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Line Balancing Heuristics for Productivity Enhancement in Beverage Factory

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Abstract

The Assembly Line Balancing (ALB) objectives focus on improving the line efficiency, aiming at enhancing the productivity. Assembly line balancing seeks to tightly pack each station along the production line with respective tasks to minimize total ideal time and standardize the cycle time for production of particular product. This article adapted Longest Operating Time (LOT) heuristic to enhance productivity of production line in a beverage factory (Varun Beverages, Bhiwadi). Possible objectives functions of ALB, basing on task time, cycle time, station count either free or constrained, a time study is carried in this article and a new theoretical design of production line is made over initial operating production line with the values obtained from time study using the principles of Longest operating time. This proposition shows enhancement in productivity by optimizing total number of workstations and by reducing workers along the production line. There will be noticeable reduction in net cost per unit production on new production line design.

Keywords: Assembly Line Balancing, Cycle Time, Ideal Time, Longest Operating Time, Productivity, Task Time, Work Station

1. Introduction

Industrial revolution has encapsulated for various inventions and discoveries in field of material processing technologies, energy and transport[9], with prominence to technology industrial revolution has cratered modern factory system. Exact origin of line production is uncertain, but a series of developments on machine tooling technology during early 1800's allowed for hand crafted components to be replaced by machine fabricated interchangeable parts. This brought the manufacturing costs and time down, made industrially standard parts reliable[9]. The first usage of line production system for assembly was made at Old's motor vehicle in 1901 by its owner Sir Ransom Old. Old's assembly line did not use conveyor system, vehicles were rolled on wheels to respective assembly stations[9]. In 1913 Henry Ford's model T assembly has integrated the assembly line concept with conveyance, this lead to new standards in manufacturing sector. Leu Y., Matheson L.A., and Ress L.P, 1996 explained Sir Henry Ford's principles of assembly[6]:(a) The part which is being processed along the production line should be made to travel the least possible distance by placing the tools and men in an efficient sequence of operation (b)Using work slides or some other form of carrier so that when a workman completes his operation, he drops the part always in the same place which must always be the most convenient place to his hand and if possible have gravity carry the part to the next workman for his operation (c)Using sliding assembling lines by which the parts to be assembled are delivered at convenient distances.

A measure for efficiency of machinery, plant or system in converting inputs to outputs is termed as productivity, it can be computed by dividing net outputs in a given period by total costs incurred or resources (energy, material, labor….etc). A production process operated with line balancing principles breaks the

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manufacture of product into finite steps of different tasks that are performed in a pre defined sequence to obtain a finished good, Assembly line balancing is the most commonly used technique for mass production of goods. It is loaded with right combination of men and machinery to complete specific tasks in specific time periods as the product moves along the production line. Companies/ manufacturing industries use Design for Assembly (DFA) approach to analyze a product and its design in order to determine series of tasks and assembly order. More the number of workstations and labor, more is the overall production cost per unit. Small changes and adjustments in performance of these mass production can lead to significant improvements in the throughputs of production[5].

Assembly line balancing seeks to minimize the total idle time in the production line, packing each station with tasks so that cycle time constraint is tight for all the stations along the line. From the above optimization objectives type -1 focuses on reducing the net cost per unit production by reducing the number of stations and work labor. In type -2 optimizes the assembly line by reducing the cycle time, throughput is maximized by minimizing the cycle time. Type -3 problem draws the economic motivations of both type-1 and type-2 problems in tandem. A mixed model assembly line in an intermixed sequence produce different products, (Thomopoulos) and (Macaskill) converted this mixed model problem into single model by considering the demand average time for each task at stations.

2. Assembly Line Balancing Objectives

A study on general assembly line balancing modeling methods and techniques by (Bryan Pearce) made three possible objectives, depending on whether the cycle time and station count parameters are free or constrained (Refer table-1 Assembly line balancing objectives)

Assembly line balancing seeks to minimize the total idle time in the production line, packing each station with tasks so that cycle time constraint is tight for all the stations along the line. From the above optimization objectives type -1 focuses on reducing the net cost per unit production by reducing the number of stations and work labor. In type -2 optimizes the assembly line by reducing the cycle time, throughput is maximized by minimizing the cycle time. Type -3 problem draws the economic motivations of both type-1 and type-2 problems in tandem. A mixed model assembly line in an intermixed sequence produce different products, (Thomopoulos) and (Macaskill) converted this mixed model problem into single model by considering the demand average time for each task at stations.

Table 1. Assembly line balancing objectives

No.	Objective
Type-1	Minimize the number of stations, given a fixed cycle time
Type-2	Minimize the cycle time, given a fixed station count
Type-3	Maximize Utilization, while varying both the cycle time and station count

2.1 Minimal Criteria for Assembly Line Balancing Solution

- All the stations must be assigned with tasks such that the component must be finished with all the processing and assemblies at the exit of the final station along the production line.
- The precedence relationship must be satisfied, this can be done by ensuring that no same task is assigned to an earlier station or later station.
- Task times at stations cannot exceed the cycle time.

2.2 Heuristics Methods used for the Study

Line balancing heuristical approaches, provide satisfactory results but does not gurantee the optimal solutions or best solutions.

- *Rank position weight (Helgeson – Birnie)*From table above objective of assembly line balancing type-1 is the suited model of our study, RPW is designed for solution to fixed cycle time in simple line balancing problems. This method tries to assign the stations with tasks one at a time starting from beginning of the assembly. RPW uses weight principles, where each task is given weight which is equal to sum of task times of that particular task and its successor tasks. These tasks are then sorted according to the obtained weights, proceeding further each task is assigned to earliest station along the line satisfying the below criteria:
  - Sufficient time capacity exist at station for placing the task.
  - No predessor tasks are assigned at later stations.

- *Longest operating time (LOT)*Principle involved in LOT "largest time consuming task or group of tasks must be assigned to first station, after assigning task look out for ideal time for the station, which can be utilized, if station can contribute time assign a tasks to it such that the ideal time reduces at that particular station[5]. Allocation of tasks should be done such that the precedence relation of the tasks must be satisfied. Most followed tasks. Least followed tasks, shortest operating time are few other principles used for similar applications

3. Assumptions and Problem Description

The Repeatable Glass Bottle's (RGB) are filled with carbonated and non-carbonated soft drinks here at Varun Beverages, Bhiwadi. For this study, we considered filling of beverage into a pallet with 300ml RGB's. Each pallet consists of 48 crates and each crate has capacity of holding 24 RGB, in total 1152 bottles. During this process of filling, bottles move along the line on motorized conveyors, speeds of these conveyors are not constant along the line. It was noticeably complex to calculate exact time of travel for these bottles as the conveyor width vary continuously and frequent stoppage of conveyor occurs due to various reasons. So we considered the transportation as an interconnected task and added 194 seconds (equal to cycle time) during calculations such that there is no disturbance in the cycle time. Whenever there is dominos action of bottles falling along the conveyor the labor near to the incident tries to arrange the bottles either by stopping the conveyor or without stopping, this makes transportation very labor intensive on this reason. Now that the final assembly being labor intensive there is possibility to analyze the wage distribution and compensation which contributes to the net production cost per unit. Under this perception of wage allocation, possibilities of minimizing the worklabor in addition to workstation is an added advantage. So there is need for assigning the tasks in a way such that there is minimization in both workstations and worklabor, this is a technique suggested by M.D. Kildbridge and L. Wester, 1961[3]. Also distribution of wages is a critical task, it depends on difficulties and complexity of tasks that are being performed[5]. Though there are wage rate differences in developed industrial nations, this article neglects this concept of wage rate difference (Refer Fig.1. Process flow diagram)

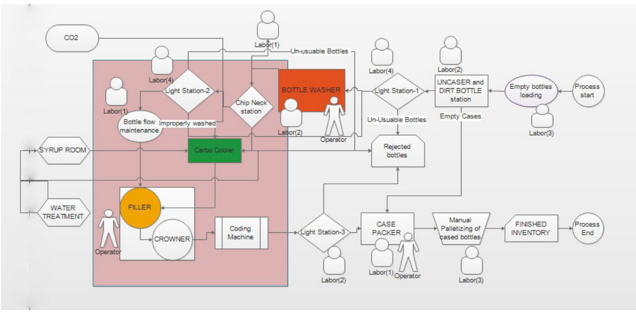

Figure 1. Process flow diagram.

4. Methodology Adopted

The article tried and used the Longest operating heuristics, for this a series of methods have been adopted. Following below are the series of steps followed in this case study.

- Determining the list of tasks that have to be performed in completing one unit of product.
- Drawing a precedence network diagram with precedence diagram construction rules.
- Assigning the tasks to the stations by obeying the precedence relationship and comparing with original working line.
- Manually finding the task times at various stations using a stop watch - Time Study.
- Calculating the Cycle time and daily production using referred formulae for original working line.
- Finding out the ideal times on every task at stations, Line efficiency.
- Finding out optimum number of Workstations and designing new theoretical production line.
- Optimum work labor and reduction in Labor cost for new production line.

(Refer Fig.2. Methodology of case study)

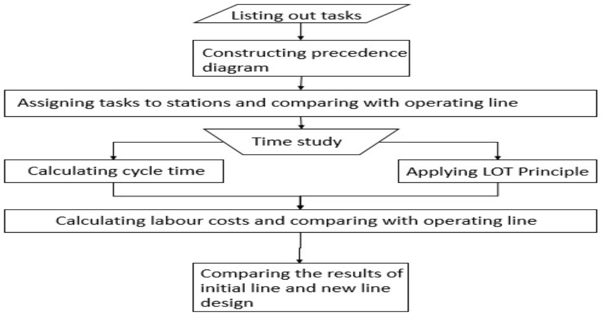

Figure 2. Methodology of case study.

Operation Sequence

Empty Repeatable Glass Bottles (RGB) are bought from store to production line through forklift. Forklift vehicle unloads the pallet near the conveyor chain and moves to store for repetition. The work labor available at the unload station manually de-palletize the crates onto the conveyor chain. The crates move towards Un-caser, uncasing the empty bottles. Inspection of empty RGB at Light station is done to scrap broken bottles and dirty bottles. Next is the important station in the production line, washing of Bottles at Bottle washer. Once the bottles exit out of washer inspection will be done for caustic carryover and mold, yeast remaining check. Also an inspection station is arranged to check for chip neck on bottles at exit to the Bottle washer. Inspection of washed bottles at Light station is the next operation. Later filling and crowning of bottles with beverage is done and coding on bottles will be followed. Final inspection of filled bottles at Light station is done before the filled bottles move for case packaging at case packer station. Once packing is done with the filled bottles into Crates, Crates are manually palletized. Fork lift carry the pallets to store. Look for the process map of line-2 CSD-RGB (Refer TABLE II Current operation scenario at VBL, Bhiwadi (Time to Station Arrangement, Fig.3. For Network diagram of process along the production line)

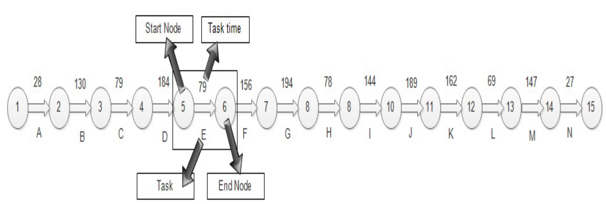

Figure 3. Network diagram of process along the line.

5. Calculations

From table II,

1. *Total station time(T_s)* $= \sum_{t=1}^{14}(Tt * wt)$

$= 2946$ sec

2. *Standard time per pallet (T_{st})* $= \sum_{t=1}^{14}(Tt)$

$= 1666$ sec

(Transportation time is taken as 194 sec per pallet and shall be added for calculations)

3. *Cycle time (T_c)*= 194 sec

4. *Total work labor*= 23

5. *Total number of stations (n)*= 12

Assuming production time as 12 hrs per day, one pallet contains 48 cases and each case loaded with 24 RGB's.

1. Maximum daily output:

[(Available time per day) / (T_c)]

[12*3600]/194 = 223 pallets/day

2. Idle time per day:

$T_i = S*T_c - (T_{st})$

[12*194] – [1666] = 662 sec

3. Line efficiency (η_l):

[((T_{st})*100) / (n * T_c)]

[((1666+194)*100) / (12*194)] = 79.89%

4. *Balance Delay:* = 100 - η_l

= 100 – 79.89= 20.11%

5. *Theoretical minimum workers:* = (T_s) / (T_c)

2946/194 = 16

6. Theoretical utilization:

(Theoretical minimum workers) / (total work labor)

16 / 23 = 69.56%

7. Theoretical number of stations:

(T_{st} * Maximum output per day) / (total available time per day)

[(1666+194) * 10,800] / (12 * 3600) = 10 stations

For tabular representation of above calculation

Refer TABLE 3 - IDLE TIME (Cycle time per pallet = 194 sec) Total idle time during the original operation is 662 sec. Also Fig.4. Graph showing initial operating line station time, cycle time

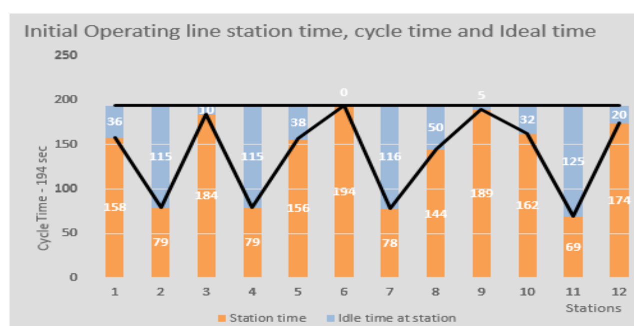

Figure 4. Graph showing initial operating line station time, cycle time.

Table 2. Current operation scenario at VBL, Bhiwadi (Time to Station Arrangement)

Station name	Work Station	No. of Workers (w_t)	Task	Task times (T_t)	Task time / station	Station time
De palletizing	1	2	A	28	158	316
			B	130		
Un-caser	2	1	C	79	79	79
Dirt bottle	3	1	D	184	184	184
L.S-1	4	4	E	79	79	316
BW	5	2	F	156	156	312
Chip neck	6	1	G	194	194	194
L.S-2	7	4	H	78	78	312
Filler	8	1	I	144	144	144
Coding	9	0	J	189	189	0
L.S-3	10	2	K	162	162	324
Case pack	11	1	L	69	69	69
Palletizing	12	4	M	147	174	696
			N	27		
	Total			**1666**	**1666**	**2946**

Table 3. Idle Time (Cycle time per pallet = 194 sec)

Station	1	2	3	4	5	6	7	8	9	10	11	12
Task time	158	79	184	79	156	194	78	144	189	162	69	174
Idle Time	36	115	10	115	38	0	116	50	5	32	125	20

Total idle time during the original operation is 662 sec.

Table 4. New Design Idle Table

Station	1	2	3	4	5	6	7	8	9	10
Tasks	A,B	C	D,E	F	G,H	I	J	K	L	M,N
Task time	158	79	184	156	194	144	189	162	69	174
Idle Time	36	115	10	38	0	50	5	32	125	20

Idle time for new design of production line using Longest operating time principles is 431 sec and total task time is 1509 sec.

7. Longest Operation Time Application

New design of the production line falls in type-1 category from table 1, which aims in minimizing the station count and labor keeping the cycle time constant. Start assigning tasks to the first station, if there is any ideal time left at that particular station then assign the predecessor task to the same station such that total sum of tasks at the station does not exceed the cycle time of line.

In our present study, for initial operating design at station 3 one labor performs task D which consumes 184 seconds and has successor activity of L.S-1(task E) which is performed by 4 labors for 79 seconds. Also at station 6 one labor performs the task G of checking the chip necks for 194 sec from the exit of bottle washer has successor activity of L.S-2 (task H) which is again performed by 4 labor for 78 seconds.

Now using the LOT principles, we can combine task D and task E, at single station which uses 4 labors and performs task in 184 secs i.e. both dirt bottles and broken bottles are checked at single station. This adjustment reduces one labor and saves the task time for new line design at station-3. Similarly for new line design the station-5 is loaded with parallel tasks i.e. task G and task H are performed parallel at station-5

Refer TABLE VI -- New Design Idle Table Idle time for new design of production line using Longest operating time principles is 431 sec and total task time is 1509 sec.

Table 6. Comparison of initial and final design

Initial design				New design		
Station	Workers	Tasks		Station	Workers	Tasks
1	2	A,B		1	2	A,B
2	1	C		2	1	C
3	1	D		3	4	D,E
4	4	E		4	2	F
5	2	F		5	4	G,H
6	1	G		6	1	I
7	4	H		7	0	J
8	1	I		8	2	K
9	0	J		9	1	L
10	2	K		10	3	M,N
11	1	L				
12	4	M,N				
12	**23**	**14 Tasks**	**Total**	**10**	**20**	**14 Tasks**

8. New Line Design after Lot Application

Refer TABLE – V, New Design Station to task Arrangement.

9. New Production Line Sample Calculations

1. New idle time per day:

$$T_i = S_{new} * T_{c,new} - (T_{st,\ new})$$

$$[10 * 194 - (1509)] = 431 \text{ sec}$$

2. New Line efficiency:

$$[(T_{st})) / (\text{new total work stations} * T_c)]$$

$$(1509+194) / (10 * 194) = 87.70\%$$

3. New Balance delay:100 – 87.70 = 12.3 %

4. New Utilization:

[Theoretical number of workers] / [new total number of workers]

16/20= 80%

Refer Fig.5. Graph showing new line design- station time, cycle time

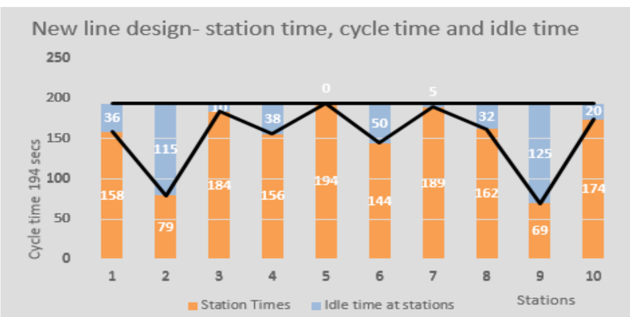

Figure 5. Graph showing new line design- station time, cycle time.

10. Cost Analysis and Comparison

At VBL, Bhiwadi a total of Rs.370 /- is allocated to the labor for 24 hours of working.

From calculations, it is observed that number of worklabor is 23, company pays to its labor Rs. 370 per day for 24 hours. It will we Rs. 185/- for 12 hours.

Therefore , total labor cost for initial operating design are:

Daily labor cost = Rs 185 * 23 i.e. Rs. 4225 /-

Monthly labor cost = Rs 4225 * 30 i.e. Rs. 1,26,750 /-

Top management pays Rs. 1,26,750 /- per month to the work labor.

New design to the production line:

Daily labor cost = Rs.185 * 20 i.e Rs.3700 /-

Monthly labor cost = Rs 3700 * 30 i.e Rs.1,11,000 /-

By comparison, new design in production line will improve the productivity of plant by reducing the labor cost per unit production. Difference in labor costs between the initial line and new design per month is Rs. 126750 – Rs. 111000 = Rs. 15,750 /- per shift per month. In short we can say that production line at VBL, is balanced with Largest operating time (LOT). A modified or new production line of 10 workstations and 20 labor was designed out of previously operated 12 stations and 23 labor. (Refer VI. TABLE Comparison of initial and final design)

Table 5. New Design Station to task Arrangement

Station name	Work Station	No. of Workers	Task	Task time / station
De palletizing	1	2	A B	158
Un caser	2	1	C	79
Dirt bottle + L.S-1	3	4	D E	184
BW	4	2	F	156
Chip neck + L.S-2	5	4	G H	194
Filler	6	1	I	144
Coding	7	0	J	189
L.S-3	8	2	K	162
Case pack	9	1	L	69
Palletizing	10	3	M N	174
Total		**20**	**14 tasks**	**1509**

11. Conclusion

The theses concludes saying that the line balancing heuristics can be used as effective tools to improve the productivity of the mass production line with various tasks and work stations. It considered idle time at stations as a king pin in reducing the production cost. Usually the wok labor utilization is an overlooked portion at the management level. Once we statistically analyze the labor costs and the percentage of ideal time, a need for improvement will roll out. Theses presented has just done that as a case study in a beverage factory. Where the high speed machinery require skilled labor, also in optimum quantity. In this study initial production line used 23 labor at various stations, after application of longest operating heuristic the quantity was optimized to 20. The total work stations initially were reduced from 12 to 10 using the same principle.

Below are attached few important graphs headlined station, work labor, station time, idle time, utilization, line efficiency and costs. The figures clearly represent the improvement in all the important attributes of a production line.

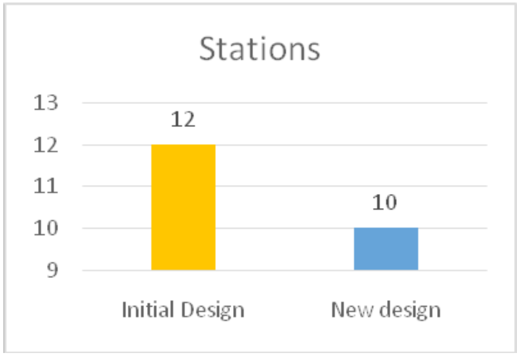

Figure 6. comparison of stations.

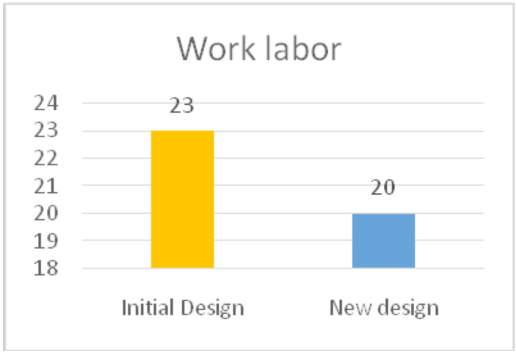

Figure 7. Comparison of work labor count.

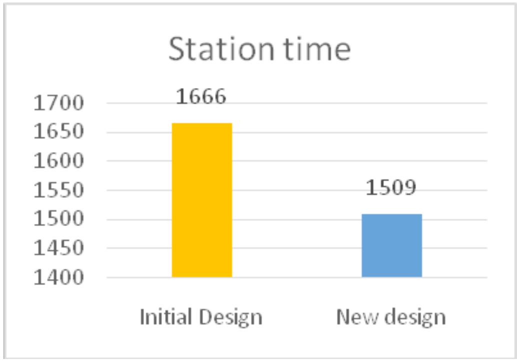

Figure 8. comparison of station time.

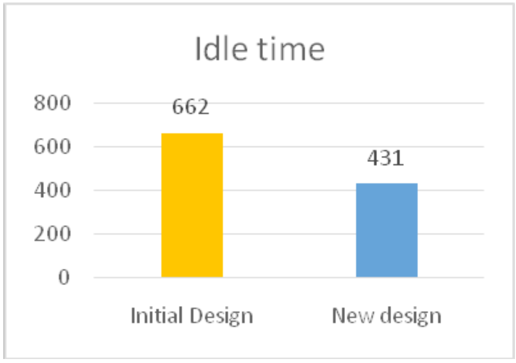

Figure 9. Comparison of idle time.

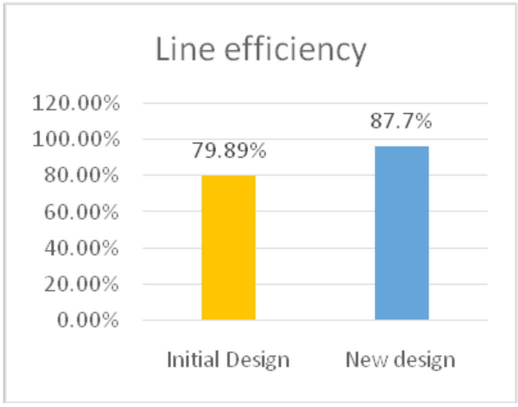

Figure 10. comparison of Line efficiency.

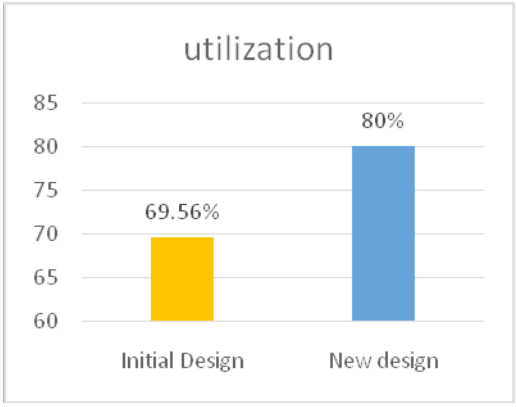

Figure 11. Comparison of utilization.

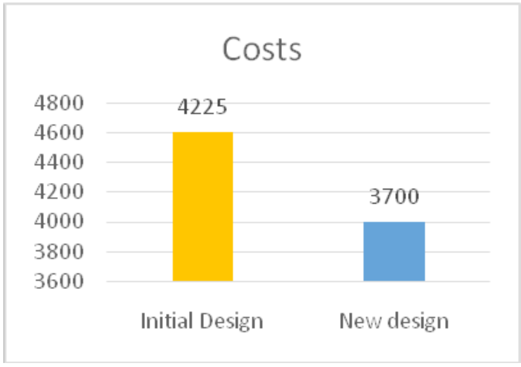

Figure 12. comparison of work labor costs.

Table 7. Time Study

Task number	Task Description	Observed time (sec) 1	2	3	4	5	Total time (sec)	basic time (sec)	Allowance Fatigue (4%)	Personal Allowance (6%)	Standard time per pallet	standard time per crate
1	Bringing empty bottles from store to production line with Fork lift	25	27	26	24	24	126	25	1	2	28	1
2	De palletizing onto the conveyor chain	124	126	123	123	94	590	118	5	7	130	3
3	Uncasing the empty bottles at Un Caser	72	73	71	74	70	360	72	3	4	79	2
4	Removal of Dirty bottles	164	167	170	168	168	837	167	7	10	184	4
5	Inspection of empty bottles at Light station-1	70	80	75	68	65	358	72	3	4	79	2
6	Washing of Bottles at Bottle washer			142			142	142	6	9	156	3
7	Inspection at Chip neck station exit to the Bottle washer	174	186	168	172	180	880	176	7	11	194	4
8	Inspection of washed bottles at Light station-2	68	70	74	67	75	354	71	3	4	78	2
9	Filling and Crowning of bottles with beverage			131			131	131	5	8	144	3
10	Coding Station			172			172	172	7	10	189	4
11	Inspection of filled bottles at Light station-3			147			147	147	6	9	162	3
12	Packing the Filled bottles into Crates	58.9	61	66.3	63.3	63.8	314.3	63	3	4	69	1
13	Loading the Crates on to Pallets	126	93	121	185	144	669.6	134	5	8	147	3
14	Moving the pallets to store by forklift	26	22	24	27	24	123	25	1	1	27	1
	Total						**5204**	**1514**	**61**	**91**	**1666**	**36**

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