation for defining Conwip throughput as an expression of WIP. Finally, they used the first relationship between Kanban and Conwip to approximate the throughput of Kanban. After empirically testing their approximation, they compared the two systems using simulation. According to the results of this simulation, they concluded that

Conwip performed better than Kanban with less average WIP for the same throughput in the assembly line case.

Bonvik and Gerhwin (1996) developed a hybrid system between Kanban and Conwip. In this proposed system, Conwip was supplemented with secondary Kanban cells. These detect the problems in the line and block release to the line if the parts cannot be processed further. They compared their hybrid system with Kanban and Conwip using simulation under variable demand, variable processing times, and exponentially distributed failure and repair times. They also determined the system parameters using simulation, and the comparison was made using these determined parameters. Objectives included fill rate, inventory, average backlog length, and waiting time. According to these objectives, under normal conditions, the hybrid system behaves more like Conwip and better than Kanban. However, there are certain conditions under which the hybrid system is better than Conwip and Kanban.

Gstettner and Kuhn (1996) developed a heuristic procedure for optimum distribution of card count for Kanban system under exponential service time, unlimited demand, and unrestricted buffer space assumptions. Using this distribution heuristic for Kanban and Duenyas, Hopp and Spearman's (1993) approximation for Conwip, they developed a simulation model to compare Kanban and Conwip. The results showed that Kanban distribution has significant effect on the performance. If the card distribution is made according to the proposed heuristic, Kanban is superior to Conwip. This result was in conflict with other comparison studies. They argued that, the reason of this conflict was that they did not use the proposed heuristic for Kanban card distribution when comparing the systems.

Graves and Milne (1997) developed a heuristic to release jobs to the shop floor under the assumptions that process, failure and repair times are exponential, each job has the same production sequence and the same process time, a single machine is used in every station, unsatisfied demand turns to lost sale, exponential customer arrivals and shared bottleneck. According to this heuristics, job releases are made only if their predicted waiting time is sufficiently small (predetermined value). Waiting times and system parameters were estimated using simulation. They also used simulation for comparison of the proposed method with Conwip and DBR. The results of the simulation showed that, according to the reduced lead time and improved service time objectives, the new heuristic and DBR are superior to Conwip whereas in low lead time environment the new heuristic is superior to DBR and Conwip.

Herer and Masin (1997) developed a mathematical programming model for a Conwip based multi-product flow shop for sequencing the backlog so as to minimize cost (inventory holding cost+overtime and backorder cost). Their assumptions were sequence dependent set-up, known demand, penalty for early and overdue deliveries, deterministic processing times, known linear holding cost, and known lot size. MVA approximation was used for throughput and WIP relationship.

Duenyas and Patananake (1998) presented a simple approximation method for computing the parameters of base stock policy (Target WIP level for every stage) for multiple stage make-to-stock systems with a limit on the WIP on the shop floor. They assumed different WIP holding costs for every stage and known backorder cost. They used simulation to test their approximation. According to their results, approximation works well for highly or moderately variable systems. For less variable systems, approximation overestimates the optimum level. They also used simulation to compare base stock policy with the WIP cap, Conwip, and standard base stock policy. When WIP costs are different between stages, base stock with WIP cap is better than the other two policies. Best parameters of Conwip and standard base stock policy was determined using simulation.

Hopp and Roof (1998) developed a simple adaptive production control method (statistical throughput control) for setting and maintaining WIP levels to meet the target production rate in a Conwip environment. STS uses real time data to automatically adjust the WIP Levels. When the observed mean cycle time is greater than the determined maximum cycle time, the system alerts for changing the capacity or the target throughput level. In addition, when the observed interoutput time is significantly less than the target, the system alerts for removing a card from the shop floor. A card is added to the system for the opposite case. Simulation was used to demonstrate the effectiveness of STC under a variety of conditions including single and multiple products, simple flow lines, routing with shared resources and an assembly system

Huang, Wang and Ip (1998) introduced a practical method to determine the number of cards for the Conwip system for a production line with a bottleneck. They used simulation to verify the introduced method. They also used simulation to compare the Conwip system with the previous push system for a cold rolling plant in terms of average WIP and inventory, average inventory cost, throughput rate and utilization objectives. The results showed that Conwip is an effective method for semi-continuous manufacturing.

Ryan, Baynat and Choobineh (1998) developed a mathematical model for multi-product, Conwip controlled job-shop manufacturing environment to determine WIP levels for every item under the assumption that products share the same resources, each product type may have a distinct routing through the processing stations and its own processing time distribution on each station it visits, and alternative routes with known probability. They employed a two-stage model and solution. Firstly a model is solved under heavy demand assumption and card distribution is determined according to this solution using the card dealing heuristic. The solution of this first problem is used in the solution of the second model which takes demand into consideration.

Ayhan and Wortman (1999) developed an analytical model for expression of throughput for Conwip based assembly lines under the assumption that job processing times on a given machine form a sequence of independent identically distributed random variables.

Golany, Dar-El and Zeev (1999) developed a mixed integer linear programming model to determine the optimum WIP level and job sequencing simultaneously by minimizing a cost function for multi-family product, multi-cell, Conwip based manufacturing environment. This was an NP-Complete model and they employed a simulated annealing heuristic to solve this model. They developed the model under the assumptions of several product families, different routes, several production cells, set-up between cells, production of end items or intermediate items, deterministic process times, and no machine breakdowns. Simulation was used for testing the performance of the solution and to compare Conwip with Kanban. The results showed that heuristic solution is very close to optimum and Conwip is superior to Kanban.

Duri, Frein and Lee (2000) proposed an analytical method to evaluate performance of Conwip based flow shop with inspection under the assumption that inspection is made randomly with given probability, inspection time is negligible, rework is made at the station where inaccuracy occurs, processing times are exponentially or N-Stage Coaxian distributed, and demand is Poisson distributed. They showed through examples how the proposed analytical method could be used to determine the optimal policy for a chosen design criterion.

Gaury, Pierreval and Kleihnen (2000) developed a generic model for pull systems and proposed a mathematical formulation for this generic model to minimize the WIP and maximize the throughput. A simulation based evolutionary algorithm was used to solve this model. They compared Kanban, Conwip and hybrid of Conwip and Kanban according to solution. They showed that, hybrid system is superior to Kanban and Conwip.

Luh, Zhou and Tomastik (2000) proposed a mathematical model to schedule jobs in the shop-floor for a Conwip based, job-shop manufacturing environment. A lagrangian relaxation based algorithm was developed to solve the model.

Framinan, Usano and Leisten (2001) proposed a sequencing heuristic for backlog to minimize make span. Regarding the simpler and faster heuristics, the proposed dispatching rule outperforms those commonly used heuristics for the unconstrained permutation flow shop problems especially in lower card counts. (Comparison is made with SPT (Shortest Processing Time, LPT (Longest Processing Time), SIRO (Service in Random Order) and other fastest heuristics for the flow shop sequencing (RA, GUPTA, PALMER).

Gillard (2002) compared push, Conwip and DBR systems using simulation for Intel Corporation assembly and test facility. Simulation was made under the assumptions of significant set-up times, strong demand, heavily utilized bottleneck resources, series of single work stations, and exponentially distributed process times. Single bottleneck and multiple bottlenecks were analyzed separately. Mean value analysis approximation was used to determine the best parameters of Conwip system. The result of the simulation in terms of the output rate showed that, for single bottleneck scenario, DBR outperformed other release rules. For double bottlenecks, pull from bottleneck (a specific version of Conwip proposed when there is a defined bottleneck) outperformed other rules including classic Conwip.

CHAPTER 4

DETERMINATION OF CONWIP PARAMETERS FOR THE COMPANY

Our aim is to implement Conwip in the company to obtain the benefits of the pull system without making drastic changes in the hierarchical planning system in use. We aim to reduce the WIP level while maintaining the same throughput level with the aid of Conwip.

The first step in implementing a Conwip system is to determine the Conwip parameters. Parameters required for a Conwip Line are given below (Spearman et al. , 1990).

1. Production quota: Target production quantity during a period.
2. Maximum work ahead amount: If the production quantity exceeds the production quota plus the maximum work ahead amount, then the line is stopped.
3. Capacity shortage trigger: If at the end of the production period, the produced quantity stays below the production quota minus the capacity shortage trigger, this trigger indicates that an additional capacity should be utilized, e.g. overtime must be scheduled.
4. Determination and sequencing of the parts in the backlog list
5. WIP setting or WIP cap.

The most important parameter in our implementation is the WIP setting. We describe the setting of this parameter in the remaining of this chapter. However, before the WIP setting details, it is useful to discuss briefly how to set the other parameters for Conwip implementation.

Production quota (target production)

Production quotas for the parts to be produced will be determined by the master demand schedule. Monthly forecasts and sales orders are used to determine the production quota as described in Chapter 2.

Maximum work ahead amount

Maximum work ahead amount indicates the tolerable limit on the over-production. When the amount of parts produced in a given period exceeds the target production plus the maximum work ahead amount, the production will be stopped. The company can tolerate a maximum of one week work ahead amount, which is determined as the monthly production quota divided by four.

Capacity shortage trigger

Capacity shortage trigger indicates the tolerable backlog amount. When the backlog amount exceeds the capacity shortage trigger, overtime should be planned. For all parts, 25% of the production quotas are used as the capacity shortage trigger.

Backlog list determination

Backlog list shows the jobs waiting in queue to enter the production line. Prioritized work orders with material requirements list, which is the output of the procedure called Priority Assignment to Work Orders and Purchase Orders (Figure 2.2), is used as the backlog list in our Conwip implementation. Sequencing of the parts is determined by the priorities assigned to them by the same procedure.

WIP cap

The most important parameter of the Conwip system is the determination of the WIP cap. WIP cap setting for the Conwip implementation is carried out in two stages.

1) WIP setting for each telecommunication sub-line given in Figure 2.5.
2) Distribution of the WIP settings of the sub-lines, calculated in stage 1, to different product groups assigned to these sub-lines.

Approximated mean value analysis (MVA) algorithm is used in WIP setting for the sub-lines. In the remaining of this chapter we describe the approximated MVA algorithm, adaptation of the approximated MVA algorithm for the company, and retrieval of the values of the parameters from the ERP system to implement Conwip.

4.1 Approximated MVA Algorithm

There are two approaches in the literature for WIP setting: analytical methods and simulation based methods. Simulation based methods are time consuming as they require long simulation runs to decide on the parameters. In addition, simulation software investment is required. Because of these reasons, we did not find them practical for the Conwip implementation in the company and we decided to use an analytical method for the WIP setting.

There are various analytical methods proposed by researchers for different manufacturing environments. These are listed below including their main features.

Hopp and Spearman (1991): Deterministic process times, exponential failure and repair times in a flow line.

Duenyas, et al. (1993): Deterministic process times, exponential failure and repair times in a flow line.

Duenyas and Keblis (1995): General distribution for process times in an assembly line.

Herer and Masin (1997): MVA approximation is used for Conwip based multi-product flow line.

Huang, et al. (1998): Best case approximation with a correction factor, especially good for a single product, balanced flow line.

Golany, et al. (1999): Mixed integer programming for multi-family product, multi-cell environment with deterministic process times and set-up.

Duri, et al. (2000): Assembly line with inspection.

Ryan, et al. (2000): Mathematical programming model for job-shop environment.

In addition to these studies, Hopp and Spearman (1986) propose to set the WIP cap to the existing WIP level and reduce this level by using statistical throughput control. They also propose another WIP setting method to apply Conwip to newly constructed lines: WIP= (target throughput level/calculated cycle time) * correction factor.

Another analytical method used in the literature is MVA approximation. This is a practical iterative approach which is exact for manufacturing environments with exponential process times, no machine breakdowns, single product, and single server production lines.

4.1.1 Choice of the Approximated MVA Algorithm

We evaluated the above analytical approaches using the following criteria and we decided to use the approximated MVA for general distribution process times.

1) Ease of implementation
2) Ease of integration to the existing hierarchical system
3) Suitability to the production environment in the company

In real applications, it is desirable to focus on a solution approach that is easy to describe, easy to implement, and easy to adjust, yet still performs well on the two criteria of high output and low WIP inventory, rather than focusing on precise solutions.

MVA is very easy to implement and can easily be integrated to the existing system. However, at first glance it does not seem suitable for the environment in the company. MVA requires a single product production line, exponential processing times, and single server stations for exact solution. On the other hand, the telecommunication production line environment in the company can be characterized with multiple products, deterministic process times, and a multiple server production line.

As we gathered more information about the MVA approach and its extensions, we have realized that MVA approach does not provide an exact solution but it can still perform well for the telecommunication production line.

Single product assumption of MVA

Herer and Masin (1997) used the MVA approach in their study and evaluated it as follows.

> "The MVA approach is both robust and simple, and is based on interactive determination of the system's mean throughput and flow time for increasing WIP inventory levels (number of containers). The approach assumes the existence of only one product having an exponential processing time distribution. However, production today is rarely comprised of one product, especially one whose processing time is exponentially distributed. Instead, production usually includes a variety of parts, each having deterministic, but differing, processing times. Fortunately, this range of deterministic processing times can often be modeled as one product having a general processing time distribution (*Karmarkar 1987*)."

In the light of Herer and Masin's (1997) research, we re-modeled the telecommunication production line as a single product line with general distribution processing times.

Single Server assumption of MVA

MVA approximation requires a single server in every station. In the telecommunication production line, there exist multiple servers in stations. However, the sizes of the transfer batches are relatively very high compared to the number of servers in the stations. Hence, when a batch comes to a station, every server at the station processes the same batch until the batch is completed. In this environment, if we take every batch as one product, we can assume the group of multiple servers as a single faster server.

Exponential process times assumption of MVA

We re-modeled the production environment as having only one product with general distribution process times and a single server per station by assuming each batch of a product as one product, but our new environment characteristics were not suitable yet for using the MVA approach.

We decided to investigate MVA extensions and found the approximated MVA algorithm suitable for general distribution process times (Curry and Feldman, 2009). In the light of the above information we decided to use the approximated MVA algorithm to determine the WIP level.

4.1.2 Description of the Approximated MVA Algorithm

Mean Value Analysis approach is a technique for estimating expected queue lengths in a closed queuing network having exponentially distributed service times, single server stations and only one product. It was developed by Reiser and Lavenberg (1980). The approximated MVA algorithm defined below is an extended version of MVA for general distributed processing times (Curry and Feldman, 2009).

.

Inputs

n: the number of stations

te(j): mean effective processing time at station j.

ce2(j): squared coefficient of variation (SCV) for effective processing time at station j.

Outputs

TH(W): the line throughput when operated with WIP level W.

CT(W): expected job cycle time through the line when the WIP level is W.

$CTj(W)$: expected job cycle time at station j when the WIP level is W.

$WIPj(W)$: expected WIP level at station j when the WIP level is W.

$uj(W)$: utilization of the server at station j when the WIP level is W.

Formulation

The following formulation is due to Curry and Feldman (2009).

CTj(W) = E[remaining processing time for the job at the server of station j] +
{E[number of jobs at station j]-E[number of jobs in service]}te(j) +
te(j)

where

E[remaining processing time for the job at the server of station j] =
Prob(server of station j busy)*E[remaining processing time | busy] =
uj(W-1)*E[remaining processing time | busy] ≈
uj(W-1)* te(j)* (ce2(j)+1)/2 (Kleinrock, 1964)

E[number of jobs at station j] ≈ WIPj(W-1)
E[number of jobs in service] ≈ uj(W-1)
uj(W-1) = TH(W-1)*te(j)

Combining the results given above, we obtain the following.

$$CTj(W) \approx [te(j)^2/2] * [ce2(j)-1] * TH(W-1) + [WIPj(W-1)+1]\, te(j) \qquad \textbf{(1)}$$

$$CT(W) = \sum_{j=1}^{n} CTj(W) \quad \textbf{(2)}$$

$$TH(W) = W / CT(W) \text{ (Little's Law)} \quad \textbf{(3)}$$

$$WIPj(W)= TH(W)* CTj(W) \text{ (Little's Law)} \quad \textbf{(4)}$$

For W=0, it is obvious that

$CT(0) = TH(0) = WIPj(0) = 0$

for W=1, we have

$CTj(1)= te(j)$

$CT(1) = \sum te(j)=T_0$

$TH(1) = 1 / CT(1)=1/ T_0$

$WIPj(1)= (1/ T_0) * te(j) = uj(1)$

Using the recursion given by equations (1)-(4), the throughput can be approximated for W=2,3,4,... until achieving the maximum throughput, and the minimum WIP level yielding the maximum throughput is set as the WIP cap.

4.2 Adaptation of the Approximated MVA Algorithm for the Problem

We aim to calculate the minimum WIP level providing the maximum throughput for product groups produced in each telecommunication production sub-line given in Figure 2.5. We intend to use the approximated MVA algorithm to solve this problem. For this purpose, we firstly need to calculate the inputs of MVA indicated below for each telecommunication production sub-line separately.

te(j): mean effective processing time at station j

ce2(j): squared coefficient of variation (SCV) for effective processing time at station j.

As we noted in Section 4.1.1, the production environment in the company does not fit exactly to the assumptions of the approximated MVA algorithm and we need some adaptation to use this algorithm in the solution of the problem.

First of all, the approximated MVA algorithm requires a single product in every sub-line, but there exist multiple products in the company. In this situation we think every batch of a different product produced in the sub-line as one product. Because of these batches of different products have different processing times, we assume that they are a single product having a general processing time distribution.

Another requirement of the approximated MVA algorithm is a single server in every workstation. There are multiple parallel servers in every workstation in the company. Transfer batch quantities of the lines are relatively high compared to the number of servers in workstations. Therefore, each batch is split and processed on all servers of a workstation. For this reason, we assume that there exists a single faster server. Processing time of this imaginary single server is calculated by dividing the processing time of the batch by the number of servers.

As we noted in Section 2.5.1, servers in stations are managed centrally. At the beginning of the month, chief of the workstations distribute the servers to the sub-lines according to the workload ratio of the sub-lines. In other words, the number of parallel servers of the workstations in sub-lines are changed every month. We need to calculate the number of these servers before calculating processing times of the batches.

Under these assumptions, we need to calculate the mean and SCV of effective processing times of the different product batches. To do this, we have available "processing times of the products", "transfer batch quantities of the sub-lines", "average monthly demand of the products" and "the total number of servers in the workstations before distribution" as inputs.

In the rest of this section, we describe calculation of the minimum WIP level providing the maximum throughput for product groups produced in each telecommunication production sub-line using the approximated MVA algorithm. The calculations need to be repeated every month in accordance with the master production schedule or whenever there is a change in this schedule. We follow the steps below for this calculation.

1. Defining notation of the problem.
2. Allocation of the servers to the sub-lines.
3. Calculation of the mean and SCV of effective processing times.
4. Modeling the problem to calculate WIP cap of the sub-lines.
5. Solving the problem using the approximated MVA algorithm.

6. Distribution of the WIP cap of the sub-lines to the product groups.

4.2.1 Notation of the Problem

Indices

i : product index

g: product group index

h : sub-line index, where

1: Small and medium sized PABX sub-line

2: Large sized PABX sub-line

3: Consoles sub-line

4: Accessories sub-line

(These sub-lines can be seen in Figure 2.5.)

j: station index, where

1: smd eye inspection

2: assembly

3: eye inspection

4: test

(These stations can also be seen in Figure 2.5).

Parameters:

d_i: average monthly demand of product i

b_h : transfer batch size of line h defined by the pallet size of the line.

n_j: number of servers available for station j

x_{ig} : 1 if item i is assigned to group g

0 otherwise

y_{gh}: 1 if group g is assigned to sub-line h

0 otherwise

Values of the x_{ig} and y_{gh} are determined by production engineering department of the company depending on the type of products.

t_{ij}: average processing time of item i at station j

n_{jh}: number of servers of station j allocated to sub-line h

D_h : total monthly demand of products processed in sub-line h

P_{hi} : Probability of occurrence of the batches of product i in sub-line h

te_{hj} : average processing times of the batches in sub-line h at station j

ss_{hj} : standard deviation of processing times of the batches in sub-line h at station j

ce_{hj}^2 : squared coefficient of variation of processing times of the batches in sub-line h at station j

TH^*_h = Target throughput (in units of batches) to be produced in sub-line h

W_h : WIP level of sub-line h

TH_h (W_h) = throughput of sub-line h when operated with WIP level W_h

CT_h (W_h) = expected batch cycle time through line h with WIP level W_h

$CT_{h\,j}$ (W_h) = expected batch cycle time at station j in line h with WIP level W_h

WIP_{hj} (W_h) = expected WIP level at station j in line h with WIP level W_h

Y_{gh} : Monthly workload of product group g in line h

Y_h : Monthly workload of line h

W_{hg}^*: WIP cap of product group g in sub-line h

4.2.2 Allocation of the Servers to the Sub-lines

Servers of the workstations are distributed to the sub-lines according to the workload share of the sub-line in the total workload of the workstation. Workload of a product in a workstation is calculated by multiplying the average monthly demand with the processing time of the product at that workstation. Sum of these workloads over products gives the total workload of the workstation. Sum of these workloads over sub-lines gives the workload of the sub-lines in this workstation type.

$n_{jh}= (\sum_{i,g} di * t_{ij} * x_{ig} * y_{gh} \ / \ \sum_{i,g,h} di * t_{ij} * x_{ig} * y_{gh}) * n_j$ for all h =1,..,4 and j=1,..,4 **(5)** where $\sum_{i,g}$ $di * t_{ij} * x_{ig} * y_{gh}$ is the workload of station j in sub-line h

and $\sum_{i,g,h}$ $di * t_{ij} * x_{ig} * y_{gh}$ is the total workload of station j.

The values of n_{jh} are in general not integer. These values are used as they are, because it is possible to use servers in multiple sub-lines. These servers are assembly workers and they can be shared by multiple sub-lines.

4.2.3 Calculation of the Mean and SCV of Effective Processing Times

We assume each batch of a different product in a sub-line as one product and te_{hj} shows the average processing time of this imaginary single product in sub-line h at station j.

Before calculating the average processing time of the batches in a sub-line, we need to estimate the probability of occurrence of the batch of a specific product. We find this probability as the proportion of the monthly demand of the product to the total monthly demand of the sub-line.

$D_h = \sum_{i,g} d_i * x_{ig} * y_{gh}$ for all h = 1,..,4 **(6)**

$P_{hi} = di / D_h$ for all i and h = 1,..,4 **(7)**

Process time of the batch of a product is calculated by multiplying the batch size of the sub-line (there is a fixed transfer batch quantity for all products produced in a sub-line) by the processing time of the product, and dividing this amount by the number of parallel servers. Using the P_{hi}, the mean, standard deviation and SCV of effective processing times of the sub-lines are estimated.

$te_{hj} = \sum_{i,g} (b_h * \ t_{ij} * x_{ig} * y_{gh} / n_{jh}) \ * \ P_{hi}$ for all h =1,..,4 and j=1,..,4 **(8)**

$ss_{hj} = \left(\sum_{i,g} (b_h * \ t_{ij} / n_{jh} - te_{hj})^2 * P_{hi} * x_{ig} * y_{gh}\right)^{1/2}$ for all h =1,..,4 and j=1,..,4 **(9)**

$ce_{hj}^2 = \ ss_{hj}^{\ 2} / \ te_{hj}^2$ for all h =1,..,4 and j=1,..,4 **(10)**

4.2.4 Model of the Problem to Calculate WIP Cap

Using the above intermediate results we can formulate the WIP cap calculation as follows for a particular sub-line.

min W_h

s.t.

$n_{jh} = (\sum_{i,g} \ di * t_{ij} * x_{ig} * y_{gh} \ / \ \sum_{i,g,h} \ di * t_{ij} * x_{ig} * y_{gh}) * \ n_j$ **(5)**

$D_h = \sum_{i,g} \ d_i * x_{ig} * y_{gh}$ **(6)**

$P_{hi} = d_i / D_h$ **(7)**

$te_{hj} = (\sum_{i,g} (b_h * \ t_{ij} * x_{ig} * y_{gh} / n_{jh}) \ * \ P_{hi})$ (for h =1...4, j=1...4) **(8)**

$ss_{hj} = \left(\sum_{i,g} \left((b_h * \ t_{ij} / n_{jh} - te_{hj})^2 * P_{hi} * x_{ig} * y_{gh}\right)\right)^{1/2}$ **(9)**

$ce_{hj}^2 = \ ss_{hj}^{\ 2} / \ te_{hj}^2$ **(10)**

$TH^*_h = D_h / b_h / 208$ where 208 is the number of work hours in a month **(11)**

$$CT_{hj}(W_h) = (te_{hj}^{\ 2}/2) * (ce_{hj}^{\ 2} - 1) * TH_h(W_h - 1) + (WIP_{hj}(W_h - 1) + 1) * te_{hj} \quad \textbf{(1)}$$

$$CT_h(W_h) = \sum_{j=1} CT_{hj}(W_h) \quad \textbf{(2)}$$

$$TH_h(W_h) = W / CT_h(W_h) \quad \textbf{(3)}$$

$$WIP_{hj}(W_h) = TH_h(W_h) * CT_{hj}(W_h) \quad \textbf{(4)}$$

$$TH_h(W_h) > TH^*_h \quad \textbf{(12)}$$

Using the approximated MVA, $TH_h(W_h)$ is estimated for $W_h = 0,1,2,..$ for every sub-line separately, until $TH_h(W_h)$ reaches the target throughput (TH^*_h) of line h. The minimum WIP level (W_h^*) that provides TH^*_h is set as the WIP cap of the sub-line h.

If there is no feasible solution to the problem, $TH_h(W_h) > TH^*_h$ condition is relaxed and the minimum WIP level providing the maximum $TH_h(W_h)$ is set as the WIP cap.

This model is implemented in MS Excel, which is usable in future Conwip applications in the company.

4.2.5 Distribution of WIP cap of the Sub-lines to the Product Groups

We distribute the calculated WIP cap for line h (W_h^*) to the product groups assigned to this line (W_{hg}^*). For this purpose, we use the proportion of the workload of groups to the total workload of this sub-line.

$$Y_{gh} = \sum_{i,j} d_i * t_{ij} * x_{ig} * y_{gh} \quad \textbf{(13)}$$

$$Y_h = \sum_{i,g,j} d_i * t_{ij} * x_{ig} * y_{gh} \quad \textbf{(14)}$$

$$W_{hg}^* = W_h^* * b_h * (Y_{gh} / Y_h) \quad \textbf{(15)}$$

4.3 Retrieval of Data and Calculation of the Input Parameter Values

The data needed to find the values of the inputs can be retrieved from the ERP system. SQL programs are written to retrieve the data from ERP system and to calculate the values of the parameters. In this section, samples of resulting values of these SQL programs are presented. Complete SQL Programs and all the resulting values can be seen in Appendix A.

4.3.1 Item Information (i , d_i)

Values of item id, item code (which generates the item index i), item description, planner code and average monthly demand of the item (d_i) are taken from the ERP system. A sample of resulting values is given in Table 4.1. The total number of items is 170.

Table 4.1 Item Information

ITEM_ID	SEGMENT1 (i)	DESCRIPTION	PLANNER_CODE	MALZ_ORT (d_i)
28000	YSNT00099-FPIO	DS200 CPU III FPIO YM	44	109
38400	YEXT00096	EXP48C (2/6) GENISLETME KARTI YM	32	257
11257	YEXT00039	EXP38 (2/0) GENISLETME KARTI	32	3
11260	YEXT00042	EXP38 (1T0/S0) GENISLETME KARTI	32	5
11272	YEXT00053	EXP48S (0/16) GENISLETME KARTI	32	15
11273	YEXT00054	EXP48S (2/6) GENISLETME KARTI	32	10
11274	YEXT00055	EXP48S (4/12) GENISLETME KARTI	32	7
11366	YPSU00001	BC200 BP YM	44	13
11368	YPSU00045	SPS200-AZ YM	44	100

4.3.2 Product Groups (g)

Group names (which generate group index g) and group descriptions are taken from the ERP System. A sample of resulting values is given in Table 4.2. There are 34 product groups.

Table 4.2 Product Groups

GRUP (g)	GRUP_TNM
AKS	AKSESUAR
BP-DS	DS BACKPLANE
BP-OS	MS ORTA BACKPLANE
CPU-DS	DS CPU
CPU-OS	MS ORTA CPU
DCC	DCC
DSS	DSS
ESKI	URETILMEYEN URUN
EVM	EVM

4.3.3 Sub-line Information (h , b_h)

Sub-line names (which generate sub-line index h), transfer lot-sizes of the sub-lines (b_h) and descriptions of the sub-lines are taken from the ERP system. Resulting values are given in Table 4.3. Conwip is applicable to the first four sub-lines and the fifth line is out of our scope.

Table 4.3 Sub-Lines and Transfer Batch Sizes

HAT (h)	HAT_LOT (b_h)	TNM
HAT1	50	MS_KUCUK/EXT
HAT2	20	DS/MS_ORTA
HAT3	30	KONSOL
HAT4	10	AKSESUAR
HAT5	1	DIGER

4.3.4 Work Station Information (j, n_j)

Workstation id, name of the station (j) and the number of servers available for workstations (n_j) information taken from the ERP system are summarized in Table 4.4.

Table 4.4 Workstations and the Number of Servers

RESOURCE_ID	RESOURCE_CODE (j)	CAPACITY_UNITS (n_j)
12	T_MONT_ISC	11
8	T_GT_ISCI	13
16	T_SMDGT_IS	17
17	T_TEST_ISC	21

4.3.5 Assignment of Items to Groups (x_{ig})

Item code (i), description of the item and assigned group of the item information are taken from the ERP system. A sample of resulting values is given in Table 4.5.

Table 4.5 Item Assignments to Groups

SEGMENT1 (i)	DESCRIPTION	GRUP (g)
YSNT00046	DS200 SPS BACKPLANE YM	BP-DS
YSNT00050	DS200 MAIN BP YM (ILAVE RACK)	BP-DS
YSNT00062	DS200 MAIN BP SMD YM (TEK RACK)	BP-DS
YSNT00065	DS200S BACKPLANE YM	BP-DS
YSNT00084	DS200M BACKPLANE YM	BP-DS
YSNT00094	DS200 2XSPS248 BACKPLANE YM	BP-DS
YSNT00095	DS200 MAIN BP SMD DUAL CPU YM	BP-DS
YSNT00101	DS200 MAIN BP U3-U4 YAMA YM	BP-DS
YSNT00109	DS200 MIL PABX BACKPLANE YM	BP-DS
YSNT00039	DS200 CPU YM	CPU-DS
YSNT00063	DS200S CPU YM	CPU-DS
YSNT00081	DS200S CPU MB YM	CPU-DS
YSNT00082	CPU MODULU YM	CPU-DS
YSNT00089	CPU MODULU CPU852T	CPU-DS

4.3.6 Assignment of Groups to Sub-Lines (y_{gh})

Group name (g) and sub-line name (h) information taken from ERP system are given in Table 4.6.

Table 4.6 Group Assignment to Lines

GRUP (g)	HAT(h)
EXT-KS	HAT1
KS_26	HAT1
KS_38	HAT1
KS_48	HAT1
BP-DS	HAT2
CPU-DS	HAT2
EXT-DS	HAT2
SPS-DS	HAT2
UTL-DS	HAT2
FT-ST	HAT3
IP	HAT3
OP-LT	HAT3
NT	HAT3
EVM	HAT4
GT	HAT4
IVM	HAT4
SPS-KS	HAT5
BP-OS	HAT5
FTST-LCD	HAT5
CPU-OS	HAT5
DIGER	HAT5
AKS	HAT5
GT-LED	HAT5
EXT-OS	HAT5
KNK-DS	HAT5
KNK-OS	HAT5
SPS-OS	HAT5
DCC	HAT5
DSS	HAT5
ESKI	HAT5
EXT-20	HAT5
IPX20	HAT5
IRIS	HAT5
SPS-20	HAT5

4.3.7 Average Processing Times of Items at Workstations (t_{ij})

Sub-line name (h), group name (g), item id, item code (i), workstation id, and average processing time of item on work station (t_{ij}) information are taken from the ERP system. In this SQL query, processing times of the items and workstation values are taken from the product routing tables in the ERP system. Sub-line name and group name are taken from the item-group and group-sub-line assignment tables. A sample of resulting values is provided in Table 4.7.

Table 4.7 Process Times of Items

HAT(h)	**GRUP(g)**	**ASSEMBLY ITEM_ID**	**SEGMENT1(i)**	**RESOURCE_ID**	**USAGE_RATE OR_AMOUNT(t_{ij})**
HAT2	EXT-DS	11258	YEXT00040	16	0,183
HAT2	EXT-DS	11258	YEXT00040	12	0,175
HAT2	EXT-DS	11258	YEXT00040	8	0,083
HAT2	EXT-DS	11258	YEXT00040	17	0,25
HAT1	EXT-KS	11260	YEXT00042	16	0,133
HAT1	EXT-KS	11260	YEXT00042	12	0,1
HAT1	EXT-KS	11260	YEXT00042	8	0,09
HAT1	EXT-KS	11260	YEXT00042	17	0,1
HAT2	EXT-DS	11261	YEXT00043	16	0,183
HAT2	EXT-DS	11261	YEXT00043	12	0,1
HAT2	EXT-DS	11261	YEXT00043	8	0,066667
HAT2	EXT-DS	11261	YEXT00043	17	0,2
HAT2	EXT-DS	11262	YEXT00044	16	0,25
HAT2	EXT-DS	11262	YEXT00044	12	0,25
HAT2	EXT-DS	11262	YEXT00044	8	0,217
HAT2	EXT-DS	11262	YEXT00044	17	0,35
HAT2	EXT-DS	11258	YEXT00040	16	0,183
HAT2	EXT-DS	11258	YEXT00040	12	0,175
HAT2	EXT-DS	11258	YEXT00040	8	0,083
HAT2	EXT-DS	11258	YEXT00040	17	0,25

4.3.8 Number of Servers and Their Allocation to Sub-Lines (n_{jh})

Workstation id, workstation name (j), sub-line (h) and the total number of servers available for workstations (n_j) are taken from the ERP system. The number of the servers of workstations assigned to sub-lines (n_{jh}) are calculated by the SQL program. A sample of resulting values is provided in Table 4.8.

Table 4.8 Number of Servers Allocated to Sub-Line

RESOURCE_ID	RESOURCE_CODE	HAT	CAPACITY_UNITS	CAP_ALLOC
8	T_GT_ISCI	HAT1	13	2
8	T_GT_ISCI	HAT3	13	3
12	T_MONT_ISC	HAT3	11	2
12	T_MONT_ISC	HAT4	11	1
16	T_SMDGT_IS	HAT3	17	2
16	T_SMDGT_IS	HAT4	17	1
16	T_SMDGT_IS	HAT5	17	7
17	T_TEST_ISC	HAT1	21	6
17	T_TEST_ISC	HAT2	21	2

4.3.9 Total Monthly Demand of Products Processed on Sub-Lines (D_h)

Sub-lines are taken from the ERP system. Total monthly demand of boards processed in sub-lines and the number of items processed in sub-lines are calculated by the SQL program. A sample of resulting values is given in Table 4.9.

Table 4.9 Total Monthly Demand of Boards Processed on Sub-Line

HAT (h)	HAT_ORT(D_h)	HAT_KALEM_SAYI
HAT1	4784	16
HAT2	2365	21
HAT3	4374	23
HAT4	4081	11
HAT5	10790	105

4.3.10 Average Processing Times of Batches at Workstations of Sub-Lines (te_{hj})

Sub-line (h), workstation id, name of the workstation (j) information are taken from the ERP system. Average times of the batches (te_{hj}) are calculated by the SQL program. A sample of resulting values is given in Table 4.10.

Table 4.10 Average Processing Times of Batches

HAT(h)	RESOURCE_ID	RESOURCE_CODE(j)	HAT_AVG_PTS (te_{hj})
HAT1	8	T_GT_ISCI	2,441
HAT1	12	T_MONT_ISC	2,347
HAT1	16	T_SMDGT_IS	2,005
HAT1	17	T_TEST_ISC	1,914
HAT2	8	T_GT_ISCI	1,975
HAT2	12	T_MONT_ISC	1,899
HAT2	16	T_SMDGT_IS	1,622
HAT2	17	T_TEST_ISC	1,548
HAT3	8	T_GT_ISCI	1,017
HAT3	12	T_MONT_ISC	1,027
HAT3	16	T_SMDGT_IS	0,877
HAT3	17	T_TEST_ISC	0,807
HAT4	8	T_GT_ISCI	0,573
HAT4	12	T_MONT_ISC	0,550
HAT4	16	T_SMDGT_IS	0,470
HAT4	17	T_TEST_ISC	0,449

4.3.11 Standard Deviation and SCV of Batch Processing Times (ss_{hj}, ce_{hj}^2) and Target Throughput (TH^*_h)

In this SQL program, sub-line (h), name of the workstation (j) and formerly calculated average time of the batches (te_{hj}) are taken from the ERP system. Standard deviation of the batch times (ss_{hj}), squared coefficient of variation of the batch times (ce_{hj}^2) and target throughput of the sub-line (TH_h^*) information are calculated by the SQL program. A sample of resulting values is provided in Table 4.11.

Table 4.11: Average Process Time, Standard Deviation, SCV, Target TH

HAT (h)	RESOURCE_CODE (j)	HAT_AVG_PTS (te_{hj})	HAT_SS_PTS (ss_{hj})	HAT_SCV_PTS (ce_{hj}^2)	TARGET_TH (TH^*_h)
HAT1	T_GT_ISCI	2,441	0,546	0,050	0,460
HAT1	T_MONT_ISC	2,347	0,443	0,036	0,460
HAT1	T_SMDGT_IS	2,005	0,712	0,126	0,460
HAT1	T_TEST_ISC	1,914	0,945	0,244	0,460
HAT2	T_GT_ISCI	1,975	1,439	0,531	0,569
HAT2	T_MONT_ISC	1,899	1,048	0,305	0,569
HAT2	T_SMDGT_IS	1,622	1,211	0,558	0,569
HAT2	T_TEST_ISC	1,548	1,303	0,708	0,569
HAT3	T_GT_ISCI	1,017	0,496	0,238	1,051
HAT3	T_MONT_ISC	1,027	1,405	1,872	1,051
HAT3	T_SMDGT_IS	0,877	0,461	0,277	1,051
HAT3	T_TEST_ISC	0,807	0,862	1,141	1,051
HAT4	T_GT_ISCI	0,573	0,236	0,170	1,962
HAT4	T_MONT_ISC	0,550	0,188	0,117	1,962
HAT4	T_SMDGT_IS	0,470	0,741	2,483	1,962
HAT4	T_TEST_ISC	0,449	0,375	0,697	1,962
HAT5	T_GT_ISCI	0,021	0,011	0,282	51,875
HAT5	T_MONT_ISC	0,021	0,011	0,275	51,875
HAT5	T_SMDGT_IS	0,018	0,016	0,782	51,875
HAT5	T_TEST_ISC	0,017	0,016	0,912	51,875

4.3.12 MVA Spreadsheet Solution to Calculate WIP Cap of the Sub-lines (W_h^*)

Formerly calculated standard deviation of the batches times (ss_{hj}), SCV of the batch times (ce_{hj}^2) and target throughput of the sub-line (TH_h^*) information are used as input and WIP cap of the sub-lines (W_h^*) are calculated using MVA spreadsheet solution in MS Excel. Details of the solution are given in Appendix A. Resulting values for sub-line 1 are provided in Table 4.12.

Table 4.12 MVA Spreadsheet Solution

W	**TH^*_h**	Te1	Te2	Te3	Te4	Ce1	Ce2	Ce3	Ce4	CT1	CT2	CT3	CT4	CT	TH	SG	W1	W2	W3	W4
0	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	0	0	0	0	0	0	1	0	0	0	0
1	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	2	2,37	2,44	1,9	8,76	0,1141	1	0,2	0,27	0,28	0,2
2	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	2,3	2,7	2,78	2,2	7,74	0,2585	1	0,6	0,7	0,72	0,6
3	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	2,7	3,3	3,43	2,6	9,41	0,3188	1	0,9	1,05	1,09	0,8
4	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	3,1	3,98	4,17	2,9	11,3	0,3557	1	1,1	1,41	1,48	1
5	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	3,5	4,73	5	3,3	13,3	0,3768	1	1,3	1,78	1,89	1,3
6	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	4	5,55	5,93	3,7	15,4	0,389	1	1,5	2,16	2,31	1,4
7	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	4,3	6,4	6,92	4	17,7	0,3964	1	1,7	2,54	2,74	1,6
8	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	4,7	7,28	7,96	4,3	19,9	0,4012	1	1,9	2,92	3,19	1,7
9	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	5	8,18	9,05	4,5	22,3	0,4045	1	2	3,31	3,66	1,8
10	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	5,3	9,09	10,2	4,8	24,6	0,4068	1	2,2	3,7	4,14	1,9
11	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	5,6	10	11,4	5	26,9	0,4086	1	2,3	4,09	4,64	2
12	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	5,8	10,9	12,6	5,1	29,3	0,4099	1	2,4	4,48	5,14	2,1
13	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6	11,9	13,8	5,3	31,6	0,4108	1	2,5	4,88	5,67	2,2
14	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,2	12,8	15,1	5,4	34	0,4116	1	2,5	5,27	6,2	2,2
15	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,3	13,7	16,4	5,5	36,4	0,4122	1	2,6	5,66	6,74	2,3
16	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,4	14,6	17,7	5,5	38,8	0,4126	1	2,7	6,04	7,3	2,3
17	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,6	15,6	19,1	5,6	41,2	0,413	1	2,7	6,43	7,87	2,3
18	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,7	16,5	20,4	5,7	43,6	0,4133	1	2,8	6,81	8,44	2,3
19	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,8	17,4	21,8	5,7	46	0,4135	1	2,8	7,18	9,03	2,4
20	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,8	18,3	23,3	5,8	48,4	0,4136	1	2,8	7,56	9,62	2,4
21	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,9	19,2	24,7	5,8	50,8	0,4138	1	2,9	7,92	10,2	2,4
22	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,9	20	26,2	5,8	53,2	0,4138	1	2,9	8,29	10,8	2,4
23	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7	20,9	27,7	5,9	55,6	0,4139	1	2,9	8,65	11,5	2,4
24	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7	21,7	29,2	5,9	58	0,414	1	2,9	9	12,1	2,4
25	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,1	22,6	30,8	5,9	60,4	0,414	1	2,9	9,35	12,7	2,4
26	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,1	23,4	32,3	5,9	62,8	0,414	1	2,9	9,69	13,4	2,4
27 **W_h^***	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,1	24,2	33,9	5,9	65,2	0,414	-1	3	10	14	2,5
28	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,1	25	35,5	5,9	67,6	0,414	-1	3	10,4	14,7	2,5
29	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,2	25,8	37,1	5,9	70,1	0,414	-1	3	10,7	15,4	2,5
30	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,2	26,6	38,7	5,9	72,5	0,414	-1	3	11	16	2,5
31	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,2	27,3	40,4	5,9	74,9	0,414	-1	3	11,3	16,7	2,5
32	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,2	28,1	42	5,9	77,3	0,414	-1	3	11,6	17,4	2,5

WIP cap of sub-line 1 is the W value where SG value turned to -1, which means that estimated throughput cannot be increased further and target throughput cannot be realized..

4.3.13 Distribution of WIP cap of the Sub-Lines to Product Groups (W_{hg}^{*})

Sub-line (h), group name (g) values are taken from the ERP system. WIP cap of the groups (W_{hg}^{*}) are calculated by the SQL program. A sample of resulting values is provided in Table 4.13.

Table 4.13: WIP cap of the groups in the sub-line

HAT(h)	GRUP (g)	GRUP_WIPCAP (W_{hg}^{*})
HAT3	FT-ST	1087,949757
HAT3	OP-LT	611,8458273
HAT1	KS_48	478,7280326
HAT2	SPS-DS	450,9808542
HAT4	SPS-KS	407,0299646
HAT1	EXT-KS	402,1016093
HAT2	CPU-DS	363,5961067
HAT1	KS_26	272,0318757
HAT2	BP-DS	199,6614765
HAT1	KS_38	197,1384825
HAT4	EVM	144,2075041
HAT3	NT	136,5917446
HAT2	UTL-DS	125,7615626
HAT3	IP	123,6126709
HAT4	GT	18,76253139

CHAPTER 5

INTEGRATION OF THE CONWIP SYSTEM WITH THE EXISTING HIERARCHIAL SYSTEM

In Chapter 4 we presented the calculation of Conwip parameters. Before beginning Chapter 5 it is useful to remind these parameters:

1) Production quota: Target production
2) Maximum work ahead amount: Allowable over-produced quantity
3) Capacity shortage trigger: Allowable shortage quantity
4) Backlog list: Sorted orders waiting to enter the production lines
5) WIP cap: Constant WIP of the sub-lines and of the product groups in these sub-lines

In Chapter 5 we present the flow of the Conwip system in the company and the integration of this Conwip system to the existing hierarchical system. When we started to integrate the new system to the existing system, we saw that it was possible to do so without any important changes in the existing one. We did not need to change the demand management, material requirements planning, supply chain planning, and flow of raw materials from supplier to our inventory. We also did not need to change the planning process of the automated insertion machine group and shipping process of the end-products. We needed small changes in the inventory management. The only important change was made in the job release process of telecom production lines.

5.1 Demand Management and Production Planning

As indicated in Figure 5.1, we did not need to make any change in the demand management and production planning but it is useful to remind the existing system briefly.

Demands are collected from internal and external customers. These demands are merged and converted to weekly master demand schedule. Master production schedule is run using this master demand schedule. The “rescheduling” and “plan order” messages are revised and realized by planners, and the new work orders are created.

5.2 Supply-Demand Assignment and Prioritizing Work Orders

This stage is very important for creation of the backlog list for the Conwip system. Work orders in the backlog list are sorted according to the priorities.

In the supply chain assignment procedure, all the supplies of the items are assigned to their demands. When all the assignments are connected to each other, a supply-demand chain is generated from the purchase orders of raw materials to the sales orders of end items.

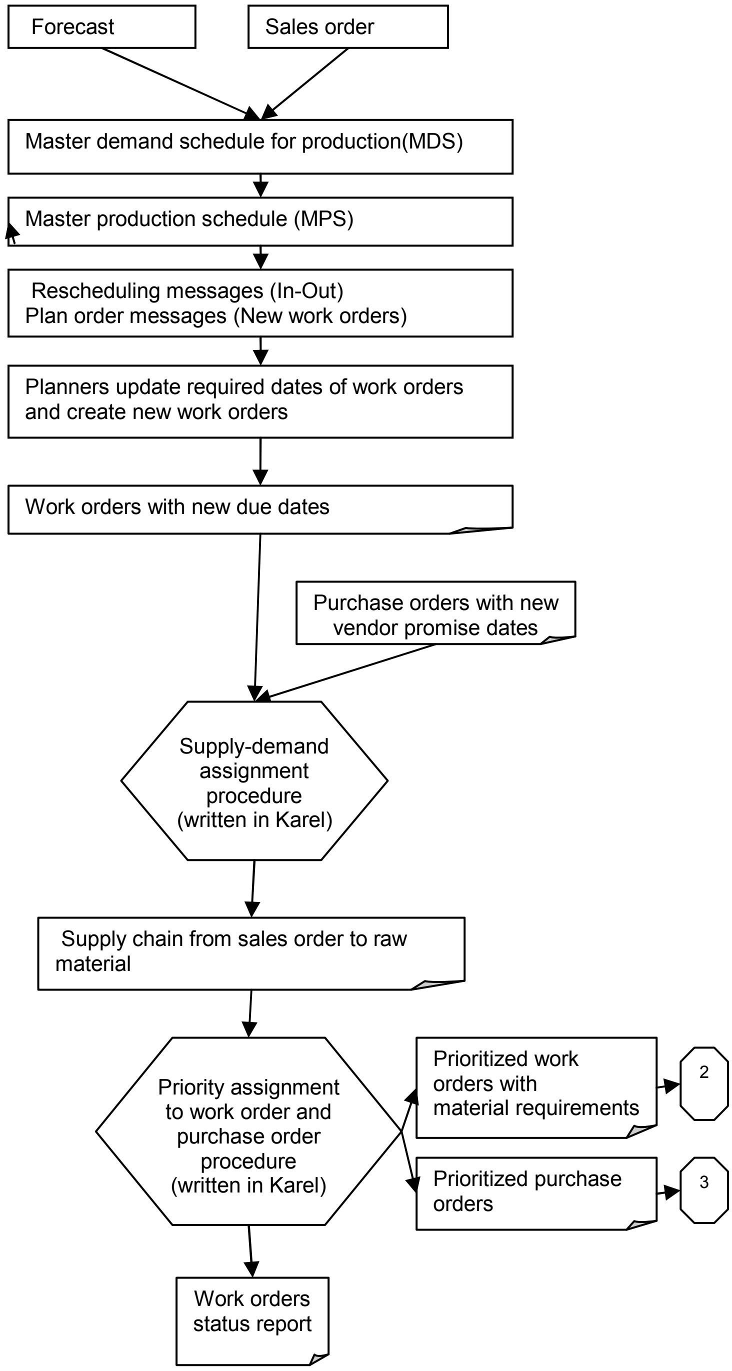

Figure 5.1 Flow of Production Planning in New System

This supply-demand chain is also used in prioritizing the work orders. Priorities of sales orders, which are given by the sales department and customers, are easily exploded to work orders and purchase orders using this supply-demand chain. The priority assignment explosion is made by “priority assignment to work orders and purchase orders” procedure. The outputs of this procedure are the prioritized work orders and material shortages of these work orders, as shown in Figure 5.1.

5.3 Determination of Conwip Parameters

Determination of Conwip parameters is summarized in Figure 5.2. At the beginning of every month or whenever a demand change occurs, production quota is calculated for every Conwip semi-product, using the master demand schedule. The production quota of a semi-product is determined as the total monthly demand of the product.

Maximum work ahead amount and capacity shortage trigger amount are also calculated using the production quota. One week over production is allowable in the company. Therefore, the maximum work ahead is simply calculated as production quota/4.

Demand shipment performance is reviewed weekly in the company. According to this routine, we determine the shortage trigger amount as one week’s production. In other words, shortage trigger amount is also calculated as production quota/4.

5.4 Release of Materials of Work Orders to Production

Raw materials of the work orders are prepared according to the push system principles. Each board contains many components and sometimes preparation of these components takes more than two days. For this reason, we decided to prepare all the components according to the push system and to release the semi-finished boards produced in automated machine according to Conwip system. Preparation of the raw materials earlier allows us to reduce the release period to one day.

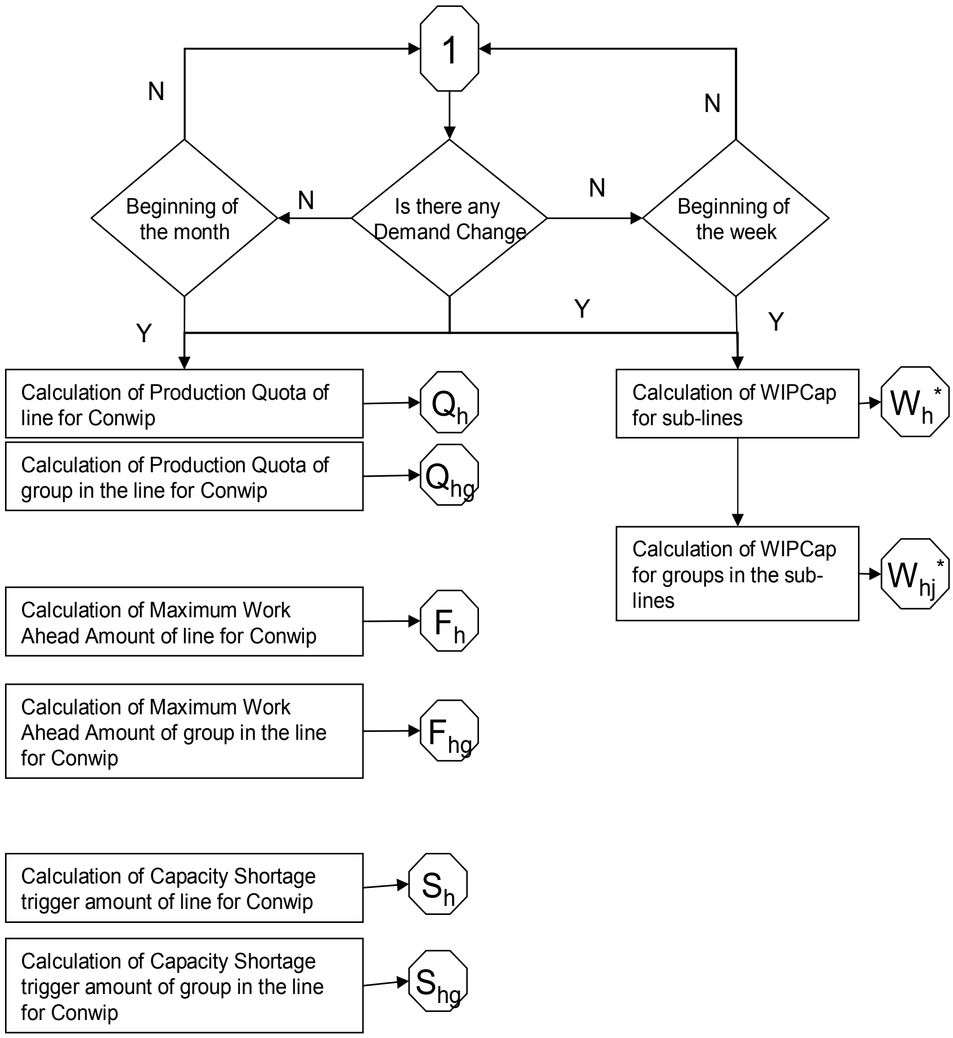

Figure 5.2 Determination of Conwip Parameters

Everyday, work orders having due dates in the current week are examined by the planners. Work orders having all raw materials in stock are determined and "automated work order release and material issue to production" procedure is run for these work orders. Material issue list is taken from the system and raw materials are prepared according to this list.

Table 5.1 Sample Backlog List

HAT	GRUP	SEGMENT1	DESCRIPTION	PC	IE	PR	DUE_DT	CREATION_DT	MIKTAR
HAT1	EXT-KS	YEXT00082	EXP38 CID GENISLETME KARTI YM	32	562618	1	25.11.2009	24.11.2009 11:47	52
HAT1	EXT-KS	YEXT00096	EXP48C (2/6) GENISLETME KARTI YM	32	556179	2	25.11.2009	14.10.2009 10:58	10
HAT1	EXT-KS	YEXT00095	EXP48C (4/12) GENISLETME KARTI YM	32	556176	2	26.11.2009	14.10.2009 10:58	1
HAT1	KS_48	YSNT00105	MS48C YM	32	550774	4	30.11.2009	28.08.2009 09:24	141
HAT1	EXT-KS	YEXT00082	EXP38 CID GENISLETME KARTI YM	32	557630	4	30.11.2009	19.10.2009 10:10	160
HAT1	EXT-KS	YEXT00095	EXP48C (4/12) GENISLETME KARTI YM	32	557633	4	30.11.2009	19.10.2009 10:10	45

After the procedure is run, the backlog list is regenerated. Backlog list includes the work orders for which components are prepared. All these work orders are sorted according to priorities, due dates and creation dates. When the components of the new orders are issued to production, these are added to the backlog list and backlog list is re-ordered. This process is summarized in Figure 5.3. and a sample backlog list is given in Table 5.1.

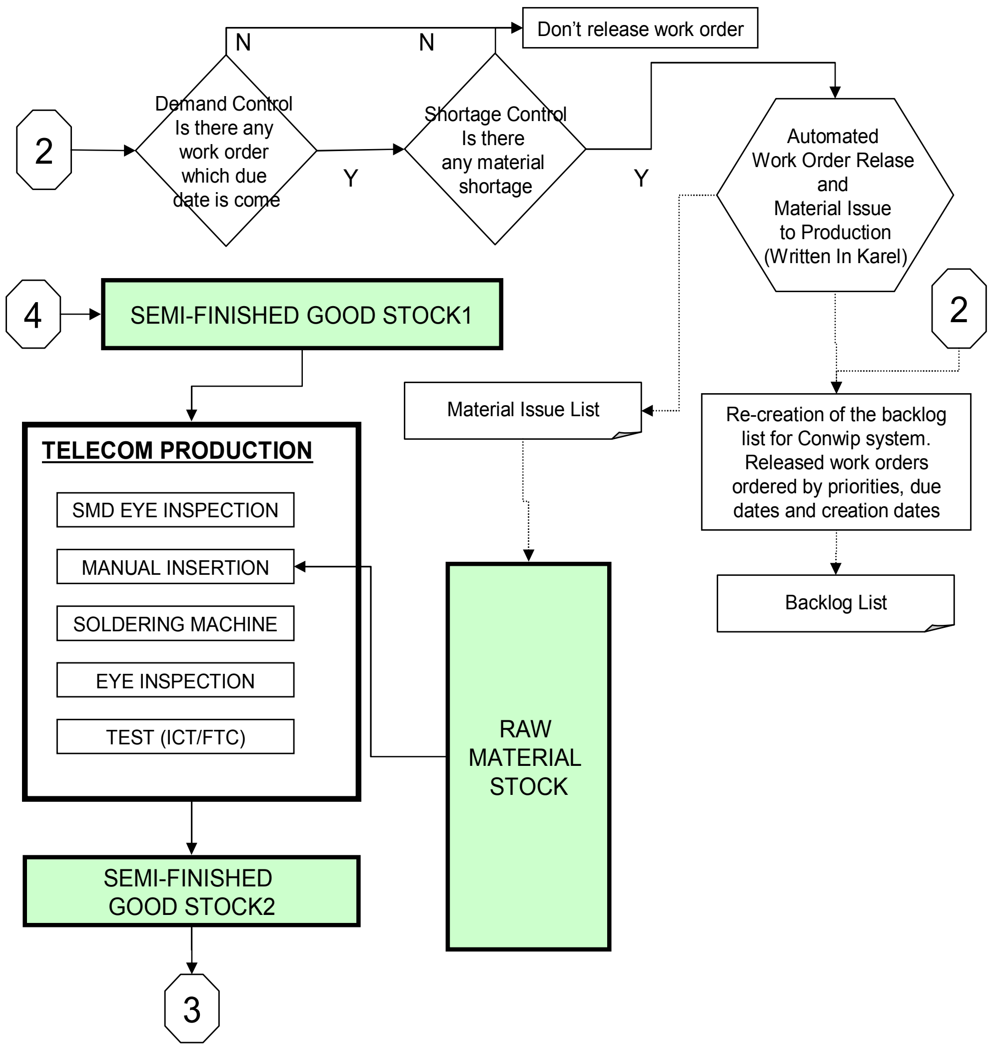

Figure 5.3 Work Order Material Release to Production in the New System

5.5 Release of the Jobs to Production

At the beginning of every week, actual production is compared with the target production. This comparison is made for every product group in the sub-lines. If actual production of a group is one week ahead of the target production of the group, production of this group is stopped until the next comparison.

Another comparison is made to take action for overtime. If actual production of a group in the sub-line is one week behind of the target production, overtime is planned for this group. An example of production control report can be seen in Table 5.2.

Table 5.2 Sample Weekly Production Control Report

HAT	GRUP	Q	F	S	URETIM	HEDEF_URETIM	FAZLA URETIM	EKSIK URETIM
HAT1	KS_26	1014	254	254	138	101		
HAT1	KS_38	663	166	166	166	66		
HAT1	KS_48	1439	360	360	275	144		
HAT1	EXT-KS	1771	443	443	69	177		
HAT2	BP-DS	606	152	152	20	61		
HAT2	CPU-DS	871	218	218	77	87		
HAT2	SPS-DS	702	176	176	40	70		
HAT3	IP	264	66	66	1	26		

At the beginning of everyday, actual WIP of the product groups in sub-lines are compared with WIP cap of the groups. If actual WIP of the group is less than the WIP cap of the group, the difference is rounded up to the multiples of the batch size of the line. The first work order of the group is selected from the backlog list and the calculated amount is released to production as a new job. An example of job release report is indicated in Table 5.3.

Table 5.3 Job Release Report

HAT	GRUP	GRUP_WIPCAP	WIP	DIFF	HAT_LOT	RELEASE_QTY
HAT1	KS_26	111	240	-129	20	0
HAT1	KS_38	78	485	-407	20	0
HAT1	KS_48	210	704	-494	20	0
HAT1	EXT-KS	159	109	50	20	60
HAT2	BP-DS	86	138	-52	10	0
HAT2	CPU-DS	181	379	-198	10	0
HAT2	SPS-DS	183	268	-85	10	0
HAT2	UTL-DS	58	0	58	10	60
HAT3	IP	121	1	120	20	120
HAT3	NT	108	22	86	20	100
HAT3	FT-ST	1165	367	798	20	800
HAT3	OP-LT	564	832	-268	20	0
HAT4	GT	30	0	30	10	30
HAT4	EVM	138	328	-190	10	0
HAT4	SPS-KS	421	659	-238	10	0
HAT4	IVM		0		10	0

If there are no available work orders of a certain group in the backlog list, the first available work order belonging to another group is released to production in the calculated amount. The released job is marked with the original group name and it is counted in the WIP of the original group. In other words, because the original group has no available work orders, it “lends” some of its WIP cap to another group. This borrowing mechanism allows us to increase the utilization of the resources and is used especially in the existence of the short term material shortages.

The semi-finished board requirements of the released jobs are listed and sent to the “semi-finished goods stock1”. These requirements are prepared and released to production. These boards are also used as job orders for the production department. Flow of the job release to production is described in Figure 5.4.

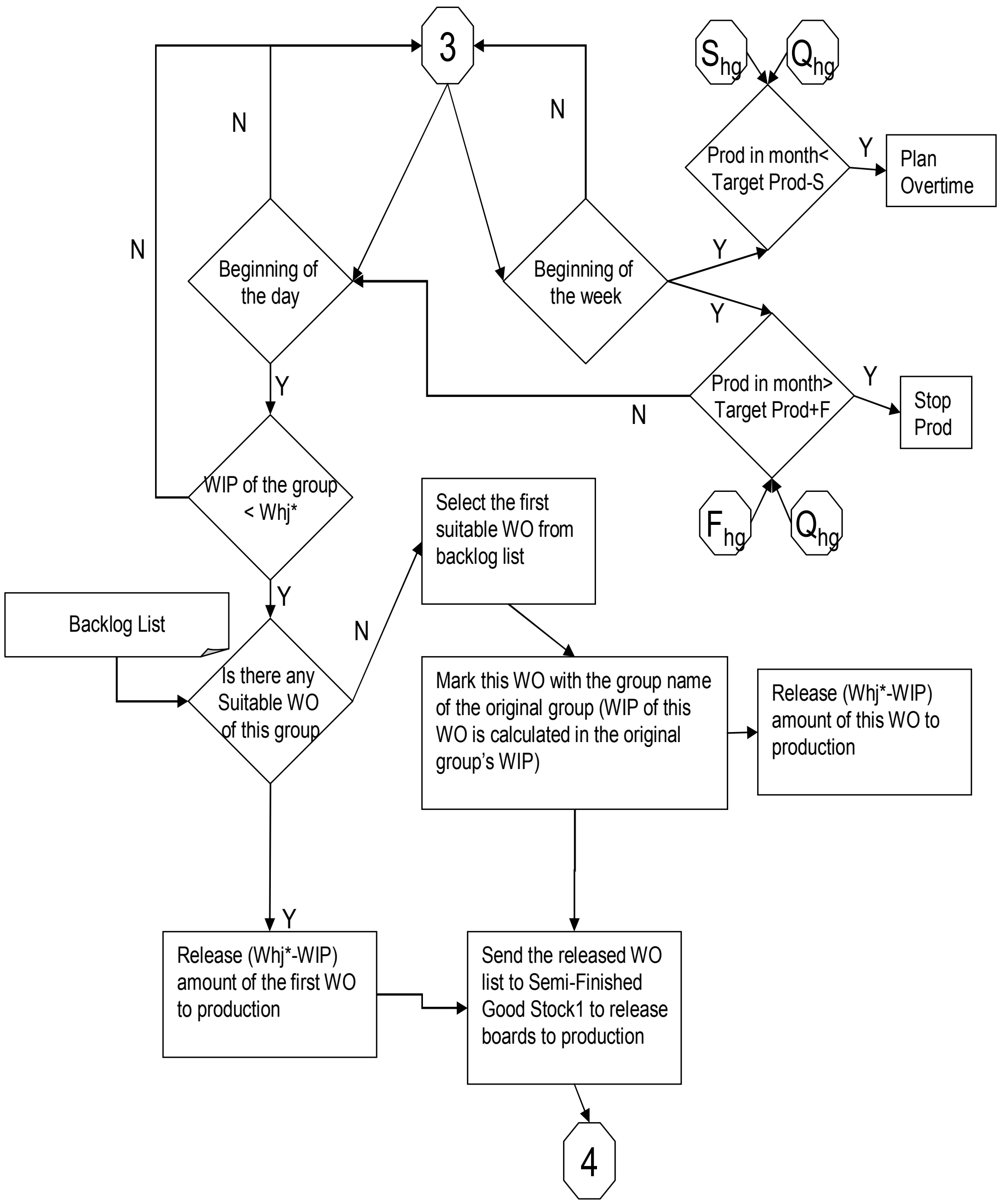

Figure 5.4 Flow of Job Release to Production

5.6 Exceptions of the Conwip System in the Company

We predict two possible exceptions concerning about the defined Conwip system in the company.

1) Long term, multiple component shortages: We currently have this situation in the company. Electronic components market stopped production due to the crisis. As the effects of the crisis diminish, they could not supply the increased demand of the company immediately. Because of this reason, currently, lots of work orders have material shortages. In this situation, using the WIP cap of the sub-line (pull from the sub-line) method is more efficient than using individual WIP caps of the product groups (pull from the groups). Using WIP caps of the groups causes frequent borrowing of the WIP cap between groups and complexity of the system increases. We implemented the Conwip system in the company to support both of these methods. We used pull from the sub-line method for comparison of the existing and the new systems. Pull from the sub-line flow can be seen in Figure 5.5. An example of weekly production control report for sub-lines can be seen in Table 5.4 and an example of job release report for sub-lines can be seen in Table 5.5.

2) Very low demand: In the presence of short term lack of demand, some jobs can be released to the system without Conwip cards to meet the future demand. In our system, although actual WIP is greater than the WIP cap, if we know the demand will increase in the short term, we can release new jobs to the system to increase the utilization of the production. But this is made very rarely and with the approval of the management.

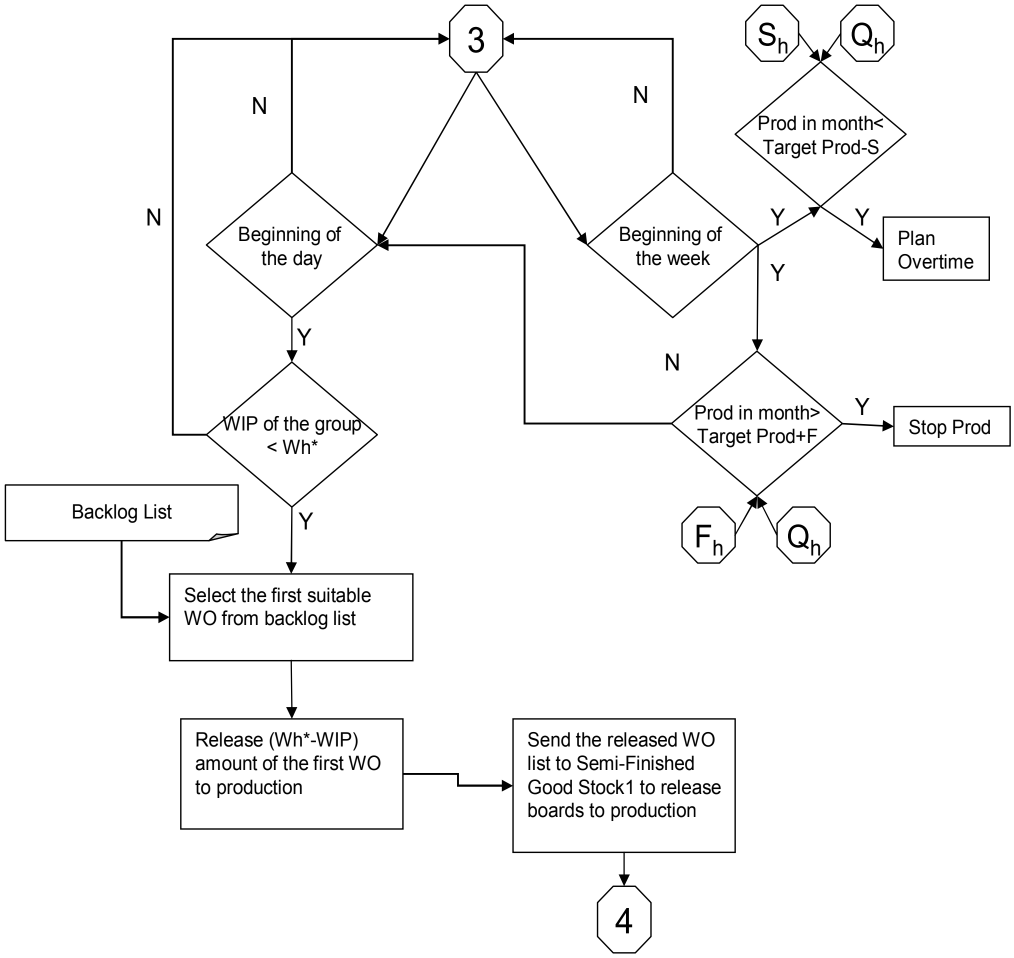

Figure 5.5 Flow of Pull From the Sub-Line Method

Table 5.4 Weekly Production Report for Sub-Lines

HAT	Q	F	S	URETIM	HEDEF_URETIM	FAZLA_URETIM	EKSIK_URETIM
1	HAT1	4887	1223	1223	680	488	
2	HAT2	2411	604	604	176	241	
3	HAT3	4630	1158	1158	217	463	

Table 5.5 Job Release Report for Sub-Lines

HAT	HAT_WIPCAP	WIP	DIFF	HAT_LOT	RELEASE_QTY
HAT1	560	1538	-978	20	0
HAT2	510	785	-275	10	0
HAT3	1960	1222	738	20	740
HAT4	590	987	-397	10	0

CHAPTER 6

COMPARISON OF THE NEW CONWIP SYSTEM WITH THE EXISTING HIERARCHICAL SYSTEM

In this chapter, we compare the existing system with the proposed system. In making this comparison, firstly we select the pilot test area and the Conwip pull method as “PABX sub-line of telecommunication production” and “pull from the sub-line method”, respectively. The reasons of these selections are presented in Section 6.1.

After the selection of pilot test area and pull method, we determine the performance criteria for comparison. Our aim is reducing WIP inventory level while keeping throughput level unchanged. For this reason, we determine two performance criteria for comparison: WIP inventories and throughput.

As we noted in introduction, we want to make a comparison using the real data sets. For this purpose, we use the ERP system for data collection and develop some SQL programs to collect data from the real system. Existing and the proposed systems are monitored during two months and the WIP and throughput data are collected from the system. The details of the data collection methods and collected data are presented in Section 6.2.

WIP inventory and throughput data sets of the existing and the proposed systems are compared using hypothesis tests. Software package Minitab is used for statistical analysis of data and hypothesis testing. Results of the WIP comparison are discussed in Section 6.3 and results of the throughput comparison are summarized in Section 6.4.

Finally, accuracy of the approximated MVA algorithm for general process time distribution is discussed in Section 6.5.

6.1 Selection of Pilot Test Area and Conwip Pull Method

We selected the small PABX sub-line of telecommunication production as the pilot test area. The main reasons of this selection are indicated below:

1) Most of the components used in the small PABX sub-line are more common electronic components. Availability of these common components is relatively less affected from the crisis in the electronic component market, compared to other special ones. In other words, we can find the common components more easily than the other special components, and we fewer less work orders with material shortage in this sub-line.

2) Another reason of this selection is the stability of the demand in this sub-line. Demand of the products produced in the small PABX line does not change at least during a month and this allows us to make a fair comparison of the two systems.

As we stated in Section 5.6, we decided to use pull from the sub-line method instead of pull from the groups in the sub-line. The main reason of this decision is the considerable material shortages caused by the crisis. In the second method, when a job of a group leaves the production line, we should be able to release a job of the same group to the line. However, with these shortages, it is not always possible to find a suitable job of the same group to release. On the other hand, in the first method, when a job leaves the production line, we can release a job of any group produced in this sub-line. The probability of finding a suitable job is considerably higher in the first method.

Pull from bottleneck could be another alternative for Conwip lines. However, we do not consider this alternative, because there are around fifteen different product types produced in a sub-line during a week, and the bottleneck shifts from one station to another from time to time. Although bottleneck determination and WIP cap calculation can be repeated for shorter periods during which there is a single type of product, implementation of this approach is not very practical.

6.2 Data Collection

Fortunately, all the data we need to monitor WIP inventory and throughput are recorded in the ERP system. We only need to write proper SQL queries to retrieve these data from the system, process and convert them to WIP and throughput information.

6.2.1 Data Collection for Throughput

We used "mtl_material_transactions" table of the ERP system to collect throughput data. This table contains all the inventory transactions of the items, but our concern is semi-product completion type transactions for throughput. This transaction type defines the transactions of produced items from the WIP to semi-finished products inventory. We select only the semi-product completion type transactions from the table and can collect the time and the quantity of the items completed.

This is not sufficient for throughput information. We define throughput as the quantity produced in a fixed period of time. However, in the company, the transactions can be made at any time in a day and there is not a fixed period of time between these transactions. For this reason, we decided to create a template time table to group and sum the transactions, and recorded throughput according to the fixed time periods (time buckets) in this table.

We used "bom_calendar_dates" table to select the dates of the data collection. For adding time buckets to these dates we created a time bucket table. Using this table, we divide a work day into time buckets of two hours. We mach this time template with the transaction table to collect the throughput data from system at the end of every two hour period. We group these transactions according to their sub-lines, dates and time buckets and we sum transaction quantities for every group. This summation gives us produced quantities in these time buckets (throughput). A sample of the collected data grouped by sub-line can be seen in Table 6.1. SQL programs developed for collection of throughput data and all collected data can be seen in Appendix B.

Table 6.1 Sample Throughput Values

LINE	DT	HR_GR	DT_HR	TH	TARGET TH	WEEK	PUSH/ CONWIP	WIP LEVEL
HAT1	01.12.2009	5	01.12.2009 17:30:00	42	42	30.11.2009	PUSH	H
HAT1	02.12.2009	1	02.12.2009 10:00:00	89	42	30.11.2009	PUSH	H
HAT1	02.12.2009	2	02.12.2009 12:00:00	90	42	30.11.2009	PUSH	H
HAT1	02.12.2009	3	02.12.2009 14:00:00	30	42	30.11.2009	PUSH	H
HAT1	02.12.2009	4	02.12.2009 16:00:00	63	42	30.11.2009	PUSH	H
HAT1	02.12.2009	5	02.12.2009 17:30:00	60	42	30.11.2009	PUSH	H
HAT1	03.12.2009	1	03.12.2009 10:00:00	34	42	30.11.2009	PUSH	L
HAT1	03.12.2009	2	03.12.2009 12:00:00	96	42	30.11.2009	PUSH	L
HAT1	03.12.2009	3	03.12.2009 14:00:00	30	42	30.11.2009	PUSH	L
HAT1	03.12.2009	4	03.12.2009 16:00:00	62	42	30.11.2009	PUSH	L
HAT1	03.12.2009	5	03.12.2009 17:30:00	40	42	30.11.2009	PUSH	L
HAT1	04.12.2009	1	04.12.2009 10:00:00	85	42	30.11.2009	PUSH	L
HAT1	04.12.2009	2	04.12.2009 12:00:00	75	42	30.11.2009	PUSH	L
HAT1	04.12.2009	3	04.12.2009 14:00:00	15	42	30.11.2009	PUSH	L
HAT1	04.12.2009	4	04.12.2009 16:00:00	75	42	30.11.2009	PUSH	L

6.2.2 Data Collection for WIP Inventory

Current WIP status of the work orders at the workstations are also kept by the ERP system. We used “wip_operations” table of the ERP system to collect these WIP data. This table contains information about the work orders at the workstations such as in-process quantities, planned start and finished dates of the work orders. We used in-queue and in-move quantity fields of this table to collect WIP quantities of every workstation. We also used item, group and sub-line tables to find the group and the sub-line of the WIP inventory.

Resulting information of these queries give us the current WIP status of the groups in the sub-lines. SQL program developed for calculating the current status of WIP is presented in Appendix B.

ERP system collects the current status of the WIP, but there is not a history table for WIP as in the case of throughput. For this reason, we created a WIP history table and a batch job running at every two hour period inserting the current WIP status to the history table with creation dates and times. SQL program to insert current WIP status to the WIP history table and all the collected data for WIP are presented in Appendix B. A sample of the collected data grouped by sub-line can be seen in Table 6.2.

Table 6.2 Sample WIP Values

HAT	TARIH	WIP	WIPCAP	WEEK	PUSH/ CONWIP
HAT1	03.12.2009 13:01:05	1145	1350	30.11.2009	PUSH
HAT1	03.12.2009 15:01:06	1100	1350	30.11.2009	PUSH
HAT1	03.12.2009 17:01:07	1028	1350	30.11.2009	PUSH
HAT1	04.12.2009 09:01:28	983	1350	30.11.2009	PUSH
HAT1	04.12.2009 11:01:29	913	1350	30.11.2009	PUSH
HAT1	04.12.2009 13:01:28	868	1350	30.11.2009	PUSH
HAT1	04.12.2009 15:01:29	808	1350	30.11.2009	PUSH
HAT1	04.12.2009 17:01:30	876	1350	30.11.2009	PUSH
HAT1	07.12.2009 09:02:52	860	1350	07.12.2009	CONWIP
HAT1	07.12.2009 11:02:55	930	1350	07.12.2009	CONWIP
HAT1	07.12.2009 13:02:58	915	1350	07.12.2009	CONWIP
HAT1	07.12.2009 15:02:59	893	1350	07.12.2009	CONWIP
HAT1	07.12.2009 17:03:01	876	1350	07.12.2009	CONWIP
HAT1	08.12.2009 09:03:23	861	1350	07.12.2009	CONWIP
HAT1	08.12.2009 11:03:23	831	1350	07.12.2009	CONWIP

6.3 WIP Comparison of the Existing and the Proposed Systems

We started to collect the WIP values on 02.11.2009 and we activated the Conwip application on 07.12.2009. Time series chart of the collected WIP values can be seen in Figure 6.1.

We can see a drastic decrease in the WIP level during 03-14 December 2009. We analyzed the component inventory levels of the monitoring time span to understand the reason of this decrease.

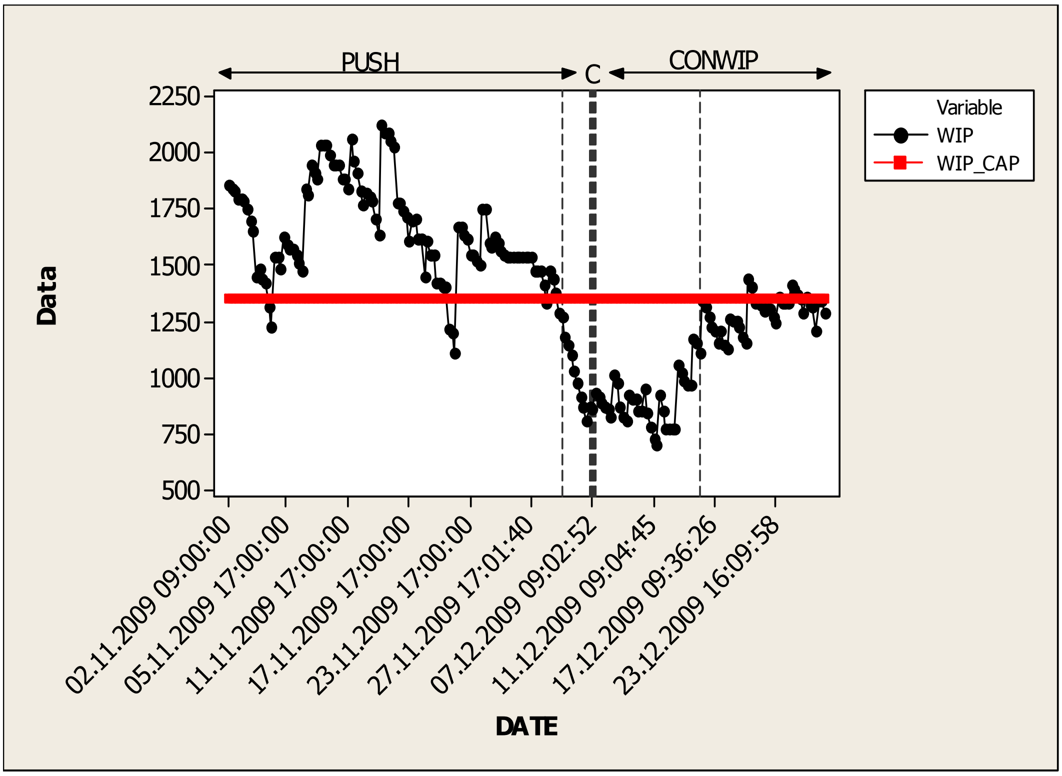

Figure 6.1 Time Series Chart of WIP Level

Firstly, we found the historical inventory availability of the components used in the line by dividing the stock quantities of the components by their average monthly consumption quantities. Then, we found the minimum component inventory availability during November and December 2009. SQL program developed for calculating these values is presented in Appendix B. Time series plot of these minimum inventory availability values can be seen in Figure 6.2.

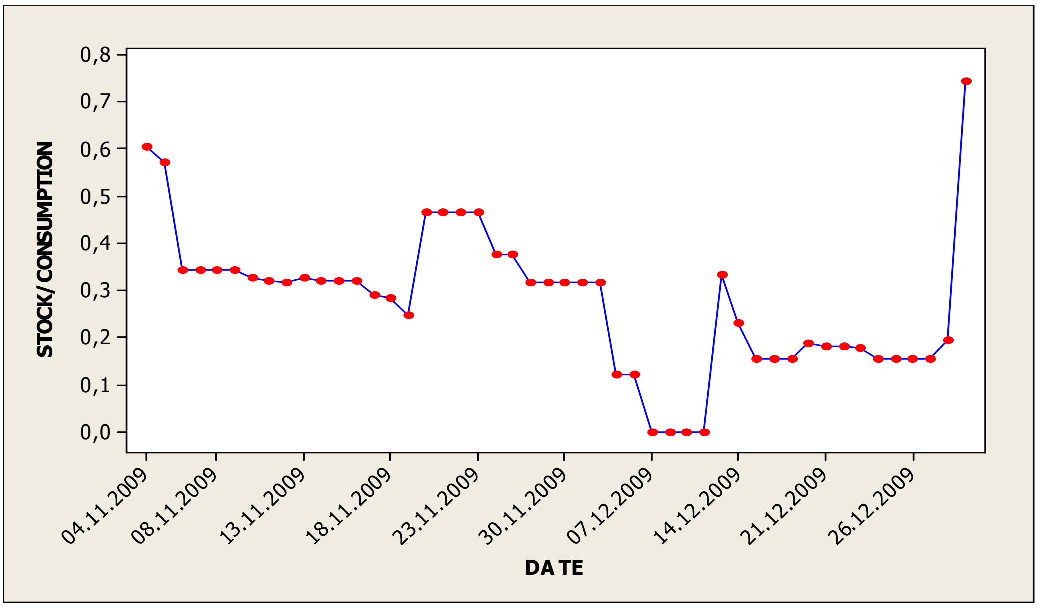

Figure 6.2 Time Series Chart of Minimum Inventory Availability

Figure 6.2 explains the drastic decrease in the WIP level between 03.12.2009 and 14.12.2009. In other words, during this period, component shortages determine the WIP levels instead of push or pull production policies. For this reason, we exclude the WIP values in this period while comparing WIP levels of the existing and the proposed systems. After the exclusion, we have a sample size of 109 for the existing system and 42 for the proposed system.

In Figure 6.1. we can see the decrease in WIP level after the Conwip implementation. However, we should conduct hypothesis testing to see if this decrease is statistically significant.

> H_0: The average WIP level of the existing system is the same as the average WIP level of the Conwip system

H_1: The average WIP levels of the two systems are different

Before comparing the average WIP levels, we make the normality tests for the WIP values of the existing and the proposed systems. Results of the normality test are presented in Appendix C, Figure C.1. According to the results of the normality test, WIP values of the existing (push) system do not fit to normal distribution at $\alpha=0.05$ but normality assumption is supported at $\alpha=0.01$.

We use Levene's test to compare the variances of the WIP values in two systems. Results of the Levene’s test are presented in Appendix C, Figure C.2. According to the results of the Levene's test, p-value is very small, therefore we can say that variances of the WIP values are different.

We apply the “two sample t-test” to compare the average WIP values having different variances. Results of the t-test are presented in Appendix C, Figure C.3. According to these results, p-value is less than 0.05, therefore the average WIP level of the existing (push) system is different from the average WIP level of the proposed (Conwip) system at $\alpha=0.05$. The estimated average WIP level of the proposed system is 1290.4 and lower than the average WIP level of the existing system, which is 1657.

Time series chart of the WIP levels for product groups is presented in Figure 6.3.
When we look at the WIP levels of product groups separately, we can see that WIP levels of the groups are not very close to their WIP cap values. This is expected, because in the pilot implementation we did not use individual WIP cap values of the groups, and we imposed only the overall WIP cap.

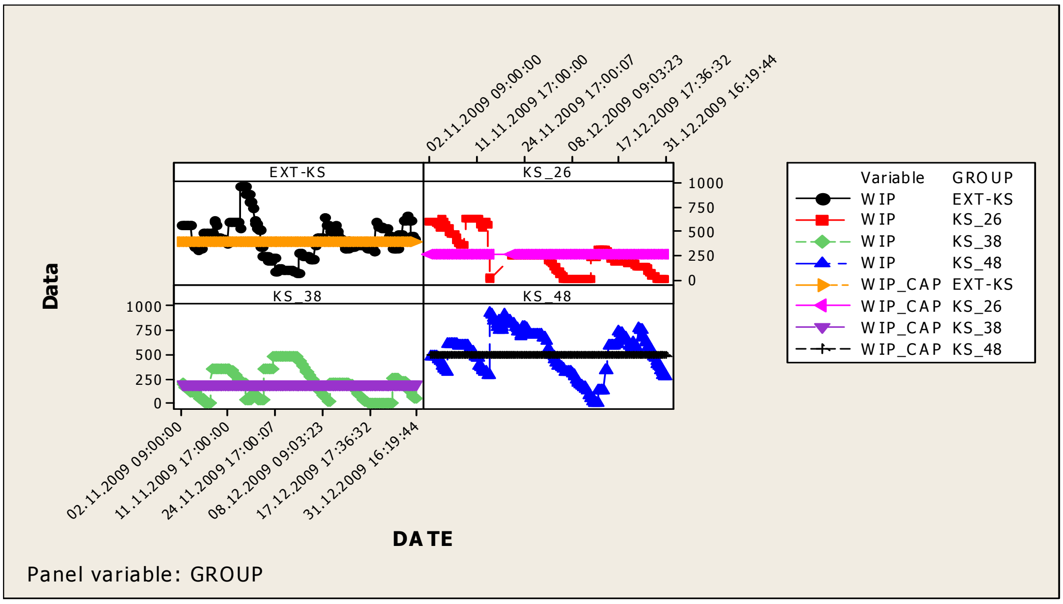

Figure 6.3 Time Series Chart of the WIP Levels for Product Groups

6.4 Throughput Comparison of the Existing and the Proposed Systems

Time series chart of the throughput is presented in Figure 6.4. According to this chart, we do not see a remarkable difference in the throughput level before and after the Conwip implementation. However, we should conduct hypothesis testing to see if the throughput differs.

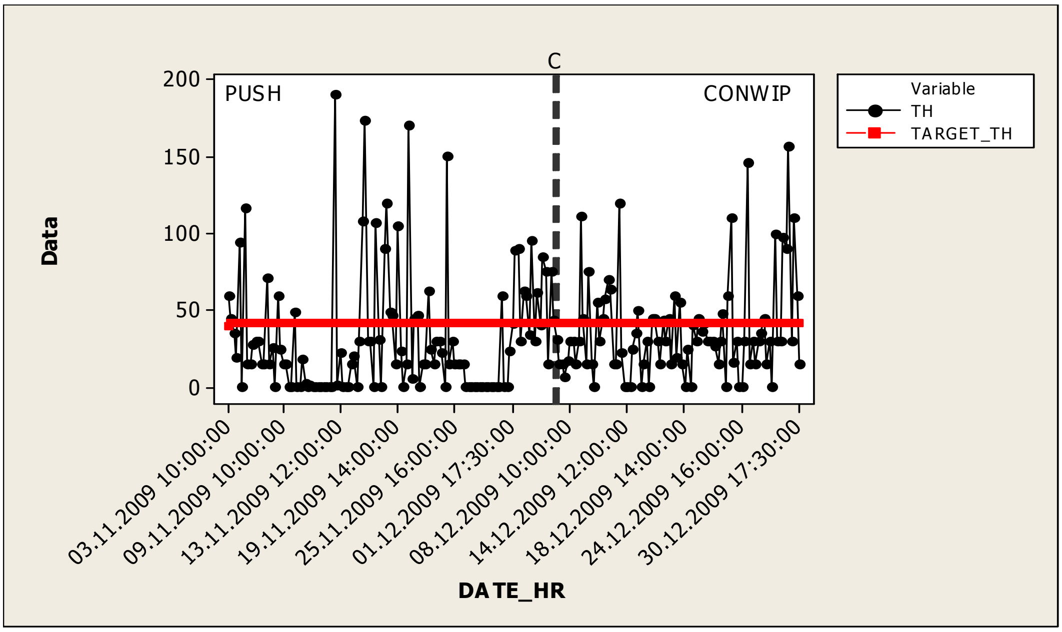

Figure 6.4 Time Series Chart of the Throughput

H_0: The average throughput of the existing system is the same as the average throughput of the Conwip system

H_1: The average throughputs level of the two systems are different

Before comparing the average throughput levels, we conduct the normality tests for the throughput values of the existing and the proposed systems. Results of the normality tests are presented in Appendix C, Figure C.4. The results show that the normality assumption is not satisfied for either system. However, moderate deviation from normality is acceptable.

Results of the Levene's test for equal variances are presented in Appendix C, Figure C.5. According to the results of the Levene's test, we cannot say that the variances are different (p-value=0.113 is larger than α=0.05).

We apply the “two sample t-test” to compare the average throughput values having equal variances. Results of the t-test are presented in Appendix C, Figure C.6. These results show that the p-value is larger than 0.05. Therefore, the average throughput of the existing (push) system is not different from the average throughput of the proposed (Conwip) system. The sample averages of the throughput are 36.6 and 36.4 for the push and the Conwip systems, respectively.

When we look at the throughputs of the product groups separately in Figure 6.5, we can see that when throughputs of some groups decrease in a period, throughputs of the other groups increase in the same period, as expected.

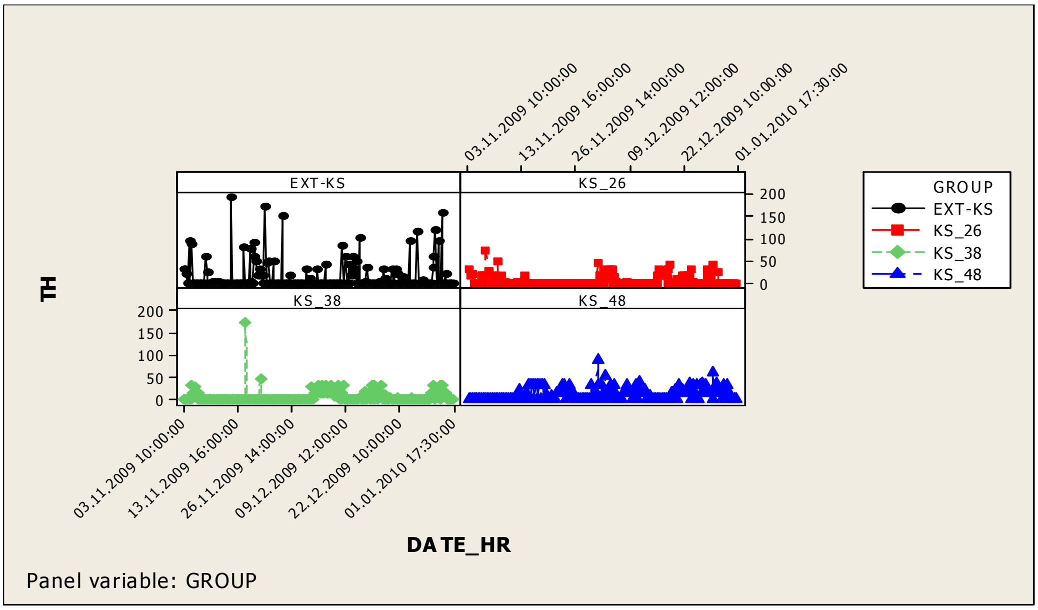

Figure 6.5 Time Series Chart of the Throughput Values for Product Groups

6.5 Throughput of the High and Low WIP Periods

According to the charts presented in Figure 6.1 and Figure 6.4 we do not see a remarkable difference between the throughputs of the low WIP period (03-14 December 2009) and the high WIP period. We conduct a hypothesis test for this.

> H_0: The average throughput of the low WIP period is same as the average throughput of the high WIP period
>
> H_1: The average throughputs of the two periods are different

When we apply the normality test, throughput values of both high and low WIP periods do not fit to normal distribution as seen in Appendix C, Figure C.7. According to the results of the Levene's test presented in Appendix C, Figure C.8., we cannot say variances of the two data sets are different.

Results of the "two sample t-test" to compare the mean throughputs of high and low WIP periods are presented in Appendix C, Figure C.9. According to the results, we cannot say that the throughputs are different.

At first glance, this is an unexpected result, but when we look at the data of the MVA spreadsheet plotted in Figure 6.6, the throughput values are very stable as long as the WIP level is larger than 550. Our minimum WIP level is 700 in the low WIP period and, according to the data in MVA spreadsheet, throughput is 41.15 when the WIP level is 700. On the other hand, throughput is 41.40 when the WIP level is equal to our WIP cap of 1350. According to the data in MVA Spreadsheet, we can reduce the WIP inventory to lower levels than 1350 with a negligible decrease in the throughput.

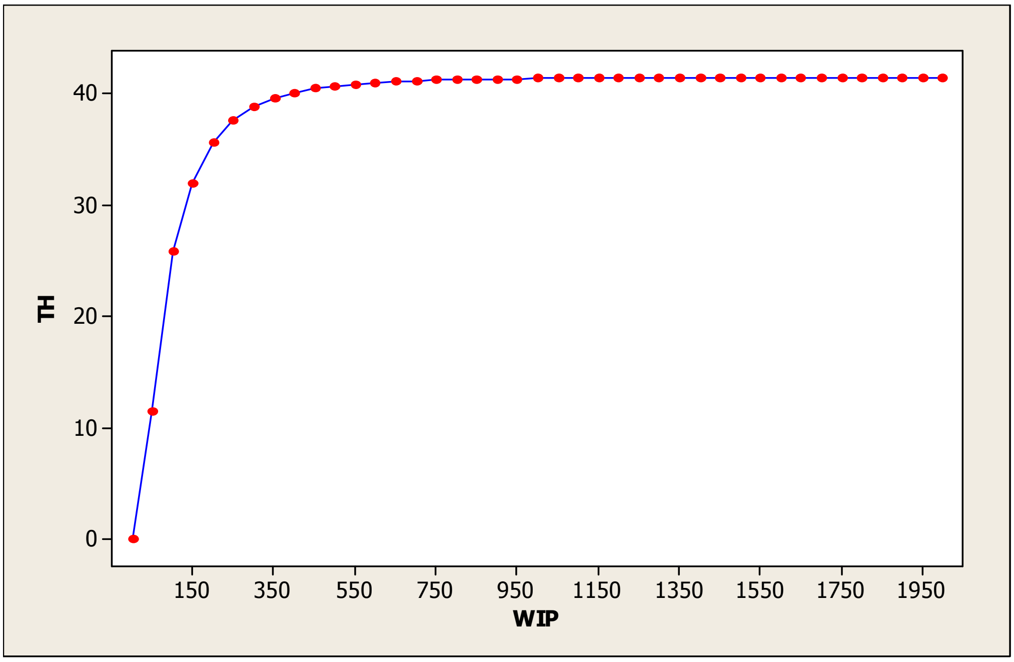

Figure 6.6 Throughput versus WIP From MVA Spreadsheet

6.6 Accuracy of the Approximated MVA Approach

WIP values of the Conwip application are presented in Figure 6.7. We activated the Conwip system on 07.12.2009, but the first WIP value close to WIP cap appears on 16.12.2009 because of the component shortages. For this reason we assume the time period between 16.12.2009 and 30.12.2009 as the Conwip application period.

According to Figure 6.7, the average WIP value is 1290.4 during the Conwip application.

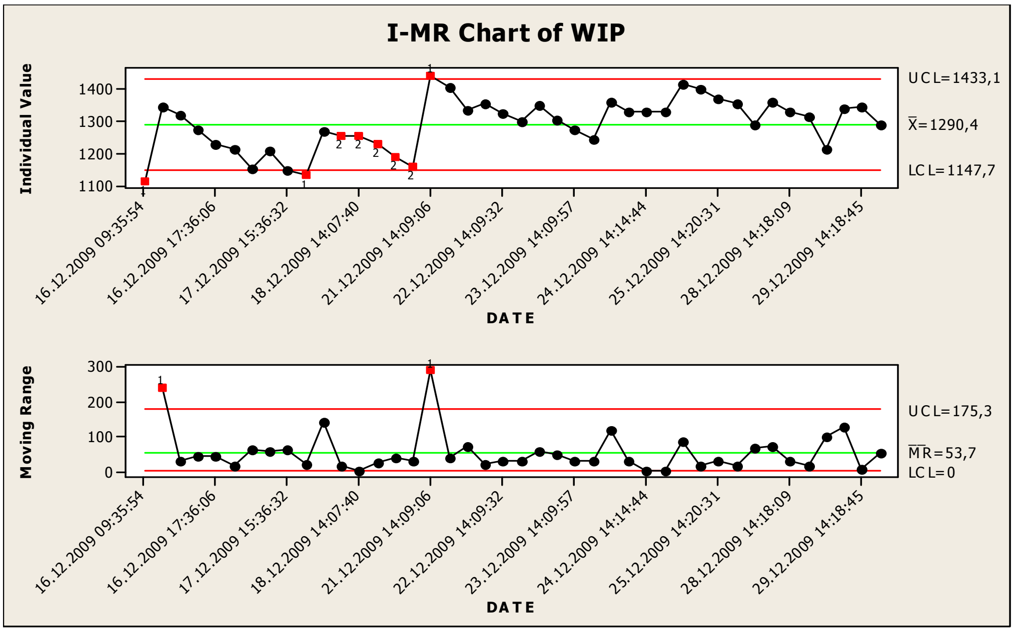

Figure 6.7 WIP Values of Conwip Application

Throughput values of the Conwip applications are presented in Figure 6.8. The actual average throughput value during the Conwip application period is 39.5.

WIP and throughput values derived from MVA Spreadsheet given in Table 4.12 are presented in Table 6.3. According to the values in Table 6.3, throughput level is approximated as 41.4 where WIP value is about 1290.4. However, in real world, the average throughput is observed as 39.5 when the average WIP level is 1290.4. According to these results, the MVA approach approximated the throughput with 95% accuracy. When we consider complexities of the real world, this is a good approximation.

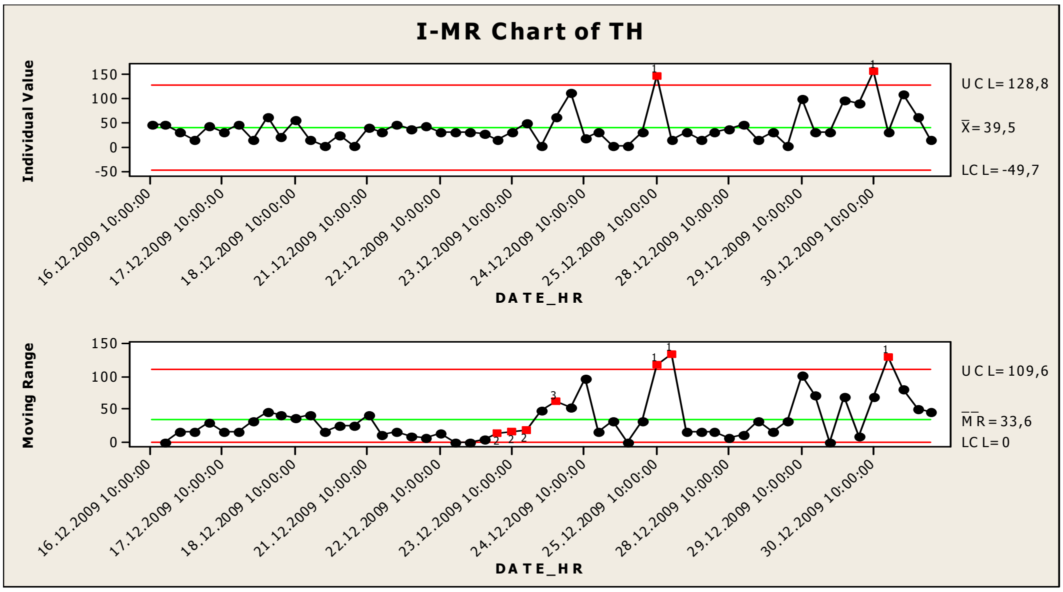

Figure 6.8 Throughput Values of Conwip Application

Table 6.3 WIP versus Throughput of MVA Approximation

WIP	TH /2HR	WIP	TH /2HR
0	0	1050	41.37549467
50	11.41239416	1100	41.38469905
100	25.8535792	1150	41.39142778
150	31.8774669	1200	41.39616764
200	35.57075692	1250	41.39930532
250	37.68109277	1300	41.40114942
300	38.89602838	1350	41.40194721
350	39.63503967	1400	41.40194721
400	40.11553661	1450	41.40194721
450	40.44577996		
500	40.68194088		
550	40.85550338		
600	40.9855197		
650	41.08424633		
700	41.15993809		
750	41.21835122		
800	41.26360984		
850	41.29873343		
900	41.32597195		
950	41.34702645		
1000	41.36319862		

CHAPTER7

CONCLUSION

The work in this thesis has been motivated by the need to develop an efficient and practical solution to the problem of achieving a lower WIP level while maintaining the same throughput level in telecommunication board production line in the company. We have achieved this by implementing a Conwip control system.

We started by describing the multi-product production environment of the company in Chapter 2. Main production characteristics include deterministic process times for every product, multiple parallel servers at stations, and fixed transfer batch sizes for sub-lines, negligible set-up times and negligible machine breakdowns. The existing production control system in telecommunication board production line in the company is also described in this chapter.

The basic concepts of the Conwip control system and the comparison of Conwip with other systems are introduced in Chapter 3. Studies about Conwip system are also classified and summarized in this chapter. The literature provides an extensive body of knowledge on the use of Conwip and determination of Conwip parameters. However, none of these studies propose a ready to use solution for the production environment in the company.

The most important issue for Conwip control system is the determination of the optimum WIP level (WIP cap). Proposed approaches in the literature are evaluated for the solution of the problem, and approximated MVA approach is selected regarding the ease of implementation, ease of integration to the existing hierarchical system, and suitability to the production environment in the company.

Although its assumptions do not fit exactly to the production environment of the company, it is possible to make some adaptation in the environment for using the approximated MVA approach. These adaptations, generated model to determine WIP cap after these adaptations, and the solution of the model are presented in Chapter 4.

Determination of the WIP cap is the most important issue for a Conwip control system, but it is not enough to implement it in a real system. Determination of WIP cap answers the “what to do” question, but in a real application the answer of “how to do” question is just as important. In Chapter 5, we present how Conwip control system can be used in the company, the flow of the Conwip system, and its integration to the existing hierarchical system.

In Chapter 6, real WIP and throughput data sets of the proposed Conwip control system are compared with the respective data sets of the existing system using hypothesis tests. The results of the hypothesis tests lead us to the conclusion that the Conwip control system offers better performance than the original system in the company. It reduces the WIP level while keeping the same throughput rate.

The secondary result of the comparison study is about the accuracy of the approximated MVA approach. According to the WIP and throughput values, MVA approach approximates the throughput as a function of WIP with 95% accuracy. This is a good approximation accuracy regarding the complexities of the real world.

The following future work can be considered to further improve the Conwip application in the company.

- Assignment of items to product groups and assignment of product groups to sub-lines can be studied simultaneously together with WIP cap determination.

- Transfer batch sizes of the products are currently determined by the pallet sizes of the sub-lines, and we choose to split these batches among multiple servers of stations. A lot sizing study can be conducted to determine batch sizes that will improve the performance of the Conwip system.

- Distribution of WIP cap to product groups can be handled in problem formulation. Instead of finding a single WIP cap and then distributing this quantity to product groups, a formulation and a solution procedure can be developed to directly find WIP cap amounts specific to product groups.

- Backlog list can be sequenced according to known or developed sequencing rules instead of using the given priorities by the sales department. Different sequencing rules can be tried and their effect on Conwip can be estimated by means of simulation.

- The WIP levels in different workstations of the sub-line can be analyzed to see if a bottleneck station emerges.

- Utilization of the workstations and balance of the sub-lines can be analyzed and the sub-lines can be re-balanced.

- The Conwip application can be extended to electro mechanical assembly processes of the company.

REFERENCES

Ayhan, H. and Wortman, M. A., 1999, An approximation for computing the throughput of closed assembly-type queuing networks. European Journal of Operational Research, 112: 107–121.

Bonvik, A. M. and Gerhwin, S. B., 1996, Beyond Kanban: Creating and analyzing lean shop floor control policies. Manufacturing and Service Operations Management Conference Proceedings, Dortmouth College, The Amos Tuck School.

Curry, G.L., Feldman, R.M., 2009, Manufacturing Systems Modeling and Analysis. (Springer Verlag: Berlin Heidelberg).

Duenyas, I. and Keblis, M. F., 1993, Release policies for assembly systems. Department of Industrial and Operations Engineering, Technical Report 93-15, University of Michigan, Ann Arbor.

Duenyas, I. and Patananake, P., 1998, Base-stock control for single product tandem make-to-stock systems. IIE Transactions, 30: 31–39.

Duenyas, I., Hopp, W. J. and Spearman, M. L., 1993, Characterizing the output process of a CONWIP line with deterministic processing and random outages. Management Science, 39: 975–988.

Duri, C., Frein, Y. and Lee, H.-S., 2000, Performance evaluation and design of a CONWIP system with inspections. International Journal of Production Economics, 64: 219–229.

Framinan, J. M., Ruiz-Usano, R. and Leisten, R., 2001, Sequencing CONWIP flow-shops: analysis and heuristics. International Journal of Production Research, 39(12): 2735–3749.

Framinan, J. M., Ruiz-Usano, R. and Gonzales, P.L., 2003, The Conwip production control system: review and research issues. Production Planning and Control, 14(3): 255–265.

Gaury, E. G. A., Pierreval, H. and Kleihnen, J. P. C., 2000, An evolutionary approach to select a pull system among Kanban, Conwip and Hybrid. Journal of Intelligent Manufacturing, 11(2): 157–167.

Gillard, W., 2002, A simulation study comparing performance of Conwip and bottleneck-based release rules. Production Planning and Control, 13(2): 211–219.

Golany, B., Dar-El, E., M. and Zeev, N., 1999, Controlling shop floor operations in a multi-family, multi-cell manufacturing environment through constant work-in-process. IIE Transactions, 31: 771–781.

Goldratt E., Fox, R.E., 1986, The Race. (North River Press: New York).

Graves, R. J. and Milne, R. J., 1997, A new method for order release. Production Planning and Control, 8(4): 332–342.

Gstettner, S. and Kuhn, H., 1996, Analysis of production control systems kanban and Conwip. International Journal of Production Research, 34(11): 3253–3274.

Herer, Y. T. and Masin, M., 1997, Mathematical programming formulation of CONWIP based production lines and relationships to MRP. International Journal of Production Research, 35: 1067–1076.

Hopp, W. J., and Roof, M. L., 1998, Setting WIP levels with statistical throughput control (STC) in CONWIP production lines. International Journal of Production Research, 36(4): 867–882.

Hopp, W. J. and Spearman, M. L., 1991, Throughput of a constant work in process manufacturing line subject to failures. International Journal of Production Research, 29: 635–655.

Hopp, W. J. and Spearman, M. L., 1996, Factory Physics. (Irwin: Chicago).

Hopp, W. J. and Spearman, M. L., 2004, To pull or not to pull: what is the question?. Manufacturing and Service Operations Management, 6(2): 133–148.

Huang, M., Wang, D. and Ip, W. H., 1998, Simulation study of CONWIP for a cold rolling plant. International Journal of Productions Economics, 54: 257–266.

Luh, P. B., Zhou, X. and Tomastik, R. N., 2000, An effective method to reduce inventory in job shops. IEEE Transactions on Robotics and Automation, 16(4): 420–424.

Ohno, T., 1988, Toyota Production System: Beyond Large Scale Production. (Productivity Press: Cambridge, MA.).

Orlicky, J., 1975, Material Requirements Planning: The New Way of Life in Production and Inventory Management. (McGraw-Hill: New York).

Ovalle, O.R. and Marquez, A.C., 2003, Exploring the utilization of a Conwip system for supply chain management: a comparison with fully integrated supply chains. International Journal Production Economics, 83: 195–215.

Ryan, M., Baynat, B. and Choobineh, F., 2000, Determining inventory levels in a CONWIP controlled job shop. IIE Transactions, 32: 105–114.

Shanthikumar, J.G. and Gocmen, M., 1983, Heuristic analysis of closed queuing networks. International Journal of Production Research 21: 675-90.

Spearman, M. L., Woodruff, D. L. and Hoop, W. J., 1990, Conwip: a pull alternative to Kanban. International Journal of Production Research, 28(5): 879–894.

Spearman, M. L., Hopp, W. J. and Woodruff, D. L., 1989, A hierarchical control architecture for Constant Work-in-Process (CONWIP) production systems. Journal of Manufacturing and Operations Management, 2: 147–171.

Womack, J.P., Jones, D.T. and Ross, D.,1990, The Machine That Change World: The Story of Lean Production. (Herper Collins: NewYork).

APPENDIX A

SQL PROGRAMS TO DETERMINE WIP CAP

A.1 Item Information

View Name:

xxupk_ms2_kalem

Collecting Fields:

Item_id: ID No of Item

Segment1: Item Code (i)

Description: Description of Item

Planner Code: Planner Code of Item (Gives info about production place of item)

Malz_Ort: Average monthly requirement of the item (di)

SQL:

```
CREATE OR REPLACE VIEW  xxupk_ms2_kalem AS
SELECT
   msi.inventory_item_id,
   msi.segment1,
   msi.description,
   msi.planner_code,
   round(ort.malz_ort) malz_ort

FROM
   mtl_system_items_b msi,
 (select *  from xxupk_malz_aylik_ort t
      where
      t.malz_ort is not null and t.malz_ort>0) ORT

WHERE
   msi.organization_id=83 and
   msi.planner_code in (19,32,44,46) and
   --These planner codes determines the telecom production products--
   msi.segment1 like 'Y%' and
   --Products begin with 'Y' means semi-finished boards--
   msi.segment1 not like 'YDSK%' and
```

```
msi.segment1 not like 'YKBL%' AND
msi.segment1 not like 'YYRL%' and
msi.segment1 not like 'YSVK%' and
msi.segment1 not like '%-S%' and
--YDSK: Programmed DVD, YKBL: Cable,
--YYRL: Programmed processor, YSVK: Shipment kit,
--Y...-S: Finished product produced for service purpose.
--None of these are semi-finished product groups and
--these product groups are out of our purpose
msi.inventory_item_id=ORT.inventory_item_id
```

Derived Data:

Table A.1 Item Information

ITEM_ID	SEGMENT1 (i)	DESCRIPTION	PLANNER_CODE	MALZ_ORT (d_i)
28000	YSNT00099-FPIO	DS200 CPU III FPIO YM	44	109
38400	YEXT00096	EXP48C (2/6) GENISLETME KARTI YM	32	257
11257	YEXT00039	EXP38 (2/0) GENISLETME KARTI	32	3
11260	YEXT00042	EXP38 (1T0/S0) GENISLETME KARTI	32	5
11272	YEXT00053	EXP48S (0/16) GENISLETME KARTI	32	15
11273	YEXT00054	EXP48S (2/6) GENISLETME KARTI	32	10
11274	YEXT00055	EXP48S (4/12) GENISLETME KARTI	32	7
11366	YPSU00001	BC200 BP YM	44	13
11368	YPSU00045	SPS200-AZ YM	44	100
11374	YSNT00038	MS38S YM	32	655
11378	YSNT00045	SPS200 YM	44	128
11379	YSNT00046	DS200 SPS BACKPLANE YM	44	134
11382	YSNT00050	DS200 MAIN BP YM (ILAVE RACK)	44	88
11392	YSNT00061	MS26S YM	32	272
11396	YSNT00065	DS200S BACKPLANE YM	44	44
11397	YSNT00066	SPS200S GUC KAYNAGI YM	44	203
11408	YSNT00080	DS200 CPU MB YM	44	42
11409	YSNT00081	DS200S CPU MB YM	44	187
11410	YSNT00082	CPU MODULU YM	44	264
11412	YSNT00084	DS200M BACKPLANE YM	44	123
11414	YSNT00087	MS48S SMD YM	32	525
15988	YPSU00248	SPS248 YM (+5V GUCLU)	44	249
22432	YSNT00093	MS26C (2/6) SANTRAL (CAGRI TANIYICILI) YM	32	743
23312	YSNT00094	DS200 2XSPS248 BACKPLANE YM	44	96
24054	YSNT00095	DS200 MAIN BP SMD DUAL CPU YM	44	109
11398	YSNT00068	MS38S ISDN YM	32	6

Table A.1 (continued)

ITEM_ID	SEGMENT1 (i)	DESCRIPTION	PLANNER_CODE	MALZ_ORT (d_i)
24774	YSNT00097	CPU MODULU CPU852T 100MHZ 32M RAM 8M FLASH MT	44	68
25240	YSNT00099	DS200 CPU III MB YM	44	109
25246	YSNT00100	DS200 UTILITY LV YM	44	221
25762	YPSU00005	BC200 GOSTERGE GUC YM	44	13
28158	YEXT00082	EXP38 CID GENISLETME KARTI YM	32	441
30814	YEXT00086	EXP48 CID GENISLETME KARTI YM	32	774
37820	YSNT00105	MS48C YM	32	777
38370	YEXT00095	EXP48C (4/12) GENISLETME KARTI YM	32	204
38406	YEXT00097	EXP48C (0/16) GENISLETME KARTI YM	32	90
46172	YSNT00111	CPU MODULU CPU852T 100MHZ 64M RAM 16M FLASH MT YM	44	58
53348	YSNT00119	DS200L CPU4 MB YM	44	7

A.2 Item Groups:

Table Name:

xxupk_ms2_grup

Collecting Fields:

Grup: Group Name (g)

Grup_tnm: Group Description

SQL:

SELECT * **FROM** xxupk_ms2_grup

Derived Data:

Table A.2 Item Groups

GRUP (g)	**GRUP_TNM**
NT	NT KONSOL
AKS	AKSESUAR
BP-DS	DS BACKPLANE
BP-OS	MS ORTA BACKPLANE
CPU-DS	DS CPU
CPU-OS	MS ORTA CPU
DCC	DCC
DSS	DSS
ESKI	URETILMEYEN URUN
EVM	EVM
EXT-20	DS20 GENISLETME KARTI
EXT-DS	DS GENISLETME KARTI
EXT-KS	MS KUCUK GENISLETME KARTI
EXT-OS	MS ORTA GENISLETME KARTI
FT-ST	FT-ST KONSOL
FTST-LCD	FT-ST KONSOL LCD
GT	GSM GATEWAY
GT-LED	GSM GATEWAY LED
IP	IP
IPX20	DS20 IPX
IRIS	IRIS KONSOL
IVM	IVM
KNK-DS	DS200 KONNEKTOR KARTI
KNK-OS	MS ORTA KONNEKTOR KARTI
KS_26	MS26
KS_38	MS38
KS_48	MS48
OP-LT	OP-LT KONSOL
SPS-20	DS20 GUC KAYNAGI
SPS-DS	DS200 GUC KAYNAGI
SPS-KS	MS KUCUK GUC KAYNAGI
SPS-OS	MS ORTA GUC KAYNAGI
UTL-DS	DS200 UTILITY

A.3 Lines Information (h , b_h)

Table Name:

xxupk_ms2_hotlotsize

Collecting Fields:

Hat: Sub-line Name (h)

Hat_Lot: Transfer lot-size of the sub-line (b_h)

Tnm: Description of the Sub-line

SQL:

SELECT * **FROM** xxupk_ms2_hotlotsize

Derived Data:

Table A.3 Lines Information

HAT	HAT_LOT	TNM
HAT1	50	MS_KUCUK/EXT
HAT2	20	DS/MS_ORTA
HAT3	30	KONSOL
HAT4	10	AKSESUAR
HAT5	1	DIGER

A.4 Work Station Information (j, n_j)

View:

xxupk_ms2_kaynak

Collecting Fields:

Resource_id: ID No of station

Resource Code: Name of the station (j)

Capacity_Units: Number of the resources (servers) (n_j)

SQL:

```
CREATE OR REPLACE VIEW xxupk_ms2_kaynak AS
SELECT
   a.resource_id,
   a.resource_code,
   b.capacity_units
FROM
   bom_resources a,
   bom_department_resources b
WHERE
   a.resource_id=b.resource_id and
   a.resource_code in
   ('T_GT_ISCI','T_MONT_ISC','T_SMDGT_IS','T_TEST_ISC')


   --'T_SMDGT_IS':  SMD Eye Inspection
   --'T_MONT_ISC': Assembly
   --'T_GT_ISCI':  Eye Inspection
   --'T_TEST_ISC': Test
```

Derived Data:

Table A.4 Work Station Information

RESOURCE_ID	RESOURCE_CODE (j)	CAPACITY_UNITS (n_j)
12	T_MONT_ISC	11
8	T_GT_ISCI	13
16	T_SMDGT_IS	17
17	T_TEST_ISC	21

A.5 Assignment of items to groups (x_{ig})

Table:

xxupk_ms2_grupkalem

Collecting Fields:

Segment1: Item Code

Description: Description of item

Grup: Group of Item

SQL

SELECT * FROM xxupk_ms2_grupkalem

Derived Data:

Table A.5 Assignment of Items to Groups

SEGMENT1 (i)	DESCRIPTION	GRUP (g)
YSNT00046	DS200 SPS BACKPLANE YM	BP-DS
YSNT00050	DS200 MAIN BP YM (ILAVE RACK)	BP-DS
YSNT00062	DS200 MAIN BP SMD YM (TEK RACK)	BP-DS
YSNT00065	DS200S BACKPLANE YM	BP-DS
YSNT00084	DS200M BACKPLANE YM	BP-DS
YSNT00094	DS200 2XSPS248 BACKPLANE YM	BP-DS
YSNT00095	DS200 MAIN BP SMD DUAL CPU YM	BP-DS
YSNT00101	DS200 MAIN BP U3-U4 YAMA YM	BP-DS
YSNT00109	DS200 MIL PABX BACKPLANE YM	BP-DS
YSNT00039	DS200 CPU YM	CPU-DS
YSNT00063	DS200S CPU YM	CPU-DS
YSNT00081	DS200S CPU MB YM	CPU-DS
YSNT00082	CPU MODULU YM	CPU-DS
YSNT00089	CPU MODULU CPU852T	CPU-DS
YSNT00097	CPU MODULU CPU852T 100MHZ 32M RAM 8M FLASH MT	CPU-DS
YSNT00099	DS200 CPU III MB YM	CPU-DS
YSNT00111	CPU MODULU CPU852T 100MHZ 64M RAM 16M	CPU-DS
YSNT00130	CPU MODULU CPU852T 100 MHz 128M RAM 16M FLASH MT YM	CPU-DS
YSNT00039-S-I	DS200 CPU YM IHR (YEDEK PARCA)	CPU-DS
YSNT00063-S-I	DS200S CPU YM IHR (YEDEK PARCA)	CPU-DS
YSNT00080-S-I	DS200 CPU MB YM IHR (YEDEK PARCA)	CPU-DS
YSNT00081-S-I	DS200S CPU MB YM IHR (YEDEK PARCA)	CPU-DS
YSNT00099-S-I	DS200 CPU III MB YM IHR (YEDEK PARCA)	CPU-DS
YSNT00099-FPIO	DS200 CPU III FPIO YM	CPU-DS
YSNT00056	MS48 ISDN YM	KS_48
YSNT00069	MS48 ISDN (2T0/12) YM	KS_48
YSNT00115	MS48D ANAKART YM	KS_48
YPSU00001	BC200 BP YM	BP-DS
YPSU00045	SPS200-AZ YM	SPS-DS
YPSU00248	SPS248 YM (+5V GUCLU)	SPS-DS
YPSU00005	BC200 GOSTERGE GUC YM	SPS-DS
YPSU00200	SPS200PFC GUC KAYNAGI YM	SPS-DS
YSNT00119	DS200L CPU4 MB YM	CPU-DS

Table A.5 (continued)

SEGMENT1 (i)	DESCRIPTION	GRUP (g)
YEXT00006	EXP48 (0/16) GENISLETME KARTI	EXT-KS
YEXT00007	EXP48 (4/12) GENISLETME KARTI	EXT-KS
YEXT00011	EXP48 (2/6) GENISLETME KARTI	EXT-KS
YEXT00027	EXP48 (2T0/12) GENISLETME KARTI	EXT-KS
YEXT00042	EXP38 (1T0/S0) GENISLETME KARTI	EXT-KS
YEXT00082	EXP38 CID GENISLETME KARTI YM	EXT-KS
YEXT00086	EXP48 CID GENISLETME KARTI YM	EXT-KS
YEXT00095	EXP48C (4/12) GENISLETME KARTI YM	EXT-KS
YEXT00096	EXP48C (2/6) GENISLETME KARTI YM	EXT-KS
YEXT00097	EXP48C (0/16) GENISLETME KARTI YM	EXT-KS
YEXT00109	EXP48D 4/12 YM	EXT-KS
YEXT00110	EXP48D 0/16 YM	EXT-KS
YSNT00038	MS38S YM	KS_38
YSNT00061	MS26S YM	KS_26
YSNT00085	MS38S YARIMAMUL IHR	KS_38
YSNT00087	MS48S SMD YM	KS_48
YSNT00093	MS26C (2/6) SANTRAL (CAGRI TANIYICILI) YM	KS_26
YSNT00105	MS48C YM	KS_48
YSNT00042	SPS248 YM	SPS-DS
YSNT00045	SPS200 YM	SPS-DS
YSNT00066	SPS200S GUC KAYNAGI YM	SPS-DS
YSNT00037	DS200 UTILITY YM	UTL-DS
YSNT00100	DS200 UTILITY LV YM	UTL-DS
YSNT00037-S-I	DS200 UTILITY YM IHR. (YEDEK PARCA)	UTL-DS
YSNT00100-S-I	DS200 UTILITY LV YM IHR (YEDEK PARCA)	UTL-DS
YEXT00039	EXP38 (2/0) GENISLETME KARTI	EXT-KS
YEXT00053	EXP48S (0/16) GENISLETME KARTI	EXT-KS
YEXT00054	EXP48S (2/6) GENISLETME KARTI	EXT-KS
YEXT00055	EXP48S (4/12) GENISLETME KARTI	EXT-KS
YSNT00080	DS200 CPU MB YM	CPU-DS
YEXT00031	MS48 ISDN 2S0/12 YM	EXT-KS
YSNT00068	MS38S ISDN YM	KS_38

A.6 Assignment of Group to Lines (y_{gh})

Table:

xxupk_ms2_hatgrup

Collecting Fields:

Grup: Group Name

Hat: Line Name

<u>SQL:</u>

SELECT * FROM xxupk_ms2_hatgrup

<u>Derived Data:</u>

Table A.6 Assignment of Group to Lines

GRUP (g)	HAT (h)
EXT-KS	HAT1
KS_26	HAT1
KS_38	HAT1
KS_48	HAT1
BP-DS	HAT2
CPU-DS	HAT2
EXT-DS	HAT2
SPS-DS	HAT2
UTL-DS	HAT2
FT-ST	HAT3
IP	HAT3
OP-LT	HAT3
NT	HAT3
EVM	HAT4
GT	HAT4
IVM	HAT4
SPS-KS	HAT5
BP-OS	HAT5
FTST-LCD	HAT5
CPU-OS	HAT5
DIGER	HAT5
AKS	HAT5
GT-LED	HAT5
EXT-OS	HAT5
KNK-DS	HAT5
KNK-OS	HAT5
SPS-OS	HAT5
DCC	HAT5
DSS	HAT5
ESKI	HAT5
EXT-20	HAT5
IPX20	HAT5
IRIS	HAT5
SPS-20	HAT5

A.7 Average Processing Times of Items on Workstations (t_{ij})

View Name:

xxupk_ms2_kalempts

Collecting Fields:

Hat: Sub-line name (h)

Grup: Group name (g)

Assembly_Item_Id: ID Number of Item

Segment1: Item Code (i)

Resource_Id: Resource (Work Station) Id

Usage_Rate_Or_Amount: Average processing time of item on work station (t_{ij})

SQL:

```
CREATE OR REPLACE VIEW xxupk_ms2_kalempts AS
SELECT
   nvl(y.hat,'HAT5') hat ,
   NVL(x.grup,'YENI') grup,
   rt.assembly_item_id,
   i.segment1,
   wr.resource_id,
   wr.usage_rate_or_amount
FROM
   xxupk_ms2_kalem i,
   xxupk_ms2_grupkalem x,
   xxupk_ms2_hatgrup y,
   bom_operational_routings rt,--Header information of routes table
   bom_operation_sequences wor,-- Sequence information of routes
   bom_operation_resources wr --Process Time information of routes
WHERE
   i.segment1=x.segment1(+) and
   x.grup=y.grup(+) and
   i.inventory_item_id=rt.assembly_item_id and
   rt.routing_sequence_id=wor.routing_sequence_id and
   wor.operation_sequence_id=wr.operation_sequence_id(+) and
   rt.organization_id=83 and
```

```
rt.alternate_routing_designator is null and
wr.basis_type=1 and
(wr.standard_rate_flag=1 or wr.standard_rate_flag is null) and
wor.effectivity_date<sysdate and
(wor.disable_date>sysdate or wor.disable_date is null) and
wr.resource_id in (16,12,8,17)
--'T_SMDGT_IS':  SMD Eye Inspection (Resource Id: 16)
--'T_MONT_ISC': Assembly (Resource Id: 12)
--'T_GT_ISCI':  Eye Inspection (Resource Id: 8)
--'T_TEST_ISC': Test (Resource Id: 17)
```

<u>Derived Data:</u>

Table A.7 Average Processing Times of Items on Workstations

HAT(h)	GRUP(g)	ASSEMBLY ITEM_ID	SEGMENT1(i)	RESOURCE_ID	USAGE_RATE OR_ AMOUNT(t_{ij})
HAT1	EXT-KS	11257	YEXT00039	16	0,083
HAT1	EXT-KS	11257	YEXT00039	12	0,067
HAT1	EXT-KS	11257	YEXT00039	8	0,017
HAT1	EXT-KS	11257	YEXT00039	17	0,0667
HAT1	EXT-KS	11260	YEXT00042	16	0,133
HAT1	EXT-KS	11260	YEXT00042	12	0,1
HAT1	EXT-KS	11260	YEXT00042	8	0,09
HAT1	EXT-KS	11260	YEXT00042	17	0,1
HAT1	EXT-KS	11272	YEXT00053	16	0,217391
HAT1	EXT-KS	11272	YEXT00053	12	0,1
HAT1	EXT-KS	11272	YEXT00053	8	0,1
HAT1	EXT-KS	11272	YEXT00053	17	0,2
HAT1	EXT-KS	11273	YEXT00054	16	0,166667
HAT1	EXT-KS	11273	YEXT00054	12	0,1
HAT1	EXT-KS	11273	YEXT00054	8	0,083333
HAT1	EXT-KS	11273	YEXT00054	17	0,1
HAT1	EXT-KS	11274	YEXT00055	16	0,25
HAT1	EXT-KS	11274	YEXT00055	12	0,133333
HAT1	EXT-KS	11274	YEXT00055	8	0,083333
HAT1	EXT-KS	11274	YEXT00055	17	0,066667
HAT1	EXT-KS	11274	YEXT00055	17	0,2
HAT1	EXT-KS	28158	YEXT00082	16	0,083333
HAT1	EXT-KS	28158	YEXT00082	12	0,1
HAT1	EXT-KS	28158	YEXT00082	8	0,083333

Table A.7 (continued)

HAT(h)	GRUP(g)	ASSEMBLY ITEM_ID	SEGMENT1(i)	RESOURCE_ID	USAGE_RATE OR_ AMOUNT(t_{ij})
HAT1	EXT-KS	28158	YEXT00082	17	0,0833
HAT1	EXT-KS	30814	YEXT00086	16	0,222222
HAT1	EXT-KS	30814	YEXT00086	12	0,1
HAT1	EXT-KS	30814	YEXT00086	8	0,083333
HAT1	EXT-KS	30814	YEXT00086	17	0,1417
HAT1	EXT-KS	38370	YEXT00095	16	0,37037
HAT1	EXT-KS	38370	YEXT00095	12	0,1166
HAT1	EXT-KS	38370	YEXT00095	8	0,083333
HAT1	EXT-KS	38370	YEXT00095	17	0
HAT1	EXT-KS	38370	YEXT00095	17	0,2417
HAT1	EXT-KS	38400	YEXT00096	16	0,166667
HAT1	EXT-KS	38400	YEXT00096	12	0,1
HAT1	EXT-KS	38400	YEXT00096	8	0,083333
HAT1	EXT-KS	38400	YEXT00096	17	0,15
HAT1	EXT-KS	38406	YEXT00097	16	0,384615
HAT1	EXT-KS	38406	YEXT00097	12	0,083333
HAT1	EXT-KS	38406	YEXT00097	8	0,083333
HAT1	EXT-KS	38406	YEXT00097	17	0,2417
HAT1	KS_38	11374	YSNT00038	16	0,19
HAT1	KS_38	11374	YSNT00038	12	0,125
HAT1	KS_38	11374	YSNT00038	8	0,068
HAT1	KS_38	11374	YSNT00038	17	0,05
HAT1	KS_38	11374	YSNT00038	17	0,2833
HAT1	SPS-KS	11390	YSNT00059	16	0,012
HAT1	SPS-KS	11390	YSNT00059	12	0,067843
HAT1	SPS-KS	11390	YSNT00059	8	0,175439
HAT1	SPS-KS	11390	YSNT00059	17	0,090204
HAT1	KS_26	11392	YSNT00061	16	0,166667
HAT1	KS_26	11392	YSNT00061	12	0,083333
HAT1	KS_26	11392	YSNT00061	8	0,067
HAT1	KS_26	11392	YSNT00061	17	0,217
HAT1	KS_38	11398	YSNT00068	16	0,166667
HAT1	KS_38	11398	YSNT00068	12	0,167
HAT1	KS_38	11398	YSNT00068	8	0,05
HAT1	KS_38	11398	YSNT00068	17	0,2833
HAT1	SPS-KS	11405	YSNT00077	16	0,016667
HAT1	SPS-KS	11405	YSNT00077	12	0,076923
HAT1	SPS-KS	11405	YSNT00077	8	0,090909
HAT1	SPS-KS	11405	YSNT00077	17	0,033333
HAT1	KS_48	11414	YSNT00087	16	0,37
HAT1	KS_48	11414	YSNT00087	12	0,166667
HAT1	KS_48	11414	YSNT00087	8	0,125
HAT1	KS_48	11414	YSNT00087	17	0,2833
HAT1	KS_26	22432	YSNT00093	16	0,2
HAT1	KS_26	22432	YSNT00093	12	0,1083

Table A.7 (continued)

HAT(h)	GRUP(g)	ASSEMBLY ITEM_ID	SEGMENT1(i)	RESOURCE_ID	USAGE_RATE OR_ AMOUNT(t_{ij})
HAT1	KS_26	22432	YSNT00093	8	0,125
HAT1	KS_26	22432	YSNT00093	17	0,25
HAT1	KS_48	37820	YSNT00105	16	0,278862
HAT1	KS_48	37820	YSNT00105	12	0,119617
HAT1	KS_48	37820	YSNT00105	8	0,099404
HAT1	KS_48	37820	YSNT00105	17	0,342466
HAT2	EXT-DS	11256	YEXT00036	16	0,25
HAT2	EXT-DS	11256	YEXT00036	12	0,267
HAT2	EXT-DS	11256	YEXT00036	8	0,133
HAT2	EXT-DS	11256	YEXT00036	17	0,166667
HAT2	EXT-DS	11258	YEXT00040	16	0,183
HAT2	EXT-DS	11258	YEXT00040	12	0,175
HAT2	EXT-DS	11258	YEXT00040	8	0,083
HAT2	EXT-DS	11258	YEXT00040	17	0,25
HAT2	EXT-DS	11261	YEXT00043	16	0,183
HAT2	EXT-DS	11261	YEXT00043	12	0,1
HAT2	EXT-DS	11261	YEXT00043	8	0,066667
HAT2	EXT-DS	11261	YEXT00043	17	0,2
HAT2	EXT-DS	11262	YEXT00044	16	0,25
HAT2	EXT-DS	11262	YEXT00044	12	0,25
HAT2	EXT-DS	11262	YEXT00044	8	0,217
HAT2	EXT-DS	11262	YEXT00044	17	0,35
HAT2	EXT-DS	11265	YEXT00046	16	0,25
HAT2	EXT-DS	11265	YEXT00046	12	0,083333
HAT2	EXT-DS	11265	YEXT00046	8	0,083333
HAT2	EXT-DS	11265	YEXT00046	17	0,166
HAT2	EXT-DS	11266	YEXT00047	16	0,25
HAT2	EXT-DS	11266	YEXT00047	12	0,108
HAT2	EXT-DS	11266	YEXT00047	8	0,05
HAT2	EXT-DS	11266	YEXT00047	17	0,183
HAT2	EXT-DS	11267	YEXT00048	16	0,266667
HAT2	EXT-DS	11267	YEXT00048	12	0,066
HAT2	EXT-DS	11267	YEXT00048	8	0,058
HAT2	EXT-DS	11267	YEXT00048	17	0,333
HAT2	EXT-DS	12492	YEXT00051-01	16	0,325
HAT2	EXT-DS	12492	YEXT00051-01	12	0,083
HAT2	EXT-DS	12492	YEXT00051-01	8	0,066667
HAT2	EXT-DS	12492	YEXT00051-01	17	0,2
HAT2	EXT-DS	11271	YEXT00052	16	0,25
HAT2	EXT-DS	11271	YEXT00052	12	0,1
HAT2	EXT-DS	11271	YEXT00052	8	0,083333
HAT2	EXT-DS	11271	YEXT00052	17	0,1
HAT2	EXT-DS	11275	YEXT00056	16	0,25
HAT2	EXT-DS	11275	YEXT00056	12	0,083333
HAT2	EXT-DS	11275	YEXT00056	8	0,083333

Table A.7 (continued)

HAT(h)	GRUP(g)	ASSEMBLY ITEM_ID	SEGMENT1(i)	RESOURCE_ID	USAGE_RATE OR_ AMOUNT(t_{ij})
HAT2	EXT-DS	11275	YEXT00056	17	0,4
HAT2	EXT-DS	11276	YEXT00058	16	0,283286
HAT2	EXT-DS	11276	YEXT00058	12	0,083333
HAT2	EXT-DS	11276	YEXT00058	8	0,083333
HAT2	EXT-DS	11276	YEXT00058	17	0,2
HAT2	EXT-DS	11277	YEXT00059	16	0,283286
HAT2	EXT-DS	11277	YEXT00059	12	0,083333
HAT2	EXT-DS	11277	YEXT00059	8	0,1
HAT2	EXT-DS	11277	YEXT00059	17	0,116279
HAT2	EXT-DS	23474	YEXT00074	16	0,166667
HAT2	EXT-DS	23474	YEXT00074	12	0,125
HAT2	EXT-DS	23474	YEXT00074	8	0,125
HAT2	EXT-DS	23474	YEXT00074	17	0,333333
HAT2	EXT-DS	24172	YEXT00075	16	0,325
HAT2	EXT-DS	24172	YEXT00075	12	0,083333
HAT2	EXT-DS	24172	YEXT00075	8	0,05
HAT2	EXT-DS	24172	YEXT00075	17	0,4
HAT2	EXT-DS	24974	YEXT00077	16	0,275
HAT2	EXT-DS	24974	YEXT00077	12	0,108
HAT2	EXT-DS	24974	YEXT00077	8	0,05
HAT2	EXT-DS	24974	YEXT00077	17	0,183
HAT2	EXT-DS	26130	YEXT00081	16	0,277778
HAT2	EXT-DS	26130	YEXT00081	12	0,09
HAT2	EXT-DS	26130	YEXT00081	8	0,05
HAT2	EXT-DS	26130	YEXT00081	17	0,181818
HAT2	EXT-DS	37676	YEXT00090	16	0,25
HAT2	EXT-DS	37676	YEXT00090	12	0,05
HAT2	EXT-DS	37676	YEXT00090	8	0,133333
HAT2	EXT-DS	47690	YEXT00104	16	0,325
HAT2	EXT-DS	47690	YEXT00104	12	0,1
HAT2	EXT-DS	47690	YEXT00104	8	0,083333
HAT2	EXT-DS	47690	YEXT00104	17	0,1
HAT2	EXT-DS	47702	YEXT00105	16	0,325
HAT2	EXT-DS	47702	YEXT00105	12	0,1
HAT2	EXT-DS	47702	YEXT00105	8	0,083333
HAT2	EXT-DS	47702	YEXT00105	17	0,1
HAT2	EXT-DS	57726	YEXT00114	16	0,25
HAT2	EXT-DS	57726	YEXT00114	12	0,2
HAT2	EXT-DS	57726	YEXT00114	8	0,1
HAT2	EXT-DS	57726	YEXT00114	17	0,5
HAT2	BP-DS	11366	YPSU00001	12	0,285714
HAT2	BP-DS	11366	YPSU00001	8	0,2
HAT2	BP-DS	11366	YPSU00001	17	0,05
HAT2	SPS-DS	25762	YPSU00005	16	0,083333
HAT2	SPS-DS	25762	YPSU00005	12	0,05

Table A.7 (continued)

HAT(h)	GRUP(g)	ASSEMBLY ITEM_ID	SEGMENT1(i)	RESOURCE_ID	USAGE_RATE OR_ AMOUNT(t_{ij})
HAT2	SPS-DS	25762	YPSU00005	8	0,016667
HAT2	SPS-DS	25762	YPSU00005	17	0,025
HAT2	SPS-DS	11368	YPSU00045	12	0,285714
HAT2	SPS-DS	11368	YPSU00045	8	0,333333
HAT2	SPS-DS	11368	YPSU00045	17	0,421
HAT2	SPS-DS	15988	YPSU00248	12	0,317
HAT2	SPS-DS	15988	YPSU00248	8	0,454545
HAT2	SPS-DS	15988	YPSU00248	17	0,083
HAT2	SPS-DS	11378	YSNT00045	12	0,25
HAT2	SPS-DS	11378	YSNT00045	8	0,333
HAT2	SPS-DS	11378	YSNT00045	17	0,3332
HAT2	BP-DS	11379	YSNT00046	12	0,125
HAT2	BP-DS	11379	YSNT00046	8	0,066667
HAT2	BP-DS	11379	YSNT00046	17	0,03
HAT2	BP-DS	11382	YSNT00050	16	0,133
HAT2	BP-DS	11382	YSNT00050	12	0,1
HAT2	BP-DS	11382	YSNT00050	8	0,333333
HAT2	BP-DS	11382	YSNT00050	17	0,125
HAT2	BP-DS	11396	YSNT00065	16	0,067
HAT2	BP-DS	11396	YSNT00065	12	0,166667
HAT2	BP-DS	11396	YSNT00065	8	0,2
HAT2	BP-DS	11396	YSNT00065	17	0,0916
HAT2	SPS-DS	11397	YSNT00066	16	0,11
HAT2	SPS-DS	11397	YSNT00066	12	0,283
HAT2	SPS-DS	11397	YSNT00066	8	0,3
HAT2	SPS-DS	11397	YSNT00066	17	0,1
HAT2	CPU-DS	11408	YSNT00080	16	0,166667
HAT2	CPU-DS	11408	YSNT00080	12	0,1
HAT2	CPU-DS	11408	YSNT00080	8	0,083333
HAT2	CPU-DS	11408	YSNT00080	17	0,15
HAT2	CPU-DS	11409	YSNT00081	16	0,277778
HAT2	CPU-DS	11409	YSNT00081	12	0,083333
HAT2	CPU-DS	11409	YSNT00081	8	0,083333
HAT2	CPU-DS	11409	YSNT00081	17	0,11
HAT2	CPU-DS	11410	YSNT00082	16	0,25
HAT2	CPU-DS	11410	YSNT00082	12	0,083333
HAT2	CPU-DS	11410	YSNT00082	8	0,083333
HAT2	CPU-DS	11410	YSNT00082	17	0,46
HAT2	BP-DS	11412	YSNT00084	16	0,05
HAT2	BP-DS	11412	YSNT00084	12	0,083333
HAT2	BP-DS	11412	YSNT00084	8	0,2
HAT2	BP-DS	11412	YSNT00084	17	0,0916
HAT2	BP-DS	23312	YSNT00094	12	0,125
HAT2	BP-DS	23312	YSNT00094	8	0,117647
HAT2	BP-DS	23312	YSNT00094	17	0,016667

A.8 Number of servers allocated to sub-lines (n_{jh})

View:

xxupk_ms2_resource_alloc

Collecting Field:

resource_id : Resource (Workstation) ID (j)

resource_code: Name of the resource (Workstation)

hat : Line name (h)

capacity_units: Total number of the servers of workstation (n_j)

cap_alloc : Number of the servers assigned to workstation on sub-line (n_{jh})

SQL:

```
CREATE OR REPLACE VIEW xxupk_ms2_resource_alloc AS
SELECT
   hat_ger.resource_id,
   hat_ger.resource_code,
   hat_ger.hat,hat_ger.capacity_units,
   round((hat_ger.kaynak_ger/res_cap.kaynak_sure)*
   hat_ger.capacity_units,3) cap_alloc
   -- (Work load of station j on sub-line h/
   --Total work load of station j)*
   --(number of capacity units of station j)

FROM
   (select
   k.resource_id,
   k.resource_code,
   k.capacity_units,
   sum(nvl(t.usage_rate_or_amount,0)*nvl(a.malz_ort,0))
   kaynak_sure,
   sum(nvl(t.usage_rate_or_amount,0)*nvl(a.malz_ort,0))
   /k.capacity_units/8 kaynak_yuk
   from
   xxupk_ms2_kaynak k,
   xxupk_ms2_kalempts t,
   xxupk_ms2_kalem a
   where
   k.resource_id=t.resource_id and
   t.assembly_item_id=a.inventory_item_id
   group by
   k.resource_id,k.resource_code,k.capacity_units) res_cap,
```

```
--Total work load of station j --

(select
k.resource_id,
k.resource_code,
k.capacity_units,
hg.hat,
sum(nvl(t.usage_rate_or_amount,0)*nvl(a.malz_ort,0)) kaynak_ger
from
xxupk_ms2_kaynak k,
xxupk_ms2_kalempts t,
xxupk_ms2_kalem a,
xxupk_ms2_grupkalem gk,
xxupk_ms2_hatgrup hg
where
k.resource_id=t.resource_id and
t.assembly_item_id=a.inventory_item_id and
a.segment1=gk.segment1(+) and
gk.grup=hg.grup(+)
group by
k.resource_id,k.resource_code,k.capacity_units,hg.hat) hat_ger
--Work load of station j on sub-line h--

WHERE
  RES_CAP.resource_id=HAT_GER.resource_id
```

Derived Data:

Table A.8 Number of Servers Allocated to Sub-Lines

RESOURCE_ID	RESOURCE_CODE	HAT	CAPACITY_UNITS	CAP_ALLOC
8	T_GT_ISCI	HAT1	13	2
8	T_GT_ISCI	HAT2	13	2
8	T_GT_ISCI	HAT3	13	3
8	T_GT_ISCI	HAT4	13	2
8	T_GT_ISCI	HAT5	13	5
12	T_MONT_ISC	HAT1	11	2
12	T_MONT_ISC	HAT2	11	2
12	T_MONT_ISC	HAT3	11	2
12	T_MONT_ISC	HAT4	11	1
12	T_MONT_ISC	HAT5	11	4
16	T_SMDGT_IS	HAT1	17	6
16	T_SMDGT_IS	HAT2	17	2
16	T_SMDGT_IS	HAT3	17	2
16	T_SMDGT_IS	HAT4	17	1
16	T_SMDGT_IS	HAT5	17	7
17	T_TEST_ISC	HAT1	21	6
17	T_TEST_ISC	HAT2	21	2
17	T_TEST_ISC	HAT3	21	4
17	T_TEST_ISC	HAT4	21	2
17	T_TEST_ISC	HAT5	21	7

A.9 Total Monthly Demand of Boards Processed on Line (D_h)

View:

xxupk_ms2_hatorttuk

Collecting Field:

Hat: Line Name

Hat_Ort: Total Monthly Demand of Boards processed on Line

Hat_Kalem_Sayi: Number of items processed in line

SQL:

```
CREATE OR REPLACE VIEW xxupk_ms2_hatorttuk AS
SELECT
   hg.hat,
```

```
   sum(nvl(k.malz_ort,0)) hat_ort,
   count(k.segment1) hat_kalem_sayi

FROM
   xxupk_ms2_hatgrup hg,
   xxupk_ms2_grupkalem gk,
   xxupk_ms2_kalem k

WHERE
   gk.segment1=k.segment1 AND
   k.malz_ort>0 and
   gk.grup=hg.grup

GROUP BY
   hg.hat
```

Derived Data:

Table A.9 Total Monthly Demand of Boards Processed on Line

HAT (h)	HAT_ORT(D_h)	HAT_KALEM_SAYI
HAT1	4784	16
HAT2	2365	21
HAT3	4374	23
HAT4	4081	11
HAT5	10790	105

A.10 Average processing times of the batches in workstations, on sub-lines (te_{hj})

View:

xxupk_ms2_avgpts

Collecting Field:

Hat: Sub-line (h)

resource_id: Resource (Workstation) ID (j)

resource_code : Name of the resource (Workstation)

hat_avg_pts: Average time of the batches (tehj)

SQL:

```
CREATE OR REPLACE VIEW xxupk_ms2_avgpts AS
SELECT
   t.hat,
   t.resource_id,
   j.resource_code,


   sum((t.usage_rate_or_amount*b.hat_lot/nj.cap_alloc)
   *(di.malz_ort/d.hat_ort)) hat_avg_pts

   --average processing times of line—


FROM
   xxupk_ms2_kalempts t,
   xxupk_ms2_kalem di,
   xxupk_ms2_hotlotsize b,
   xxupk_ms2_resource_alloc nj,
   xxupk_ms2_hatorttuk d,
   xxupk_ms2_kaynak j


WHERE
   t.assembly_item_id=di.inventory_item_id(+) and
   t.hat=nj.hat(+) and
   t.resource_id=nj.resource_id(+) and
   t.hat=b.hat(+) and
   t.hat=d.hat(+) and
   t.resource_id=j.resource_id(+)


GROUP BY
   t.hat,t.resource_id,j.resource_code
```

Derived Data:

Table A.10 Average Processing Times of the Batches in Workstations, on Sub-Lines

HAT(h)	RESOURCE_ID	RESOURCE_CODE(j)	HAT_AVG_PTS (te_{hj})
HAT1	8	T_GT_ISCI	2,441
HAT1	12	T_MONT_ISC	2,347
HAT1	16	T_SMDGT_IS	2,005
HAT1	17	T_TEST_ISC	1,914
HAT2	8	T_GT_ISCI	1,975
HAT2	12	T_MONT_ISC	1,899
HAT2	16	T_SMDGT_IS	1,622
HAT2	17	T_TEST_ISC	1,548
HAT3	8	T_GT_ISCI	1,017
HAT3	12	T_MONT_ISC	1,027
HAT3	16	T_SMDGT_IS	0,877
HAT3	17	T_TEST_ISC	0,807
HAT4	8	T_GT_ISCI	0,573
HAT4	12	T_MONT_ISC	0,550
HAT4	16	T_SMDGT_IS	0,470
HAT4	17	T_TEST_ISC	0,449
HAT5	8	T_GT_ISCI	0,021
HAT5	12	T_MONT_ISC	0,021
HAT5	16	T_SMDGT_IS	0,018
HAT5	17	T_TEST_ISC	0,017

A.11 Standard deviation of batch processing times (ss_{hj}), Squared Coefficient of Variation (ce_{hj}^2),Target Throughput (TH^*_h)

View:

xxupk_ms2_avgssscv_pts

Collecting Fields:

Hat: Sub-line (h)

resource_code: Name of the resource (Workstation)

hat_avg_pts: Average time of the batches (tehj)

hat_ss_pts: Standard deviation of the time of the batches (ss hj) hat_scv_pts : Squared deviation of variation of the time of the batches (cehj2)

target_th: target throughput of the sub-line

SQL:

```
CREATE OR REPLACE VIEW xxupk_ms2_avgssscv_pts AS
SELECT
   t.hat,
   j.resource_code,
   tehj.hat_avg_pts,


   power(sum(power((t.usage_rate_or_amount*b.hat_lot/nj.cap_alloc)-
   tehj.hat_avg_pts,2)* (di.malz_ort/d.hat_ort)),0.5) hat_ss_pts,
   --standard deviation of processing times-

   sum(power((t.usage_rate_or_amount*b.hat_lot/nj.cap_alloc)-
   tehj.hat_avg_pts,2)* (di.malz_ort/d.hat_ort)) /
   power(tehj.hat_avg_pts,2) hat_scv_pts ,
   --squared coefficient of variance of processing times-

   d.hat_ort/b.hat_lot/208 target_th

FROM
   xxupk_ms2_kalempts t,
   xxupk_ms2_kalem di,
   xxupk_ms2_hotlotsize b,
   xxupk_ms2_resource_alloc nj,
   xxupk_ms2_hatorttuk d,
   xxupk_ms2_kaynak j,
   xxupk_ms2_avgpts tehj

WHERE
   t.assembly_item_id=di.inventory_item_id(+) and
   t.hat=nj.hat(+) and
   t.resource_id=nj.resource_id(+) and
   t.hat=b.hat(+) and
   t.hat=d.hat(+) and
   t.resource_id=j.resource_id(+) and
   t.hat=tehj.hat(+) and
   t.resource_id=tehj.resource_id(+)

GROUP BY
   t.hat,j.resource_code,tehj.hat_avg_pts,
   d.hat_ort/b.hat_lot/208
```

Derived Data:

Table A.11 Stddev of Batch Processing Times ,SCV ,Target Throughput

HAT (h)	RESOURCE_CODE (j)	HAT_AVG_PTS (te_{hj})	HAT_SS_PTS (ss_{hj})	HAT_SCV_PTS (ce_{hj}^2)	TARGET_TH (TH^*_h)
HAT1	T_GT_ISCI	2,441	0,546	0,050	0,460
HAT1	T_MONT_ISC	2,347	0,443	0,036	0,460
HAT1	T_SMDGT_IS	2,005	0,712	0,126	0,460
HAT1	T_TEST_ISC	1,914	0,945	0,244	0,460
HAT2	T_GT_ISCI	1,975	1,439	0,531	0,569
HAT2	T_MONT_ISC	1,899	1,048	0,305	0,569
HAT2	T_SMDGT_IS	1,622	1,211	0,558	0,569
HAT2	T_TEST_ISC	1,548	1,303	0,708	0,569
HAT3	T_GT_ISCI	1,017	0,496	0,238	1,051
HAT3	T_MONT_ISC	1,027	1,405	1,872	1,051
HAT3	T_SMDGT_IS	0,877	0,461	0,277	1,051
HAT3	T_TEST_ISC	0,807	0,862	1,141	1,051
HAT4	T_GT_ISCI	0,573	0,236	0,170	1,962
HAT4	T_MONT_ISC	0,550	0,188	0,117	1,962
HAT4	T_SMDGT_IS	0,470	0,741	2,483	1,962
HAT4	T_TEST_ISC	0,449	0,375	0,697	1,962
HAT5	T_GT_ISCI	0,021	0,011	0,282	51,875
HAT5	T_MONT_ISC	0,021	0,011	0,275	51,875
HAT5	T_SMDGT_IS	0,018	0,016	0,782	51,875
HAT5	T_TEST_ISC	0,017	0,016	0,912	51,875

A.12 MVA Spreadsheet Solution calculation of W_h^* (WIP cap of the Sub-Lines)

Average process times (te_{hj}) and Squared Coefficient of Variations (ce_{hj}^2) calculated in view “xxupk_ms2_avgssscv_pts” in step11, are used as input in the MVA Spreadsheet Solution. The spreadsheet solutions are created for every sub-line separately. The data indicated in Table A.12 are calculated for Sub-line 1 as sample.

Column W shows the WIP level

Columns Te1, Te2, Te3, Te4 show the average processing times of the workstations smd eye insp, assembly, eye insp, test in sub-line1 respectively.

Ce1, Ce2, Ce3, Ce4 columns show the squared coefficient of variations of the workstations smd eye insp, assembly, eye insp, test in sub-line1 respectively.

Every row in the columns CT1, CT2, CT3 and CT4 shows the cycle times of the workstations smd eye insp, assembly, eye insp, test in sub-line1 respectively for the W value in this row.

CT column shows the cycle time and TH column shows the throughput of the sub-line

SG column shows the increment or decrement of the TH. The first "-1" value of this column shows the WIP level row provide the max throughput.

W1, W2, W3, W4 columns show the WIP level of the workstations smd eye insp, assembly, eye insp, test in sub-line1 respectively.

$CT_{hj}(W_h) = (te_{hj}{}^2/2)*(ce_{hj}{}^2-1)*TH(W_h-1)+(WIP_{hj}(W_h-1)+1)*te_{hj}$ **(1)**

Formulation of second row of CT1 column: =(((C3^2)/2)*(G3^2-1)*$P2) +(($R2+1)*C3). This formulation is copied to all rows of CT1, CT2, CT3 and CT4 columns.

$CT_h(W_h) = \sum_{J=1} CT_{hj}(W_h)$ **(2)**

Formulation of second row of CT column: =SUM(K3:N3). This formulation is copied to all rows of CT column.

$TH_h\ (W_h) = W\ /\ CT_h\ (W_h)$ **(3)**

Table A.12 MVA Spreadsheet Solution

W	TH^*_h	Te1	Te2	Te3	Te4	Ce1	Ce2	Ce3	Ce4	CT1	CT2	CT3	CT4	CT	TH	SG	W1	W2	W3	W4
0	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	0	0	0	0	0	0	1	0	0	0	0
1	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	2	2,37	2,44	1,9	8,76	0,1141	1	0,2	0,27	0,28	0,2
2	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	2,3	2,7	2,78	2,2	7,74	0,2585	1	0,6	0,7	0,72	0,6
3	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	2,7	3,3	3,43	2,6	9,41	0,3188	1	0,9	1,05	1,09	0,8
4	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	3,1	3,98	4,17	2,9	11,3	0,3557	1	1,1	1,41	1,48	1
5	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	3,5	4,73	5	3,3	13,3	0,3768	1	1,3	1,78	1,89	1,3
6	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	4	5,55	5,93	3,7	15,4	0,389	1	1,5	2,16	2,31	1,4
7	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	4,3	6,4	6,92	4	17,7	0,3964	1	1,7	2,54	2,74	1,6
8	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	4,7	7,28	7,96	4,3	19,9	0,4012	1	1,9	2,92	3,19	1,7
9	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	5	8,18	9,05	4,5	22,3	0,4045	1	2	3,31	3,66	1,8
10	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	5,3	9,09	10,2	4,8	24,6	0,4068	1	2,2	3,7	4,14	1,9
11	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	5,6	10	11,4	5	26,9	0,4086	1	2,3	4,09	4,64	2
12	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	5,8	10,9	12,6	5,1	29,3	0,4099	1	2,4	4,48	5,14	2,1
13	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6	11,9	13,8	5,3	31,6	0,4108	1	2,5	4,88	5,67	2,2
14	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,2	12,8	15,1	5,4	34	0,4116	1	2,5	5,27	6,2	2,2
15	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,3	13,7	16,4	5,5	36,4	0,4122	1	2,6	5,66	6,74	2,3
16	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,4	14,6	17,7	5,5	38,8	0,4126	1	2,7	6,04	7,3	2,3
17	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,6	15,6	19,1	5,6	41,2	0,413	1	2,7	6,43	7,87	2,3
18	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,7	16,5	20,4	5,7	43,6	0,4133	1	2,8	6,81	8,44	2,3
19	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,8	17,4	21,8	5,7	46	0,4135	1	2,8	7,18	9,03	2,4
20	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,8	18,3	23,3	5,8	48,4	0,4136	1	2,8	7,56	9,62	2,4
21	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,9	19,2	24,7	5,8	50,8	0,4138	1	2,9	7,92	10,2	2,4
22	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	6,9	20	26,2	5,8	53,2	0,4138	1	2,9	8,29	10,8	2,4
23	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7	20,9	27,7	5,9	55,6	0,4139	1	2,9	8,65	11,5	2,4
24	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7	21,7	29,2	5,9	58	0,414	1	2,9	9	12,1	2,4
25	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,1	22,6	30,8	5,9	60,4	0,414	1	2,9	9,35	12,7	2,4
26	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,1	23,4	32,3	5,9	62,8	0,414	1	2,9	9,69	13,4	2,4
27 **W_h^***	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,1	24,2	33,9	5,9	65,2	0,414	-1	3	10	14	2,5
28	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,1	25	35,5	5,9	67,6	0,414	-1	3	10,4	14,7	2,5
29	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,2	25,8	37,1	5,9	70,1	0,414	-1	3	10,7	15,4	2,5
30	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,2	26,6	38,7	5,9	72,5	0,414	-1	3	11	16	2,5
31	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,2	27,3	40,4	5,9	74,9	0,414	-1	3	11,3	16,7	2,5
32	0,5	2	2,4	2,4	1,9	0,1	0	0,1	0,3	7,2	28,1	42	5,9	77,3	0,414	-1	3	11,6	17,4	2,5

Formulation of second row of TH column: =A3/O3. This formulation is copied to all rows of TH column.

Formulation of second row of SG column: =SIGN(P4-P3). This formulation is copied to all rows of SG column.

$WIP_{hj} (W_h) = TH_h (W_h) * CT_{hj} (W_h)$ **(4)**

Formulation of second row of W1 column: =$P3*K3. This formulation is copied to all rows of W1, W2, W3 and W4 columns.

WIP Level of the first row that throughput reaches the target WIP level (TH^*_h) or SG column is "-1" where throughput reaches the maximum throughput is set as WIP cap (W_h^*) of the sub-line. WIP cap calculation using MVA Spreadsheet solution is made for every sub-line separately.

A.13 Distribution of WIP cap of the sub-lines to the product groups (W_{hg}^*)

<u>View:</u>
xxupk_ms2_grupwipcap

<u>Collecting Fields:</u>
Hat: Sub-line (h)
Grup: Group name (g)
Grup_wipcap: WIP-Cap of the group (W_{hg}^*)

<u>SQL:</u>

```
CREATE OR REPLACE VIEW xxupk_ms2_grupwipcap AS
SELECT
   y.hat,
   y.grup,
   w.hat_wipcap*b.hat_lot*
   grup.grup_yuk/hat.hat_yuk grup_wipcap
```

```
FROM
   xxupk_ms2_hatgrup y,
   xxupk_ms2_hatwipcap w,
   xxupk_ms2_hotlotsize b,

   (select
   t.hat, t.grup,
   sum(t.usage_rate_or_amount * i.malz_ort) grup_yuk
   from xxupk_ms2_kalempts t, xxupk_ms2_kalem i
   where t.assembly_item_id=i.inventory_item_id
   group by t.hat, t.grup) grup,
   --Group work load--

   (select t.hat, sum(t.usage_rate_or_amount * i.malz_ort) hat_yuk
   from xxupk_ms2_kalempts t, xxupk_ms2_kalem i
   where t.assembly_item_id=i.inventory_item_id
   group by t.hat) hat
   --Line work load--
   WHERE
   y.hat=w.hat(+) and
   y.hat=b.hat(+) and
   y.hat=grup.hat(+) and
   y.grup=grup.grup(+) and
   y.hat=hat.hat(+)
```

Derived Data:

Table A.13 Distribution of WIP Cap of the Sub-Lines to the Product Groups

HAT	GRUP	GRUP_WIPCAP
HAT3	FT-ST	1087,949757
HAT3	OP-LT	611,8458273
HAT1	KS_48	478,7280326
HAT2	SPS-DS	450,9808542
HAT4	SPS-KS	407,0299646
HAT1	EXT-KS	402,1016093
HAT2	CPU-DS	363,5961067
HAT1	KS_26	272,0318757
HAT2	BP-DS	199,6614765
HAT1	KS_38	197,1384825
HAT4	EVM	144,2075041
HAT3	NT	136,5917446
HAT2	UTL-DS	125,7615626
HAT3	IP	123,6126709
HAT4	GT	18,76253139

APPENDIX B

SQL PROGRAMS FOR DATA COLLECTION

B.1 SQL for Throughput Collection

B.1.1 Time bucket table

Table Name:

xxupk_ms2_thizleme_temp

Collecting Fields:

hr: Hours of the day

gr: Time buckets

SQL:

```
SELECT * FROM xxupk_ms2_thizleme_temp t
```

Derived Data:

Table B.1 Time Bucket Table

HR	GR
8	1
9	1
10	2
11	2
12	3
13	3
14	4
15	4
16	5
17	5

B.1.2 Throughput Collection

View Name:

xxupk_ms4_thizleme

Collecting Fields:

Hat: Sub-line name

Grup: Group name

Dt: Date of the transaction

Hr_gr: Time buckets

Dt_hr: Date of the transaction with hour

Th: Throughput

Weekday: Weekday of the date (to select the weekend data)

SQL:

```
SELECT
  sablon.hat,
  sablon.grup,
  sablon.calendar_date dt,
  sablon.gr hr_gr,
     decode( sablon.gr,0, to_date(to_char(sablon.calendar_date)||' '||'20:00:00','DD.MM.YY
HH24:MI:SS'),
    1, to_date(to_char(sablon.calendar_date)||' '||'10:00:00','DD.MM.YY HH24:MI:SS'),
    2,to_date(to_char(sablon.calendar_date)||' '||'12:00:00','DD.MM.YY HH24:MI:SS'),
    3,to_date(to_char(sablon.calendar_date)||' '||'14:00:00','DD.MM.YY HH24:MI:SS'),
    4,to_date(to_char(sablon.calendar_date)||' '||'16:00:00','DD.MM.YY HH24:MI:SS'),
    5,to_date(to_char(sablon.calendar_date)||' '||'17:30:00','DD.MM.YY HH24:MI:SS')) dt_hr,
  nvl(th.th,0) th,
  grup_ort.grup_orttuk target_th,
  to_number(to_char(sablon.calendar_date,'d')) weekday

FROM
    (select
      nvl(y.hat,'HAT5') hat,
      nvl(x.grup,'YENI') grup,
      hrgr.gr hrgr,
      trunc(t.creation_date) dt,
      sum(t.transaction_quantity) th
    from
      xxupk_ms2_kalem i,
```

```
      xxupk_ms2_grupkalem x,
      xxupk_ms2_hatgrup y,
      mtl_material_transactions t,
      mtl_transaction_types tip,
      xxupk_ms2_thizleme_temp hrgr
   where
      i.segment1=x.segment1(+) and
      x.grup=y.grup(+) and
      i.inventory_item_id=t.inventory_item_id and
      (t.transaction_date>sysdate-60 and
      t.transaction_date<sysdate) and
      t.transaction_type_id=tip.transaction_type_id and
      tip.transaction_type_name='WIP ürün tamamlama' and
      to_number(to_char(t.Creation_Date,'HH24'))=hrgr.hr
   group by
      nvl(y.hat,'HAT5'),
      nvl(x.grup,'YENI'),
      trunc(t.creation_date ),
      hrgr.gr) TH,
   --Wip completition transactions-


   (select
      t.calendar_date,
      gr.gr,b.hat ,b.grup
   from
      bom_calendar_dates t,
      (select a.gr from xxupk_ms2_thizleme_temp a
      group by a.gr) gr,
      xxupk_ms2_hatgrup b
    where
       t.calendar_date<sysdate and
       t.calendar_date>sysdate-60

    order by
       t.calendar_date, gr.gr) sablon,
    --Date template-
    xxupk_ms2_gruporttuk grup_ort

WHERE

  sablon.calendar_date=th.dt(+) and
  sablon.gr=th.hrgr(+) and
  sablon.hat=th.hat(+) and
  sablon.grup=th.grup(+) and
  to_number(to_char(sablon.calendar_date,'d')) not in (1,7) and
  sablon.gr<>0 and
  sablon.hat=grup_ort.hat(+) and
  sablon.grup=grup_ort.grup(+)

ORDER BY
  sablon.hat, sablon.calendar_date, sablon.gr
```

B.1.3 Grouping of Throughput by Line

View Name:

xxupk_ms4_thizleme_line

Collecting Fields:

Hat: Sub-line name

Dt: Date of the transaction

Hr_gr: Time buckets

Dt_hr: Date of the transaction with hour

Th: Throughput

Target_th: Target throughput

Weekday: Weekday of the date (to select the weekend data)

SQL:

```
CREATE OR REPLACE VIEW xxupk_ms4_thizleme_line AS
SELECT
   t.hat,t.dt,t.hr_gr,t.dt_hr,sum(t.th) th,
   sum(t.target_th) target_th,t.weekday
FROM
   xxupk_ms4_thizleme t
WHERE
   t.hat='HAT1'
GROUP BY
   t.hat,t.dt,t.hr_gr,t.dt_hr,t.weekday
```

Derived data for throughput:

Week, Push/Conwip and WIP Level values are added to data manually

Table B.2 Throughput of Sub-Line1

LINE	DT	HR_GR	DT_HR	TH	TARGET TH	WEEK	PUSH/ CONWIP	WIP LEVEL
HAT1	03.11.2009	1	03.11.2009 10:00:00	60	42	02.11.2009	PUSH	H
HAT1	03.11.2009	2	03.11.2009 12:00:00	45	42	02.11.2009	PUSH	H

Table B.2 (continued)

LINE	DT	HR_GR	DT_HR	TH	TARGET TH	WEEK	PUSH/ CONWIP	WIP LEVEL
HAT1	03.11.2009	3	03.11.2009 14:00:00	35	42	02.11.2009	PUSH	H
HAT1	03.11.2009	4	03.11.2009 16:00:00	19	42	02.11.2009	PUSH	H
HAT1	03.11.2009	5	03.11.2009 17:30:00	95	42	02.11.2009	PUSH	H
HAT1	04.11.2009	1	04.11.2009 10:00:00	0	42	02.11.2009	PUSH	H
HAT1	04.11.2009	2	04.11.2009 12:00:00	117	42	02.11.2009	PUSH	H
HAT1	04.11.2009	3	04.11.2009 14:00:00	15	42	02.11.2009	PUSH	H
HAT1	04.11.2009	4	04.11.2009 16:00:00	15	42	02.11.2009	PUSH	H
HAT1	04.11.2009	5	04.11.2009 17:30:00	28	42	02.11.2009	PUSH	H
HAT1	05.11.2009	1	05.11.2009 10:00:00	30	42	02.11.2009	PUSH	H
HAT1	05.11.2009	2	05.11.2009 12:00:00	30	42	02.11.2009	PUSH	H
HAT1	05.11.2009	3	05.11.2009 14:00:00	15	42	02.11.2009	PUSH	H
HAT1	05.11.2009	4	05.11.2009 16:00:00	15	42	02.11.2009	PUSH	H
HAT1	05.11.2009	5	05.11.2009 17:30:00	71	42	02.11.2009	PUSH	H
HAT1	06.11.2009	1	06.11.2009 10:00:00	15	42	02.11.2009	PUSH	H
HAT1	06.11.2009	2	06.11.2009 12:00:00	26	42	02.11.2009	PUSH	H
HAT1	06.11.2009	3	06.11.2009 14:00:00	0	42	02.11.2009	PUSH	H
HAT1	06.11.2009	4	06.11.2009 16:00:00	60	42	02.11.2009	PUSH	H
HAT1	06.11.2009	5	06.11.2009 17:30:00	25	42	02.11.2009	PUSH	H
HAT1	09.11.2009	1	09.11.2009 10:00:00	15	42	09.11.2009	PUSH	H
HAT1	09.11.2009	2	09.11.2009 12:00:00	15	42	09.11.2009	PUSH	H
HAT1	09.11.2009	3	09.11.2009 14:00:00	0	42	09.11.2009	PUSH	H
HAT1	09.11.2009	4	09.11.2009 16:00:00	0	42	09.11.2009	PUSH	H
HAT1	09.11.2009	5	09.11.2009 17:30:00	49	42	09.11.2009	PUSH	H
HAT1	10.11.2009	1	10.11.2009 10:00:00	0	42	09.11.2009	PUSH	H
HAT1	10.11.2009	2	10.11.2009 12:00:00	0	42	09.11.2009	PUSH	H
HAT1	10.11.2009	3	10.11.2009 14:00:00	18	42	09.11.2009	PUSH	H
HAT1	10.11.2009	4	10.11.2009 16:00:00	2	42	09.11.2009	PUSH	H
HAT1	10.11.2009	5	10.11.2009 17:30:00	0	42	09.11.2009	PUSH	H
HAT1	11.11.2009	1	11.11.2009 10:00:00	1	42	09.11.2009	PUSH	H
HAT1	11.11.2009	2	11.11.2009 12:00:00	0	42	09.11.2009	PUSH	H
HAT1	11.11.2009	3	11.11.2009 14:00:00	0	42	09.11.2009	PUSH	H
HAT1	11.11.2009	4	11.11.2009 16:00:00	0	42	09.11.2009	PUSH	H
HAT1	11.11.2009	5	11.11.2009 17:30:00	0	42	09.11.2009	PUSH	H
HAT1	12.11.2009	1	12.11.2009 10:00:00	0	42	09.11.2009	PUSH	H
HAT1	12.11.2009	2	12.11.2009 12:00:00	0	42	09.11.2009	PUSH	H
HAT1	12.11.2009	3	12.11.2009 14:00:00	0	42	09.11.2009	PUSH	H
HAT1	12.11.2009	4	12.11.2009 16:00:00	0	42	09.11.2009	PUSH	H
HAT1	12.11.2009	5	12.11.2009 17:30:00	191	42	09.11.2009	PUSH	H

Table B.2 (continued)

LINE	DT	HR_GR	DT_HR	TH	TARGET TH	WEEK	PUSH/ CONWIP	WIP LEVEL
HAT1	13.11.2009	1	13.11.2009 10:00:00	1	42	09.11.2009	PUSH	H
HAT1	13.11.2009	2	13.11.2009 12:00:00	22	42	09.11.2009	PUSH	H
HAT1	13.11.2009	3	13.11.2009 14:00:00	0	42	09.11.2009	PUSH	H
HAT1	13.11.2009	4	13.11.2009 16:00:00	0	42	09.11.2009	PUSH	H
HAT1	13.11.2009	5	13.11.2009 17:30:00	0	42	09.11.2009	PUSH	H
HAT1	16.11.2009	1	16.11.2009 10:00:00	15	42	16.11.2009	PUSH	H
HAT1	16.11.2009	2	16.11.2009 12:00:00	20	42	16.11.2009	PUSH	H
HAT1	16.11.2009	3	16.11.2009 14:00:00	0	42	16.11.2009	PUSH	H
HAT1	16.11.2009	4	16.11.2009 16:00:00	30	42	16.11.2009	PUSH	H
HAT1	16.11.2009	5	16.11.2009 17:30:00	108	42	16.11.2009	PUSH	H
HAT1	17.11.2009	1	17.11.2009 10:00:00	174	42	16.11.2009	PUSH	H
HAT1	17.11.2009	2	17.11.2009 12:00:00	30	42	16.11.2009	PUSH	H
HAT1	17.11.2009	3	17.11.2009 14:00:00	30	42	16.11.2009	PUSH	H
HAT1	17.11.2009	4	17.11.2009 16:00:00	0	42	16.11.2009	PUSH	H
HAT1	17.11.2009	5	17.11.2009 17:30:00	107	42	16.11.2009	PUSH	H
HAT1	18.11.2009	1	18.11.2009 10:00:00	31	42	16.11.2009	PUSH	H
HAT1	18.11.2009	2	18.11.2009 12:00:00	0	42	16.11.2009	PUSH	H
HAT1	18.11.2009	3	18.11.2009 14:00:00	90	42	16.11.2009	PUSH	H
HAT1	18.11.2009	4	18.11.2009 16:00:00	120	42	16.11.2009	PUSH	H
HAT1	18.11.2009	5	18.11.2009 17:30:00	49	42	16.11.2009	PUSH	H
HAT1	19.11.2009	1	19.11.2009 10:00:00	47	42	16.11.2009	PUSH	H
HAT1	19.11.2009	2	19.11.2009 12:00:00	15	42	16.11.2009	PUSH	H
HAT1	19.11.2009	3	19.11.2009 14:00:00	105	42	16.11.2009	PUSH	H
HAT1	19.11.2009	4	19.11.2009 16:00:00	24	42	16.11.2009	PUSH	H
HAT1	19.11.2009	5	19.11.2009 17:30:00	0	42	16.11.2009	PUSH	H
HAT1	20.11.2009	1	20.11.2009 10:00:00	15	42	16.11.2009	PUSH	H
HAT1	20.11.2009	2	20.11.2009 12:00:00	171	42	16.11.2009	PUSH	H
HAT1	20.11.2009	3	20.11.2009 14:00:00	5	42	16.11.2009	PUSH	H
HAT1	20.11.2009	4	20.11.2009 16:00:00	45	42	16.11.2009	PUSH	H
HAT1	20.11.2009	5	20.11.2009 17:30:00	47	42	16.11.2009	PUSH	H
HAT1	23.11.2009	1	23.11.2009 10:00:00	0	42	23.11.2009	PUSH	H
HAT1	23.11.2009	2	23.11.2009 12:00:00	15	42	23.11.2009	PUSH	H
HAT1	23.11.2009	3	23.11.2009 14:00:00	15	42	23.11.2009	PUSH	H
HAT1	23.11.2009	4	23.11.2009 16:00:00	63	42	23.11.2009	PUSH	H
HAT1	23.11.2009	5	23.11.2009 17:30:00	25	42	23.11.2009	PUSH	H
HAT1	24.11.2009	1	24.11.2009 10:00:00	15	42	23.11.2009	PUSH	H
HAT1	24.11.2009	2	24.11.2009 12:00:00	30	42	23.11.2009	PUSH	H
HAT1	24.11.2009	3	24.11.2009 14:00:00	30	42	23.11.2009	PUSH	H

Table B.2 (continued)

LINE	DT	HR_GR	DT_HR	TH	TARGET TH	WEEK	PUSH/ CONWIP	WIP LEVEL
HAT1	24.11.2009	4	24.11.2009 16:00:00	22	42	23.11.2009	PUSH	H
HAT1	24.11.2009	5	24.11.2009 17:30:00	0	42	23.11.2009	PUSH	H
HAT1	25.11.2009	1	25.11.2009 10:00:00	151	42	23.11.2009	PUSH	H
HAT1	25.11.2009	2	25.11.2009 12:00:00	15	42	23.11.2009	PUSH	H
HAT1	25.11.2009	3	25.11.2009 14:00:00	30	42	23.11.2009	PUSH	H
HAT1	25.11.2009	4	25.11.2009 16:00:00	15	42	23.11.2009	PUSH	H
HAT1	25.11.2009	5	25.11.2009 17:30:00	15	42	23.11.2009	PUSH	H
HAT1	26.11.2009	1	26.11.2009 10:00:00	15	42	23.11.2009	PUSH	H
HAT1	26.11.2009	2	26.11.2009 12:00:00	15	42	23.11.2009	PUSH	H
HAT1	26.11.2009	3	26.11.2009 14:00:00	0	42	23.11.2009	PUSH	H
HAT1	26.11.2009	4	26.11.2009 16:00:00	0	42	23.11.2009	PUSH	H
HAT1	26.11.2009	5	26.11.2009 17:30:00	0	42	23.11.2009	PUSH	H
HAT1	27.11.2009	1	27.11.2009 10:00:00	0	42	23.11.2009	PUSH	H
HAT1	27.11.2009	2	27.11.2009 12:00:00	0	42	23.11.2009	PUSH	H
HAT1	27.11.2009	3	27.11.2009 14:00:00	0	42	23.11.2009	PUSH	H
HAT1	27.11.2009	4	27.11.2009 16:00:00	0	42	23.11.2009	PUSH	H
HAT1	27.11.2009	5	27.11.2009 17:30:00	0	42	23.11.2009	PUSH	H
HAT1	30.11.2009	1	30.11.2009 10:00:00	0	42	30.11.2009	PUSH	H
HAT1	30.11.2009	2	30.11.2009 12:00:00	0	42	30.11.2009	PUSH	H
HAT1	30.11.2009	3	30.11.2009 14:00:00	0	42	30.11.2009	PUSH	H
HAT1	30.11.2009	4	30.11.2009 16:00:00	0	42	30.11.2009	PUSH	H
HAT1	30.11.2009	5	30.11.2009 17:30:00	0	42	30.11.2009	PUSH	H
HAT1	01.12.2009	1	01.12.2009 10:00:00	60	42	30.11.2009	PUSH	H
HAT1	01.12.2009	2	01.12.2009 12:00:00	0	42	30.11.2009	PUSH	H
HAT1	01.12.2009	3	01.12.2009 14:00:00	0	42	30.11.2009	PUSH	H
HAT1	01.12.2009	4	01.12.2009 16:00:00	24	42	30.11.2009	PUSH	H
HAT1	01.12.2009	5	01.12.2009 17:30:00	42	42	30.11.2009	PUSH	H
HAT1	02.12.2009	1	02.12.2009 10:00:00	89	42	30.11.2009	PUSH	H
HAT1	02.12.2009	2	02.12.2009 12:00:00	90	42	30.11.2009	PUSH	H
HAT1	02.12.2009	3	02.12.2009 14:00:00	30	42	30.11.2009	PUSH	H
HAT1	02.12.2009	4	02.12.2009 16:00:00	63	42	30.11.2009	PUSH	H
HAT1	02.12.2009	5	02.12.2009 17:30:00	60	42	30.11.2009	PUSH	H
HAT1	03.12.2009	1	03.12.2009 10:00:00	34	42	30.11.2009	PUSH	L
HAT1	03.12.2009	2	03.12.2009 12:00:00	96	42	30.11.2009	PUSH	L
HAT1	03.12.2009	3	03.12.2009 14:00:00	30	42	30.11.2009	PUSH	L
HAT1	03.12.2009	4	03.12.2009 16:00:00	62	42	30.11.2009	PUSH	L

Table B.2 (continued)

LINE	DT	HR_GR	DT_HR	TH	TARGET TH	WEEK	PUSH/ CONWIP	WIP LEVEL
HAT1	03.12.2009	5	03.12.2009 17:30:00	40	42	30.11.2009	PUSH	L
HAT1	04.12.2009	1	04.12.2009 10:00:00	85	42	30.11.2009	PUSH	L
HAT1	04.12.2009	2	04.12.2009 12:00:00	75	42	30.11.2009	PUSH	L
HAT1	04.12.2009	3	04.12.2009 14:00:00	15	42	30.11.2009	PUSH	L
HAT1	04.12.2009	4	04.12.2009 16:00:00	75	42	30.11.2009	PUSH	L
HAT1	04.12.2009	5	04.12.2009 17:30:00	44	42	30.11.2009	PUSH	L
HAT1	07.12.2009	1	07.12.2009 10:00:00	31	42	07.12.2009	CONWIP	L
HAT1	07.12.2009	2	07.12.2009 12:00:00	15	42	07.12.2009	CONWIP	L
HAT1	07.12.2009	3	07.12.2009 14:00:00	15	42	07.12.2009	CONWIP	L
HAT1	07.12.2009	4	07.12.2009 16:00:00	7	42	07.12.2009	CONWIP	L
HAT1	07.12.2009	5	07.12.2009 17:30:00	17	42	07.12.2009	CONWIP	L
HAT1	08.12.2009	1	08.12.2009 10:00:00	30	42	07.12.2009	CONWIP	L
HAT1	08.12.2009	2	08.12.2009 12:00:00	30	42	07.12.2009	CONWIP	L
HAT1	08.12.2009	3	08.12.2009 14:00:00	15	42	07.12.2009	CONWIP	L
HAT1	08.12.2009	4	08.12.2009 16:00:00	30	42	07.12.2009	CONWIP	L
HAT1	08.12.2009	5	08.12.2009 17:30:00	112	42	07.12.2009	CONWIP	L
HAT1	09.12.2009	1	09.12.2009 10:00:00	45	42	07.12.2009	CONWIP	L
HAT1	09.12.2009	2	09.12.2009 12:00:00	15	42	07.12.2009	CONWIP	L
HAT1	09.12.2009	3	09.12.2009 14:00:00	75	42	07.12.2009	CONWIP	L
HAT1	09.12.2009	4	09.12.2009 16:00:00	15	42	07.12.2009	CONWIP	L
HAT1	09.12.2009	5	09.12.2009 17:30:00	0	42	07.12.2009	CONWIP	L
HAT1	10.12.2009	1	10.12.2009 10:00:00	55	42	07.12.2009	CONWIP	L
HAT1	10.12.2009	2	10.12.2009 12:00:00	30	42	07.12.2009	CONWIP	L
HAT1	10.12.2009	3	10.12.2009 14:00:00	45	42	07.12.2009	CONWIP	L
HAT1	10.12.2009	4	10.12.2009 16:00:00	57	42	07.12.2009	CONWIP	L
HAT1	10.12.2009	5	10.12.2009 17:30:00	70	42	07.12.2009	CONWIP	L
HAT1	11.12.2009	1	11.12.2009 10:00:00	64	42	07.12.2009	CONWIP	L
HAT1	11.12.2009	2	11.12.2009 12:00:00	15	42	07.12.2009	CONWIP	L
HAT1	11.12.2009	3	11.12.2009 14:00:00	15	42	07.12.2009	CONWIP	L
HAT1	11.12.2009	4	11.12.2009 16:00:00	120	42	07.12.2009	CONWIP	L
HAT1	11.12.2009	5	11.12.2009 17:30:00	22	42	07.12.2009	CONWIP	L
HAT1	14.12.2009	1	14.12.2009 10:00:00	0	42	14.12.2009	CONWIP	L
HAT1	14.12.2009	2	14.12.2009 12:00:00	0	42	14.12.2009	CONWIP	L
HAT1	14.12.2009	3	14.12.2009 14:00:00	0	42	14.12.2009	CONWIP	L
HAT1	14.12.2009	4	14.12.2009 16:00:00	25	42	14.12.2009	CONWIP	L
HAT1	14.12.2009	5	14.12.2009 17:30:00	35	42	14.12.2009	CONWIP	L

Table B.2 (continued)

LINE	DT	HR_GR	DT_HR	TH	TARGET TH	WEEK	PUSH/ CONWIP	WIP LEVEL
HAT1	15.12.2009	1	15.12.2009 10:00:00	50	42	14.12.2009	CONWIP	L
HAT1	15.12.2009	2	15.12.2009 12:00:00	0	42	14.12.2009	CONWIP	L
HAT1	15.12.2009	3	15.12.2009 14:00:00	15	42	14.12.2009	CONWIP	L
HAT1	15.12.2009	4	15.12.2009 16:00:00	30	42	14.12.2009	CONWIP	L
HAT1	15.12.2009	5	15.12.2009 17:30:00	0	42	14.12.2009	CONWIP	L
HAT1	16.12.2009	1	16.12.2009 10:00:00	45	42	14.12.2009	CONWIP	H
HAT1	16.12.2009	2	16.12.2009 12:00:00	45	42	14.12.2009	CONWIP	H
HAT1	16.12.2009	3	16.12.2009 14:00:00	30	42	14.12.2009	CONWIP	H
HAT1	16.12.2009	4	16.12.2009 16:00:00	15	42	14.12.2009	CONWIP	H
HAT1	16.12.2009	5	16.12.2009 17:30:00	44	42	14.12.2009	CONWIP	H
HAT1	17.12.2009	1	17.12.2009 10:00:00	30	42	14.12.2009	CONWIP	H
HAT1	17.12.2009	2	17.12.2009 12:00:00	45	42	14.12.2009	CONWIP	H
HAT1	17.12.2009	3	17.12.2009 14:00:00	15	42	14.12.2009	CONWIP	H
HAT1	17.12.2009	4	17.12.2009 16:00:00	60	42	14.12.2009	CONWIP	H
HAT1	17.12.2009	5	17.12.2009 17:30:00	19	42	14.12.2009	CONWIP	H
HAT1	18.12.2009	1	18.12.2009 10:00:00	55	42	14.12.2009	CONWIP	H
HAT1	18.12.2009	2	18.12.2009 12:00:00	15	42	14.12.2009	CONWIP	H
HAT1	18.12.2009	3	18.12.2009 14:00:00	0	42	14.12.2009	CONWIP	H
HAT1	18.12.2009	4	18.12.2009 16:00:00	25	42	14.12.2009	CONWIP	H
HAT1	18.12.2009	5	18.12.2009 17:30:00	0	42	14.12.2009	CONWIP	H
HAT1	21.12.2009	1	21.12.2009 10:00:00	40	42	21.12.2009	CONWIP	H
HAT1	21.12.2009	2	21.12.2009 12:00:00	30	42	21.12.2009	CONWIP	H
HAT1	21.12.2009	3	21.12.2009 14:00:00	45	42	21.12.2009	CONWIP	H
HAT1	21.12.2009	4	21.12.2009 16:00:00	36	42	21.12.2009	CONWIP	H
HAT1	21.12.2009	5	21.12.2009 17:30:00	42	42	21.12.2009	CONWIP	H
HAT1	22.12.2009	1	22.12.2009 10:00:00	30	42	21.12.2009	CONWIP	H
HAT1	22.12.2009	2	22.12.2009 12:00:00	30	42	21.12.2009	CONWIP	H
HAT1	22.12.2009	3	22.12.2009 14:00:00	30	42	21.12.2009	CONWIP	H
HAT1	22.12.2009	4	22.12.2009 16:00:00	27	42	21.12.2009	CONWIP	H
HAT1	22.12.2009	5	22.12.2009 17:30:00	15	42	21.12.2009	CONWIP	H
HAT1	23.12.2009	1	23.12.2009 10:00:00	30	42	21.12.2009	CONWIP	H
HAT1	23.12.2009	2	23.12.2009 12:00:00	48	42	21.12.2009	CONWIP	H
HAT1	23.12.2009	3	23.12.2009 14:00:00	0	42	21.12.2009	CONWIP	H
HAT1	23.12.2009	4	23.12.2009 16:00:00	60	42	21.12.2009	CONWIP	H
HAT1	23.12.2009	5	23.12.2009 17:30:00	111	42	21.12.2009	CONWIP	H
HAT1	24.12.2009	1	24.12.2009 10:00:00	16	42	21.12.2009	CONWIP	H

Table B.2 (continued)

HAT1	24.12.2009	2	24.12.2009 12:00:00	30	42	21.12.2009	CONWIP	H
HAT1	24.12.2009	3	24.12.2009 14:00:00	0	42	21.12.2009	CONWIP	H
HAT1	24.12.2009	4	24.12.2009 16:00:00	0	42	21.12.2009	CONWIP	H
HAT1	24.12.2009	5	24.12.2009 17:30:00	30	42	21.12.2009	CONWIP	H
HAT1	25.12.2009	1	25.12.2009 10:00:00	147	42	21.12.2009	CONWIP	H
HAT1	25.12.2009	2	25.12.2009 12:00:00	15	42	21.12.2009	CONWIP	H
HAT1	25.12.2009	3	25.12.2009 14:00:00	30	42	21.12.2009	CONWIP	H
HAT1	25.12.2009	4	25.12.2009 16:00:00	15	42	21.12.2009	CONWIP	H
HAT1	25.12.2009	5	25.12.2009 17:30:00	30	42	21.12.2009	CONWIP	H
HAT1	28.12.2009	1	28.12.2009 10:00:00	35	42	28.12.2009	CONWIP	H
HAT1	28.12.2009	2	28.12.2009 12:00:00	45	42	28.12.2009	CONWIP	H
HAT1	28.12.2009	3	28.12.2009 14:00:00	15	42	28.12.2009	CONWIP	H
HAT1	28.12.2009	4	28.12.2009 16:00:00	30	42	28.12.2009	CONWIP	H
HAT1	28.12.2009	5	28.12.2009 17:30:00	0	42	28.12.2009	CONWIP	H
HAT1	29.12.2009	1	29.12.2009 10:00:00	100	42	28.12.2009	CONWIP	H
HAT1	29.12.2009	2	29.12.2009 12:00:00	30	42	28.12.2009	CONWIP	H
HAT1	29.12.2009	3	29.12.2009 14:00:00	30	42	28.12.2009	CONWIP	H
HAT1	29.12.2009	4	29.12.2009 16:00:00	98	42	28.12.2009	CONWIP	H
HAT1	29.12.2009	5	29.12.2009 17:30:00	90	42	28.12.2009	CONWIP	H
HAT1	30.12.2009	1	30.12.2009 10:00:00	157	42	28.12.2009	CONWIP	H
HAT1	30.12.2009	2	30.12.2009 12:00:00	30	42	28.12.2009	CONWIP	H
HAT1	30.12.2009	3	30.12.2009 14:00:00	110	42	28.12.2009	CONWIP	H
HAT1	30.12.2009	4	30.12.2009 16:00:00	60	42	28.12.2009	CONWIP	H
HAT1	30.12.2009	5	30.12.2009 17:30:00	15	42	28.12.2009	CONWIP	H

B.2 SQL for WIP Collection

B.2.1 Current WIP Status SQL

View Name:

xxupk_ms4_wipizleme

Collecting Fields:

Hat: Sub-line name

Grup: Group Name

Wip: WIP

WIP cap: WIP cap

SQL:

```
SELECT
   nvl(y.hat,'HAT5') hat,
   nvl(x.grup,'YENI')grup,
   sum(op.quantity_in_queue)+sum(op.quantity_waiting_to_move) wip,
   gwipcap.grup_wipcap wipcap
FROM
   xxupk_ms2_kalem t,
   xxupk_ms2_grupkalem x,
   xxupk_ms2_hatgrup y,
   xxupk_ms2_grupwipcap gwipcap,
      (select
      msi.inventory_item_id,
      we.wip_entity_id,
      wo.operation_seq_num,
      dep.department_code,
      wo.description op_dec,
      wo.scheduled_quantity,
      wo.quantity_in_queue,
      wo.quantity_waiting_to_move,
      wo.quantity_completed
      FROM
      wip_operations wo,
      wip_entities we,
      wip_discrete_jobs wdj,
      bom_departments dep,
      mtl_system_items_b msi
      where
      wdj.status_type in (1,3) and
      we.wip_entity_id=wdj.wip_entity_id and
      wdj.primary_item_id=msi.inventory_item_id and
      msi.organization_id=83 and
      wdj.wip_entity_id=wo.wip_entity_id(+) and
      wo.department_id=dep.department_id(+)
      order by
      we.wip_entity_name,
      wo.operation_seq_num) op
WHERE
   t.segment1=x.segment1(+) and
   x.grup=y.grup(+) and
   y.hat=gwipcap.hat(+) and
   y.grup=gwipcap.grup(+) and
   t.inventory_item_id=op.inventory_item_id(+)
```

```
GROUP BY
   nvl(y.hat,'HAT5'),
   nvl(x.grup,'YENI'),
   gwipcap.grup_wipcap
```

B.2.2 Creation of WIP history table SQL

The wip information in view “xxupk_ms4_wipizleme” is inserted into history table with current date via the following job. Job is set as running at every two hours.

```
begin
  sys.dbms_job.submit(job => :job,
  what => 'INSERT INTO XXUPK_MS4_WIPIZLEME_HISTGRUP
             SELECT SYSDATE TARIH, T.*  FROM
             XUPK_MS4_WIPIZLEME T;
             COMMIT;',
  next_date => to_date('04-12-2009 19:01:29', 'dd-mm-yyyy hh24:mi:ss'),
  interval => 'SYSDATE+120/1440');
  commit;
end;
```

B.2.3 Grouping of WIP Values by Line

View Name:

xxupk_ms4_wipizleme_histline

Collecting Fields:

Hat: Sub-line name

Tarih: Data collection date

Wip: Line WIP

WIP cap: Line wipcap

SQL:

```
CREATE OR REPLACE VIEW xxupk_ms4_wipizleme_histline AS
SELECT
   t.hat,t.tarih,sum(t.wip) wip,sum(t.wipcap) wipcap
   from xxupk_ms4_wipizleme_histgrup t
group by
   t.hat,t.tarih
```

Derived data for WIP

Week and Push/Conwip values are added manually

Table B.3 WIP of Sub-Line1

HAT	TARIH	WIP	WIP CAP	WEEK	PUSH/ CONWIP
HAT1	02.11.2009 09:00:00	1861	1350	02.11.2009	PUSH
HAT1	02.11.2009 11:00:00	1846	1350	02.11.2009	PUSH
HAT1	02.11.2009 13:00:00	1831	1350	02.11.2009	PUSH
HAT1	02.11.2009 15:00:00	1801	1350	02.11.2009	PUSH
HAT1	02.11.2009 17:00:00	1801	1350	02.11.2009	PUSH
HAT1	11.11.2009 15:00:00	1889	1350	09.11.2009	PUSH
HAT1	11.11.2009 17:00:00	1845	1350	09.11.2009	PUSH
HAT1	12.11.2009 09:00:00	2065	1350	09.11.2009	PUSH
HAT1	12.11.2009 11:00:00	1970	1350	09.11.2009	PUSH
HAT1	12.11.2009 13:00:00	1910	1350	09.11.2009	PUSH
HAT1	12.11.2009 15:00:00	1835	1350	09.11.2009	PUSH
HAT1	06.11.2009 13:00:00	1548	1350	02.11.2009	PUSH
HAT1	06.11.2009 15:00:00	1512	1350	02.11.2009	PUSH
HAT1	06.11.2009 17:00:00	1480	1350	02.11.2009	PUSH
HAT1	09.11.2009 09:00:00	1840	1350	09.11.2009	PUSH
HAT1	09.11.2009 11:00:00	1816	1350	09.11.2009	PUSH
HAT1	09.11.2009 13:00:00	1946	1350	09.11.2009	PUSH
HAT1	09.11.2009 15:00:00	1916	1350	09.11.2009	PUSH
HAT1	09.11.2009 17:00:00	1886	1350	09.11.2009	PUSH
HAT1	10.11.2009 09:00:00	2037	1350	09.11.2009	PUSH
HAT1	10.11.2009 11:00:00	2037	1350	09.11.2009	PUSH
HAT1	10.11.2009 13:00:00	2037	1350	09.11.2009	PUSH
HAT1	10.11.2009 15:00:00	1992	1350	09.11.2009	PUSH
HAT1	03.11.2009 09:00:00	1786	1350	02.11.2009	PUSH

Table B.3 (continued)

HAT	TARIH	WIP	WIP CAP	WEEK	PUSH/ CONWIP
HAT1	10.11.2009 17:00:00	1949	1350	09.11.2009	PUSH
HAT1	11.11.2009 09:00:00	1949	1350	09.11.2009	PUSH
HAT1	11.11.2009 11:00:00	1949	1350	09.11.2009	PUSH
HAT1	11.11.2009 13:00:00	1889	1350	09.11.2009	PUSH
HAT1	12.11.2009 17:00:00	1775	1350	09.11.2009	PUSH
HAT1	13.11.2009 09:00:00	1822	1350	09.11.2009	PUSH
HAT1	13.11.2009 11:00:00	1807	1350	09.11.2009	PUSH
HAT1	13.11.2009 13:00:00	1792	1350	09.11.2009	PUSH
HAT1	13.11.2009 15:00:00	1705	1350	09.11.2009	PUSH
HAT1	13.11.2009 17:00:00	1640	1350	09.11.2009	PUSH
HAT1	16.11.2009 09:00:00	2123	1350	16.11.2009	PUSH
HAT1	16.11.2009 11:00:00	2093	1350	16.11.2009	PUSH
HAT1	16.11.2009 13:00:00	2088	1350	16.11.2009	PUSH
HAT1	16.11.2009 15:00:00	2058	1350	16.11.2009	PUSH
HAT1	16.11.2009 17:00:00	2028	1350	16.11.2009	PUSH
HAT1	17.11.2009 09:00:00	1776	1350	16.11.2009	PUSH
HAT1	17.11.2009 11:00:00	1776	1350	16.11.2009	PUSH
HAT1	17.11.2009 13:00:00	1746	1350	16.11.2009	PUSH
HAT1	17.11.2009 15:00:00	1716	1350	16.11.2009	PUSH
HAT1	17.11.2009 17:00:00	1609	1350	16.11.2009	PUSH
HAT1	18.11.2009 09:00:00	1699	1350	16.11.2009	PUSH
HAT1	18.11.2009 11:00:00	1713	1350	16.11.2009	PUSH
HAT1	18.11.2009 13:00:00	1623	1350	16.11.2009	PUSH
HAT1	18.11.2009 15:00:00	1623	1350	16.11.2009	PUSH
HAT1	18.11.2009 17:00:00	1454	1350	16.11.2009	PUSH
HAT1	19.11.2009 09:00:00	1614	1350	16.11.2009	PUSH
HAT1	19.11.2009 11:00:00	1552	1350	16.11.2009	PUSH
HAT1	19.11.2009 13:00:00	1552	1350	16.11.2009	PUSH
HAT1	19.11.2009 15:00:00	1423	1350	16.11.2009	PUSH
HAT1	19.11.2009 17:00:00	1423	1350	16.11.2009	PUSH
HAT1	20.11.2009 09:00:00	1408	1350	16.11.2009	PUSH
HAT1	20.11.2009 11:00:00	1408	1350	16.11.2009	PUSH
HAT1	20.11.2009 13:00:00	1222	1350	16.11.2009	PUSH
HAT1	20.11.2009 15:00:00	1201	1350	16.11.2009	PUSH
HAT1	20.11.2009 17:00:00	1109	1350	16.11.2009	PUSH
HAT1	23.11.2009 09:00:00	1669	1350	23.11.2009	PUSH

Table B.3 (continued)

HAT	TARIH	WIP	WIP CAP	WEEK	PUSH/ CONWIP
HAT1	23.11.2009 11:00:00	1669	1350	23.11.2009	PUSH
HAT1	23.11.2009 13:00:00	1639	1350	23.11.2009	PUSH
HAT1	23.11.2009 15:00:00	1624	1350	23.11.2009	PUSH
HAT1	23.11.2009 17:00:00	1551	1350	23.11.2009	PUSH
HAT1	24.11.2009 09:00:02	1549	1350	23.11.2009	PUSH
HAT1	24.11.2009 11:00:03	1519	1350	23.11.2009	PUSH
HAT1	24.11.2009 13:00:06	1504	1350	23.11.2009	PUSH
HAT1	24.11.2009 15:00:06	1754	1350	23.11.2009	PUSH
HAT1	24.11.2009 17:00:07	1754	1350	23.11.2009	PUSH
HAT1	25.11.2009 09:00:27	1603	1350	23.11.2009	PUSH
HAT1	25.11.2009 11:00:29	1588	1350	23.11.2009	PUSH
HAT1	25.11.2009 13:00:32	1628	1350	23.11.2009	PUSH
HAT1	25.11.2009 15:00:37	1598	1350	23.11.2009	PUSH
HAT1	25.11.2009 17:00:40	1568	1350	23.11.2009	PUSH
HAT1	26.11.2009 09:01:01	1553	1350	23.11.2009	PUSH
HAT1	26.11.2009 11:01:06	1538	1350	23.11.2009	PUSH
HAT1	26.11.2009 13:01:08	1538	1350	23.11.2009	PUSH
HAT1	26.11.2009 15:01:10	1538	1350	23.11.2009	PUSH
HAT1	26.11.2009 17:01:12	1538	1350	23.11.2009	PUSH
HAT1	27.11.2009 09:01:31	1538	1350	23.11.2009	PUSH
HAT1	27.11.2009 11:01:33	1538	1350	23.11.2009	PUSH
HAT1	27.11.2009 13:01:35	1538	1350	23.11.2009	PUSH
HAT1	27.11.2009 15:01:37	1538	1350	23.11.2009	PUSH
HAT1	27.11.2009 17:01:40	1538	1350	23.11.2009	PUSH
HAT1	01.12.2009 11:00:02	1478	1350	30.11.2009	PUSH
HAT1	01.12.2009 13:00:06	1478	1350	30.11.2009	PUSH
HAT1	01.12.2009 15:00:06	1478	1350	30.11.2009	PUSH
HAT1	01.12.2009 17:00:10	1412	1350	30.11.2009	PUSH
HAT1	02.12.2009 09:00:31	1338	1350	30.11.2009	PUSH
HAT1	02.12.2009 11:00:36	1473	1350	30.11.2009	PUSH
HAT1	02.12.2009 13:00:38	1443	1350	30.11.2009	PUSH
HAT1	02.12.2009 15:00:39	1383	1350	30.11.2009	PUSH
HAT1	02.12.2009 17:00:41	1290	1350	30.11.2009	PUSH
HAT1	03.12.2009 09:01:01	1271	1350	30.11.2009	PUSH
HAT1	03.12.2009 11:01:02	1181	1350	30.11.2009	PUSH
HAT1	03.12.2009 13:01:05	1145	1350	30.11.2009	PUSH
HAT1	03.12.2009 15:01:06	1100	1350	30.11.2009	PUSH
HAT1	03.12.2009 17:01:07	1028	1350	30.11.2009	PUSH

Table B.3 (continued)

HAT	TARIH	WIP	WIP CAP	WEEK	PUSH/ CONWIP
HAT1	04.12.2009 09:01:28	983	1350	30.11.2009	PUSH
HAT1	04.12.2009 11:01:29	913	1350	30.11.2009	PUSH
HAT1	04.12.2009 13:01:28	868	1350	30.11.2009	PUSH
HAT1	04.12.2009 15:01:29	808	1350	30.11.2009	PUSH
HAT1	04.12.2009 17:01:30	876	1350	30.11.2009	PUSH
HAT1	07.12.2009 09:02:52	860	1350	07.12.2009	CONWIP
HAT1	07.12.2009 11:02:55	930	1350	07.12.2009	CONWIP
HAT1	07.12.2009 13:02:58	915	1350	07.12.2009	CONWIP
HAT1	07.12.2009 15:02:59	893	1350	07.12.2009	CONWIP
HAT1	07.12.2009 17:03:01	876	1350	07.12.2009	CONWIP
HAT1	08.12.2009 09:03:23	861	1350	07.12.2009	CONWIP
HAT1	08.12.2009 11:03:23	831	1350	07.12.2009	CONWIP
HAT1	08.12.2009 13:03:26	1012	1350	07.12.2009	CONWIP
HAT1	08.12.2009 15:03:27	982	1350	07.12.2009	CONWIP
HAT1	08.12.2009 17:03:27	870	1350	07.12.2009	CONWIP
HAT1	09.12.2009 09:03:48	826	1350	07.12.2009	CONWIP
HAT1	09.12.2009 11:03:51	810	1350	07.12.2009	CONWIP
HAT1	09.12.2009 13:03:52	927	1350	07.12.2009	CONWIP
HAT1	09.12.2009 15:03:52	912	1350	07.12.2009	CONWIP
HAT1	09.12.2009 17:03:57	912	1350	07.12.2009	CONWIP
HAT1	10.12.2009 09:04:16	857	1350	07.12.2009	CONWIP
HAT1	10.12.2009 11:04:21	857	1350	07.12.2009	CONWIP
HAT1	10.12.2009 13:04:24	951	1350	07.12.2009	CONWIP
HAT1	10.12.2009 15:04:26	849	1350	07.12.2009	CONWIP
HAT1	10.12.2009 17:04:25	779	1350	07.12.2009	CONWIP
HAT1	11.12.2009 09:04:45	730	1350	07.12.2009	CONWIP
HAT1	11.12.2009 11:04:48	700	1350	07.12.2009	CONWIP
HAT1	11.12.2009 13:04:50	929	1350	07.12.2009	CONWIP
HAT1	11.12.2009 15:04:50	854	1350	07.12.2009	CONWIP
HAT1	11.12.2009 17:04:51	772	1350	07.12.2009	CONWIP
HAT1	14.12.2009 09:34:49	772	1350	14.12.2009	CONWIP
HAT1	14.12.2009 11:34:50	772	1350	14.12.2009	CONWIP
HAT1	14.12.2009 13:34:53	772	1350	14.12.2009	CONWIP
HAT1	14.12.2009 15:34:54	1055	1350	14.12.2009	CONWIP
HAT1	14.12.2009 17:34:58	1020	1350	14.12.2009	CONWIP
HAT1	15.12.2009 09:35:21	990	1350	14.12.2009	CONWIP
HAT1	15.12.2009 11:35:25	970	1350	14.12.2009	CONWIP
HAT1	15.12.2009 13:35:28	970	1350	14.12.2009	CONWIP

Table B.3 (continued)

HAT	TARIH	WIP	WIP CAP	WEEK	PUSH/ CONWIP
HAT1	15.12.2009 15:35:30	1171	1350	14.12.2009	CONWIP
HAT1	15.12.2009 17:35:30	1156	1350	14.12.2009	CONWIP
HAT1	16.12.2009 09:35:54	1111	1350	14.12.2009	CONWIP
HAT1	16.12.2009 11:35:55	1348	1350	14.12.2009	CONWIP
HAT1	16.12.2009 13:35:58	1318	1350	14.12.2009	CONWIP
HAT1	16.12.2009 15:36:02	1273	1350	14.12.2009	CONWIP
HAT1	16.12.2009 17:36:06	1229	1350	14.12.2009	CONWIP
HAT1	17.12.2009 09:36:26	1214	1350	14.12.2009	CONWIP
HAT1	17.12.2009 11:36:28	1154	1350	14.12.2009	CONWIP
HAT1	17.12.2009 13:36:31	1209	1350	14.12.2009	CONWIP
HAT1	17.12.2009 15:36:32	1149	1350	14.12.2009	CONWIP
HAT1	17.12.2009 17:36:32	1130	1350	14.12.2009	CONWIP
HAT1	18.12.2009 10:07:37	1268	1350	14.12.2009	CONWIP
HAT1	18.12.2009 12:07:36	1253	1350	14.12.2009	CONWIP
HAT1	18.12.2009 14:07:40	1253	1350	14.12.2009	CONWIP
HAT1	18.12.2009 16:07:43	1228	1350	14.12.2009	CONWIP
HAT1	21.12.2009 10:09:03	1188	1350	21.12.2009	CONWIP
HAT1	21.12.2009 12:09:10	1158	1350	21.12.2009	CONWIP
HAT1	21.12.2009 14:09:06	1443	1350	21.12.2009	CONWIP
HAT1	21.12.2009 16:09:08	1407	1350	21.12.2009	CONWIP
HAT1	22.12.2009 10:09:29	1335	1350	21.12.2009	CONWIP
HAT1	22.12.2009 12:09:29	1355	1350	21.12.2009	CONWIP
HAT1	22.12.2009 14:09:32	1325	1350	21.12.2009	CONWIP
HAT1	22.12.2009 16:09:38	1298	1350	21.12.2009	CONWIP
HAT1	23.12.2009 10:09:54	1353	1350	21.12.2009	CONWIP
HAT1	23.12.2009 12:09:54	1304	1350	21.12.2009	CONWIP
HAT1	23.12.2009 14:09:57	1274	1350	21.12.2009	CONWIP
HAT1	23.12.2009 16:09:58	1244	1350	21.12.2009	CONWIP
HAT1	24.12.2009 10:14:41	1361	1350	21.12.2009	CONWIP
HAT1	24.12.2009 12:14:42	1331	1350	21.12.2009	CONWIP
HAT1	24.12.2009 14:14:44	1331	1350	21.12.2009	CONWIP
HAT1	24.12.2009 16:14:44	1331	1350	21.12.2009	CONWIP
HAT1	25.12.2009 10:20:24	1415	1350	21.12.2009	CONWIP
HAT1	25.12.2009 12:20:29	1400	1350	21.12.2009	CONWIP
HAT1	25.12.2009 14:20:31	1370	1350	21.12.2009	CONWIP
HAT1	25.12.2009 16:20:32	1355	1350	21.12.2009	CONWIP
HAT1	28.12.2009 10:18:06	1290	1350	28.12.2009	CONWIP
HAT1	28.12.2009 12:18:08	1359	1350	28.12.2009	CONWIP

B.3 SQL for Calculating Minimum Inventory Levels of Components

View Name:

xxupk_msr2_malzstokay_min

Collecting Fields:

Calendar Date: Date

Min_Stokay: Minimum inventory level of the components in terms of month in a given date

SQL:

```
CREATE OR REPLACE VIEW xxupk_msr2_malzstokay_min AS
SELECT
   stokay.calendar_date,min(stokay.stokay2) min_stokay
FROM
   (select
   tarih.calendar_date, m.grup,m.malzeme_kalem, m.malzeme_tanim,m.malz_id,
   m.stok,
   m.malz_ort,
   m.stok_ay,
   sum(tr.transaction_quantity) trs, m.stok-sum(tr.transaction_quantity) stok2,
   (m.stok-sum(tr.transaction_quantity))/m.malz_ort stokay2
   from
   xxupk_msr2_tarih tarih,
       (select
       t.inventory_item_id,
       decode(t.transaction_source_type_id,1,t.transaction_date,
       t.creation_date) transaction_date,
       t.transaction_quantity
       from mtl_material_transactions t
       where
       decode(t.transaction_source_type_id,1,t.transaction_date,
       t.creation_date)>'02-NOV-2009' AND
       decode(t.transaction_source_type_id,1,t.transaction_date,
       t.creation_date)<'30-DEC-2009' AND
       T.INVENTORY_ITEM_ID in (
       select a.malz_id from xxupk_msr2_malzdurum_t a)) tr,
       -- transactions--
       (select
       x.grup,
       a.comp_kalem malzeme_kalem,
       a.comp_desc malzeme_tanim,
       a.comp_id malz_id,
       max(a.qpa) qpa,
```

```
        xxupk_net_stok(a.comp_id) stok,
        ort.malz_ort,
        xxupk_net_stok(a.comp_id)/ort.malz_ort stok_ay
        from xxupk_ms2_kalem i, xxupk_ms2_grupkalem x, xxupk_ms2_hatgrup y,
        xxupk_bom a,
        xxupk_malz_aylik_ort ort

        where
        i.segment1=x.segment1 and
        x.grup=y.grup and
        y.hat='HAT1' and
        i.inventory_item_id=a.urun_id and
        a.comp_id=ort.inventory_item_id
        group by
        x.grup,
        a.comp_kalem,
        a.comp_desc,
        a.comp_id,
        xxupk_net_stok(a.comp_id),
        ort.malz_ort,
        xxupk_net_stok(a.comp_id)/ort.malz_ort) m
        --Components used in line1--
    where
    tr.transaction_date>tarih.calendar_date and
    tr.inventory_item_id=m.malz_id
    group by

    tarih.calendar_date, m.grup,m.malzeme_kalem, m.malzeme_tanim,m.malz_id,
    m.stok,m.malz_ort,m.stok_ay) stokay
GROUP BY
stokay.calendar_date
```

APPENDIX C

RESULTS OF THE STATISTICAL TESTS

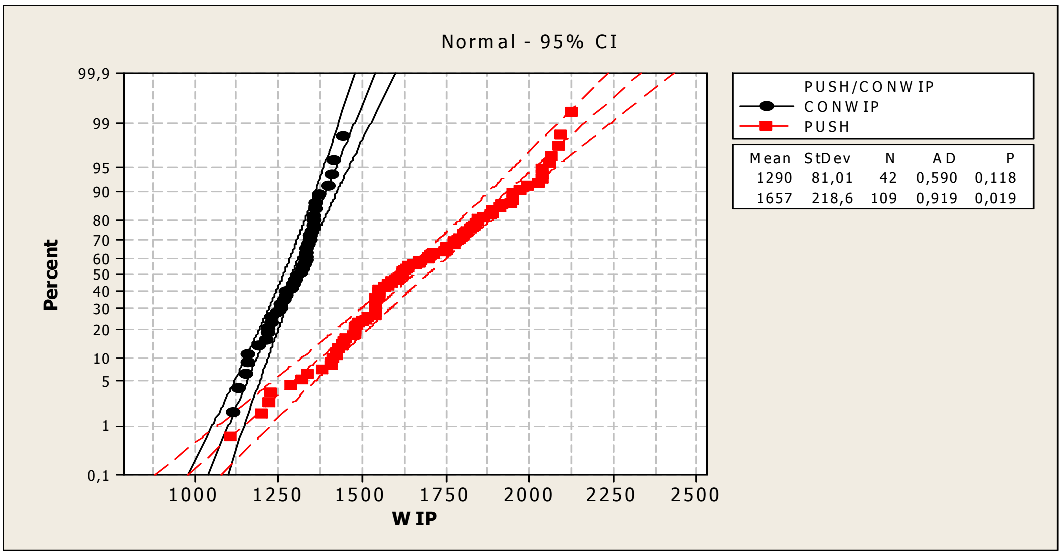

Figure C.1. Normality Test for WIP Values

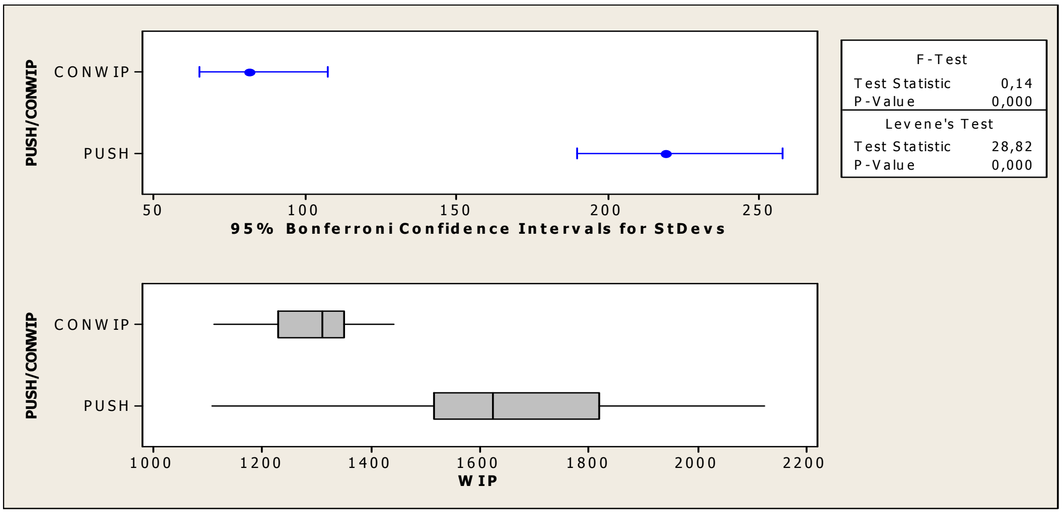

Figure C.2. Levene's Test to Compare Variances of the WIP Values

---

Two-Sample T-Test and CI: WIP; PUSH/CONWIP

```
Two-sample T for WIP

                                            SE
PUSH/CONWIP      N     Mean  StDev      Mean
CONWIP          42   1290,4   81,0        12
PUSH           109     1657    219        21


Difference = mu (CONWIP) - mu (PUSH)
Estimate for difference:  -366,5
95% CI for difference:  (-414,7; -318,3)
T-Test of difference = 0 (vs not =): T-Value = -15,03  P-Value = 0,000
DF =148
```

Figure C.3. Results of the Two-Sample t-Test for WIP Comparison

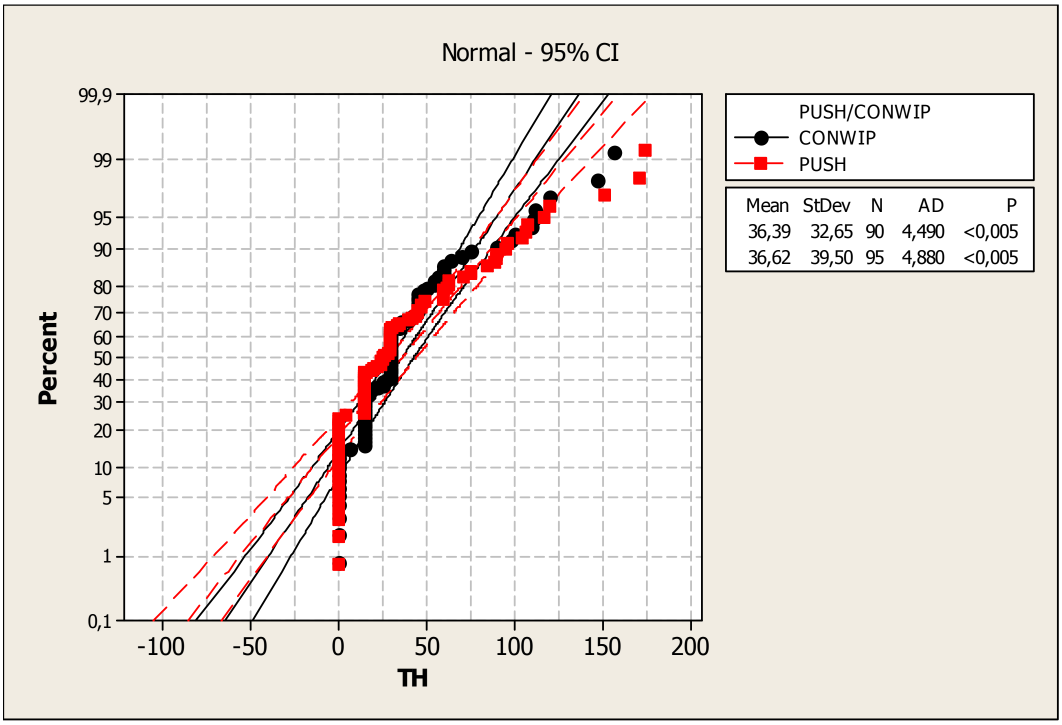

Figure C.4. Normality Test for Throughput Values

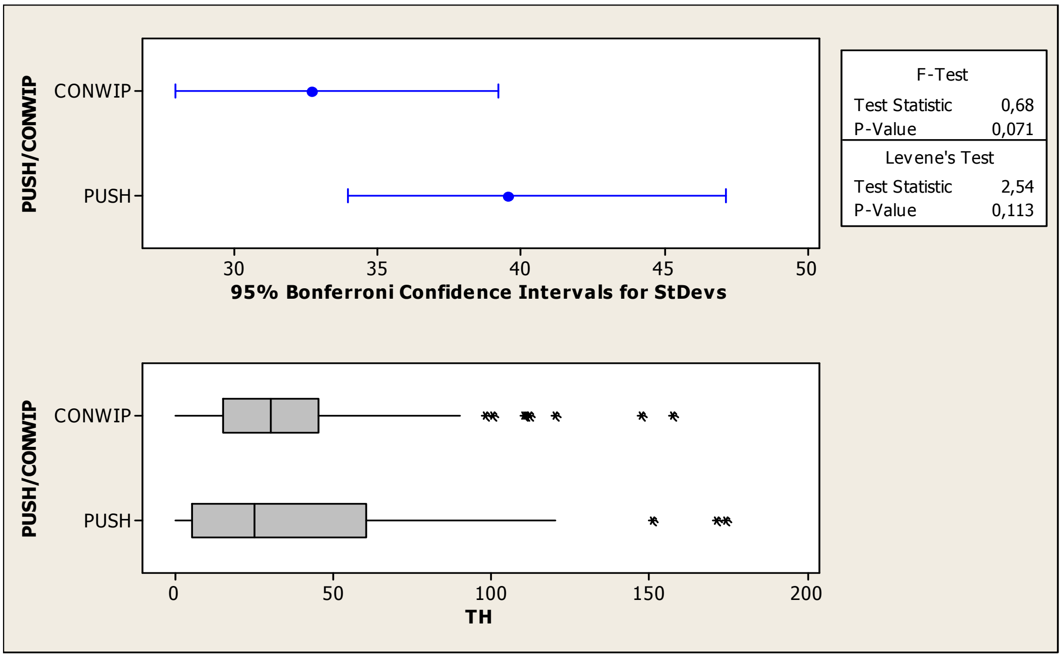

Figure C.5. Levene’s Test to Compare Variances of the Throughput Values

---

Two-Sample T-Test and CI: TH; PUSH/CONWIP

```
Two-sample T for TH

PUSH/CONWIP   N  Mean  StDev  SE Mean
CONWIP       90  36,4   32,7      3,4
PUSH         95  36,6   39,5      4,1


Difference = mu (CONWIP) - mu (PUSH)
Estimate for difference:  -0,23
95% CI for difference:  (-10,78; 10,31)
T-Test of difference = 0 (vs not =): T-Value = -0,04  P-Value = 0,965  DF
= 183
Both use Pooled StDev = 36,3307
```

Figure C.6. Results of the Two-Sample t-Test for Throughput Comparison

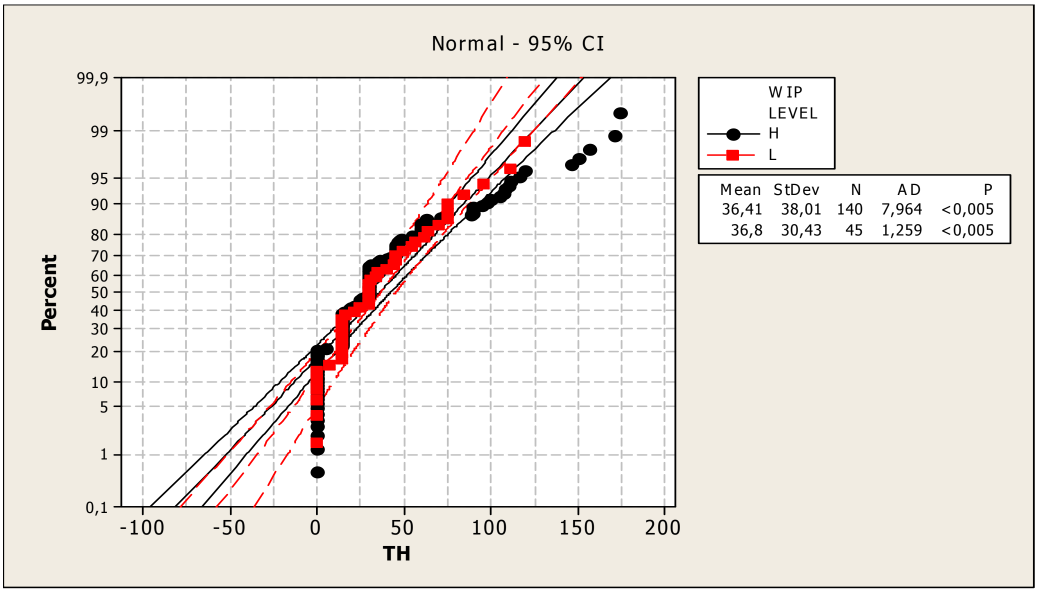

Figure C.7. Normality Test for Throughput of High and Low WIP Level Periods

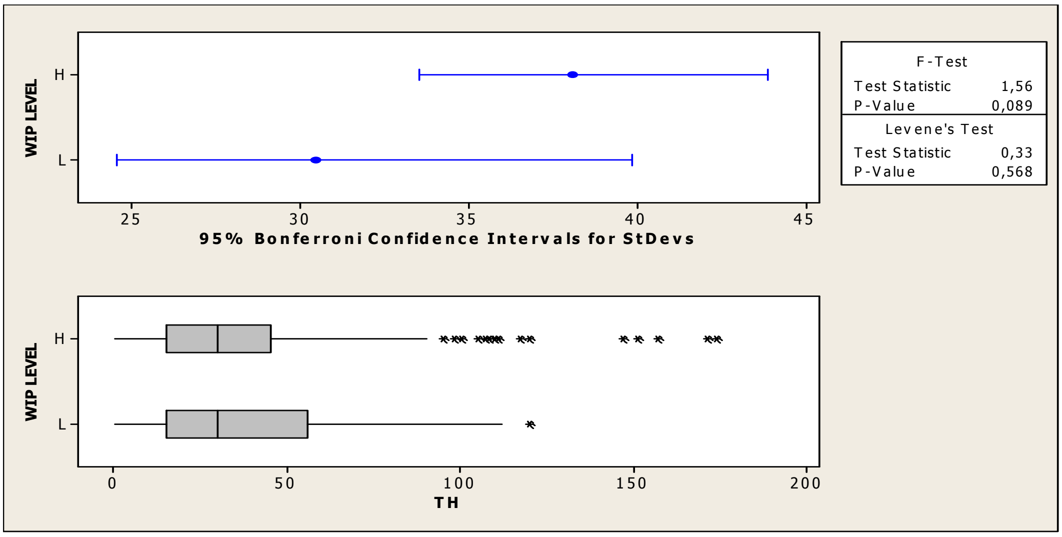

Figure C.8. Levene’s Test for Throughput of High and Low WIP Level Periods

---

Two-Sample T-Test and CI: TH; WIP LEVEL

```
Two-sample T for TH

WIP
LEVEL     N  Mean  StDev  SE Mean
H       140  36,4   38,0      3,2
L        45  36,8   30,4      4,5


Difference = mu (H) - mu (L)
Estimate for difference:  -0,39
95% CI for difference:  (-12,67; 11,90)
T-Test of difference = 0 (vs not =): T-Value = -0,06  P-Value = 0,951  DF
= 183
Both use Pooled StDev = 36,3305
```

Figure C.9. Two-Sample t-Test for Throughput of High and Low WIP Level