Analysis of a Manual Mixed-Model Assembly Line in Food Processing Industry: A Case Study

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Abstract- Several factors affect productivity of Food Processing Assembly Lines (FPAL). Engineers and line managers usually do not recognize some of these factors and underutilize their production/assembly lines. In this paper, a special food processing assembly line is studied in detail and procedures are presented to illustrate how productivity and efficiency of such lines can be increased. The assembly line considered produces ten different types of freshly prepared salads on the same line, which is called mixed model assembly line. Problems causing delays and inefficiencies on the line are identified. Line balancing and related tools are used to increase line efficiency and minimize balance delays. The procedure and the approach utilized in this paper can be useful for the operation managers and industrial engineers dealing with similar assembly lines in food processing industry.

Keywords- Mixed-Model Assembly Line, Line Balancing, Line Efficiency, Productivity.

I. INTRODUCTION

Manufacturing assembly lines were first introduced by Henry Ford in 1900s for assembling automobiles in mass production and to take into consideration the effects of learning curve of the workers on the line. Ever since, assembly lines have been applied to all types of manufacturing systems, including food industry. In today's consuming society and ever increasing demand for products, only mass production can cope with high demand in competitive environment. Assembly lines in Food Processing Industry (FPI) are designed to assemble a huge variety of food products on the same line since it is extremely expensive to use a dedicated assembly line for each food product. These lines are called mixed model assembly lines.

A very common mixed-model assembly line in FPI is manual mixed-model assembly line. Manual assemblies are preferred since the quality of different ingredients must be inspected visually while assembling the final product. It is difficult to automate the quality control procedures in many cases. However, one of the first drawbacks in using workers for manual assembly is that the workers get fatigued easily and their assembly speed is limited. Also, high percentage of waste, non-value added activities, bottlenecks and congestions can occur within stations when using manual assembly. Each worker on the assembly line usually represents a workstation. The speed or the throughput of each workstation on the line is the numbers of products produced in a set time. The speed may differ between workstations which results in a bottleneck and congestion. Line balancing is necessary to minimize bottleneck effects, to reduce wasted time, and to increase line productivity.

Assembly lines have been studied by several researchers. Each researcher considered a different problem with specific set of goals, or the objectives. Production efficiency is one of main objectives for a manufacturing company. Cycle time is also an important factor that most authors have mentioned. Different authors define the cycle time differently. Zupan and Herakovic [1] considered production efficiency and improved the throughput through production leveling. They defined the cycle time as the time between end products that is pre-determined by the production rate. Adnan, et al. [2] defined the cycle time as the time it takes to do a process. It includes the time from the start of an operator until the work is ready to be passed on. The cycle time for each workstation is measured from the start of picking a part until it arriives at the next workstation. Adnan, et al. [2] and Zhang and Kucukkoc [3] studied the issue of how to reduce either the cycle times or the number of work elements. Zhang and Kucukkoc [3] considered work order constraints to reduce workstations and work-elements. Peng [4] found out that two-sided assembly lines should be preferred, in which work is added on both sides of the conveyor. Peng [4] also stated that to increase the production capacity, number of workstations must be minimized. Most authors agreed on grouping work families and taking their sequences into consideration. Perishability of a product is another issue in multi-product assembly lines. Buyukozkan et al. [5] considered product quality defects caused by stations and the importance of line reliability. He also stated that if the workload is different between the workstations, the cycle time will become more critical. Grzechca [6] also defined the cycle time as Zupan and Herakovic [1]. He indicated that if processing time of a workstation is more than the cycle time, then the workstation would become idle and have to wait.

A useful time measurement tool is “takt time”. Adnan et al. [2] defined it as the maximum time allowed in a workstation to meet the demand. The takt time and conveyor speeds are used to determine the production plan. Performance of the system is also measured differently depending on the objective being considered. Zupan and Herakovic [1] and Adnan et al. [2] agreed that throughput is a very efficient way of measuring system performance. Adnan et al. [2] defined throughput as “the average number of jobs produced per hour”. Adnan et al. [2] also defined efficiency as the ratio of current productivity to the largest productivity achievable. Grzechca [6] said that a good performance measure, especially for systems with conveyors, is to find the smoothness index. Zupan and Herakovic [1] and Grzechca [6] both conceded that arrangement or order of tasks that must be performed on the line is another important issue to consider.

In this paper, several problems causing inefficiencies and delays on the assembly lines are determined and procedures are proposed to increase production efficiency and balance delays on the lines. Line balancing tools are utilized to distribute the workload evenly and eliminate the bottleneck from the assembly line in order to increase its efficiency and productivity. Furthermore, various types of products are scheduled for production on the same line in such a way as to reduce the average work flow time.

II. MIXED MODEL ASSEMBLY LINE

The company selected for this case study was one of the biggest food processing industry in the Middle East. It had several assembly lines. However, one of the most intriguing lines was the manual salad production line. Ten different salad variants are produced on the same line with 9 workers. The products are all perishable and cannot be made-to-stock. Therefore they are made-to-order. The main processes on the salad assembly line are all in series. These main processes usually start with the plastic bowl, manually handled and filled with the core ingredient; then a plastic separator is manually added along with the specified dressing according to the salad variant; and then finally rest of the ingredients are consecutively added. After the main assembly of the variant, a salad sleeve is placed around the closed salad bowl. Every 12 finished salad bowls are manually placed in a carton box, where it is then stored in a chilled storage area waiting to be distributed during the night shift to local stores. Figure 1 shows the layout of the salad line.

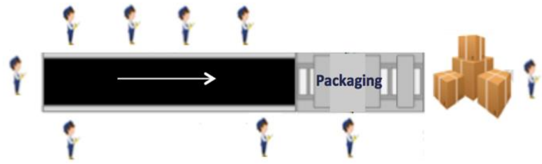

Figure 1: Salad assembly line layout

A shift analysis was conducted on the line in order to identify the bottleneck. As seen from Table 1, 23.42% of total time was lost due to minor stoppages. Figure 2 shows the distribution of minor stoppage percentage with respect to workers. 67% was due to sleeve worker while about 13% was due to packaging labor, who puts the finished products into the carton box.

Table 1. Shift Analysis for salad line

Line Status	State	Activity Duration (Hours)	Total Duration (Hours)	Percentage of Total (Hours)
Run/Up	Processing	3.36	3.36	43.47%
Down	Minor Stoppages	1.81	2.1	23.42%
	Wasted Time	0.29		3.75%
Setup	Preparation	0.35	1.27	4.53%
	Changeovers	0.5		6.47%
	Cleaning	0.42		5.43%
Break	Lunch break	1	1	12.94%
Total			7.73	100%

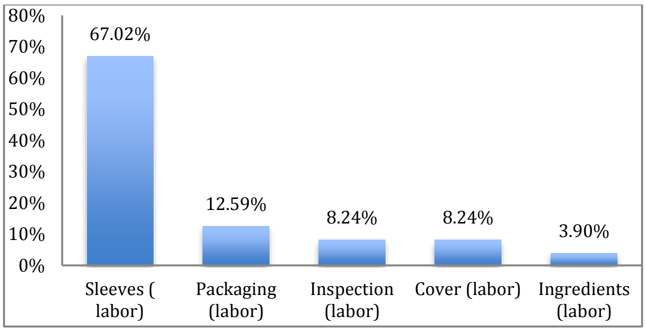

Figure 2: Pareto analysis of line stoppage reasons

The salad line consisted of nine workstations with one worker in each station. Each work station consisted of maximum of two work elements, which is the smallest division of a task. Added work elements in the same work station make up one task. The defined cycle time [Tc] is the time it takes to produce one product. Allowances are very important when deciding a standard cycle time, which is used to balance the line. In order to get the workstation cycle time, each work element must be observed and enough data should be collected. For our purpose, we have collected 35 data values for each work element in each station. The minimum time value represents the best processing time observed for each work element. It is combined with an allowance to give workstation cycle time.

Using the observed data for the assembly line for different types of products, allowances are calculated for each work element, which are then utilized to calculate work element cycle times, as well as the cycle time of each station (task). Table 2 shows the related times for different types of salads, assembled on the same line. The first row for each salad in the table is the sum of minimum observed times for the station i cycle time; the second row shows the calculated cycle time for station i (Tc_i) after adding the allowances in each case.

III. ASSEMBLY BALANCING AND IMPROVEMENT

Computer Method of Sequencing Operations for Assembly Lines (Groover [7]) was used to balance the line based on the station (task) cycle times obtained in the previous section. After line balancing, number of workers for some salad variants decreased. Number of workers for four season salad and Mexican salad decreased from 9 to 8 workers while for pasta salad it was decreased from 9 to 7 workers. The packaging labor had to assemble the box, fill it with salad products, seal it and sign it off. This caused many stoppages on the line. The best solution is to use two workers at the beginning of the shift to start opening the boxes. After that, one will continue assembling the boxes while the other will go on to the production line. Since opening the box is not done on the line, related work element is removed from line system.

Another problem for the minor stoppages was due to the sleeves worker's workload, which was distributed between the original worker and the inspection worker. Inspection worker was already putting sleeves for some products in some cases. By fractioning the workload, sleeve worker will be able to keep up with the line speed and reduce the minor stoppages. Calculated cycle time for each workstation was used to balance the line with an efficiency of 31.9%, cycle time 0f 7.85 seconds and

9 workstations. After modifying and improving the workstations, and rebalancing the line, efficiency was increased to 47.7% which was an increase of almost 50%. Number of stations was 8 and cycle time was 4.73 seconds. Work elements for mixing of some salad ingredients were combined and number of workers for some variants were removed and made as external work.

Table 2. Station/task cycle times calculated from data

Worker/Station/ Task No →		1	2	3	4	5	6	7	8	9
Caesar Salad	**Min Value**	1.46	2.38	1.28	1.27	1.2	1.33	1.06	6.53	-
	Cycle Time	1.46	2.66	1.28	1.27	1.2	1.33	1.06	7.86	-
Chickn Caesar Salad	**Min Value**	1.46	2.38	1.73	1.32	1.2	1.33	1.06	6.53	-
	Cycle Time	1.46	2.66	2.35	1.32	1.2	1.33	1.06	7.86	-
Greek Salad	**Min Value**	1.46	2.38	2.25	0.93	1.2	1.33	1.06	6.53	-
	Cycle Time	1.46	2.66	2.49	0.93	1.2	1.33	1.06	7.86	-
Pasta Salad	**Min Value**	1.43	2.38	1.16	0.97	0.86	1.2	1.33	1.06	6.53
	Cycle Time	1.43	2.66	1.16	0.97	0.86	1.2	1.33	1.06	7.86
Four Season Salad	**Min Value**	1.46	1.73	2.38	3.63	2.73	1.2	1.33	1.06	6.53
	Cycle Time	1.46	1.99	2.66	3.96	3.81	1.2	1.33	1.06	7.86
Tabul. Salad	**Min Value**	1.61	2.38	1.84	1.24	1.2	1.33	1.06	6.53	-
	Cycle Time	1.61	2.66	1.84	1.24	1.2	1.33	1.06	7.86	-
Corn Salad	**Min Value**	1.45	1.59	2.38	2.66	1.56	1.2	1.33	1.06	6.53
	Allowances	0	0.38	0.29	0	0	0	0	0	1.33
	Cycle Time	1.45	1.97	2.66	2.66	1.56	1.2	1.33	1.06	7.86
Mexic. Salad	**Min Value**	1.49	2.38	2.99	2.66	1.24	1.2	1.33	1.06	6.53
	Cycle Time	1.49	2.66	3.02	2.66	1.24	1.2	1.33	1.03	7.86
Seafd. Salad	**Min Value**	2.78	3.99	2.38	1	2	2.36	1.2	2.39	6.53
	Cycle Time	3.07	3.99	2.66	1	2.37	2.61	1.2	2.79	7.86
Fatosh Salad	**Min Value**	2.66	1.71	1.6	3.02	0.46	1.81	1.2	2.39	6.53
	Cycle Time	2.9	1.82	1.83	2.43	2.48	2.25	1.2	2.79	7.86

Line balancing was applied on each salad product. Table 3 summarizes the efficiency improvements after balancing the workload. Cycle time was reduced from 3.8 seconds to 2.3 seconds per product. In addition, shift time was reduced from 7.73 hours to 4.29 hours. After reduction of shift time by removing minor stoppages, line efficiency was increased from the varying range of 27% to 55% for different salads (average of 40% for all salads) to about 61%.

Furthermore, sequencing the variants of salads based on the number of workers while taking into consideration the shared ingredients between variants was also implemented for productivity improvement. Line 1 needed 7 workers, Lines 2-7 needed 8 workers; and lines 8-10 needed 9 workers and ordered in this sequence.

Table 3. Salad line variant and average efficiency

Salad Variant	Current LB	Adjusted LB	Adjusted Number of Workers
Greek Salad	30.9%	44%	8
Fatoush Salad	38.6%	54.5%	9
Chicken Ceaser Salad	30.6%	42.6%	8
Four Season Salad	35.8%	53.4%	8
Ceaser Salad	28.8%	39.6%	8
Seafood Salad	38.5%	53.7%	9
Corn Salad	34.9%	46.4%	9
Mexican Salad	31.9%	47.7%	8
Taboula Salad	29.9%	41.4%	8
Pasta Salad	26.2%	46.5%	7
Average	32.61%	46.98%	

IV. CONCLUSIONS

Mixed-model assembly lines must be very carefully analyzed and various available tools, including line balancing tools, must be utilized in order to increase line efficiency and its production rate. Manual mixed-model assembly lines are straightforward, where the workload and worker processing time defines many attributes for the assembly line. Line-balancing techniques are the best approach to solve most problems related to time and bottleneck analysis. As it has been shown in the analysis of a relatively simple assembly line in food processing industry in this paper, line efficiency was increased by as much as 44% and cycle time, as well as the required shift time, was reduced by as much as 40% and 45% respectively. The procedures and concepts presented in this paper can be utilized by operations managers and production engineers in order to improve their assembly lines and achieve higher efficiency and production output rate.

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Biograpy

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Angie K. Elsaadany, Rana Hassneiah and Altaf Alajmi are Industrial Engineers graduated from Kuwait University in 2016. They all work in the areas of production and operations management. They have worked on a project related to assembly line balancing and roductivity improvement in food processing industry under the supervision of Prof. M. Savsar.