DEVELOPMENT OF AN INTERACTIVE SIMULATION GAME FOR ISE-5204 MANUFACTURING SYSTEMS ENGINEERING

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(ABSTRACT)

The purpose of this research was to take the first steps in the creation of a simulation game, tailored for the needs of ISE-5204 Manufacturing Systems Engineering, that will provide students with the opportunity of applying their knowledge in realistic situations. The needs of ISE-5204 were established based on the course material and on interviews with appropriate faculty members. A game review showed that there is not a game available which combines all of the characteristics desirable to fit these needs. Therefore the a new simulation game is needed for use in the course.

This research developed a simulation game framework, unique in driving a strategic business type game by low level production decisions. The framework consists of three components: conceptual, organizational and structural framework. The conceptual framework is based on a competitive game with a multiproduct environment, with operational decisions being the driving force. The organizational framework specifies that periodic decision are made by competing student companies and input into the game for production simulation and generation of status reports. The structural framework specifies that a discrete, next event simulation model of shop floor operation is used to model the production system and create output reports.

A prototype model demonstrated the feasibility of running a high level strategic game by low level production modeling. Three competing companies were simulated for three production periods. Each company made decisions that were representative of a different strategy. Simulation outputs were indicative of the behavior characterized by the company decisions and inputs.

Acknoledgements

I would like to thank my parents, Margarita and Werner. There is not enough space in the document to write the things I am thankful for. All my moments of joy, I owe to them. I can only hope that I can be as good a parent to my children, as they have been for me.

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CHAPTER 1 - INTRODUCTION

Simulation games allow the application of theory to realistic situations, making abstract concepts meaningful for students, who are able to appreciate the consequences of their own decisions. High interaction is achieved among the participants, when individuals are placed into the situations of making day to day decisions associated with the operations of a modern manufacturing organization.

At the present a simulation game has not been incorporated into the introductory graduate course in the Manufacturing Systems Engineering program at Virginia Polytechnic Institute and State University. However, the syllabus of ISE-5204 Manufacturing Systems Engineering states that "students completing the course should have comprehensive knowledge of the functional activities that typically occur within manufacturing organizations, process industries, and service organizations. Further, they should have the ability to associate industrial engineering methodologies to these functional activities for the purpose of analysis, problem solving and managerial control." The implementation of a simulation game will provide the students with the opportunity to implement these methodologies in a dynamic environment of a simulated manufacturing enterprise.

1.1. Problem Statement

The student mix in ISE-5204 Manufacturing Systems Engineering is typically both international and interdisciplinary. The methodologies taught in this course are applied in industry by such heterogeneous work teams, in which different branches of a company are represented. The learning potential of interactive situations among students of such diverse backgrounds can be exploited by using simulation games in this course.

Simulation games achieve personal experience through participation in enjoyable situations. They allow students to experiment with simulated systems where reality is too expensive, complex, dangerous, fast or slow. Compared to more conventional teaching techniques, games accomplish higher participant motivation, students remember more, discover the basics for themselves, and get better grades [31]. In order to provide this experiential learning to the students of Manufacturing Systems Engineering, the implementation of a simulation game becomes necessary.

A review of existing games showed that contemporary games often do not include many of the desirable characteristics, avoiding detailed production planning in competitive fluctuating markets. Additionally, Dr. Machuca [23] affirms that there is a need for a new generation of business games in education, because contemporary simulation games are based on an analytical approach, which presents the following problems:

1) Firms are broken into basic subsystems, that are studied individually, thereby promoting local optimums and loosing the systems point of view.
2) The business system is regarded as closed, and is unaffected by changes in its environment.
3) Traditional management games regard organization departments as "black boxes," so the players do not really understand what is behind their errors or successes, and the full learning experience is not achieved. The sources of problems are difficult to isolate, so the players often tackle the symptoms leaving intact the underlying cause.

There is an excellent academic potential in the application of a simulation game in Manufacturing Systems Engineering. Contemporary games exclude some fundamental characteristics, therefore there is a need to develop a new simulation game that will integrate the concepts taught at Manufacturing Systems Engineering, while considering the systems approach and the changing nature of the manufacturing environment.

1.2. The Objective

A manufacturing simulation game will provide the students of ISE-5204 Manufacturing Systems Engineering with the opportunity of applying their knowledge in realistic situations, thereby achieving a deeper understanding of the theory. A game review showed that contemporary games do not include some characteristics, which are desirable for this course. Therefore a new simulation game, tailored for the needs of this course, should be developed.

But the design and development of such a game is complex, since it should simulate the complexity of a manufacturing system. The development of such an elaborate simulation cannot be achieved with an individual effort. Therefore the objective of this research is to take the first step in the creation of the game, by completing three main tasks:

1) Determining the needs of ISE-5204 Manufacturing Systems Engineering, in terms of the concepts that should be included in the design of the simulation game.
2) Defining the framework that would suit the defined needs.
3) Developing a prototype that would illustrate the interaction between low level decisions and high level performance.

The first step taken was to establish the needs of the ISE-5204 Manufacturing Systems Engineering in terms of the concepts that should be incorporated into the simulation game. Since this course covers a wide variety of topics, consideration was given as to what to include and what to eliminate. This was accomplished by interaction with the members of the research committee. Dr. Deisenroth, the committee chairman, is the instructor for this course. Dr. Badinelli and Dr. Reasor are committee members who have a broad knowledge of Industrial Engineering and Management Sciences. Additional interviews were held with Dr. W. J. Fabrycky, who has taught the course in the past, and Mr. Kenneth Harmon, who teaches this course in Northern Virginia.

Framework design was based on the needs of ISE-5204 Manufacturing Systems Engineering, established by the mentioned interviews. The framework is defined in three aspects: *conceptual, organizational* and *structural*. The *conceptual framework* includes the objectives of the game and the issues involved in achieving them. This section includes details of the game design involving market allocation, external influences, internal environment, and player decisions. The activities and the game dynamics are described in the *organizational framework*. The functions of the players, the administrator, the database and the different modules are established. The format used in input sheets and output reports is identified. The *structural framework* describes the code organization and data requirements. The internal mathematical processes are described in this section, including demand generation, market allocation, costs factors, quality and random effects.

The design has a high level of complexity, therefore only a prototype was develop, that encompassed the basic functions defined in the framework, and illustrates the interaction between low level decisions and the macro-performance of a company. The prototype also permits test runs of the simulation, which can provide feedback for the final design. Simulation runs were made, that characterized different company strategies.

1.3. Document Contents

Chapter 1 of this thesis, is the introduction. It establishes the need for the development of a simulation game specifically designed for ISE-5204 Manufacturing Systems Engineering. This is justified based on two reasons: the learning potential of implementing a simulation game in this international multidisciplinary class, and the lack of manufacturing simulation games that incorporate the required characteristics. Additionally, the scope of this research and the methodology to achieve the objectives are established in this first section.

Chapter 2 discusses the origin of simulation games and their advantages as academic tools. It summarizes the results of surveys concerning the popularity of simulation games in the United States of America, the United Kingdom, and Australia. It finishes by establishing a design philosophy for simulation games and describing the content of ISE-5204 Manufacturing Systems Engineering.

Chapter 3 is an extensive game review that encompasses 34 games in the areas of Accounting and Finance; Marketing; Personnel and Human Resources; Production and Operations; and Total Enterprise. A table is presented, which evaluates each game based on characteristics that are considered to be important for the course.

In Chapter 4 the needs of ISE-5204 are identifies in terms of the concepts that are to be included into the simulation game. A general description of the game functions is given at the beginning of this section. The conceptual framework gives a detailed description of the way the simulation game works. It deals with performance measures, external environmental influences, the internal environment, and decisions. The organizational framework provides an understanding of the game dynamics, outlining the interaction between players, data, code modules and game administrator. The code and data structures required to support the described simulation is defined in the final section of Chapter 4.

In order to illustrate the relation between low level decisions and high level performance, a prototype was developed and is presented in Chapter 5. The model abstraction is described along with its initial conditions and assumptions. Three companies are simulated with different attitudes, reflected in their decisions. The results of the simulated runs are the summarized and included in this section.

Chapter 6 summarizes the results of the research and presents an outline of the steps to be taken toward implementation of the framework. Details associated with the prototype runs can be found in the Appendices.

CHAPTER 2 - LITERATURE REVIEW

2.1. Origin of Simulation Games

Simulation games originate from three different activities: computer simulation, role-playing, and games [17] [32]. Computer simulation has its roots in the field of mathematics, where it was used to find solutions to complex problems quickly and accurately.

In role-playing a person assumes a role in order to experience and learn from a particular setting. This leads to a better understanding of the situation. Psychodrama, a type of mental illness therapy used by Dr. Moreno in 1956, is believed to be the first practical application of role-playing [32].

Games are group dynamics governed by a set of rules and procedures, that permit players to interact in competition, cooperation, or conflict. The beginning of games can be traced back to 3000 B. C. to a Chinese war game called "Wei-Chei" (game of encirclement). In the eighteenth century war gaming became a popular way of studying and symbolically representing battle situation. War games provided the possibility of replaying scenarios, experimenting with different strategies, without physical losses.

The first simulation game was developed in 1955 by the Rand Corporation. It was called *Monopologs* and it successfully trained United States Air Force personnel in logistics [8]. The next year, the American Management Association introduced TOPMAN, a computer based management game. In that same year, the University of Washington began its applications for academic purposes. By 1961 there were over 100 management games in existence and over 30,000 executives that had played them [22].

2.2. Role of Simulation Gaming in Education

There has been controversy over the real significance and specific usage of games in teaching. Dr. Enrico Hsu published a review of 61 papers in 1989 [17], providing an overall perspective of past research in this field. The results portrayed games as a good teaching technique (32 studies has this conclusion), even though 25 research papers were inconclusive and 12 had a negative outcome.

In order to explain the role of simulation games in education, Dr. Hsu presents a learning model consisting of four phases: *Retaining Information, Organizing Knowledge, Experiencing,* and *Firming Through Evaluative Feedback.* Table 1 presents the application of this model to management education, using Mintzberg's concepts on the nature of managerial work.

Table 1: Learning Process Model Applied to Management Education

Phases	Objectives	Tools	Methods
1	Retaining Information	Management principles, concepts, theories, models, names, dates	Books, notes, lectures, readings, video presentations, computer-based instruction
2	Organizing Knowledge	Issues, cases, applications, numeric exercises, computer exercises	Discussions, debates, case discussions, simple deterministic management workshop
3	Experiencing Knowledge	Simulation, management games, role playing	Games, roles, labs, gaming, simulation, on-the-job training, tutoring
3a	Informational & Interpersonal Knowledge	Information processing skills, peer skills, leadership skills, conflict resolution skills, skills of introspection	Role play, organizational simulation, dressed prèsentation
3b	Decisional Role	Entrepreneurial skills, resources allocation skills, decision making skills under ambiguity	Computerized management games, decision support systems, group decisions support systems
4	Firming Through Evaluative Feedback	Game performance, observation	Tests, projects, monitoring, game performance, evaluation, rating, grading.

In Phase One, *Retaining Information,* there is an unidirectional flow of information, organized by the author or presenter. A logical structure of concepts will ease the understanding of materials. Students may participate and share past experiences related to the subject, but this is not considered "experiential learning" in the application of knowledge. This phase includes learning of:

1) Historical events and specific or quantitative facts
2) Theories attributed to the particular writers
3) General management principles and concepts
4) Rules, norms, and regulations prevailing in society
5) Procedures

In Phase Two, *Organizing Knowledge*, students digest the learned concepts by discussing and applying them to hypothetical situations. The information is organized into knowledge, incorporating it into their long term memory. Phases One and Two correspond to "cognitive learning" according to Mintzberg.

In Phase Three, *Experiencing,* the students apply their knowledge in realistic situations. Mintzberg establishes eight top management skills, in which people can be trained through experiential learning. It is in this phase where simulation games are most effective, since they help develop these eight skills:

1) Peer Skill
2) Leadership Skill
3) Conflict-resolution Skill
4) Information Processing Skill
5) Skills in Decision Making under Ambiguity
6) Resource Allocation Skill
7) Entrepreneurial Skill
8) Skills of Introspection

In Phase Four, *Firming Through Evaluative Feedback,* students learn the outcome of their decisions, when the instructor indicates mistakes and merits relating them to the theoretical concepts that he or she wants to reinforce.

To ensure an effective learning experience, the correct teaching tools must be selected based on clear specific objectives. In his paper Dr. Hsu concludes that management games are not a replacement for the case method or other conventional delivery systems of factual information and conceptual principles. Games provide the equivalent of a laboratory exercise, in which students can apply the concepts learned through other methods, achieving higher understanding and retention of the principles. Games are also a more efficient way of acquiring managerial, technical, and problem solving skills.

Dr. Kenneth T. Henson [14] summarizes the advantages of simulation games as teaching tools as follows:

1) They involve student actively, putting students closer to the managerial responsibilities and increasing the ability to recognize unstructured problems.

2) They create a high degree of interest and enthusiasm. Students participating in game simulations usually find it to be an exciting, different and an easy way of studying.
3) They make abstract concepts meaningful for students, providing a better understanding and long term retention.
4) They provide feedback to students, allowing them to appreciate the consequences of their decisions.
5) They allow students to experiment with concepts and new skills. The repetition of mathematical tasks, such as forecasting and production planning, incorporated in business games improve the quantitative skills of the participants.
6) They allow students to practice their communications and group dynamics skills, as the very nature of management involves group interaction.

There are some disadvantages to games, and they have to be complemented with other teaching techniques. They are not an efficient way of delivering general abstract concepts. They cannot be adjusted easily and are not as flexible as case or lecture materials. Finally, it often takes weeks to complete the game learning cycle.

2.3. Use of Games in Academia

Even though simulation games like the OPT-Games and PROSIM have been used extensively in Industrial Engineering courses, it was not possible to find any formal study concerning the popularity of such games in engineering schools. Their use in business schools has been documented by several researchers, which presents a good parallel example, especially since some of these games are implemented in the areas of management science and operations research.

A survey in 1962 by Dale and Klasson showed that 71% of 107 schools belonging to the American Assembly of Collegiate Schools of Business (AACSB) used some kind of simulation game in at least one of their courses to represent situations in which students would have to make decisions based on their theoretical knowledge. The rapid increment of game popularity in academic institutions became evident with the studies of Day 94% in 1968, Graham and Gray 91% in 1969, and Robert and Strauss 95% in 1975 [8].

The latest survey was conducted by A. J. Faria of the University of Windsor, in 1987. Three sets of questionnaires were mailed to school deans and instructors and to training and development managers in industry. A group of 315 colleges of the AACSB was selected for the survey, 64% of them (202) answered the questionnaire. The results show that 95.1% of business schools use simulations game in the areas shown in Table 2.

Table 2: Disciplines in Which Games are Used in Academia

Discipline	Total Quantity	Equivalent Percentage
Business Policy	107	53
Marketing	103	51
Finance	50	25
Management	36	18
Accounting	18	9
Other	34	17

An increment in game usage from 1982 to 1987 was indicated by 63.4% of the surveyed deans, 24.7% agreed there had been no change, and 11% suggested a decrease in their popularity. Most of them (95.1%) expected the application of simulation games in academia to increase.

A similar questionnaire was sent to 500 instructors, 271 answers were received. It was determined that 17.3% of the instructors were currently using simulation games in at least one course. Class time dedicated to these games varied from 5% to 100% among the users, with an average of 29%. The survey asked deans and instructors to rate the effectiveness of various teaching methods using a scale form 1 (low) to 10 (high), the results are shown in Table 3.

Table 3: Teaching Method Ranking

Teaching Method	Deans	Game Users	Non users
Cases	8.2	6.2	7.8
Business Games	7.8	7.1	5.8
Lectures	7.4	6.8	7.7
Textbooks (readings)	6.9	5.2	5.5

The final group targeted by this survey was composed by training and development managers in industry. A sample of 500 companies with more than 1000 employees was first selected, from which 219 returned answered questionnaires. Of these organizations, 121 (55.3%) stated that they use simulation games in their training programs.

Similar research was conducted in the United Kingdom [3] and in Australia [25]. In the British higher educational system, 43.4% of the academic institutions used simulation games. A particularly significant popularity was identified in polytechnic schools, where this ratio increased to 81%. Over half of the responding deans expected game usage to increase from 1991 to 1993, and only 1.7% indicated the contrary. Table 4 illustrates the results of the instructors' opinions on game usefulness.

Table 4: Usefulness of Games According to British Instructors

Respondent's View	Users	Non users	Total
Extremely useful	72	23	95
Moderately useful	39	61	100
Limited usefulness	7	40	47
No use at all	-	6	6

The Australian case involves a much smaller population, with 58 completed questionnaires from 40 academic institutions. Of the 40 institutions, 21 (52.5%) are using simulations games as part of their curricula. User respondents were asked to rate the effectiveness of games compared to six other teaching methods, using a scale of 1 (low) to 5 (high). Table 5 displays the results.

Table 5: Australian Evaluation of Teaching Methods

Teaching Method	Evaluation
Simulation	4.156
Project	4.031
Cases	3.781
Seminars	3.438
Lectures	3.188
Readings	2.844
Role-play	2.625

The increasing interest on simulation games as teaching techniques is obvious in different parts of the world. The former Soviet Union, hungry for free market dynamics knowledge, has already organized two "International Seminars on Gaming Simulation in Education and Scientific Research" in St. Petersburg, Russia; and Kiev, Ukraine [33] [34].

2.4. Design Philosophy for Business Games

Dr. Machuca, who has a Doctorate degree in Industrial Engineering from the University of Sevilla and is now Head of the Department of Finance and Operations Management of that same institution, affirms that there is a need for a new generation of business games in management education, due to the following problems [23]:

1) Firms are broken into basic subsystems, that are studied individually, thereby promoting local optimums and loosing the systems point of view.
2) The business system is regarded as closed, unaffected by changes in its environment.
3) Traditional management games regard organization departments as "black boxes," so the players do not really understand what is behind their errors or successes, and the full learning experience is not achieved. The sources of problems are difficult to isolate, so the players often tackle the symptoms leaving intact the underlying cause.

He affirms that in order to cover these deficiencies it is necessary to ensure that:

1) The real situation is understood in all its complexity, including internal interactions and the influence of the environment.
2) The decisions are made on the basis of previous discovery of the real causes of the problems and not the symptoms; which will be facilitated by knowledge of internal structure.
3) The capacity for adaptation to new situations is increased.

Dr. Ian Hunt presents a design philosophy for business games that regards particularly four elements: *Freedom, Fairness, Veracity and Complexity* [18].

The *freedom* of the model relates to the amount of influence that participants can exercise through inputs and decisions on the output of the simulation. In designing the game, pathways of influence must be provided to allow player decisions to affect the dynamics of the different subsystems.

Random levels in the program must not be allowed to interfere with the *fairness* of the simulation. The model should be *fair* in producing the desired outcome, if players correctly apply theoretical concepts.

Veracity dictates that information generated by the model for the participants must be in a form, which they can accept as genuine and relevant for the simulated environment.

The issue of *complexity* has to be resolved by minimizing the use of "black boxes," so as to permit players to fully understand the internal dynamics of the simulated model, providing a richer learning experience.

2.5. Manufacturing Systems Engineering

The course ISE-5204 Manufacturing Systems Engineering was taught for the first time at Virginia Polytechnic Institute and State University in the fall semester of 1989. In Blacksburg, it has been taught once by Dr. W. J. Fabrycky and four times by Dr. M. P. Deisenroth, who is the current instructor for the course. At the Northern Virginia campus it is taught by Mr. Kenneth Harmon. Every two years the course is televised from Blacksburg.

Recently the original textbook for this course, *Design and Analysis of Integrated Manufacturing Systems* [6], was replaced by *Modeling and Analysis of Manufacturing Systems* by Ronald G. Askin and Charles R. Standridge [1]. Additionally, *The Goal*, by Eliyahu M. Goldratt, is required reading [10].

At the beginning of the course the students read *The Goal*, which provides them with a broad view of the production environment and the complexity of a manufacturing system. Goldratt affirms that the goal of a manufacturing organization is to make money [10] [11]. The elements of the organization should strive towards achieving this common objective, and stop concentrating on local optimums. The role of critical constraint resources or bottlenecks in production planning and control is thoroughly discussed in this book.

The book by Askin and Standridge covers materials flow in assembly lines, transfer lines, shop scheduling and flexible manufacturing systems. The topics of facilities layout, material handling, queuing models and empirical simulation models are also addressed in this text. Finally the course addresses the role of quality in manufacturing, human factors considerations in the manufacturing systems, and manufacturing information systems.

CHAPTER 3 - GAME REVIEW

Many articles distinguish between strategic decisions, which affect the entire organization, and functional area decisions, whose effects are concentrated in a specific function of the organization [3]. Management games are classified according to the decision making process that they simulate:

1) Accounting / Finance
2) Marketing
3) Personnel / Human Resources
4) Production / Operations
5) Total Enterprise (strategic decisions)

This review includes thirty four simulation games, encompassing all of the areas above. The games are described based on information obtained from articles, manuals, video tapes, books, and interviews with players. With such diverse sources of information it was impossible to achieve a standard portrait, resulting in different degrees of detail in each description.

The review showed that the majority of contemporary manufacturing simulation games do not include some factors that are desirable in a game with academic purposes. The following characteristics are generally not combined in existing manufacturing games:

1) *Competition* gives students a more realistic view of the industrial environment, and leads to the implementation of different competitive strategies. It is a powerful motivator, making students aware of their relative performance, encouraging continuos improvement.
2) *Sales forecasting* requires a high level of precision, since failure in these predictions leads to stock-outs or overproduction. The uncertainty of the market will make players experience the real stakes of reducing inventories in a manufacturing system.
3) Participants should base their *production schedules for individual stations* on the sales forecasts. This will require participants to deal with work-in-process inventories, setups, bottlenecks and cycle times.

4) Students should engage in *material planning*, based on the productions requirements, making decisions on when, how much and which raw materials to buy.
5) A multiproduct market forces manufacturing plants to share resources among their products, so the correct *product mix* should be established. With it setup time becomes a more important variable, and scheduling a more complex task.
6) Success in companies leads to larger market share and higher sales. To deal with greater production volumes the simulation models should be able to *change their production capacity*.

Table 6 summarizes the presence or absence of these characteristics in the reviewed games. It only includes Production and the Total Enterprise Games, because only these could have incorporated the relation between manufacturing system and market.

The majority of these games either assume an infinite market, where everything produced is sold, and deal with the production dynamics; or they concentrate on the market and regard the production function as a black box. The most complex production function encountered in Total Enterprise games consists of two stages. None of the games simulate the effect of uncertain sales forecast on production scheduling and material purchasing. This latter function is further simplified in some games, by defining a fix material to product ratio and allowing the computer to schedule the arrival to the raw materials. In most cases, capacity expansion was simplified in a similar way, by defining a fixed investment to capacity ratio, and limiting the decision to the amount of money spent for this purpose.

3.1 Financial and Accounting Games

FINANSIM: A Financial Management Simulation (Greenlew, 1982) [2] is designed to be played in teams of three to five members, in a non-competitive manner. Participants enter fourteen decisions for a period representing a year. The majority of those decisions, thirteen, regard finance and accounting. It has stochastic effects, and decisions variables concentrate on the areas of working capital, long-term financial sources, cash flow, financial ratios, capital budgeting, and dividend policy. The output consists of an income statement, a balance sheet, and a statement of supplemental information.

Table 6: Characteristics of Reviewed Games

Games	Competitive	Sales Forecast	Material Planning	Production Scheduling	Product Mix	Capacity Change
Production Games						
ADVANTIG		X	?	?	X	X
Comp. Manufacturing G. *	X		X	X	X	X
P/OM		X	X	X	X	X
Manufacturing Game			X	X	X	X
PROSIM		X	X	X	X	X
OPT-Game			X	X	X	
Prod. Sched. Man. Game	X		X	X	X	
Swift Shoe *		X	X	X	X	X
Total Enterprise Games						
Business Game	X	?		?	?	X
BML	X	X	X	X (2 stages)	X	X
Business Policy Game	X	X				X
Business Str. & Pol. Game	X	X	X			X
Decide	?	?	X			X
Executive Game	X	X	X			
Hogwash	X	X	X			X
ICT Executive Game	X	X	?		X	?
Manager	X	X				X
MANSYM IV	X	X	X	X (2 stages)	X	X
Micromatic	?	?	X			X
Microtronic	X	X				
M. M. G.	X	X			X	X
STRAT-PLAN	X	X			X	X
Strategic Man. Game	X	X	?		X	X
Tempomatic	X	X	X		X	X

* Not computerized

FINGAME: The Financial Management Decision Game (Brooks, 1982) [2] does not regard competition, since it is designed to allow only one team. Nineteen decisions are made every game period of three months. Fifteen of those decisions concern finance and accounting, remaining decisions are related to marketing, production, and personnel issues. Working capital, long-term financial sources, cash flow, financial ratios, capital budgeting, dividend policy are the focuses of this game. The output of the game consists of an income statement, a balance sheet, and a statement of supplemental information.

Introduction to Managerial Accounting (Goosen, 1973) [2] is a non-competitive game that involves one product, four market areas and three production processes, designed for teams of three or four persons. Even though it comprises numerous marketing, production/operations, personnel/human resources, and accounting/finance decisions; the game is not classified as a total enterprise game, because it concentrates on accounting decisions, output and analysis. The game incorporates stochastic effects into its dynamics.

Participants make forty decisions for a period of one year. In the marketing area participants make sales forecasts, set prices and invest on advertising. Production decisions involve determining production volume, new equipment selection, labor allocation, ordering two raw materials, selecting supplier, and scheduling overtime. The personnel/human resources decisions encompass setting salaries, labor wages and commission rates for salespersons. In the area of accounting / finance decisions involve setting credit terms, payment of accounts and notes payable, retirement of bonds, attaining bank loans, issuing bonds and stock, payment of dividends, and factoring accounts receivable. The outputs consists of balance sheets, income statements, cost of goods manufactured statements, and a fixed manufacturing overhead statement.

3.2. Human Resources Games

The Human Resources Simulation (Schreier) [2] was the only game of its nature found. It involves thirty-seven decisions that regard acquisition, development, rewarding, and maintenance of human resources. It has stochastic events, and it includes an extraordinary unpredictable incident every decision period. It is not competitive, it doesn't regard the product or the market. This game deals primarily with discrimination, affirmative action and equal opportunity issues regarding female and minorities groups. It also deals with some budget decisions for the personnel area. Outputs of the game include the quantity of persons in each position, expected vacancies for the next period, percentage of females and minorities, grievances, productivity, quality level, morale, turnover, and wage rates, accident rates and their costs.

3.3. Marketing Games

Marketing Games seem to be the most widely spread. Decisions variables of these games include price, place, promotion, product, marketing and research, advertising, sales force size and commissions. It is not surprising that most of these games are competitive, because this area is the one that interacts the most with the company's environment.

COMPETE (Faria, Nulsen and Roussos, 1984) [2] [9] is a marketing game, in which the production function is ignored completely. Plant capacity is not a constraint, it is assumed that companies are able to produce whatever quantities they manage to market. There are three products, and no raw material or labor decisions are taken. Competition among the teams (three or four persons) takes places in three different market areas. Input from the companies is entered every three simulation months and include 101 decisions, of which 85 concern marketing, 13 personnel and human resources, and 3 production and operations. Decisions variables become more because of the multiple products and markets, for example, this game has nine prices variables, because the three products are sold in three geographic areas. It is one of the most complete marketing simulations, with stochastic effects, some quality control and efficiency concepts. Its outputs include regional income statements, balance sheet, marketing information and inventory analysis.

Executive Simulation Game (Keys and Leftwich, 1985) [9] emphasizes on marketing, and includes a production function that is regarded as a "black box", with a limited capacity. The manufacturing plants capacity can be expanded or contracted by fixed dollar-to-plant increase or decrease ratio. There are multiple outputs and there are no raw material or labor decisions.

MARKETER: A Simulation (Smith, 1985) [2] is a game in which twenty decisions are taken for every input period, representing a quarter. Thirteen of these decisions contemplate marketing, 4 personnel and human resources, and 2 in production and operations. The game considers the stochastic nature of the business environment. Each decision period the players are presented with an incident, and with ten alternative solutions. Teams are made of two or three persons, and they compete in the same market with two products obtained by one production process. The reports given to the players are: income statement, asset information, marketing information and inventory analysis.

MARKISM: A Marketing Decision Simulation (Greenlaw and Kniffen, 1964) [2] is a competitive game designed for teams of three to five members. Each team represents a company that produces one product, through three production processes for one market area. Every three months twelve decisions are taken. Ten variables regard marketing, 1 accounting and finance, and 1 production and operations. The games involves some distribution logistics and stochastic effects. The outputs include income statement, balance sheet, marketing information and inventory analysis.

MARKOPS: The Simulation for Marketing Training was created in 1988 by J. C. Larreche at INSEAD Paris. [21] The objective of the game is to maximize the cumulative net market contribution of a company's subdivision over a period of five simulated years. The player (or teams of players) assumes the position of vice-president of marketing, and competes against other three companies, on four marketing areas with four products, each on a different stage of the products life. The competitors are controlled by the computer. The manufacturing element is conceived as a capacity that cannot be exceeded. Manufacturing costs have fixed and variable components and are related to the utilization (operations/capacities) at which the plants are being used. Production capacity can be increased, but not decreased (except if a product is taken out of the market). Players are expected to make decisions related to manufacturer's selling price, sales force, sales support, technical support, credit terms, maximum price discount, new product (R&D) investment and distribution logistics.

MIA: Marketing in Action, a Decision Game (Ness and Day, 1983) [2] allows teams of three to five persons to compete in the market of three articles, produced in one production process for one area. Every decision period represents three months and includes fifty-three decisions, of which 48 regard marketing, 2 accounting and finance, and 3 production and operations. The game dynamics include stochastic effects. Feedback to the players is achieved through income statements, balance sheets, marketing information and inventory analysis for each quarter.

3.4. Production-Operations Games

ADVANTIG (Sweet, Duke, Morris and Skweirtz, 1986) [24] is a non-competitive game designed for a team of ten to eighteen players, that focuses on technology changes and their repercussions on the manufacturing organizations. It allows players to operate a manufacturing organization over a period of five years (five 40 minute simulation runs), by letting them assume key management, engineering, and worker roles. Strategic planning and operating decisions are made in order to remain competitive in a dynamic environment affected by technology evolution and growing markets.

Outside forces are simulated including bankers, raw material brokers, equipment/technology vendors, and customers in the automotive industry, for which the company produces multiple components. All manufacturing functions are represented; production workers must manufacture according to specifications, provided by engineering; marketing must promote the products; and finance must provide reports and controls. The overall director of the game can introduce new variables into the simulation, like strikes and foreign competitors. The financial and technological success of the company depends on its flexibility to adapt to the varying demands.

The Competitive Manufacturing Game is a board game (not computerized) created by the California Institute for Competitive Manufacturing. [4] The object of the game is to maximize a company's Total Assets measure, which is determined by the value of the investment (different upgrades of the process), the total cash, and the number of pieces of equipment. Two players or teams run companies that manufacture two products for the same market, requiring three raw materials. A decision period represents a week, for which demand is determined in a stochastic manner by drawing a card that symbolizes a contract. Once it has been established, it is fixed.

Players make decisions regarding material purchase, lot sizes, setup time, equipment relocation, product movement within the factory, labor force size, equipment purchasing/repairing/upgrading, and investments in improvement projects such as: Statistical Process Control, Automated Work-in-Process Transport, Computer Integrated Manufacturing, Total Productive Maintenance, and Robust Product Design.

The actions of each player are totally transparent to the other, so the competitive strategies of cannot be kept secret. If a player decides to copy the other ones action it might be able to beat him. The game is designed to be played in one and a half hour. Teams usually take longer, because of the decisions making process.

Decide-P/OM: An Integrative Computer Simulation for Production-Operations Management, (Pray, Strang, Gold, Burlingame, 1985) [2] [9] [26] reinforces "systems approach" to manufacturing by constructing into its dynamics the effects of management decisions on each of the organization's functions. It is a non-competitive game, in which a company manufactures two products with a process composed of the five stages. Forecast techniques are used by the players to predict the demand; high accuracy is needed in order to purchase required materials and schedule production (that can include overtime).

Participants have to make fifty-two decisions per play period, that involve price, materials purchase, labor requirements, maintenance, capital investment, training expenditures, demand forecasting, acceptance sampling, output quality control. The outputs of the decisions are: cash flow statements, operational income statement, sales and pricing summary report, balance sheet, material management report, machine utilization and productivity report, labor availability and training report, forecast of economics index and index of price related goods, interfirm management effectiveness report.

There is a downtime percentage (nonproductive labor), which is a function of production level, maintenance expenditures, uncertainty, and capital intensification policy. This game is designed to give the student experience as an operations manager in the key production/operations management topics such as, productivity, quality control, MRP, inventory control, forecasting, maintenance, scheduling, capital investment and replacement, training and labor allocation, cost-benefit studies and trade-off analysis.

The information about **The Manufacturing Game** (by Jenner, 1986) was obtained from two introductory video tapes that explain the dynamics of the game to the participants. There are three objectives to this game:

1) Provide an experience in controlling a process line.
2) Demonstrate the value of information systems in decision making.
3) Provide a group dynamics experience.

Two types of printed circuit board are manufactured in the simulated process, that consists of five stages, and twenty five operations, that requires eighteen technicians each shift. The boards use the same simplified manufacturing process except for one extra operation for the larger board. A group of twelve to fifteen participants is divided into four groups, management, operations, engineering and manufacturing. The management group is responsible for the overall control of the plant and approving overtime; the manufacturing group oversees production; engineering is concerned with the yield, tools and processes; and the operations group is responsible for work in process (WIP), floor control, and quality assurance. Feedback to the team is provided through a daily report called the Production Summary Report.

The players must continually try to maintain quotas and balance WIP throughout the plant. During the game the students are taught the potential problems associated with cycle time, work in process inventory, yield loss, capacity, throughput, stock outs, training, the implementation of new equipment, and bottlenecks. This game does not simulate a competitive environment, and does not include economics or distribution logistics. Each production stage receives an input, that forms part of the WIP inventory waiting to be processed, it is later transformed into one of two outputs: acceptable throughput or defective production .

PROSIM: A production Management Simulation (Cutright, Mize and Herring, 1993) [7] is a game intended for to be used as a learning aid in courses of production control and production management. This game is able to simulate several finished products, with independent fluctuating demands. Each product is composed of subassemblies that may be common to different product types. Lead time for purchased parts, processing times, assembly times and repair times for breakdowns are associated with a random variable. Quality of parts is regarded as a defective percentage. It allows a team of 3-5 players, who, in a non-competitive environment, make decisions for a period. These regard mainly issues like sales forecasting, raw materials purchasing, production programming and management, maintenance and quality control. Other decision areas are personnel and training.

The description of the **OPT-Game** (Goldratt, 1985), is based on a video taped presentation of this game for ISE-5204 Manufacturing Systems Engineering, recorded on September 11, 1990. This game provides an on-line simulation in which participants assign jobs to each individual machine. The sequence of operations, the cycle times of the machines and their setup times are is fixed.

The objective of this non-competitive game is to maximize the companies profits (sales minus operations and materials costs) by selling product P and its components P1 and P2 that can be sold as spare parts. The number of spare parts that can be sold is limited by the quantity of P products in the market.

The market is not a constraint; it is assumed it can absorbed whatever production volume, with no effects on prices. Two raw materials (RM1 and RM2) are required in the manufacturing process. There is no delivery time, so they are received immediately. There are five operations A, B, C, D and E and three machines. Machines have to perform multiple tasks, which forces players to constantly schedule setups throughout the game. Playtime is six simulation weeks of forty hour a work shifts. The speed at which time passes can be controlled. Decisions are made on-line. Starting cash is $1,500 and weekly operations and maintenance cost is $2,500. This forces the players to achieve high earnings from the first simulation period.

Production Scheduling Management Game (Greene and Sisson, 1971) [15] is a competitive game designed for more than four participants to be divided in groups of two or three persons. The object of the game is to maximize profit by accepting all possible jobs, minimizing cost per part and delivering on time. The total playing time is five hours in twelve 25 minute segments. The teams schedule up to twenty jobs in their manufacturing process, which is composed of three machines. Every machine is different and all of them must be visited to complete any job. Cycle times and sequences vary in every job. Materials are delivered in periods that vary between one and thirteen days. Costs of material, operation and overtime are fixed.

The Swift Shoe Company (Harms and Huff, 1988) [12] is composed of two cases that emphasizes the interaction between in the marketing-logistics-production areas. The first case regards short term planning and the second one concentrates on medium term decisions. These cases are designed to be solved individually, so they do not promote competition. The use of computers is limited to the number crunching of the case. Decision variables are related to sales forecasting, inventory control, distribution planning, location analysis, aggregate planning, quality control, process design and work measurements, capacity planning, long term project scheduling.

3.5. Total Enterprise Business Games

Total enterprise games are those that include all the main functions of business enterprise as its decision inputs: marketing, production, finance and human resources [20]. These games promote the systems approach, by teaching the players that local optimums do not achieve the organizations goal, and that a decision of a single function affects the rest of the system. There are only two games that incorporate more than one stage in their production function, but they are still rather simplistic, because in both cases the production system are composed of two stages.

The Business Game (Mills and McDowell, 1985) [9] increases the number of decision variables with time. It follows a specific sequence of events. In period five, teams are presented with the opportunity of modernize their plants and reduce their labor costs (capacity does not change). Normally raw materials are automatically purchased once the production schedule is established, except in period seven, when firms consider quantity discounts and additional materials purchases. In the eighth period, the teams can opt for its plant expansions programs, with the objective of proportionally reducing costs.

Business Management Laboratory (BML), (by Jensen and Cherrington, 1984) [9] [20] simulates a competitive multimarket multiproduct environment. The products are stainless steel flatware and cookware. Decisions are input every three months. The products require two raw materials.

This game has one of the most sophisticated production functions, including two production phases with independent plant capacity expansion possibilities. Capacity is expressed in terms of labor with a constant output/labor ratio. The game permits capacity expansion in terms of fixed dollar to capacity ratio with time lags; once capacity has been enlarged, it cannot be reduced or sold. Scheduling encompasses the products in two manufacturing facilities; labor and overtime are automatically assigned to the manufacturing sites with the schedule. Overtime is also a possibility in this game. Production requires two kinds of raw materials, that are used in a constant ratio to output. It requires constant maintenance investments to keep full production capacity, assigned independently in each stage. There are ways of investing in product quality improvements and cost reductions (through an engineering study) that do not affect capacity. It allows the implementation of LIFO, FIFO, standard cost and weighted cost for inventory costs evaluations. When demand is high noncompetitive fabricators can be contracted.

Finish goods may be transferred from one market area to another. R&D can develop new products, and improve cost, quality and plant efficiency. These investments stimulate "distinctive product improvement" to increase market share. Players must forecast demand volumes, set price, establish sales force size, salaries, and commissions. Management must allocate money to promotion and advertising.

BML includes finance options as factoring, accounts payable, accounts receivables, emergency loans, short term loans, term loans, private placements with venture capital firms, bonds and common stock. It allows teams to invest in any of four short-term portfolios with different degrees of risk that serve as collateral in event of cash shortage.

Business Policy Game (Cotter and David, 1986) [20] creates a competitive environment among teams, that must input decisions for periods representing three months. Once the multistage process production schedule has been established, materials orders are automatically placed. Production scheduling assigns overtime and multiple shifts to the individual operation steps. Maintenance expenditures vary for each production line. Flexibility and capacity can be incremented by purchasing new equipment. It incorporates ways of investing to improve product quality.

The marketing function allows participants to invest periodically in R&D, which eventually results in products quality improvements. This also introduces new products to the market, and provides management with marketing studies of the new products potential. Marketing regards other variables such as forecasting, price setting, sales force size, salesmen salaries, commissions, and advertising budget.

Responsibilities in the finance department include taxes, short term loans, issuing bonds, stock purchasing and selling, dividend payment, and investments.

Business Strategy and Policy Game (Eldredge and Donald, 1980) [20] simulates a competitive environment, in which teams make decisions concerning operations, marketing and finance every three simulation months. Production quantities are determined from the sales forecasts. The scheduling process involves material purchase (materials choosing), hiring, discharging and laying off workers. The game permits transfer of finished goods among marketing areas. There is a chapter on personnel for sales persons, hourly workers, training, and hourly wages. It permits the utilization of training programs or profit sharing to improve productivity in units per person-hour, and raw materials requirements per unit.

The program automatically assigns "disaster loans" at very high interest rates when cash flow is negative. The companies can deposit and withdraw from an interest paying savings account. Other finance and accounting decisions involve accounts receivables, bond issues, stock purchasing and selling, dividend payment and tax issues.

The marketing department must forecast sale, establish prices. Sales force decisions include size, training, salaries and commissions. Research and development can decrease product cost, affecting therefore the acceptance of the product in the market.

Decide (Pray and Strang, 1980) [9] is a competition game that regards its production functions as a "black box" with three inputs (labor, materials and capital) and one output. Plant expansion is performed with a fixed dollar-to-increase capacity ratio. Production scheduling is limited to the input of a required quantity, specifying the available capital, raw materials and labor. Overtime can be scheduled. Raw material decisions are subject to waste and loss.

The Executive Game (Henshaw and Jackson, 1984) [5] [20] is a competitive game, allowing up to nine teams, representing companies, to manufacture and sell, technologically complex consumer durable product. Every simulation quarter, players make decisions regarding price, marketing, research, maintenance expenditures; production scheduling; plant investment; raw materials purchases; and dividends.

All teams compete in the same market selling the same article, that has a seasonal demand pattern. Participants forecast the industry averages for price and marketing as a part of the process of forecasting market share. They also have to foresee the delayed effect of R&D investments, that decrease product costs and increase potential market share. It also incorporates ways of investing to improve product quality. Maintenance expenditures lower materials and labor expenses. The players cannot allow the factory to deteriorate, because of the negative impact on operations.

The return on investment, that is an optional performance measure, can be calculated through a program provided for the users. Short term loans with above normal interest rates are immediately awarded to cover negative cash flows. Inflation effects are included, which is very rare in a game.

Hogwash is a game that was played in the spring semester of 1989 in the Applied Industrial Management course (ISE-4984 at Virginia Polytechnic Institute and State University). This description is based on an interview with Eileen van Aken, a student of that class. Decisions were input two or three times per week, for thirty-two decisions periods, each representing three months. It is a competitive game with an objective of achieving high profits. Decisions involved advertising, publicity, production quantities, price and financial sources. Outcomes included income statements, inventory and market share reports.

ICT Executive Game (Institute of Clay Technology) [13] is designed to provided its participants with a thorough understanding of the problems of integrating the different business functions: production, marketing and finance. It includes operational and strategic decision making.

Each team represents a division of a large corporation that produces three product groups. Competition is encouraged among divisions for resources and between product groups in different divisions for market share. Sales are classified in two types: open market and contract. Consequently financial, marketing and production decisions are made for each product group for every type of sales. These have to be integrated into a strategic plan, for example a reduction of prices, that would provoke losses, but would capture a market share, has to be balanced by profits from other products. The dynamics of this are sufficiently complex to provide roles to large groups of players (up to 20 in every division). The game uses a hierarchical organizational structure to delegate responsibilities.

Manager, A Simulation (Smith, 1984) [20] is a competitive game, in which decisions are input for a period of one quarter. It projects its forecasts six quarters into the future, allowing the players to adopt a strategic long term approach to competition. The main business functions are included. Marketing decisions variables include forecasting, R&D investments, price, promotion, and marketing research information. The production department is concern with capacity, quality and production scheduling issues. There is no need for material planning, since these are automatically ordered with the production schedule. Finance regards the areas of taxes, long term loans, stock purchasing and selling, and dividend payment.

MANSYM IV (Schellenberger and Lance, 1986) [20] incorporates a very versatile real product line description, allowing products parameters to be changed by the game administrator. This changes allow the simulation of the competitive markets of small kitchen appliances industry, textiles, wood, and food products industry. Players make decisions every quarter to compete in a multiproduct market. R&D can introduce functional changes in the product, allowing releases of new products after periodic intervals of R&D investments. Management has to decide on price, promotion budget, sales force size, salaries, commissions, and marketing research information acquisition. Demand is simulate in a stochastic manner.

Once plant capacity has been enlarged it cannot be reduced or sold. Production is concerned with scheduling, and overtime assignments for the different process stages. Materials must be acquired in time to meet production requirements. Productivity improvements are possible through profit sharing programs, maintenance and automation (cost saving) investments, requiring a one quarter log for use and payment in the quarter scheduled. Investments can be targeted to improve product quality, thereby augmenting market share.

The game allows players to invest by a sort of negative loan. Taxes, short-term loans, accounts receivables, stock, and other investment must be consider in order to keep a positive cash flow.

Micromatic (Scott and Stickland, 1985) [9] needs three inputs: labor, materials and capital to manufacture a products. Competition of teams is based on the volume of sales. Supplier selection is based on material quality of their deliveries, and the consequent waste. Plant capacity expansion is permitted with fixed dollar-to-increase capacity ratio. Overtime can further augment a periods production quantity. Labor turnover is one of the controlled parameters.

Microtronics (Keys and Wells, 1987) [20] includes variables from production, marketing and finance. Decisions are input for a period of one quarter. Additionally participants must respond to a series of behavioral incidents in each decision round.

Production materials are automatically ordered with the production schedule. Throughput is a direct function of labor, capacity can only be expanded by hiring additional employees and scheduling overtime. The labor variable is very complex, workers can be hired or terminated, pay raises have a positive effect on worker productivity, turnover and absenteeism. Marketing decisions involve forecasting, price, sales force size, commissions, advertising, and R&D investments, which can decrease product cost and increase market share. It allows transfer of finished goods from area to area.

It allows players to borrow funds and sell or purchase stock. Finance issues include also taxes, accounts receivables, emergency loans, long term loans, and dividend payment.

The Multinational Management Game: (Edge, Keys and Remus, 1985) [9] [20] places more emphasis on marketing than on the production or the finance function. Teams compete in three different markets each representing another nation: United States, Germany and Japan. It utilizes an economic indexes based one the history and commercial relations of these three economies. Products are described in a generic way, product A consists of a branded consumer good sold to retailers, whereas product B consists of an unfinished good sold directly to industrial customers. The companies must be based in the United States, and have divisions in the other two countries.

By including different nations in the game, decisions concerning forecasting, R&D investments, promotions, prices, sales force, training, commissions and advertising must be taken independently for each market segment. Each area has different rates of grow and different currency, which exchange rates are based on real rates. Transfers of finished goods and funds among countries are allowed. The game incorporates price/elasticity, which means higher revenues will be generated by lowering price in the elastic range, and by raising price in the inelastic range; provided other parameters remain constant. The market for the industrial products is much more elastic than that of the consumer product.

No raw material or labor (including overtime) decisions are made, these are automatically entered with the production schedule. Plant size can be expanded or contracted by fixed dollar-to-plant increase or decrease ratio. It incorporates ways of investing to improve product quality.

This games operates in an international market, with international currencies and taxes. Finance sources include accounts receivables, long term loans, cash transfer among divisions, stock purchasing and selling. The special loan variable used covers potential cash outages, but charges above normal rate for this coverage.

STRAT-PLAN (Hinton and Daniel, 1985) [20] emphasizes on long term strategic issues rather than on short term problems, by requiring players to input decisions for periods representing one year. Therefore some of the day-to-day business dynamics are left out, like inventories, seasonal demands variations, or shipping delays; while strategic issues take on new vitality.

The game administrator defines up to three geographical market areas, two of which may be international, allowing transfer of cash and finished goods among them. Each market area has different grow rates, and currencies, whose exchange rates are equivalent to the reported exchange rates from real world. The sales forecasts are projected one year into the future. R&D investments affects cost and quality of the product, increasing market share. Players have to determine the sales force size and their commissions.

The game provides opportunities to expand facilities, reduce production costs, abandon markets. Materials are automatically ordered with the production schedule. The production department must also keep track of inventory levels, product transfers, and quality control.

Since this is a multinational company, that operates in different countries, finance deals international currencies and taxes. Expenditures, including dividend payments, are aborted in they cause the organization's cash flow to be negative. Financial option include short-term loans, accounts payables, emergency loans, cash transfer among divisions, stock purchasing and selling.

The Strategic Management Game: The Products Simulation (Aronson, Gekoski and Spero, 1987) [30] provides three to six teams of three to six players (nine to thirty-six participants) with opportunities for group decisions making in the context of a competitive, multimarket, multiproduct environment. It is estimated that the game requires 1.5 hours of initial instruction, 3 to 4 hours each for the first two group sessions, and 1 to 2 hours for each subsequent session. The game concentrates in the areas of strategic and financial management, competitive analysis and cash flow planning. Every simulation year fifty decisions are input, regarding advertising, sales force size, commission rates, R&D, process improvement, shifts worked, factory expansion, and several types of financing are regarded.

Production capacity requirements must be predicted two years into the future. Each product starts at a different life cycle stage, and each proceeds through the stages at a different rate. At the beginning of the game, one product is still in undergoing research, so it has to be decided whether the company should invest in bringing it to market. Constant investments in R&D increments quality of the product.

This game has been used in academic programs in Wharton, Penn State, Cornell, the University of Colorado, and Fairleigh Dickinson.

Tempomatic IV, A Management Simulation (Scott and Strickland, 1984) [20] requires competing teams to use of Business Week indexes, thereby tying the game to fluctuations in the real world economy. The game administrator has therefor no control over these indexes.

Companies sell a generic product, which is defined only in terms of price ranges or customers covered. Sales forecasts are estimated by market area in terms of total unit sales potential, they are modified by the Business Weeks indexes. Sales force must be trained, paid and allocated among the market segments. Other decisions involve R&D investments, prices, promotion.

Crews of three semiskilled workers compose the work force. Each one is paid $2,500 per quarter, plus overtime. Workers can be laid-off, but they return automatically in the quarter, unless permanently discharged. Simulated employees and crews provides very realistic dynamics for labor content negotiations. Production decisions regard multiple plants, capacity changes, production scheduling, material purchase, hourly wages, and product quality.

The game allows short term investments and withdrawal at an interest rate preset by the game administrator. The finance director must also deal with issuing bonds, purchasing and selling stock, and paying dividends.

CHAPTER 4 - FRAMEWORK

4.1 Needs of ISE-5204

The simulation game is intended to provide a realistic exercise, in which students can apply the theory learned in ISE-5204 Manufacturing Systems Engineering. Therefore the framework of the game has to fit the needs of this course. The selection of the concepts that are to be incorporated into the game was based on the theoretical content of the course and on interviews held with the following members of the faculty:

1) Dr. Michael P. Deisenroth
2) Dr. Ralph D. Badinelli
3) Dr. Roderick J. Reasor
4) Dr. Wolter J. Fabrycky
5) Mr. Kenneth Harmon

The following areas of knowledge were judged to be important:

1) *Forecasting*

Students must be able to predict market demand from historic data. This data should have both a trend component and a seasonal characteristic. Multiple products should be used to provide for both growth predictions and mature markets. Market share for individual student companies should be based on price, availability and product quality.

2) *Aggregate Planning*

Based on inventory costs and future demands, students must set production quantities for the next period of the game. Demand should be sufficiently seasonal that production to stock should be considered for peak demand periods. Aggregate planning should also include decisions on raw material orders. Multiple suppliers with different characteristics and capabilities should be presented. Some products should require common raw materials while other products have unique raw materials. Aggregate planning should also involve decisions regarding overtime scheduling.

3) *Shop Floor Control*

Student companies should determine batch sizes, production order releases and scheduling / sequencing rules. Schedules should be established by analyzing daily production requirements, inventory levels and policies, and production capacities.

4) *Inventory Control*

Inventory levels should occur as a normal result of shop order releases and market demand. Holding cost should be included to deter having large inventories. But these inventories may be necessary to cope with seasonal demands. Inventory levels must be managed through shop order releases and production balancing.

5) *Material Purchasing*

Production plans will dictate raw materials requirement. Suppliers must be chosen based on their lead times, quality, price and reliability. Closer cooperation with suppliers should result in improved inputs to the production process.

6) *Equipment Selection / Replacement.*

Student companies should be able to influence process design. Minimally equipment selection decisions should be available for replacement purposes. Ideally student companies should be able to reformulate material flows with alternative (or parallel) processes or dedicated flow lines.

7) *Assembly Line Balancing*

The simulated production system should include an assembly line, which can be reorganized in order to reduce cycle time. Additionally new stations can be introduced to further decrease cycle time, but with an appropriate increase in production costs. The assembly system should address multiple products.

8) *Quality*

Product quality should influence market acceptance of a companies production. Since operational characteristics of the game prohibit direct application of statistical process control and control charts, quality should be measured in terms of defective production. Placement of inspection stations should be a design decision.

9) *Maintenance*

Machines should have a breakdown probability distribution, and corrective maintenance should affect costs and machine availability. Preventive maintenance measures should have an impact on breakdown frequency, repair time and costs.

10) *Machine Control*

Players should monitor data on individual machines, to evaluate their processing times, defective production, setup times, breakdowns, and costs. Process improvements can be done through machine replacement or redesign of the process.

4.2. The General Framework of the Game

Student participants will be divided into teams that will represent companies competing in a multiproduct market. Initially a game administrator will distribute data representing historic information about the past market performance and the present status of the specific student companies. Additionally there will be basic data on the manufacturing assembly operations, production capacities, and supplier data.

The student teams must then analyze the available data and make production decisions which will govern one month's production (four weeks). A thirteen month year with exactly four weeks per month is assumed. During a week, each company will work five days, with two shifts of eight hours. The total number of regular hours worked in a month is 320. Overtime can be scheduled but is limited to 40 hours per month. The decisions from all of the companies are collected and input into the game, which simulates market demand and production for the month, and produces reports to be distributed to each of the companies indicating their company's performance. This continues until the administrator indicates that the game is at an end.

There are three sets of input data every period:

1) Administrative input data
2) Input data from previous period
3) Decision input data

The game administrator has the capability of programming certain special events, that affect all competitors. These influences from the external environment are announced to the players by memos, and are used in the long term planning of the companies.

Input from previous periods consists of information regarding the state at which the production process was left at the end of last period. It includes the location and state of inventories of raw materials, work in process and finished goods. Data regarding the current process configuration is stored in the database and is also considered input from the previous period.

Companies make decisions that affect the manufacturing systems internal dynamics, by establishing the sequence, batch size, priority rules, and maximum queue sizes. They can improve their processes with investment projects that affect the production of defective parts, setups, downtime, overtime and processing times. Players will also make decision that deal with external factors like price policies and supplier selection.

The size of the total market is a function of the number of companies participating in the simulation game. Demand is generated based on historical data. The procedure to determine daily market requirements is represented in Figure 1. Students determine the trend and seasonal behavior of the market, in order to predict sales potential for each product in each month. Sales in a month are distributed among weeks according to a general trend for that month. Daily market requirements remain constant during a week. Initially there will be three products to be manufactured.

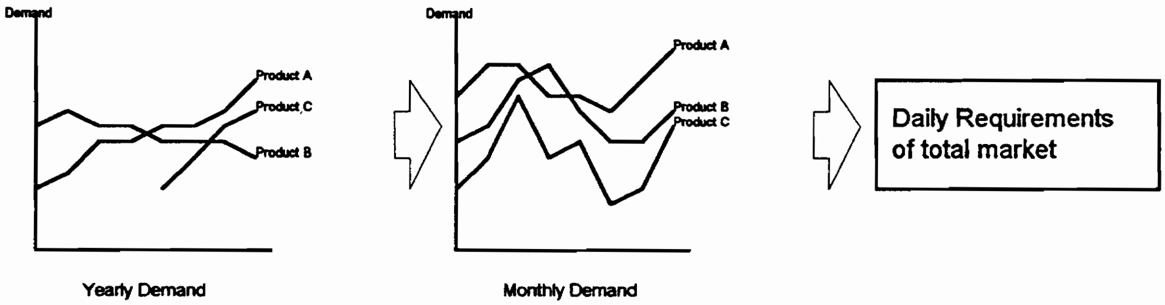


Figure 1: Daily Requirements Definition Procedure

The manufacturing system will consist of two production lines converging into a single assembly line. Products will consists of multiple components which will be processed on these two lines prior to assembly. Inspection can be done by individual operators at processing stations or inspection stations can be included. Daily production will be accumulated in finished goods inventories which will then be used to satisfy company specific demand.

Market share will be updated each month and is allocated based on the company's price, availability of goods, product quality and the companies market share from the previous period. At the end of a simulation month, a series of reports are given to the players, to provide feedback on their performance. Students are able to evaluate the consequences of their decisions and receive the required information for their next set of decisions. A monthly summary report is also given to the game administrator to evaluate intercompany performance.

As illustrated in Table 7, the simulation game will be organized into three phases: Input, Simulation and Output.

Table 7: Game Phases

Input	Simulation	Output
Sales generation	Production simulation	Total Demand of Period
Environmental Influences	Market Simulation	Fuzzy Market Share Report
Input from previous periods		Sales and lost sales
Input decisions		Machine Time Report
		Defective parts
		Inventories
		Production Costs

The input phase of the game will generate the product demand for the time period being modeled and process model inputs - administrative, historic and company. The production and market simulation will be a low level, discrete event production simulation of the individual manufacturing processes. Data from the production simulation will then be used to create output reports for the participants and the administrator.

This game will be unique in its application of a low level production simulation for estimating the effects of company wide performance in a competitive market place. Games which focus on process level decisions typically are not competitive, while company wide games tend to treat production operations as a black box. This game will let day by day production establish market competitiveness.

4.3. The Conceptual Framework of the Game

4.3.1. Performance Measures

In general companies should be encouraged to constantly improve their production processes, while growing in term of sales and market share. The performance score of a company should be influenced by the following factors:

1) *Profit*
2) *Market Share*
3) *Cash Flow*
4) *Production Position*

Profit is an absolute measure of a company's capacity to make money through sales, while market share is a way of measuring the relative performance of a company in the market. Cash flow is a survival requirement, that have to maintain positive throughout all simulation periods. Production position is a measure potential production capacity of a company, and it will be specifically included to evaluate the state at which the company is left at the end of the simulation game.

A multi-objective performance evaluation method is required, since a single objective would encourage students to make unrealistic drastic decisions in the last periods of the simulation game. For example, if the objective was to maximize net profit, companies would tend to avoid investments and raise prices in the last simulation periods. If the objective was to maximize market share, student teams would be encouraged to sell at very low prices, disregarding profits. A company could go broke in the last period and still be the best at achieving the objective.

The score of a company "i" in period "n" will be given by:

$$\begin{aligned} SCORE_{in} &= (W_{pr}*PR_{in}) + (W_{msa}*MSA_{in}) + (W_{msb}*MSB_{in}) + \\ &\quad (W_{msc}*MSC_{in}) + (W_{msd}*MSD_{in}) + (W_{pp}*PP_{in}) \\ CF_{in} &> 0 \end{aligned}$$

where PR_i, PP_i, MSA_i, MSB_i, MSC_i, and MSD_{in} are the profit, production position and market share for products A, B, C and D respectively, and W_{pr}, W_{pp}, W_{msa},

W_{msb}, W_{msc} and W_{msd} are the corresponding weights assigned by the game administrator.

The final score of the teams is given by the weighted average of the companies scores throughout the simulation periods:

$$SCORE_{Final,\ i} = W_1 * SCORE_{i1} + W_2 * SCORE_{i2} + ... + W_F * SCORE_{iF}$$

where W_1, W_2 and W_F are the weights for the scores of periods 1, 2, ..., F (final), assigned by the game administrator, and $SCORE_{i1}$, $SCORE_{i2}$, ..., $SCORE_{iF}$ are the score obtained by company "i" during periods 1, 2, ..., N.

4.3.2. Production Position

Since there is a limited number of simulation periods in which students will manage the companies, one of the performance measures has to be directed towards hindering students from making drastic unrealistic last period decisions, like selling all the assets or decreasing the prices to zero. The production position measure achieves this function, since it is affected by the price, the defective production percentage and the production capacity (based on the bottleneck operation). This measure should be affected by the following factors:

$$PP_{in} = \frac{(PC_{in}) * F(P)_{in} * F(D\%)_{in-1}}{\Sigma\,[(PC_{ijn}) * F(P) * F(D\%)]}$$

where PP_{in} is the production position of company "i" for in month "n"; PC_{in} is the production capacity of the bottleneck operation in company "i" in period "n", $F(P)_i$ is the price factor and $F(D\%)_{ij}$ is the defective percentage factor of the previous production period. In order to normalize these fractions, the denominator is the summation of the production positions of all companies.

4.3.3. Market Share

At the beginning of the simulation game, market share will be assigned in equal proportion, in order to provide a fair starting point. From the moment students take control of their companies, the performance of their product in the market will be recorded and incorporated to the historical data. Market share is updated at the beginning of each month, and is allocated based on the company's product price, availability, market share in the previous period, and percentage of defects in the shipped products. Market share is given by:

$$MS_{ijn} = \frac{(MS_{ijn-1}) * F(P)_{ijn} * F(Av)_{ijn-1} * F(D\%)_{ijn-1}}{\Sigma\,[(MS_{ijn-1}) * F(P) * F(Av) * F(D\%)]}$$

where MS_{ijn} is the market share of company "i" for product "j" in month "n"; MS_{ijn-1} is the market share in the previous period, $F(P)_{ij}$ is the price factor, $F(Av)_{ij}$ is the availability factor and $F(D\%)_{ij}$ is the defective percentage factor. The denominator of the market share equation is necessary to fix the sum of all company shares to 1. Without this term it is possible to have a total market share that exceeds 100% or is below the desired level.

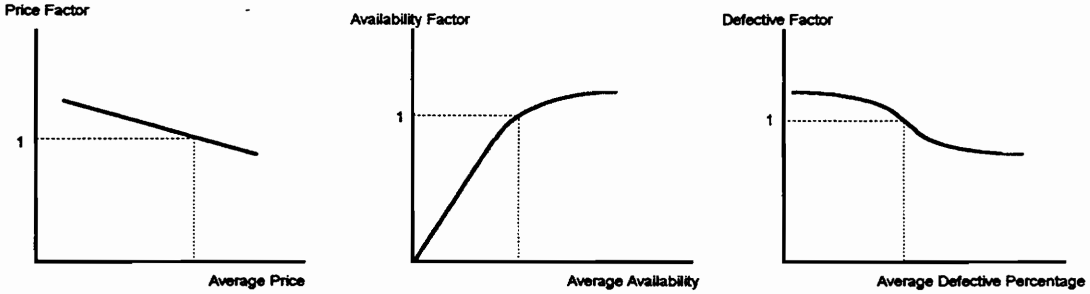


Figure 2: Functions for Factors that Affect Market Share

A company producing at the right price, with good availability and minimal defective parts will have all three factors equal to one. If the price is high, the price factor drops below one with the potential of lower market share. Likewise poor availability or excessive defective parts can decrease market share as illustrated in Figure 2.

The price factor will be indexed on the ratio of the company's current price divided by the average price. Hence if all companies increase price, nobody losses. The availability factor will be indexed on a moving average of the companies availability over a number of time periods. This is to reflect the fact that the market tends to remember outages and react accordingly. The defective percentage factor is also indexed on a moving average.

The market share factors will be expressed in tables, so that they can be modified by the game administrator. This will permit changes in the base values for each factor as well as the influence of that factor on the market. If it is desired to make the market more sensitive to a specific factor, the slope of the curve can be increased. The administrator also controls the number of periods being considered in calculating the indices for product availability and percentage of defects.

4.3.4. External Environmental Influences

The Game Administrator has the capability of introducing external factor or events that affect all companies. These factors or events called external environmental influences and programmed into the game during the initialization process by the administrator. Both the influences to be included and their respective timing are user defined. These include the following:

1) *New Products / Obsolescence:* This event will cause the demand level of one of the products to start decreasing, at the same pace that the demand of a new substitute product grows. Eventually the old product is no longer demanded, and companies have to get rid of left over obsolete inventories. Such an event will be announced to the players by a memorandum, that will permit them to anticipate the introduction of the new product and the decline of the old. Investment in research and development will allow the company to introduce the new product into the production process.

2) *Raw Materials Shortages:* A shortage of raw materials can be programmed by the game administrator. Only those companies that have selected the most reliable suppliers will receive the entire quantities that they request. Investments in

research and development might have resulted in the implementation of new substitute raw materials, in which case the company is unaffected by this event.

3) *Unexpected Demand Fluctuations*: The game coordinator will have the option of introducing unexpected fluctuations at some desired point in time. This could be in the form of a change in trend or an increase in variability of demand. Use of this option would insure constant updating of market forecasts by the student companies.

4) *New Competitor:* A new, offshore competitor can be introduced into the game that would share in market demand. The companies would be warned of the possibility and given information on the expected position the competitor would assume. The impact of the new competitor would be somewhat minimal but that would change as its share of the market increased. Market share of this competitor would be based on the same factors as those of the student companies, with actual values of price, availability and quality being determined by the game administrator.

5) *Increases in Costs:* External cost factors can be changed by the game administrator. Specifically this includes material and machinery costs, and holding costs.

4.3.5. Internal Environment

The individual processing station is the basic building block of the production model as illustrated in Figure 3. The input to a station is in the form of product batches which arrive and queue before the station. A batch is defined by its product type and size. These two characteristics establish the processing time at each station. If two subsequent batches are of different product type, a setup is required. Time and cost associated with the setup depend on the type of machine being used at the station. Each station has a probability of breakdown associated with it, and it is a function of the number of units processed.

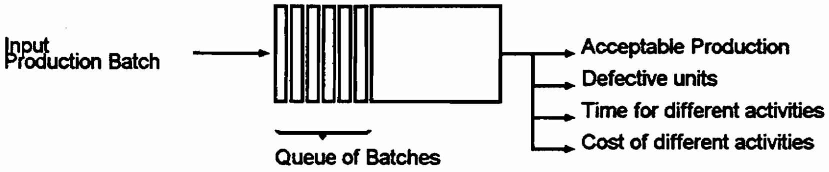


Figure 3: Basic Building Block

Cumulative costs and status of each station are maintained in the end of period database, and are summarized in the output reports. There is a probability of producing a defective unit for each part processed at the station, which varies according to the machine type.

The manufacturing process consists of two parallel production lines of three stations each, that converge into an assembly line. Each station is represented by one of the basic building blocks described above; the output of one becomes the input to the next one as shown in Figure 4.

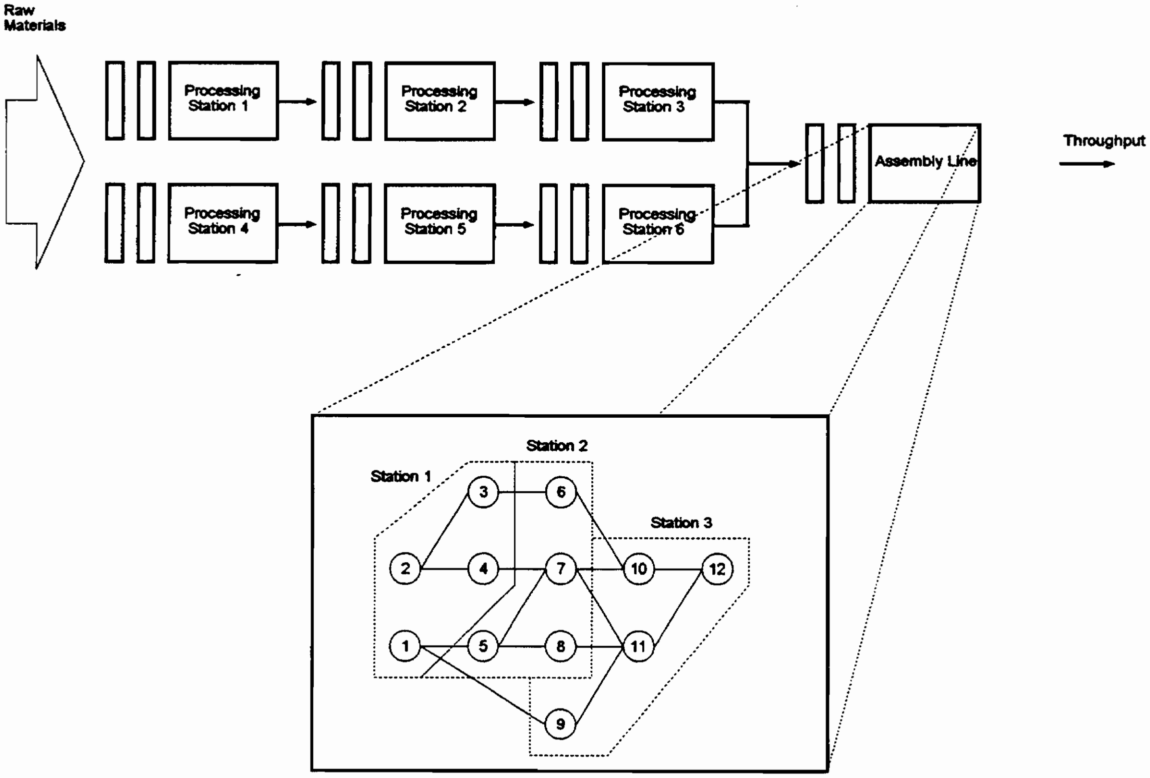


Figure 4: The Production Process

Initially there are three possible products: A, B, and C. Each product consists of two components that are assembled in the final step. One component is produced on the first line, while the other component is produced on the second line. Their processing times and costs differ, but the processes and the sequence of operations is common to all products. There are six types of raw materials, one for each subassembly. For each product, one component raw material will enter the process through station 1 and the corresponding one through station 4.

The assembly station will be paced and unbuffered. It will not require a setup, but a production batch will have to clear the entire line, before a batch of a different product can be processed. Data will be provided on each product for the assembly line tasks - time and precedence. This will permit students to balance the line. Even though there are three products going through the assembly line, balancing the line is not a typical mixed model problem. The initial configuration is set in such a way, that by balancing the stations for one product type, it is automatically balanced for the other products. The assembly line station is the bottleneck at the beginning of the simulation, so it is expected that the students will first tackle this problem to augment throughput.

Inspection operations can be used to separate defective from acceptable units. Inspection can be implemented as a task performed by the operator after he or she finishes processing a batch, or as a separate operation station. The first way increases the processing time at this station, while the second alternative requires a new station to be added.

Companies are able to invest in replacing equipment in order to change the characteristics of the station. As shown in Figure 5, teams may opt to introduce parallel station or dedicated production lines.

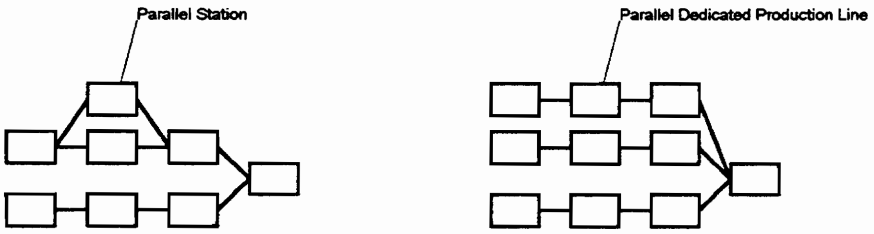


Figure 5: Parallel Station and Dedicated Production Line

4.3.6. Decisions

4.3.6.1. Internal Decisions

There are two types of internal decisions: Repetitive or periodic decisions and one time projects. The first type of decisions is made every month and specifically deals with one of the following areas:

1) *Scheduling and Sequencing*: Daily market requirements and inventory levels for the period, will be the base to make decisions regarding the following issues:

    a) Batch Size: Players will determine the size of the batches for each production release. A batch is the smallest size group of products that can be handled or shipped. If a batch is not completed at the end of a day, it cannot be shipped.

    b) Monthly Releases: Companies will establish the sequence and the time at which batches are released to the shop floor during the company month.

    c) Priority Rules: When a station has a queue of more than one batch, it is necessary to select which batch is processed first. Priority can be based on batch arrival order, type of setup performed last, size of batch, shortest processing time, and the level of the respective finished good inventory.

2) *Overtime Scheduling:* It is expected that in some periods production capacity will not be enough to satisfy demanded volumes. During these periods one possible solution will be to work overtime with higher production costs. There is a limit to number of overtime hours that can be scheduled per month.

3) *Maximum Buffer Size:* Players will be able to control the work in process inventory by defining a maximum buffer size before each station. If this maximum is reached, then the station feeding the buffer is blocked and it remains in that state until the buffer size is reduced.

Projects are decisions implemented with a lower frequency; they usually involve an investment and change the way in which the system works, with a certain implementation period. Companies can invest in the following projects:

1) *Equipment Selection / Replacement*: Players will have the option of changing equipment to upgrade the production process. This involves two kinds of decisions: replacing equipment at one station, and introducing additional equipment to create parallel or dedicated stations. For each station there will be a list of available alternative machines and their characteristics regarding:

   Mean processing time for products A, B, C, and D.
   Standard deviation of processing time for products A, B, C, and D
   Operating cost for product A, B, C, and D
   Mean setup time
   Standard deviation of setup time
   Setup cost
   Initial acquisition cost
   Periodical depreciation
   Defective part production probability for products A, B, C, and D
   Standard deviation of repair time
   Breakdown probability
   Repair cost
   Mean repair time
   Standard deviation of repair time

2) *Assembly Line Balancing*: The assembly line is regarded as one additional station with its own set of characteristics. It cannot be replaced, it is to be reorganized in order to achieve a better balance and shorter processing times.

3) *Inspection*: Defective production is separated by inspection in one of two ways. Machine operators can inspect their own production, thereby increasing the processing time of the station; or an inspection station can be set up, which increase costs but does not affect processing time. Uninspected batches contain both good and defective products.

4) *Quality Control Project*: The overall probability of a defective unit being produced is a function of the specific machinery being used at a processing station.

A quality control projects can be used to improve this probability. Quality control projects are implemented on a machine by machine basis and require an investment in capital with a process improvement being realized in future months. Results are necessarily immediate, there is a probability associated with the implementation time and the percentage in which the probability of producing a defective unit is reduced.

5) *Preventive Maintenance Project*: The effect of this process is to reduce the breakdown probability and the repair time of a machine. These projects are therefore station specific. Once the capital investment is made, a implementation period is necessary, before the effects of the projects become obvious.

6) *Setup Reduction Project*: The setup reduction project reduces the overall setup time and cost of the processing stations. These projects are also implemented on a machine by machine basis.

7) *Research and Development Project*. Investments in research and development will increase the probability of the company being able to incorporate the solutions to events programmed by the game administrator as environmental influence. During each period there is a probability that the company will achieve one of the following improvements:

    - New products
    - Substitute raw materials

   These are the specific solutions to obsolescence and raw material shortage events respectively.

4.3.6.2 External Decisions

External decisions are those decisions that are associated with the external environment. Some external decisions are used as the basis for other decisions while others are used as game inputs.

1) *Sales Forecast*: This analysis is required to established the sales quantity that will be allocated in future months. It is based on historical data on the market size and the market share prediction. While the actual student forecast are not entered as data in the game, they form the basis for other decisions. The companies are provided with a five year history of the market on a year by year basis and a monthly history for the previous 13 months. Additionally data is available on their own sales.

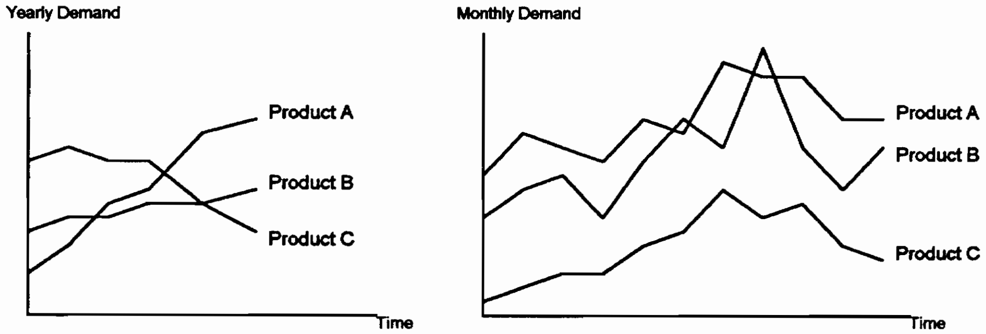


Figure 6: Demand Forecast

2) *Aggregate Planning:* Since the companies are competing in a multiproduct market with seasonal demands and limited production capabilities, consideration must be given to the following questions:

1) When should I produce what product?
2) How much should I produce?
3) Should I plan to inventory for peak periods?
4) Should I upgrade production capacity?

Monthly production requirements for each product will have to be established by companies in light of expected demand. Production capacity limitations will have to be considered as insufficient capacity will exist during forecasted seasonal peaks. These are not actually inputs to the game but are reflected in other decisions.

3) *Price Definition*: Companies will establish prices for each product based on their production costs and the historic average market price. Cost allocation will be an

important task, since not all expenses can be easily assign to specific products. Price affects company income as well as its performance in the market.

4) *Raw Material Acquisition*: Players will define the raw materials arrival system by determining the size of the shipments and the frequency of arrival based on the required materials quantities for the planned production. Raw material units are expressed in terms of units required for a production unit; i.e. a batch of size X requires X raw materials units. Raw material acquisition also involves the selection of the best supplier based on quality, price, lead time and reliability.

5) *Supplier Change*: Suppliers can be changed in order to better adapt the arrival of raw materials to the necessities of the company. These changes affect the following parameters:

Price of raw materials
Quality of raw materials
Frequency and flexibility of arrivals of raw materials
Reliability and punctuality
Minimum and maximum delivery quantities

4.4. Organizational Framework

As illustrated in Figure 7, there is a database where the default settings area stored. By running the initialization routine, the game administrator will enter the number of participating teams, and will program the external influences that will affect the student companies throughout the game. With this information, the initial period database and the administrative database are established. Companies are given reports regarding the initial conditions of the systems, and base data information that includes supplier profiles, alternative machine characteristics and effects of improvement projects.

Each period thereafter the procedure indicated in Figure 8 is followed, in which companies will make decisions and will present them as input sheets. These decisions are entered into the simulation run module along with data from files that regard the status of last period and the administrative database. Based on this information the market module determines demand and allocates sales, while the production module runs the individual simulations and generates daily throughput. At the end of the month output files for each company are created and reports are printed. There is a special report for the game administrator, that summarizes the performance of each company and provides accurate information on market share. The status of the system at the end of the period is written into a file, which becomes an input to the next month.

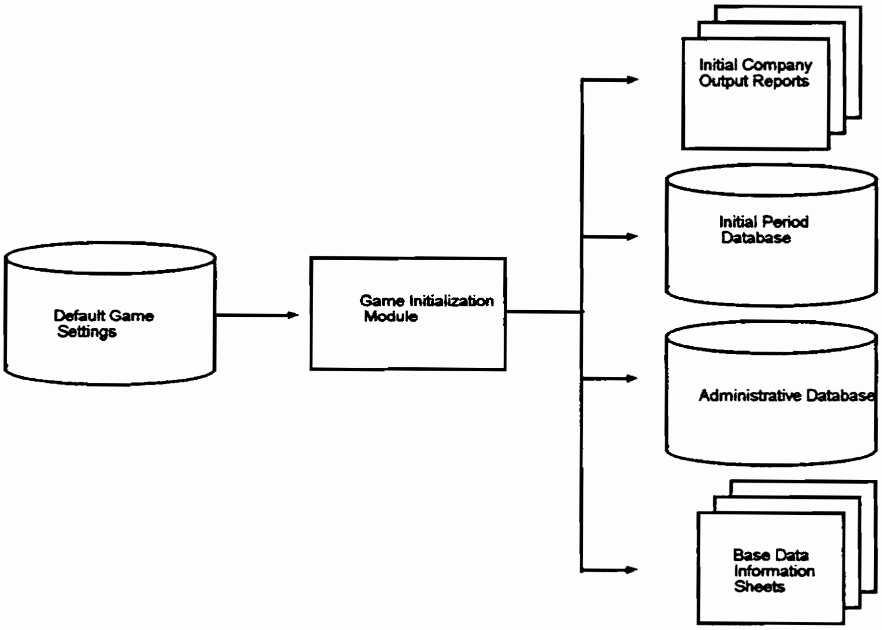


Figure 7: Game Initialization Run

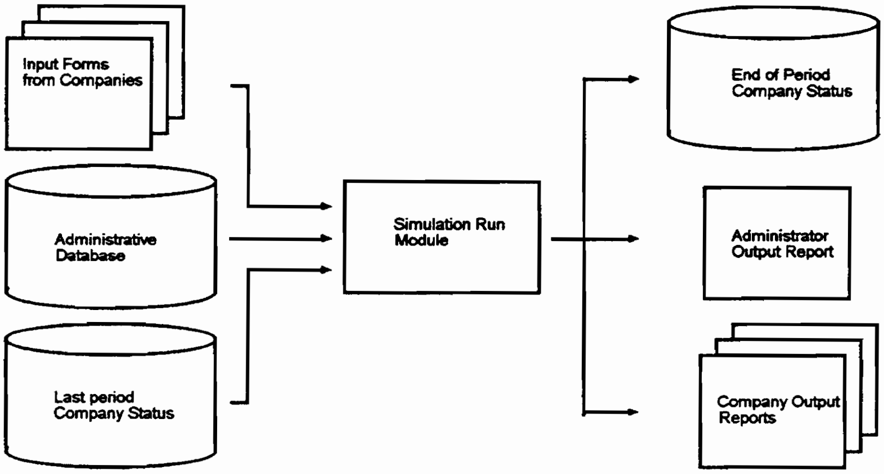


Figure 8: Periodic Game Execution

4.4.1. Default Game Setting

The default settings database stores the following information regarding machines, stations, suppliers, original decisions, and effect of projects. For each machine the following is defined:

Machine Type
Station where it can be used
Mean of processing time for products A, B, C, and D
Standard deviation of processing time for products A, B, C, and D
Operating cost for products A, B, C, and D
Mean setup time
Standard deviation of setup time
Setup cost
Initial acquisition cost
Periodical depreciation
Defective part production probability for product A, B, C, and D
Breakdown probability
Mean repair time
Standard deviation of repair time
Repair cost
Fixed Costs

For each station there are a number of alternative machines than can performed the task. The changes in this parameter that each different machine can introduce for each station are defined in this database.

Machine being used at station
Next station (s)

The assembly station original configuration is defined by the following parameters:

Precedence relationships for all tasks
Operation time for product A, B, C, and D
Initial number of assembly stations
Initial task assigned to each assembly station

Each possible supplier will be defined in terms of the following:

Supplier
Material
Price
Quality
Maximum frequency of delivery
Minimum size of delivery
Maximum size of delivery
Standard deviation of delivery time (in relation to the mean)
Standard deviation of delivery quantity (in relation to the mean)

Environmental influences are introduced by the game administrator in the initialization period. The following parameters must be defined:

Unexpected demand level
Unexpected demand period
Insertion of new product to the market period
Raw materials shortage type
Raw materials shortage period
Percentage of unsatisfied raw material orders
Increases in costs factor
Increases in costs period
Costs affected by increase
New competitor introduction period
New competitor initial market share
New competitor production capacity
New competitor initial defective unit production level

The exact effects of each improvement project is stored in the default database, by the following parameters:

Defective probability reduction factor
Setup reduction factor
Breakdown frequency reduction factor
Repair time reduction factor.
Research and development probability for new product
Research and development probability for substitute raw material

Students will receive reports that will include the company's decisions for the period before they take control of the system. This will give student a general idea of the range of prices and other decision parameters, as well as an evaluation the effect of previous decisions on the company's functions. The default decisions involve the following:

Prices for each product
Batch sizes for each product
Priority rule
Work order releases schedule
Raw material order placement
Assembly balance
Overtime decision
Suppliers

Initial conditions for the first period are defined by data structures with the parameters specified in the next section, Initial Period Data Base.

4.4.2. Administrative Database

The administrative database is created during the game initialization and is used as a data resource during the monthly executions of the game. It is not changed by the monthly executions. Rather, it is a roadway of the game that is to be played as specified by the administrator. The administrative database contains for each of the future simulation periods, the following information regarding environmental influences is found in the administrative database:

Period
Total demand for products A, B, C, and D for the period
New product insertion event flag
Raw materials shortage event flag
Suppliers affected by raw material shortage event
Unexpected demand fluctuations event flag
Unexpected demand fluctuation variable
New competitor insertion event flag
Increases in costs event flag

There will be a list of machines available for each station. The characteristics of this machines are copied from the default database and have the same data structure.

The assembly station configuration is defined by the following parameters:

Precedence relationships for all tasks
Operation time for product A, B, C, and D
Number of assembly stations
Task assigned to each assembly station

The administrative database will have a list of all existing suppliers, for which the following characteristics will be defined:

Supplier
Raw material
Price
Quality
Maximum frequency
Minimum size of delivery
Maximum size of delivery
Standard Deviation of delivery time
Standard deviation of delivery quantity

Additionally the administrative database contains tables that define the relation between the average price, availability and defective productions, and the value of the corresponding market share factors. This relation is represented in Figure 2.

4.4.3. Initial Period Data Base

The initial period database is a representation of the system configuration at the beginning of the game. Structurally it is identical to the end of period company status. databases that are created by the periodic execution of the game.

This database contains data on the status of each station in the process:

Company
Station
Next station
Machine used at station
Quality control project flag
Quality control project counter

Preventive maintenance project flag
Preventive maintenance project counter
Setup reduction project flag
Setup reduction project counter
Inspection operation flag
Overtime scheduling variable
Present status

The assembly station original configuration is defined by the following parameters:

Precedence relationships for all tasks
Operation time for product A, B, C, and D
Initial number of assembly stations
Initial task assigned to each assembly station

For each queue the following is specified:

Company
Queue number
Next station
Number of batches the queue
Batch size of each batch
Total queue size (in units)
Batch identification number for each batch
Product type of the batches
Cumulative number of defective parts in each batch
Batch arrival number

Four variables are needed to keep track of finished goods inventory and eight are associated with raw materials:

Company
Finished goods inventory of products A, B, C, and D
Raw materials inventory levels of AI, AII, BI, BII, CI, CII, DI, and DII

The list of events is recorded in this file specifying the following for each event:

Event Time
Event Type
Company
Entity
Location

The performance of the companies will be recorded in the Initial Period Data Base, it will include information on the following variables:

Market Share for products A, B, C, and D
Profit
Production Position
Cash Flow

4.4.4. Base Data Information Sheets

Base data information sheets provide information that involves supplier profiles, machine characteristics, assembly station configuration and possible process upgrades, that students will require when evaluating investment alternatives. This information does not vary throughout the simulation, so one print out of this report at the beginning of the game will be sufficient.

For each station there will be a list of machines that can be used in that location, for which the following characteristics will be specified:

Machine Type
Station where it can be used
Mean of processing time for products A, B, C, and D
Standard deviation of processing time for products A, B, C, and D
Operating cost for products A, B, C, and D
Mean setup time
Standard deviation of setup time
Setup cost
Initial acquisition cost
Periodical depreciation
Defective part production probability for product A, B, C, and D
Breakdown probability
Mean repair time
Standard deviation of repair time
Repair cost
Fixed Cost

Assembly stations information will include the following:

Precedence relationships for all tasks
Operation time for product A, B, C, and D
Number of assembly stations
Task assigned to each assembly station

For every raw materials there will be a list of supplier that can distribute it. The following characteristics will define the supplier:

Price
Quality
Maximum frequency
Minimum size of delivery
Maximum size of delivery
Standard Deviation of delivery time
Standard deviation of delivery quantity

There will be a list of improvement projects, for which the investment cost and a general description of the expected effect on the process will be included.

4.4.5. Input Format

Each simulation period, decisions will be presented by the students in the form of input sheets, which will have the format defined in Figures 9 and 10.

Players will enter the product's price and the size of the batch as a quantity. One priority rule is chosen with the necessary specifications. To schedule production order releases in a month, it is necessary to enter the type of product, the time, the number of occurrences, and the frequency of releases. Since parallel production lines might be introduced into the process, it is necessary to specify the location, where the batch is to be released. Raw materials orders are placed in a similar way, but a location is not needed. For each supplier there are different probabilistic distributions that determine the size and the time of arrival of each order.

INPUT SHEET - COMPANY: _____ PERIOD: ___

Price Product A:___
B:___
C:___
D:___

Batch Size A:___
B:___
C:___
D:___

Priority Rules:

- ☐ **First In First Out**
- ☐ **Earliest Finishing Time**
- ☐ **Avoid Setup** **Repetitions:___**
- ☐ **Final Inventory Replacement** **Repetitions:___**
  - **Inventory Lower Limit** **A:___ B:___ C:___ D:___**

Work Order Releases

Location	Type	First Time	Occurrences	Frequency

Raw Material Orders

Type	Supplier	First Time	Occurrences	Frequency

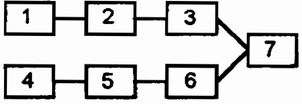
Figure 9: Input Sheet 1

[] Assembly Line Balancing

Task	Precedence	Op.Prod. A	Op. Prod. B	Op. Prod. C	Assg. Station	New Assgt.
1	6	4	4	1	1	
2	-	2	2	2	1	
3	1	7	6	5	1	
4	1	3	3	3	1	
5	2	1	1	1	2	
6	3	2	2	2	2	
7	4, 5	2	2	1	2	
8	5	4	3	3	2	
9	2	1	1	1	3	
10	6, 7	3	2	2	3	
11	7, 8, 9	2	2	2	3	
12	10, 11	5	4	3	3	

Process Redesign

Current Process Configuration



[] Replace Station ___ with machine model ___
[] Add parallel station to station ___. Machine ___
[] Add inspection station after station ___
[] Add inspection operation in station ___
[] Arrange stations ___, ___, ___, as dedicated production line with machine types ___, ___, ___.

Overtime Scheduling

Station								
Scheduled Overtime								[]

[] Setup Reduction Project	Number:	Stations:
[] Quality Control Project	Number:	Stations:
[] Preventive Maintenance	Number:	Stations:
[] Research and Development		

Figure 10: Input Sheet 2

In Input Sheet 1, different suppliers can be chosen for each raw material, their individual characteristics will be presented in the base data information sheets. To balance the assembly line, students will alter the right most column of Input Sheet 2. If the number of stations is changed, costs, operation and setup times are updated for the next simulation run. A process redesign project allows the players to replace a machine, add a parallel station, arrange a group of station as a dedicated production line, add an inspection station, or add an inspection operation to a station. Students need to specify the supplier that will provide each raw material. Overtime is scheduled specifically for each station. This permits companies to work overtime only with the capacity constrained resources.

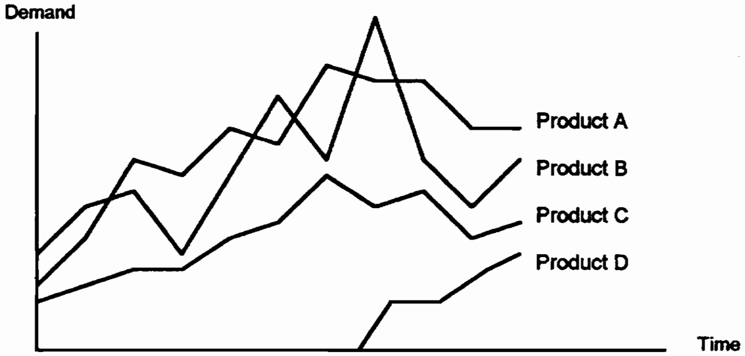
The projects regarding setup reduction, quality control, preventive maintenance are station specific, and can be performed more than one time on a same station. The research and development project has a predictable effect; the corresponding decisions is limited to either making the investment, or not.

4.4.6. Output Reports

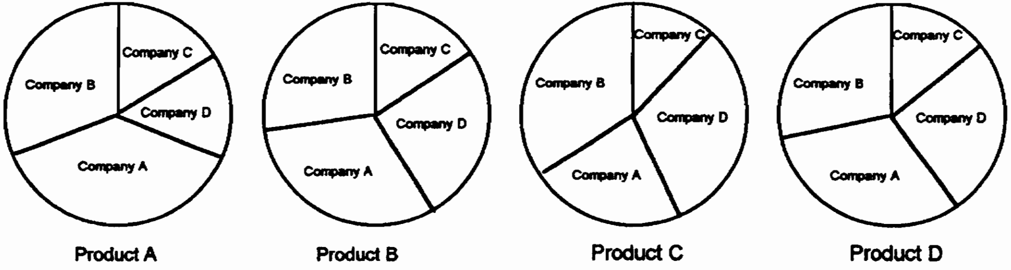
Reports are intended to provide feedback to the students regarding their performance in achieving the multiple objectives of the game. There are two types of output information: public domain information and company information. Memorandums are an additional form of printed output, that the game administrator utilizes to provide information to the students regarding the environmental influences.

Common domain information regards mainly the market. Teams need to have a general idea of their relative performance regarding their competitors, therefore each team is given reports that specifies the total market size and each competitor's share, subjected to a margin of uncertainty. Demanded quantities will be incorporated as historical data for future predictions. A graphics support tool will be used to present market data in the form of a pie chart. This information is presented Output Sheet 1, which format is illustrated in Figure 11. Company confidential information is presented Output Sheets 2 and 3, and regards the following areas of cost, machine status, inventory and throughput.

Output Report Sheet 1
Historic Market Demand



Period \ Product:	Mkt Size A	Mkt Size B	Mkt Size C	Mkt Size D
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				



Margin of Error = ± X%

Figure 11: Output Report Sheet 1 (Common Domain Information)

Company Throughput Report									
Day	Prod. A	Sales A	Inv. A	Prod. B	Sales B	Inv. B	Prod. C	Sales C	Inv. C
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
Total									

Figure 12: Output Report Sheet 2

Cash Flow / Cost Report

Sales
    Product A
    Product B
    Product C
Operating Costs
Setup Costs
Materials
    Raw Material AI and AII
    Raw Material BI and BII
    Raw Material CI and CII
    Raw Material DI and DII
Repair Cost
Maintenance Cost
Inventory holding
Fixed Cost
Investment Budget
Operational Margin

Inventory Report

Queue	Average Size	Final Size
Station 1		
Station 2		
...		
Station n		
Assembly component line 1		
Assembly component line 2		

Machine Status

Machine	Processing	Setup	Down	Blocked	Starving
Station 1					
Station 2					
...					
Station n					

Figure 13: Output Report Sheet 3

4.4.7. Administrator Output Report

The administrator output report contains a summary of companies performance including the exact value of market share and production position factors. The game administrator has also access to all companies' output report information, with no margin of error.

4.5. Structural Framework

The manufacturing game will consist of two separate programming modules as discussed earlier. A system initialization module will read default configuration settings and create the necessary reports and data files for the first run of the game. This program will be interactive and thus permit the game administrator to modify the initial data when desired. The second program will process the month by month decisions, simulate the manufacturing operations and produce the operational reports for the student companies.

4.5.1. The System Initialization

The system initialization module will establish the initial conditions of the game. Two sources of information will be used in the process. Default configuration settings will exist within a data file representative of a standard five company game. Additionally an interactive dialog with the game administrator will permit modification of the default configuration for the specific game session to be run.

The general flow of the program is given in Figure 14. The program first requests the game administrator to input the number of companies to be included in the game and names for each of the companies. This information is necessary to establish the total market size and for the creation of the output reports.

Next the historic demand is presented to the game administrator for possible modification. Three products are included in the default configuration - a mature almost dying product, a growing product, and a new product. The game administrator indicates the types of trends desired and the amount of variability associated with the data. The program randomly generates the actual data points to avoid identical games from one run to the next.

Information on the default processing stations is then presented. Again, the data is randomly generated to avoid duplication of data from one run to the next. If the administrator chooses to modify the data, a warning is given indicating that the data has been created with the default demand being considered and modification could lead to unbalanced operations.

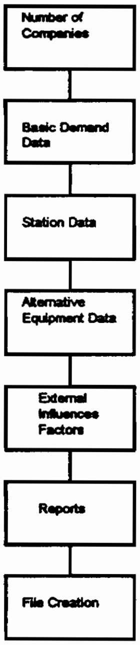


Figure 14 Initialization Procedure

Default information on alternative equipment is then presented with the option of possible modification. The game administrator may wish to limit the options students have in modifying the processes. For example, a simplistic game would only permit students to replace processing stations. Parallel stations or dedicated flow lines would not be permitted.

Finally, information on external influencing factors is presented to the game administrator. If it is desired to incorporate a specific factor, information is presented associated with the conditions of that factor.

After all the different configuration settings have been reviewed and modified, output reports are generated for distribution to the individual companies. These reports represent the initial period game conditions. Additionally fact sheets are created indicating information about external conditions available, alternative equipment, supplier profiles and the effect of improvement projects.

The last step in the procedure is to create the administrative database and the company status data base. These files are written to the disk for operational purposes and are archived on floppy disk for backup. All files are encrypted for security purposes.

4.5.2. The Game / Simulation Module

The game / simulation module is a computer program that is run repeatedly to process student decisions and generate monthly status reports. The program organization and execution can be divided into three phases. The first phase of the program deals with processing student decisions and generating daily demand for the products for the coming month. Next, a simulation of the month's production is executed for all companies running in parallel, appropriate statistics area generated and the company status data file is written.

4.5.2.1. The Game / Simulation, Initialization Phase

The general flow of the game / simulation module is illustrated in Figure 15. The program must first read the administrator database to get administrative input into what should be the external inputs into the coming month. Total market demand for products can then be created and stored for use during the simulation. Additionally the administrative database contains information on any desired external influencing events for the month. These factors are incorporated into the basic simulation data and memorandums are created for the companies as needed.

Next the program will read the company status files which contains information that represents the status of each company at the end of the last simulation run. The simulation module is preloaded with work in processes and existing inventories. Equipment configurations are verified.

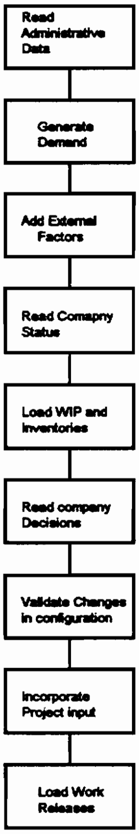


Figure 15 Game Initialization Phase

Inputs from students companies are then read. Equipment configurations are updated if needed and adjustments made are made to work in process. Project information is then incorporated into the simulation data structures. The simulation is then preloaded with work order releases. Control is then passed to the simulation phase of the program.

4.5.2.2. The Game / Simulation, Simulation Phase

The simulation phase of the game / simulation program will be a discrete next event simulation that models one month of production given the inputs from the initialization and demand generation phase. The program framework was designed to take advantage of the existing work done by Fazal Khan in his thesis: "Development of a C-based Simulation Toolkit supporting discrete, continuous and combined simulation [19]."

4.5.2.2.1. Simulation Data Structures

At the beginning of the simulation there are seven stations. Inspection stations are optional and may be included after each decision period. The production system may be redesigned to include additional stations. Therefore the number of stations throughout the game is variable. The initial configuration includes processing stations 1, 2 and 3 for component type I processing, and processing station 4, 5 and 6 for component type II processing and an assembly station.

There are eight types of entities:

Component I type A
Component I type B
Component I type C
Component I type D
Component II, type A
Component II, type B
Component II, type C
Component II type D

The simulation will incorporate eleven data structures to track the progress of the companies. These included a data structures related to stations (machining, inspection or assembly), entities, events, queues, job releases, raw material orders, finished goods inventory, raw material inventory, sales and station statistics.

1) Machine
    Mean processing time for product A, B, C, and D
    Standard deviation of processing time for product A, B, C, and D
    Operating cost for product A, B, C, and D
    Mean setup time
    Standard deviation of setup time
    Setup cost
    Initial acquisition cost
    Periodical depreciation
    Defective part production probability for product A, B, C, and D
    Mean repair time
    Standard deviation of repair time
    Breakdown probability
    Repair cost
    Fixed Cost

2) Station

- Company
- Station
- Next station (s)
- Machine used at station
- Quality control project flag
- Quality control project counter
- Preventive maintenance project flag
- Preventive maintenance project counter
- Setup reduction project flag
- Setup reduction project counter
- Cumulative separated defective units of A, B, C, and D
- Inspection operation flag
- Overtime scheduling variable
- Present status

3) Entity (batch)

- Company
- Batch identification number
- Product type
- Batch size
- Current location of batch
- Cumulative number of defective parts in batch
- Batch arrival number

4) Event

- Time
- Type
- Entity
- Location
- Company

5) Queue

- Company
- Location
- Next station
- Number of batches in queue
- Batch size of each batch
- Total queue size (in units)
- Batch identification number for each batch
- Product type of the batches

Cumulative number of defective parts in each batch
Batch arrival number

6) Job Release Data
- Company
- Type of product
- Location
- Time of release
- Frequency
- Size of release

7) Raw Material Order
- Company
- Type of raw material
- Supplier
- Time of order
- Frequency
- Size of order

8) Finished Inventory Data
- Company
- Quantity of finished product A
- Quantity of finished product B
- Quantity of finished product C
- Quantity of finished product D

9) Raw Material Inventory
- Company
- Quantity of raw material A
- Quantity of raw material B
- Quantity of raw material C
- Quantity of raw material D

10) Sales
- Company
- Demanded quantity for product A
- Quantity of units of product A sold
- Demanded quantity for product B
- Quantity of units of product B sold
- Demanded quantity for product C
- Quantity of units of product C sold
- Demanded quantity for product D
- Quantity of units of product D sold

11) Station Historic Statistics
    Processed units counter for product A, B, C, and D
    Defective units counter for products A, B, C, and D
    Operating time variable
    Operating cost variable
    Setup time variable
    Setup cost variable
    Starving time variable
    Idle time variable
    Down time variable
    Repair cost variable

4.5.2.2.2. Event Logic

There are eight types of events that will be included in the simulation program structure. These are illustrated in Figure 16:

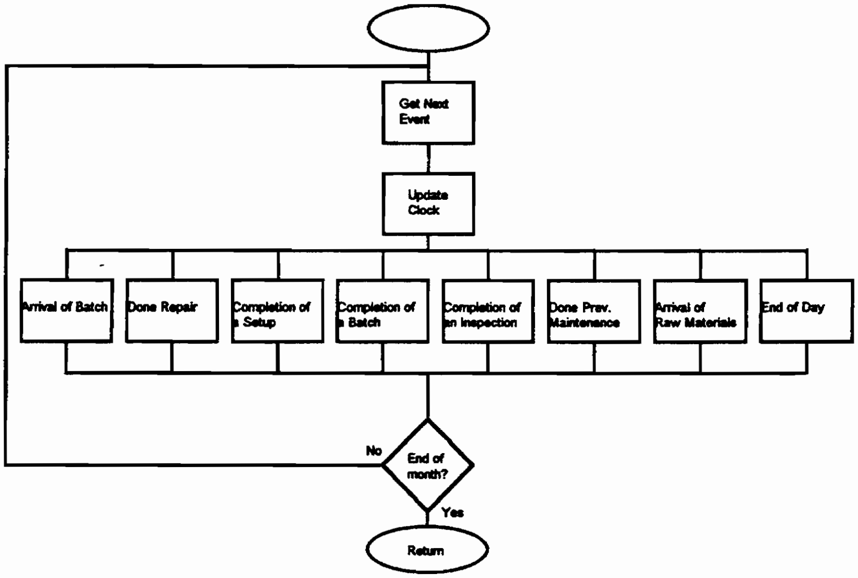


Figure 16: Discrete Simulation Events

4.5.2.2.2.1. Arrival of a Batch

Figure 17 describes the logic corresponding to the event - *Arrival of a Batch.* There are three different cases associated with for this event:

1) In processing stations 1 and 4, batches and raw materials arrive separately. So a batch arrival represents the work order that is scheduled according to a sequence established by the players.

2) In processing stations 2, 3, 5 and 6, and in all inspection stations, the batch arrives and does not require any additional material.

3) Two kinds of batch arrive at the assembly line station, one from each component line. Both component batches have to be present in order to allow the station to work on a batch.

In all three situations the scheduling of the arrival of a batch does not depend directly on a probabilistic distribution. It depends on the sequence established by the players or on the output of previous stations.

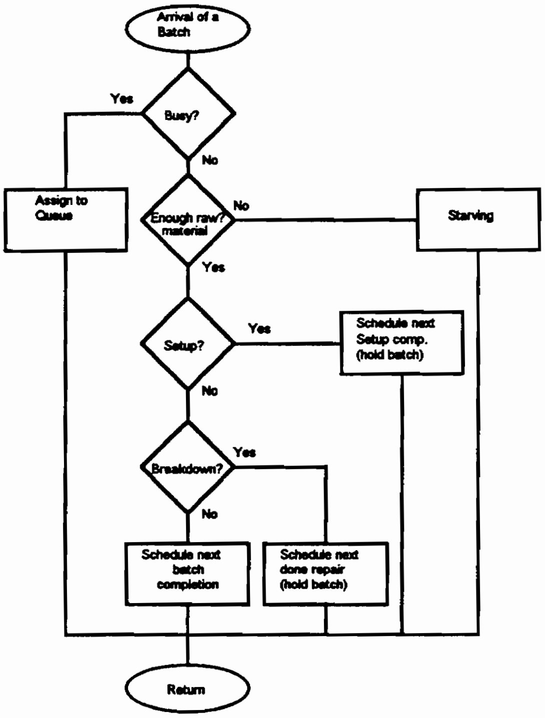


Figure 17: Arrival of a Batch Logic

When a batch arrives at a station the program checks whether the station is busy. If it is busy, then the batch is assigned to the queue in front of the station; the number of batches in the queue is increased by one; the size of the queue is increased by the number of units in the batch; and the batch is assigned a queue arrival number.

If the station is not busy, the existence of the required raw materials is checked. This procedure varies according to the station in the following way:

1) At processing stations 1 and 4, if the batch size is smaller or equal to the inventory of raw materials, then the program checks whether a setup is required, and the inventory is updated by subtracting the batch size from it. If there is not enough raw materials to complete the batch, the batch is placed in the queue and the station status is set to status.
2) At all other processing stations and inspection stations, there is no need to check for raw materials.
3) At the assembly station a component batch can be taken from the queue only if the correspondent batch from the other subassembly line is present. If only one of the component batches arrives, then the station remains in the starving state until both are present.

It is possible that these batches have different sizes due to defective parts and inspections. If one batch is larger that the other, the logic checks if the inventory of components is enough to compensate for the difference in size. If this is the case, the batch size is equal to that of the larger batch, and the inventory is updated. If the inventory is smaller than the difference in size of the component batches, then the batch size is equal to the smallest of the two component batches plus the inventory.

If raw material is required and is available or if no raw material is required, the logic checks to determine if a setup is required. If a setup is required, the next *Done Setup* event is scheduled according to a probability distribution.

If not the program checks whether there's going to be a breakdown, based on a probability of breakdown per part and the batch size. There will be a maximum of one breakdown per batch. If it is determined that there is a breakdown, then the batch is held, and the next *Done Repair* time is scheduled.

If no breakdown occurs, the *Completion of the Batch* is scheduled.

4.5.2.2.2.2. Done Repair

When a station is repaired, counters regarding repair cost, downtime and number of breakdowns are updated. The time for the next *Completion of a Batch* event is scheduled, based on a probabilistic distribution. Figure 18 illustrates the logic executed after this event.

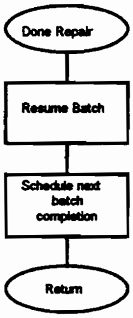


Figure 18: Done Repair Logic

4.5.2.2.2.3. Completion of a Setup

When a setup is completed the corresponding costs and time variables are updated. As illustrated in Figure 19, the logic regarding checking for breakdowns is executed after this event.

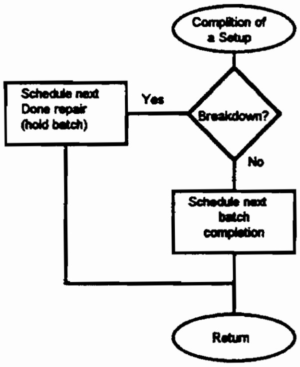


Figure 19: Completion of a Setup Logic

4.5.2.2.2.4. Completion of a Batch

Figure 20 illustrates the logic executed after the completion of a batch at a processing station. This logic is valid for machining operations, inspection stations and the assembly line.

When operations on a batch are completed at a station, the corresponding cost, quantity, and time variables are updated.

The quantity of defective units produced at the station in the batch is determined, based on a probabilistic distribution and the size of the batch. The program keeps track of defective units, that are separated when an inspection is performed. If the operator performs an inspection, then the next *Done inspecting* event is scheduled. If there is no inspection operation, then the batch continues with defective parts and the next *Arrival of batch* event is introduced immediately at the next station

If the batch is currently at the last station, then the finished goods inventory of the batch product type is increased by the batch size. The final quantity of defective parts is recorded.

If a preventive maintenance project has been implemented, there is a counter that controls the number of parts processed since last preventive maintenance session. When this counter reaches a certain limit a preventive maintenance session is required and the next *Done Preventive Maintenance* event is scheduled.

If no preventive maintenance session is required, then the program checks the size of the queue in front of it. If the queue in front of the station has reached its maximum level, then the station is blocked, and remains in that status until the that queue reduces its size enough to accept the batch.

If in the queue before the station, no batch is waiting to be processed, then the station becomes idle and waits for the next *Arrival of a Batch.* If there is one batch in the queue before the station, it is chosen to be the next one processed. If there is more than one batch in the queue before the station, then the selection of the next batch is not obvious. It is based on the priority rules the company has selected, which is one of the following:

1) *FIFO*: When this rule is applied, the resources serve entities in the order that they arrive at the station, based on the batch arrival number.

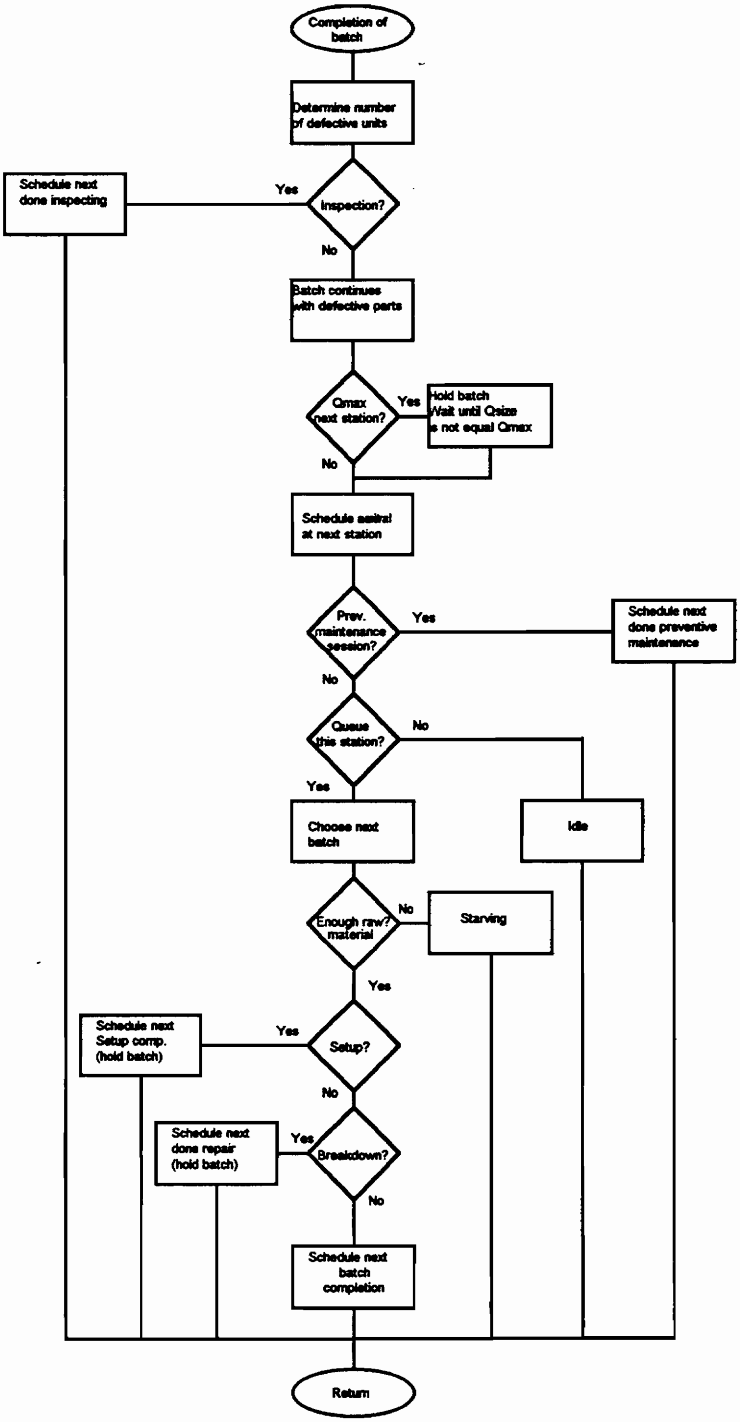


Figure 20: Completion of a Batch Logic

2) *Avoid setup (R)*: This rule gives priority to those batches that do not require a setup. The selection is repeated a limited number of times R, and then it forces the change to the next type of batch in arriving order.
3) *Final inventory replacement (R, LA, LB, LC)*: Priority is assigned to those batches which belong to the product type with the largest final inventory slack. Slack is calculated by subtracting the current inventory of finished goods from a limit (LA, LA and LC) of finished inventory for each type of product, which is established by the players. This is also executed a limited number of times (R), after which a changed is forced to the next lowest slack.
4) *Earliest finishing time*: This rule will evaluate which of the batches in the queue would require less time to be processed. This is calculated by adding the setup time (if required) to the expected processing time of the batch.

The program then goes on to execute the subroutines regarding setup, breakdowns, and raw materials.

4.5.2.2.2.5. Done Inspecting at Processing Stations

When a station is done inspecting, if there are any defective units, they are separated from the rest of the batch. If there are no defective units, then the batch maintains its size.

Figure 21 shows the rest of the logic involved with this event: Preventive maintenance, batch selection, setup, breakdown, and raw material subroutines.

4.5.2.2.2.6. Arrival of Raw Materials

Figure 22 illustrates the logic executed after a raw materials arrival. When a delivery of raw materials arrives, the variables regarding cost, and inventory are updated. If at the time of arrival, a station was in the starving state, the program determines whether the quantity that arrived is enough to cover the batch for which the station is starving. If is it not enough, the station continues starving. If it is enough, the program executes the logic involving setups, breakdowns and completion of the batch. If the station is not starving, then the inventory of raw materials is updated.

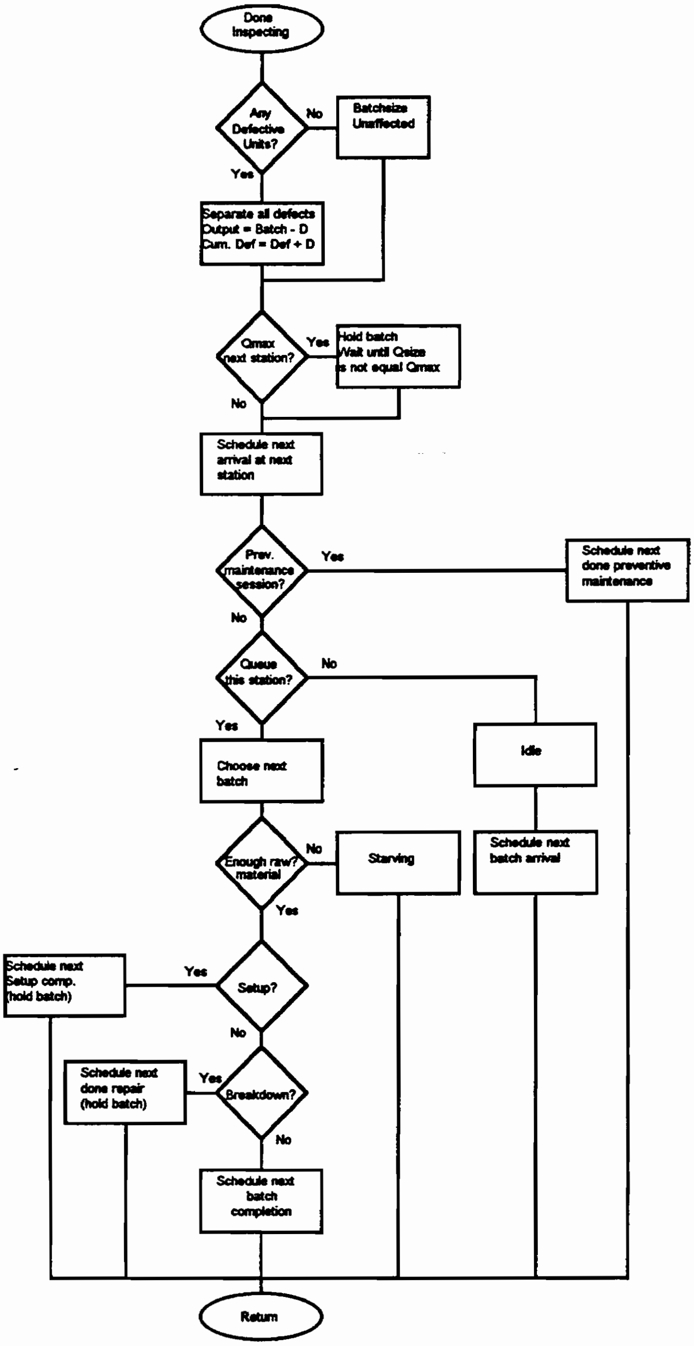


Figure 21: Done Inspection at Processing Station Logic

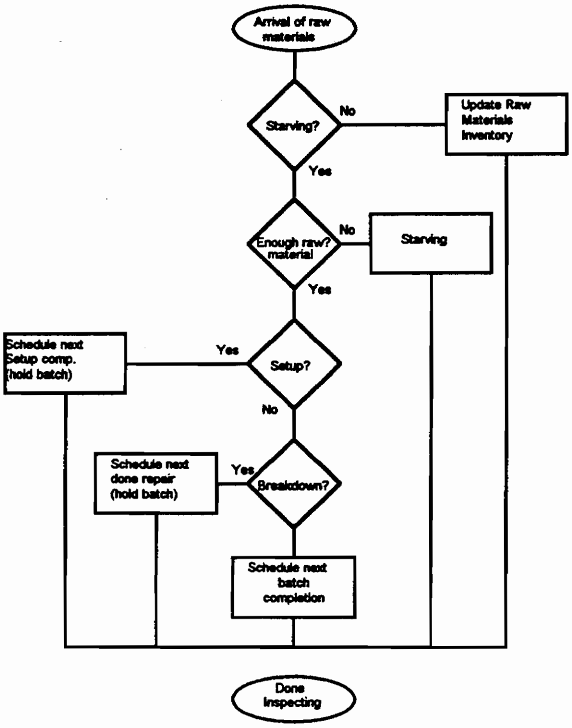


Figure 22: Arrival of Raw Material Logic

4.5.2.2.2.7. Done Preventive Maintenance

Figure 23 shows the logic related with the end of a preventive maintenance session. It includes subroutines involving choosing the next batch, setups, breakdowns and raw materials.

4.5.2.2.2.8. End of day

Figure 24 shows the procedure to follow after an *End of Day*. The first step is to hold all activities being executed at the stations. Time left to finish each activity is calculated and recorded.

Then the market logic is executed. If at the end of a day, the available quantity (AvQ_{ij}) of a company "i" of product "j" is lower than its market share (MS_{ijn}) multiplied by the demand for that day (DD_j), then there is unsatisfied demand (UD_{ij}) for that company, and the company sells only the quantity it has available for the market.

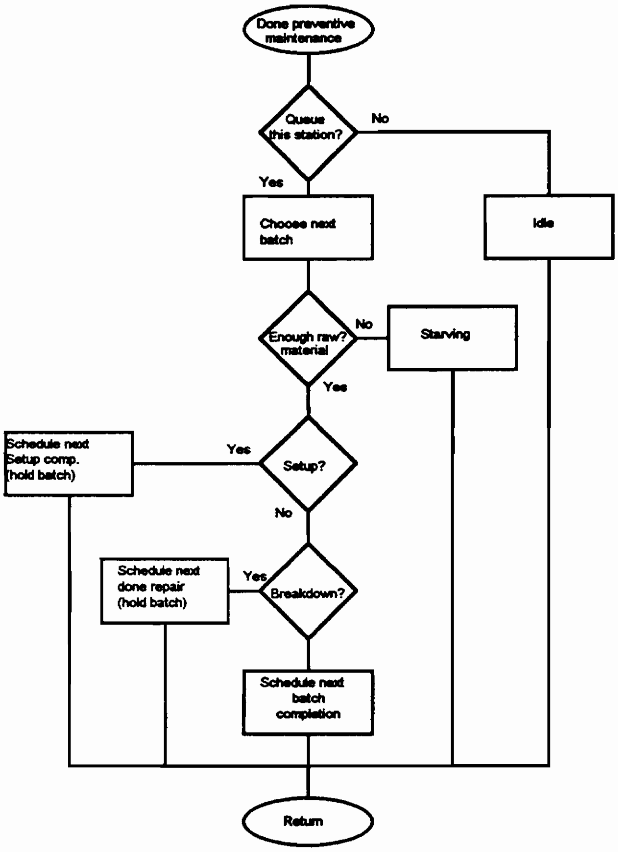


Figure 23: Done Preventive Maintenance Logic

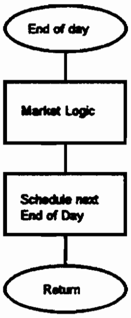


Figure 24: End of Day Logic

If $AvQ_{ij} < MS_{ijn} * DD_j$

$$UD_{ij} = (MS_{ijn} * DD_j) - AvQ_{ij}$$
$$Sales_{ij} = Sales_{ij} + AvQ_{ij}$$
$$AvQ_{ij} = 0$$

A portion of the total unsatisfied demand can be distributed among competitors that still have inventory after satisfying their respective sales. These allocated additional sales (AAS_{ij}) are given by,

$$AAS_{ij} = \frac{MS_{ij}}{\Sigma\, MSI_{ij}} * (\Sigma UD_{ij}) * P\%$$

where AAS_{ij} represents the allocated additional sales of a product for a company in a day, MS_{ij} is the market share of that company, ΣMSI_{ij} is the summation of the market shares of companies with inventories, ΣUD_{ij} represents the total unsatisfied demand in that day, and P% is the percentage of the unsatisfied demand that can be supplied by other competitors. It is important to distinguish among AAS_{ij} and AS_{ij}, the first expression represents the allocated additional sales, while the second one represents the actual number of units sold, that are added to the days sales.

If for a company

$$AAS_{ij} > AvQ_{ij}$$

then all units in the inventory become additional sales, the inventory level drops to zero, and the actual number of additional sold units is give by,

$$AS_{ij} = AvQ_{ij}$$
$$AvQ_{ij} = 0$$

If $AAS_{ij} > AvQ_{ij}$

then all allocated additional sales can be covered with the inventory.

$$AS_{ij} = AAS_{ijd}$$
$$AvQ_{ij} = AvQ_{ij} - AAS_{ijd}$$

The difference between the total additional sales and the unsatisfied demand represents lost sales, and they have no impact on future share.

$$\text{Lost sales} = \Sigma UD_{ij} - \Sigma AS_{ij}$$

With each *End of Day* event a counter is increased, to control the number of days in a month. While this counter is lower than twenty, activities are resumed for next day, and the next *End of Day* is scheduled considering overtime specifications. When the counter reaches twenty, the month is completed, and the simulation phase of the Game / Simulation is over.

4.5.2.3. Game / Simulation, Report Phase

When the simulation phase of the game / simulation program is completed, the report phase can begin. As illustrated in Figure 25, the logic is strait forward. First company status report are printed for distribution to the student companies. Additionally a status report is created for the game administrator.

The company status report database is written to the hard drive and a backup copy is written to a floppy disk. The names given to these files are based on the following convention: XXXXXXnn.DB. The first six characters on the name are defined by the game administrator during initialization and represent that particular series of play of the game - MPD94F might indicate that Dr. M. P. Deisenroth was the administrator of the game played in the Fall of 1994. The two digits that are appended to this character sequence specify the period in question - 00, 01, 02, etc. Hence the game does not overwrite the database on subsequent executions. All data files are encrypted for security.

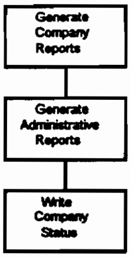


Figure 25: Report Phase Procedure

CHAPTER 5 - PROTOTYPE

5.1. Prototype Design

In order to illustrate the feasibility of a production level simulation in driving a strategic business type game, a prototype of the game was developed. The production simulation module was developed using the simulation software ProModel for Windows [27] [28], while the market module and output reports were based on Microsoft Excel. The functions of players and databases were adopted by the game administrator and the procedure illustrated in Figure 26 was followed.

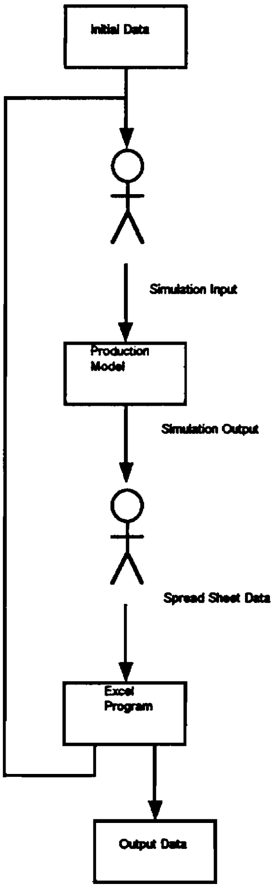


Figure 26: Prototype Abstraction

To provide a fair starting point, and to assure that teams obtain advantages based solely on their decisions, all parties start managing exactly equal companies, with identical production systems, market shares and inventories.

5.1.1. Prototype Simulation Module

The simulated production model consisted of two component lines, with three processing stations each, that converge into an assembly line as shown is Figure 27. The initial processing times are given in Table 7; the frequency of breakdown, setup times and repair times are presented in Table 9.

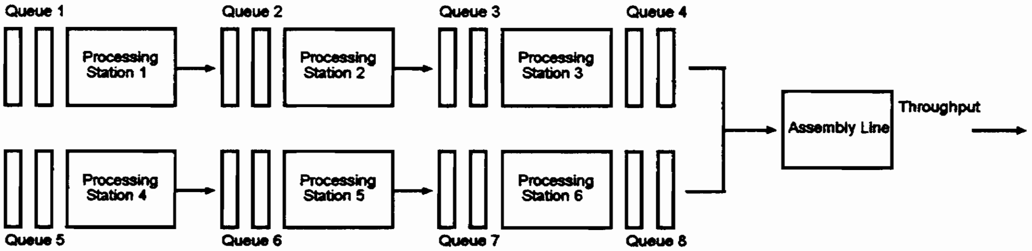


Figure 27: Prototype Production Module

Table 8: Initial Processing Times (minutes)

	Processing time Prod.A		Processing time Prod.B		Processing time Prod.C	
Station	Mean	St. Dev.	Mean.	St. Dev.	Mean	St. Dev.
1	11	2	10	1	8	1
2	8	1	7	1	6	1
3	13	2	11	2	9	2
4	9	2	7	1	6	1
5	11	2	9	2	13	2
6	10	2	9	1	7	1
7	18	0.5	15	0.5	14	0.5

Table 9: Initial Setup, Breakdown and Repair Times (minutes)

	Setup Time		Breakdown (frequency)		Repair Time	
Station	Mean	St. Dev.	Mean.	St. Dev.	Mean	St. Dev.
1	34	5	20	8	180	45
2	26	5	20	8	180	45
3	41	4	20	8	180	45
4	30	4	20	8	180	45
5	36	3	20	8	180	45
6	32	3	20	8	180	45
7		2	36	4	90	15

ProModel has a function to model arrival of entities at any station. This function was used to simulate the *Arrival of Batch* event. In the prototype it is assumed that there is always enough raw materials for the scheduled production orders, so the *Arrival of Raw Material* event is not included. The time and sequence in which production orders are released to the shop floor are established using arrivals to the first queues of each component line.

In this simulation package, locations can be programmed to have downtimes associated with time, entries, production time and setup. This capability allows the simulation of breakdowns, related to number of processed units, and setups. Since the logic accounts for batches and not units, the mean number of processed entities between breakdowns has to be set inversely proportional to the average batch size. The *Done Repair* event is scheduled based on a normal distribution. When two subsequent batches are of different product type, a setup is performed, which duration is determined by a normal distribution.

A preventive maintenance project can be implemented by the companies, with a resulting reduction of repair time of 20%, but preventive maintenance sessions have to be scheduled (*Done Preventive Maintenance* event), their duration is determine by a probabilistic distribution.

After a *Completion of Batch* event, the entities move to the next station. When they reach the assembly station, component I batches are joined to component II batches to be processed. It is necessary to have a set of two corresponding component batches in order to start the assembly operation. Until both batches arrive the assembly line station remains idle. After the assembly line the batches are ungrouped into finished goods units, according to their sizes. To represent the different products, there are nine main entities:

Batch of component I product A
Batch of component I product B
Batch of component I product C
Batch of component II product A
Batch of component II product B
Batch of component II product C
Finished unit A
Finished unit B
Finished unit C

The initial probability of producing a defective unit is 3% at the processing stations and 2% at the assembly line. A random real number between 0 and 100 is generated with the processing of each unit, if it is equal or lower than the respective probability of defective production, then a batch specific counter is updated. Defective parts produced in one station are added to the those produced in the next; it is assumed that each defect is build into a new unharmed part.

After a *Completion of an Inspection* event defective units are separated from the batch. A different entity type separated defective unit was defined for each potential inspection location, in order to allow the identification of the locations were a defective unit was separated.

This procedure might cause corresponding batches from the two component lines to have different sizes when they reach the assembly line. When they are joined, the batch assumes the size of the smallest one, and the extra unmatched units stop existing. At the assembly station the number of defective parts in the batch is equal to the highest number of defective parts in either one of the corresponding component batches.

There are three entity types to represent the defective units that are produced and sold:

Defective units in A production
Defective units in B production
Defective units in C production

Each month is assumed to have twenty days of sixteen hours. The total duration of the month is 320 hours, after which the simulation model stops and presents reports. To start next month's simulation, inventories of WIP left at the end of last months are introduced as a one time arrival at the beginning. Defective percentage is approximated by the cumulative probability of a defective part being produced.

5.1.2. Performance Measures

In the prototype, company performance is measured by market share and operational margin. Market share is influenced by availability of products, price, defective percentage of sales, and market share of the previous period:

$$MS_{ijn} = \frac{(MS_{ijn-1}) * F(P)_{ij} * F(Av)_{ij} * F(D\%)_{ij}}{\Sigma\,[(MS_{ijn-1}) * F(P) * F(Av) * F(D\%)]}$$

where MS_{ijn} is the market share of company "i" for product "j" in month "n"; MS_{ijn-1} is the market share in the previous period, $F(P)_{ij}$ is the price factor, $F(Av)_{ij}$ is the availability factor and $F(D\%)_{ij}$ is the defective percentage factor. In order to normalize these fractions, the denominator is the summation of the modified shares of all companies.

$F(P)_{ij}$ is equal to the average price in the market for that product, divided by the price of the company:

$$F(P)_{ij} = \frac{(P_{Aj} + P_{Bj} + P_{Cj})}{(3 * P_{ij})}$$

where P_{Aj}, P_{Bj}, and P_{Cj} are the prices of product "j" for companies A, B and C.

$F(Av)_{ij}$ is equal to the sales for company "i" for product "j" ($Sales_{ij}$), divided by the allocated sales (MS_{ijn} * DDj):

$$F(Av)_{ij} = \frac{Sales_{ij}}{(MS_{ijn} * DDj)}$$

$F(D\%)_{ij}$ is determined by the average percentage of defective production:

$$F(D\%)_{ij} \quad = \quad \frac{(D_{Aj}/PV_{Aj} + D_{Bj}/PV_{Bi} + D_{Cj}/PV_{Cj})}{(3 * D_{ij}/PV_{ij})}$$

where D_{Aj} D_{Bj} and D_{Cj} are the quantity of defective parts of product "j" produced by companies A, B and C; and PV_{Aj}, PV_{Bi}, and PV_{Cj} are the respective production volumes.

The expected market size for the four simulated periods is presented in Table 16.

Table 16: Total Market Size for Prototype Simulation

Period	Demand Prod. A	Demand Prod. B	Demand Prod. C
1	780	1,440	1,080
2	1,020	1,605	1,230
3	1,300	1,700	1,400
4	1,201	2,200	1,649

Operational margin is calculated by subtracting from sales operational costs. For the prototype these cost were common to all companies and were defined in the following way:

1) Operation Cost:	$ 20 / hour
2) Setup Cost:	$ 25 / hour
3) Repair Cost:	$ 75 / hour
4) Holding Cost	
Component:	$ 5 / unit month
Finished Product:	$ 10 / unit month
5) Raw Materials	
Component A	$ 20 / unit
Component B	$ 17.5 / unit
Component C	$ 15 / unit
6) Fixed Costs:	$ 75,000 / month

5. 2 Simulation Results Discussion

The prototype simulation runs illustrated the interaction between production level decisions and the macro-performance of a company. By changing the batch size and the process characteristics, the companies affected the availability, costs and defective percentage of the production; which impacted the market share and the operational margin of the company. Since the only three production runs were to be simulated, the utilized formulas to determine market share and operational margin had to be particularly sensitive, to show the effect of decision in a very short period. The exact decision input sheets and output reports regarding performance measures, throughput, machine status, quality, inventories, raw materials and costs are presented in Appendixes 1, 2, 3 and 4.

Three companies were simulated in the prototype simulation runs. Each adopted a different strategic posture, consistent throughout the three simulation periods. At the starting point all were given an exactly equal manufacturing systems to manage, with identical market shares and starting inventories. Input decisions for the initial period were common to all companies.

Company A, the "greedy" competitor, focused on maximizing operational margin, avoiding investments and increasing prices. This strategy resulted in the desired outcome only in the short term. After reaching the highest operational margin among competitors in the first simulation period, it declined constantly. By the second and third periods, company A had the lowest operational margin among competitors.

In order to reduce setup costs, company A increased the size of the batches. The decline in setup costs achieved in period one (from \$8800 to \$5500) was not sufficient to compensate for the growth of the holding costs related to work in process inventory (from \$2340 to \$7020).

Company A did not invest in improvement projects for its production process, so its market share decreased gradually, until it reached the point in which its production capacity was larger than its sales potential. Since this company did not reduce its production rhythm, it accumulated finished goods inventory, which increased its costs and reduced its operational margin.

The narrow perspective of Company A, of concentrating only on the operational margin growth, worked only in the short term. In the long term it achieved the exact opposite of the desired outcome. Company A had the lowest operational margin in the last simulated period. It became clear that a company cannot concentrate on one area alone, it has to adopt a systematic approach.

Company B adopted a quality conscious posture, primarily investing in quality control and preventive maintenance. It maintained the original prices and batch sizes, and replaced bottleneck machines with new, more efficient machines.

Since the quality level directly affects market share, the demand of their products for the third period increased extremely. Demand was so high that the company was not able to produce enough, and their availability factor reduced the market share for the next period. This showed that by allocating demand based on the selected factors, a balance is achieved, in which a company can grow until the point where it cannot longer supply the demanded quantities

From period 2 to period 3 company B lost market share for product B, even though it maintained the same prices, availability and an approximate percentage of defective parts. This is due to the fact that market share is allocated based on relative performance of the competing teams. During period 3, Company C's defective production was so low, that its market share outgrew that of its competitors. A company's performance doesn't depend only on its own decisions, but also on those of its competitors.

Company C concentrated on maximizing throughput. It assumed the lowest prices in the market and secured the availability of the products, by building flexibility and capacity into their production systems. This company invested in several improvement projects including setup reduction, quality control, inspection stations introduction, and equipment replacement. Batches were reduced, and production orders were released in such a way as to avoid setups. Even though the prototype exaggerated the effect time of decisions, there was a certain forced implementation time due to work in process inventory. The significance of inventories in the implementation of decisions became clear, for when the batch size was changed, the entire work in process inventory had to be drained, before the first batch with the desired new size came out of the last station.

With the implementation of inspection stations in the third period, it became clear that a zero percent of defective units would provide an extreme advantage to any competitor, due to the formulas being used. Therefore these formulas need to be further researched to incorporate higher sensitivity to the long term performance.

Formulas, costs, and investments need to be researched extensively for the implementation of this game in ISE-5204, in order to provide a more realistic environment. Students will achieve a better understanding of the implementation period of some investments and the long term effect of decisions.

CHAPTER 6 - CONCLUSIONS AND RECOMMENDATIONS

Pray et al. state: "Like students in biology, chemistry and physics have experimental laboratories in which they make their own discoveries that reinforce their classroom lectures, simulation games permit the students of production and operations management to experiment, discover and reinforce their classroom learning [26]." The purpose of this research was to initiate efforts towards the development of a simulation game that will be used in ISE 5204-Manufacturing Systems Engineering in order to give the students the opportunity of applying the concepts learned in this course to realistic situations. This will achieve a deeper understanding of the theory and the difficulties encountered in its application.

The research has produced an extensive review of business games, with thirty-four games being referenced in Chapter 3. This review has provided insight into the various characteristics of business games that are available. Additionally it has revealed that there is not a game available which combines all of the desirable characteristics into a single game appropriate for ISE-5204 Manufacturing Systems Engineering. Finally the review of games and of the literature has shown that there has not been a comprehensive survey of the application of these games within the Industrial Engineering area.

The needs of ISE-5204 were established through review of the course material and interviews with appropriate faculty members. The process indicated that the game to be developed should encompass the following areas:

1) Forecasting
2) Aggregate Planning
3) Shop Floor Control
4) Inventory Control
5) Material Purchasing
6) Equipment Selection / Replacement
7) Assembly Line Balancing
8) Quality Control
9) Maintenance
10) Machine Control

Additionally the literature review indicated that the desirable characteristics of the game were:

1) Competition among company teams
2) Sales forecasting
3) Detailed Production simulation
4) Material planning
5) Multiproduct Production
6) Capability to introduce changes in production capacity

A framework was created for the development of the game. The framework consisted of three components, regarding the conceptual, the organizational and structural aspects. The conceptual framework was based on a competitive game with a multiproduct environment and operational decisions being the driving force. The organizational framework specified periodic decision that would be made by the competing student companies and input into the game for the simulation of a month's production and the generation of status reports. The structural framework dictated that a discrete, next event simulation model of shop floor operation would be used to establish the results of the student decisions. This design philosophy is unique in allowing a strategic business type game to be run by low production level simulation.

A prototype model was constructed by using ProModel for Windows and Microsoft Excel. Three competing companies were simulated for three production periods. Each company made decisions that were representative of a different strategy. The simulation runs showed that high level performance of the companies can be driven by a production simulation.

Thus the research has shown a need to implement a simulation game in ISE-5204 Manufacturing Systems Engineering. The development of the framework has created the foundation to a simulation game tailored to the needs of this course. The prototype has shown the feasibility of using a low level simulation to drive a strategic business type game.

Further development of the simulation game is recommended, using the simulation Toolkit developed by Fazal Khan [19]. A suggested approach is to create first a minimal set that incorporates the basic functions of the game. This minimal simulation set should be run with participating teams in order to build enough feedback to fixed parameters and factors regarding performance measures, internal environment characteristics, demand levels and external influences.

Finally it was identified that there is a need for a survey to study the use of simulation games in Industrial Engineering Schools. This survey will provide important information to establish the potential research areas regarding the implementation of manufacturing simulation games.

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APPENDIX 1

Output Reports for Initial Period

INPUT SHEET
COMPANIES: A, B, C; INITIAL PERIOD

Price Product	A: 225	Batch Size	A: 10
	B: 175		B: 20
	C: 200		C: 15

Priority Rule

First In First Out

Work Order Releases

Type	First Time	Occurrences	Frequency
A	0	inf	550
B	150	inf	550
C	390	inf	550

Projects

[ ] Setup Reduction Project
[ ] Quality Project
[ ] Preventive Maintenance Project
[ ] Assembly Line Balancing
[ ] Process Redesign

Performance Report, Initial Period

Market Share

Product A

	Price Fac.	Def. Fac.	Av. Fac	M.S. (t-1)	Mkt. S.	Norm.
Company A	1.000	1.000	1.000	0.333	0.333	0.333
Company B	1.000	1.000	1.000	0.333	0.333	0.333
Company C	1.000	1.000	1.000	0.333	0.333	0.333
					1.000	

Product B

	Price Fac.	Def. Fac.	Av. Fac	M.S. (t-1)	Mkt. S.	Norm.
Company A	1.000	1.000	1.000	0.333	0.333	0.333
Company B	1.000	1.000	1.000	0.333	0.333	0.333
Company C	1.000	1.000	1.000	0.333	0.333	0.333
					1.000	

Product C

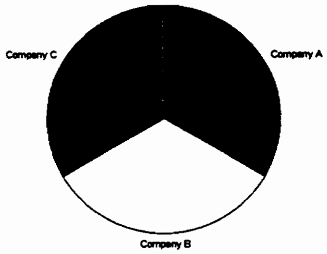
	Price Fac.	Def. Fac.	Av. Fac	M.S. (t-1)	Mkt. S.	Norm.
Company A	1.000	1.000	1.000	0.333	0.333	0.333
Company B	1.000	1.000	1.000	0.333	0.333	0.333
Company C	1.000	1.000	1.000	0.333	0.333	0.333
					1.000	

Operational Margin

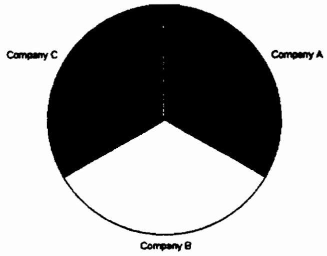
Company A	31643
Company B	31643
Comapny C	31643

Sales (Volume)

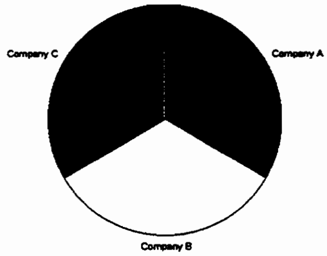
	Product A	Product B	Product C
Company A	260	480	360
Company B	260	480	360
Company C	260	480	360
Total Market Size	780	1440	1080



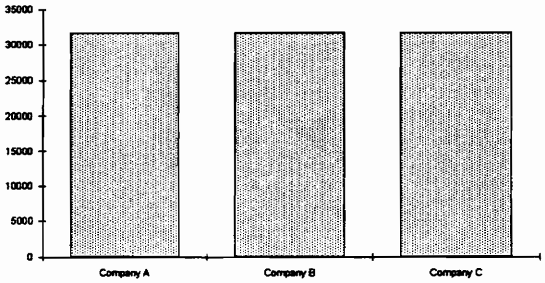
Market Share, Product A, Initial Period



Market Share, Product B, Initial Period



Market Share, Product C, Initial Period



Operational Margin, Initial Period

Companies A, B and C

Throughput Report Companies A, B and C, Intitial Period

Day	Prod. A	Market	Sales	Inventory	In. Inv.	50
1	10	7	7	53	Tot. Sales	260
2	10	7	7	56	Fin. Inv.	30
3	10	7	7	59	Av. Inv.	58
4	10	7	7	62	Defective	25
5	20	7	7	75	Price	225
6	10	12	12	73	Mkt. Shar	0.3333
7	10	12	12	71	Batch	10
8	10	12	12	69		
9	10	12	12	67		
10	20	12	12	75		
11	10	15	15	70		
12	10	15	15	65		
13	10	15	15	60		
14	10	15	15	55		
15	20	15	15	60		
16	10	18	18	52		
17	10	18	18	44		
18	10	18	18	36		
19	10	18	18	28		
20	20	18	18	30		
	240	260	260	58		

Day	Prod. B	Market	Sales	Inventory	In. Inv.	50
1	0	19	19	31	Tot. Sales	480
2	40	19	19	52	Fin. Inv.	38
3	20	19	19	53	Av. Inv.	49.25
4	20	19	19	54	Defective	47
5	20	19	19	55	Price	175
6	20	23	23	52	Mkt. Shar	0.3333
7	40	23	23	69	Batch	20
8	20	23	23	66		
9	20	23	23	63		
10	20	23	23	60		
11	20	26	26	54		
12	20	26	26	48		
13	40	26	26	62		
14	20	26	26	56		
15	20	26	26	50		
16	20	28	28	42		
17	20	28	28	34		
18	40	28	28	46		
19	20	28	28	38		
20	20	28	28	30		
	460	480	480	49.2		

Throughput Report Companies A, B, and C, Initial Period

Day	Prod. C	Market	Sales	Inventory
1	0	14	14	36
2	15	14	14	37
3	15	14	14	38
4	30	14	14	54
5	15	14	14	55
6	15	18	18	52
7	15	18	18	49
8	15	18	18	46
9	30	18	18	58
10	15	18	18	55
11	15	19	19	51
12	15	19	19	47
13	15	19	19	43
14	30	19	19	54
15	15	19	19	50
16	15	21	21	44
17	15	21	21	38
18	15	21	21	32
19	30	21	21	41
20	15	21	21	44
	345	360	360	

In. Inv.	50
Tot. Sales	360
Fin. Inv.	32
Av. Inv.	41.95
Defective	8
Price	200
Mkt. Shar	0.3333
Batch	15

Machine Status Report, Comapnies A, B and C, Initial Period

	Opration	Setup	Idle	Downtime	Blocked
Station 1	0.7493	0.1784	0.0024	0.0698	0
Station 2	0.5855	0.1651	0.2114	0.038	0
Station 3	0.5355	0.1305	0.306	0.0281	0
Station 4	0.7737	0.1737	0.0094	0.0432	0
Station 5	0.7311	0.1847	0.019	0.0652	0
Station 6	0.6048	0.1512	0.2071	0.037	0
Assembly	0.8462	0.1172	0.0286	0.0079	0

Quality Report, Companies A, B, and C, Initial Period

	Separeted Units
Station 1	0
Station 2	0
Station 3	0
Station 4	0
Station 5	0
Station 6	0
Assembly	0

Inventory Report, Companies A, B, And C, Initial Period

	Av. Occu.	Av. Size	Fin. (B)	FInal Size in units
Receive I	0.0038	22.8	4	60
Receive II	0.0002	1.2	0	0
Q. St. 2	0.0002	0.6	12	180
Q. St. 5	0.0303	90.9	13	195
Q. St. 3	0.0336	100.8	0	0
Q. St. 6	0.0004	1.2	15	225
Q. Ass. I	0.0366	109.8	20	300
Q. Ass. II	0.0466	139.8	0	0
Total		467.1		

Raw Materials Report, Companies A, B, and C, Initial Period

	Quantity	Batchsize	Price	Total/Comp.
Comp. AI	35	10	20	7000
Comp. BI	35	20	20	14000
Comp. CI	35	15	17.5	9187.5
Comp. AII	35	10	17.5	6125
Comp. BII	35	20	15	10500
Comp. CII	35	15	15	7875
Total				54687.5

Cash Flow Report, Companies A, B, and C
Initial Period

Sales				
	Prod A	58500		
	Prod B	84000		
	Prod C	72000		
				214500
Raw Materials				54687.5
Processing				
	Station 1	4795.52		
	Station 2	3747.2		
	Station 3	3427.2		
	Station 4	4951.68		
	Station 5	4679.04		
	Station 6	3870.72		
	Assembly	8123.52		
				33594.88
Repair				
	Station 1	1675.2		
	Station 2	912		
	Station 3	674.4		
	Station 4	1036.8		
	Station 5	1564.8		
	Station 6	888		
	Assembly	189.6		
				6940.8
Setup				
	Station 1	1427.2		
	Station 2	1320.8		
	Station 3	1044		
	Station 4	1389.6		
	Station 5	1477.6		
	Station 6	1209.6		
	Assembly	937.6		
				8806.4
Inventory				
	WIP		2335.5	
	Finished Goods		1492	
				3827.5
Fixed Costs				75000
OPERATIONAL MARGIN				31642.92

APPENDIX 2

Output Reports for Period 2

INPUT SHEET

COMPANY A, PERIOD: 2

Price Product	A: 240 (+15)	Batch Size	A: 20 (+10)
	B: 185 (+10)		B: 40 (+20)
	C: 200 (+10)		C: 30 (+15)

Priority Rule

First In First Out

Work Order Releases

Type	First Time	Occurrences	Frequency
A	0	inf	980
B	260	inf	980
C	700	inf	980

Projects

[ ] Setup Reduction Project
[ ] Quality Project
[ ] Preventive Maintenance Project
[X] Assembly Line Balancing
[ ] Process Redesign

The assembly line balancing project has a cost of $1,000, and the new cycle time are 14, 12 and 10 minutes for products A, B, and C respectively.

INPUT SHEET

COMPANY B, PERIOD: 2

Price Product	A: 225	Batch Size	A: 10
	B: 175		B: 20
	C: 200		C: 15

Priority Rule

First In First Out

Work Order Releases

Type	First Time	Occurrences	Frequency
A	0	inf	550
B	150	inf	550
C	390	inf	550

Projects

[ ] Setup Reduction Project
[X] Quality Project
[ ] Preventive Maintenance Project
[X] Assembly Line Balancing
[ ] Process Redesign

The assembly line balancing project has a cost of $1,000, and the new cycle time are 14, 12 and 10 minutes for products A, B, and C respectively. The quality project reduces the probability of producing a defective part from 3% to 2% at the processing stations, and from 2% to 1.5% at the assembly station. It has a cost of $10,000

INPUT SHEET

COMPANY C, PERIOD: 2

Price Product A: 210 (-15)
B: 165 (-10)
C: 190 (-10)

Batch Size A: 5 (-5)
B: 10 (-10)
C: 8 (-7)

Priority Rule

First In First Out

Work Order Releases

Type	First Time	Occurrences	Frequency
A	0	inf	555
A	75	inf	555
B	150	inf	555
B	270	inf	550
C	390	inf	550
C	470	inf	550

Projects

[ ] Setup Reduction Project
[ ] Quality Project
[ ] Preventive Maintenance Project
[X] Assembly Line Balancing
[ ] Process Redesign

The assembly line balancing project has a cost of $1000, and the new cycle time are: 14, 12 and 10 minutes for products A, B, and C respectively.

Performance Report, Period 2

Market Share

Product A

	Price Fac.	Def. Fac.	Av. Fac	M.S. (t-1)	Mkt. S.	Norm.
Company A	0.938	1.030	1.000	0.333	0.322	0.318
Company B	1.000	1.133	1.000	0.333	0.378	0.374
Company C	1.071	0.872	1.000	0.333	0.311	0.308
					1.011	

Product B

	Price Fac.	Def. Fac.	Av. Fac	M.S. (t-1)	Mkt. S.	Norm.
Company A	0.946	0.737	1.000	0.333	0.232	0.214
Company B	1.000	1.448	1.000	0.333	0.483	0.444
Company C	1.061	1.050	1.000	0.333	0.371	0.342
					1.086	

Product C

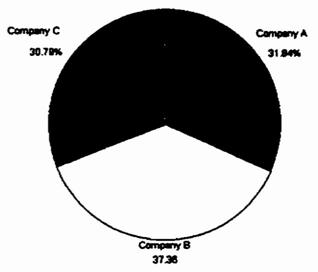
	Price Fac.	Def. Fac.	Av. Fac	M.S. (t-1)	Mkt. S.	Norm.
Company A	0.952	0.841	1.000	0.333	0.267	0.252
Company B	1.000	1.423	1.000	0.333	0.474	0.448
Company C	1.053	0.902	1.000	0.333	0.317	0.299
					1.058	

Operational Margin

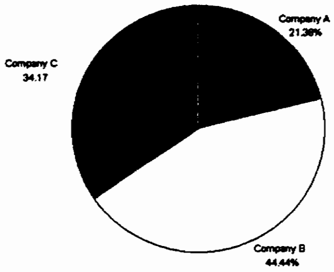
Company A	72902
Company B	54402
Comapny C	49424

Sales (Volume)

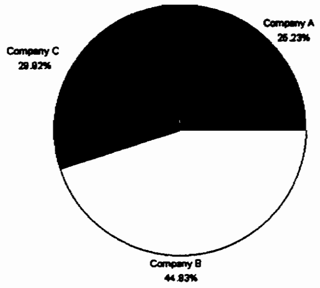
	Product A	Product B	Product C
Company A	340	535	410
Company B	340	535	410
Company C	340	535	410
Total Market	1020	1605	1230



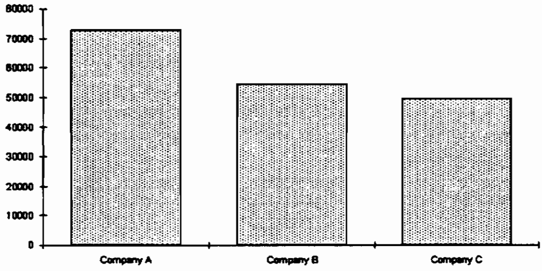
Market Share, Product A, Period 2



Market Share, Product B, Period 2



Market Share, Product C, Period 2



Operational Margin, Period 2

Company A

Throughput Report, Company A, Period 2

Day	Prod. A	Market	Sales	Inventory
1	20	18	18	32
2	10	18	18	24
3	20	18	18	26
4	10	18	18	18
5	20	18	18	20
6	20	15	15	25
7	10	15	15	20
8	20	15	15	25
9	20	15	15	30
10	20	15	15	35
11	20	16	16	39
12	20	16	16	43
13	0	16	16	27
14	20	16	16	31
15	20	16	16	35
16	20	19	19	36
17	20	19	19	37
18	20	19	19	38
19	20	19	19	39
20	0	19	19	20
	330	340	340	30

In. Inv.	30
Tot. Sales	340
Fin. Inv.	20
Av. Inv.	30
Defective	22
Price	240
Mkt. Shar	0.3333
Batch	20

Day	Prod. B	Market	Sales	Inventory
1	20	28	28	30
2	40	28	28	42
3	20	28	28	34
4	40	28	28	46
5	20	28	28	38
6	40	26	26	52
7	40	26	26	66
8	40	26	26	80
9	0	26	26	54
10	40	26	26	68
11	40	26	26	82
12	40	26	26	96
13	40	26	26	110
14	40	26	26	124
15	40	26	26	138
16	0	27	27	111
17	40	27	27	124
18	40	27	27	137
19	40	27	27	150
20	40	27	27	163
	660	535	535	87.25

In. Inv.	38
Tot. Sales	535
Fin. Inv.	163
Av. Inv.	79.1
Defective	57
Price	185
Mkt. Shar	0.3333
Batch	40

Throughout Report, Company A, Period 2

Day	Prod. C	Market	Sales	Inventory	In. Inv.	32
1	30	19	19	43	Tot. Sales	410
2	15	19	19	39	Fin. Inv.	57
3	30	19	19	50	Av. Inv.	53.4
4	15	19	19	46	Defective	44
5	30	19	19	57	Price	210
6	15	20	20	52	Mkt. Shar	33.33%
7	30	20	20	62	Batch	30
8	0	20	20	42		
9	30	20	20	52		
10	30	20	20	62		
11	30	21	21	71		
12	0	21	21	50		
13	30	21	21	59		
14	30	21	21	68		
15	30	21	21	77		
16	0	22	22	55		
17	30	22	22	63		
18	30	22	22	71		
19	0	22	22	49		
20	30	22	22	57		
	435	410	410	56.25		
	345	360	360			

Machine Status Report, Company A, Period 2

	Opration	Setup	Idle	Downtime	Blocked
Station 1	0.8685	0.1023	0.0052	0.024	0
Station 2	0.6557	0.0918	0.2429	0.0097	0
Station 3	0.6156	0.0809	0.2798	0.0236	0
Station 4	0.8717	0.0967	0.0157	0.0159	0
Station 5	0.8282	0.1031	0.0342	0.0344	0
Station 6	0.839	0.1302	0	0.0307	0
Assembly	0.9012	0.082	0.0088	0.0079	0

Quality Report, Company A, Period 2

	Separeted Units
Station 1	0
Station 2	0
Station 3	0
Station 4	0
Station 5	0
Station 6	0
Assembly	0

Inventory Report, Company A, Period 2

	Av. Occu.	Av. Size	Fin. (B)	Final Size in units
Receive I	0.0938	1125.6	90	2700
Receive II	0.0031	37.2	0	0
Q. St. 2	0.0003	1.8	0	0
Q. St. 5	0.0265	159	10	300
Q. St. 3	0.022	13.2	8	240
Q. St. 6	0	0	0	0
Q. Ass. I	0.0045	27	2	60
Q. Ass. II	0.0068	40.8	2	60
Total		1404.6		

Raw Materials Report, Company A, Period 2

	Quantity	Batchsize	Price	Total/Comp.
Comp. AI	20	20	20	8000
Comp. BI	20	40	20	16000
Comp. CI	19	30	17.5	9975
Comp. AII	20	20	17.5	7000
Comp. BII	20	40	15	12000
Comp. CII	19	30	15	8550
Total				61525

Cash Flow Report, Company A, Period 2

Sales				
	Prod A	81600		
	Prod B	98975		
	Prod C	86100		
				266675
Raw Materials				61525
Processing				
	Station 1	5558.4		
	Station 2	4196.48		
	Station 3	3939.84		
	Station 4	5578.88		
	Station 5	5300.48		
	Station 6	5369.6		
	Assembly	8651.52		
				38595.2
Repair				
	Station 1	576		
	Station 2	232.8		
	Station 3	566.4		
	Station 4	381.6		
	Station 5	825.6		
	Station 6	736.8		
	Assembly	189.6		
				3508.8
Setup				
	Station 1	818.4		
	Station 2	734.4		
	Station 3	647.2		
	Station 4	773.6		
	Station 5	824.8		
	Station 6	1041.6		
	Assembly	656		
				5496
Inventory				
	WIP		7023	
	Finished Goods		1625	
				8648
Fixed Costs				75000
Investments				
	Line Balancing			1000
OPERATIONAL MARGIN				72902

Throughput Report, Company B, Period 2

Day	Prod. A	Market	Sales	Inventory	In. Inv.	30
1	20	18	18	32	Tot. Sales	340
2	10	18	18	24	Fin. Inv.	10
3	10	18	18	16	Av. Inv.	20.5
4	20	18	18	18	Defective	20
5	20	18	18	20	Price	225
6	10	15	15	15	Mkt. Shar	0.3333
7	20	15	15	20	Batch	10
8	20	15	15	25		
9	10	15	15	20		
10	20	15	15	25		
11	20	16	16	29		
12	10	16	16	23		
13	20	16	16	27		
14	10	16	16	21		
15	20	16	16	25		
16	10	19	19	16		
17	20	19	19	17		
18	20	19	19	18		
19	10	19	19	9		
20	20	19	19	10		
	320	340	340	20.5		

Day	Prod. B	Market	Market	Inventory	In. Inv.	38
1	20	28	28	30	Tot. Sales	535
2	40	28	28	42	Fin. Inv.	123
3	20	28	28	34	Av. Inv.	68.1
4	40	28	28	46	Defective	29
5	20	28	28	38	Price	175
6	40	26	26	52	Mkt. Shar	0.3333
7	20	26	26	46	Batch	20
8	40	26	26	60		
9	40	26	26	74		
10	20	26	26	68		
11	40	26	26	82		
12	20	26	26	76		
13	40	26	26	90		
14	20	26	26	84		
15	40	26	26	98		
16	40	27	27	111		
17	20	27	27	104		
18	40	27	27	117		
19	20	27	27	110		
20	40	27	27	123		
	620	535	535	74.25		

Throughput Report Companies B, Period 2

Day	Prod. C	Market	Market	Inventory
1	15	19	19	28
2	30	19	19	39
3	15	19	19	35
4	30	19	19	46
5	15	19	19	42
6	15	20	20	37
7	30	20	20	47
8	15	20	20	42
9	15	20	20	37
10	30	20	20	47
11	30	21	21	56
12	15	21	21	50
13	30	21	21	59
14	15	21	21	53
15	30	21	21	62
16	30	22	22	70
17	15	22	22	63
18	30	22	22	71
19	15	22	22	64
20	30	22	22	72
	450	410	410	51

In. Inv.	32
Tot. Sales	410
Fin. Inv.	72
Av. Inv.	47.4
Defective	26
Price	200
Mkt. Shar	0.3333
Batch	15

Machine Status Report, Company B, Period 2

	Opration	Setup	Idle	Downtime	Blocked
Station 1	0.7654	0.1799	0.0054	0.0492	0
Station 2	0.581	0.1627	0.2217	0.0347	0
Station 3	0.5494	0.1399	0.2694	0.0412	0
Station 4	0.7629	0.1706	0.0086	0.0579	0
Station 5	0.74	0.1914	0.0188	0.0498	0
Station 6	0.7577	0.1923	0	0.0499	0
Assembly	0.8588	0.1207	0.0088	0.0117	0

Quality Report, Company B, Period 2

	Separeted Units
Station 1	0
Station 2	0
Station 3	0
Station 4	0
Station 5	0
Station 6	0
Assembly	0

Inventory Report, Company B, Period 2

	Av. Occu.	Av. Size	Fin. (B)	Final Size in units
Receive I	0.0018	10.8	1	15
Receive II	0.0001	0.6	0	0
Q. St. 2	0.0005	1.5	0	0
Q. St. 5	0.0314	94.2	13	195
Q. St. 3	0.0349	10.47	13	195
Q. St. 6	0.0827	248.1	5	75
Q. Ass. I	0.1274	382.2	30	450
Q. Ass. II	0.051	153	26	390
Total		900.87		

Raw Materials Report, Company B, Period 2

	Quantity	Batchsize	Price	Total/Comp.
Comp. AI	35	10	20	7000
Comp. BI	35	20	20	14000
Comp. CI	35	15	17.5	9187.5
Comp. AII	35	10	17.5	6125
Comp. BII	35	20	15	10500
Comp. CII	35	15	15	7875
Total				54687.5

Cash Flow Report, Company B, Period 2

Sales				
	Prod A	76500		
	Prod B	93625		
	Prod C	82000		
				252125
Raw Materials				54687.5
Processing				
	Station 1	4898.56		
	Station 2	3718.4		
	Station 3	3516.16		
	Station 4	4882.56		
	Station 5	4736		
	Station 6	4849.28		
	Assembly	8244.48		
				34845.44
Repair				
	Station 1	1180.8		
	Station 2	832.8		
	Station 3	988.8		
	Station 4	1389.6		
	Station 5	1195.2		
	Station 6	1197.6		
	Assembly	280.8		
				7065.6
Setup				
	Station 1	1439.2		
	Station 2	1301.6		
	Station 3	1119.2		
	Station 4	1364.8		
	Station 5	1531.2		
	Station 6	1538.4		
	Assembly	965.6		
				9260
Inventory				
	WIP		4504.35	
	Finished Goods		1360	
				5864.35
Fixed Costs				75000
Investments				
	Line Balancing			1000
	Quality Project			10000
OPERATIONAL MARGIN				54402.11

Company C

Throughput Report, Company C, Period 2

Day	Prod. A	Market	Sales	Inventory	In. Inv.	30
1	20	18	18	32	Tot. Sales	340
2	10	18	18	24	Fin. Inv.	10
3	20	18	18	26	Av. Inv.	15
4	10	18	18	18	Defective	26
5	10	18	18	10	Price	210
6	20	15	15	15	Mkt. Shar	0.3333
7	10	15	15	10	Batch	5
8	10	15	15	5		
9	20	15	15	10		
10	20	15	15	15		
11	10	16	16	9		
12	20	16	16	13		
13	20	16	16	17		
14	20	16	16	21		
15	10	16	16	15		
16	20	19	19	16		
17	20	19	19	17		
18	10	19	19	8		
19	20	19	19	9		
20	20	19	19	10		
	320	340	340	15		

Day	Prod. B	Market	Sales	Inventory	In. Inv.	38
1	40	28	28	50	Tot. Sales	535
2	20	28	28	42	Fin. Inv.	143
3	40	28	28	54	Av. Inv.	82.1
4	20	28	28	46	Defective	40
5	40	28	28	58	Price	165
6	20	26	26	52	Mkt. Shar	0.3333
7	40	26	26	66	Batch	10
8	30	26	26	70		
9	30	26	26	74		
10	40	26	26	88		
11	40	26	26	102		
12	20	26	26	96		
13	40	26	26	110		
14	20	26	26	104		
15	40	26	26	118		
16	20	27	27	111		
17	40	27	27	124		
18	40	27	27	137		
19	30	27	27	140		
20	30	27	27	143		
	640	535	535	89.25		

Throughput Report Compan C, Period 2

Day	Prod. C	Market	Sales	Inventory	In. Inv.	32
1	30	19	19	43	Tot. Sales	410
2	15	19	19	39	Fin. Inv.	99
3	30	19	19	50	Av. Inv.	68.3
4	15	19	19	46	Defective	41
5	30	19	19	57	Price	190
6	15	20	20	52	Mkt. Shar	0.3333
7	30	20	20	62	Batch	8
8	16	20	20	58		
9	32	20	20	70		
10	24	20	20	74		
11	24	21	21	77		
12	16	21	21	72		
13	32	21	21	83		
14	32	21	21	94		
15	16	21	21	89		
16	32	22	22	99		
17	16	22	22	93		
18	32	22	22	103		
19	24	22	22	105		
20	16	22	22	99		
	477	410	410	73.25		

Machine Status Report, Company C, Period 2

	Opration	Setup	Idle	Downtime	Blocked
Station 1	0.7764	0.1792	0.0045	0.0399	0
Station 2	0.5934	0.164	0.2072	0.0354	0
Station 3	0.5586	0.135	0.2593	0.0472	0
Station 4	0.7891	0.1707	0.0052	0.0349	0
Station 5	0.7458	0.186	0.0111	0.0571	0
Station 6	0.7644	0.1905	0	0.0451	0
Assembly	0.8653	0.1159	0.0091	0.0097	0

Quality Report, Company C, Period 2

	Separeted Units
Station 1	0
Station 2	0
Station 3	0
Station 4	0
Station 5	0
Station 6	0
Assembly	0

Inventory Report, Company C, Period 2

	Av. Occu.	Av. Size	Fin. (B)	Final Size in units
Receive I	0.0057	17.48	4	31
Receive II	0.0014	4.293333	0	0
Q. St. 2	0.0009	1.38	0	0
Q. St. 5	0.067	102.7333	24	184
Q. St. 3	0.0789	12.098	31	238
Q. St. 6	0.1734	265.88	20	153
Q. Ass. I	0.2514	385.48	53	406
Q. Ass. II	0.0985	151.0333	44	337
Total		940.378		

Raw Materials Report, Company C, Period 2

	Quantity	Batchsize	Price	Total/Comp.
Comp. AI	69	5	20	6900
Comp. BI	68	10	20	13600
Comp. CI	68	8	17.5	9520
Comp. AII	69	5	17.5	6037.5
Comp. BII	70	10	15	10500
Comp. CII	69	8	15	8280
Total				54837.5

Cash Flow Report, Company C, Period 2

Sales				
	Prod A	71400		
	Prod B	88275		
	Prod C	77900		
				237575
Raw Materials				54837.5
Processing				
	Station 1	4968.96		
	Station 2	3797.76		
	Station 3	3575.04		
	Station 4	5050.24		
	Station 5	4773.12		
	Station 6	4892.16		
	Assembly	8306.88		
				35364.16
Repair				
	Station 1	957.6		
	Station 2	849.6		
	Station 3	1132.8		
	Station 4	837.6		
	Station 5	1370.4		
	Station 6	1082.4		
	Assembly	232.8		
				6463.2
Setup				
	Station 1	1433.6		
	Station 2	1312		
	Station 3	1080		
	Station 4	1365.6		
	Station 5	1488		
	Station 6	1524		
	Assembly	927.2		
				9130.4
Inventory				
	WIP		4701.89	
	Finished Goods		1654	
				6355.89
Fixed Costs				75000
Investments				
	Line Balancing			1000
OPERATIONAL MARGIN				49423.85

APPENDIX 3

Output Reports for Period 3

INPUT SHEET
COMPANY A, PERIOD 3

Price Product A: 250 (+10)
B: 190 (+5)
C: 200 (+10)

Batch Size A: 40 (+20)
B: 40
C: 30

Priority Rule
First In First Out

Work Order Releases

Type	First Time	Occurrences	Frequency
A	0	inf	1200
B	480	inf	1200
C	920	inf	1200

Projects

[ ] Setup Reduction Project
[ ] Quality Project
[ ] Preventive Maintenance Project
[X] Assembly Line Balancing
[X] Process Redesign

The assembly line balancing projectachieves cycle times of 10, 9 and 8 minutes for products A, B, and C respectively. It includes a new station and increases fixed costs by $5000.

Two inspection station are introduced, one for each component line. They raise fix costs by $5000. The inventory of finished goods is inspected to eliminate defective parts produced previously.

INPUT SHEET
COMPANY B, PERIOD: 3

Price Product	A: 225	Batch Size	A: 10
	B: 175		B: 20
	C: 200		C: 15

Priority Rule

First In First Out

Work Order Releases

Type	First Time	Occurrences	Frequency
A	0	inf	550
B	150	inf	550
C	390	inf	550

Projects

[X] Setup Reduction Project
[ ] Quality Project
[X] Preventive Maintenance Project
[X] Assembly Line Balancing
[X] Process Redesign

The assembly line balancing project achieves cycle times of 10, 9 and 8 minutes for products A, B, and C respectively. It includes a new station and increases fixed costs by $5000.

Two inspection station are introduced, one for each component line. They raise fix costs by $5000. The inventory of finished goods is inspected to eliminate defective parts produced previously. The machine in processing station is replaced by a new one with processing times 7/7/10 for products A, B, and C, with a cost of $20000.

The setup reduction project reduces setup time by 20% for a sum of $10000, while the preventive maintenance project decreases repair time by 50% for an equal amount.

INPUT SHEET
COMPANY C, PERIOD 3

Price Product	A: 210	Batch Size	A: 5
	B: 165		B: 10
	C: 190		C: 8

Priority Rule

First In First Out

Work Order Releases

Type	First Time	Occurrences	Frequency
A	0	inf	720
A	64	inf	720
A	128	inf	720
A	192	inf	720
A	256	inf	720
B	320	inf	720
B	4400	inf	720
C	560	inf	720
C	640	inf	720

Projects

[X] Setup Reduction Project
[X] Quality Project
[ ] Preventive Maintenance Project
[X] Assembly Line Balancing
[X] Process Redesign

The assembly line balancing project achieves cycle times of 10, 9 and 8 minutes for products A, B, and C, at a cost of $5000. Another $5000 are spent to introduce an two inspection stations. The inventory of finished goods is inspected to eliminate defective parts produced previously. The setup reduction project and qulaity control projects are implemented with a cost of $10000 each.

Performance Report, Period 3

Market Share

Product A

	Price Fac.	Def. Fac.	Av. Fac	M.S. (t-1)	Mkt. S.	Norm.
Company A	0.913	0.737	1.000	0.318	0.214	0.213
Company B	1.015	1.349	0.827	0.374	0.423	0.419
Company C	1.087	1.108	1.000	0.308	0.371	0.368
					1.008	

Product B

	Price Fac.	Def. Fac.	Av. Fac	M.S. (t-1)	Mkt. S.	Norm.
Company A	0.930	0.938	1.000	0.214	0.187	0.181
Company B	1.010	0.935	1.000	0.444	0.420	0.408
Company C	1.071	1.157	1.000	0.342	0.423	0.411
					1.029	

Product C

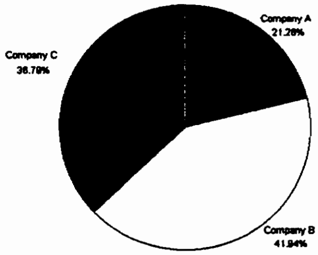
	Price Fac.	Def. Fac.	Av. Fac	M.S. (t-1)	Mkt. S.	Norm.
Company A	0.924	0.797	1.000	0.252	0.186	0.190
Company B	1.017	0.911	1.000	0.448	0.415	0.425
Company C	1.070	1.172	1.000	0.299	0.375	0.384
					0.977	

Operational Margin

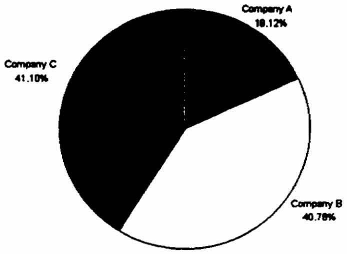
Company A	38769
Company B	110775
Comapny C	23860

Sales (Volume)

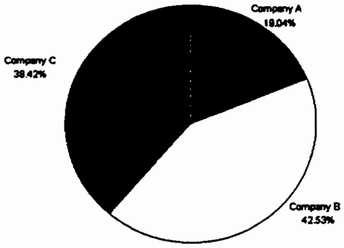
	Product A	Product B	Product C
Company A	414	364	353
Company B	402	756	627
Company C	400	581	422
Total Market	1300	1701	1402



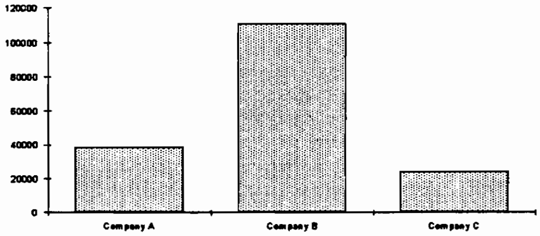
Market Share, Product A, Period 3



Market Share, Product B, Period 3



Market Share, Product C, Period 3



Operational Margin, Period 3

Company A

Throughput Report, Company A, Period 3

Day	Prod. A	Market	Sales	Inventory
1	36	16	16	39
2	36	16	16	59
3	18	16	16	61
4	36	16	16	81
5	36	16	16	101
6	36	19	19	118
7	37	19	19	136
8	33	19	19	150
9	36	19	19	167
10	35	19	19	183
11	32	22	22	193
12	0	22	22	171
13	37	22	22	186
14	34	22	22	198
15	35	22	22	211
16	0	25	25	186
17	37	26	26	197
18	40	26	26	211
19	37	26	26	222
20	0	26	26	196
	591	414	414	153.3

In. Inv.	19
Tot. Sales	414
Fin. Inv.	196
Av. Inv.	153.3
Defective	11
Price	250
Mkt. Shar	0.3184
Batch	40

Day	Prod. B	Market	Sales	Inventory
1	18	14	14	141
2	36	14	14	163
3	36	14	14	185
4	18	14	14	189
5	51	14	14	226
6	35	18	18	243
7	33	18	18	258
8	34	18	18	274
9	34	18	18	290
10	0	18	18	272
11	36	20	20	288
12	36	20	20	304
13	33	20	20	317
14	34	20	20	331
15	0	20	20	311
16	38	20	20	329
17	39	21	21	347
18	0	21	21	326
19	34	21	21	339
20	38	21	21	356
	583	364	364	274.45

In. Inv.	137
Tot. Sales	364
Fin. Inv.	356
Av. Inv.	256.65
Defective	12
Price	190
Mkt. Shar	0.2139
Batch	40

Throughput Report Company A, Period 3

Day	Prod. C	Market	Sales	Inventory
1	14	14	14	44
2	28	14	14	58
3	28	14	14	72
4	15	14	14	73
5	0	14	14	59
6	29	15	15	73
7	0	15	15	58
8	28	15	15	71
9	29	15	15	85
10	30	15	15	100
11	27	19	19	108
12	30	19	19	119
13	27	19	19	127
14	0	19	19	108
15	29	19	19	118
16	27	22	22	123
17	29	22	22	130
18	30	23	23	137
19	27	23	23	141
20	30	23	23	148
	457	353	353	97.6

In. Inv.	44
Tot. Sales	353
Fin. Inv.	148
Av. Inv.	90.2
Defective	10
Price	220
Mkt. Shar	0.2523
Batch	30

Machine Status Report, Company A, Period 3

	Opration	Setup	Idle	Downtime	Blocked
Station 1	88.72%	8.23%	0.41%	2.64%	0.00%
Station 2	68.27%	7.52%	22.22%	2.00%	0.00%
Station 3	62.53%	6.09%	29.98%	1.40%	0.00%
Station 4	85.45%	7.94%	2.01%	4.61%	0.00%
Station 5	84.16%	8.54%	4.25%	3.05%	0.00%
Station 6	68.98%	6.82%	23.26%	0.94%	0.00%
Assembly	79.14%	5.54%	13.71%	1.61%	0.00%
Ins1	14.99%		85.01%		
Ins2	15.06%		84.94%		

Quality Report, Company A, Period 3

	Separeted Units
Station 1	0
Station 2	0
Station 3	172
Station 4	0
Station 5	0
Station 6	194
Assembly	0

Inventory Report, Company A, Period 3

	Av. Occu.	Av. Size	Fin. (B)	Final Size in units
Receive I	1.10%	161.3333	2	73
Receive II	0.00%	0	0	0
Q. St. 2	0.02%	1.466667	0	0
Q. St. 5	1.22%	89.46667	13	477
Q. St. 3	1.53%	11.22	11	403
Q. St. 6	0.02%	1.466667	0	0
Q. Ass. I	0.11%	8.066667	0	0
Q. Ass. II	2.15%	157.6667	0	0
Total	1.67%	430.6867	26	953

Raw Materials Report, Company A, Period 3

	Quantity	Batchsize	Price	Total/Comp.
Comp. AI	20	40	20	16000
Comp. BI	20	40	20	16000
Comp. CI	19	30	17.5	9975
Comp. AII	20	40	17.5	14000
Comp. BII	20	40	15	12000
Comp. CII	19	30	15	8550
Total				76525

Cash Flow Report, Company A, Period 3

Sales				
	Prod A	103500		
	Prod B	69160		
	Prod C	77660		
				250320
Raw Materials				76525
Processing				
	Station 1	5678.08		
	Station 2	4369.28		
	Station 3	4001.92		
	Station 4	5468.8		
	Station 5	5386.24		
	Station 6	4414.72		
	Assembly	7597.44		
				36916.48
Repair				
	Station 1	633.6		
	Station 2	480		
	Station 3	336		
	Station 4	1106.4		
	Station 5	732		
	Station 6	225.6		
	Assembly	386.4		
				3900
Setup				
	Station 1	658.4		
	Station 2	601.6		
	Station 3	487.2		
	Station 4	635.2		
	Station 5	683.2		
	Station 6	545.6		
	Assembly	443.2		
				4054.4
Inventory				
	WIP		2153.433	
	Finished Goods		5001.5	
				7154.933
Fixed Costs				75000
Investments				
	Second Line Balancing			5000
	Inspection Stations			5000
	Final Inventory Inspection			2000
OPERATIONAL MARGIN				34769.19

Company B

Throughput Report, Company B, Period 3

Day	Prod. A	Market	Sales	Inventory	In. Inv.	9
1	29	19	19	19	Tot. Sales	402
2	19	19	19	19	Fin. Inv.	0
3	20	19	19	20	Av. Inv.	6.9
4	19	19	19	20	Defective	4
5	20	19	19	21	Price	225
6	20	24	24	17	Mkt. Shar	37.36%
7	19	24	24	12	Batch	10
8	20	24	24	8		
9	18	24	24	2		
10	20	24	22	0		
11	20	25	20	0		
12	19	25	19	0		
13	20	25	20	0		
14	19	25	19	0		
15	20	25	20	0		
16	18	29	18	0		
17	20	29	20	0		
18	18	29	18	0		
19	20	29	20	0		
20	15	30	15	0		
	393	486	402	6.9		

Day	Prod. B	Market	Sales	Inventory	In. Inv.	105
1	38	29	29	114	Tot. Sales	756
2	38	29	29	123	Fin. Inv.	124
3	39	29	29	133	Av. Inv.	146.85
4	40	29	29	144	Defective	16
5	39	29	29	154	Price	175
6	40	34	34	160	Mkt. Shar	44.44%
7	39	34	34	165	Batch	20
8	38	34	34	169		
9	37	34	34	172		
10	39	34	34	177		
11	40	41	41	176		
12	39	41	41	174		
13	38	41	41	171		
14	38	41	41	168		
15	36	41	41	163		
16	40	47	47	156		
17	38	47	47	147		
18	39	47	47	139		
19	40	47	47	132		
20	40	48	48	124		
	775	756	756	153.05		

Throughput Report Company B, Period 3

Day	Prod. C	Market	Market	Inventory
1	15	25	25	50
2	29	25	25	54
3	28	25	25	57
4	30	25	25	62
5	30	25	25	67
6	28	29	29	66
7	29	29	29	66
8	29	29	29	66
9	27	29	29	64
10	27	29	29	62
11	30	33	33	59
12	30	33	33	56
13	38	33	33	61
14	38	33	33	66
15	30	33	33	63
16	27	38	38	52
17	26	38	38	40
18	29	38	38	31
19	30	39	39	22
20	28	39	39	11
	578	627	627	53.75

In. Inv.	60
Tot. Sales	627
Fin. Inv.	11
Av. Inv.	53.2
Defective	9
Price	200
Mkt. Shar	0.4484
Batch	15

Machine Status Report, Company B, Period 3

	Opration	Setup	Idle	Downtime	Blocked
Station 1	0.8511	0.1317	0	0.0172	0
Station 2	0.7437	0.1316	0.1036	0.0211	0
Station 3	0.6207	0.1002	0.2558	0.0233	0
Station 4	0.7735	0.1597	0.0427	0.0241	0
Station 5	0.7917	0.1429	0.0217	0.0437	0
Station 6	0.7911	0.145	0.0379	0.026	0
Assembly	0.8122	0.1781	0	0.0097	0
Ins1	0.1184		0.8816		
Ins2	0.1455		0.8545		

Quality Report, Company B, Period 3

	Separeted Units
Station 1	54
Station 2	28
Station 3	27
Station 4	50
Station 5	38
Station 6	21
Assembly	0

Inventory Report, Company B, Period 3

	Av. Occu.	Av. Size	Fin. (B)	Final Size in units
Receive I	0.0122	73.2	10	150
Receive II	0.0001	0.6	0	0
Q. St. 2	0.0003	0.9	0	0
Q. St. 5	0.0016	4.8	0	0
Q. St. 3	0.0229	6.87	8	120
Q. St. 6	0.0025	7.5	1	15
Q. Ass. I	0.1614	484.2	10	150
Q. Ass. II	0.1197	359.1	27	405
Total		937.17		

Raw Materials Report, Company B, Period 3

	Quantity	Batchsize	Price	Total/Comp.
Comp. AI	35	10	20	7000
Comp. BI	35	20	20	14000
Comp. CI	35	15	17.5	9187.5
Comp. AII	35	10	17.5	6125
Comp. BII	35	20	15	10500
Comp. CII	35	15	15	7875
Total	35			54687.5

Cash Flow Report, Company B, Period 3

Sales				
	Prod A	90450		
	Prod B	132300		
	Prod C	125400		
				348150
Raw Materials				54687.5
Processing				
	Station 1	5447.04		
	Station 2	4759.68		
	Station 3	3972.48		
	Station 4	4950.4		
	Station 5	5066.88		
	Station 6	5063.04		
	Assembly	7797.12		
				37056.64
Repair				
	Station 1	412.8		
	Station 2	506.4		
	Station 3	559.2		
	Station 4	578.4		
	Station 5	1048.8		
	Station 6	624		
	Assembly	232.8		
				3962.4
Setup				
	Station 1	1053.6		
	Station 2	1052.8		
	Station 3	801.6		
	Station 4	1277.6		
	Station 5	1143.2		
	Station 6	1160		
	Assembly	1424.8		
				7913.6
Inventory				
	WIP		4685.85	
	Finished Goods		2069.5	
				6755.35
Fixed Costs				75000
Investments				
	Second Line Balancing			5000
	Setup Reduciton Project			10000
	Maintenace Project			10000
	Inspection Stations			5000
	Machine Replacement (St.5)			20000
	Final Inventory Inspection			2000
OPERATIONAL MARGIN				110774.5

Company C

Throughput Report, Company C, Period 3

Day	Prod. A	Market	Sales	Inventory	In. Inv.	9
1	20	15	15	14	Tot. Sales	400
2	19	15	15	18	Fin. Inv.	174
3	14	15	15	17	Av. Inv.	70.55
4	20	15	15	22	Defective	7
5	14	15	15	21	Price	210
6	13	19	19	15	Mkt. Shar	0.308
7	15	19	19	11	Batch	5
8	20	19	19	12		
9	25	19	19	18		
10	44	19	19	43		
11	43	21	21	65		
12	28	21	21	72		
13	46	21	21	97		
14	23	21	21	99		
15	48	21	21	126		
16	27	25	25	128		
17	40	25	25	143		
18	36	25	25	154		
19	33	25	25	162		
20	37	25	25	174		
	565	400	400	70.55		

Day	Prod. B	Market	Market	Inventory	In. Inv.	131
1	28	26	26	133	Tot. Sales	581
2	39	26	26	146	Fin. Inv.	149
3	29	26	26	149	Av. Inv.	162.35
4	27	26	26	150	Defective	10
5	40	26	26	164	Price	165
6	29	27	27	166	Mkt. Shar	0.3417
7	40	27	27	179	Batch	10
8	29	27	27	181		
9	27	27	27	181		
10	38	27	27	192		
11	20	30	30	182		
12	38	30	30	190		
13	19	30	30	179		
14	38	30	30	187		
15	19	30	30	176		
16	37	33	33	180		
17	29	33	33	176		
18	28	33	33	171		
19	27	33	33	165		
20	18	34	34	149		
	599	581	581	169.8		

Throughput Report Company C, Period 3

Day	Prod. C	Market	Market	Inventory
1	15	25	25	50
2	29	25	25	54
3	28	25	25	57
4	30	25	25	62
5	30	25	25	67
6	28	29	29	66
7	29	29	29	66
8	29	29	29	66
9	27	29	29	64
10	27	29	29	62
11	30	33	33	59
12	30	33	33	56
13	38	33	33	61
14	38	33	33	66
15	30	33	33	63
16	27	38	38	52
17	26	38	38	40
18	29	38	38	31
19	30	39	39	22
20	28	39	39	11
	578	627	627	53.75

In. Inv.	60
Tot. Sales	627
Fin. Inv.	11
Av. Inv.	53.2
Defective	9
Price	200
Mkt. Shar	0.4484
Batch	15

Machine Status Report, Company C. Period 3

	Opration	Setup	Idle	Downtime	Blocked	
Station 1	0.8504	0.0962	0	0.0533	0	0.9999
Station 2	0.8043	0.0984	0.0516	0.0456	0	0.9999
Station 3	0.6505	0.0742	0.2349	0.0404	0	1
Station 4	0.8578	0.0969	0.0041	0.0412	0	1
Station 5	0.8246	0.0983	0.0098	0.0673	0	1
Station 6	0.7158	0.0864	0.1655	0.0323	0	1
Assembly	0.7774	0.2022	0	0.0203	0	0.9999
Ins1	0.123		0.877			
Ins2	0.1337		0.8663			

Quality Report, Company C, Period 3

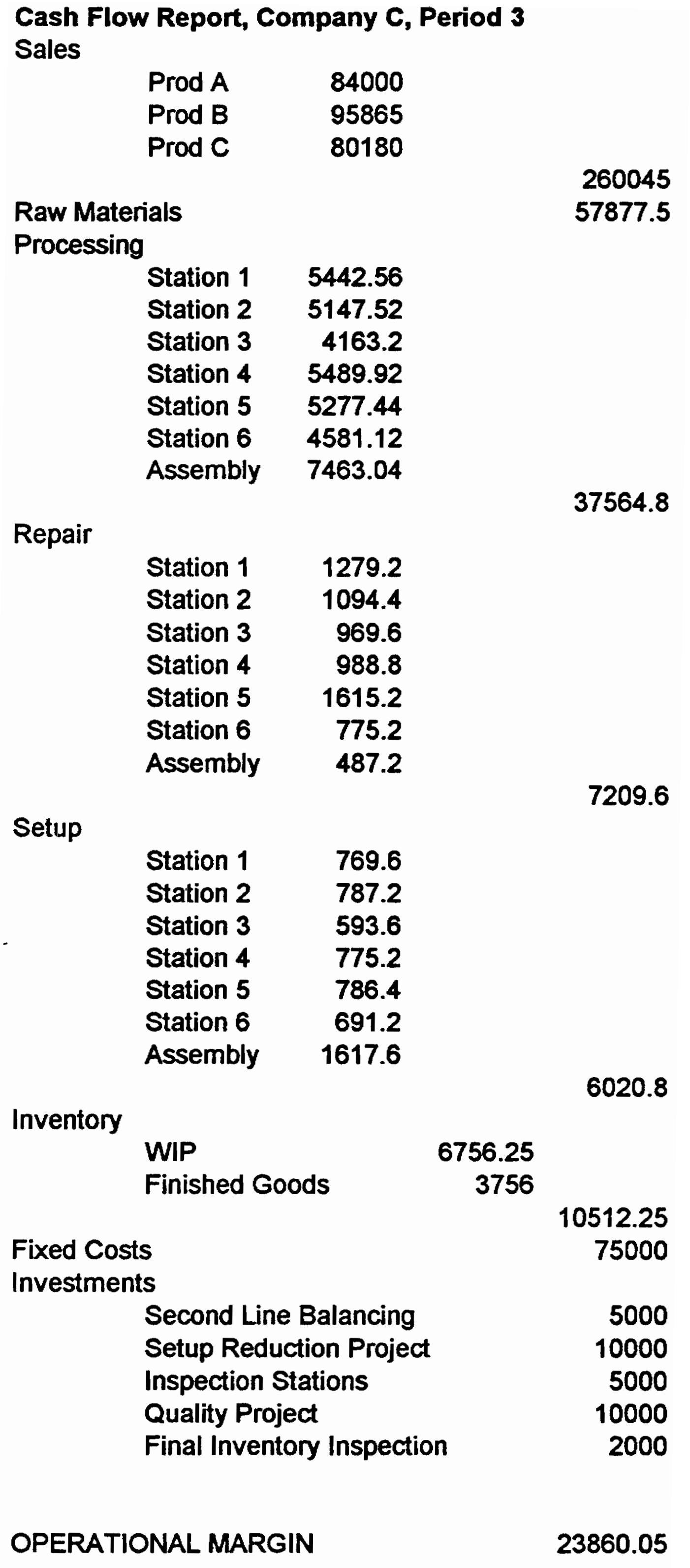
	Separeted Units
Station 1	0
Station 2	0
Station 3	72
Station 4	0
Station 5	0
Station 6	81
Assembly	0

Inventory Report, Company C, Period 3

	Av. Occu.	Av. Size	Fin. (B)	Final Size in units
Receive I	0.0465	142.6	41	314
Receive II	0.0042	12.88	1	8
Q. St. 2	0.0007	1.073333	0	0
Q. St. 5	0.1214	186.1467	54	414
Q. St. 3	0.0695	10.65667	26	199
Q. St. 6	0.0011	1.686667	0	0
Q. Ass. I	0.3402	521.64	19	146
Q. Ass. II	0.3095	474.5667	31	238
Total		1351.25		

Raw Materials Report, Company C, Period 3

	Quantity	Batchsize	Price	Total/Comp.
Comp. AI	133	5	20	13300
Comp. BI	54	10	20	10800
Comp. CI	54	8	17.5	7560
Comp. AII	133	5	17.5	11637.5
Comp. BII	54	10	15	8100
Comp. CII	54	8	15	6480
Total				57877.5



Cash Flow Report, Company C, Period 3

Sales				
	Prod A	84000		
	Prod B	95865		
	Prod C	80180		
				260045
Raw Materials				57877.5
Processing				
	Station 1	5442.56		
	Station 2	5147.52		
	Station 3	4163.2		
	Station 4	5489.92		
	Station 5	5277.44		
	Station 6	4581.12		
	Assembly	7463.04		
				37564.8
Repair				
	Station 1	1279.2		
	Station 2	1094.4		
	Station 3	969.6		
	Station 4	988.8		
	Station 5	1615.2		
	Station 6	775.2		
	Assembly	487.2		
				7209.6
Setup				
	Station 1	769.6		
	Station 2	787.2		
	Station 3	593.6		
	Station 4	775.2		
	Station 5	786.4		
	Station 6	691.2		
	Assembly	1617.6		
				6020.8
Inventory				
	WIP		6756.25	
	Finished Goods		3756	
				10512.25
Fixed Costs				75000
Investments				
	Second Line Balancing			5000
	Setup Reduction Project			10000
	Inspection Stations			5000
	Quality Project			10000
	Final Inventory Inspection			2000
OPERATIONAL MARGIN				23860.05

APPENDIX 4

Output Reports for Period 4

INPUT SHEET

COMPANY A, PERIOD 4

Price Product A: 250
B: 190
C: 200

Batch Size A: 40
B: 40
C: 30

Priority Rule

First In First Out

Work Order Releases

Type	First Time	Occurrences	Frequency
A	0	inf	1500
B	480	inf	1500
B	900	inf	1500
C	1320	inf	1500

Projects

[ ] Setup Reduction Project
[ ] Quality Project
[ ] Preventive Maintenance Project
[ ] Assembly Line Balancing
[ ] Process Redesign

INPUT SHEET
COMPANY B, PERIOD 4

Price Product A: 225
B: 175
C: 200

Batch Size A: 10
B: 20
C: 15

Priority Rule

First In First Out

Work Order Releases

Type	First Time	Occurrences	Frequency
A	0	inf	750
B	150	inf	750
B	370	inf	750
C	590	inf	750

Projects

[ ] Setup Reduction Project
[ ] Quality Project
[ ] Preventive Maintenance Project
[X] Assembly Line Balancing
[X] Process Redesign

The assembly line balancing project achieves cycle times of 8, 7 and 6 minutes for products A, B, and C respectively. It includes a new station and increases fixed costs by $5000. The machine in processing station 1 is replaced by a new one with processing times 9/9/7 for products A, B, and C, with a cost of $20000.

INPUT SHEET
COMPANIES: C; PERIOD 4

Price Product	A: 210	Batch Size	A: 5
	B: 165		B: 10
	C: 190		C: 8

Priority Rule

First In First Out

Work Order Releases

Type	First Time	Occurrences	Frequency
A	0	inf	795
A	68	inf	795
A	136	inf	795
B	205	inf	795
B	310	inf	795
B	415	inf	795
B	520	inf	795
C	625	inf	795
C	710	inf	795

Projects

[ ] Setup Reduction Project
[ ] Quality Project
[ ] Preventive Maintenance Project
[X] Assembly Line Balancing
[X] Process Redesign

The assembly line balancing project achieves cycle times of 8, 7 and 6 minutes for products A, B, and C, by including a new station, which increases fixed costs by $5,000. The machine in station 5 is replaced at a cost of $20,000. The new machine has processing times of 7, 7 and 10 minutes for products A, B, and C.

Performance Report, Period 4

Market Share

Product A

	Price Fac.	Def. Fac.	Av. Fac	M.S. (t-1)	Mkt. S.	Norm.
Company A	0.913	0.978	1.000	0.213	0.190	0.238
Company B	1.015	1.139	0.507	0.419	0.246	0.307
Company C	1.087	0.909	1.000	0.368	0.364	0.455
					0.799	

Product B

	Price Fac.	Def. Fac.	Av. Fac	M.S. (t-1)	Mkt. S.	Norm.
Company A	0.930	0.852	1.000	0.181	0.143	0.143
Company B	1.010	1.133	1.000	0.408	0.466	0.464
Company C	1.071	1.060	0.905	0.384	0.395	0.393
					1.004	

Product C

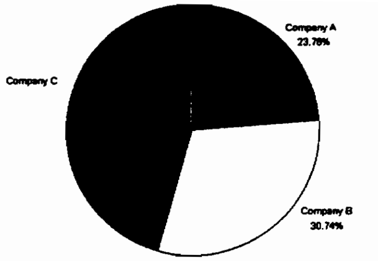
	Price Fac.	Def. Fac.	Av. Fac	M.S. (t-1)	Mkt. S.	Norm.
Company A	0.924	0.932	1.000	0.190	0.164	0.220
Company B	1.017	1.207	0.556	0.448	0.306	0.410
Company C	1.070	0.862	0.781	0.384	0.277	0.371
					0.747	

Operational Margin

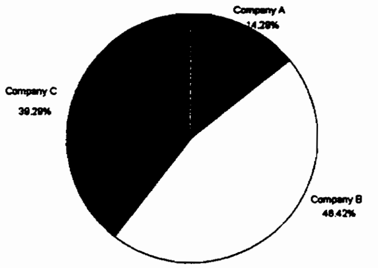
Company A	225
Company B	75070
Company C	73800

Sales (Volume)

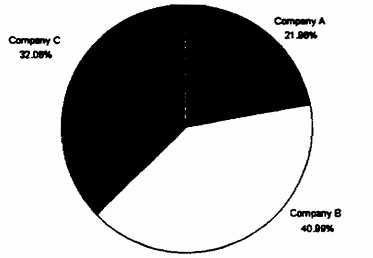
	Product A	Product B	Product C
Company A	256	398	314
Company B	255	898	390
Company C	442	818	495
Total Market	1201	2200	1649



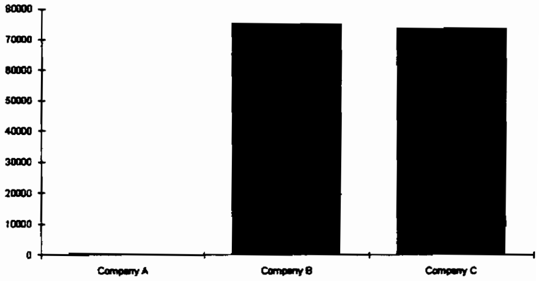
Market Share, Product A, Period 4



Market Share, Product B, Period 4



Market Share, Product C, Period 4



Operational Margin 4, Period 4

Company A

Throughput Report, Company A, Period 4

Day	Prod. A	Market	Sales	Inventory
1	35	11	11	220
2	0	11	11	209
3	36	11	11	234
4	0	11	11	223
5	36	11	11	248
6	37	11	11	274
7	38	11	11	301
8	36	11	11	326
9	0	11	11	315
10	40	11	11	344
11	0	13	13	331
12	35	13	13	353
13	0	13	13	340
14	33	13	13	360
15	0	13	13	347
16	40	16	16	371
17	0	16	16	355
18	38	16	16	377
19	0	16	16	361
20	34	17	17	378
	438	256	256	313.35

In. Inv.	196
Tot. Sales	256
Fin. Inv.	378
Av. Inv.	313.35
Defective	8
Price	250
Mkt. Shar	0.2126
Batch	40

Day	Prod. B	Market	Sales	Inventory
1	36	15	15	377
2	0	15	15	362
3	34	15	15	381
4	0	15	15	366
5	34	15	15	385
6	36	18	18	403
7	0	18	18	385
8	37	18	18	404
9	36	18	18	422
10	36	18	18	440
11	32	22	22	450
12	37	22	22	465
13	34	22	22	477
14	32	22	22	487
15	34	22	22	499
16	35	24	24	510
17	36	24	24	522
18	39	25	25	536
19	36	25	25	547
20	71	25	25	593
	635	398	398	450.55

In. Inv.	356
Tot. Sales	398
Fin. Inv.	593
Av. Inv.	420.9
Defective	13
Price	190
Mkt. Shar	0.1812
Batch	40

Throughput Report Company C, Period 4

Day	Prod. C	Market	Sales	Inventory
1	27	12	12	163
2	0	12	12	151
3	0	12	12	139
4	26	12	12	153
5	28	12	12	169
6	0	15	15	154
7	26	15	15	165
8	0	15	15	150
9	27	15	15	162
10	0	15	15	147
11	28	17	17	158
12	0	17	17	141
13	26	17	17	150
14	0	17	17	133
15	30	17	17	146
16	0	18	18	128
17	26	19	19	135
18	0	19	19	116
19	27	19	19	124
20	0	19	19	105
	271	314	314	144.45

In. Inv.	148
Tot. Sales	314
Fin. Inv.	105
Av. Inv.	139.2
Defective	5
Price	220
Mkt. Shar	0.1904
Batch	30

Machine Status Report, Company A, Period 4

	Opration	Setup	Idle	Downtime	Blocked
Station 1	0.9106	0.0639	0.0008	0.0247	0
Station 2	0.7371	0.0582	0.185	0.0197	0
Station 3	0.6369	0.0469	0.3007	0.0155	0
Station 4	0.911	0.0676	0	0.0214	0
Station 5	0.899	0.072	0	0.029	0
Station 6	0.7582	0.0569	0.1759	0.009	0
Assembly	0.6411	0.0302	0.3177	0.011	0
Ins1	0.1582		0.8418		
Ins2	0.1684		0.8316		

Quality Report, Company A, Period 4

	Separeted Units
Station 1	0
Station 2	0
Station 3	126
Station 4	0
Station 5	0
Station 6	166
Assembly	0

Inventory Report, Company A, Period 4

	Av. Occu.	Av. Size	Fin. (B)	Final Size in units
Receive I	0.0048	70.4	4	147
Receive II	0.0001	1.466667	0	0
Q. St. 2	0.0001	0.733333	0	0
Q. St. 5	0.0773	566.8667	24	880
Q. St. 3	0.0724	53.09333	18	660
Q. St. 6	0.0004	2.933333	0	0
Q. Ass. I	0	0	0	0
Q. Ass. II	0.0043	31.53333	0	0
Total	0.001	727.0267	2	1687

Raw Materials Report, Company A, Period 4

	Quantity	Batchsize	Price	Total/Comp.
Comp. AI	13	40	20	10400
Comp. BI	26	40	20	20800
Comp. CI	12	30	17.5	6300
Comp. AII	13	40	17.5	9100
Comp. BII	26	40	15	15600
Comp. CII	12	30	15	5400
Total				67600

Cash Flow Report, Company A, Period 4

Sales				
	Prod A	64000		
	Prod B	75620		
	Prod C	69080		
				208700
Raw Materials				67600
Processing				
	Station 1	5827.84		
	Station 2	4717.44		
	Station 3	4076.16		
	Station 4	5830.4		
	Station 5	5753.6		
	Station 6	4852.48		
	Assembly	6154.56		
				37212.48
Repair				
	Station 1	592.8		
	Station 2	472.8		
	Station 3	372		
	Station 4	513.6		
	Station 5	696		
	Station 6	216		
	Assembly	264		
				3127.2
Setup				
	Station 1	511.2		
	Station 2	465.6		
	Station 3	375.2		
	Station 4	540.8		
	Station 5	576		
	Station 6	455.2		
	Assembly	241.6		
				3165.6
Inventory				
	WIP		3635.133	
	Finished Goods		8734.5	
				12369.63
Fixed Costs				85000
Investments				
OPERATIONAL MARGIN				225.0867

Company B

Throughput Report, Company B, Period 4

Day	Prod. A	Market	Sales	Inventory
1	28	19	19	9
2	20	19	19	10
3	19	19	19	10
4	10	19	19	1
5	19	19	19	1
6	19	24	20	0
7	10	24	10	0
8	10	24	10	0
9	8	24	8	0
10	8	24	8	0
11	9	27	9	0
12	9	27	9	0
13	10	27	10	0
14	9	27	9	0
15	9	27	9	0
16	10	30	10	0
17	19	30	19	0
18	10	31	10	0
19	10	31	10	0
20	9	31	9	0
	255	503	255	1.55

In. Inv.	0
Tot. Sales	255
Fin. Inv.	0
Av. Inv.	1.55
Defective	4
Price	225
Mkt. Shar	0.4194
Batch	10

Day	Prod. B	Market	Sales	Inventory
1	40	38	38	126
2	58	38	38	146
3	20	38	38	128
4	39	38	38	129
5	20	38	38	111
6	54	42	42	123
7	38	42	42	119
8	40	42	42	117
9	59	42	42	134
10	38	42	42	130
11	37	46	46	121
12	38	46	46	113
13	37	46	46	104
14	40	46	46	98
15	35	46	46	87
16	38	53	53	72
17	39	53	53	58
18	39	54	54	43
19	33	54	54	22
20	38	54	54	6
	780	898	898	99.35

In. Inv.	124
Tot. Sales	898
Fin. Inv.	6
Av. Inv.	99.05
Defective	12
Price	175
Mkt. Shar	0.4076
Batch	20

Throughput Report, Company B, Period 4

Day	Prod. C	Market	Sales	Inventory	In. Inv.	11
1	28	30	30	9	Tot. Sales	390
2	30	30	30	9	Fin. Inv.	0
3	39	30	30	18	Av. Inv.	2.55
4	15	30	30	3	Defective	5
5	39	30	30	12	Price	200
6	14	32	26	0	Mkt. Shar	0.4484
7	13	32	13	0	Batch	15
8	15	32	15	0		
9	15	32	15	0		
10	13	32	13	0		
11	28	37	28	0		
12	0	37	0	0		
13	14	37	14	0		
14	14	37	14	0		
15	29	37	29	0		
16	15	41	15	0		
17	15	41	15	0		
18	14	41	14	0		
19	15	41	15	0		
20	14	42	14	0		
	379	701	390	2.55		

Machine Status Report, Company B, Period 4

	Opration	Setup	Idle	Downtime	Blocked
Station 1	0.8787	0.1061	0	0.0152	0
Station 2	0.7834	0.0956	0.0984	0.0226	0
Station 3	0.7133	0.0841	0.185	0.0175	0
Station 4	0.7971	0.1167	0.0581	0.0281	0
Station 5	0.8526	0.1126	0	0.0348	0
Station 6	0.8513	0.102	0.0387	0.0081	0
Assembly	0.5041	0.1125	0.376	0.0074	0
Ins1	0.1308		0.8692		
Ins2	0.1573		0.8427		

Quality Report, Company B, Period 4

	Separeted Units
Station 1	49
Station 2	30
Station 3	24
Station 4	59
Station 5	29
Station 6	30
Assembly	0

Inventory Report, Company B, Period 4

	Av. Occu.	Av. Size	Fin. (B)	Final Size in units
Receive I	0.0283	169.8	13	195
Receive II	0.0001	0.6	0	0
Q. St. 2	0.0004	1.2	0	0
Q. St. 5	0.0012	3.6	0	0
Q. St. 3	0.0709	21.27	25	375
Q. St. 6	0.0029	8.7	1	15
Q. Ass. I	0.1259	377.7	0	0
Q. Ass. II	0.0052	15.6	38	570
Total		598.47		

Raw Materials Report, Company C, Period 4

	Quantity	Batchsize	Price	Total/Comp.
Comp. AI	26	10	20	5200
Comp. BI	52	20	20	20800
Comp. CI	25	15	17.5	6562.5
Comp. AII	26	10	17.5	4550
Comp. BII	52	20	15	15600
Comp. CII	25	15	15	5625
Total				58337.5

Cash Flow Report, Company B, Period 4

Sales				
	Prod A	57375		
	Prod B	157150		
	Prod C	78000		
				292525
Raw Materials				58337.5
Processing				
	Station 1	5623.68		
	Station 2	5013.76		
	Station 3	4565.12		
	Station 4	5101.44		
	Station 5	5456.64		
	Station 6	5448.32		
	Assembly	4839.36		
				36048.32
Repair				
	Station 1	364.8		
	Station 2	542.4		
	Station 3	420		
	Station 4	674.4		
	Station 5	835.2		
	Station 6	194.4		
	Assembly	177.6		
				3208.8
Setup				
	Station 1	848.8		
	Station 2	764.8		
	Station 3	672.8		
	Station 4	933.6		
	Station 5	900.8		
	Station 6	816		
	Assembly	900		
				5836.8
Inventory				
	WIP		2992.35	
	Finished Goods		1031.5	
				4023.85
Fixed Costs				85000
Investments				
	New Assembly Line Balance			5000
	Machine Replacement (St.5)			20000
OPERATIONAL MARGIN				75069.73

Company C

Throughput Report, Company C, Period 4

Day	Prod. A	Market	Sales	Inventory	In. Inv.	174
1	30	17	17	187	Tot. Sales	442
2	50	17	17	220	Fin. Inv.	139
3	24	17	17	227	Av. Inv.	218.5
4	23	17	17	233	Defective	8
5	37	17	17	253	Price	210
6	10	21	21	242	Mkt. Shar	0.3679
7	22	21	21	243	Batch	5
8	37	21	21	259		
9	29	21	21	267		
10	14	21	21	260		
11	14	24	24	250		
12	13	24	24	239		
13	9	24	24	224		
14	19	24	24	219		
15	13	24	24	208		
16	9	26	26	191		
17	17	26	26	182		
18	15	26	26	171		
19	12	27	27	156		
20	10	27	27	139		
	407	442	442	218.5		

Day	Prod. B	Market	Market	Inventory	In. Inv.	149
1	38	40	40	147	Tot. Sales	818
2	40	40	40	147	Fin. Inv.	0
3	19	40	40	126	Av. Inv.	45.7
4	39	40	40	125	Defective	11
5	20	40	40	105	Price	165
6	19	45	45	79	Mkt. Shar	0.3842
7	17	45	45	51	Batch	10
8	39	45	45	45		
9	35	45	45	35		
10	36	45	45	26		
11	39	46	46	19		
12	36	46	46	9		
13	37	46	46	0		
14	37	46	37	0		
15	33	46	33	0		
16	34	49	34	0		
17	39	50	39	0		
18	35	50	35	0		
19	40	50	40	0		
20	37	50	37	0		
	669	904	818	45.7		

Throughput Report Company C, Period 4

Day	Prod. C	Market	Market	Inventory
1	30	27	27	147
2	32	27	27	152
3	15	27	27	140
4	24	27	27	137
5	23	27	27	133
6	0	30	30	103
7	24	30	30	97
8	24	30	30	91
9	14	30	30	75
10	15	30	30	60
11	16	33	33	43
12	15	33	33	25
13	14	33	33	6
14	16	33	22	0
15	16	33	16	0
16	16	36	16	0
17	15	37	15	0
18	14	37	14	0
19	13	37	13	0
20	15	37	15	0
	351	634	495	60.45

In. Inv.	144
Tot. Sales	495
Fin. Inv.	0
Av. Inv.	60.45
Defective	7
Price	190
Mkt. Shar	0.3842
Batch	8

Machine Status Report, Company C, Period 4

	Opration	Setup	Idle	Downtime	Blocked
Station 1	0.8321	0.1018	0	0.0661	0
Station 2	0.6404	0.094	0.205	0.0606	0
Station 3	0.5866	0.078	0.2829	0.0524	0
Station 4	0.7997	0.1315	0	0.0688	0
Station 5	0.8036	0.1071	0	0.0993	0
Station 6	0.8219	0.1124	0.0096	0.0561	0
Assembly	0.5237	0.1	0.3578	0.0185	0
Ins1	0.144		0.856		
Ins2	0.1872		0.8128		

Quality Report, Company C, Period 4

	Separeted Units
Station 1	0
Station 2	0
Station 3	98
Station 4	0
Station 5	0
Station 6	123
Assembly	0

Inventory Report, Company C, Period 4

	Av. Occu.	Av. Size	Fin. (B)	FInal Size in units
Receive I	0.1041	319.24	48	368
Receive II	0.0029	8.893333	1	8
Q. St. 2	0.0009	1.38	0	0
Q. St. 5	0.1428	218.96	10	77
Q. St. 3	0.187	28.67333	52	399
Q. St. 6	0.0637	97.67333	22	169
Q. Ass. I	0.1966	301.4533	0	0
Q. Ass. II	0.0158	24.22667	67	514
Total		1000.5		

Raw Materials Report, Company C, Period 4

	Quantity	Batchsize	Price	Total/Comp.
Comp. AI	75	5	20	7500
Comp. BI	96	10	20	19200
Comp. CI	48	8	17.5	6720
Comp. AII	75	5	17.5	6562.5
Comp. BII	96	10	15	14400
Comp. CII	48	8	15	5760
Total				60142.5

Cash Flow Report, Company C, Period 4

Sales				
	Prod A	92820		
	Prod B	134970		
	Prod C	94050		
				321840
Raw Materials				60142.5
Processing				
	Station 1	5325.44		
	Station 2	4098.56		
	Station 3	3754.24		
	Station 4	5118.08		
	Station 5	5143.04		
	Station 6	5260.16		
	Assembly	5027.52		
				33727.04
Repair				
	Station 1	1586.4		
	Station 2	1454.4		
	Station 3	1257.6		
	Station 4	1651.2		
	Station 5	2383.2		
	Station 6	1346.4		
	Assembly	444		
				10123.2
Setup				
	Station 1	814.4		
	Station 2	752		
	Station 3	624		
	Station 4	1052		
	Station 5	856.8		
	Station 6	899.2		
	Assembly	800		
				5798.4
Inventory				
	WIP		5002.5	
	Finished Goods		3246.5	
				8249
Fixed Costs				85000
Investments				
	Third Line Balancing			5000
	Machine Replacement			20000
OPERATIONAL MARGIN				73799.86

VITA

Niels Ketelhohn was born on August 13, 1968 in Managua, Nicaragua. He is the second child of Margarita Gron and Werner Ketelhohn. He graduated from the University of Costa Rica with a "Licenciatura en Ingeniería Industrial." He completed his Master of Science degree in Industrial and System Engineering in July, 1994, at Virginia Polytechnic Institute and State University.

Mr. Ketelhohn has lived and studied in Nicaragua, Costa Rica, Guatemala, Switzerland and the United States of America. He has worked as a consultant in Costa Rica, Switzerland and Brazil.