IMPROVING PRODUCTIVITY THROUGH LINE BALANCING – A CASE STUDY

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ABSTRACT

This paper describes a case study conducted at a manufacturing company aimed at improving productivity using line balancing. Two alternatives were generated using different assignment rules. However selection of the most suitable alternatives cannot be made based on line balancing alone as they appear similar based on line balance loss. Thus the robustness of the alternatives were tested and evaluated using a 16 factorial ANOVA. Selection of the most suitable solution is then made based on these results.

Keyword : Productivity improvement, Line balancing, Simulation.

1.0 INTRODUCTION

Many researchers have reported various productivity techniques and performance measures designed to monitor and improve system performance in an organization [1,2,3,4]. Some deal with specific problems such as inventory, scrap and set-up time reduction, with the aim of increasing manufacturing productivity. One of these techniques is line balancing.

Line balancing aims to match the output rate to the production plan [5]. This will assist management in ensuring on-time delivery and prevents buildup of unwanted inventory. Johnson [6] expresses the problem of line balancing as 'a set of nondivisible tasks to be performed. Each task has a known deterministic performance time. A partial ordering of tasks by precedence constraints is specified. The problem is to assign these tasks to assembly stations, so that the necessary number of station is minimized.' The steps to line balancing has been detailed out by Hoffman [7].

This paper reports an effort to improve the productivity of a manufacturing company by improving the line balancing of one of its assembly lines. Two alternatives were generated and evaluated. Both alternatives showed marked improvements as compared to the existing line. However the difference between both alternatives in terms of line balance loss is too small to enable a clear choice between the two to be made. The robustness of each alternative is checked using

simulation and 16-factorial ANOVA. Based on these results the appropriate alternative is recommended.

2.0   PROBLEM DEFINITION

Currently, the SL-D assembly line faces the problem of fulfilling the targeted production plan. To fulfill the production plan, overtime work is conducted. This increases the production costs and reduces company profit.

Figure 1 shows the comparison between the actual output and the production target for the month of July. It is representative of other months. This output is based on normal working period of one shift per day without overtime. The line across the graph is the targeted output of the product which is 850 units per day. This production capacity is calculated by the production planner based on the available machines and human resources. It shows that only a few of the daily actual outputs reached the targeted production capacity. Although 20% of the time output surpassed the targeted production, it cannot compensate for the other 80%. Observations and investigations show that the main cause for this is due to unbalanced assembly line. Figure 2 shows graphically the line balance loss (LBL) of each work station. It also shows that some workstations tend to be the cause for bottlenecks as these stations handled more workload as compared to other stations, for example workstations 3, 5, 14 and 39. In contrast, workstations 35 and 38 are very often idle.

The LBL percentage is presented to identify the seriousness of the problem. LBL is calculated as follows:

Line Balance Loss Percentage:

$$\%LBL = \frac{nT_{max} - \sum t_i}{nT_{max}} \times 100\%$$

$$= \frac{(39)(35.84) - 519.46}{(39)(35.84)} \times 100\%$$

$$= 62.84\%$$

where;

n = number of workstations
T_{max} = value of the highest cycle time
$\sum t_i$ = Total cycle time

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The result shows that this assembly line is more than 60% unbalanced. Thus, some effective action must be taken to balance the assembly line, as well as to increase the productivity of the assembly line.

To facilitate line balancing, other information related to the line such as precedence relationship of the work tasks or workstation was also collected. Precedence requirements are physical restrictions on the order in which operations are performed on the assembly line. Figure 3 illustrates the precedence diagram for the assembly line SL-D. It portrays the elemental tasks to be performed and sequence requirements of the assembly processes.

3.0 PROPOSED SOLUTION

The assembly process involves a set of workstations, each carrying out a specific task or tasks in a restricted sequence. It is important that tasks be allocated to each workstation as evenly as possible to avoid bottlenecks and excessive idle time. Line balancing involves assigning and balancing tasks between workstations of the assembly line in order to minimise balance delay, labour force and ultimately minimising the total production cost. Two alternative solutions are proposed. Ranked positional weight was used to generate Alternative 1. Whereas, Alternative 2 is generated by modifying Alternative 1 based on the concept of eliminating, combining, simplifying the assembly process without any additional machine and manpower in the hope that further improvement may be achieved.

The cycle time of each workstation is kept to within 29 seconds. This value is calculated based on the required production rate and the cycle time.

3.1 Alternative 1

The alternative solution is generated based on the 'ranked positional weight' rule in selecting tasks for workstations. Specifically, this rule states that tasks that meet precedence criteria are assigned according to their positional weights, which are times for a given task plus the task times of all those that follow. The task with the highest positional weight would be assigned to the first station. Recommended changes to the assignment of task to each operator in the line are:

- Transfer work task of operator 3 to operator 2 (back board sub-assembly). Thus saving one manpower in the line.
- Combined work task of operators 4, 5 and 6 in baffle board sub-assembly to meet total process time of 25 seconds. In this case, using multiskilled operator to operate the workstation as a team rather than as independent workers.
- Transfer work task of operator 12 to operator 11 (triangle wood attachment) and adjacent operator 10 to assist operator 11. Thus, saving one manpower in the line.
- Combined work tasks of operator 14 (sanding and touching up) with operator 13 to eliminate the slack time between workstations 7 and 8.
- Transfer work task of operator 25 (lens fixing) to operator 24.

- Combine work task of operator 31 (duct fixing) and operator 30, and using multiskilled operator to operate the workstation as a team rather than as independent workers.
- Transfer work task of operator 44 (polyfoam placement) to operator 43. Thus, saving one manpower in the line.

3.2 Alternative 2

The second alternative solution is generated by modifying the Alternative 1. Modification is made based on the concept of eliminating, combining and simplifying the assembly process without any additional machine and manpower. Changes to the assignment of work task to each operator in the line are:

- Transfer work task of quality operator QA2 (electronic component checking) to QA1 (terminal cord plug in), to eliminate QA2 in the line.
- Transfer work task of operator 24 (wood ADH) to operator 23 (layer protection).
- Transfer work task of operator 26 (lens screwing) to operator 25 (lens fixing), and operator 25 would take over the entire combined work tasks.
- Eliminate operator 29 (screwing), and operator 28 (front panel fixing) would take over the combined work tasks. Improve work method of operators 27 and 28 (station 13) to deal with cycle time in 29 seconds by reducing the task time.
- Combine workstation 28 (QC appearance checking) and workstation 27 (set cleaning and matching). In this case, using two multiskilled operators to operate the workstation as a team rather than as independent workers. Thus, saving two manpower in the line.

Tables 1 and 2 show the workstations and process time of each station in SL-D assembly line for Alternatives 1 and 2 respectively.

In formulating Alternatives 1 and 2, these assumptions have been made;

i. The process cycle time for every work task is based on existing records.
ii. Mean time between failure and mean time to repair is modelled using the exponential distribution [8].
iii. For the combined work tasks, the new process cycle time is the average of total time of the work tasks.
iv. For the task that is assigned to another operator, the cycle time is based on records of the existing system.
v. The machine speed or production rate is constant.
vi. The skill and experience level of all operators are considered to be the same.

Both alternatives need to be evaluated to quantify the amount of improvement possible over the existing situation and also to determine the optimum alternative.

4.0   EVALUATION OF PROPOSED SOLUTIONS

Figures 4 and 5 show the bar charts for process time and idle time for Alternatives 1 and 2 respectively based on Tables 1 and 2 respectively. Table 3 summarises the differences in the results of various parameters of the existing and alternative systems. These parameters include line balance loss, number of operator, number of station, total lead-time of line and total distance of line. It shows that Alternatives 1 and 2 have the potential of producing significant improvement over the existing situation.

However comparison between Alternatives 1 and 2 shows that overall Alternative 2 is slightly better. Alternative 2 requires less operator as compared to Alternative 1 while all other parameters are almost equal. To further verify that Alternative 2 is indeed the best alternative the robustness of both alternatives is tested.

Simulations have been carried out to test the robustness of these alternatives. Witness software was used for this purpose. The model of each alternative is subjected to extreme levels of station downtime, processing time and inventory as shown in Table 4. This simulation uses a 2 x 2 x 2 x 2 (16) factorial ANOVA along with pair-wise comparisons and family confidence intervals to study the following;

i.   The effect of high and low levels of station coefficient of variation to the performance of each line.
ii. The effect of high and low levels of station downtime to the performance of each line.
iii. The effect of high and low levels of inventory in the system to the performance of each line.

Figures 6, 7 and 8 show the results of the simulation experimentations. Performance is measured based on the total output of each line. These results indicate that Alternative 2 is less affected by variability within the system than Alternative 1. Alternative 2 appears to be able to achieve higher output level under both levels of system down time, coefficient of variation and extreme levels of inventory. Assembly lines less affected by variability within the system should enable management of factory to provide more reliable delivery of product. Thus, Alternative 2 is selected as the best alternative as it not only uses the least number of operators, it is also robust and less sensitive to changes.

5.0   CONCLUSION

The objective of this study is to improve the productivity of the assembly line SL-D using line balancing. Two alternatives have been generated and evaluated. Evaluation based on line balancing loss shows that both alternatives

outperformed the existing system. However, it was difficult to choose the best alternative as they were almost equal to each other. Thus the robustness of each alternative were simulated and evaluated using a 16-factorial ANOVA. Alternative 2 was found to be more robust than Alternative 1 and it is proposed to the management of the company.

This study also shows that in line balancing problem, line balancing loss may not be the only criterion or measurement that may be used to determine the optimum alternative especially in cases where alternatives are almost equal to each other. The robustness of these solutions against the varyingly important parameters should also be considered. A robust system will be able to perform better in a real life environment where change and uncertainty are common.

ACKNOWLEDGEMENT

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Table 1 Workstation balance based on Ranked Positional Weight (Alternative 1)

Station	Work Task Description		Task Time (sec)	RPW	Station Process Time (sec)
WS1	O4, O5, O6	Baffle board assy.	35.84	480.85	29.00
WS2	O2	Back board assy.	22.06	467.07	22.06
WS3	O7	Back & baffle board assy.	18.51	445.04	18.51
WS4	O1 & M1	Automation gluing	16.55	443.05	16.55
WS5	O8 & O9	SPK box assy. (I)	25.21	426.5	25.21
WS6	O10	SPK box assy. (II)	16.52	401.29	22.11
	O11 & M2	Triangle wood attachment	5.59	384.77	
WS7	O13	Acoustic sponge fixing	13.25	379.18	29.00
		Sanding & touching	16.25	265.93	
WS8	O15, M3	Drilling	9.59	349.68	25.11
	O16	Speaker plug in	8.85	340.09	
	017	Tweeter plug in	6.67	331.24	
WS9	O18	Woofer placement	16.85	324.57	16.85
WS10	O19,20,21,22	Screwing	26.53	307.72	26.53
WS11	QA1	Terminal cord plug in	10.16	281.19	25.96
	QA2	Testing & checking	9.05	271.03	
	O23	Remove protect layer	6.75	261.98	
WS12	O24	Apply wood ADH	5.08	255.23	22.28
		Lens fixing	5.56	250.15	
	O26	Lens screwing	11.64	244.59	
WS13	O27	Front panel assy.	11.63	232.95	19.94
	O28	Front panel fixing	8.31	221.32	
WS14	O29	Front panel screwing	11.47	213.01	29.00
	O30	Apply PCV ADH	12.52	201.54	
		Duct fixing	6.23	189.02	
WS15	O32	Duct screwing	15.54	182.79	27.45
	O33 & O34	Set cleaning & matching	11.91	167.25	
WS16	QA3 & QA 4	QC appearance checking	14.76	155.34	23.76
	QA5	QC polarity checking	9.00	140.58	
WS17	QA6	QC acoustic checking	12.79	131.58	26.81
	QA7	QC final checking	14.02	118.79	
WS18	O35	Back label attachment	15.76	104.77	29.00
	O36	Back label attachment	15.94	89.01	
WS19	O37 & O38	PE bag packing	8.16	73.07	29.00
	O39	Top polyfoam fixing	2.51	64.91	
	O40 & O41	Foot fixing	19.01	62.4	
WS20	O41 & O43	PE bag tapping	17.47	43.39	20.00
		Bottom polyfoam fixing	2.53	25.92	
WS21	O45 & M4	Carton packing	23.39	23.39	23.39

Table 2 Workstation balance for Alternative 2

Station	Work Task Description		Task Time (sec)	Improved Station Process Time (sec)
WS1	O4, O5, O6	Baffle board assy.	35.84	25.00
WS2	O2	Back board assy.	22.06	22.06
WS3	O7	Back & baffle board assy.	18.51	18.51
WS4	O1 & M1	Automation gluing	16.55	16.55
WS5	O8 & O9	SPK box assy. (I)	25.21	25.21
WS6	O10	SPK box assy. (II)	16.52	22.11
	O11 & M2	Triangle wood attachment	5.59	
WS7	O13	Acoustic sponge fixing	13.25	29.00
	O14	Sanding & touching	16.25	
WS8	O15, M3	Drilling	9.59	25.11
	O16	Speaker plug in	8.85	
	017	Tweeter plug in	6.67	
WS9	O18	Woofer placement	16.85	16.85
WS10	O19, 20,21,22	Screwing	26.53	26.53
WS11	QA1	Terminal cord plug in	10.16	19.21
		Testing & checking	9.05	
WS12	O23	Remove protect layer	6.75	29.00
		Apply wood ADH	5.08	
	O25	Lens fixing	5.56	
		Lens screwing	11.64	
WS13	O27	Front panel assy.	11.63	29.00
	O28	Front panel fixing	8.31	
		Front panel screwing	11.47	
WS14	O30	Apply PCV ADH	12.52	29.00
		Duct fixing	6.23	
	O32	Duct screwing	11.91	
WS15	O33 & O34	Set cleaning & matching	15.54	29.00
		QC appearance checking	14.76	
WS16	QA5	QC polarity checking	9.00	21.79
	QA6	QC acoustic checking	12.79	
WS17	QA7	QC final checking	14.02	29.00
	O35	Back label attachment	15.76	
WS18	O36	Back label attachment	15.94	29.00
	O37	PE bag packing	8.16	
		Top polyfoam fixing	2.51	
WS19	O40 & O41	Foot fixing	19.01	19.01
WS20	O42 & O43	PE bag tapping	17.47	20.00
		Bottom polyfoam fixing	2.53	
WS21	O45 & M4	Carton packing	23.39	23.39

Table 3 Comparison between existing line, Alternative 1 and Alternative 2

System	Existing	Alternative 1	Alternative 2
1. Number of operators	53	47	41
2. Number of stations	39	21	21
3. Total lead time of line (second)	519.46	485.91	484.05
4. Total distance of line (m)	80.05	76.55	65.15
5. Line balance loss (%)	62.84	15.54	17.19

Table 4 Simulation model parameters

Independent Variables	Levels
Line design (LD)	1 = Alternative 1 2 = Alternative 2
Coefficient of variation (CV) of cycle time	1 = 5 percent 2 = 50 percent
Downtime (DT)	1 = 10 percent* 2 = 30 percent**
Total inventory (INV)	1 = 10 units 2 = 80 units

Notes

* The mean time between failures (MTBF) is distributed with a mean of 270, and the mean time to repair (MTR) is log normally distributed with a mean of 30 and a standard deviation of 9.

** The MTBF is exponentially distributed with a mean of 117, and the MTR is log normally distributed with a mean of 50 and a standard deviation of 15.
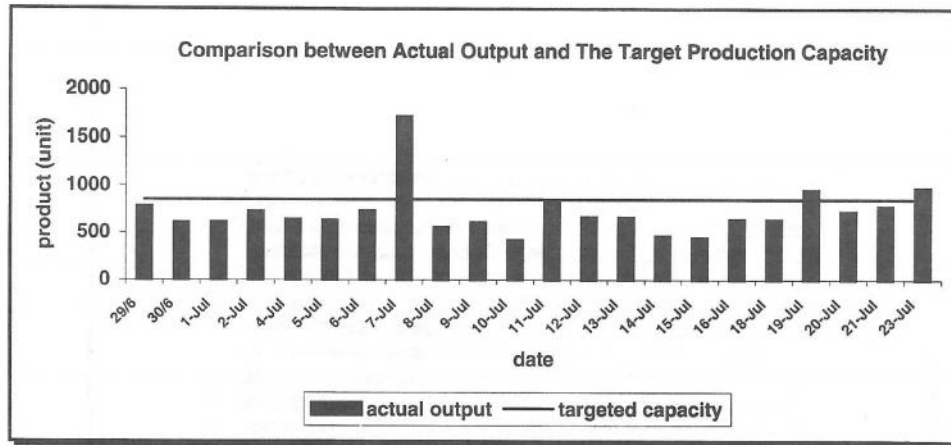
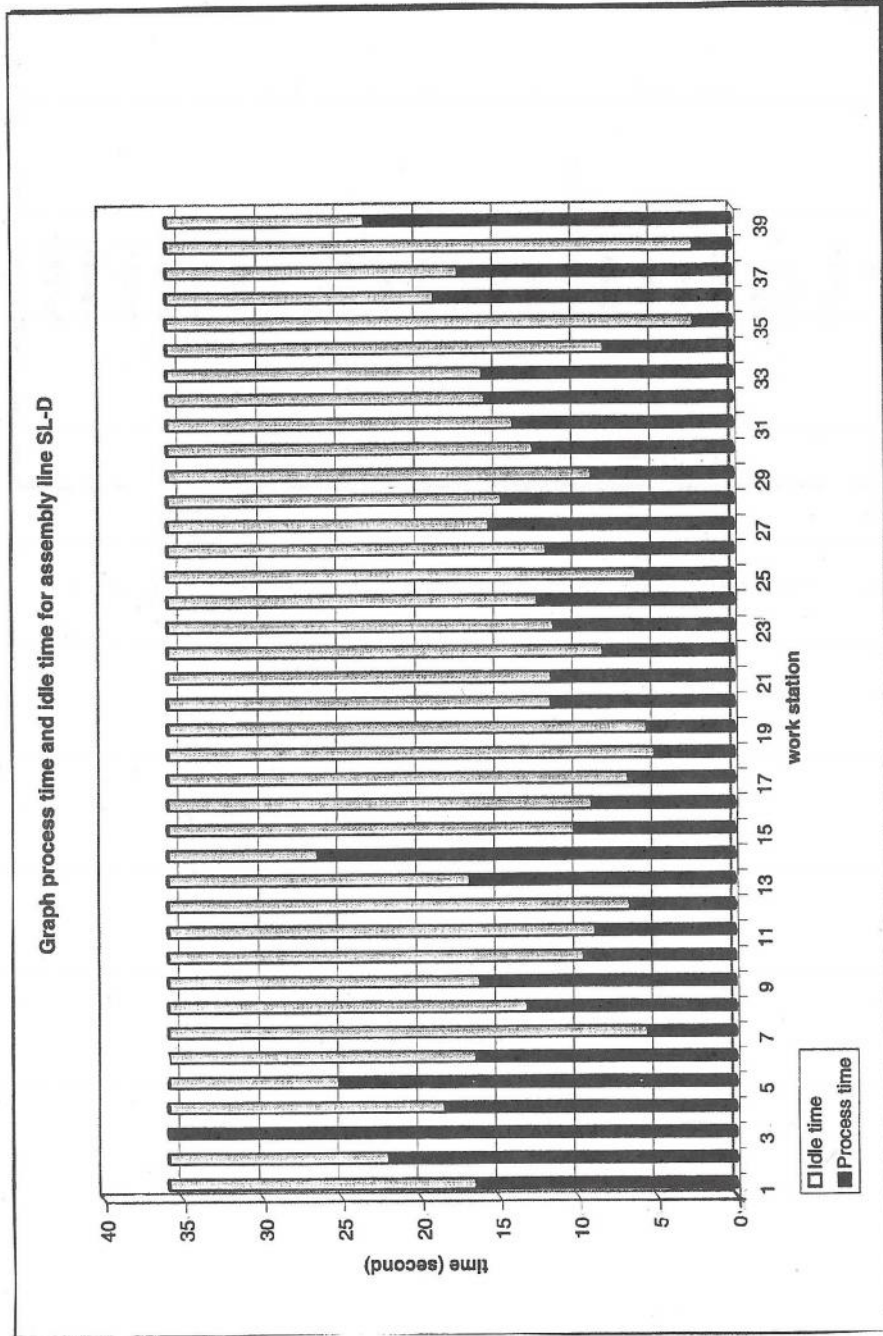Figure 1 The daily output of Model SP-MXGT 80 Series for July 2001

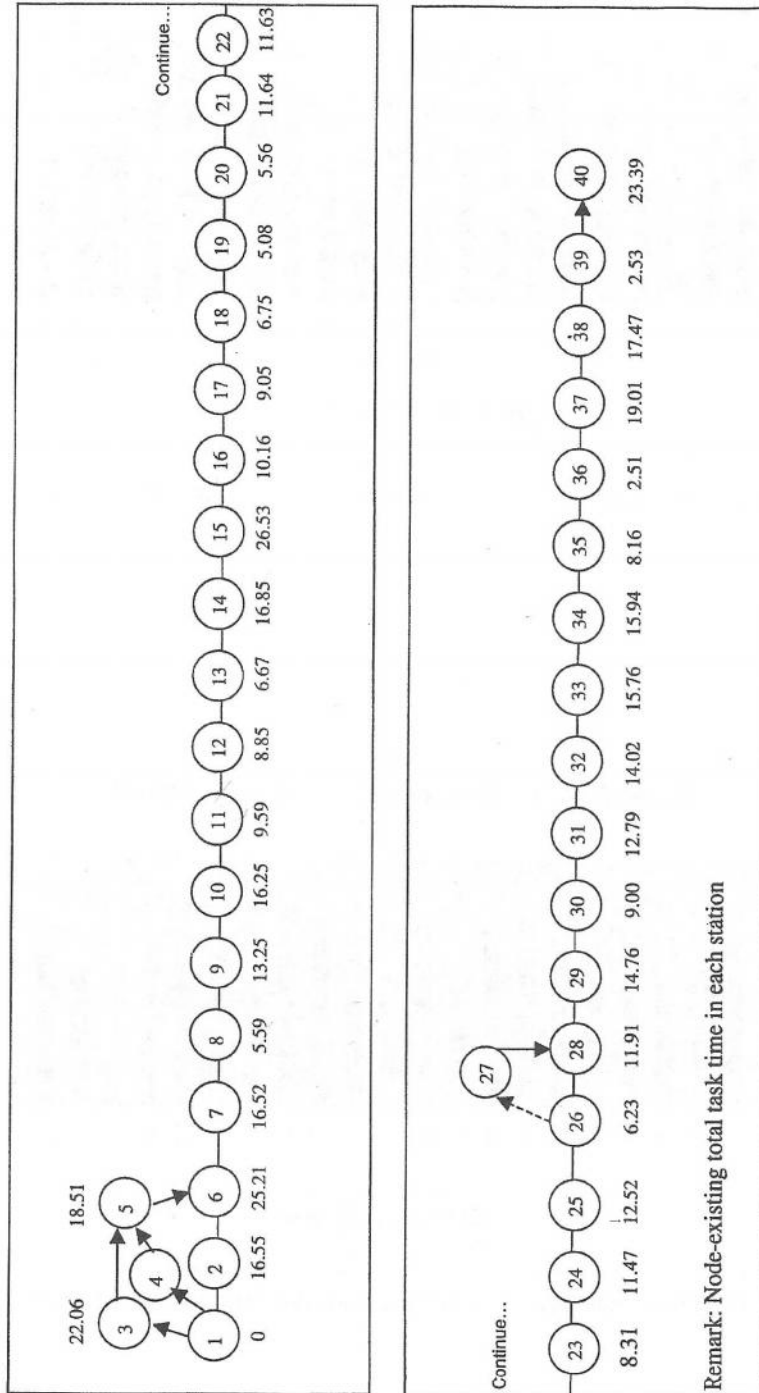Figure 2 Line balance loss for assembly line SL - D

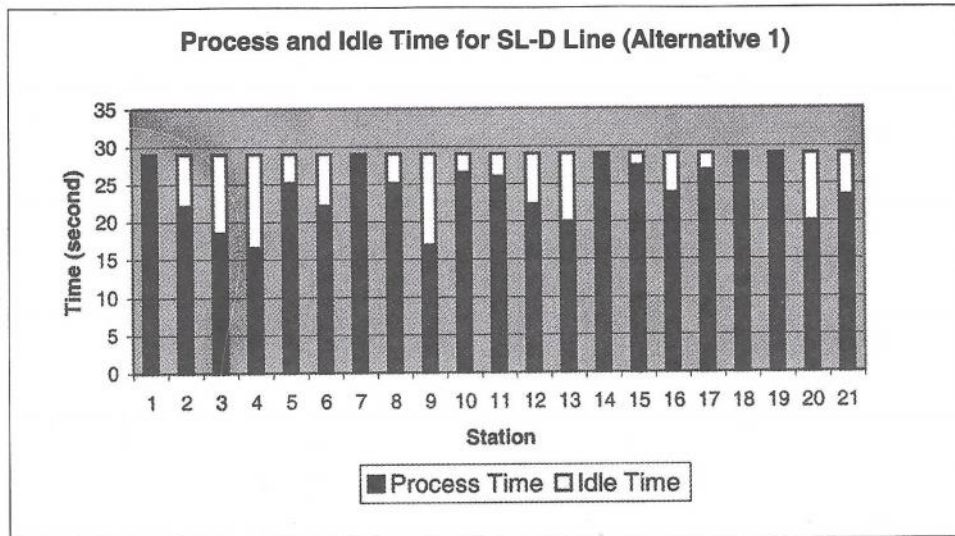Figure 3 Precedence diagram of work task in every station in line SL - D

Remark: Node-existing total task time in each station

Figure 4 Bar chart for process time and idle time for Alternative 1
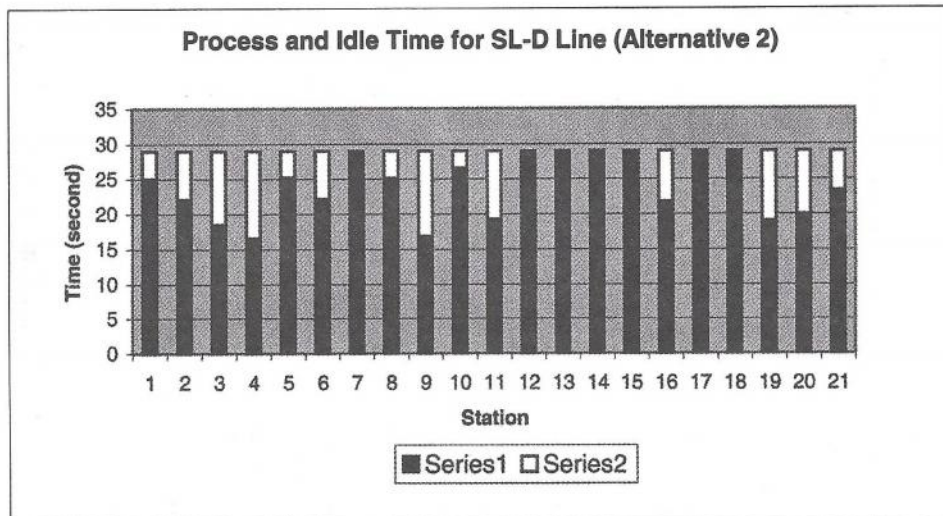
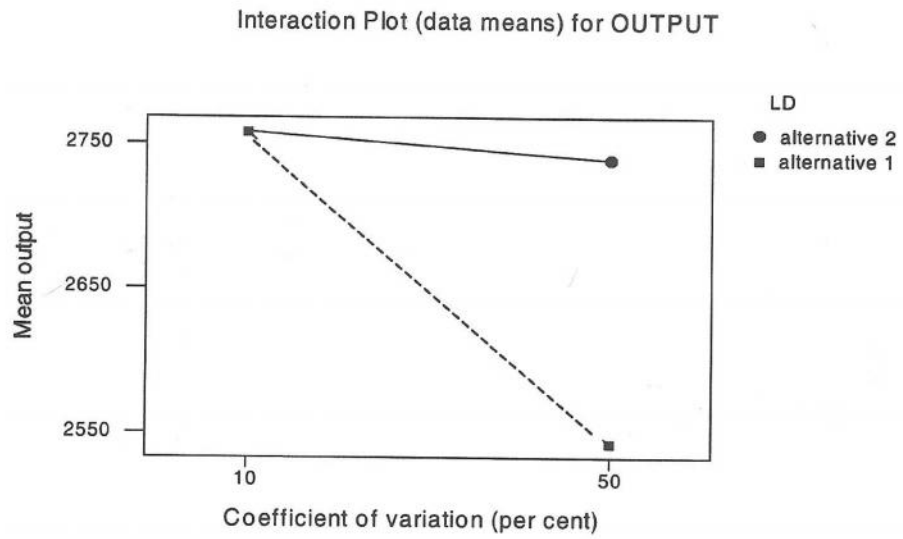Figure 5 Bar chart for process time and idle time for Alternative 2

Interaction Plot (data means) for OUTPUT

Figure 6 Mean output versus coefficient of variation

Interaction Plot (data means) for OUTPUT
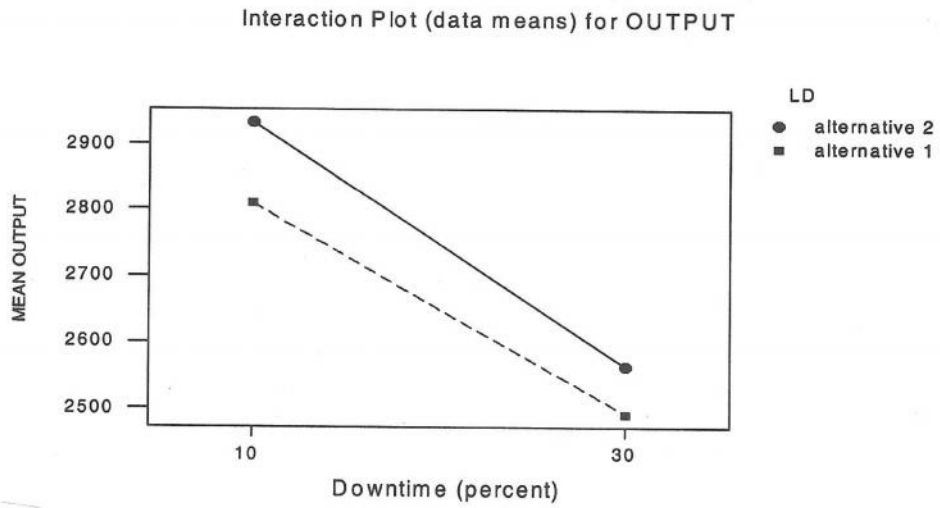
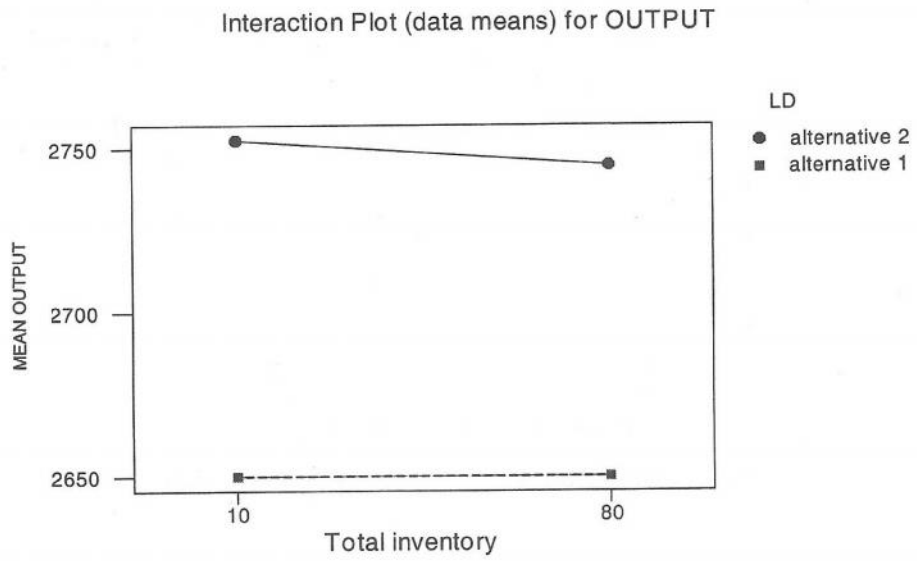
Figure 7 Line design versus down time

Interaction Plot (data means) for OUTPUT

Figure 8 Mean output versus total inventory