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Line Balancing and Performance Improvements: A Case Study of a Television Assembly Plant

Susila Munisamy[1] and **Kok Soak Chen**

Department of Applied Statistics, Faculty of Economics and Administration, University of Malaya, 50603 Kuala Lumpur, Malaysia.
[1]susila@um.edu.my (corresponding author)

ABSTRACT Ever-increasing customer demand and its diversification necessitates organizations to respond by continuously increasing their production throughput and making changes in their production mix. An important strategy to increase productivity is to improve the efficiency of the production or assembly lines, so that production throughput can be increased close to the production capacity of the system. Line balancing can improve the efficiency of an assembly line. This paper focuses on the assembly line of a local television assembly plant. The objective of this study is to improve the efficiency of the television assembly line by assigning tasks to workstations to balance work across stations such as to minimise the number of works stations along the television assembly line, given the production rate or cycle time. We use a modified incremental utilisation heuristic to redesign the local television assembly plant and show that significant improvements in resource utilisation and reduction in operational costs can be achieved.

ABSTRAK Permintaan pelanggan yang kian meningkat disertai pempelbagaiannya menuntut organisasi supaya terus meningkatkan daya pemprosesan pengeluaran di samping membuat perubahan pada campuran pengeluaran mereka. Satu strategi penting untuk meningkatkan produktiviti adalah dengan menambahbaikan kecekapan rangkaian pengeluaran atau pemasangan, supaya daya pemprosesan pengeluaran dapat ditingkatkan sejajar dengan keupayaan sistem pengeluaran. Pengimbangan rangkaian boleh menambahbaik kecekapan rangkaian pemasangan. Kertas ini memberi fokus kepada rangkaian pemasangan di sebuah loji pemasangan televisyen tempatan. Objektif kajian ini ialah untuk menambahbaik kecekapan rangkaian pemasangan televisyen dengan pengagihan tugas yang seimbang di antara stesyen kerja-stesyen kerja supaya meminimumkan bilangan stesyen kerja di sepanjang rangkaian pemasangan, dengan diberi kadar pengeluaran atau masa kitaran. Kami menggunakan heuristik penggunaan tokokan yang telah diubahsuai untuk merekabentuk semula loji pemasangan televisyen tempatan tersebut dan menunjukkan penambahbaikan yang ketara pada penggunaan sumber dan pengurangan kos operasi boleh dicapai.

(production, assembly line, line balancing, television, mixed models)

INTRODUCTION

Ever-increasing customer demand and diversification of product demand necessitates organizations to respond by continuously increasing their production throughput and making changes in their production mix. An important strategy to increase productivity is to improve the efficiency of the production or assembly lines, so that production throughput can be increased close to the production capacity of the system. In an assembly line, a product visits a series of workstations in a given sequence in which one or more assembly operation or task is carried out. In order for the assembly line to operate efficiently, the length of time a product spends at each of the workstation should be as equal as possible. Otherwise, large imbalances in workload would occur and the assembly line will experience bottlenecks — workstations with less work are forced to wait on preceding station which has more work assigned. This will result in decreased overall productivity as workers experience idle time, and excessive costs as workers get paid for unnecessary idling. Hence it is important to equally divide work to be done among workstations so that the time spend at each station is relatively balanced. This is known as line balancing. Line balancing is very important for industry as it provides increased production speed, considerable planning and helps organizations to solve their economic problems (Render and Heizer [1], Ma [2]).

This paper focuses on the assembly line of a local television assembly plant. The plants' single assembly line consists of a series of workstations which handle many separate and distinct assembly tasks to be performed on the television. The assembly tasks are done by hand using very simple tools such as screwdrivers, pliers and trolleys. The single assembly line assembles seven models of televisions while observing the precedence ordering of the tasks. The televisions are assembled at a specific production rate in order to satisfy customer demand. The demand for the television models has steadily and considerably increased over the years. Demand increased 73% in 2003 and 55% in 2004 compared to the previous year.

Currently, the plants' production specification is based on experience, in which assembly tasks are assigned to workstations according to the rule of thumb. In order to conform to the increasing customer demand and diversification of product demand, it is necessary for efficient planning and organization of the television assembly line that leads to maximum productivity. In particular, it is important to design an assembly line that operates efficiently to improve resource utilisation and to reduce operational costs. The objective of this study is to assign tasks to workstations to balance work across stations such as to minimise the number of works stations along the television assembly line, given the production rate or cycle time. When the number of workstation is minimised, the idle or slack time will be minimised resulting in improved manpower utilisation.

The usual approaches in assigning and balancing work between stations have relied upon the assumption that the task times are less than the cycle time of the product. However, in our case study this assumption is not satisfied and, hence, we use Gaither's [3] *incremental utilisation heuristics* approach that relaxes this assumption. This approach can be used to solve assembly line balancing problems with one or more task time greater than the cycle time. However, this approach is only applicable to the single model assembly line balancing problems. We use a modified version of Gaither's approach to address the mixed or multi model assembly line balancing problem in this study and redesign the local television assembly plant. Significant improvements in resource utilisation and reduction in operational costs are shown to be achieved.

The layout of this paper is as follows. The next section reviews the literature relating to assembly line balancing problems. Then in the section that follows, we present the formulation of the *modified incremental utilisation heuristic* for solving mixed or multi model assembly line balancing problems with deterministic task times. Next, the television assembly line process is described and the application of the approach to the local television assembly plant is performed in the section that follows. In the final section of the paper, we conclude the paper and offers some recommendations.

LITERATURE REVIEW

The assembly line balancing problem was formulated by Bryton in 1954 (see [4]) and first published in a mathematical form in 1955 by Salveson (see [5]). Since then, it has received considerable attention in the literature. Researchers have focused on two types of assembly line balancing problems. A type 1 problem is to minimise the total cycle time, given the number of workstations. A type 2 problem is to minimise the number of workstations, given the maximum allowable cycle time (that meets the specified production requirements). However, there are variants of these simple forms. A variety of solution techniques have been proposed to solve assembly line balancing problems, including mathematical programming models, heuristic procedures and simulation. However, computational complexity grows with the number of tasks and variety of models produced, so that heuristic techniques has been most popular for addressing large scale, read-world assembly line balancing problems (Ghosh and Gagnon [6]; Silverman [7]).

Traditionally, production has been organized in assembly lines for mass production, where a single product is manufactured in large quantities for long periods. Most of the research performed on the balancing problem dealt with the single product assembly, generally known as the simple assembly line balancing (SALB) problem (see for example Salveson [5]; Bowman [8]; Hu [9]; Thangavellu and Shetty [10]; Patterson and Albracht [11]; and Johnson [12, 13]). Comprehensive surveys by Baybars [14] and Ghosh and Gagnon [6] details the methods for solving the SALB problem and their underlying assumptions.

The diversification of product demand, increasing global competition, rapid changes in technology have made product life cycles shorter and a higher variety of product models to be produced in smaller quantities. To handle the increasing product variety, the mixed model assembly line balancing approach was used. Kilbridge and Wester [15] were among the first researchers to mention the mixed model version of the balancing problem in which two or more similar models are produced in batches or simultaneously. Since then, a number of studies have been published dealing with issues related to the mixed model balancing problem (see Thomopoulos [16, 17]; Macaskill [18]; Dar-El and Cother [19]; Berger *et al.*, [20]). The balancing procedure is similar to the SALB solution procedure, but it assumes a stable and defined model-mix for which the combined workload is balanced for the duration of the entire shift, and not on the basis of cycle time (Dar-El and Nadivi [21]; Macaskill [18]; Thomopoulos [16]). In the mixed model line balancing, a model sequencing decision has also to be made in addition to the task allocation problem (Dar-El and Cother [19], Dar-El and Nadivi [21] and Dar-El and Cucuy [22]).

The analysis of the literature reveals that the majority of the approaches in solving the line balancing problem make the standard assumption that the task time is less than the cycle time of the product and task times are deterministic. Gaither [3] proposed the *incremental utilisation heuristic* solution technique for solving single model assembly line balancing problems in which one or more of the task time is larger than the cycle time. Gaither's procedure was modified by McMullen and Frazier [23] to solve the mixed model line balancing problems where task times are stochastic. We adapt McMullen and Frazier [23] approach to transform a mixed model problem into a single model problem and then modify Gaither's procedure to introduce a deterministic solution technique to solve mixed model line balancing problems.

THE MODIFIED INCREMENTAL UTILISATION HEURISTIC FOR MIXED/MULTI MODEL BALANCING WITH DETERMINISTIC TASK TIMES

In this section we introduce the notation as well as our precise assumptions, and present the *modified incremental utilisation heuristic* solution procedure to solve the mixed or multi model assembly line balancing problem with deterministic task times. The proposed algorithm aims to minimise the number of stations for a given cycle time that meets the required production rate. The workstations' task times may in some cases exceed the given cycle time. Gaithers' incremental utilisation heuristic for single model assembly line simply adds task to a work centre in order of task precedence one at a time until utilisation is 100 percent or is observed to fall. Then this procedure is repeated at the next work centre for the remaining tasks until all the tasks have been assigned to work centres. The proposed balancing algorithm is similar to Gaither's solution algorithm but considers mixed models for which the combined workload is balanced across the work centres. Both Gaither's and the modified balancing algorithm permits paralleling of workstations where multiple workers perform an identical set of tasks within work centres. At the end of the balancing procedure a performance measure i.e. the utilisation of the overall line is derived.

In balancing a mixed model line, it would seem to be possible to consider each television model independently, and consequently to balance the work among workers for each separate model. This procedure reduces the larger problem of balancing a mixed model line to a number of smaller single product balancing problems. Unfortunately, this approach leads to serious difficulties. For each of the television model, the worker may be assigned to different workstations with different tasks. Since, a worker is trained to perform a task which requires some skills, it is desirable, if not imperative, to assign tasks of a specified class to one worker or at most to a small group of workers. An approach solving the balancing problem of a mixed model assembly line is by transforming the mixed model problem into a single model problem. The methods for this transformation can be classified into two different approaches. The first approach combines the precedence diagrams of the different models into a single, so-called combined precedence diagram (shift basis) (see Dar-El and Nadivi [21]; Macaskill [18]; Thomopoulos [16]). The second method uses adjusted task processing times (cycle time basis) (see Arcus [24]; Johnson [13]; McMullen and Frazier [23]). In this study, the latter will be used for the balancing procedure because all the television models produced by the television plant have the same precedence diagram, i.e. a single precedence diagram. However, the task time varies between models. The adjusted task processing times that is used to transform the mixed model line balancing problem into a single model line balancing problem determines *composite task processing times* for tasks that are required by more than one model (Arcus [24], Johnson [13]; McMullen and Frazier [23]). The balancing procedure is applied using the composite task processing times to determine the assignment of the tasks to work centres.

The notation used to define parameters and variables in the problem is given as follows.

D = total annual output or total demand for n models
C = cycle time (time/unit)
P_s = annual operation time
d_i = output for model i $(i = 1,\ldots,n)$
w_i = weight of model i
t_{ij} = observed task time of task j $(j = 1,\ldots,h)$ for model i
t_j = composite task time for task j
WS_T = theoretical minimum number of workstations required
$IWSk$ = actual number of workstations
U_k = workstation utilisation for workstation k $(k = 1,\ldots,m)$
U_s = utilisation of the overall line
WS_a = the actual number of workstations

Before the procedure is introduced, the following assumptions are made regarding the assembly line balancing problem addressed here:

1. A task cannot be assigned to a work centre until all of its immediate predecessors have been assigned to a work centre.
2. Task time is known and depends on the television model type.
3. The assembly system is designed for multiple television models.
4. Precedence diagrams of all television model types are same.
5. The number of parallel workstations is unrestricted.
6. The first station is never starved and the last station is never full.
7. Changeover times between models are negligible.
8. All workers on the assembly line possess the same level of skill.
9. Any needed equipment is readily available.
10. The line production policy is 'make-to-order'.

The *modified incremental utilisation heuristic* is described in the following paragraphs.

Step 1: Attain the process and technological data i.e. the task times and precedence diagram for each model $(i = 1,..,n)$.

Step 2: Attain output data i.e. the volume and rate of production of each model.

Step 3: Produce a table of composite task times using equations 1, 2 and 3 below:

$$D = \sum_{i=1}^{n} d_i \qquad (1)$$

$$w_i = \frac{d_i}{D} \qquad (2)$$

$$t_j = \sum_{i=1}^{n} w_i (t_{ij}) \qquad (3)$$

Step 4: Calculate the cycle time and the theoretical minimum number of stations required using equations 4 and 5 below:

$$C = \frac{Ps}{D} \qquad (4)$$

$$WS_T = \frac{1}{C}\sum_{j=1}^{h} t_j \qquad (5)$$

Step 5: Construct a *precedence diagram* for the composite product, showing which task depend on others.

Step 6: Construct a *Computation Table* to assign tasks to work centres (see Appendix 1). This table lists down all tasks that are ready for assignment into work centres. When opening a new work centre, the accumulated time of work centre, T_q, and its' utilisation, U_k, is initialised to zero.

Step 7: Calculate work centre statistics using the following equations:

$$T_q = T_q + t_j \quad (6)$$

$$WS_k = \frac{T_q}{C} \quad (7)$$

$$IWS_k = \begin{cases} integer\,(WS_k) + 1, & \text{if } WS_k \text{ is non-integer,} \quad (8) \\ WS_k, & \text{if } WS_k \text{ is integer.} \quad (9) \end{cases}$$

$$U_k = \frac{WS_k}{IWS_k} \quad (10)$$

Step 8: Assign task to work centres. This is done by strictly following the sequence of tasks. From the *Computation Table*, a task will be added to the current work centre until the utilisation of the work centre is 100% or until the utilisation of the work centre is observed to fall, and then a new work centre is started.

Step 9: If all tasks have been assigned, proceed to step 10, otherwise return to step 6 and update the *Computation Table.*

Step 10: Calculate statistics on the performance of the line balance using equations 11 and 12:

$$WS_a = \sum_{k=1}^{m} IWS_k \quad (11)$$

$$U_s = \frac{WS_T}{WS_a} \,. \quad (12)$$

THE TELEVISION ASSEMBLY PROCESS

The television assembly plant has only one assembly line that is used to produce seven different television models. The structure of the production system is a pipeline in which components are moved by a one-way transportation system-conveyor. In the existing assembly line, there are 38 workstations within 23 work centres. The 38 workstations consists of 29 workers and 9 powers supply points. The workstations are totally ordered, so that components can only move from work centre 1 to work centre 23. There is no variation in work content between the different models at each work centre though there may be variation in terms of time taken to complete a particular task. Only simple tooling is used for assembling the seven different types of model and the tools are adapted to all types of model. Hence, the change over time between models is zero. The current production flow and layout of the television plant is shown in Figure 1.

An assembly flow chart for the television manufacturing system in the study is presented in Figure 2. Basically, there are three assembly processes consisting of preparation, assembly and finishing. The preparation process consists of two phases. In the first phase, the Cathode Ray Tube (CRT) supporter is installed to the front casing. Then the front casing and the back covers are loaded onto manual trolleys to be transported to the start of the line. Similarly the Cathode Ray Tube (CRT), and manuals and useful materials are loaded onto forklifts and brought to the start of the assembly line. In the second phase, the front casing and back cover is transferred to the workstations along the assembly line and the Cathode Ray Tube (CRT) is loaded onto the conveyor. The assembly process include Printed Circuit Board (PCB) circuit assembly, Cathode Ray Tube (CRT) wiring assembly, locking assembly, Printed Circuit Board (PCB) circuit connection assembly, pre-aging, Radio Frequency (RF) alignment, Phase Alternation by Line (PAL) pattern alignment, National Television Systems Committee (NTSC) pattern alignment, aging, White Balance (WBP) adjustment, the first stage of Production Quality Checking (PQC1), back cover assembly, the second stage of Production Quality Checking (PQC2), the third stage of Production Quality Checking (PQC3), High Voltage (HV) inspection, front casing cleaning and inspection, back cover cleaning and inspection, logo assembly and performance inspection, and packing and serial number sticking. The finishing process includes outgoing Quality Control (QC) inspection, loading to outgoing store, and delivering to warehouse.

Only the preparation and assembly processes only will be analysed and the finishing process is excluded from the study. In the television plant, the arrival sequence of television models to the line is determined by customer order. As such, our approach focuses on the balancing procedure, and not on sequencing.

APPLICATION AND RESULTS

The modified incremental utilisation heuristics presented in the third section was used to balance the television assembly line. The algorithm was implemented using Excel.

Table 1 presents the 23 assembly tasks and its' identification, the existing number of workstations and the composite task times for the each of the task in the television assembly process. The composite task time was calculated with equations (1), (2) and (3). The composite task time is the weighted task time depending on demand for each television and ranges between 10 to 300 seconds. The total composite work content to produce one unit of television is 1262 seconds or 21 minutes.

The demand/output data and the results for the target cycle time and theoretical minimum number of workstation using equations (4) and (5) are presented in Table 2.

The target cycle time is 66.57 seconds. If any workstation spends more than 66.57 seconds on a television unit, the workstation will have a bottleneck, and the target output per day cannot be reached. To solve the bottleneck, we allow paralleling of workstations. The least number of workstations that can provide the required production rate is 19, where each workstation is fully occupied all the time.

There are seven models of television produced in the television plant, but they share the same precedence diagram, since the processes in manufacturing all models of the television are exactly the same. The complete precedence diagram with task identifications and composite task times is shown in Figure 3.

Appendix 1 presents the detailed computations using equations (6), (7), (8) (9) and (10). The results from the computation table are summarized in Table 3.

Table 3 shows that the achieved assembly line has 21 works stations within 10 work centres. Only 15 workers and 6 power supply points are needed.

The performance results from the current assembly line and the achieved assembly line are summarized in Table 4. After applying the modified incremental utilisation heuristics, the performance of the assembly line improves tremendously where the overall system utilisation increases to 90.48% from 50% (using equations 11 and 12). The improvement in the value of the overall system utilisation increases by 40.48%. The number of workstation decreases from 38 to 21 and the number of workers is reduced from 29 to 15, a reduction of almost half the workers, while the number of power supply point is also reduced from the existing 9 to 6.

CONCLUSIONS AND RECOMMENDATIONS

The demand for electronic products is rapidly increasing in the global market. Due to the nature of mass production systems in electronic assembly plants, it is necessary to solve multi-model line balancing problems in order to minimise number of workstations, given a specified cycle time in order to improve efficiency. In this study, the modified incremental utilisation heuristic approach is developed and applied to improve the assembly line efficiency in a television assembly plant. This heuristic approach is appropriate in a situation where the longest task time exceeds the specified cycle time. This study helps the television plant manager to solve the balancing problem in the television assembly line and improve the performance of the line in terms of resource utilisation. The benefits of this study can also be applied to other production assembly lines.

We also suggest that the television plant in this study redesigns its layout to further improve its productivity. Redesigning a new layout is mainly concerned with the physical location, which is re-deciding how and where to relocate all the facilities, machines, equipments and workers in the operation so that the target output can be achieved. The current production plant layout of television plant is shown in Figure 1. There are 38 workstations within 23 work centres. We can observe wall partitions and 2 sets of conveyor belts which obstruct flow as well as reduce production space. The recommended layout for television assembly plant is shown in Figure 4. The structure of the recommended production system is also a pipeline. There are 21 workstations within 10 work centres in the new assembly line. Wall partitions are dismantled and the separated conveyors are joined together to convenience the direction of flow and reduce transfer time. This also helps to enhance supervision. The workstations are totally ordered, so that the component moves from work centre 1 to 10. The raw materials (i.e. CRT, PCB frame, PCB, front casing, back cover, useful materials and carton box) are located near to the workstations and shorten the travel distance. These changes help reduce overall operation time.

In general, assembly plants are labor-intensive. Research into cost-oriented assembly line balancing is needed to minimise the production cost. The wage rate of each worker depends on the difficulty of the tasks assigned to a workstation. The more difficult tasks receive a higher wage rate. The worker has to be paid for the whole cycle time irrespective of the task duration and idle time. Hence, it is important to balance the line with the objective of minimising production costs.

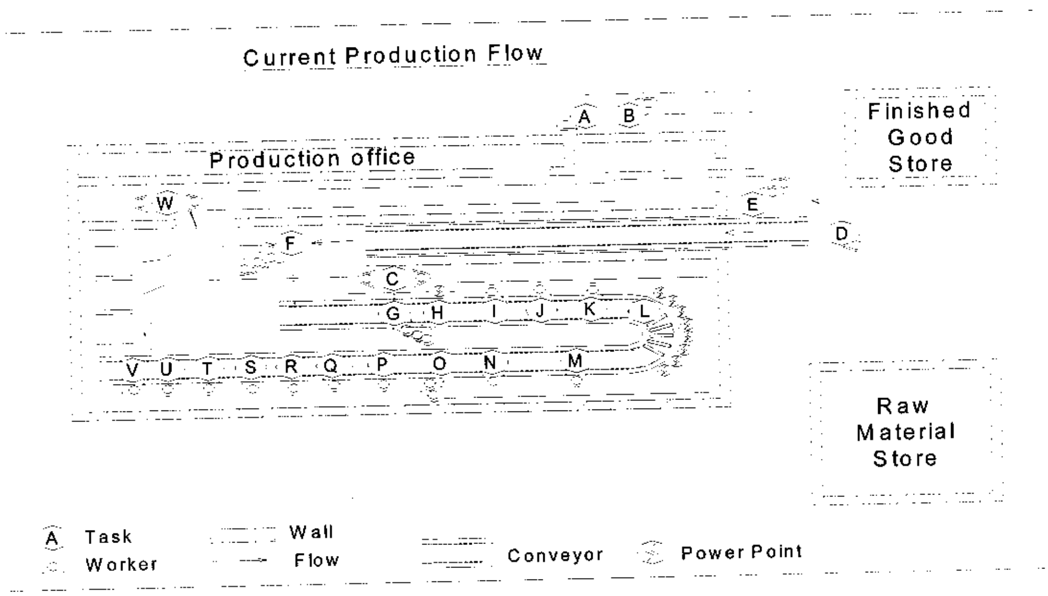

Figure 1. The current production flow and layout of the television plant

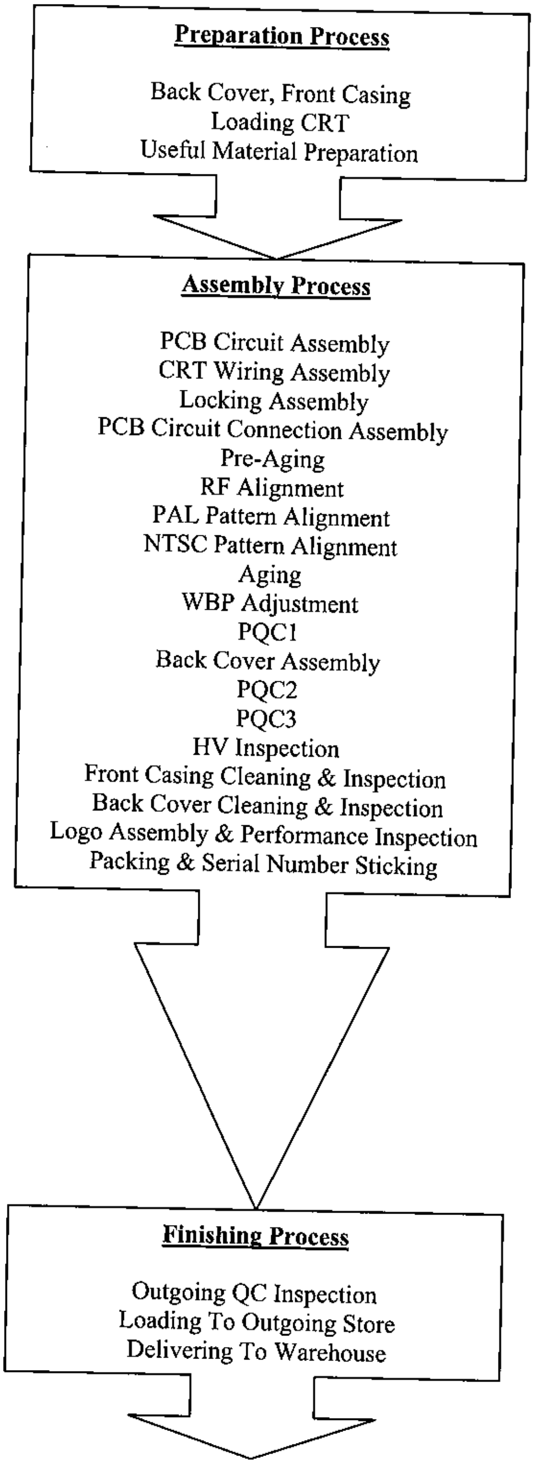

Figure 2. Flow Chart for Television Manufacturing System

Table 1. The Operations Information and Composite Task Time for each Task

TASK	IDENTIFICATION OF THE TASK	NO. OF WORK STATIONS	COMPOSITE TIME (SEC)
BACK COVER PREPARATION	A	1	36.95
FRONT CASING PREPARATION	B	1	36.95
PCB CIRCUIT MODIFICATION & SCREW	C	2	60.00
CRT LOADING	D	1	65.86
CRT WIRING ASSEMBLE	E	2	90.00
CRT LOCKING WITH FRONT COVER ASSEMBLY	F	3	71.72
PCB CIRCUIT CONNECTION ASSEMBLE	G	3	65.00
PRE-AGING	H	1*	60.00
CHANNEL RF TEST / RECEIVE / ALIGNMENT	I	1	60.00
PAL PATTERN ALIGNMENT	J	1	23.91
NTSC PATTERN ALIGNMENT	K	1	30.00
AGING	L	8*	300.00
WBP ADJUSTMENT	M	1	50.00
PQC1	N	1	40.00
BACK COVER ASSEMBLE	O	2	80.00
PQC2	P	1	30.00
PQC3	Q	1	30.00
PCB Vs VOLTAGE INSPECTION	R	1	10.00
CASING CLEANING & INSPECTION	S	1	10.00
COVER CLEANING & INSPECTION	T	1	10.00
USEFUL MATERIAL PREPARATION	U	1	20.00
LOGO & PERFORMANCE INSPECTION	V	1	15.00
PACKING	W	2	66.64
TOTAL:		**38**	**1262.03**

* power supply points

Table 2. The Results for Cycle Time and Theoretical Minimum Number of Workstations

Annual Working Days (Including Over Time)	299 days
Average Daily Operation Hours (Including Over Time)	9.5 hours
Annual Operation Hours (Including Over Time)	2840.5 hours
Total Annual Output for All Television Models	153600 units
Target Cycle Time	66.57 seconds
Theoretical Minimum Number of Workstations	19 workstations

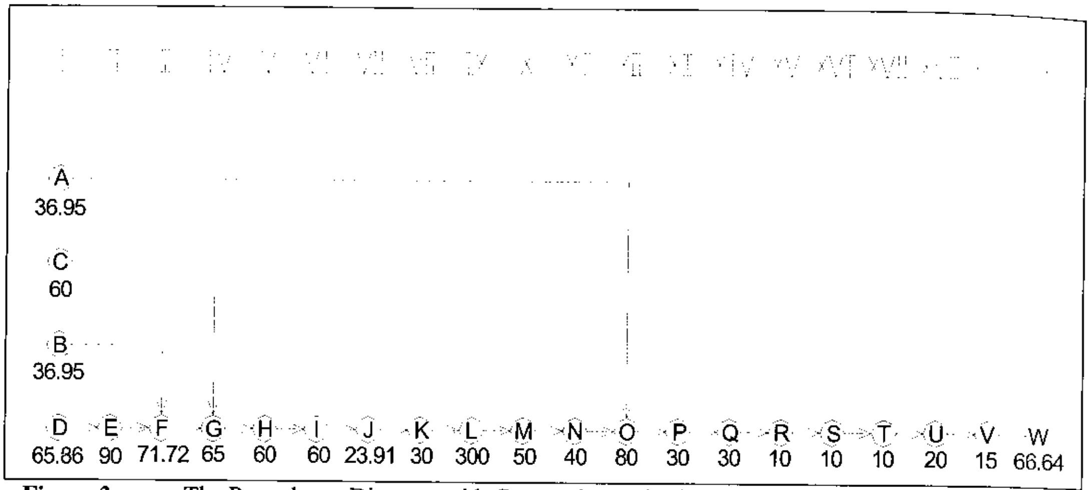

Figure 3. The Precedence Diagram with Composite Task Time

Table 3. Summary of Work Centre, Workstation, Task and Worker/Power Supply Allocation in the Achieved Assembly Line

Work Centre	Workstation	Tasks	No. of Workers/Power supply
1	1	D	1
2	2 - 4	E, B, F	3
3	5 and 6	C, G	2
4	7 and 8	H, I	1 (+ 1 power supply)
5	9 - 14	J, K, L	1 (+ 5 power supplies)
6	15	M	1
7	16	N	1
8	17 and 18	A, O	2
9	19	P, Q	1
10	20 and 21	R, S, T, U, V, W	2
Total:	**21**		**15 workers and 6 powers supply points**

Table 4. Comparisons of performance for the achieved assembly line and the current assembly line

	Before Balancing (Current Assembly Line)	After Balancing (Achieved Assembly Line)
Overall System Utilisation, U_s	50.00%	90.48%
Actual Number of Workstation, WS_a	38	21
Number of Workers	29	15
Number of power supply points	9	6

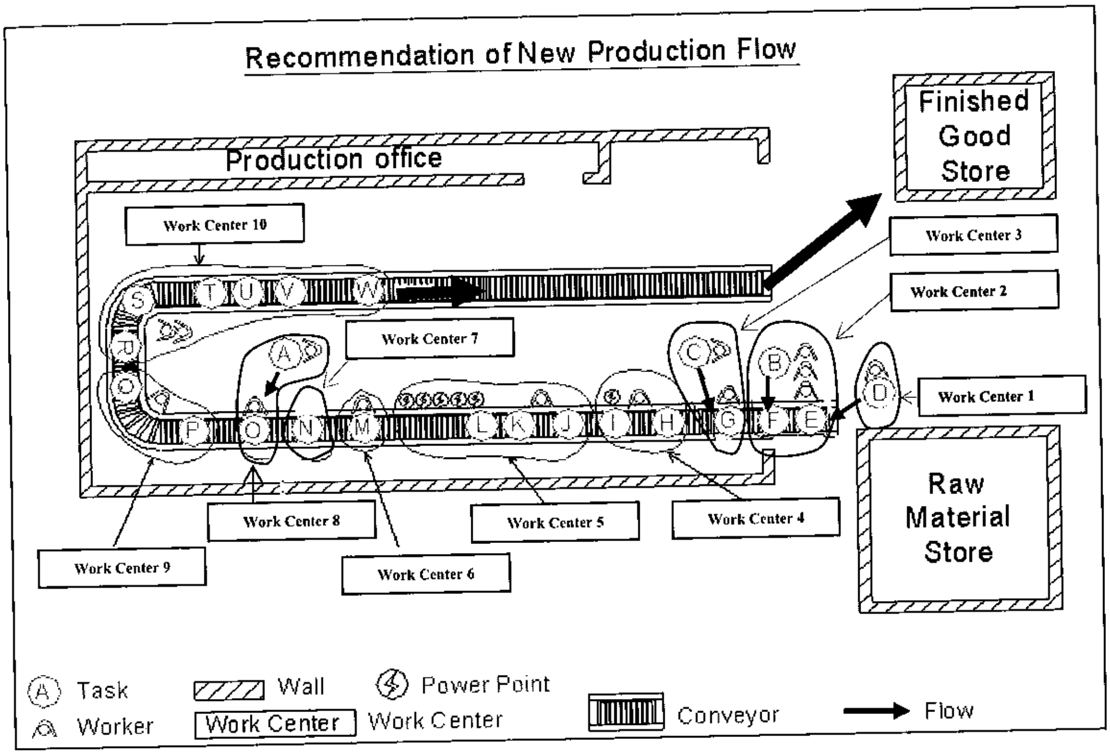

Figure 4. Redesigned layout diagram

APPENDIX 1

The Computation Table

Work Centre k	Tasks	Accumulated Time T_q	No. Of Workstations Working, WS_k	Actual Number of Workstations Required IWS_k	Utilisation of Work centre (%) U_k
1	D	65.86	0.989	1	98.93%
	D+E	155.86	2.341	3	78.04%
	E	90.00	1.352	2	67.59%
	E+B	126.95	1.907	2	95.35%
2	E+B+F	198.67	2.9842	3	99.47%
	E+B+F+C	258.67	3.885	4	97.14%
	C	60.00	0.901	1	90.12%
3	C+G	125.00	1.878	2	93.88%
	C+G+H	185.00	2.779	3	92.63%
	H	60.00	0.901	1	90.12%
4	H+I	120.00	1.802	2	90.12%
	H+I+J	143.91	2.162	3	72.05%
	J	23.91	0.359	1	35.91%
	J+K	53.91	0.810	1	80.97%
5	J+K+L	353.91	5.316	6	88.60%
	J+K+L+M	403.91	6.067	7	86.67%
6	M	50.00	0.7510	1	75.10%
	M+N	90.00	1.352	2	67.59%
7	N	40.00	0.601	1	60.08%
	N+A	76.95	1.156	2	57.79%
	A	36.95	0.555	1	55.51%
8	A+O	116.95	1.757	2	87.84%
	A+O+P	146.95	2.207	3	73.58%
	P	30.00	0.451	1	45.06%
9	P+Q	60.00	0.901	1	90.12%
	P+Q+R	70.00	1.051	2	52.57%
	R	10.00	0.150	1	15.02%
	R+S	20.00	0.300	1	30.04%
	R+S+T	30.00	0.451	1	45.06%
	R+S+T+U	50.00	0.751	1	75.10%
	R+S+T+U+V	65.00	0.976	1	97.64%
10	R+S+T+U+V+W	131.64	1.977	2	98.87%
			Total:	**21**	

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