

**ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES**

**A PETRI NET APPROACH TO BOTTLING LINE
MODELING AND PERFORMANCE ANALYSIS**

A CASE STUDY ON META ABO BREWERY SHARE COMPANY

**A Thesis submitted to the School of Graduate Studies of Addis Ababa
University in partial fulfillment of the requirements for the Degree
of Masters of Science in Mechanical Engineering (Industrial
Engineering Stream)**

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Abbreviations

AI: Artificial intelligence

AMS: Automated manufacturing system

CAD/CAM: Computer Aided Design and Manufacturing

CIM: Computer Integrated Manufacturing

CNC: Computer Numerically Controlled

DEDS: Discrete Event Dynamic Systems

DMS: Decision-Making Subsystem

FIFO: First In First Out

FMS: Flexible Manufacturing System

GreatSPN: Graphical Editor and Analyzer for Timed and Stochastic Petri Nets

LIFO: Last In First Out

MABSCo: Meta Abo Brewery Share Company

OO: Object Oriented

PNs: Petri nets (introduced by Carl Adam Petri in his Ph.D. thesis in 1962).

PNM: Petri net model

SPNP: Stochastic Petri Net Package.

Abstract

Increasing global competition has made many business leaders and policy makers turn their attention to such critical issues as productivity and quality. Businesses seek new approaches to production processes and manufacturing techniques and explore new boundaries of technology. One of the frequently prescribed remedies for the problem of decreased productivity and declining quality is the automation of factories. To achieve strategic benefits of automation in line with improved quality, greater flexibility, and cost reduction, firms must carefully manage the implementation of their techniques.

In the light of the above, because of capital intensive and complex nature of automated manufacturing system (AMS), the design and operation of these systems require modeling and analysis in order to select the optimal design alternative and operational policy. Besides, errors in the modeling process can substantially contribute to the development time and cost. Therefore, special attention should be paid to the correctness of the models that are used at all planning levels. Petri nets as a graphical and mathematical tool provide a uniform environment for modeling, formal analysis and design of manufacturing systems.

This study therefore, focuses on both traditional analysis of manufacturing system after setting key performance factors and the application of Petri nets in modeling and analysis of an AMS. It also includes a comprehensive review of

Petri nets and manufacturing system in view of Petri nets application domain. In the view to give more emphasis in the practical and realistic industrial application of Petri nets, particularly in modeling and analysis of AMS, a case study on an existing manufacturing firm was carried. In this regard, Meta Abo Brewery S. Co (MABSCo) is believed to serve as a model.

Above all, the success of Petri nets and related technologies can be greatly achieved only when more industrial engineers and designers use them together with other techniques in system development and operation. The author, being an industrial engineer, developed the sample model attributed to the bottling line of MABSCo through a careful study of relevant literatures, systematic data collection, and after systematic survey of the plant, particularly the bottling line. Further research in the future that includes other classes of Petri nets is also proposed to make the study more complete.

CHAPTER ONE

INTRODUCTION

1.1 Background

Increasing global competition has made many business leaders and policy makers turn their attention towards critical issues such as productivity and quality. Businesses seek new approaches to production processes and manufacturing techniques and explore new boundaries of technology. One of the frequently prescribed remedies for the problems of decreased productivity and declining quality is the automation of factories. Automation is the technology by which a process or procedure is accomplished without human assistance. In order to achieve strategic competitive benefits of automated manufacturing system (AMS)-improved quality, greater flexibility, and cost reduction, firms must carefully manage the implementation of these technologies. What has kept manufacturers from getting serious about AMS is probably the improper performance evaluation criteria used to evaluate by managers. While there is little disagreement about the necessity of rapid movement toward the automation of manufacturing processes, there is also a great deal of confusion about the fundamental approaches necessary to do so. As a result of this, tools that are useful to specify, model, design, evaluate, control, and monitor AMS are required. Such tools serve as a common medium among several personnel involved in the production activities. Hence, using such tools the integration between the people and between the tasks of the system can be easily achieved.

Petri Nets (PNs) that have been originated from Carl Adam Petri's doctoral dissertation work on communication with automata in 1962 is generally considered as integrated tool and methodology in AMS design. Petri net as a graphical and mathematical tool provides a uniform environment for modeling, formal analysis, and design of discrete parts manufacturing systems. One of the major advantages using Petri net model is that the same model is used for the analysis of behavioral properties and performance evaluation. Petri net as a graphical tool provide a powerful communication medium among customers, users, requirement engineers, designers, and analysts.

Due to their numerous features and various applications there are many ways to introduce Petri nets. Hence, modeling of action is considered that depends on a limited set of conditions, restrictions, etc. which could be called the local environment. Petri nets model actions by the change of their local environment. This principle of locality is the basis of the superiority of Petri nets in modeling concurrency. In the light of the above, some essential features of Petri nets will appear, namely the principles of locality, concurrency, graphical and algebraic representation.

Although other models (such as Queuing, State-transition and object oriented) are available, due to many advantages that Petri nets are found superior in modeling, analysis and performance evaluation of AMS, particularly when the system becomes more complex. This is the reason why a Petri net approach manufacturing system modeling is chosen as a research topic.

In consideration to make the study more practical and realistic, Meta Abo Brewery Share Company (MAB S.Co) was chosen due to the following reasons:-

- Previous professional experience of the author in breweries, willingness of the brewery management to cooperate in the process of the research work, the need of performance improvements by the brewery, and the size of the brewery to be taken as a model to similar manufacturing firms is among other criteria that give MAB S.Co.a priority.
- Since the study focuses in particular on the bottling line of the brewery, it will help to develop the local capacity of modeling, analysis and performance evaluation of other systems such as processing of underground water for drinking purpose with certain modification or treatment.

1.2 Objectives

The general objectives of the thesis are to make analysis of the manufacturing system of MAB S.Co. for the reason that:

- Introduce advanced production system setup that will help in upgrading of the product quality and improves the production processes.
- Maximize the capacity utilization and increase industrial productivity.

The specific objectives of the study include:

- To introduce the industrial application of Petri Net as a manufacturing system modeling and performance analysis in Meta Abo Brewery.
- To make use of Petri Net for manufacturing system analysis

- To evaluate performance of the manufacturing subsystem and propose improvements.
- To identify facilities required for improvements.

1.3 Methodology

The following methodology is used to conduct the study.

1. Literature review of manufacturing.
2. Literature review of Petri net in view of manufacturing.
3. Assess the existing production process of the brewery in general, the beer packaging sub system in particular.
4. Analyze processes in the manufacturing system with respect to key performance factors.
5. Propose alternatives manufacturing setup for performance upgrading of the beer packaging subsystem and select one among others.
6. Modeling of the selected manufacturing system setup using Petri net.
7. Evaluate performance of the subsystem with data collected from shop floor
8. Develop software to evaluate performance of the bottling line with the application of object oriented modeling technique and Petri net.
9. Evaluate performance of the bottling line with the developed software varying some of performance parameters.

1.4 Application of the Results

Among others, this thesis has the following applications

- To show the industrial use of Petri nets
- To identify better system organization, controlling method and implementation procedure
- Serves as a source for further study in this area.

1.5 Scopes and Limitation

Due to time constraint while conducting this thesis work, some classes of Petri nets and the algebraic representation are not discussed to the level the author thought sufficient and difficulty to access simulation software such as Graphical Analyzer and Evaluation of Stochastic Petri Net (GreatSPN) and Stochastic Petri Net Package (SPNP) are also another limitation faced in this work that need to be mentioned. In light of the above, software is developed which ignores the graphical representation of the model and that performs small tasks concerning performance evaluation.

1.6 Organization of the Thesis

This thesis is organized as follow. Chapter 1 discusses the background, objective methodology, application of results, and scope and limitations of this thesis. Chapter 2 presents review of manufacturing system and that of Petri net. Chapter 3 discusses factory background and concludes by emphasizing the need of manufacturing system improvement for the factory under consideration. Chapter 4 presents identification and

formulation of the problem. A significant portion of this chapter is based to the analysis of Meta Abo brewery's existing beer bottling line with respect to key performance factors.

Alternative for improvement of bottling line is introduced in chapter 5. In the process, selection criteria, which in turn consist of objective, methodology and constraints, are established in facilitation to options proposal and selection among improvement alternatives. Cognizant to the need of improvement, this chapter includes the hardware and consultancy requirements, and cost benefit analysis at the end.

Chapter 6 briefly discusses the application of Petri nets and object modeling techniques to model, validate, and development of performance evaluation software for the selected solution. In its entirety, this chapter presents review of manufacturing system modeling techniques in short along with their merit and demerit, and proposal of the best option for the system under study. It extends to present the model and simple analysis that is drawn from the graphical model representation. At the end, it brings into picture a software development approaches for the performance evaluation of the bottling line.

Chapter 7, the last portion of the thesis, presents conclusion and recommendation for the implementation of the identified system setups in the factory under consideration.

CHAPTER TWO

LITERATURE REVIEW

2.1 Manufacturing Systems

2.1.1 Definition

In a narrow sense, production is understood to be the transformation of raw materials into products by a series of processes with exhaustive energy applications. Each process brings a change in the physical characteristics of the materials. Since this definition applies only to producing tangible goods such as in the manufacturing and process industries, it is termed manufacturing [2].

The original meaning of manufacturing was to make things by hand. However the present meaning has quite widened: 'manufacturing' is 'the conversion of a design into a finished product', and 'production' has a narrower sense, namely the physical act of making the product [2].

Manufacturing should be recognized as a series of production activities: planning, design, procurement, production, inventory, marketing, distribution, sales, and management. It can also view as an input-output system.

2.1.2 Importance of Manufacturing

Manufacturing matters in three features

Manufacturing, which is the production of tangible goods or products, has a history that extends several thousand years and contains the following three important features [2].

- a. *Providing basic means of human existence*: Without the manufacture or production of goods a human being can not continue to live, and this is increasingly so in modern society.
- b. *Creation of wealth of nations*: Manufacturing creates the wealth of a country or a nation. A country where manufacturing has been exhausted becomes poor and weak.
- c. *Steps towards human happiness and the world's peace*: An affluent and prosperous country provides security, welfare and happiness to its people.

2.1.3 System Fundamentals

As described in the previous section, manufacturing is an input-output system; hence a system approach is effective for solving manufacturing issues.

2.1.3.1 Definition

A system is an organized or connected group of objects; a set or assemblage of things, connected, associated, or independent, so as to form a complex unity; a whole composed of parts in orderly arrangement according to some scheme or plan; rarely applied to a simple or small assemblage or things;...; a set of principles, ideas, or statements belonging to some department of knowledge or belief; a department of knowledge or

belief considered as an organized whole; a comprehensive body of doctrines, conclusions, speculations, or theses...[2].

2.1.3.2 Synergy effect of a system

A system is an 'organized whole' of a plural number of units. The essential sense of this term captures its organic (or materialistic) characteristic, or the synergy effect; that is, the total optimization is greater than the sum of the partial optimizations.

This effect was suggested by Laozi, a Chinese philosopher, about 2500 years ago; some time later it was noted independently by the Greek philosopher Aristotle. The German philosopher G.W.F.Hegel also mentioned this concept 200 year ago.

2.1.3.3 Chaos

A state, which is not systematized, is 'chaos'. This was first recognized and mentioned by the Chinese philosopher Zhuanzi about 2400 years ago. Chaos now means a mode, which creates unforeseen irregular behavior or pattern in spite of deterministic character following a certain specific rule/law.

2.1.3.4 System integration

If a unit forming part of a system behaves with strong independence/autonomy, this unit is called a module or holon; a system consisting of autonomous modules is called a total system.

The total system often has a mode of system integration with the following three features [2].

- Syncretism which is integrating different fields whilst maintaining their own autonomy;
- Symbiosis that is obtaining symbiotic gain;
- Synergy meaning that synergistically obtaining amplification effect.

2.1.3.5 Characteristics of a System

Many Characteristics are concerned with systems; some are size, complexity, totality, mission or functions, objectives, internal or external relationships, equilibrium or balance, hierarchy dimensionality, dynamic behavior, etc.

Among the many characteristics four basic attributes, which play basic roles to characterize a system, are described as stated below [2].

a. Assemblage. A system consists of a plural number of distinguishable units (elements, components, factors, subsystems, etc.), which may be physical or conceptual, natural or artificial.

b. Relationship. Several units assembled together are merely a ‘group’ or a ‘set’ for such a group to be admissible as a system; a relationship or an interaction must exist among the units.

c. Goal-seeking. An actual system as a whole performs a certain function or aims at single or multiple objectives. Whenever these objectives are attained at their maximum/minimum levels, system optimization is said to have been performed. For this

purpose it is necessary to be able to measure, objectively or subjectively, the degree of attainment of the objectives. An objective that is measurable by any means is called a goal/target.

d. Adaptability to environment. A specific, factual system behaves so as to adapt to the change in its surroundings, or external environment. This external environment influenced and it is influenced by the system, in that matter and/or energy and/or information's are received from and given to each other. A system that is capable of controlling itself in such a way as to be always optimal even under changes in the external environment is called an adaptive (or cybernetic) system. If this system possesses dynamic adaptability, approaching a desired state with the list time lag by changing its internal structure and functions as the environment changes, it is a self-organizing system. In its structure a sort of 'fluctuation' exists; the system has a dissipative structure, evolving into a new state whenever fluctuation exceeds the critical limit.

2.1.4 Historical Perspective of Manufacturing Systems

Production has evolved from labor intensive production system, mass production lines, automated mass production lines, job shop, group/cellular manufacturing cells, to flexible manufacturing systems, agile manufacturing systems, and computer integrated manufacturing systems. They can be shown roughly into four stages given in Fig 2-1 [6].

Labor-intensive production systems remained as a primary way before the 19th century. Highly skilled craftsmen made a complex product, e.g., watch, by using crude tools and materials. Human energy was the main source of energy with limited usage of wind and

waterpower. The invention and development of steam engine in the eighteenth century empowered human being in producing more complex products such as locomotives.

Mass production arose from the need to supply a large volume of uniform products, such as automobiles, to satisfy the market at the end of the 19th century. The early production and assembly systems were rigid and expensive, thus impossible to change to handle many variations in product types. Developments of electrical devices, such as electrical switches and motors led to better control of machines and resulted in machines with certain flexibility. Computer technologies allowed researchers and engineers to develop computer numerically controlled and programmable logic controllers to automate manufacturing operations. Recent developments in information technology including computer hardware/software and network techniques make it feasible to achieve the purpose of rapid product prototyping, concurrent engineering, flexible and agile automation and computer integrated manufacturing.

The invention and application of steam engine and other water driven power generator in the eighteenth century triggered industrial revolution. It freed people from heavy labor work. Meanwhile, the concept of the division of labor was developed and used to increase the productivity. Continuous flow manufacturing systems were introduced and shifted toward mass production oriented factories. Each individual was responsible for a small part of a product. Entering the nineteenth century, the communication and transportation infrastructure started to be significantly and increasingly improved for further industrial growth. Electricity was introduced to develop electrically powered machine tools. The internal combustion engines developed around 1900-triggered mass

production of products such as automobiles. Large-scale assembly and mass production became very popular over the world. Another revolution lied ahead.

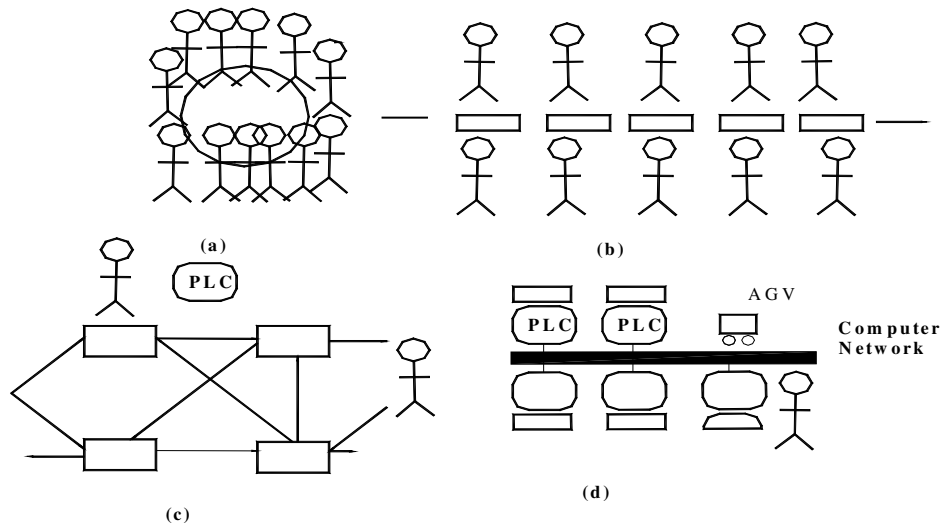


Figure 2-1 production evolvment (a) Labor-intensive systems, (b) Mass production lines; (c) Job-shops, and (d) Flexible manufacturing systems/Computer integrated manufacturing systems

In the late 1940s, the first transistor was invented. The integrated circuits as well as digital computers were developed in the 1950s. In the manufacturing field, the first numerically controlled milling machine was developed. In 1967, computer numerically controlled (CNC) machines were developed and put into practice. Integration of computers and machines greatly improved the flexibility associated with the machines and manufacturing systems. Fixed automation started to evolve into flexible automation.

The fast development of computers and information technologies led to information revolution in many fields including manufacturing. In the early 1970s, computer integrated manufacturing (CIM) was coined to provide a new concept and direction to grow manufacturing enterprises. The CIM concept has changed over time from computerized work cell, flexible manufacturing systems, large scale automation,

computer aided design and manufacturing (CAD/CAM), interfacing and communications concepts to the current state: an information system that controls data flow among all the function units in a manufacturing enterprises. CIM as a system provides computer assistance to all business functions within an enterprise- from customer needs, product design, order entry to product manufacturing and shipment. The goal of CIM is to reduce the product cycle time, improve the product quality and reliability, increase the productivity, and lower product cost, thus maintain and improve manufacturing competitiveness in the world [6].

2.1.5 Historical Perspective of Manufacturing Industries in Ethiopia

Modern manufacturing was introduced to the Ethiopian economy towards the end of 19th century, with the emergence of strong central government and political stability. By 1927, about 25 factories were established in different cities of the country, like Addis Ababa, DireDawa, Asmara and Messawa which includes 5 wood and clay factories, 2 tanneries, 5 soap and edible oil plants, 1 grain mill, and 2 salt factories. Thus except the two ammunition plants and the printing press, all were established by private entrepreneurs.

During 1928-1941 about 10 manufacturing industries were set up, including the Dire Dawa cement factory and Dire Dawa textile factory that were established by the Italians. The remaining factories were setup by the Armenian and Greek settlers [10].

During the immediate post war period of 1941-1959 the manufacturing sector increased rapidly. It was promoted for two main reasons [10]: -

- The government realized that the victory of Italy over Ethiopia was attributed to military superiorities, like use of superior mechanized armaments and weapons by Italy during 1935-40, and thus the need for modernization and economic development began to be perceived; and
- The close relation of Ethiopian government with the government of United States and United Kingdom, which encouraged social and economic development.

The increase in the number of establishments up to 1950 was not nevertheless a result of a conscious and deliberate development action. The development stages of manufacturing industries can be classified into the following three major political events.

2.1.5.1 Manufacturing Industries Before 1974

The level of industrialization during the imperial period was considered as at an incipient stage. A conscious effort towards developing and establishing a modern industrial sector did not start till the 1950's. The main agents for the expansion of the industrial sector during this period were foreign nationals residing in the country. It was believed that the settlement of foreigners along with the expansion of commercial farms would continue to give inertia to the growth and expansion of the industrial sector.

As result of the conducive environment created during the later years of this era, a considerable number of manufacturing firms were established. By the end of this era,

there were some 430 manufacturing establishment with a low level of employment creation comparing to the population size. These industries were designed to satisfy the limited domestic market and were seriously handicapped by poor infra-structure facilities and lack of clearly articulated government economic policies towards the development of the sector. The majority of the industries were in nature employing very few skilled personnel with rudimentary concept of quality and market.

However, whenever private initiatives failed to come forth, the government made direct investment and establish factories. These include cement factories, the petroleum refinery, tyres factory for strategic reason. Some factories like Bahir-Dar Textile and Debre-Berhan Wool factories were established by the government to distribute industries to disadvantaged area based on available local materials. The Awash tannery was established to process raw hides and skins for export. The tobacco factory was built for revenue purposes. The government also entered into joint ventures with foreign companies to establish factories like the Ethio-Japanese Nylon, Corrugated Iron Sheets and meat concentrates (with Japanese firms), a textile mill with an Indian group, a pulp and paper factory with an American company, sugar mill with a Dutch group, and an abattoirs with a UK group [10].

During this period, large scale and medium sized manufacturing industries were concentrated in the hands of private foreign nationals. There were low management and technical skill transfer as higher management positions and technical department were

fully in foreign hands. Ethiopians were limited to small and cottage industries and as wage earners in foreign owned companies.

2.1.5.2 Manufacturing Industries during the Derg Era

After the 1974 revolution, Derg changed the structure of ownership as part of its “socialist” policy, and nationalized virtually almost all medium and large-scale industrial enterprises owned by Ethiopian and foreigner alike. This made, the industrial sector to be dominated by public manufacturing enterprise.

The era showed its intention to move into production of intermediate and capital goods in its ten years perspective plan. The plan had envisaged to a strong self-reliant national economy with adequate inter-sectoral linkage but it was not materialized.

As a result of the Derg socialist policy, the private sector investment in manufacturing was restricted to small scale-industries and handicrafts and cottage industries with the maximum ceiling of Birr 500,000 in investment. Handicrafts and cottage industries were organized into producers cooperatives based on socialist systems with heavy subsidies. Thus the development and investment in manufacturing sector was monopolized by the state. Besides, imports were restricted and local industries monopolized the domestic market.

The intention to build a strong self-reliant national economy with inter-sectoral linkages was neutralized by an objective to satisfy basic needs of the population as a result of

which projects in the food, beverages and textiles sectors took over 90 percent of the total investment in between 1976 to 1984. Though industrial production increased during this era, less emphasis was paid to quality and productivity. Together with this, less attention was paid to deepening industrial production and the development of basic industries such as chemicals, metals and engineering, which would have strengthened the linkage within the industrial sector, reduces dependence on imported inputs and increase the range of industrial processing domestic materials [10].

2.1.5.3 Post 1991 Manufacturing Industries

Following the collapse of socialism, the only choice that developing countries have in terms of planning their development strategy was following the line of an economic system that goes liberalized the existing economy of the country following its development so as to destine in the more liberalized capitalist system. Accordingly, the transitional government of Ethiopia, which took power from the Derg, announced an economic policy whose basic elements characterized as “cautious capitalism”. The government accepted structural adjustment program although with some reservations to make conducive environment for investment.

The government of the EPRDF (Ethiopian People Revolutionary Democratic Front) led federal republic of Ethiopia, which took over the transitional government, indicated its intentions about the future of the Ethiopian economy by outlining its broad five year development program.

According to this strategy, the primary focus of development in short and medium terms will be expanding agricultural production through increased availability of modern inputs and extension services. This will increase the income of the rural people, which will in turn raise the purchasing power of the larger proportion of the population for industrial outputs.

2.2 Petri Net as Tool of Manufacturing System

Analytical model building of automated manufacturing system (AMS)/flexible manufacturing system (FMS) is a significant area, which has to be cleared before installation, integration, and implementation. There are numerous simulation and analytical models dealing with various aspects of manufacturing systems. Among them are queuing networks, artificial intelligence, and more recently Petri nets. From the point of this study, a Petri nets approach to manufacturing system modeling and performance analysis will be dealt in depth.

2.2.1 Review of Petri net

Petri nets have been originated from Carl Adam Petri's doctoral dissertation work on communication with automata in 1962. He described using a net the casual relation ships between events in a computer system. His work came to the attention of A.W. Holt and others of the Information System Theory Project of Applied Research, Inc. in the United States. Their work illustrated how Petri nets could be used to model and analyze systems of many concurrent components. Petri's work also came to the attention of The Computation Structure Group of Massachusetts Institute of Technology, led by Professor

J.B.Dennis. Several Doctoral theses and technical reports were published during the early 1970s on the topic.

Starting in the late 70's, Petri nets became a very active area, especially in Europe. Annual conferences on Application and Theory of Petri Nets have been held since 1979 and the proceeding published in the series of lecture notes of computer science by Springer-Verlag. Most of the studies focused on information processing systems in the computer science community. Professor T. Murata gave an excellent tutorial paper in 1989, which comprehensively presented properties, analysis, and application of Petri nets and a list of references of significance. Most of the earlier applications and theory of Petri nets aimed to information processing systems. The books and most of the papers were primarily targeted at computer scientists and graduate students [6].

Researchers with engineering background started their probe into the application of Petri nets in engineering system particularly automated manufacturing systems in the early 1980's. They found that Petri nets were powerful tool in describing event-driven systems. These systems may be asynchronous, contain sequential and concurrent operations, and involve conflicts, mutual exclusion and non-determinism. Such systems termed as discrete event systems or discrete event dynamic systems (DEDS).

While many activities are being conducted in Petri nets applications on manufacturing automation, the following foci could be observed since the late 70's [6]:

- a. Early interest in Petri nets (PNs) aroused from the need to specify and model discrete-products manufacturing system. The activities in this area started with the Petri nets representation of simple production lines with buffers such as machine shops, and automotive production systems, and proceeded to modeling of flexible manufacturing systems, automated assembly lines, resource sharing systems, and more recently just-in- time and Kanban manufacturing systems. The work has continued to specify and model plant-wide production systems under different operational policies such as push and pull paradigms.
- b. Early research focused on qualitative analysis of PN models of manufacturing systems. Reachability analysis shows whether a system can reach a certain state. Desired sequences of events are validated according to the system requirements. Other PN properties are used to derive DEDS stability, cyclic behavior, and absence of deadlocks. Deadlock avoidance policies and their evaluation in a PN framework are still a hot research topic.
- c. Temporal or quantitative properties became an important consideration; timed PNs are used to drive the cycle time of repetitive and concurrent manufacturing systems. To deal with stochastic nature of many production operations, stochastic PNs are used to drive the system production rates or throughputs, critical resource utilization, and reliability measures. Their underlying models are Markov or semi-Markov processes. The direct construction of Markov chains is avoided thanks to the conversion algorithms for stochastic PNs.
- d. When state explosion problem arise or the underlying stochastic model are not amenable for traceable mathematical analysis, simulation must be conducted for

analysis of both qualitative and quantitative properties. Fortunately, PN models can be easily utilized to derive complex discrete event simulation. Several packages based on PN exist for simulation purpose.

- e. Programmable logic controllers (PLC) are commonly used in industrial sequence control of automated systems. They are designed through ladder logic diagrams that are known to be very difficult to debug and modify. It is observed that PLC can be converted into a PN and vice versa for a sub class of PNs. Early work includes the conversion of a PN into a ladder logic diagram for PLC implementation. Direct PN controllers without help of PLCs can also be implemented through either a Petri net interpreter or their corresponding control code. For most case additional information to represent the real time signals and status needs to be incorporated to such PN models. The advantages of PNs include their relative ease to represent and modify the control logic, and their potential for mathematical analysis and graphical simulation to validate a design. It can be proved that the graphical complexity of PN grows with system complexity less than that of ladder logic diagrams.
- f. With mathematical representation available, designers are able to use PNs for rapid prototyping of process control system or discrete event control. Virtual factories can be realized through computer graphics using PNs. Stepwise testing and implementation can be achieved by connecting the actual equipment into a PN based design system, thereby reducing design and development time.
- g. Petri nets have been combined with other approaches to achieve various purposes in process planning and scheduling, intelligent control, expert system

construction, knowledge representation, and uncertainty reasoning. For example, the correspondence between a PN and an expert system can be established. This can greatly aid in consistency checking of an expert system. Optimal or sub-optimal schedulers can be derived with heuristic search algorithms. The research over the past several years demonstrated the efficiency of the PN- based approaches.

Since the introduction of the classical Petri net by Carl Adam Petri in the '60s, Petri net have been used to model and analyze all kinds of processes with applications ranging from protocols, hardware, embedded systems to flexible manufacturing systems, user interaction, and business processes. However, the main application domains to be mentioned are manufacturing, workflow management and telecommunications. Here from the objective of this thesis, manufacturing application of Petri net is assessed.

2.2.2 Manufacturing Systems in view of Petri Net Application

A manufacturing system involves manufacturing activities, which, as defined in section 2.1, is “the transformation process by which raw material, labor, energy and equipment are brought together to produce high quality goods”. Hence a manufacturing system is composed of two main subsystems [7].

- The physical subsystem composed of resources (hardware components) such as conveyors, robots, buffers, workstations, etc.

- The control subsystem, also called Decision-Making Subsystem (DMS), which determines how to use the physical subsystem in order to organize and optimize the production process.

Usually manufacturing transformation processes are classified into continuous (chemical and oil industries, for instance) and discrete parts manufacturing (consumer goods and computer industries, for instance). According to the type of transformations to be carried out during the manufacturing process, discrete manufacturing systems are classified into assembly and non-assembly processing. The assembly process combines several components to obtain a different product, while the non-assembly process concern the transformation of raw materials.

In order to address some problems related to mass manufacturing systems (very efficient for large production of a small number of products, but inflexible when faced a changing market), and in parallel with the developments in computer and automation technologies, a new type of production system appeared: the flexible manufacturing system (FMS). The adjective “flexible” indicates the ability of the system to respond effectively to changes in the market. These changes can be internal, breakdowns and quality problems for instance, or external, changes in the design and demand for instance. Eight types of flexibility are summarized as indicated below [7].

- Machine flexibility (which refers to the time required to change the machines necessary to produce a new types of part),

- Process flexibility (related to the mixture of jobs that the system can produce simultaneously),
- Product flexibility (the ability to produce new types of products),
- Routing flexibility (the ability to route parts via several routes),
- Volumes flexibility (the ability to operate at different production volumes),
- Expansion flexibility (the ability to expand the system in a modular way),
- Operation flexibility (the ability to interchange the ordering of several operations for each part type), and production flexibility (the set of part type that the system can produce).

Figure 2-2 indicates an FMS/AMS plant. The global coordinating system communicates via a local area network and with the controllers of each cell. Each of these cell controllers is in charge of the controller of the programmable controllers (PC) that are in charge of the control of each of the physical hardware components in the cell. The complexity of these systems makes the hierarchical organization of the control system necessary [6, 7].

FMS/AMS hardware components are typically a set of workstations; an automated material handling system (conveyors, industrial robots, automated guided vehicles, etc.) allowing a flexible routing of parts through the different workstations; a load unload station for the entry/exit of parts; some storage means for the work in process; some (local and central) tool magazines; and a computer control system that is usually organized in a hierarchical way [7].

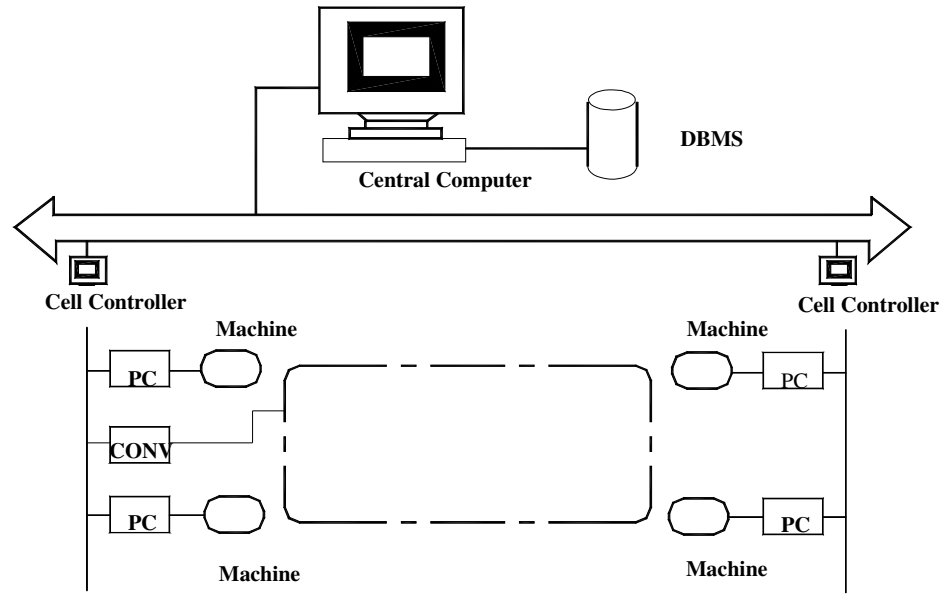


Figure 2-2 An abstract view of Flexible Manufacturing System

To introduce these systems in a more detailed way, Figure 2-3 presents in an intuitive and informal way, a small FMS/AMS.

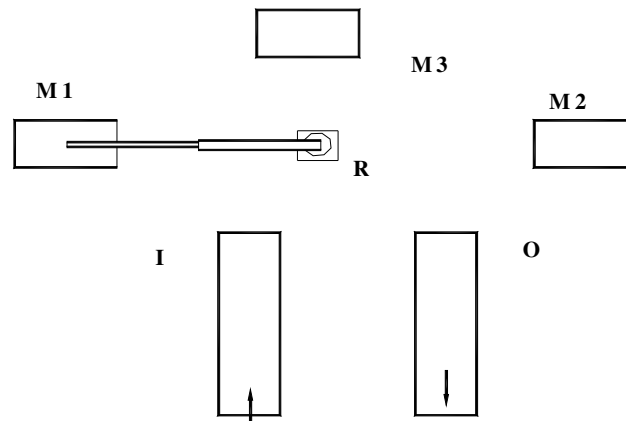


Figure 2-3 Small Manufacturing Cell

To describe some important characteristics that are common to almost all FMSs, consider the above cell that two different types of parts must be processed. Parts of type one must

be processed first in either machine M1 or M3 and then in M2; parts of type two must be processed first in M2 and then in M1 (at the moment, we are not considering what kind of processing operation must be carried out in each machine and for each type of part)[7].

- *It is event driven.* The system behavior consists of a discrete state space where a change to state occurs when certain events are triggered (a new part enters or leaves the cell, a machine loads a part, etc.).
- *It is asynchronous.* Some events in the system occur in asynchronous way: the end of a processing of a part in machine M1 is asynchronous (in time) with respect to the loading of a new part in machine M2.
- *It has sequential relations.* Some events must occur in a sequential way. For a part to be unloaded from machine M1, this machine must have been previously loaded and the processing of the part must be finished.
- *It has concurrency.* The processing of a part in M1 and a second part in M2 can be done concurrently, and these two actions do not interact with each other.
- *It has conflicts.* A part of type one that has been held by the robot can be loaded either into M1 or into M3 (assuming that both machines have free slots for new parts). So a decision must be taken.
- *It has non-determinism.* As a sequence of conflicts, some non-determinism can appear. In the previous situation, we cannot make a priori predict which action will be taken: either the part is loaded into M1 or into M3.
- *It has deadlocks.* In the case in which all three machines are fully busy and the robot holds a raw part that must be loaded into one of the machines, the system is in a (total) deadlock situation: no action can be executed since no machine can be

unloaded (the robot is busy) and the robot can not release the part (since it has to go to a machine).

- *Mutual exclusion.* Lets consider the process corresponding of a part of type one and a part of type two. These processes cannot be simultaneously in the state “the part is being held by the robot”. So this state implies a mutual exclusion for these two processes.

From the above discussion, it can be concluded that the design of manufacturing system is a very complex task: many different elements have to be combined, and many different aspects must be taken into account. This complexity has raised two important needs [7]:

- The design of the production control in a hierarchical way,
- The use of formal methods in order to validate the system.

The first part, the DMS is usually split into the following levels [7]:

- **Planning.** This considers both the whole plant and the estimated demand. It considers the production on a long time horizon, establishing the way in which the products needed to be produced during this time interval.
- **Scheduling.** Going down in the DMS hierarchy, this level establishes when each operation on each product must be carried out.
- **Global coordination.** This level must have an updated state of the workshop and must also make real-time decisions taking into consideration the state of each resource and the state of the parts being processed.

- **Subsystem coordination.** The global coordination system can be decomposed into modules specialized for the coordination and supervising of subsystems: a transport system, a robot, a buffer, etc.
- **Local control.** This is the lowest level of the hierarchy. And it is in charge of the interaction with sensors and other low level components.

The second important need was the use of formal methods. The use of a formal framework has some important benefits:

- a. In the process of formalizing the system requirements omissions, ambiguities, and contradictions can be discovered.
- b. A formal method can allow automatic system development.
- c. Mathematical methods can be applied to verify system correctness.
- d. A formally verified subsystem can be incorporated into larger systems with greater confidence.
- e. Different designs for the same system can be compared.

However, the use of different formalisms (Markov chains, queuing networks or simulation for performance evaluation, mathematical programming for planning, Petri nets for modeling and analysis) for the different problems generates a “Babel Tower” where communication of people working at different stages in the design process is very difficult [7].

As proposed in [7], a good solution is to use a family of formalisms, which, sharing the basic principles, allows the transformation (in automatic way if possible) from one to another. The family of Petri net formalisms is a good choice for the manufacturing system environment. The family has the following advantages [7]:

- a. Easy representation of concurrency, resource sharing, conflict mutual exclusion, and non-determinism.
- b. Application of top-down and bottom-up designs methodologies, and the possibility of having different levels of abstraction of the system.
- c. Ability to generate control code directly from the Petri net model.
- d. A well defined-semantics that allows qualitative and quantitative analysis for the system validation.
- e. A graphical interface that allows an intuitive view of the system.

2.2.3 Essential Features of Petri Nets

Due to their numerous features and various applications there are many ways to introduce Petri nets. With regard to the above, modeling of actions, which depend on a limited set of conditions, restrictions, etc. that is to be called by the local environment is considered. Petri nets model actions by the change of their local environment. This principle of locality is the basis of the superiority of Petri nets in modeling concurrency.

A basic set of such principles, namely locality and concurrency, graphical and algebraic/textual representation will be discussed loosely to start with the application of Petri nets.

2.2.3.1 Locality and Concurrency

Identifying and, in particular, separating passive elements (such as conditions) from active elements (such as actions) is a very important step in the design of systems. This duality is strongly supported by Petri nets. Hence the first principle the principle of duality is formulated [7].

I. The Principle of Duality for Petri nets

There are two disjoint sets of elements: P elements (state elements, places) and T-elements (transition element, transitions).

Entities of the real world, interpreted as passive elements, are represented by P-elements (conditions, places, resources, waiting pools, channels etc.).

Entities of the real world, interpreted as active elements, are represented by T-elements (events, transitions, actions, execution of statements, transmission of message etc.).

II. The Principle of Locality for Petri nets

The behavior of a transition is exclusively depends on its locality, which defined as a totality of its input and output objects (pre-and post-conditions, input and output places,...) together with the element itself.

III. The Principle of Concurrency for Petri nets

Transitions having disjoint locality occur independently (concurrently).

2.2.3.2 Graphical and Algebraic Representation

In Figure 2-4 shown below, action t1, and t4 are drawn with their pre-and post conditions. In this formal form they are called transitions. Conditions are represented by circles, which are called places. Places, transitions and arcs together form a net. Fusing places bearing identical names, give a net of type Figure 2-5. Some places contain tokens that mark the initial conditions. This leads to graphical representation.

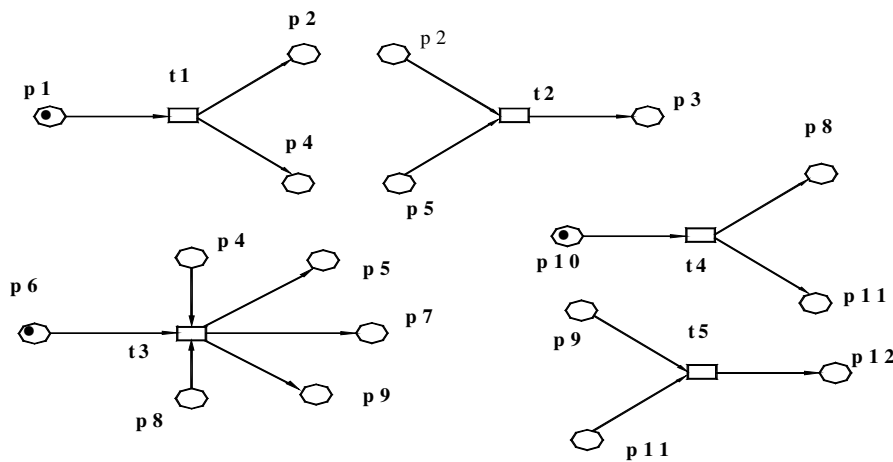


Figure 2-4 Action represented by transition

IV. The Principle of Graphical Representation for Petri nets

P-elements are represented by rounded graphical symbols (circles, ellipses...)(round like the top of the letter P).

T-elements are represented by edged graphical symbols (rectangles, bars,...)(edged like the top of the letter T).

Arcs connect each T-element with its locality, which is a set of P-elements.

Additionally, there may be inscriptions such as names, tokens, expressions, and guards.

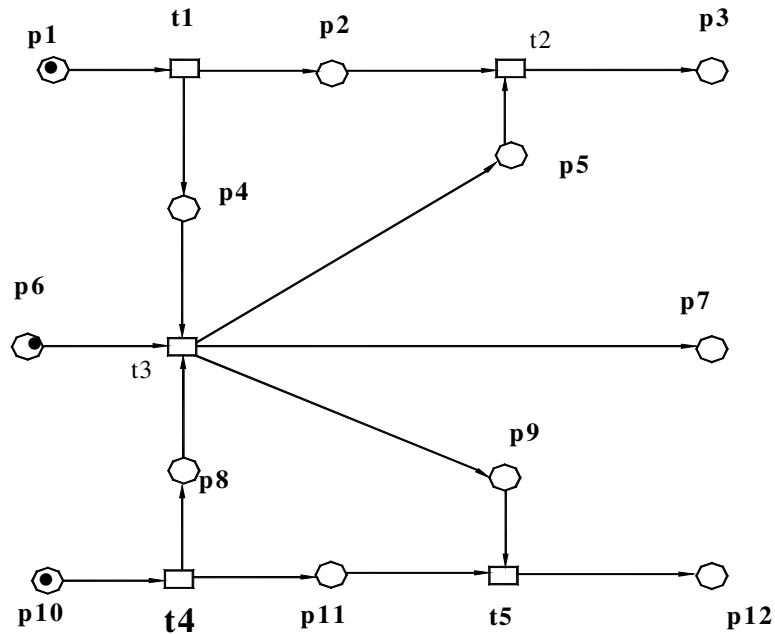


Figure 2-5 Fused net obtained from Figure 2-4

V. The Principle of Algebraic Representation for Petri Nets

For each graphical representation there is an algebraic representation containing equivalent information. It contains the set of places, transitions, and arcs, and additional information such as inscription.

2.2.4 Basic Definitions

In this part a formal definition of a net, place/transition nets and colored Petri nets are given.

2.2.4.1 Formal Definition of a Net

The base of all Petri net models is the definition of a net [7].

Definition 2.2.4.1.1 a net is a triple $N = (P, T, F)$ where

- i. P is a set of places,
- ii. T is a set of transitions, disjoint from P , and
- iii. F is a flow relation $F \subseteq (P \times T) \cup (T \times P)$ for the set of arcs.

If P and T are finite, the net N is said to be finite.

For the net described in figure 2-5, P , T and F are given by:

$P = \{p1, \dots, p12\}$, $T = \{t1, \dots, t5\}$, $F = \{(p1, t1), (t1, p2), (t1, p4), \dots\}$.

The holding of a condition is represented by a token in the corresponding place. In the net N of Figure 2-5 such token show the initial state $m1$. The occurrence rule for transition is illustrated in Figure 2-6 using transition $t3$ of Figure 2-5. Transition $t3$ “may occur” or “is activated” if all pre-conditions hold (are marked by a token) and no post-condition holds. With the occurrence of $t3$ all tokens are removed from the pre-conditions (input places) and are added to the post conditions (output places).

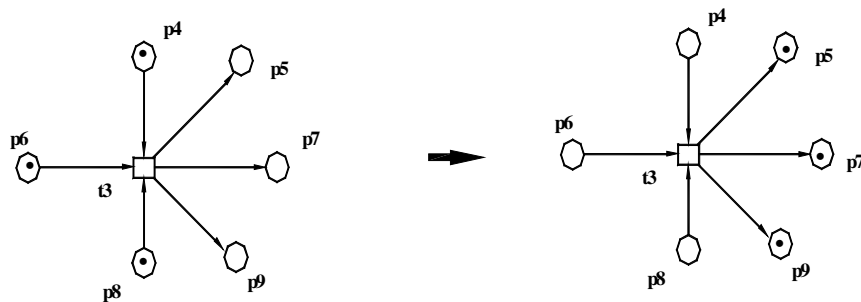


Figure 2-6 Transition Occurrence rule

Figure 2-7 indicates all possible occurrences of transitions. Thus, $t1$, $t4$ and $t2$, $t5$ are concurrent occurrences.

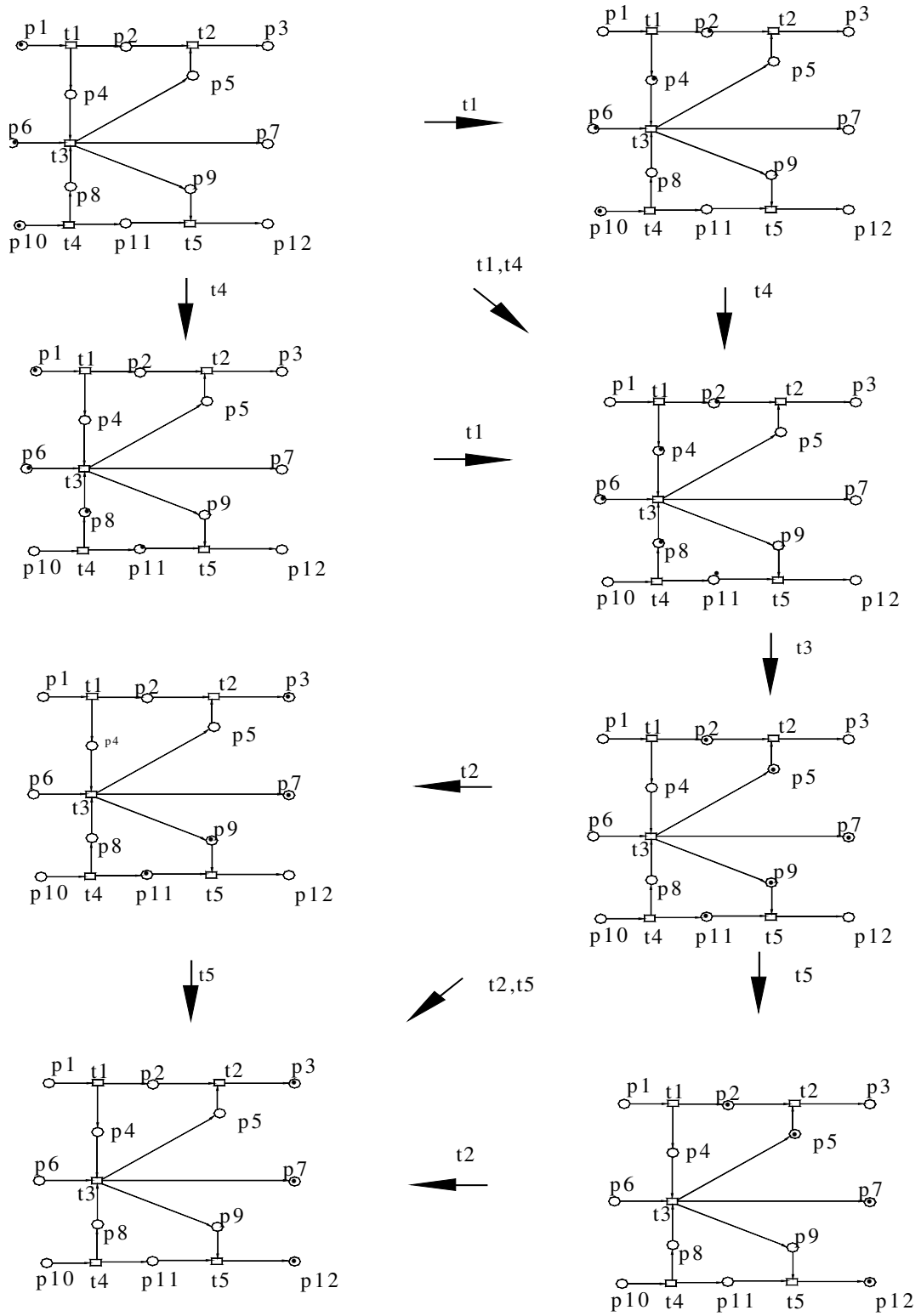


Figure 2-7 Occurrence sequences of transitions

To denote the places connected to a transition (and vice versa), the following notation is used. Given an element $x \in P \cup T$, then $\bullet x := \{y \in P \cup T \mid (y, x) \in F\}$ denotes the set of all input elements of x , and $x \bullet := \{y \in P \cup T \mid (x, y) \in F\}$ denotes the set of all output elements of x . If x is a place, then $\bullet x$ and $x \bullet$ denote the set of input and output transitions respectively. The corresponding notion holds for transitions. It is convenient to extend this definition to hold for a set $A \subseteq P \cup T$ by $\bullet A := \{y \mid \exists x \in A. (y, x) \in F\}$ and $A \bullet := \{y \mid \exists x \in A. (x, y) \in F\}$.

For instance $A = \{t1, p5, p11\}$ in the net of Figure 2.7, $\bullet A = \{p1, t3, t4\}$ and $A \bullet = \{p2, p4, t2, t5\}$. The notion of locality of a transition was used in the previous section to introduce concurrency of two transitions. Now it can formally defined as follows: $\text{loc}(t) := \{t\} \cup \bullet t \cup t \bullet$. Hence, $t1$ and $t2$ are concurrent if $\text{loc}(t1) \cap \text{loc}(t2) = \emptyset$. In a similar way we can also define the locality of a place $p \in P$ by $\text{loc}(p) := \{p\} \cup \bullet p \cup p \bullet$ [7].

2.2.4.2 Formal Definition of Place/Transition Nets

Place/transition nets are nets in the sense of Definition 2.2.4.1.1 together with a definition of arc weight.

Definition 2.2.4.2.1 A place/transition net (P/T net) is defined by a tuple $N = (P, T, \mathbf{Pre}, \mathbf{Post})$, where

- P is a finite set (the set of places of N).
- T is a finite set (the set of transitions of N), disjoint from P , and

-
- **Pre, Post** $\in \mathbb{N}^{|P| \times |T|}$ are matrices (the backward and forward incidence matrices of N). **C = Post-Pre** is called the incidence matrix of N.

There is an arc with weight $n > 0$ from a place $p \in P$ to some transition $t \in T$ iff **Pre** $[p, t] = n$ with $n > 0$ and there is an arc with weight $n > 0$ from a transition $t \in T$ to some place $p \in P$ iff **Post** $[p, t] = n > 0$. Hence, $F := \{(p, t) \in P \times T \mid \mathbf{Pre} [p, t] > 0\} \cup \{(t, p) \in T \times P \mid \mathbf{Post} [p, t] > 0\}$ is the set of arc N.

This leads to the following alternative but equivalent definition of place/transition nets, which is closer to the graphical representation.

Definition 2.2.4.2 A place/transition net (P/T net) is defined by a tuple $N = (P, T, F, W)$, where

- (P, T, F) is a net (Definition 2.2.4.1.1) with finite sets P and T, and
- $W: F \rightarrow \mathbb{N} \setminus \{0\}$ is a function (weight function).

2.2.4.3 Formal Definition of Arc-Constant Nets

For a colored net we have to specify the colors and, for all places and transitions, particular color sets (colors domains). Since arc inscriptions may contain different elements or, as in the case of P/T nets, multiple copies of an element, bags (multisets) are used.

Definition 2.2.4.3.1 An arc-constant colored Petri net (ac-CPN) is defined by a tuple

$N = (P, T, \mathbf{Pre}, \mathbf{Post}, C, cd)$, where

- P is a finite set (the set of places of N).
- T is a finite set (the set of transitions of N), disjoint from P ,
- C is the set of color classes,
- $cd : P \rightarrow C$ is the color domain mapping, and
- $\mathbf{Pre}, \mathbf{Post} \in \beta^{|P| \times |T|}$ are matrices (the backward and forward incidence matrices of N) such that $\mathbf{Pre} [p, t] \in \text{Bag} (cd (p))$ and $\mathbf{Post} [p, t] \in \text{Bag} (cd (p))$ for each $(p, t) \in P \times T$. $\mathbf{C} = \mathbf{Post} - \mathbf{Pre}$ is called the incidence matrix.

In this definition β can be taken as the set $\text{Bag} (A)$, where A is the union of all colors sets from C . the difference operator in $\mathbf{C} = \mathbf{Post} - \mathbf{Pre}$ is a formal one here, i.e. the difference is not computed as a value.

2.2.4.4 Formal Definition of Coloured Nets

In a colored Petri net the incidence matrices cannot be defined over $\beta = \text{Bag} (A)$ as for arc- CPNs. For a transition the different modes or bindings of a transitions t have to be represented. These are called colors, and are denoted by $cd (t)$. Therefore the color domain mapping cd is extended from P to $P \cup T$. In the entries of the incidence matrices for each transition color, a multiset has to be specified. This is formalized by a mapping from $cd (t)$ into the bags of color sets over $cd (p)$ for each $(p, t) \in P \times T$.

Definition 2.2.4.4.1 A colored Petri net (CPN) is defined by a tuple

$N = (P, T, \mathbf{Pre}, \mathbf{Post}, C, cd)$, where

- P is a finite set (the set of places of N).
- T is a finite set (the set of transitions of N), disjoint from P ,
- C is the set of color classes,
- $cd: P \cup T \rightarrow C$ is the color domain mapping, and
- $\mathbf{Pre}, \mathbf{Post} \in \beta^{|P| \times |T|}$ are matrices (the backward and forward incidence matrices of N) such that $\mathbf{Pre} [p, t]: cd(t) \rightarrow \text{Bag}(cd(p))$ and $\mathbf{Post} [p, t]: cd(t) \rightarrow \text{Bag}(cd(p))$ are mappings for each pair $(p,t) \in P \times T$.

β can be taken as the set of mappings of the form $f: cd(t) \rightarrow \text{Bag}(cd(p))$.

Again, $C = \mathbf{Post} - \mathbf{Pre}$ is called the incidence matrix.

2.2.5 Using Petri nets in Manufacturing System

To get an insight into the use of Petri nets in the manufacturing system modeling, the figures shown below present a series of models corresponding to some basic components such as machines and buffers or stores [7].

- Figure 2-8 describes abstract model for three different transportation systems. In the two cases the interactions with the rest of the system are represented by means of the transition tI and tO , which model the loading and unloading of parts in the module.

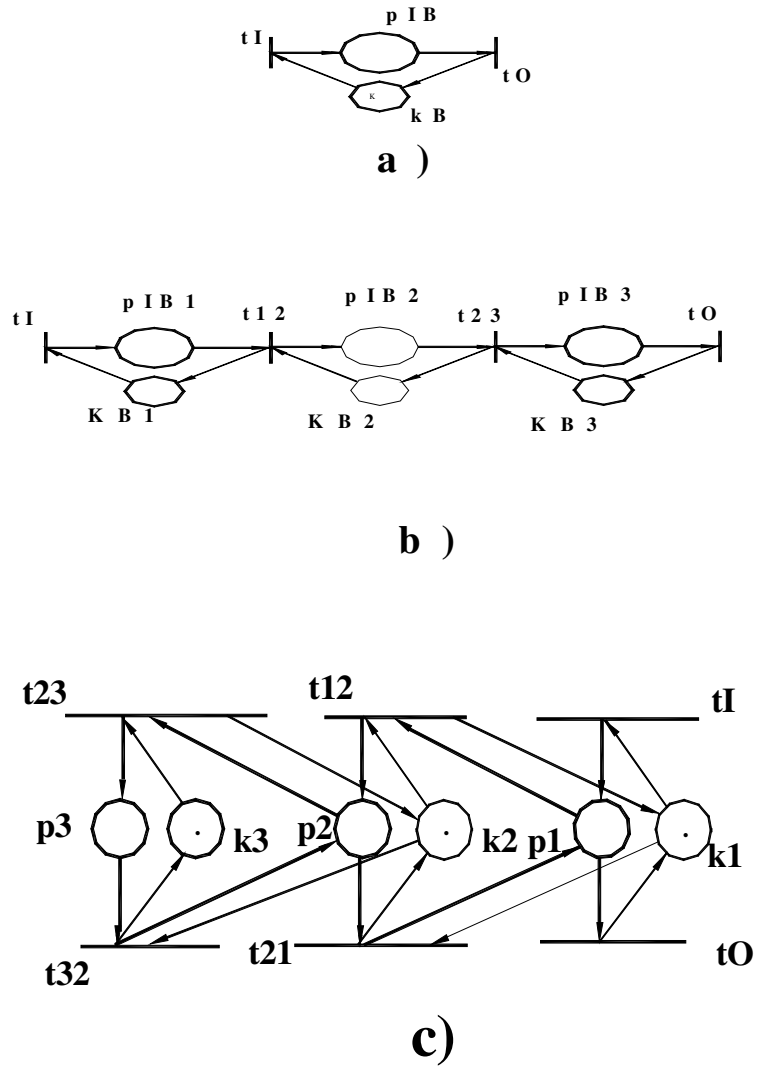


Figure 2-8 a) A generic model for a storage device; b) A model for a FIFO device; c) A model for a LIFO device.

Figure 2-8a is a model for a buffer (also a store) with capacity of k parts. Notice that if we take $k=1$ this PN can also model a robot for instance. Figure 2.8b is a model for a FIFO queue with capacity for three parts: there are three positions that can be accessed sequentially in an ordered way. Finally Fig. 2-8c models a LIFO module. This module

represents the set of states that can be reached, but not the firing sequences. Notice that nothing prevents the sequence $(t_{12}t_{21})$, which of course, must not be allowed. In the examples introduced; nothing is said about control; focus is made only on the modeling of the structure of the component. In all these cases we are assuming that the time necessary for the execution of the operation related to each transition is negligible.

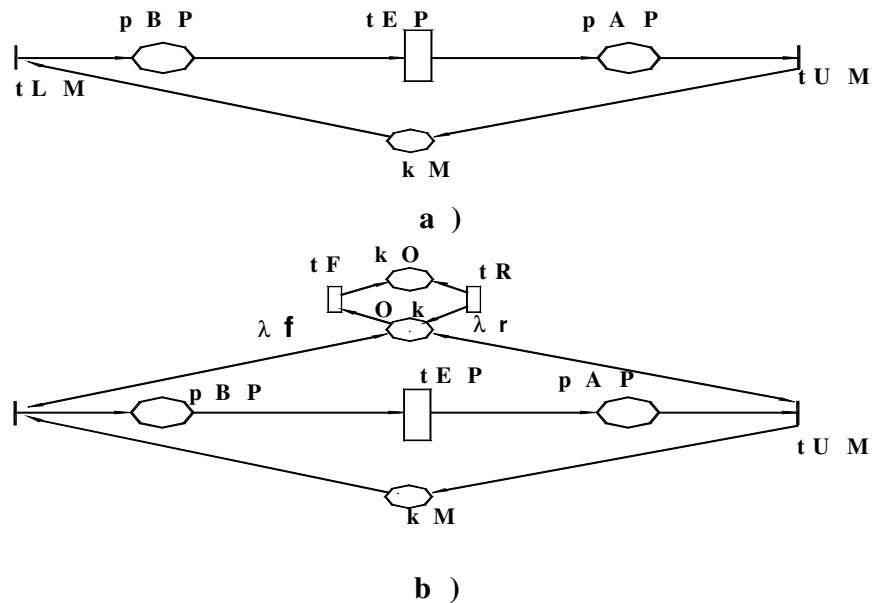


Figure 2-9 a) A model for reliable machine; b) A model for unreliable machine

Figure 2-9a shows a model of a reliable machine (breakdown is not considered). When the part is loaded into the machine (transition tLM is fired) the processing starts and, once the machine has finished, a token is put in place pAP and then transition tUM can be fired. Notice that in this model two different types of transitions appear. Thick black transition represents “immediate” actions (here immediate transitions model system actions whose execution time is negligible); square white transitions models system

actions whose execution time can be modeled by means of probability distribution function. Usually this function is taken to be an exponential, and the λ parameter, which appears near the transition, is the firing rate ($1/\lambda$ is then the mean time needed for the processing of the part).

Figure 2.9b shows the model of the same machine, but here the possibility of a breakdown has been considered. In this model, in order to load or unload a part it is necessary that the machine be in the Ok state (there are arcs joining tLM and the Ok place and also tUM and the Ok place). The machine breakdown with a rate λ_f and repaired with a rate λ_r .

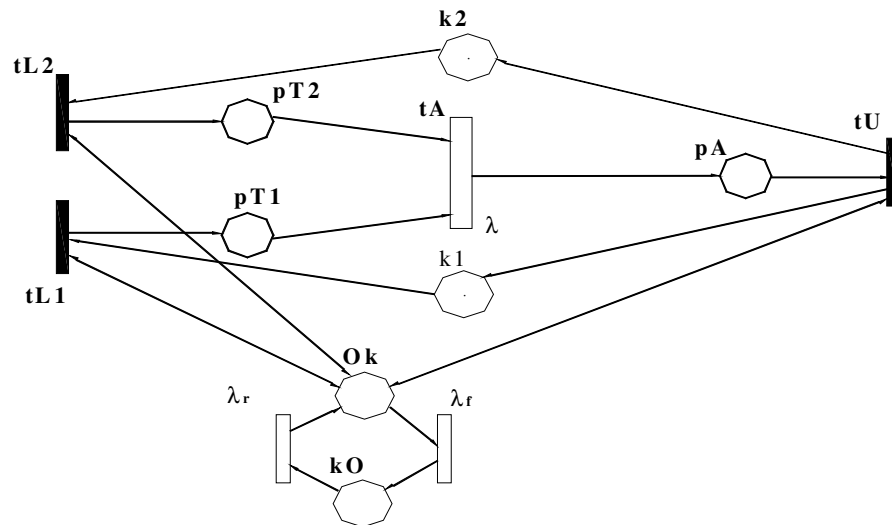


Figure 2-10 A model for unreliable assembly machine

Finally Figure 2-10 shows a model of unreliable assembly machine. Notice that in order to start the assembly; it is necessary to have loaded a part into $pT1$ and another one into $pT2$. Here λ is the time needed to carryout the assembly. The model for disassembly

machine is almost the same: it suffices to reverse the arcs related to transitions $tL1$, $tL2$, tA , and tU .

From the above figures, when using ordinary Petri nets for the modeling of automated/Flexible manufacturing systems, the main elements (places, Transitions, arcs, and tokens) can have different meanings [7]:

- i. A place can be used for the modeling of different elements: a) States in which a part that is being processed can stay. b) A partial state of a resource.
- ii. A transition usually models a sequence of system action that changes the state of some system elements. Another action that is usually modeled by means of the firing of a transition is the movement of a part between two different locations in the system. Also a transition can model the change in the state of a system resource.
- iii. Usually an arc models either a pre-condition or the flow of parts among resources.
- iv. Tokens can also have different meanings: availability of resources and represents parts that are stored in a buffer or at process. In the case of colored Petri nets, a token can carry a great deal of information.

As stated previously, one of the main problems when dealing with real applications is the complexity of the model. From the design point of view, different applications have adopted.

- i. *Hierarchical/compositional approach*: the idea behind these approaches is the modeling of the systems in a structured way. Using the first approach (also called top-down) the modeling is carried out in several steps. At each step more detailed elements

are considered. In general the process consists of the replacement of some net elements (place, transition, and path, sub-net) by some sub-net in which the replaced elements have been refined.

When using the compositional approach (bottom-up) the global model is obtained by means of simpler models that are combined using some composition mechanism: fusion of places common to a set of sub-modules (modeling the same elements), synchronization of a set of transitions, and fusion of a common paths.

Although the two approaches help in the design process, both present one important drawbacks: it is very difficult to ensure that in the modeling process (either compositionally or in a hierarchical way) desired system properties (such as boundedness, reversibility, deadlock-freeness, liveness) may not be preserved from one step to the next. This means that, we can have two live modules whose composition is non-live. The same is true for hierarchical approach. It can happen that at a given abstraction level the system behavior is live, but when a new refinement is given the new “view” of the system is not live.

To cope with the problem mentioned above, two different solutions have been adopted.

- a. The kit of refinement/composition mechanisms is restricted. This means that composition of modules or refinement must be done only when special condition hold.

b. The work is restricted to some special sub-classes such as free choice nets, marked graphs, modules synchronized by means of message passing or (restricted) resource sharing.

ii. *High level Petri net approach*: High-level Petri nets (Arc-Constant Nets), and Coloured Petri nets as a particular case, are very useful tools for modeling complex systems in which different components have analogous behavior. One of the main advantages of this class of net is the compactness and the clarity of the models generated. However, usually, they have the drawback that it is difficult to analyze properties.

iii. *Object-Oriented (OO) and Artificial intelligence (AI) approaches*: much work on the use of Petri nets in manufacturing systems has tried to extend the capacity of Petri nets for the modeling of systems with the capacity of AI techniques for reasoning about properties. Here two different approaches have been adopted. In some papers, elements of AI are used to implement and control the Petri net. Other work uses AI elements to implement the Petri net (tokens or places as frames and transitions as rules, for instance), and use the semantics of the underlying Petri net for simulation and control of the system [7].

The use of one of these approaches does not exclude the use of another. For instance, we can adopt both a hierarchical approach and a compositional approach in order to obtain a colored Petri net model.

However, once we have obtained a Petri net model for the system under consideration, what Petri net properties are interesting for the model? Let us enumerate some important behavioral properties. It is important to notice that some of the following properties are related: one property can be deduced from others [7].

- *Reachability*. From the model point of view, this property determines whether a given (vector) marking is reachable from the initial marking. From the real system point of view, this property indicates whether a system state is reachable from the initial configuration. It can be used to answer question such as the following: it is possible to reach a state where machine M is processing two parts while robot R is busy and machine M' is free? It is possible to reach a state in which buffer B is full? The answers to a set of well-defined questions can be used to establish a correct system design. A second related property is coverability. From the Petri net point of view, this determines whether a reachable marking is greater than or equal to another given marking. From this kind of property, less complete information can be obtained; but this information can be used in a similar way that provided by reachability properties.
- *Boundedness*. This property determines whether the number of tokens in a given place is always smaller than or equal to a given constant k. usually in FMS/AMS domains, using the possible meanings of a place as stated previously, all places must be bounded; the model is perhaps, incorrect. If a model is correct and a place is detected to be unbounded, some overflow problems may arise. A related property is safeness (1-boundedness).
- *Reversibility*. When verified, this property determines that the initial state can be reached from each reachable state. In the application domain considered, this property

means that each possible erroneous situation has been considered by means of some error recovery strategy. The erroneous situations include the case of system deadlocks and the case of resource failures.

- *Deadlock-freeness/liveness.* A Petri net system is said to be deadlock-free if at each reachable marking there exists at least one transition that is enabled. In our application domain this means that it is always possible to make some production activity. Deadlock-freeness is not enough for this domain. It is possible to have a part of a system that can always run correctly, but also another part of the system that is in a deadlock. For instance, it is possible to have one type of part being correctly processed, as well as other parts whose processing has been started but cannot be finished. Thus deadlock-freeness cannot be strong enough for highly automated systems; liveness is a stronger property. A Petri net system is said to be live if for each reachable marking it is always possible to fire any transition. In the application domain considered, this mean that it is always possible to execute the system actions modeled by any transition. As a consequence the processing of each part, once started, can always be finished: the transitions “driving” a token (modeling a part) to the system output can be fired. Thus the processing of the part can be finished. This also means that if there are always new raw materials, their processing can be carried out.

As has already been intuitively shown by the models of components in a manufacturing system, Petri nets have also been used for performance evaluation of manufacturing systems. To do this, the notion of time has been added to the Petri net models.

Introducing time constraints is necessary if we want to consider performance evaluation or the scheduling of the real-time control problem.

Usually time has been introduced in one of two different ways: either associated with places or with transitions. The second way is more natural since transition usually model system activities (which need some time to be executed). In this approach, time is considered as follows: a transition can fire some time after it is enabled with respect to the number of tokens in its input places. This time either deterministic, as in timed Petri nets, or random, as in stochastic Petri nets.

CHAPTER THREE

FACTORY BACKGROUND

Modern brewing was started in Addis Ababa in 1925 at St. George brewery, with initial capacity of 176 bottles/day, which was intended only to satisfy the demands of the guests of the imperial palace, and in June 1967, Meta brewery started its production, which was commissioned by the Italian Company called "Fred Barbry"[Abraham and Mesfin, 2003].

3.1 Company Profile

Meta Abo Brewery S.C, a public enterprise, was established in June 1967. It is located about 30km South West of Addis Ababa, nearby Sebeta town. It produces bottled beer and draught beer for local consumption. Currently it employs 596 permanent and 13 contract workers. It's production capacity for the product mentioned above is 500,000hl per annum. The total asset of the brewery is estimated to be Birr 224,965,898. The main inputs for the production of the beer are malt, sugar, water, hops, brewing chemicals, etc. The total area of the factory is 36.96 hectares. Unutilized land within the factory compound is used for agricultural purposes.

Meta Brewery is currently located at the top in manufacturing and distribution of lager beer in the country. However, its market is being contested by other manufacturers, the market share is estimated at 30-35% of the total.

3.2 Manufacturing Processes

The manufacturing system set up of Meta Abo brewery consists of the following four units: -

- Utilities;
- Brew house
- Fermentation and maturing section and
- Packaging section

a) Utilities: The utility section is responsible for the supply of auxiliary inputs and services, such as electric power for the factory, treated water for boilers and brewing, compressed air, steam, carbon dioxide, and cooling media. In addition modern breweries have facilities for factory waste treatment before discharging to the environment.

Efficient and reliable operation of utilities could help breweries to optimize cost of production and improve other performance parameters. In this regard, Meta's utility setup, and equipments currently in use will be discussed from performance point of view.

i. Power Supply: In general, economic use of available electric power should be given a prime importance to any manufacturing firm. The power distribution in Meta, which should preferably be organized as a group of subsystems, is configured in such a way that difficult to understand the architecture. Two diesel generators of about 1.8 MW capacity are installed as a standby system. At the time of the study, the standby diesel generators are not automatically interlocked, with the main to supply power during failure.

In light of the above, problems inherent to the power distribution system in Meta are the following:

- Lack of reliability
- Poor operational safety
- Elongate machine down time in some cases

ii. Water treatment plant: Water either from boreholes or springs is not right away suitable for brewing and makeup for boilers; rather it needs treatment to meet stated specification. Thus the water treatment plant should work accurately to safe guard the boilers from scale formation and the quality of the beer to the required standard. No treatment is employed in Meta for brewing, instead spring water tapped from ‘Mogle Mountain’ used directly for the purpose. But, ion exchanges are employed for water treatment for boilers.

iii. Steam Generation Plant: Boilers are necessary to supply steam necessary for process heating in breweries. In Meta Brewery 4 boilers of total capacity 30,000 kg/hr are installed for the purpose of process heating.

The main energy sources used in breweries are fuel and electricity. Fuel is either furnace oil or coal. As a benchmark, Table 3-1 indicates the average energy distribution in a typical brewery extracted from the Internet.

Table 3-1 Average energy distributions

Description	Thermal (%)	Electrical (%)
Energy consumption By source	70	30
Energy cost by source	52	48

Meta’s average energy cost distribution is calculated and presented in Table 3-2.

Table 3-2 Energy cost distributions by source for the year 2003.

Source of energy	Cost (‘000 birr)	% Share
Furnace Fuel	5303	70
Electricity	2273	30
Total	7576	100

Comparing related figures of the above two Tables, one is the benchmarking and the other is the actual performance of the factory, Meta’s fuel consumption cost proportion i.e., 70% is much greater than the benchmark figure, 52%. This is a result of low electricity unit price in Ethiopia. In addition, low efficiency of steam system can contribute to this condition due to the following lax:

- Low level of boiler efficiency as they worked for prolonged period of time
- Poor insulation of the steam distribution system

Nowadays, boilers are equipped with PLC controller and at the same time interlocked with the down stream and upstream processes for optimum performance of the plant. The existing status of boilers and the level of technology in Meta can be regarded as unsatisfactory and obsolete respectively; therefore a lot should be done to upgrade performance of the plant.

iv. Compressed air plant: Compressed air is required for various functions in the brewery such as opening and closing of pneumatic valves in all sections of the production

and utilities and discharge of spent grains in the brew house. Production downtime (on the average one hour a day) in Meta is caused by the failure of compressed air plant. Meta once again, like the boilers, has to give due attention to the maintenance system of compressed air production plant so that failures are avoided during operation.

In general case, breweries use two or more air compressors depending on the capacity requirement. A PLC controller with operator control panel facilitates reliable and safe operation of the system. In Meta Brewery 2 air compressors with working pressure of 7 bars and a total capacity of 53 m³/min are installed to supply the need of the factory.

v. Carbon dioxide plant: Carbon dioxide is given off from fermentation and breweries have provisions to collect this gas. The collected gas is then compressed, cooled and stored for further use by the factory and distribution for clients. Meta is equipped with such facility, but during this study, the unit was not functioning.

Using carbon dioxide in beer processing provides many advantages, to mention some:

- a. Flavor and sense of good test
- b. Biological stability and serves as a shield to protect oxidation
- c. Pressurize the beer so that to limit foam creation during the process

In Meta Brewery 1 carbon dioxide compressor with a capacity of 180kg/hr and working pressure of 16 bars is installed for production of compressed carbon dioxide. During the

study Meta was using compressed air as a substitute for carbon dioxide, which has great impact to the quality of beer produced.

vi. Cooling media generation plant: The major refrigeration loads are fermentation, wort cooling, lager cellars and fermentation rooms. Brews are made successively with fewer time gaps for economic use of facilities in the brewery. Each brew will stay in process for three to four weeks time, and in all these stages it needs cooling. To overcome the cooling load requirement by all functional units, the plant needs to operate continuously and reliably to meet the totality of the cooling load demand consistently. Electrical energy is used as power source for refrigeration. In Meta Brewery, 3 ammonia compressors of 240,000 kcal each and 1 with 300kw capacity are installed to overcome the cooling load required all over the brewing process.

Failure of this plant means stored beer loss. In other words, non-stop operation of the plant, by implementing appropriate maintenance and operation procedure, is a prime importance that is required to produce quality beer. In all state owned breweries, including Meta, as they use traditional control of this plant reliable supply of the cooling media is not guaranteed. In light of the above, features of Meta cooling media generation plant is described as stated below.

- Low level performance efficiency since the equipments are operated for a prolonged period of time
- Low level of cooling capacity since it uses chilled water as cooling medium.

- The improper lay out of equipments contribute a lot to unsafe working condition

vii. Waste treatment plant: There is no waste treatment plant in Meta Abo Brewery; instead the factory discharges the waste as it produced. The wastes generated from breweries are expected to have higher biological oxygen demand (BOD) and chemical oxygen demand (COD). Breweries, which employ environmental friendly production system, implement a waste treatment plant and hence reduce the BOD and COD to the limit not to pollute the environment. Such a plant is efficiently functioning in Dashen brewery, privately owned local company.

Even though a waste treatment plant is thought as a cost burden in view of traditional management, working friendly with the environment will give an opportunity to improve other process with regard to cost saving and new market. Meta's management must be open to new ways to be able to justify financial investment of the plant.

b) Brew House: Meta conducted an expansion and modernization projects in its brew house, hence in relative terms, the machineries and equipment setup, and their control systems are in a better condition than other sections. But it lags behind compared to other modern breweries such as Dashen.

The main processes in the brew house are:

1. Mashing: Milled malt (grist) is mixed with hot water. The temperature is then raised to 63°C and 74°C at set time intervals. The heating agent is steam.

2. Wort separation: Wort, the liquor from mashing is separated from the spent mash. During the wort is at separation, a small amount of heat is lost from the liquor.

3. Wort Boiling: Hops are added to the wort and this mixture is boiled, typically for 90 minutes, in a jacketed vessel made of stainless steel. The heating agent is again steam. The total evaporation for the process is 8-10% by volume.

4. Hop Separation: The boiled wort goes to another vessel where the hops are extracted. Meta uses whirlpool to separate the hot trub, centrifuges are still sometimes used in other breweries.

5. Wort Cooling: The Wort then passes through heat exchangers where it is cooled rapidly by cold water and brine. Meta uses water for this purpose.

6. Cleaning in place (CIP): The CIP unit located in this particular section is intended to clean all the kettles sequentially. Meta in addition equipped with high tech CIP unit.

c) Fermentation and Maturing Section: The main processes in the fermentation and maturing section are: -

1. Fermentation: Yeast is added to the cold wort and this is aerated and fermented in open/closed vessels (usually stainless steel). The temperature is maintained at 0-10 °C for a period of six days, by circulation of cold brine. Fermentation is an exothermic process. Carbon dioxide is given off and Meta has provision to collect this gas. The temperature in the areas where fermenters are located is maintained at 11-12 °C. Some characteristic features of Meta's fermentation process include:

- The temperature of the wort reaches 14 °C since water, which is exposed to the atmosphere, is used as a secondary refrigerant.

- It is difficult to maintain fermentation tanks as they installed in house with horizontal arrangement.

2. Maturation: The fermented beer is then taken to lagers where it matures over two to three weeks. Specific gravity at the end of maturation is about 1.6 with two percent of carbon dioxide in the beer. The characteristics feature of maturation is same to fermentation.

3. Filtration: The matured beer is then passed through filtration in which carbon dioxide, filter aids and water are used as input to the process and bright beer that is ready for packaging will be the output. In light of the above, Meta does accordingly, however equipments are arranged disorderly and compressed air that used for filtration process is exposed for continual leakage as observed during factory assessment.

4. Temporary Storage: Filtered beer is stored in the bright beer tanks for the purpose of decoupling the packaging and fermentation sections. Since these tanks are located at low potential than to its succeeding process, bottle filling. In some occasions this process faces problem of supply interruption due to low beer pressure.

d) The Packaging Section: The packaging section in Meta similar to other breweries constitutes two main divisions, bottle beer packaging and draught beer packaging. The facilities in bottle beer packaging unit comprised of partially modern equipments and some with obsolete ones. On the other hand facilities in draught beer packaging though small in number, are completely the result of an outdated technology.

Processes in the packaging section again divided into two main sub-sections: -

1. Bottled beer packaging; and
2. Draught beer packaging

- **Bottle beer packaging:** The main processes in Bottled beer packaging sub-section are:
 - a. **Bottle Uncasing and Washing:** Returned empty bottles go through uncasing and washing in which they receive a thorough cleaning.
 - b. **Filling and Sealing:** Bottles are filled with carbonated beer and sealed in the absence of any oxidizing agent.
 - c. **Pasteurization:** The filled bottles may then pass through a tunnel “pasteurizer”. The temperature is raised about 60 °C for a sufficient length of time to provide biological stability, and then cooled to room temperature.
 - d. **Labeling and Casing:** Emerging from the pasteurizer, the bottles are inspected, labeled, placed in boxes, stacked on pallets and carried by lift truck to the warehousing areas to await shipment.

- **Draught beer Packaging:** This process refers to the packaging of beer in keg for immediate consumption. Unlike other breweries, Meta’s draught beer is not pasteurized. The packaging operation of draught beer in Meta consists of keg washing with hot water, chemicals, rinsing, dosing of gas, filling of beer, and weighing.

CHAPTER FOUR

PROBLEM IDENTIFICATION AND FORMULATION

As discussed in the historical development section of brewing in Meta, brewing started not long ago and in the past regimes it has not been supported by appropriate technologies to flourish, instead a number of constraints imposed on meeting product quality, reduction of cost, inconsistency of product delivery (quantity and time), and absence of operational safety.

4.1 Contextual Factors

Manufacturing firms that meet delivery requirement, produce quality product, and introduce cost reduction and productivity improvement techniques have proved competitive and will stay in the market. Hence, product quality, manufacturing cost, and productivity are key factors need to be considered form manufacturing system analysis and evaluation point of view.

4.1.1 Product Quality

Quality is a characteristic of a product, as its size, shape and composition. Specifically, it is a characteristic that determines a product's value in the market and how well it will perform the function for it was designed. The quality of a product in general is expressed as a standard, and the quality of specific units of that product is measured in terms of the degree of conformance with the standard. Thus, the definition of quality must include

both the standard and conformance to the standard. Merely changing the standard does not change quality; quality must actually build into the manufacture of a good [1].

Among others areas within the firms where quality can be introduced into the product are:

i. Process design: The choice of machines and equipment will affect the quality of the produce at various stage of its processing. The layout employed, sequencing of operations and process timing, material handling and storage method used, and even maintenance policies can influence amount of defective units produced.

ii. Raw materials: In general, the better the quality of the raw materials, the better the quality of the finished product. Raw material used for brewing of beer includes: Water, Malt, Hops, Sugar, and Chemicals.

iii. Employees: In addition to materials and equipments, the third major input category is people. To achieve the quality goals, employees must be trained properly in the quality aspects of the task they are to perform, and they must be motivated to produce at the level of desired quality.

iv. Operations of the production process: Manufacturing firms might have the best equipment, the best materials, and the best employees, but if it fails to manage the quality function in its-day-to-day operations, it may not produce an acceptable product. The maintenance policy for equipment may be sound but not implemented carefully. House keeping could be lax, resulting in damage to the product during manufacturing. Supervisory styles, communications, scheduling, store control, wage and salary policies,

and many other operating policies, rules and procedures can determine whether the firms produces at or below its producing capability.

v. Packaging: Many firms incorrectly assume that their quality responsibilities end when the items come off the assembly line if it passes final inspection, a quality product has been produced; the customer however does the final inspection. If a product fails to meet the customer's quality criteria when it is put to use, then it is a defective, packaging is the first of several activities between the assembly line and the point of purchase that can influence the quality of the product. Packaging that is cost effective and commensurate with the characteristic of the product must be selected.

4.1.2 Manufacturing Cost

a. Manufacturing costs. Manufacturing costs are generally classified from the two standpoints [2].

I. Morphological classification:

- (1) Material costs-occurs by consuming materials.
- (2) Labor cost- occurs by utilizing human labor force.
- (3) Overhead- occurs by consuming cost elements other than the above two.

II. Economical classification:

- (1) Direct cost- incurred directly for producing a piece of product.
- (2) Indirect cost- not directly associated with a particular product

b. Unit Cost. One of the best “how are we doing?” measures available to a production manager is unit cost. If the production manager is doing a good job of controlling the quantity, quality and price of the inputs and is carefully planning, scheduling, and controlling the process, those efforts will be reflected in a favorable unit cost.

4.1.3 Productivity

Productivity is the ratio of value of output to the value of input.

$$\text{Productivity} = \frac{\text{value of output}}{\text{value of input}}$$

Outputs include all products-goods produced by the individual worker or by the business firm. Inputs include the four basic factors of production, labor (including direct, indirect, and managerial), material (direct and indirect such as supplies), capital (land, facilities, equipments, inventories, and other assets), and energy (gas, electricity, heating oil, and fuel).

On the other hand, an increase in production does not necessarily mean an increase in productivity. If the input of resources goes up in direct proportion to the increase in output, the productivity remains the same. If input increases by a greater percentage than output, higher products will be achieved at the expense of reduction in productivity. In short higher productivity means to produce more with the same expenditure, or with a minimum increase in expense, or the same amount is produced at less cost in terms of resources.

However, productivity is affected by many external and internal factors. Some of the external factors, influencing productivity are: the national and international policies, infrastructure supports, cultural practices, and the availability of technology, organizational policies, climate, incentives and information. And the internal factors to be mentioned are: unsuitable personnel administration policies leading to a low level of satisfaction and involvement; poor maintenance system and low level of maintenance awareness; low skill of personnel; inappropriate choice of design, tools, material and equipment; undefined standardization and quality policies; inadequate plant layout and materials handling systems; poor planning, controlling and communication systems; unsafe and unhealthy working environment.

4.2 Performance of the Factory

The gap analysis to the performance of Meta is analyzed from the viewpoint of product quality, production cost, and productivity discussed above. To facilitate the analysis, interviews were made to senior management staffs. The question presented to the management team is summarized as follows:-

i. Marketing related:

- Demand and supply condition of the factory
- Customer test to the factory product
- Market share

ii. Technical related:

- Maintenance policies, breakdown handlings and house keeping procedures
- Reliability of equipments and safety of operation

- Equipment controller and response time to parameters change.
- Level of facilities integration

iii. Human resource development

- Age group of employees in the factory
- Motivation scheme employed in the factory
- Training of employees
- Employees' attitude towards work and learning
- Work procedure for employees to follow

iv. Quality assurance

- Quality management system employed in the factory
- Methods used for performance analysis
- Quality consciousness of employees in the factory

Responses

i. Marketing

- In our case demand is higher than supply, we only hold minimum stock for safety purpose.
- There is no quality complaints from customer, instead blames arises because of supply shortage.
- The factory owned the biggest market share in the domestic market estimated 30-35% of the total.

ii. Technical

- Repair is the maintenance activity currently employed in the factory.
- Some equipment is reliable while others are not. Sudden production stoppage is a frequent occurrence in the factory.
- As the factory is equipped with high-tech. and conventional ones, sensitivity of equipment control to the set parameters varies accordingly.
- As to the facilities integration, it is located at lower side.

iii. Human resource development

- Most of the employees' age is above 40.
- The factory is on the process of devising a method for motivating employees.
- Attitudes of worker are not appreciated. Most of the employees strive strongly to get benefit without contributing much to be considered.

iv. Quality assurance

- Quality control activities are conducted by few people who belongs to this department
- None of those magnificent quality analysis tools are in practice, however, quality related data are collected from the shop floor, analyzed, and the result is forwarded to the production department for decision and implementation.
- The quality consciousness among employees and the factory as a whole is good, however implementation of advanced quality management system couldn't get significance for unknown reasons.

4.2.1 Beer Quality in Meta

The production of beer should be one of the most closely supervised and controlled manufacturing processes. Along with the interview result and issues discussed in the factory background, cause and effect analysis technique is employed in facilitation of the analysis process as depicted in the diagram shown below.

i) Factors related to product quality

- a. Employee (motivation, training, attitude, working procedure).
- b. Material (Malt, Hops, Sugar, and others).
- c. Measurement (processing time, operational parameters, standards, customer test).
- d. Machines (controls, safety, and defective equipment).
- e. Methods (Machine setting, processing time and working procedure).

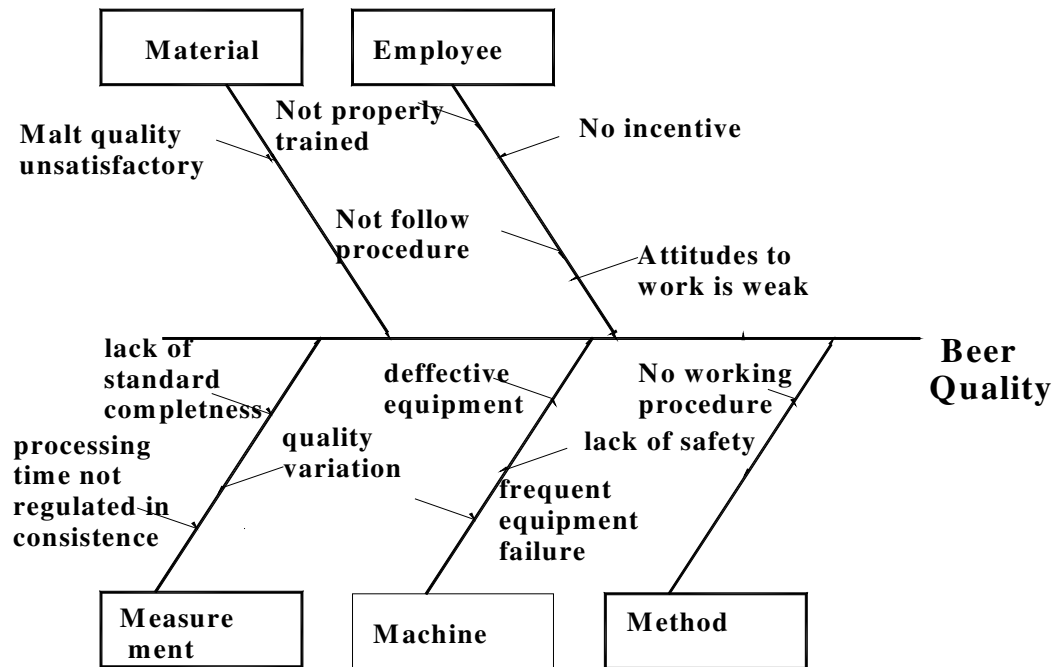


Figure 4-1 Cause and effect diagram for product quality analysis

ii) **Summary of Analysis**

a. Employee

- Motivation of worker is poor
- Training is targeted only for few people at top level
- Employee attitude towards their work is weak
- Working procedure is not available

b. Material

- The quality of malt currently in use is not satisfactory

c. Measurement

- Processing time is not consistent since power failure and operator negligence are frequent occurrence in the brewery
- Operational parameters are not kept to the requirement in consistence since there is no mechanism employed to safe guard the correctness of operations outputs.
- Standards are not complete as the packaging quality specifications are not in existence.

d. Machines

- Some of the machineries (washing, and tunnel pasteurizer), which have significant impact in the product quality, are equipped with conventional controller.
- Operational safety is not given due emphasis as dosing of corrosive chemicals is done manually with minimum protection.
- The carbon dioxide plant is not currently functioning so that the factory uses compressed air as a substitute, which has negative impact to the quality of the produce.

From the above analysis it can be concluded that the beer currently produced in Meta cannot be regarded as high quality.

4.2.2 Manufacturing Cost of Beer in Meta

Manufacturing cost in Meta is classified into three major components, namely;

- (1) Material costs-occurs by consuming materials.
- (2) Labor cost- occurs by utilizing human labor force.
- (3) Overhead- occurs by consuming cost elements other than the above two

Cost data for the year ended June 2003 are collected for analysis and Table 4-1 shows cost distribution among production divisions while Table 4-2 indicates the share between the two product types namely, bottled beer and draught beer.

Having the beginning work in process 2,651,714Eth. Birr and ending work in process Eth. birr 3,085,038, the net production cost for the year in the brewery was found 59,790,318 Eth. Birr (see Table 4-1).

From Table 4-2, bottled beer production consumed 65% of the total manufacturing cost while the remaining 35% was expended for draught beer production. The unit production cost of bottled beer and draught beer in keg were found Eth. birr 0.57 and Eth. birr 42.38 respectively.

Table 4-1 Manufacturing Cost Distribution for the year ended 30th June 2003.

S/no	Description	Brew house (Eth. Birr)	Fermentation (Eth. Birr)	Filtration (Eth. Birr)	Draught Filling (Eth. Birr)	Bottling (Eth. Birr)	Total amount (Eth. Birr)
1	Material cost	30,516,157	781,019	2,090,081	50,722	4,398,279	37,836,260
2	Labor cost	914,579	855,846	765,958	567,588	1729502	4,833,475
3	Overhead	3,915,274	3,582,264	3,584,747	1,816,966	4,654,653	17,553,906
Grand Total							60,223,642

On the other hand, Meta has great potential to reduce the manufacturing cost by reducing the various performance inefficiencies discussed in the previous section. The manufacturing criteria or principle Meta needs to be employ shall be profit maximization.

Table 4-2 Manufacturing cost distribution between product types for the year 2003.

Product types	Unit of meas.	Quantity ('000)	Prod. Cost ('000 Birr)	Percentage share	Unit cost (Birr)
Bottled beer	300ml	68,970	39,145.5	65	0.57
Draught beer	30lit	487	20,644.9	35	42.4
Total			59,790,319	100	

4.2.3 Productivity in Meta

Outputs include all products (goods) by the individual worker or by the business firm. Inputs include the four basic factors of production i.e. labor (including direct, indirect, and managerial), material (direct and indirect such as supplies), capital (land, facilities, equipments, inventories, and other assets), and energy (gas, electricity, heating oil, and fuel).

Even though reliable information in this research work is not obtained for benchmarking purpose, analysis is made on the available data and based on personal observation. To this end, productivity in Meta is discussed from the point of labor, material, capital, and energy.

i. Labor Productivity: The total number of permanent employees in Meta amounts 596, in addition overtime work is highly used to compensate the man hour shortage specifically in the production and technical departments which brings the number roughly to 900 on the basis of normal working hours. Table 4-3 shows average labor productivity in Meta calculated for two consecutive years, 2002 and 2003.

Table 4-3 Labor Productivity.

Description	2001/2002	2002/2003
	Performance	Performance
Sales ('000 Eth. birr)	93,697.3	89,771.5
Payroll ('000 Eth. birr)	4,654	4,833.5
Labor productivity	20.13	18.57

To compare the performance of Meta in the light of the above parameter, Dashen, a privately owned automated local brewery is taken as a reference. The labor productivity, though not reliable is estimated to 24.5. Comparing the actual performance with the estimate, labor productivity in Meta is low.

ii. Material Productivity: Material productivity that refers to the ratio of the amount of beer out to the amount of input materials used is calculated for its productivity and professional arguments will be proposed to come to a conclusion. Table 4-4 shows average material productivity in Meta calculated for two consecutive years, 2002 and 2003.

Table 4-4 Material Productivity

Description	2001/2002	2002/2003
	Performance	Performance
Sales ('000 Eth. birr)	93,697.3	89,771.5
Material consumption (‘000 Eth. birr)	38,760	37,836.3
Material productivity	2.41	2.37

Loss of beer as obtained from cost sheet amounts 36,458.7Hl per annum, which is 0.087% by volume. As information obtained during informal discussion with the quality people, the amount of extract from a kg of malt, the brewery currently in use, is low compared to imported ones. In the light of the above, material productivity in Meta can be considered as low.

iii. Capital Productivity: Capital productivity refers to the output to input ratios of land and facilities. Table 4-5 shows capital (machineries and equipments) utilization in Meta calculated for year ended 2003.

Table 4-5 Productivity of installed facility

Description	Performance year (2003)
Installed capacity (Hl of beer)	500,000
Actual production (Hl of beer)	415,512
Capacity utilization	0.83

The above table indicates that Meta employs only 83% of its production capacity with the absence of market constraint. In light of the above, it can be concluded that Meta is inefficient in its capital use.

iv. Energy Productivity: In this case, the ratio of beer production to the utilities used is considered as a measure of energy productivity in the brewery. In light of the above, Meta’s utility consumption (furnace fuel and electric power) in relation to the actual production is calculated and summarized as shown in Table 4-6.

Table 4-6 Energy Productivity

Description	Performance year (2003)
Actual production (HI of beer)	415,512
Total energy consumption (Eth. birr)	7,576,141
Energy productivity (HI/Eth. birr)	0.055

The above table indicates that Meta’s energy productivity is 0.055HI/birr or 18.2 birr per hectoliter of beer. When this figure is compared to that of Dashen (0.069 HI/Eth. birr) or 14.5 birr, energy productivity of Meta still fall to the low side.

4.3 Statement of the Problem

The manufacturing system of beer bottling line in Meta Abo brewery lacks integration among different operations and efficient control system, and on top of this lowers the level of beer quality, higher production cost, and productivity below the acceptable standard. The parameters whose impact on the system performance has to be investigated in this study are optimum production capacity of the unit, system cycle time, appropriate

types of process controllers, and level of integration. The goals are to improve the above stated inefficiencies, maximize system utilization, production rate, and to identify efficient controller for processes.

4.4 Problem Formulation

In line with the objective of the study, main process of the bottling line and their characteristic features will be discussed in this part of the study.

i. Washing Operation: Bottles washing can be broadly divided into three main operations namely, in feed, washing, and discharge. The three operations are synchronized in such a way that malfunction of one will stop the whole. Bottles in batch of 36pieces, production lot size (PLS) are fed to the machine depending on the set time, which is controlled automatically by means of cam switch and finger like mechanical device arrangement.

The bottles fed to the machine pass through various activities during washing. Among others, presoaking, first, second and third stages washing with caustic solution in which their concentrations are increasing progressively, warm water cleaning, and cold and fresh water rinsing are involved at the fourth and fifth staged of their pass. Spraying of liquid into the inner and outer parts of the bottles is facilitated by stationary and moving mechanical devices along with deepening into baths at some points during their movement from in feed to discharge.

The washing operation utilizes steam energy to heat up and maintain the set temperatures in caustic solutions, and warm water. Single batch bottles stay about 35 minutes in the washing process. On the other hand, the in feed is done in 3 second time interval, and once the machine gets full, discharge in batch appears in 3 seconds consecutive time. The machine is equipped with main switch cabinet, operator's console at the in feed and discharge location. In addition, various sensors and actuators are part of it to control and display some of the machine performance parameters.

Characteristic features of bottle washing operation in Meta Abo brewery may be summarized as follows:

- Frequent operation interruptions were observed during factory assessment;
- Dosing of corrosive chemicals is done manually where protection devices are not adequate in the author's perception;
- Washing agents concentration are checked intermittently by humans for adjustment and even some sensitive equipments are non-existent; and
- The subsystem (washing machine) not synchronized with the in feed and discharge conveyors, steam economizers such as steam traps are not functioning properly, and almost all motors those drive the many pumps, conveyors are not integrated and not equipped with frequency converters for optimum energy utilization.

ii. Bottle Filling and Sealing Operation: Bottle filling and sealing can be considered as assembly operation. Main activities in this operation are washed bottles in feed, beer

filling, sealing and discharge of filled bottles. Filling activity constitute extraction of air from the bottle, dosing of carbon dioxide, progressive filling of beer, and injecting small amount of hot water that creates foam and protect the beer from contact of the atmospheric air before sealing begins. The sealing activity next to filling is done progressively and discharges the bottle at completion.

The characteristic features of Meta's bottle filling and sealing operation may be summarized as follows:

- During factory assessment frequent operation interruption that caused due to failure to supply the required utilities consistently were observed;
- Some of the processes are missed such as extraction of air from empty bottles, and injecting warm water before sealing and substitution of carbon dioxide with air.

iii. Bottle Beer Pasteurization: Beer pasteurization is one of the sensitive areas that need great attention with regard to quality. Biological stability of the bottled beer is maintained in this operation keeping the pasteurization temperatures and time in close accuracy to the set value. The bottle beer temperature rises to 55 °C - 60 °C progressively, rests at this temperature for some time, and allowed to fall to 30 °C when it leaves the tunnel pasteurizer. In all stages of the operation, the bottles are allowed to move at a constant rate of speed from inlet toward outlet. In total the bottles stay for about 40 minutes during pasteurization.

The pasteurization operation utilizes steam energy to heat up and maintain the set temperature of the water in some bathes.

Characteristic features of pasteurization operation in Meta Abo brewery may be summarized as follow: -

- Considerable machine breakdowns are observed during factory assessment that caused due to the machine stays in service for prolonged period of time.
- In some cases the output variables such as temperature, operating speed are adjusted manually.
- The subsystem (tunnel pasteurizer) not synchronized with the in feed and discharge conveyors, steam economizers such as steam traps are not functioning properly, and almost all motors those drive the many pumps, conveyors are not integrated and not equipped with frequency converters for optimum energy utilization.

iv. Labeling Operation: Final product specification is attached to the bottles at the labeling operation. It provides complete product information, which is important from the customer, requirement point of view.

Characteristic features of labeling operation in Meta Abo brewery may be summarized as follows:

- Lacks to hold complete information with regard to the product quality such as the manufacturing date, time and year.

v. Casing Operation: To facilitate handling of bottled beer during storage and distribution, casing is vital. This operation can be done manually, semi automatic mode, and complete automatic modes. Meta employs the first option. Automatic operation of casing looks preferable than the other two because of the fact that breakage of high valued products and damage of worker due to routine nature of the work can be avoided. For actual investment, of course, detail cost benefit analysis should be in place before decision and implementation. Characteristic features of casing operation are:

- Operation is done manually with aged workers;
- The corky sometimes are source of accident on the worker;
- Breakage of high valued finished product due to lack of care at handling; and
- Worker fatigue at the work place.

CHAPTER FIVE

ALTERNATIVE FOR IMPROVEMENT OF BOTTLING LINE

The objective of Meta Abo Brewery with respect to manufacturing system setups and system control in the bottling line should be to establish a system that guarantees maximization of profit by minimizing process time and cost of production simultaneously.

5.1 Objectives

Objectives of the bottling line improvement are the following: -

- Enable optimal utilization of capacity and resources in the bottling line;
- To identify cost components and controlling mechanism in all its unit operations.
- Enable optimal energy utilization in such a way that it should be controlled automatically as per the demand of production requirement.
- Avail unutilized potential by efficiently coordinating all its units operations for optimal performance.
- Ensure the brewery competitiveness after being employed some of its comparative advantages (its location, labor, etc.).

5.2 Methodology

In order to achieve the above objectives the following methodology will be adopted.

- Employ a system approaches to asses the existing bottling line of the brewery.
- Assess other brewery preferably that employ the state of the art brewing technology as a benchmark on some of the factors for better performance.

The following parameters are identified as criteria for short listing and final selection improvement measures.

- Product quality (such as bottle cleanliness, filling level, corking and labeling)
- Production cost (production cost of single bottled beer)
- Production time (production cycle time)
- Simplicity of system operation (simplicity of operation and maintenance system)
- Maintainability (design features to diagnose problems and easy recovery from failure)
- Safety of operation (interlock, interruptions procedures)
- Investment requirement (additional cost incurred for improvement)

5.3 Constraints

The existing capacity, manufacturing system configuration, and labor force are considered major constraints that should be taken care of during improvement.

5.4 Improvement Measures

Using the criteria and considering the constraints stated above, the types of manufacturing and control systems alternatives for improving the bottling line are the following.

Alternative 1: Automating of each processes consisting of operator panel for manual intervention, with local integration.

Alternative 2: Automating of each process consisting of operator panel for manual intervention, with complete integration of the bottling line for central control.

The above short listed manufacturing systems are further evaluated to select the most appropriate one. However, evaluation points are not given to the aforementioned criteria to allow room for flexibility and practicability. Instead, each system in the short list is evaluated on its own merit if it meets the aforementioned criteria in part or in whole.

i. Automating of each processes consisting of operator panel for manual intervention, with local integration

Integration of each automated machines with conveyors at the in feed and discharge sides will bring an advantage in performance optimization of the bottling line as a whole. Performance optimization could be possible by organizing operations in coordination with upstream and downstream equipments for automatic regulation of the operating parameters that could maintain product quality, energy saving. Hence automation of each process consisting of operator panel for manual intervention, with local integration could

meet the selection criteria. In light of the above, building of employee skill through training particularly the technical personnel will make the option viable.

ii. Automating of each process consisting of operator panel for manual intervention, with complete integration of the bottling line for central control

Such an arrangement in addition to process automation for maximum energy saving, include process integrations for central controlling of the bottling line. However, though such a manufacturing system could meet the selection parameter, it requires higher investment and high skilled personnel in handling and maintenance of the system. Thus, such an option will not come at the forefront in the case of Meta Abo Brewery.

In addition to the above subjective analysis, cost benefit technique is employed to refine the selection. The basic concept behind this method is simply to express the costs and benefits in money terms. The cost to be incurred and the benefits expected are estimated one after the other as follows.

5.4.1 Investment Cost

The requirement of hardware and consultancy service for the new manufacturing setups, which include improvement of washing machine, pasteurizer and conveyors performance in the bottling line, are briefly discussed below.

i) Hardware Requirement

The proposed new manufacturing setup requires additional equipment particularly to upgrade controllers of the machineries as stated above.

a) Equipments for Washing Machine

To improve productivity, safety, and product quality the washing machine shall be controlled automatically by equipping it with PLC.

Based on the survey conducted and data obtained from Dashen brewery, types, quantity, and cost of the hardware needed to improve the washing machine controller are shown in Table 5-1.

Table 5-1 Requirements of hardware for washing machine improvement

Description	Type	Quantity	Cost per unit	Total cost in Eth. birr
Power supply	HV	1	5,410	5,410
Power supply	LV	1	5,410	5,410
Input board		5	9,920	49,600
Output board		4	22,690	90,760
Input board		6	3,050	18,300
Frequency converter		5	9,920	49,600
Gear motor		5	1,110	5,550
Gear motor		4	68,430	273,720
Tachometer		4	4,030	16,120

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Description	Type	Quantity	Cost per unit	Total cost in Eth. birr
Frequency converter		5	9,920	49,600
Frequency converter	VLT	1	53,340	53,340
Motor starter		5	11,700	58,500
Relay		10	7,400	74,000
Automatic valves		10	1,310	13,100
Photoelectric cell		8	3,630	29,040
Manometer switch		10	4,380	43,800
Touch screen		1	70,000	70,000
CPU		1	60,000	60,000
Power supply for CPU		1	20,000	20,000
Conductivity meter		3	6,400	19,200
Resistant thermometer		4	3,500	14,000
Contactors		60	850	51,000
Overload switch		60	850	51,000
Push buttons		160	20	3,200
Sub Total				960,440
10% contingency				96,044
Total				1,056,484

The cost of hardware needed as described in Table 5-1 is 1,056,484 Eth. birr.

b) Equipments for Tunnel Pasteurizer

Similar to the previous, the pasteurizer needs improvement to meet the requirement as discussed in the selection part of the study. Therefore it shall be controlled automatically equipped with PLC. Table 5-2 lists the types, quantity, and cost of the hardware requirement for tunnel pasteurizer.

Table 5-2 Requirements of hardware for tunnel Pasteurizer improvement

Description	Type	Quantity	Cost per unit	Total cost in birr
Power supply		1	20,000	20,000
Valves		9	2,000	18,000
Automatic valves		9	3,600	32,400
PT 100 thermometer		9	2,100	18,900
Manometer switch		9	2,500	22,500
CPU		1	50,000	50,000
Power supply for CPU		1	20,000	20,000
Contactator		25	850	21,250
Overload switch		25	850	21,250
Push buttons		60	20	1,200
Proximity switch		10	1,200	12,000
Sub Total				237,500
10% contingency				23,750
Total				261,250

As indicated in Table 5-2 cost needed to improve efficiency of the pasteurizer is estimated to be 261,250 Eth. Birr.

c) Performance Improvement of Bottle Conveyors

For maximum energy saving and to keep product quality, the conveyors shall be controlled automatically with PLC for maximum integration. Table 5-3 shown below lists the types, quantity, and cost of additional equipments for improving conveyors performance.

Table 5-3 Requirements of hardware for bottle conveyors

Description	Type	Quantity	Unit cost	Total cost in Birr
Starter		3	1,760	5,280
Frequency converter		30	1,403	42,090
Digital input board		10	6,890	68,900
Digital output board		10	7,050	70,500
Photoelectric cell		40	1,740	69,600
Proximity switch		40	1,800	72,000
Push buttons		40	20	800
Motors		80	10,000	800,000
On/off switch		80	200	16,000
Contactator		80	850	68,000
Overload relay		80	850	68,000
CPU		1	60,000	60,000

Description	Type	Quantity	Unit cost	Total cost in Birr
Power supply		1	30,000	30,000
Sub total				1,371,170
10% contingency				137,117
Total				1,508,287

The cost of hardware, as seen from Table 5-3, to improve conveyors performance and integration with other operations is estimated to be 1,508,287 Eth. Birr.

Therefore, the total cost requirements of hardware for both options are summarized in Table 5-4.

Table 5-4 Total Cost requirements for additional equipments

Description of cost item	Cost in Eth. Birr	
	Option (I)	Option (II)
Washing machine	1,056,484	1,056,484
Tunnel Pasteurizer	261,250	261,250
Bottle conveyors	1,508,287	1,508,287
Computers, other Peripherals and software for central control of the bottling line		250,000
Total	2,826,021	3,076,021

ii) Consultancy and Installation Service Costs

The consultancy and installation services include the design, installation, and implementation of the system. From practical point of view the cost elements in this category can be estimated as a percentage of the total. Hence the design, installation and implementation activities that plays major role for efficient performance might be taken as 5%, 20% and 5% respectively. Therefore, the total cost needed to meet the consultancy service requirement for bottling line performance improvement is summarized in Table 5-5 below.

Table 5-5 Financial requirements for Consultancy service

Description of cost item	Cost in Eth. Birr	
	Option (I)	Option (II)
Design	201,858.6	219,715.8
Installation	807,434.6	878,863.1
Implementation	201,858.6	219,715.8
Total	1,211,152	1,318,295

In light of the above, the total project cost for two options are calculated to be Birr 4,050,595 and 4,407,735 respectively.

5.4.2 Benefits

As it obtained from the factory cost sheet for the year ended 2002 and 2003, and including professional guess saving is estimated and summarized in Table 5-6.

Table 5-6 Cost Saving Estimates for the Bottling Section

Description	Actual Cost (‘000 Birr)	Assumed Cost Reduction (% tage)	Saving in (‘000 Birr)	Remark
Direct labor wage	814.4	23	187	35 worker at a rate of 1500birr/month
Indirect labor wage	911.1	50	456	15 worker at a rate of 2500birr/month
Labor benefits	579.4	72	417	20% workers salary
Maintenance	1444.9	50	722	Effective Maintenance implemented
Electricity	344.8	5	17	Effective use of power implemented
Furnace oil	804.3	5	40	Improved steam consumption.
Bottle breakage	764.4	50	382	Bottles breakage reduced considerably
Others	106.5	50	53	Simple assumption
Total	5769.8		2,275	

5.4.3 Evaluation

i) Evaluation consideration

- a) Estimated life of equipment is 5 years.
- b) The hardware salvage value after five years is estimated to be nil.
- c) A straight-line depreciation and the discount rate of 10% are assumed.
- d) The saving calculated above remain constant for the coming years.
- e) The income tax is taken 35%.

Table 5-7 and Table 5-8 indicate the results of cost benefit analysis. In the tables rows and columns are filled with the following formulas.

1. Saving (S) is assumed to remain constant for the investment (I) lifetime.

$$S = 2,275,000$$

2. A straight-line depreciation (D) is assumed hence,

$$D = I/5$$

3. The cost of capital (CC) is calculated from,

$$CC = r * (I - \sum_0^{i-1} D)$$

4. The gross income (GI) is calculated from,

$$GI = S - CC - D$$

5. Tax is calculated from

$$Tax = 0.35 * GI$$

6. Cash earning (CE) is calculated from

$$CE = S - CC - Tax$$

7. The discount factor (DF) is calculated from

$$DF = 1/(1+r)^n$$

8. The Discounted Cash flow (DCF) is calculated from

$$DCF = CE * DF$$

9. The Net present value is calculated from

$$NPV = \sum_{i=1}^5 DCF - I$$

Where

I is the total investment.

i, n year of payment (1,...,5).

r is discount rate (10%).

Referring Table 5-7 and Table 5-8, the net present values after five years of operations are:

Option I

NPV = 1,992,992Birr, and

Option II

NPV = 1,674,478Birr.

Since NPV values are positive at the end of equipment lifetime, investments in both options are justified. However, considering the difficulties that will be faced in handling option two with the available labor skill, and the low value of NPV compared to option I, the author propose option I for possible implementation. The payback period for both cases is four years.

Table 5.7 Calculation of Discounted Cash earnings for the Bottling line Improvement (Option I)

Year	Saving	Capital Cost	Depreciation (D)	Gross Income	Tax 35%	Cash Earning	Discount Factor (DF)	Discounted Cash Flow	Net Present Value (NPV)
1	2,275,000	405,060	810,119	1,059,822	370,938	1,499,003	0.9091	1,362,744	(2,687,851)
2	2,275,000	324,048	810,119	1,140,833	399,292	1,551,661	0.8264	1,282,292	(1,405,559)
3	2,275,000	243,036	810,119	1,221,845	427,646	1,604,318	0.7513	1,205,324	(200,235)
4	2,275,000	162,024	810,119	1,302,857	456,000	1,656,976	0.6830	1,131,715	931,480
5	2,275,000	81,012	810,119	1,383,869	484,354	1,709,634	0.6209	1,061,512	1,992,992

Table 5.8 Calculation of Discounted Cash earnings for the Bottling line Improvement (Option II)

Year	Saving	Capital Cost	Depreciation (D)	Gross Income	Tax 35%	Cash Earning	Discount Factor (DF)	Discounted Cash Flow	Net Present Value (NPV)
1	2,275,000	440,774	881,547	952,680	333438	1,500,789	0.9091	1,364,367	(3,043,368)
2	2,275,000	352,619	881,547	1,040,834	364292	1,558,089	0.8264	1,287,605	(1,755,763)
3	2,275,000	264,464	881,547	1,128,989	395146	1,615,390	0.7513	1,213,642	(542,121)
4	2,275,000	176,309	881,547	1,217,144	426000	1,672,690	0.6830	1,142,448	600,327
5	2,275,000	88,155	881,547	1,305,298	456854	1,729,991	0.6209	1,074,151	1,674,478

Note: numbers enclosed in brackets refer negative values, is to mean the amount

CHAPTER SIX

APPLICATION OF SELECTED SOLUTION

6.1 Introduction

A model is a simplified representation of some part of reality. From the manufacturing system point of view, there are three types of modeling approaches: queuing models, state transition models whose representations are state machines and Petri nets, and object oriented models.

- a) **Queuing models.** A queuing model of manufacturing system can be obtained if one treats resources such as machineries and robots as servers, storage areas and conveyor systems as buffers (queue), and jobs or parts as customers. When strict perhaps unrealistic and simplifying assumptions are made for the model, analytic results can be derived for performance evaluation. When these assumptions cannot hold, simulation or approximation methods can be used to derive the desired results.

- b) **State Transition Models.** Typical state transition models include state machines and Petri nets. When a system is complex (contains a multiplicity of machines, Automated Guided Vehicles (AGV's), etc), the graphical state machine representation may not be practical or possible due to exponential state space explosion problem. When time delays are introduced in the simulation, the event concept can be extended to include time. Two ways to associate time delays with state machine models are:-

- a) Associate time with the events.
- b) Associate time and probability with states.

Both timing techniques lead to Markov chains if all the time delays are exponentially distributed random variables. Thus analytical solutions can readily be obtained by sorting a set of algebraic equations identified with Markov Chain [6].

c) **Object Oriented Models.** A manufacturing system can be measured as a collection of objects with rules that govern their dynamic interactions to generate desired objects (products). The objects can be represented graphically as simplified images, icons, and stored in a database as members of a class of similar objects from a database to represent in system model. Such models can lead to high reuse of simulation components. The dynamic behavior in such a model could be represented by other technique, e.g. state machines, Petri nets, or high-level Petri nets.

Queuing models offer mathematically concise models to develop to analytic solutions for first-cut quick discussion making under certain restrictions. It can be difficult to map a manufacturing system in terms of only queues, servers, and customers. The development of hierarchical models with different limits of detail is not straightforward.

State transition models are easier to relate to a manufacturing system, allowing feasible validation of a simulation model. However, when a system is complex, it becomes difficult to visualize state transition model. Fortunately, they can be used for hierarchical

modeling to facilitate system understanding and perform efficient simulation. On the other hand, within state-transition models, state machines, tend to be too complex for realistic industrial system. They have also limited modeling capability in representing expertly concurrent manufacturing operations [6].

Petri nets offer a more powerful tool to handle discrete event dynamics and are more compact, in general.

Because of the various advantages that state transition represented by Petri net can offer, discussed above, a Petri net approach is presented to model and simulate the beer bottling line of Meta Abo brewery.

6.2 PN Modeling and Performance Evaluation

In this section the selected manufacturing system, Meta Abo brewery beer bottling line is modeled considering push paradigm.

6.2.1 System Configuration

The bottling line of Meta Abo brewery shown in Figure 6.1 contains four mechanized and one manual operation, Workstations (WSs). In Figure 6.1, MC1 refers bottle washing machine, MC2 refers filling and sealing machine, MC3 refers pasteurizer, MC4 labeling machine and ManOp refers to manual operation of bottle casing.

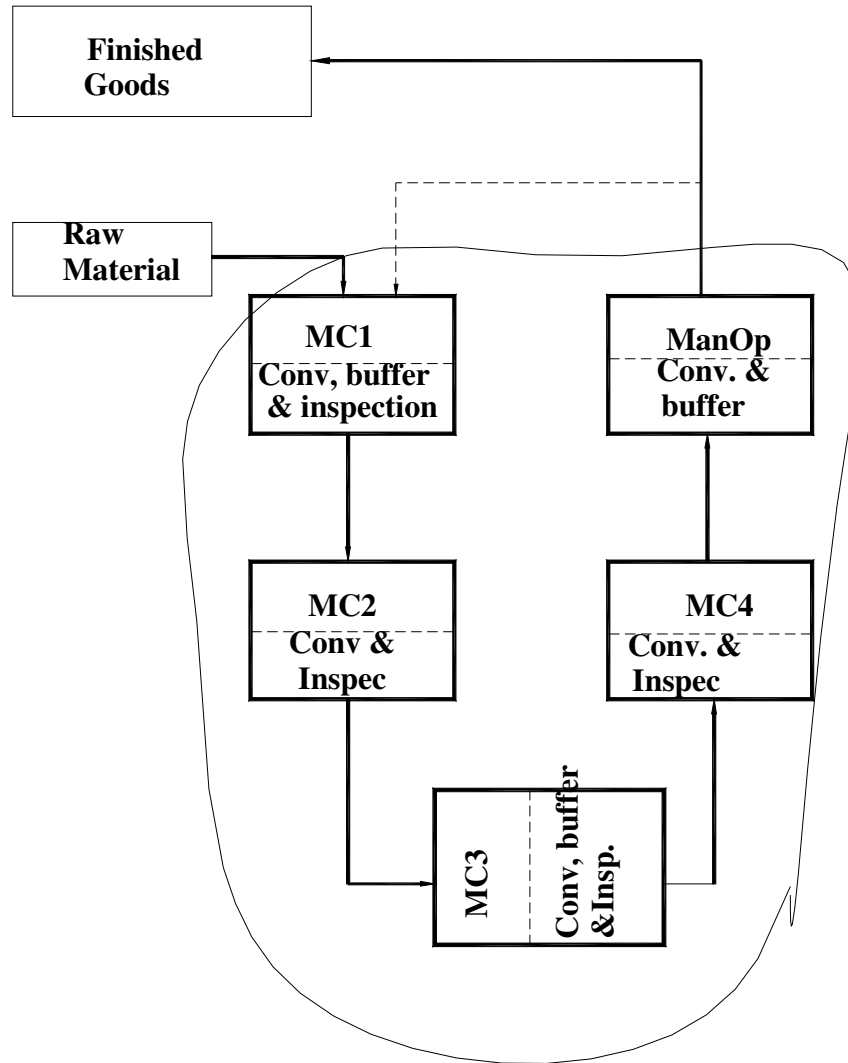


Figure 6-1 Block diagram of Meta Abo Beer Bottling line.

6.2.2 Modeling

Figure 6-2 describes Petri net model in modeling of a manufacturing system, Meta Abo brewery bottling line that is drawn from Figure 6-1. The interpretation of places and transitions are listed in Table 6-1.

Table 6-1 Places and Transitions in Figure 6-2

Places (Resources)	Interpretation
SiMC	Machine setup complete
RiMC	Machine ready
pBiMC	Place where Bottles are loaded on machine, before processing
pAiP	Place where Bottles are ready to unload, after processing
kiMC	Resource availability (Machines)
Ok and kO	Resource available and not available respectively
pBiBj	Bottles before intermediate buffers and conveyors
pAiBj	Bottles after intermediate buffers and conveyors
pCj's	Places that model change of bottles flow rate
kBj	Places that model capacity of intermediate buffers, conveyors.
Transitions	Interpretation
t _i	Receive ready signal to Machines as specified earlier
tLiMC	Loading to machine begins
tEiP	Exponential time for machine operation
tFi	Time between two successive failure
tRi	Time to repair
tUiMC	Time to unload parts from machine
t _{(j-1)j}	Loading of bottles on conveyor transportation.
t _{jj}	Bottles transport.
t _{j(j+1)}	Bottles unloading from conveyors, buffers.

t_{jj}^* and t_{jj}^{**}	Time introduced for change of bottles flow rate
Input arcs	Interpretation
(SiMC, ti)	Arc that holds signals to be sent to machines
(RiMC, tLiMC)	Signals sent to machine to begins parts loading
(pBiMC, tEiP)	Feeding of Parts to machine to start processing
(pAiP, tUiMC)	Parts unloaded from machine
(Ok, tFi)	Signal sent to controller telling that machine is not operational
(Ok, tUiMC)	Signal sent to machine to unload parts completed
(Ok, tLiMC)	Signal sent to machine to load parts
(kO, tRi)	Signal sent to machine indicating that it is operational
(kiMC, tLiMC)	Signal to machine indicating there is free space to load parts
(pBiBj, t _{jj})	Input parts to the moving conveyor.
(pAiBj, t _{j (j+1)})	Parts unloaded from a buffer or conveyor sub systems
(pCj's, t _{jj} [*] or t _{jj} ^{**})	Arcs introduced to model change in bottles flow density
(kBj, (tUiMC, t _{(j-1)j}))	Signals sent to approve availability of free resource.
Output arcs	Interpretation
(ti, RiMC)	Arcs that hold tokens to bring the machines at ready state
(tLiMC, pBiMC)	Flow of Parts during machines loading
(tEiP, pAiP)	Flow of parts completed their processing
(tUiMC, (Ok, kiMC, and pBiBj))	Flow of signals that approve resource availability, free space, and unloaded from machine respectively.
(tFi, kO)	Flow of signal to controller telling it is not operational
(tRi, Ok)	Flow of signals sent to machine to restore its availability

Output arcs	Interpretation
(tLiMC, Ok)	Flow of signals to machine to begin loading
($t_{(j-1)j}$), pBIBj)	Flow of parts loaded to buffers, conveyors.
(t_{jj} , pAIBj)	Flow of parts completed movement in the buffer sub system
($t_{j(j+1)}$, (pCj's, pBIB(j+1), kBj))	Flow of signals introduced to model change in bottles flow density

Where: i= Washing machine (WMC), Filling and corking machine (FMC), tunnel

Pasteurizer (PMC) and labeling machine (LMC), and j = buffers (1,2...13).

6.2.3 System Description

Figure 6-2, the PNM of beer bottling line of Meta Abo brewery, describes washing machine, filling and corking, tunnel pasteurizer, labeling machine, casing operation, conveyors, and intermediate buffers which are working integrally, and hence the next paragraphs, in short, discussed the model.

The modeling of production parts in washing machine (WMC), is similar to production of parts by tunnel pasteurizer (PMC), and labeling (LMC) except that the production lot size (PLS) for all cases are different. However, the variation of PLSs can be easily modeled by changing certain arc weights in the PNM as shown in Figure 6-2. Hence, the discussion on modeling production of parts in PMC and LMC is omitted.

It is assumed that initially parts (unwashed bottles) have to be loaded on the washing machine. This requires WMC to be setup to receive bottles modeled by depositing a token in place SWMC. Setup time is one unit of time and associated with t_1 modeling the activity washing machine setup. After one time unit the completion of setup is modeled by firing t_1 and depositing a token in place RWMC (ready washing machine). Upon arrival of a token in place RWMC, transition tLWMC will get enabled to begin loading parts to the washing machine. After three time units the completion of loading is modeled by firing tLWMC and depositing the number of tokens equal to the batch size in place pBWP. The batch size is modeled as a weight on the output arc from tLWMC to place pBWP. After an exponential time elapsed with a processing rate of μ_w the completion of processing is modeled by firing tEWP and depositing the number of tokens equals to the batch size of parts in place pAWP. Similar to the previous case the batch size is modeled as a weight on output arc from tEWP to place pAWP. Having a single batch of tokens in place pAWP and after three units time elapsed, the completion of unloading is modeled by firing tUWMC and depositing the number of tokens equal to the batch size in place pBIB1 (place before intermediate buffer 1). With the firing of tUWMC, place kWMC, which model the capacity constraints of washing machine, will get a single token. A token in place kWMC, among others, is one of the pre conditions to get tLWMC fired.

When washing process begins, all the tokens (350 in number) in place kWMC will be expended one after the other to fire tLWMC for loading a batch of parts until it becomes zero, which indicates the machine is full. After three units of time when place kWMC loses the last token to fire tLWMC, it will get a token when tUWMC, which model

parts unloading from machine, get fired and ready to satisfy the condition for the next loading operation.

On the other hand, the availability of machine is modeled with place OK that is connected with double arrow arcs to transitions tLWMC and tUWMC, and initially marked with a token. Attached to this place, the time between failures and repair times are modeled with a completion of the exponential time attached to those actions and by firing of tFW and tRW in that order. Firing of these transitions will deposit a token in place KO (indicating the machine is not available i.e. it is under repair) and in place OK (once again the machine is available. i.e. completion of repair) respectively.

Upon the completion of washing, bottles are transported to the filling operation loaded on conveyors, which are modeled as moving buffers and stationary buffers. Fig. 6-2 includes a subsystem of about thirteen such places and associated transitions modeled by action places such as pBIBs (places before intermediate buffer), pAIBs (places after intermediate buffer) and simple places such as kBs (capacity constraint places). Parts transportation between conveyors arranged in sequence are modeled by one unit of time associated with t_{11} , t_{12} , t_{22} , t_{23} , etc. After one time unit the completion of parts transportation is modeled by firing among the enabled transitions stated above and depositing a token in place modeled as output for the respective fired transitions. The change of arc weight (bottles flow density) is modeled by introducing simple places pCs (places for flow control) and transitions such as t_{11}' and t_{11}'' .

Production in beer filling and corking machine is considered as assembling. Only the types of places and transitions, which are not discussed in washing machine description, will be presented here. To begin the production (filling and corking), washed bottles have to be loaded on the machine. This requires FMC (filling and corking machine) to be setup to receive bottles modeled by depositing a token in place SFMC. Setup time is one unit of time and associated with t_2 modeling the activity filling and corking machine setup. After one time unit the completion of setup is modeled by firing t_2 and depositing a number of token in places RKMC (ready corking machine), RBP (ready beer pumping system) RFM (ready filling machine). Upon arrival of tokens in those ready places and one unit of time, loading of bottles, beer, and corky are modeled by firing $tLKrMC$, $tLFbMC$, and $tLFBMC$ in that order and depositing of token in places pKr (place for corky), pb (place for beer), and pB (place for bottle). Besides, two consecutive and integrated operations (filling and corking) assumed exponentially distributed time with processing rate of μ_f and μ_{kr} are represented in the model. After the associated exponential times are completed, filling and corking are modeled by firing of transitions tFB and tKr and depositing a token in places $pAFP$ (place after filling process) and $pAFKP$ (place after filling and corking process).

6.2.4 Performance Evaluation

The data collected from the shop floor is taken to simulate the cycle time of the bottling line of the brewery. For the sake of simplicity, time delays for activities, which are stochastic in nature, are assumed to be deterministic. Hence, cycle time of a strongly connected deterministic timed Petri net is given as follow:

$$\pi = \text{Max} \left\{ \frac{D_i}{N_i} \right\}$$

Where D_i is the total time delays of loop i , and N_i is the token count of loop i . The ratio D_i/N_i is called the cycle time of loop i . Table 6-2 summarized the calculation results.

. Table 6-2 Elementary loops or circuit and system Cycle time

Loops or circuits	Di	Ni	Di/Ni
pBWPtEWPpAWPtUWMCKWMCtLWMC	2100	12000	0.18
pBIB1t11pAIB1t12pC1t11'KB1tUWMC	183	1371	0.13
pBIB2t22pAIB2t23pC2t22'pC22t22''KB2t12	7	168	0.04
pBIB3t33pAIB3tLFBMCpC3t33'kB3t23	73	600	0.12
pBtfilpAFKPtUFMCKkrtLkrMC	10	84	0.12
BIB4t44pAIB4t45pC4t44'pC42t44''KB4tUFMC	89	699	0.13
pBIB5t55pAIB5t56KB5t45	18	144	0.13
pBIB6t66pAIB6tLPMCpC6t66'pC62t66''KB6t56	121	1067	0.11
pBPPtEPPpAPPtUPMCKPMCtLPMC	3600	25000	0.14
pBIB7t77pAIB7t78pC7t77'pC72t77''KB7tUPMC	38	343	0.11
pBIB8t88pAIB8t89kB8t78	55	498	0.11
pBIB9t99pAIB9tLLMCpC9t99'pC92t99''KB9t89	133	1154	0.12
pBLPtELPpALPtULMCKLMCtLLMC	7	72	0.10
pBIB10t1010pAIB10tLCpC10t1010'pC102t1010''KB10tULMC	25	240	0.10
pBIB11tCPAIB11tUCpC11tC'pC112tC''KB11tLC	16	240	0.07
pBIB12tDeCpAIB12tUDeCKB12tUC	2	24	0.083
pIB13tLWMCpC13t13'pC132t13''KIB13tUDeC	3	36	0.083

To facilitate the analysis of individual resource performance, various elementary loops are derived from Figure 6-2. While Table 6-2 displays the cycle time of each loop along with the given parameters namely, the total time delay and token counts (parts in process). Table 6-2, in addition draws a conclusion that, bottle washing is a bottleneck operation with cycle time equals 0.18 sec/part, and it needs attention if production maximization is desired.

6.3 Development of Manufacturing System Performance

Evaluation Software

In order to develop manufacturing system performance evaluation software, there is a need for integrated tools and a systematic design methodology that should be implemented in order to utilize those tools.

6.3.1 Objective

The goal of this part of the study is to develop manufacturing system performance evaluation software by the use of object oriented design (OOD) methodology and Petri net (PN) modeling techniques.

6.3.2 Scope and Limitation

The scope of this software is not that widen compared to the well-developed system simulation software, using of Petri net as a modeling tool such as *GreatSPN* and *SPNP*.

However, with a limitation of process integration the software is designed to calculate and display results of some performance parameters for each loop (considering each process as a closed system) as per the given input data to be supplied by the user.

6.3.3 Methodology

Recalling the PN model (see Figure 6-2) discussed above, manufacturing system performance evaluation software is developed for the determination of optimal production performance parameters in the bottling line. The steps to be followed in the design of the software are shown in Fig. 6-3.

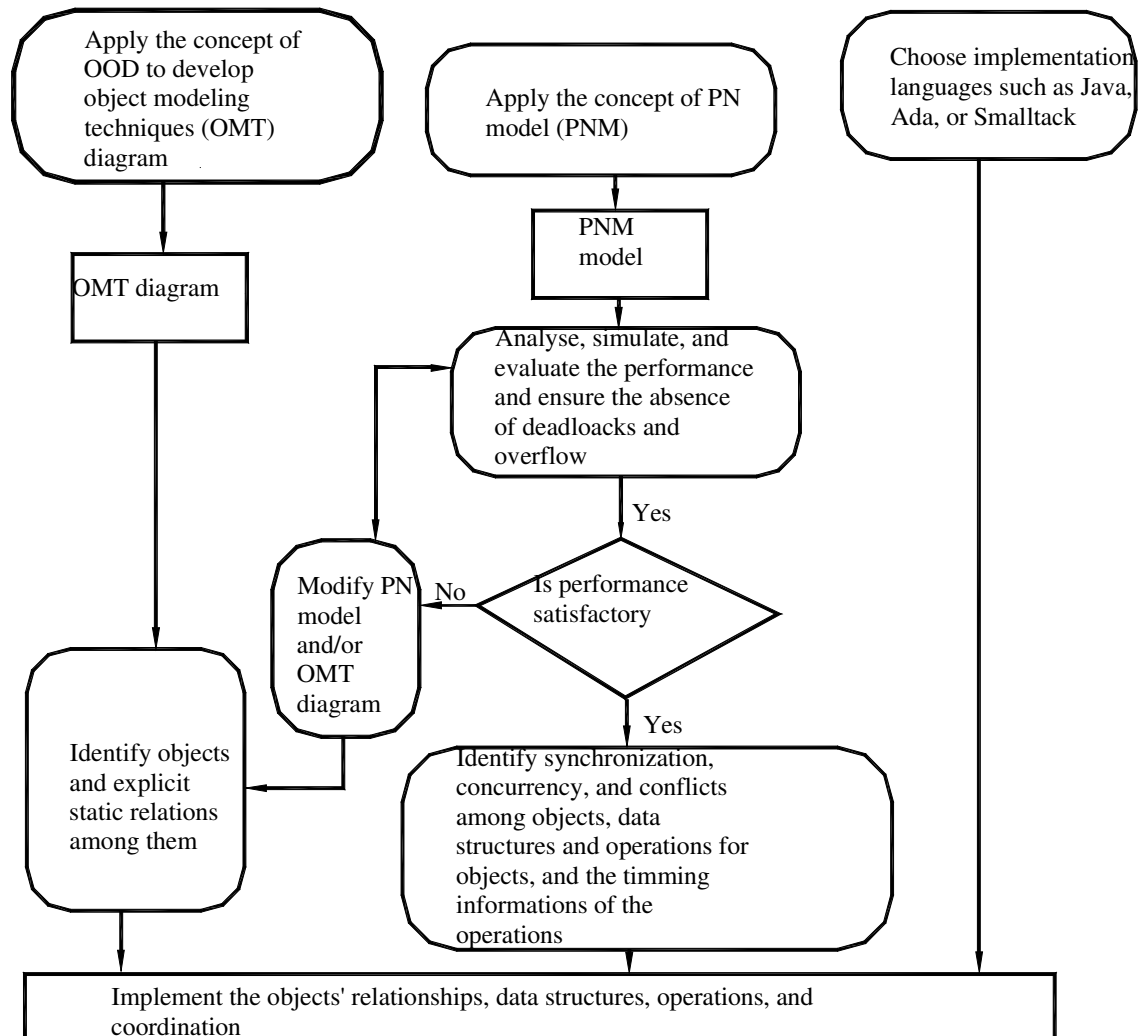


Figure 6-3 Methodology for Performance Evaluation software Development

6.3.4 Object Modeling of the Bottling line

In general the object modeling techniques (OMT) diagram allows three basic types of relations among classes, i.e. generalization, aggregation and association. From the point of the development of performance evaluation software an aggregation type relation is considered. Aggregation implies the description of a class in terms of its constituent parts. The concept of aggregation defines an “is-a-part-of” relationship between a subclass and its super class. Figure 6-4 and Figure 6-5 describe OMT diagrams developed in line to the Petri net model of Figure 6-2, and a substitute of the former that is developed for the sake of simplifying the software development respectively. In the OMT diagrams, a diamond denotes aggregation while black dot indicates multiplicity.

As shown in Fig. 6-4, objects/classes in the real operation of the bottling line is designed to include:

- Performance evaluation software (Main) to be developed for data retrieval, analysis and display results.
- Cell Controller, which integrate all resources in the bottling line through PLCs.
- PLCs to include the functionality of all resources under their control.
- Resources at the shop floor level which are directly responsible to the production.

This class includes resources of the following:

- a. Machines (bottle washing, filling and sealing, tunnel pasteurizer, and labeling)
- b. Conveyors
- c. Buffers

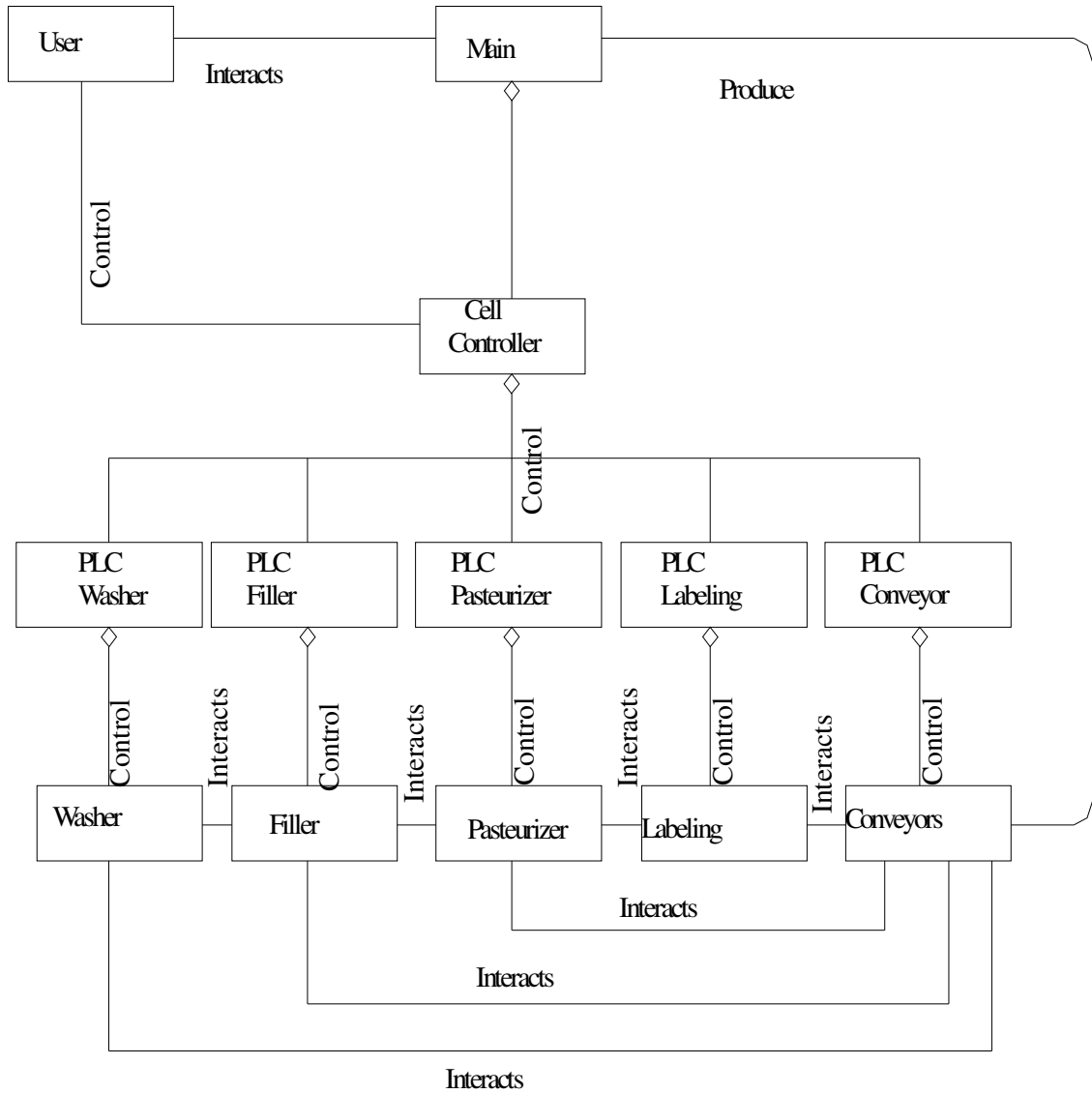


Figure 6-4 OMT diagram of Meta Abo bottling line

Since, among others, in depth knowledge of Petri net, and a great deal of analytical approach are required to establish synchronization, concurrency, conflicts, data structures and operations for objects, development of actual classes/objects and their interactions as per Figure 6-2 and Figure 6-4 is found a difficult task at this time juncture. However, a substitute objects/classes are developed in facilitation of the software development for performance evaluation of the bottling line.

Bearing the objects operating in the system in mind, Figure 6-5 shows a simplified OMT diagram indicating the static relationship among classes of the software. Therefore the new objects/classes diagram is designed to include the following: -

- Performance evaluation software to be developed for data retrieval, analysis and display results.
- Production Manager to integrate all processing sections (bottling, brewing Utilities, etc.)
- Processing section to include all the functionality of processes under same production section.
- Process data that include all relevant data of each processes.

Appendices are attached at the end of the document that describes the various stages given attention in the development of performance evaluation software.

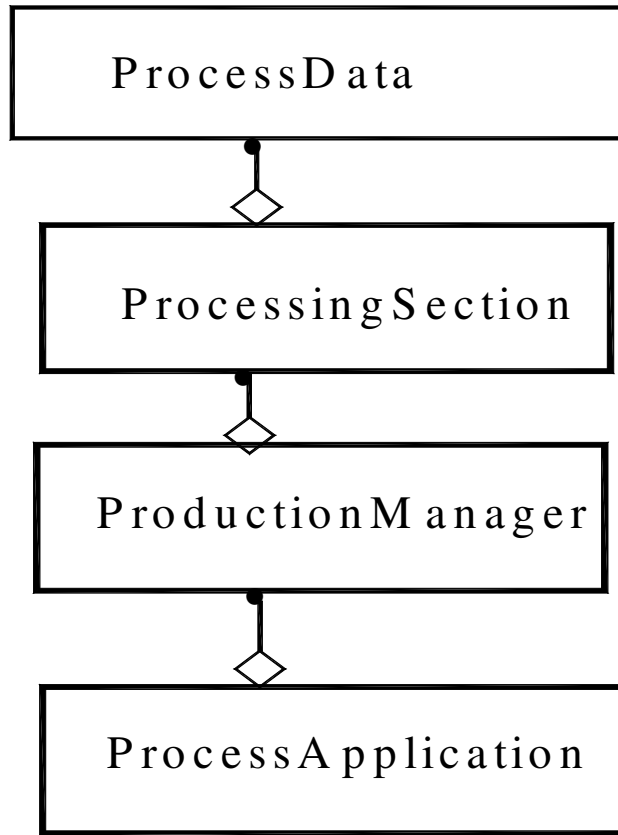


Figure 6-5 OMT diagram for Classes of the Application Software

CHAPTER SEVEN

CONCLUSION

In view of the capital intensive and complex nature of automated manufacturing system, the design and operation of these systems require modeling and analysis in order to select the optimal design alternative and operational policy. It is well known that flaws in the modeling process can substantially contribute to the development time and cost. The operational efficiency may be affected as well. Therefore, special attention should be paid to the correctness of the models that are used at all planning level. Petri nets, as a graphical and mathematical tool, provide a uniform environment for modeling, formal analysis, and design of discrete Products manufacturing systems. One of the major advantages of using Petri net model is that the same model is used for the analysis of behavioral properties and performance evaluation, as well as construction of system controller.

In addition Petri nets are found to be very useful modeling tool with a convenient graphical interpretation. Their ability to represent systems that have hundreds (or even thousands) of states makes them useful for performance analysis. As long as the net is live, bounded and reversible, it is equivalent to Markov chain. Solving this chain for steady state probabilities allows the computation of many useful performance criteria. This criteria can then be used to answer various “what if “questions. In this way, system parameters can be chosen to achieve a desired performance.

The manual analysis of Petri net models can be quite tedious. Approximately 23 software packages have been developed around the world. These software tools have a wide variety of uses including drawing, invariant analysis, simulations of token flow, and derivation of the reachability graph, finding the equivalent Markov chain, and computing steady state probabilities. During this study, efforts were made to obtain two well-developed tools one after the other, namely *GreatSPN* (Graphical Editor and Analyzer for Timed and Stochastic Petri Nets) and *SPNP* (Stochastic Petri Net Package). Even though, efforts in this line shouldn't end up with success, as a substitute a small software package is developed which could possibly be improved in the future to reflect and simulate the developed Petri net model.

As it clear from the study regarding the industrial application of Petri nets, which was used to evaluate the performance of Meta Abo Brewery bottling line, other new establishments or those seek process reengineering should pass through analysis to verify and validate their system by using this tool before going to real implementation.

The success of Petri nets and related technologies can be greatly achieved only when more industrial engineers and designers use them together with other techniques in system development and operation. In the light of the above, further research to include other classes of Petri nets which focus to handle production breakdowns and real time control that falls beyond the scope of this study, might bring the application of this valuable tool into reality.

Finally, the author wishes for Meta to implement the proposed option for its bottling line, in addition bearing in mind that nowadays competitiveness is only possible through product quality, productivity and timely delivery, intensive and detail assessment and analysis of the firm with regard to the production system, of course, by making use of Petri net methodology is recommended.

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APPENDIX

APPENDIX-A

Use Case

A use case, put simply, is a high-level definition of how a software product is going to be based. A use case is composed of the following information:

- *Use case*: sentence or two describing the use case itself.
- *Scenario*: specific set of circumstances that define the different actions that can occur during this use case; this may include several scenarios for one use case.
- *Preconditions*: what must be true for the scenario to begin.
- *Triggers*: what causes the scenario to begin.
- *Description*: A detailed description of each scenario, describing what actions the actor¹ take, what results or changes are caused by the system, what information is provided to the actors how scenario end, a logical layout of the flow of scenario. And what causes the scenario to end.
- *Post conditions*: what must be true when the scenario is complete.

Main Features

The following sections list the use cases defined by topics.

¹ Any person or system that interacts with the developed system.

Process Performance Tracking

The process performance-tracking related use cases are defined in the following sections.

Use Case #1: Add a new process to a process list

Use Case:

Add a new process to a processing section.

Scenario(s):

1. The user successfully adds a new process.

Preconditions:

1. The user has launched the process performance application.
2. The user has selected a process.

Triggers:

The user clicks in an empty row in the table.

Description:

Scenario 1:

1. The user clicks on the symbol columns of an empty row in the process table.
2. The user enters a process symbol and other information.

Post Conditions:

The process table displays the new process symbol, and it is added to the process list (processing section).

Use Case #2: Delete a process Symbol from a process list

Use Case:

Delete a process symbol from a process list.

Scenario(s):

The user successfully removes a process symbol from the process list.

Preconditions:

1. The user has launched the process performance application.
2. The user has selected a process.

Triggers:

The user selects a process and chooses Delete from the edit menu.

Description:

1. The user selects a process by clicking any where on its row.
2. The user chooses Delete from the Edit menu.
3. The process symbol is deleted from the display.
4. The process symbol is removed from the process list.

Post Conditions:

The process list no longer contains the deleted process symbol and the display no longer shows the deleted process symbol. Historical data is not deleted.

Computing Summary

Here are the use cases related to computing a summary of the process profile.

Use Case #3: Calculate the Total parts increment/Decrement in the system**Use Case:**

Calculate the Total parts increment/Decrement in the system.

Scenario(s):

The Process Performance application computes the total parts increment/Decrement in the system from buffer net increment/Decrement.

Preconditions:

1. The user has launched the process performance application.
2. The user has selected a process.

Triggers:

1. The application starts.
2. Any field in the table changes.

Description:

1. One of the aforementioned triggers occurs.
2. For all processes the application computes parts increment/Decrement to the buffer located before each processes.
3. For all process, the application computes the work in process.
4. The application computes the total work in process.
5. The application updates the display.

Post Conditions:

The display shows the total parts gain/loss in the system.

Use Case #4: Calculate the Total Percentage increment/Decrement**Use Case:**

Calculate the Total Percentage increment/Decrement of buffers in the processing section.

Scenario(s):

The Process Performance application computes the total Percentage increment/Decrement from the process information.

Preconditions:

1. The user has launched the process performance application.
2. The user has selected a process.

Triggers:

1. The application starts.
2. Any field in the table changes.

Description:

1. One of the aforementioned triggers occurs.
2. For all processes, the application computes the total parts in the buffer.
3. For all process, the application computes the current parts in the buffer.
4. The application computes the percentage change as follow:

$$\frac{((\text{Total parts before processing} - \text{Total parts after processing}) / \text{Total parts after processing}) * 100}{}$$

5. The application updates the display.

Post Conditions:

The display shows the total percentage increment or Decrement.

Historical Information

The following sections describe the use case that relate to historical data.

Use Case #5: Persist Historical Information to/from a Data File

Use Case:

Persist historical information to/from a data file.

Scenario(s):

1. The user saves historical information to a data file.
2. The user loads historical information from a data file.

Preconditions:

1. The user has launched the process performance application.

Triggers:

1. Some component has called the save historical information method of this component.
2. Some component has called the load historical information method of this component.

Description:

Scenario 1:

1. The component's save historical information method is invoked.
2. The historical information is saved to a data file in a universal format.

Scenario 2:

1. The component's load historical information method is invoked.
2. The component's loads historical information from a data file.
3. The component returns the historical information to the caller.

Post Conditions:

Scenario 1:

The historical information is saved to a data file.

Scenario 2:

The historical information is returned to the caller.

Bottling line Management

The following are use cases related to Bottling line Management.

Use Case #6: Add a Processing Section

Use Case:

Add a Processing Section.

Scenario(s):

The user creates a new processing section.

Preconditions:

1. The user has launched the process performance application.

Triggers:

1. The user chooses Add Processing Section from the Processing section menu.

Description:

1. The user chooses Add Processing Section from the Processing section menu.
2. The user prompted for a name for the new Processing section.
3. A new Processing section file for the processing section is generated.
4. The processing section is added to the Processing section list box.

Post Conditions:

A new processing Section is added to the application.

Use Case #7: Delete a processing Section

Use Case:

Delete a processing Section.

Scenario(s):

The user deletes processing section.

Preconditions:

1. The user has launched the Process performance application.
2. The user has created one or more processing sections (Use Case #6).

Triggers:

1. The user chooses Delete Processing Section from the Processing sections menu.

Description:

1. The user chooses Delete Processing Section from the Processing section menu.
2. The user prompted for Confirmation.
3. The Processing section file is deleted from the active processing sections file.
4. The processing section is deleted from the Processing section list box.

Post Conditions:

The desired processing Section is deleted.

Use Case #8: Save a processing Section

Use Case:

Save a processing Section.

Scenario(s):

The user saves the processing section.

Preconditions:

1. The user has launched the Process Performance Application.
2. The user has created one or more processing sections (Use Case #6).

Triggers:

1. The user selects a Processing Section.
2. The user chooses Save processing section from the processing section menu.

Description:

1. The user selects a Processing Section.
2. The user chooses Save Processing Section from the Processing section menu.
3. The Processing section file is updated to reflect the current process symbols in the processing section.

Post Conditions:

The processing Section is saved.

Use Case #9: Load a processing Section

Use Case:

Load a processing Section.

Scenario(s):

1. The user loads the processing section from a file.

Preconditions:

1. The user has launched the Process performance application.

Triggers:

The user chooses Load Processing Section from the processing section menu.

Description:

1. The user chooses Load Processing Section from the processing section menu.
2. The user is prompted to select the file to import.
3. The processing section is loaded from the file.
4. The processing section is added to the active processing section file.
5. The Processing section list box is updated.

Post Conditions:

The new processing Section is in the processing section list box.

Graphing

The following sections describe use cases related to graphing.

Use Case #10: Set Graphing Time-Scale**Use Case:**

Set graphing time scale.

Scenario(s):

1. The user sets a time scale to view process performance on (for example, one week, one month).

Preconditions:

1. The user has launched the Process Performance Application.
2. The user has created a processing section.
3. The user has added one or more processes to the processing section.

4. The user has enabled historical tracking.

Triggers:

The user chooses Options from the Graph menu.

Description:

1. The user chooses Options from the Graph menu.
2. The user selects the graphing interval.
3. The graphing time scale is set.

Post Conditions:

The graphing time scale is set.

Use Case #11: Graph Process Performance Points**Use Case:**

Graph process performance points.

Scenario(s):

1. A process historical performance is graphed.

Preconditions:

1. The user has launched the Process Performance Application.
2. The user has created a processing section.
3. The user has enabled historical tracking for a process.
4. The historical data file has data in it.

Triggers:

1. The user chooses the Graph tab.
2. The user selects a processing section.
3. The user selects a process with historical data.

Description:

1. The aforementioned triggers occur.
2. The time interval is retrieved.
3. The available historical data is scaled to the time interval.
4. The historical data points are plotted and connected with lines.

Post Conditions:

The graph displays the process historical performance.

CSV

The following use cases are related to Comma-Separated Variable (CSV) files.

Use Case #12: Import Historical Data from a CSV File**Use Case:**

Import historical data from a CSV file.

Scenario(s):

1. The user import historical data from a CSV file.

Preconditions:

1. The user has launched the Process performance application.
2. The user has created a processing section.

Triggers:

The user chooses Import from the history menu.

Description:

- 1.The user chooses Import from the history menu.
- 2.The user is prompted for the file to import

3.The data is retrieved.

4.The data is added to the historical file for that process symbol.

Post Conditions:

The new historical data is available to the Process Performance application.

Use Case #13: Export Historical Data to a CSV File

Use Case:

Export historical data to a CSV file.

Scenario(s):

1.Historical data is exported to a CSV file of the user's choosing.

Preconditions:

1. The user has launched the Process performance application.
2. The user has created a processing section.
3. The user has added one or more processes to the processing section.
4. The user has enabled historical tracking for a process.
5. The historical data has data in it.

Triggers:

1. The user selects a process symbol.
2. The user chooses Export from the History menu.

Description:

1. The aforementioned triggers occur.
2. The user is prompted for a file to export the historical data to.
3. The historical data is exported in CSV format to the desired file.

Post Conditions:

A new file is created in CSV with the historical data for the desired process symbol.

Use Case #14: Import a Processing Section from a CSV File

Use Case:

Import processing section from a CSV file.

Scenario(s):

1. A new processing section is imported from a CSV file into an existing processing section.
2. Processing section information is imported from a CSV file into an existing processing section.

Preconditions:

The user has launched the Process Performance Application.

Triggers:

The user chooses Import Processing section from the processing Section menu.

Description:

Scenario 1:

1. The user chooses Import processing section from the processing section menu.
2. The user is prompted for the file to import from.
3. The user is prompted for a name for the processing section.
4. The processing section data is loaded from the file.
5. The data is added to the processing section.

Scenario 2:

1. The user chooses Import processing section from the processing section menu.

- 2.The user is prompted for the file to import from.
3. The user selects the existing processing section he wants to add the imported data to.
- 4.The processing section data is loaded from the file.
- 5.The data is added to the processing section.

Post Conditions:

The new historical data is available to the Process Performance application.

Use Case #15: Export Processing Section to a CSV File

Use Case:

Export Processing Section to a CSV file.

Scenario(s):

1. The user exports a selected processing section to a CSV file.

Preconditions:

1. The user has launched the Process Performance Application.
2. The user has created a processing section.
3. The user has added one or more processes to the processing section.

Triggers:

1. The user selects a processing section.
2. The user selected Export processing section from the processing section menu.

Description:

1. The aforementioned triggers occur.
2. The user is prompted for a file to export the processing section to.
3. The data is written to the CSV file.

Post Conditions:

A new CSV file is created with the information from a selected processing section.

Use Case #16: Load All Processing Sections

Use Case:

Load All Processing Sections.

Scenario(s):

1. The application loads all its current processing sections and adds them to the Processing Section list box.

Preconditions:

None

Triggers:

1. The application is loaded.

Description:

1. The application is loaded.
2. The active processing sections list is iterated through processing sections.
3. The load processing section method is called for each processing section.

Post Conditions:

A Processing Section list box displays all the loaded processing sections.

Shutdown

The following use cases occur during shut down.

Use Case #17: Save Processing Sections

Use Case:

Save processing sections.

Scenario(s):

1. All open processing sections are saved.

Preconditions:

1. The application is running.
2. One or more processing sections have been created.

Triggers:

1. The user closes the application.

Description:

1. The user closes the application.
2. The application iterates through every processing section.
3. The application calls the processing section's save method (Use Case #8).

Post Conditions:

All processing sections are saved.

Use Case #18: Save Historical Information

Use Case:

Save Historical Information.

Scenario(s):

1. Historical information is saved for all processes.

Preconditions:

1. The user has launched the Process Performance application.
2. The user has created a processing section.

3. The user has added one or more processes to the processing section.
4. The user has enabled historical tracking for a process.
5. The historical data has data in it.

Triggers:

1. The application is closed.

Description:

1. The application iterates through every processing section.
2. The application iterates through every process symbol.
3. The application checks to see if there is new historical information available.
4. The application saves the historical information (Use Case #5).

Post Conditions:

All historical information for all processes is saved.

Appendix-B

The formal use cases in the previous section served two purposes: they concentrated our focus to the problem domain and they helped us identify classes. This section involved in identifying candidates for classes in our application.

B-1 Use Case Classes

ProcessData: A class that contains an individual process's information: process symbol, process name, production inflow rate, parts in process, parts in the buffer, and so on.

ProcessingSection: A class that has a name and maintains a collection of ProcessData items. Also knows how to persist Processing Sections.

ProductionManager: A class that maintains a collection of ProcessingSections and provides a general interface for objects to access and manipulate Processing Sections.

HistoricalDataManager: A class that manages all historical data for a process.

GraphingManager: A class that manages the graphing parameters and is responsible for scaling and drawing the performance information.

CSVManager: A class that understands how to read and write CSV files, regardless of the information in them.

FileManager A class that knows how to persist data to a file system.

Application A class that manages all user interface elements and ties everything together.

B-2 Class Diagrams

The complete structure of main object classes described in section 6.3.4 that to be used in the software development is described in Figure B-1.

Appendix-C

The software has developed to consist the following graphic user interfaces (GUI) to interact with the software users and display results (See Figure C-1 to Figure C-7).



Figure B-1 Class definitions of potential object classes in the developed software

**Manufacturing System Performance Evaluation Software Developed Based(On Meta
Abo Brewery Bottling Line**

Prepared By

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Figure C-1 The flash screen

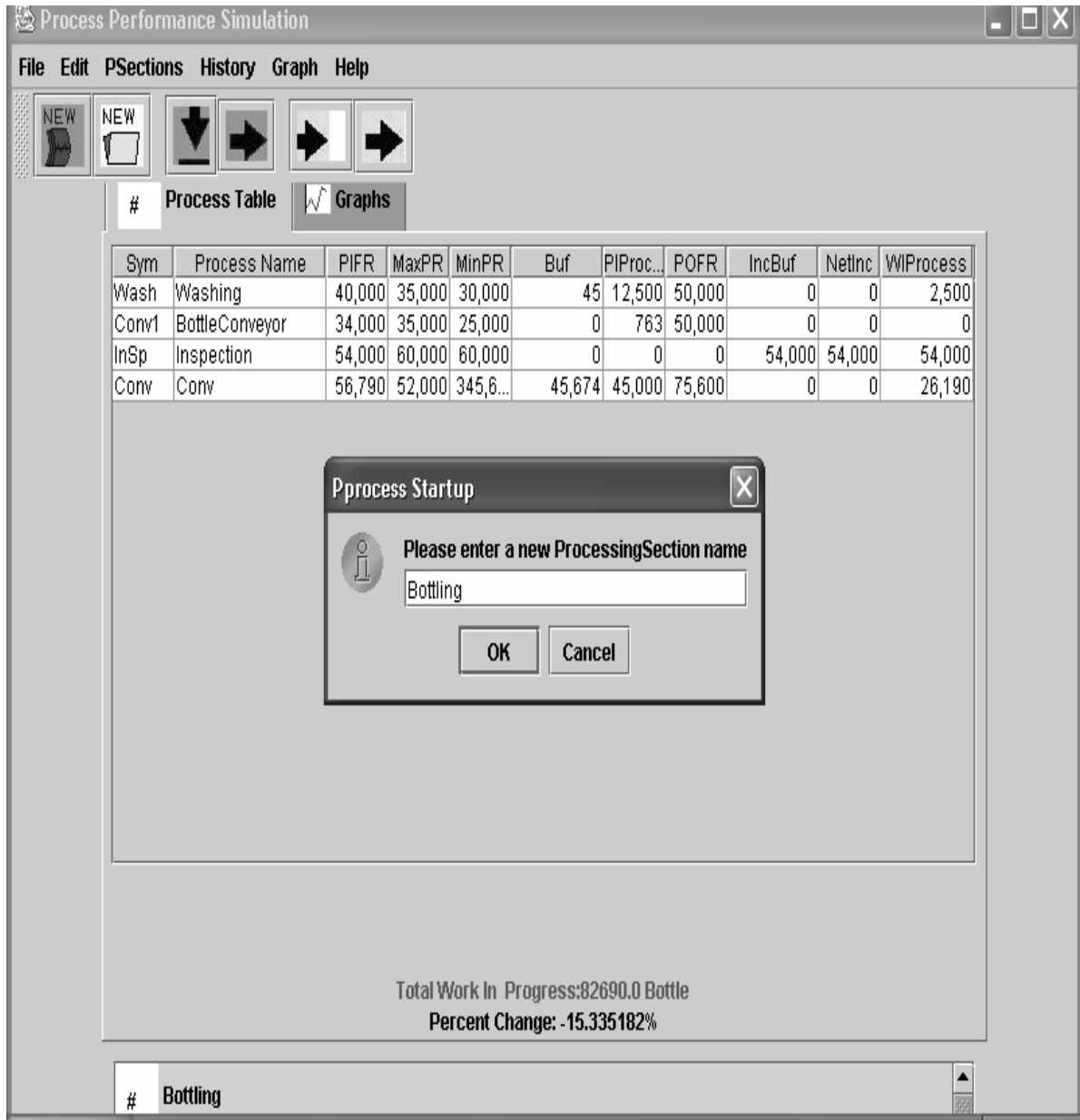


Figure C-2 Process Performance Application Screen requesting to create a new Processing Section

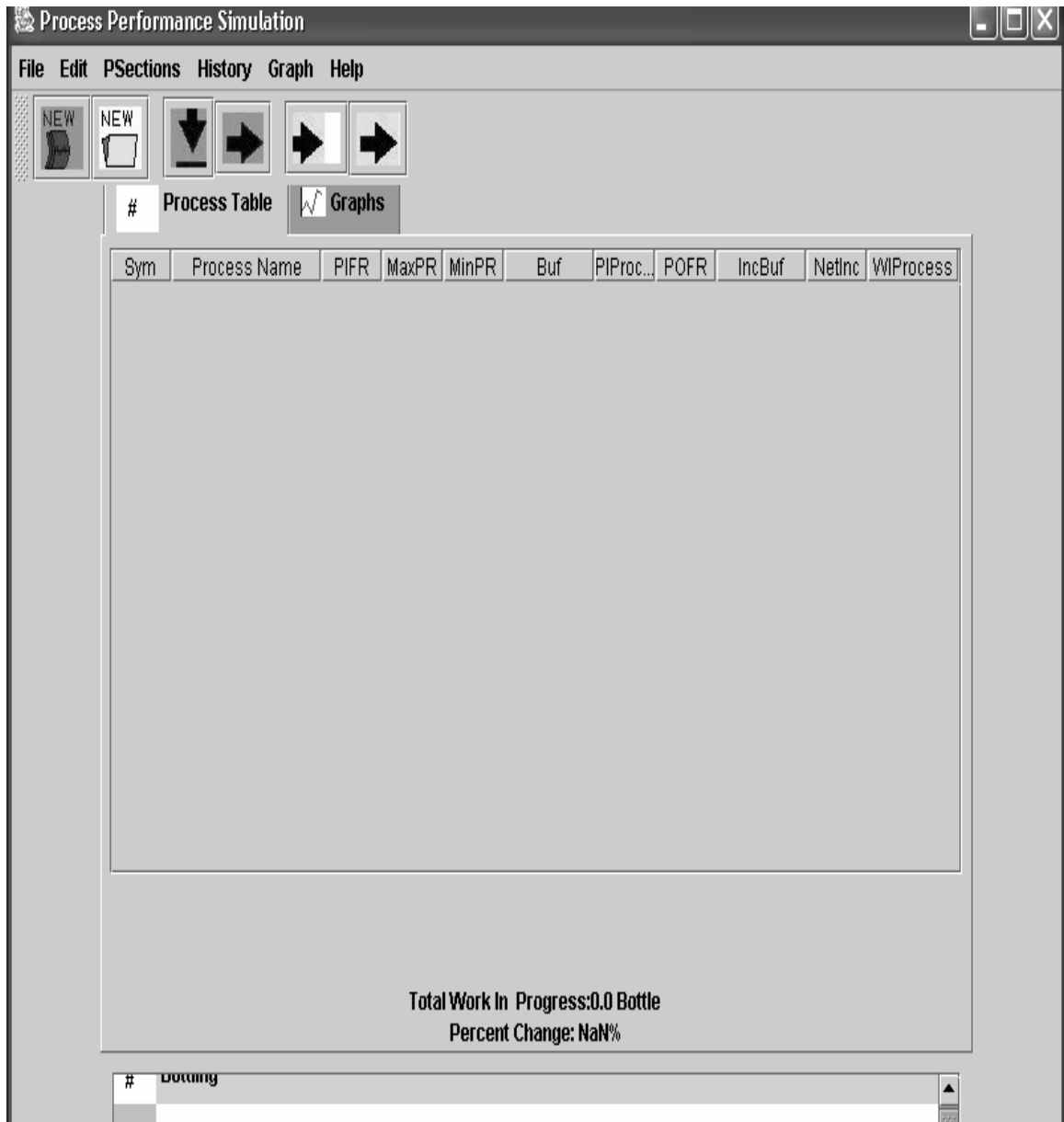


Figure C-3 The Process Performance Application Screen with at least one processing Section

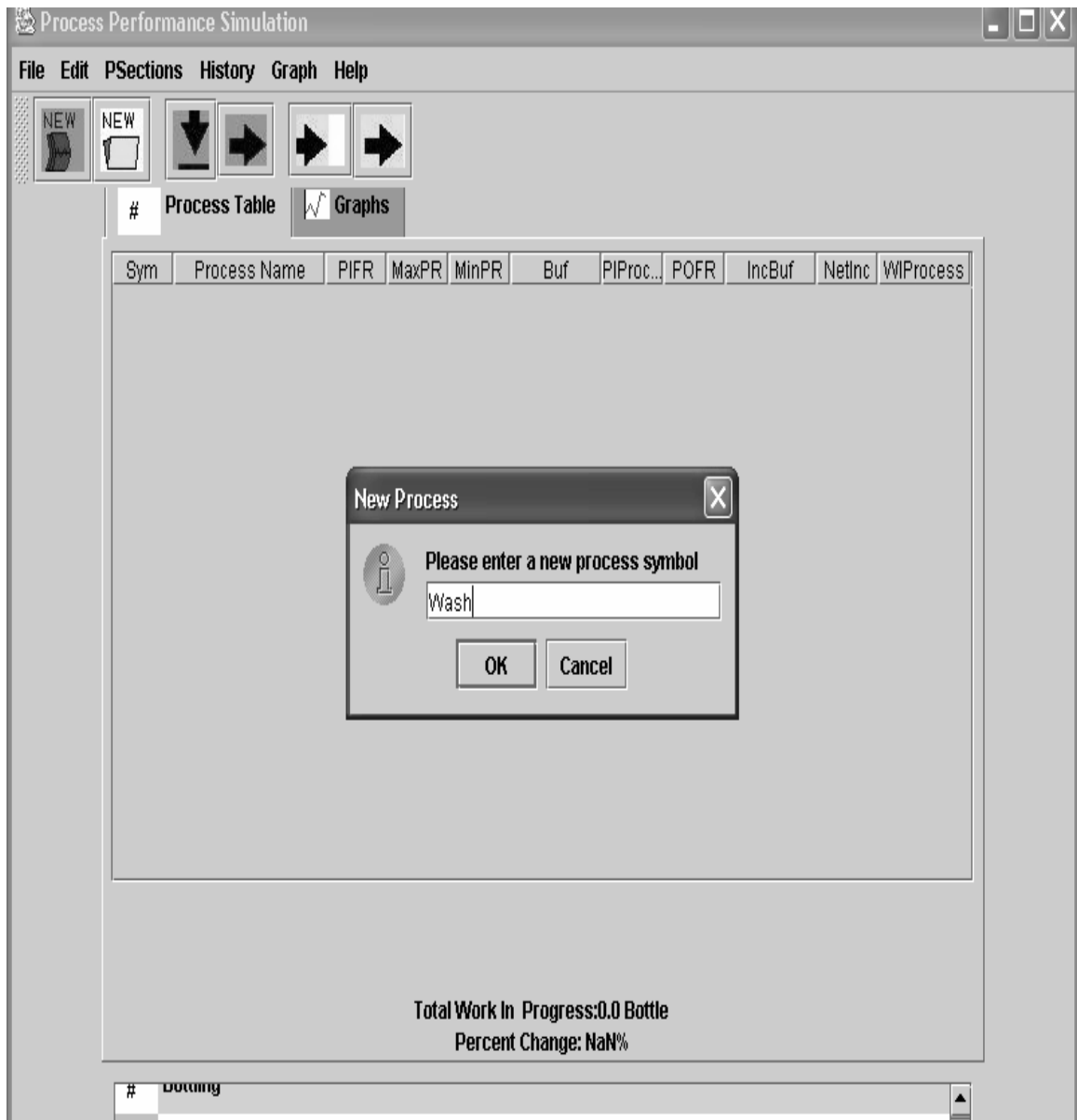


Figure C-5 The Process Performance Application that prompts to add process Information.

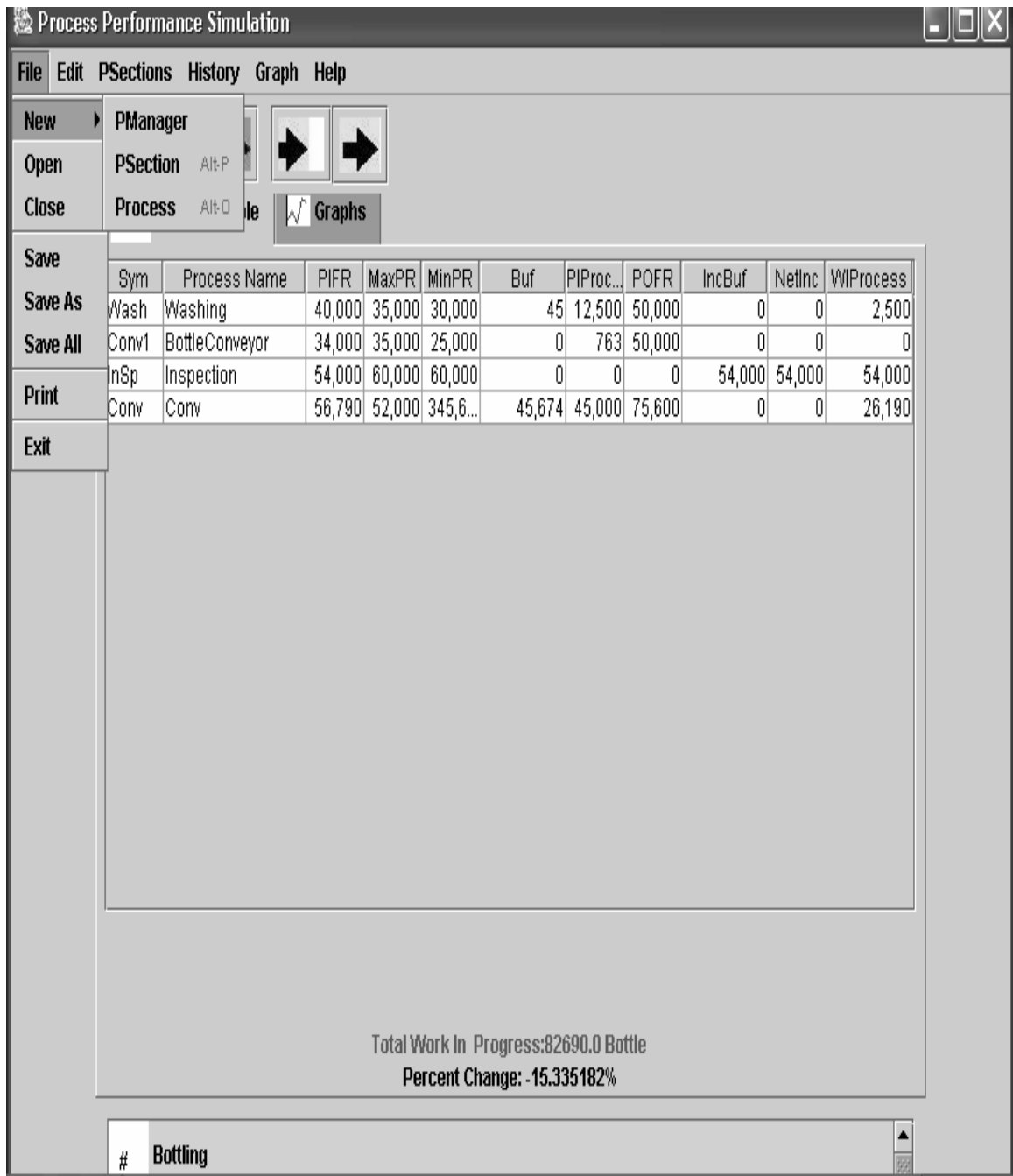


Figure C-6 The Process Performance Application that displays performance

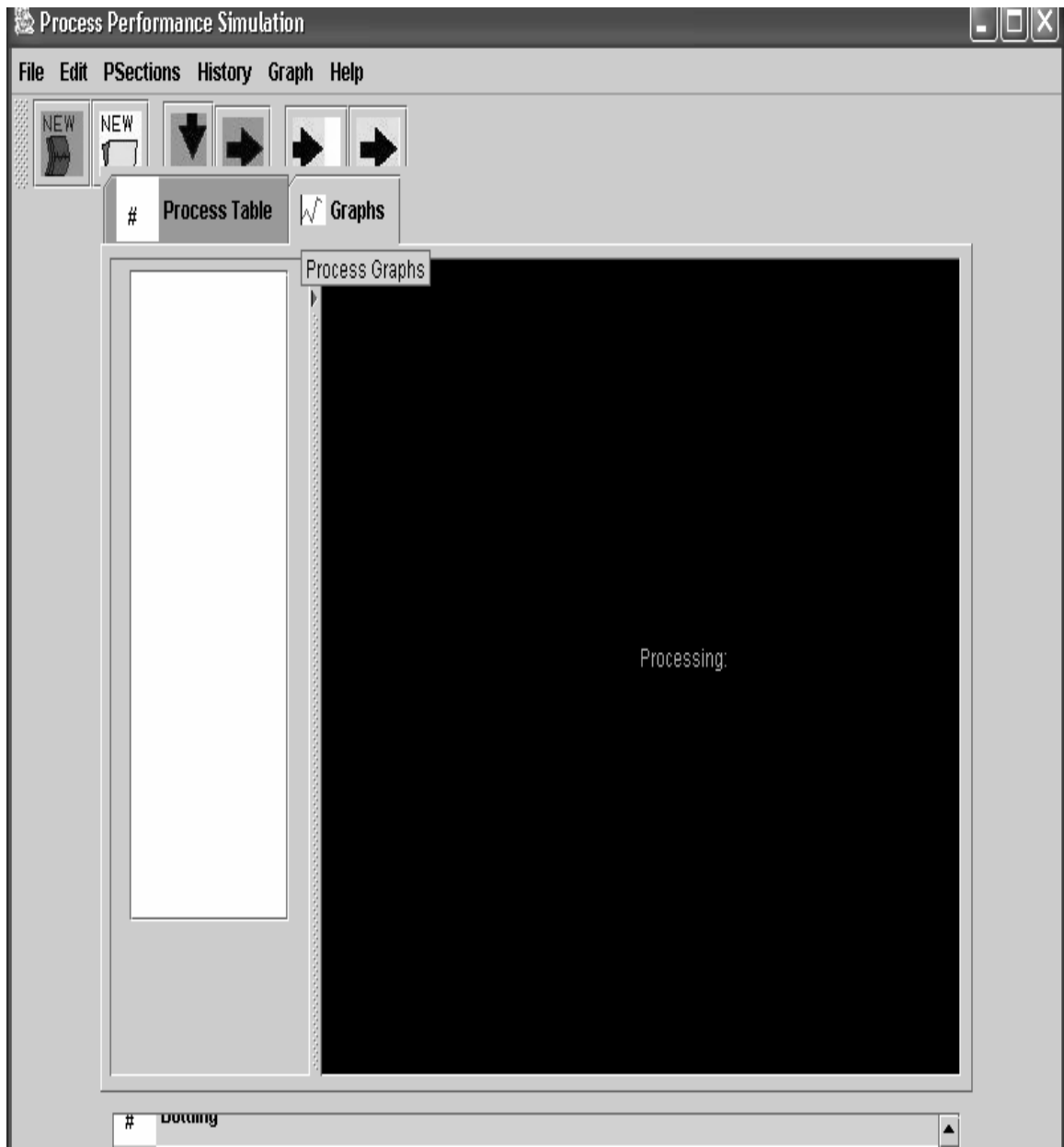


Figure C-7 The Process Performance Application that displays the graphical display of historical information