PENDEKATAN TERHADAP MASALAH REKABENTUK KEMUDAHAN LANTAI PEMASANGAN MENGGUNAKAN SIMULASI

(AN APPROACH TO ASSEMBLY FACILITIES LAYOUT DESIGN PROBLEMS USING SIMULATION)

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MANUFACTURING WITH MANAGEMENT ENGINEERING

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NOMENCLATURE

O_i Operation i.

r_j Earliest time in O_i which can be assumed as the job arrival time or the job ready time.

C_j Completion time, time when job j is completed

dj Due date, final time to complete job j

C_{max} Makespan is total time needed to complete all jobs

ABSTRAK

Projek ini menumpukan kepada proses merekabentuk kemudahan lantai pemasangan. Selain itu, kesan konfigurasi model yang berbeza dan pengurangan stesen kerja di kemudahan lantai pemasangan dikaji. Untuk merekabentuk lantai pemasangan, bilangan stesen kerja yang minimum digunakan bagi memastikan penggunaan stesen kerja dan pekerja yang optimum. Model kemudahan lantai pemasangan ini dibangunkan dengan menggunakan perisian simulasi WITNESS. Empat model kemudahan lantai pemasangan yang mempunyai konfigurasi yang berbeza dibina. Tujuan simulasi ialah untuk mendapatkan rekabentuk terbaik yang boleh dilaksanakan dalam persekitaran sebenar. Analisis statistik, ANOVA digunakan untuk mengesahkan perbezaan prestasi yang diukur bagi model kemudahan lantai yang berbeza bererti atau tidak bererti. Keputusan ujikaji menunjukkan bahawa konfigurasi kemudahan lantai pemasangan mempengaruhi prestasi kemudahan lantai yang diukur.

ABSTRACT

This project focuses on designing an assembly line. Besides, the effects of different model configuration and number of station reduction on the assembly line are studied. In order to design an assembly line, minimum number of station is use to ensure high station's and worker's utilization. The assembly line model is developing using WITNESS simulation software. Four assembly line models with different configuration are built using WITNESS. The aim of the simulation is to find the best design that will be later implemented in reality. Statistical analysis, ANOVA is used to find any significance or insignificance of performance measures for different layout model. Results from the experiment have revealed that model's configuration influence the line's performance measure.

CHAPTER 1
INTRODUCTION

1.1 Background

In new design approaches of modern assembly systems, the long traditional assembly line is replaced by a modular, semi-autonomous assembly system based on shorter lines (Buckin et.al,1997; Burbidge, 1989). These lines consist of about five to ten workstations, which make the system simpler from all aspects, fewer operations, lower WIP, and non mechanical conveyance.

In modern assembly lines, workers are expected to be more versatile and have better skills than those working in traditional systems. One can even assume that each worker is able to perform any operation in the line. This assumption is admissible in view of the small size of the assembly line due to the relatively small amount of work allocated to it, together with a policy of intensive worker training.

In general, there are many issues that must be resolved to set up and use an assembly line. These issues are; (Sarker and Pan, 1997)

1) Determination of the number of station on line
2) Determination of line cycle time
3) Model sequencing, that is, determining the order of models in which they will flow to maximize utilization of operators in the assembly line
4) Line balance, that is, balancing the work assignments among the operators and minimizing the number of operators required.

This project details the modeling process of an assembly facility layout design problems of make-to-order environment using simulation.

1.2 Problem statement

To design an assembly line of make-to-order environment for this project, personal computer (PC) has been selected as a product to be assembled on the assembly line. 50 000 units of PC need to be assembled in a month due to customer orders. The line is operating for three shifts in five days per week.

In order to reduce operating cost, number of work station is decrease from the theoretical minimum number of station required. Reducing number of station also minimizes number of operator required, because one station is assumed to be operated by one operator.

The best arrangement of station in the assembly line is studied to find out the configuration that can achieve the desired output of 50 000 units within the time allocated despite number of station is reduced from the theoretical number.

1.3 Objectives

The objectives of this project are;

1. To develop an assembly line using WITNESS simulation software
2. To analyze the effect of reducing number of station to the performance measures
3. To analyze the effect of several difference configuration to the performance measures
4. To analyze the best configuration of the assembly layout

CHAPTER 2
LITERATURE REVIEW

2.1 Assembly Layout

2.1.1 Background

An assembly system is defined as a ‘dedicated type manufacturing’ in which workstations are arranged sequentially and work is performed on products as they move from one workstation to the other (Raouf et.al., 1980). The total work content of the assembly process is divided amongst the workstations as evenly as possible, without violating precedence relations in the assembly operations. For synchronous transfer, the workload at each workstation is arranged to fulfill equal intervals of time, which is identical for all workstations. This is called ‘line balancing’ and was addressed for the first time in the mid 1950s (Jackson, 1956).

The research on assembly lines focuses mainly on the determination of the number of stations, line balancing and scheduling, minimization of make span, minimizing the length and so on (Sarker and Shanthikumar,1983). In new design approaches of modern assembly systems, the long traditional assembly line is replaced by a modular, semi-autonomous assembly system based on shorter lines (Bukchin et.al., 1997; Burbidge, 1989).

2.1.2 Assembly line design issues

Various assembly line issues such as economical cycle time, operating shift parameters, parallel line implementation, and parallel workstation requirements, are directly regarded as pre-design requirements. It has been observed that various assembly line research activities appear to have very little inter-communication with each other, and because of this there is a shortage of general knowledge in manufacturing assembly line design (Bhattacharjee and Sahu, 1987). It has even been suggested that the majority of manufacturing companies do not follow optimal design techniques for their production lines (Chase, 1993; Ghosh et. al.,1989).

Below are several assembly line design issues that usually get an attention from researchers.

a) Cycle time

Cycle time is used as a measure for the completion of an expected number of tasks per workstation (Talbot and Patterson, 1984). Controlling the cycle time has some practical implications for managers. As the magnitude of the cycle time increases, the production rate slows because units are completed less frequently.

Task times variation is the main issue in manual assembly lines where the workers' task completion times vary with time to time and from worker to worker (Buzacott and Wild, 2002).

In the absence of a common cycle time, all stations operate at an individual speed, hence work pieces may have to wait before they can enter the next station and/or stations may get idle when they have to wait for the next work piece. These difficulties are partially overcome by buffers between the stations (Buzacott, 1968; Suhail, 1983; Baker et al., 1990; Hillier and So, 1991; Hillier et al., 1993; Malakooti, 1994; Powell, 1996; Dolgui et al., 2002).

b) Duplicating stations

If there are tasks with task times greater than the desired cycle time, due to the indivisibility of tasks, paralleling of stations can resolve this conflict (Buxey, 1974). The simplest form of paralleling is the duplication of stations. Two identical stations that execute the same tasks and are provided with the same equipment are form. Duplicated stations have a local cycle time of twice the regular cycle time and are fed with work pieces and release them alternately. Due to the increased local cycle time, the number of feasible loads is greatly enlarged for parallel stations.

Another approach of duplicating stations is to arrange them side by side in a serial line (Sarker and Shantikumar, 1983). This can be useful due to space limitations or when a less complex transport system is required. In this case, buffers are needed in front of and behind duplicated stations. Inman and Leon (1994) present a stochastic approach to this problem, where random failures, repair times and processing times are varieties. In the stochastic case, duplicated stations often do not start and end their processes at the same time. As long as the first of the stations is busy, the second station cannot be loaded with the next work piece.

c) ***Multiple manning***

Another type of paralleling is to assign more than one operator to a station (multiple manning). Shtub (1984) considers the objective is to minimize the number of operators given, cycle time and number of stations. He describes a heuristic similar to that of Buxey (1974). Chakravarty and Shtub (1986) consider the case of dynamic change in manning due to learning effects. Finally, an effect similar to that of paralleling stations consists of combining stations to larger units (aggregate stations) which are operated by teams of operators. The aggregate stations have a multiple of the original cycle time available and operators may rotate increasing the job satisfaction. Respective problems are considered by Johnson (1991), Bukchin et al. (1997) and Bukchin and Masin (2003).

d) Parallel tasks

Another possibility of reducing the global cycle time below the largest task time is the concept of parallel tasks (Arcus, 1966, Pinto et al., 1975, Inman and Leon, 1994).Respective tasks are assigned to several stations of a serial line which cyclically perform them completely on different work pieces.

Pinto et al. (1975) consider the concept of parallel tasks. Long-lasting tasks are assumed to be decomposable into shorter tasks having the same precedence relations as the original one. Now these parallel tasks are assigned to different stations in order to get a feasible balance for the desired cycle time at all and/or to improve the line efficiency. Because of the indivisibility of tasks, however, the original task can be executed only by one station per cycle. This is dealt with by alternately performing this task in each of the respective stations thereby accepting the local cycle times to vary from cycle to cycle. The objective is to minimize total costs, which consist of facility costs and labor costs defined as in the parallel station case. Facility costs arise though in the parallel task case no additional stations are needed, because a transport system has to be installed, that supports temporary violations of the cycle time. Pinto et al. (1975) give a mathematical model of the problem and solve it by a branch-and-bound procedure. In their algorithm, parallel tasks must not be assigned to more than two stations and the task time is subdivided equally among the two parts of the task. Bard (1989) considers parallel tasks and stations as well as dead time, which is the time that is needed for transporting work pieces from one station to the next; meanwhile no tasks can be executed.

e) Blocking

In such queuing network as the assembly line, blocking may occur due to finite buffer capacities. Blocking depends upon what is happening to previous and subsequent workstations. There are thus significant interactions between the different work stations and they cannot treated as independent (Perros, 1994).

2.2 Simulation

2.2.1 Background

Simulation can been defined as "the process of designing a mathematical or logical model of a real system and then conducting computer-based experiments with the model to describe, explain, and predict the behavior of the real system" (Hoover and Perry, 1989). Manufacturing operations are one of the earliest and most perennially popular simulation applications because the complexity of many manufacturing systems defies improvement by "simply thinking and talking about possible approaches," (Clark, 1996), and because simulation, unlike traditional closed-form analytical techniques, can assess the effects of interactions among system components, complicated by stochastic variations, on overall system performance (Gogg and Mott, 1995, Martinich, 1997).

Reason simulation is used varies. The most reasons include; (Jayamaran and Agarwal, 1996)

1. System throughput determination
2. Bottleneck detection
3. Manpower allocation and optimization
4. Comparing operating philosophies
5. Logistics system design and analysis
6. Analysis of material storage issues
7. Optimizing shift patterns
8. Material handling systems design

On the other hand, success of a simulation study is highly dependant on correct use of a corresponding methodology. For instances, following are some potential reasons for getting unsatisfactory results from a simulation study (Gogg and Mott, 1992);

- Insufficient training of simulation team members
- Simulation objectives are not clearly defined
- Trying to build too much details into a model
- Making conclusions from a single simulation run rather than from multiple runs
- Making conclusion from animation rather than from statistical reports
- Lack of interaction between model builder, management and operational personnel

2.2.2 Advantages and disadvantages of using analytic and/or simulation model

Banks et al., (2001) note the advantages and disadvantages of using analytic and/or simulation models as follows:

• Simulation models are often easier to apply than analytic models.

• Analytic models often require many simplifying assumptions.

• Analytic models provide a limited number of system performance measures.

• Simulation models can be costly to construct and validate.

• An analytic model may serve as a simple, initial model.

• A simulation model can give early insight and estimates of behavior for more complex systems.

2.2.3 Simulation software

Simulation is a widespread tool for the design and analysis of industrial processes with many software packages available to help develop the model and undertake the analysis. However, when modeling an assembly line in which the first operation draws materials from a warehouse with readily available stock, one problem arises in the representation of this first operation in the model when using available software languages such as GPSS, SLAM and SIMAN. This problem is demonstrated by the loss of the desired statistics generated by the software, the inability of the software to complete the execution of the simulation, or an excessive simulation time that is sometimes terminated abruptly, particularly when using educational versions of the software with restricted simulation power (Moussa et. al., 1999).

Bernard et al., (1982) use network modeling and simulation with Q-GERT to demonstrate a complex production system consisting of several assembly lines, each contain several machines via a realistic case example. The statistical results of the simulation of the example system are presented and discussed. In addition, examples of how the simulation model can be used to test changes in machine repair times and breakdown rates have been presented.

WITNESS simulation software package provides an interactive model-building environment which allows a user knowledgeable about the process being analyzed to build and verify a complex model rapidly and conveniently. Further, use of WITNESS permits the modeler to develop a screen animation of the process concurrently with building logical model (Thomson, 1996).

Mehmet Savsar (1991) presents a systematic method and a computer simulation algorithm to solve flexible facility layout problems. Such objectives as the minimization of total material handling costs, maximization of total closeness ratings between departments, minimization of expected future relayout costs, and minimization of expected total material handling costs in possible future relay outs are incorporated into the model.

The alternative and more usual approach in research on the behavior of MTO production systems is simulation. Simulation experiments are used to evaluate the relationships between the workload norms, the arrival rate of jobs, the capacity provided and important performance parameters such as WIP, lead time and capacity. The large literature on priority dispatching rules for individual workstations is based on extensive simulation experiments (Haskose et al., 2004).

2.3 Performance measure

In the design of an assembly system several objectives may be desired; maximum throughput, minimum cycle time, minimum number of stations, minimum idle time, minimum flow time and minimum line length. The trade of between these objectives was examined by Gurnani and Johri (1991), and most objectives have shown poor correlation among themselves. The decision of which objective function is most appropriate depends on the characteristics of the assembly system environment including; technological factors, personnel and organizational factors and market demand (Dar-El, 1991).

CHAPTER 3
METHODOLOGY

3.1 Case study

A new assembly line is design to produce 50 000 units of PC in a month. The assembly line is operating for 3 shifts in 5 days per week. To rapidly complete the design, simulation models were utilized to solve the problem.

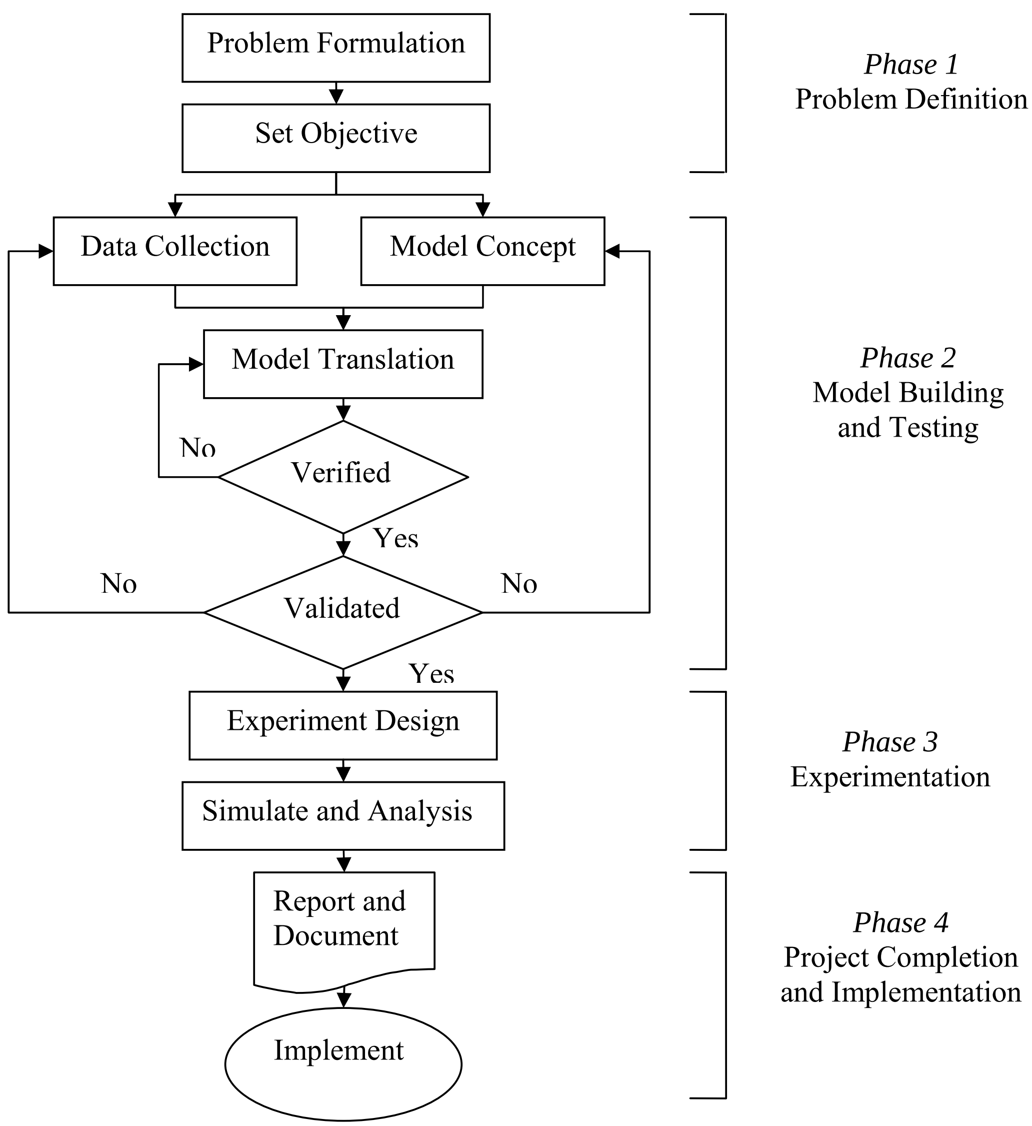

Figure 3.1 Simulation study procedure

3.2 Development of simulation model

Figure 3.1 shows that there are four main phases in a simulation project (Banks et. al., 2001). The details of the phases will be discussed in the following section.

3.2.1 Phase 1: Problem definition

The initial phase in simulation study is to understand the problem and to devise an approach for solving it. The objectives of the project can then be set, establishing the issues to be addressed and a measure of what is sough. The problem and objectives of this project has stated in Chapter 1 (Introduction).

After defining the objective, the data required are identified. These data is either immediately available or need to be collected. Some data cannot be collected and estimates have to be made. Data collection may take some time and therefore it is often performed in parallel with the other modeling activities. In order to build the PC assembly line, the data required are:

a) Types of product to be assembled
b) Bill of Materials (BOM), is a record of all the components of the product and the usage quantities
c) Number of desired output
d) Operator’s working hours

In this project, PC is the product to be assembled in the assembly line. The Bill of Materials (BOM) of PC is shown in Table 3.1. Refer to the case study, the desired output for the line is 50 000 unit PC in a month and the line is operating 3 shifts in 5 days per week.

Part name	No./ unit	Make/buy

Computer case	1	Buy
Power supply	1	Buy
CPU	1	Buy
Hard drive	1	Buy
Floppy drive	1	Buy
IDE cables	3	Buy
CD ROM drive	1	Buy
Heat sink	1	Buy
Fan	1	Buy
Motherboard	1	Buy
RAM	1	Buy
Screws	35	Buy

Table 3.1 PC Bill of Materials (BOM)

3.2.2 Phase 2 : Model Building and Testing

The model is built and then tested to ensure that it is a correct representation of the real model. This phase can be broken down into three steps; structure the model, build the model and validate the model.

Before modeling the line, there are several assumptions that have been made for the assembly line in this project. The assumptions are;

1) No buffer exists between any two adjacent stations
2) Stations in the system are connected by a moving conveyer
3) An idle operator at a station is not used at another station
4) Each station has only one operator
5) There is no more than one work piece at a station at a time
6) Workers perform at a constant rate in either direction of movement
7) The upstream speed of an operator is much more than the downstream speed of the conveyer
8) The standby operator(s) help finish the unfinished work piece off-line for a closed-station system.

STRUCTURE THE MODEL

The structure of the model is designed on paper prior to entering the model into the computer. This step ensures that, before the simulation software is used, the best method of modeling is considered. There are several steps to design the PC assembly line. The steps will be discussed in details in the following section.

Draw a precedence diagram

The operations of assembly process are studied through the exploded drawing, prototype model or real product at the beginning of design process. After analyzing the model, the assembly line details of operation need to be precise to determine the sequence of assembly process. The details of PC assembly process shows in Table 3.2. After determining the sequence of operation, precedence diagram is drawn. Precedence diagram is a diagram that allows one to visualize immediate predecessors better. The work elements are denoted by circles, with the time required to perform the work shown below each circle. Table 3.3 shows the PC precedence table and Figure 3.2 shows the precedence diagram.

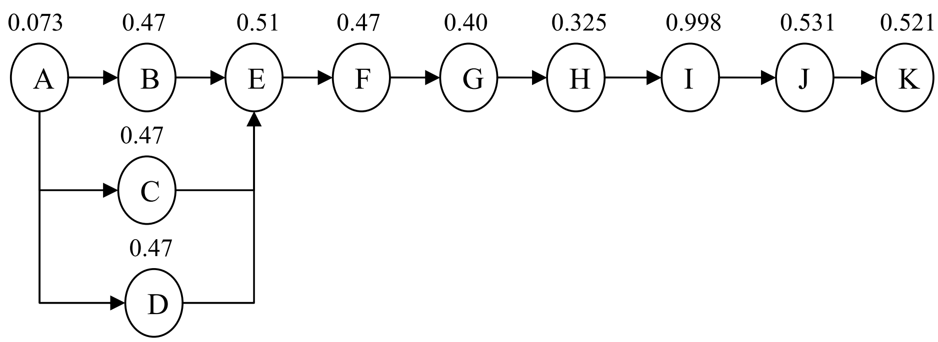

Figure 3.2 PC Precedence relationship diagram

Table 3.3 PC Precedence table

Task	Time(min)	Description	Predecessors
A	0.073	Take up casing	None
B	0.470	Assemble hard disk	A
C	0.470	Assemble floppy drive	A
D	0.470	Assemble CD Rom	A
E	0.510	Assemble power supply	B,C,D
F	0.472	Assemble motherboard	E
G	0.400	Insert connector	F
H	0.325	Assemble outer plane	G
I	0.998	Inspection	H
J	0.531	Packing	I
K	0.521	Labeling	J

Table 3.2 Details of PC assembly process and time standard

No.	Details of working process	Time (mins)
	Assemble hard disk	
1	Taking up casing from buffer	0.058
2	Place it on workbench	0.015
3	Taking up hard disk from buffer	0.032
4	Assemble the parts	0.083
5	Tighten the screw (R side)	0.097
6	Take up and release the air screw driver	0.035
7	Turn the casing	0.025
8	Tighten the screw (L side)	0.097
9	Take up and release the air screw driver	0.035
10	Take up IDE cable	0.020
11	Attach IDE connector to hard disk	0.050
	Total	**0.547**

	Assemble floppy drive	
1	Taking up floppy drive from buffer	0.032
2	Assemble the parts	0.083
3	Tighten the screw (R side)	0.097
4	Take up and release the air screw driver	0.035
5	Turn the casing	0.025
6	Tighten the screw (L side)	0.097
7	Take up and release the air screw driver	0.035
8	Take up IDE cable	0.020
9	Attach IDE connector to floppy drive	0.050
	Total	**0.470**
	Assemble CD Rom	
1	Taking up CD Rom from buffer	0.032
2	Assemble the parts	0.083
3	Tighten the screw (R side)	0.097
4	Take up and release the air screw driver	0.035
5	Turn the casing	0.025
6	Tighten the screw (L side)	0.097
7	Take up and release the air screw driver	0.035
8	Take up IDE cable	0.020
9	Attach IDE connector to CD Rom	0.050
	Total	**0.470**

	Assemble power supply	
1	Turn back the casing	0.050
2	Taking up power supply from buffer	0.042
3	Assemble the power supply	0.083
4	Tighten the screw (4 screws)	0.193
5	Take up and release the air screw driver	0.140
	Total	**0.510**
	Assemble motherboard to casing	
1	Turn the casing	0.050
2	Taking up motherboard from buffer	0.040
3	Set motherboard onto casing	0.083
4	Tighten the screw (3 screws)	0.192
5	Take up and release the air screw driver	0.105
	Total	**0.472**
	Insert connector into plug	
1	Turn the casing	0.050
2	Take up the connector (5 connectors)	0.100
3	Insert the connector into plug	0.250
	Total	**0.400**
	Assemble outer plane to casing	
1	Turn the casing	0.050
2	Taking up outer plane from buffer	0.058
3	Assemble outer plane to casing (R side)	0.083
4	Turn the casing	0.050
5	Assemble outer plane to casing (L side)	0.083
	Total	**0.325**
	Inspection	
1	Check power selector is set correctly	0.050
2	Attach connector to the backplane for mouse, keyboard, monitor and power	0.058
3	Power it up	0.500
4	Press Delete key to enter BIOS setup	0.010
5	Review BIOS settings	0.083
6	Shut down	0.250
7	Take out mouse, keyboard, monitor and power connector	0.047
	Total	**0.998**

	Packing	
1	Change the position of cab assy	0.050
2	Take up the packing add	0.078
3	Separate the packing add	0.028
4	Fix packing add to set	0.073
5	Change the position of cab assy	0.050
6	Take up the packing add	0.033
7	Fix packing add to set	0.073
8	Change the position of cab assy	0.050
9	Take up the set and insert into box	0.029
10	Close the top flap of packing case	0.067
	Total	**0.531**
	Labeling	
1	Sticking top flap with Dunlop tape	0.163
2	Take up the pasteboard	0.022
3	Pell off serial no. label	0.047
4	Place the pasteboard	0.013
5	Sticking and press serial no label	0.097
6	Take up the pasteboard	0.022
7	Pell off bar code label	0.047
8	Place the pasteboard	0.013
9	Sticking and press bar code label	0.097
	Total	**0.521**
	Total time to assemble each PC	**5.244**

Determine number of station

The time standard for assembly process is essential to calculate cycle time and number of workstation needed. Time standard is the time required to produce a product at a workstation with the following three conditions (1) a qualified, well-trained operator; (2) working at a normal pace; and (3) doing a specific task. There are five techniques of time standard development:

a) Predetermined time standard systems
b) Stopwatch time study
c) Work sampling

d) Standard data

e) Expert opinion standard and historical data

In this project, standard data technique is used because it is more accurate, fastest and consistent than any other technique of time study. Table 3.2 shows standard time for PC assembling process.

Then cycle time and theoretical minimum number (TM) of workstations are calculated. Cycle time is the maximum time allowed for work on a unit at each station. Theoretical minimum number of station is a benchmark for the smallest number of stations possible, where the total time required assembling each unit is divided by cycle time. After that, tasks are assigning to the station based on cycle time.

- Cycle time, $c = \frac{1}{r}$ (1)

where

c = cycle time in minutes per unit

r = desired output rate in units per minutes

- Theoretical minimum, $TM = \frac{\Sigma t}{c}$ (2)

where

Σt = total time required to assemble each unit (the sum of all work-element standard times)

c = cycle time in minutes per unit

Calculation:

- The demands are 50,000 units PC per month.
- It takes 5.244 minutes to assemble, inspect and packing each PC (Refer Table 3.2).
- There are 425 minutes per shift available after deduct breaks time for operator.

- There are 1275 minutes a day for three shift time and 25 500 minutes a month to produce 50 000 unit PC.
- Cycle time = time/ desired output

  = 25 500 / 50 000

  = 0.51 minutes
- Theoretical minimum (TM) = Time standard / cycle time

  = 5.244 / 0.51

  = 10.28 stations ≈ 11 stations

Assign task to workstation

Minimum number of stations in the PC assembly line is eleven. Task is assign, one at a time, to the first workstation until the sum of the task times is equal to the cycle time (0.516 minutes), or no other tasks are feasible because of time or sequence restrictions. The process is repeat for station 2, station 3 and so on, until all tasks is assigned.

The cycle time for inspection station is the longest and exceed the line cycle time as shows in table 3.4. In order to achieve better balance in the assembly line, parallel station is used to reduce the operation times of the inspection station.

Table 3.4 Station cycle time

Station	**Cycle time (min)**	**Description**
1	0.547	Assemble hard disk
2	0.470	Assemble floppy drive
3	0.470	Assemble CD Rom
4	0.510	Assemble power supply
5	0.472	Assemble motherboard
6	0.400	Insert connector
7	0.325	Assemble outer plane
8,9	0.998	Inspection
10	0.531	Packing
11	0.521	Labeling

BUILD THE MODEL

Then the model is built with the simulation software. This process consists of three distinct activities. The first activity is to entering the model into the computer which is called coding activity. The second activity namely documenting is to explain the model structure using the software facilities and the last one is verifying, which is to ensure that the code is correct.

The PC assembly line model is built using WITNESS simulation software as shown in Figure 3.3. Cycle time value at Table 3.4 is put in the details dialog for the station in the software. NEGEXP distribution is used for part inter arrival time to buffer.

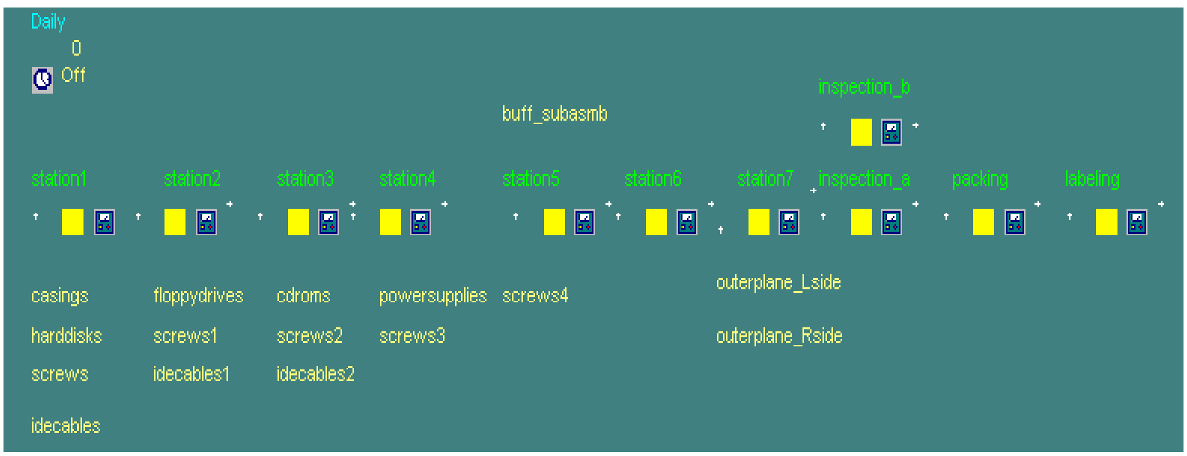

Figure 3.3 PC assembly line layout

VALIDATE THE MODEL

Validation is a step to ensure that the model is accurate and the results are realistic before experiment can begin.

3.2.3 Phase 3: Experimentation

In the experimental phase, proposed methods for achieving the projects objectives are tested. The results of the simulation experiments are analyzed to check what they have been achieved and whether the objectives of the project have been met.

In order to obtain reasonable result, models must be warmed up and run for a suitable time. As an alternative to a warm up period, starting conditions is used in this experiment. The model starts from empty with no parts, work in progress or resources available.

To obtain accurate performance of the system being modeled, a number of replications are performed. Replication is a single run of a simulation model. Further replication can be made by changing the pseudo- random number streams and running the model again. The pseudo-random number streams are changed by altering the streams referenced in the code. According to the *Rule of Thumb*, at least three to five replications should be performed.

3.2.4 Phase 4: Project Completion and Implementation

From this analysis, conclusions are drawn and recommendations are made. Lastly, the results of the experiment are documented and the recommendations are implemented.

3.3 Analysis of variance (ANOVA)

Data of make span and lateness of the simulation experiment results are collected and analyzed by one-way analysis of variance (ANOVA) under 95 % and 99 % confident level. Analysis of variance is conducted at the end of simulation experiment to test the hypothesis whether to accept or reject.

3.3.1 Null Hypothesis (H_0)

The null hypothesis is a hypothesis of no differences. It is a statistical hypothesis usually formulated for the express purpose of being rejected. If H_0 is rejected, we may accept the alternate hypothesis (H_1).

Suppose, this project is to investigate the effect of layout configuration on make span and lateness. On the basis of some theory, make span and lateness are predict to be differ due to the different layout configuration. This prediction would be the research hypothesis (H_1) and confirmation of H_1 will lend support to the theory. The null hypothesis (H_0) would be, the make span and lateness of the different configuration of layout are equal.

After formulating the null hypothesis, a statistical test is applied. If the test yields a value whose associated probability of occurrence under H_0 is equal to or less than α (level of significance set in advance of the collection of data), H_0 is reject in favor of H_1. On the other hand if the test yields a value, whose associated probability of occurrence under H_0 is greater than α, null hypothesis is accept. Result from the statistical test shows that H_1 is accepted in this project.

3.3.2 Level of significance

Level of significance is our own decision making procedure. In advance of the data collection, for the requirement of objectivity, probability of rejecting the null hypothesis is specify, which is called the significance level of the test and is indicated by α. Conventionally, $\alpha = 0.05$ and 0.01 have been chosen as the levels of significance.

3.3.3 Procedure of one way analysis of variance (ANOVA)

Step 1: Record the data in columns:

For example;

Table 3.5 General layout for a single factor experiment with repeated measures

Replicate	Model 1	Model 2	Model 3
1	X_{11}	X_{12}	X_{13}
2	X_{21}	X_{22}	X_{23}
3	X_{31}	X_{32}	X_{33}

Step 2: For each column, enter Σx, n, $\bar{x}$, Σx^2, $\frac{(\Sigma x)^2}{n}$ and Σd^2

Step 3: For each column divide Σd^2 by n-1 to obtain the variance, σ^2. Divide the highest value of σ^2 by the lowest value of σ^2 to obtain a variance ratio (F). Then look up a table of F_{max} for the number of treatments in our table of data and the degrees of freedom (number of replicates per treatment -1). If our variance ratio does not exceed the F_{max} value then we are safe to proceed. If not, the data might need to be transformed.

Step 4: Sum all the values of Σx^2 and call the sum ***A.***

Step 5: Sum all the values for $\frac{(\Sigma x)^2}{n}$ and call the sum ***B***.

Step 6: Sum all the values for Σx to obtain the ***grand total***.

Step 7: Square the grand total and divide it by total number of observations; call this ***D***.

Step 8: Calculate the ***Total sum of squares*** (S of S) = A - D

Step 9: Calculate the ***Between-treatments sum of squares*** = B - D

Step 10: Calculate the ***Residual sum of squares*** = A - B

Step 11: Construct a table as follows, where *** represents items to be inserted, and where *u* = number of treatments and *v* = number of replicates.

Source of variance	**Sum of squares (S of S)**	**Degrees of freedom (df)**	**Mean square = S of S / df**
Between treatments	***	u - 1	***
Residual	***	u(v-1)	***
Total	***	(uv)-1	

[The total df is always one fewer than the total number of data entries]