ASSEMBLY SYSTEMS FOR LOW PRODUCT DEMAND
Estimation of Final Results

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Abstract: The paper considers assembly systems for low product demand. In the last five decades a large variety of assembly line structures and solutions procedures have been proposed to balance assembly line. Author of this paper compares single assembly line and assembly rotating round table. Estimation of final results of balance of both structures is discussed. It is shown that implementation of different structures are appropriate for low product demand. Numerical example of design assembly single line and assembly rotating round table helps to understand mentioned structures.

1 INTRODUCTION

Since always people created new items for their own needs and if these appeared to be helpful they tried both to improve them and manufacture them faster. In order to balance supply and demand the development of technology was a must. Definition of production can be therefore understood as transforming raw materials into a complete valuable product. This transformation combines various tasks of human work, automation and technology. It consists of steps after which the temporary product is closer to the final state. All these processes combined together define the assembly line which formal definition states: Industrial arrangement of machines, equipment, and workers for continuous flow of workpieces in mass-production operations. An assembly line is designed by determining the sequences of operations for manufacture of each component as well as the final product. Each movement of material is made as simple and short as possible, with no cross flow or backtracking. Work assignments, numbers of machines, and production rates are programmed so that all operations performed along the line are compatible. Automated assembly lines consist entirely of machines run by other machines and are used in such continuous-process industries as petroleum refining and chemical manufacture and in many modern automobile-engine plants. Although it does not seem difficult by the definition it is a complex field of research. One of the reasons may be the fact that the first automated production line was implemented in 20th century, actually in the year 1913 in Ford Motor Company, USA. In assembly systems the most often used is the flow line – a particular example of such a structure is the assembly line. Balancing of such a line consists of assigning various tasks to work stations (Salveson, 1955). The objective of balancing leads to defining the cycle time with constant number of work stations or inversely calculating the number of stations with given cycle time. In order to start balancing we need to have a finite set of work stations, tasks with corresponding times and relationships between them i.e. in a form of a precedence diagram. Balancing of an assembly line is the answer to the question - how to allocate resources on a flow line in order to finalize the end product most effectively. Effectively in this case means assigning tasks equally between stations to minimize idle times and equalize work load. A balanced line needs to fulfill (Sury, 1971), (Scholl, 1998), (Beker and Scholl, 2005):

- precedence diagram restrictions
- positive number of stations (at least one)
- cycle time c greater or equal maximum station time.

2 ASSEMBLY LINE STRUCTURE

There exist also a classification regarding plant layout which is used to describe the arrangement of

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physical facilities in a production plant (Scholl, 1998). Five types of layout can be distinguished:

- serial lines,
- U-shaped lines,
- parallel lines,
- parallel stations,
- two-sided lines.

2.1 Serial (Single) Lines

This is a very basic layout of a flow line production systems. It is determined by the flow of materials. It is mostly used for small size products. These lines have several disadvantages:

- monotone work,
- sensibility due to failures,
- inflexibility due to changing demand rates.

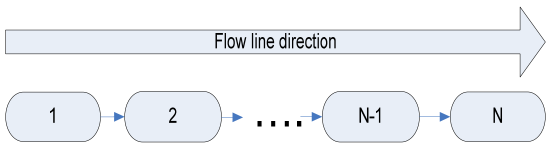

Figure 1: Serial line.

2.2 U-shaped Lines

In order to deal with the problems of a serial line it was redesigned to a form of U-shape (U-line). In such a line operators can work at more than one station simultaneously. For example first operator may both load and unload product units. As they are included in more tasks during production process they are gaining very important experience and enlarge horizons. It is very helpful in case of just-in-time production systems as it improves flexibility which is crucial in dynamically changing demand rates. What more, stations are closer together what results in better communication between operators and in case of emergency they are able to help each other effectively.

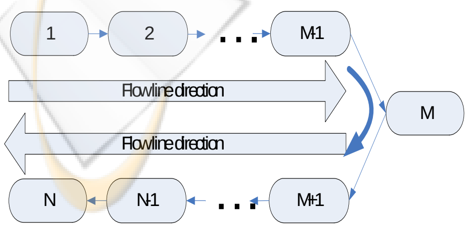

Figure 2: U-line structure.

2.3 Parallel Lines

In order to deal with problems described in case of a serial line it might be a good idea to create several lines doing the same or similar tasks.
Figure 2. U-line structure.
The advantages of such a solution (Sauer, 1997):

- increased flexibility for mixed-model systems,
- flexibility due to changing demand rates,
- lowered risk of machine breakdown stopping the whole production,
- cycle time can be more flexibly chosen which leads to more feasible solutions.

The optimal number of lines is however a subject of discussion for every single case separately.

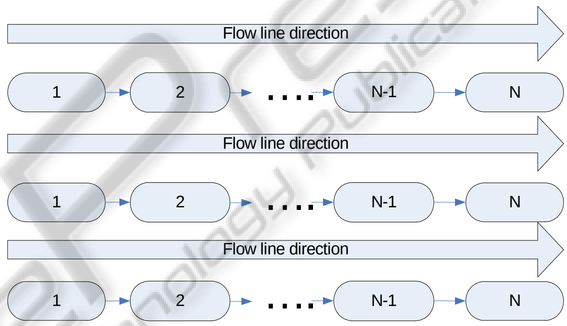

Figure 3: Parallel lines.

2.4 Parallel Stations

As an extension of serial lines bottlenecks are replaced with parallel stations. Tasks performed on parallel stations are the same and throughput is this way increased (Askin and Zhou, 1997).

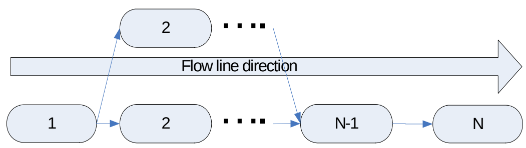

Figure 4: Parallel stations.

2.5 Two-sided Lines

This kind of flow lines is mainly used in case of heavy workpieces when it is more convenient to operate on both sides of a workpiece rather than rotating it. Instead of single working-place, there are pairs of two directly facing stations such as 1 and 2. As an example car line can be considered, and mounting some parts like: side – doors (left, right side), muffler (i.e. right side) or lights with no preference to the side. Such a solution makes the line much more flexible as the workpiece can be accessed either from left or right (Bartholdi, 1993). In comparison to serial lines:

- it can shorten the line length,
- reduce unnecessary work reaching to the other side of the workpiece.

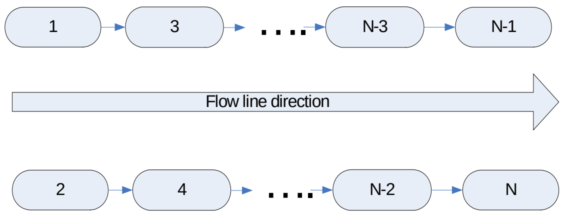

Figure 5: Two-sided line.

3 LOW MIX PRODUCT DEMAND

The volume of production is not a widely discussed topic over the literature. There are numerous articles about mixed-model assembly systems however they do not investigate the problem of low product demand. A formulation of a problem given in (Bukchin et. al, 2002) should give an idea about it. J. Bukchin indicates that it's long gone, when everybody was buying a black painted Ford T as long as it was cheap. Back than, high productivity was achieved by introducing a perfectly single model with no additional features.
Nowadays, the life cycle of a product is relatively short and the demand for varied product is high. Consequently, a set of similar products needs to be assembled in relatively low volume. The goal to such an approach is flexible responding to shorter product life cycles, low to medium production volumes, changing demand patterns and a higher variety of product models and options.

The conditions for such an installation are:

- assembly-to-order production,
- low product demand (low volume production),
- number of tasks greater than number of stations,
- lack of mechanical conveyance,
- Highly skilled workers.

It might be extended with conditions given by (Heike et. al, 2001):

- flexible fixtures,
- flexible tooling,
- delivery of material.

Such conditions give a good base for an assembly system robust to demand changes. Having a good balancing algorithm is a goal in this case.
When the demand for a set of similar products is insufficiently high in order to install a complete assembly line a solution given in (Battini et. al, 2007) might be used. Most of the authors use combined precedence diagrams in order to reduce multiple models into a single model. As the plant layout, they majority uses a straight line in some cases allowing parallel workstations for omitting the bottleneck effects. What more, some allow duplicating stations in series. Authors investigation U-shaped lines indicate their benefits over traditional serial lines. Some of them are:

- improvement in labour productivity,
- job enlargement for human operators,
- great interaction between operators,
- reduction in number of required workstations,
- lead time contraction,
- increase of flexibility.

They suggest (Aase et. al, 2004) this kind of lines in case of number of tasks less than 30 and 10 stations.
Fixed position layout should be taken into account dealing with heavy workpieces as it is more convenient to switch operators places rather than i.e. rotating the part (Heike et. al, 2001). Generally, when set-up times required between different versions are significantly high a job shop layout suits the best (McMullen, 2007).

4 ASSEMBLY ROTATING ROUND TABLE

The model and the procedure discussed in this section bases on (Battini et. al, 2007). D. Battini introduces a mixed-model assembly system consisting of a rotating assembly table with a fixed number of stations. It is a semi-automated system therefore some stations are occupied by human operators, some by machines and other are free. Human operators are indicated by "O" while automated ones as "A". The resource assignment is assumed to have no limitations, every operator or machine can be placed at any station of the table. The product assembled with such a system is assumed to be homogenous with some additional features that enable creation of joint precedence diagram with known tasks' durations. The rotating table is a multi-turn one, as a matter of fact a batch of one single product is completed in n number of turns, with $n \geq 2$. The table is an example of unpaced synchronous line controlled assembly system. It means that all the tasks performed by operators need to be completed before the shift of the table. It is assumed that it has a pneumatic motion and all operators need to press a button as an information that they finished their task. If all the tasks are finished the table switches their position with switch time $t_s \geq 2s$ (move time between 2 stations). Every switch of the table moves the workpiece to following station – one station at each table switch.

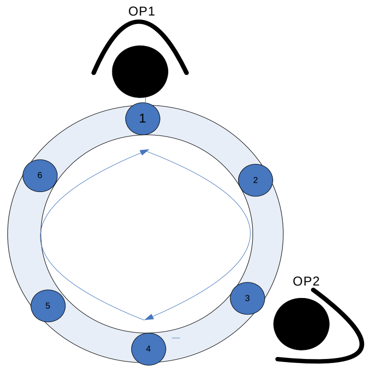

Figure 6: Example of rotating assembly round table (two human operators and six stations).

The assumption of rotating round table are:

1. The assembly rotating round table is multi-turn type.
2. Precedence diagrams of all model types can be accumulated into a single combined precedence diagram.
3. The line production policy is "assembly-to-order".
4. Workpieces are fixed on the table and there is only one workpiece at the station of the table at a time.
5. Each station has only either one operator or one actuator.
6. Idle operators cannot be used to help the operators of other stations
7. The table switches only when all the opened stations have finished their job.
8. The first task of the cycle is the load of all the workpieces of the same batch on a table and is always assigned to first operator.
9. The last task of the cycle is the download of the assembled units and can be assigned to any operator.

The objectives for this assembly system are:

1. Optimize the load balancing of each station activated in the rotating table
2. Optimize the resource positioning in order to minimize the entire make span of the assembly batch, and consequently, the average cycle time.

The goal of this paper is to compare serial assembly system and rotating round table.

5 ESTIMATION OF FINAL RESULTS OF BALANCING PROBLEM

Some measures of solution quality have appeared in line balancing problem. Below are presented three of them (Scholl, 1998).

Line efficiency (LE) shows the percentage utilization of the line. It is expressed as ratio of total station time to the cycle time multiplied by the number of workstations:

$$LE = \frac{\sum_{i=1}^{K} ST_i}{c \cdot K} \cdot 100\% \tag{1}$$

where:

K - total number of workstations,
c - cycle time.

Smoothness index (SI) describes relative smoothness for a given assembly line balance. Perfect balance is indicated by smoothness index 0. This index is calculated in the following manner:

$$SI = \sqrt{\sum_{i=1}^{K} (ST_{max} - ST_i)^2} \tag{2}$$

where:

ST_{max} = maximum station time (in most cases cycle time),
ST_i = station time of station i.

Time of the line (LT) describes the period of time which is need for the product to be completed on an assembly line:

$$LT = c \cdot (K-1) + T_K \tag{3}$$

where:

c - cycle time,
K -total number of workstations.

The average cycle time for rotating round table is calculated due to the formula:

$$C = \frac{\sum_{l=1}^{Z} \sum_{k:k \in AS_Z} \{\max[t(S_K)]_Z + t_s\} \cdot X_k}{K} \tag{4}$$

where:

C – average cycle time,
$t(S_k)$ – station load,

AS_Z – set of stations activated in turn z,
Z – 1,..,Z are table runs,
K – total number of stations,
t_s – switch time of the table,
X_k – distance in switches between the major load station and each activated in turn z.

6 NUMERICAL EXAMPLES

In this chapter an illustrative example of serial assembly line and assembly rotating round table is shown. An 8 tasks example of final product is considered. In both cases for founding end solution of balance a heuristic procedure (Update Immediately First Fit – Number of Followers) was implemented.

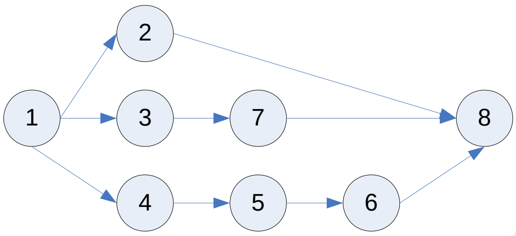

Figure 7: Precedence graph of numerical example.

Table 1: Operation time of numerical example.

Task i	Time t_i	Task i	Time t_i
1	18	5	7
2	13	6	14
3	6	7	11
4	9	8	2

6.1 Serial Assembly Line

We consider serial assembly line with two workers it means with workstation. It is a problem knows as Simple Assembly Line Balancing Problem Type 2 when the number of stations is given and value of cycle time is calculated.

$$c = \left\lceil \frac{\sum_{i=1}^{N} t_i}{K} \right\rceil \qquad (5)$$

where:
c – cycle time of serial assembly line,
t_i – operation time of task i.

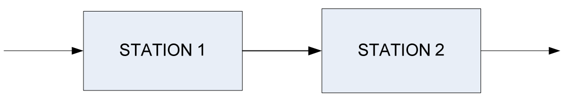

Figure 8: Serial two stations line.

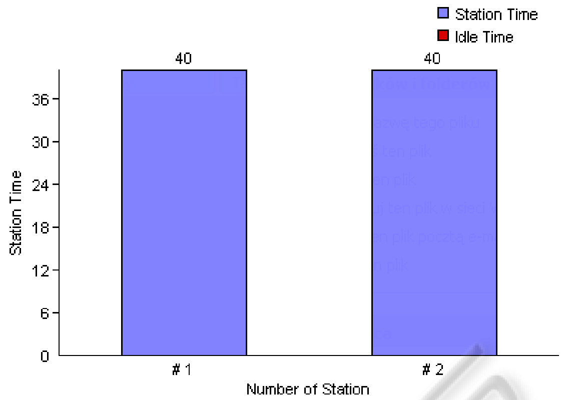

Figure 9: Balance of serial line for calculated example.

The calculated cycle time is 40 (the total operation time is 80) so we got final solution of balanced line: Station 1 {1, 4, 3, 7) and Station 2 {5, 2, 6, 8). The solution is optimal (mostly we obtain using heuristic method only feasible solution) and calculated measures are: SI = 0, LE = 100% and LT = 80).

6.2 Assembly Rotating Round Table

We consider now assembly rotating table with 2 human operators and six workstations. We obtain final results for 6 cases it means we calculate average cycle time for six different location of human workers. Starting from position 1 and 2 we relocate second operator to location 3, 4, 5 and 6. Operator 1 is always assigned to station 1. Relocation of Operator 2 causes that the distance between both workers changes.

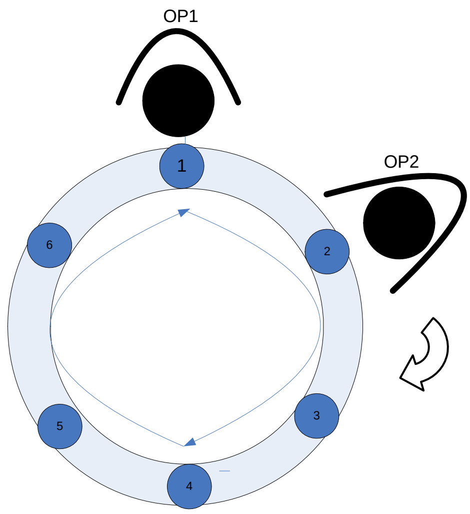

Figure 10: Location of human workers at assembly rotating round table (1st case) and direction of movement.

Using heuristic described in (Battini et. al, 2007) we obtained results which are presented in Table 2:

Table 2: Operation time of numerical example.

	OP 1	OP2	Cycle	Turns
1	Station 1	Station 2	53	2
2	Station 1	Station 3	61	3
3	Station 2	Station 3	53	2
4	Station 1	Station 4	56	3
5	Station 2	Station 4	61	3
6	Station 3	Station 4	53	2
7	Station 1	Station 5	58	3
8	Station 2	Station 5	56	3
9	Station 3	Station 5	61	3
10	Station 4	Station 5	53	2
11	Station 1	Station 6	70	2
12	Station 2	Station 6	58	3
13	Station 3	Station 6	56	3
14	Station 4	Station 6	61	3
15	Station 5	Station 6	53	2

The best average cycle time for assembly rotating round table is 53 and it occurs always when Operator 1 and Operator 2 are located next to other. In this case we need to execute only two turns. The final solution is: Operator 1 executes tasks 1 and 6 and Operator 2 executes tasks 2, 3, 4, 5, 7 and 8. Additionally we can calculate the time when final products is ready to unload from assembly system. In our case the ready product leaves the system in 216 units of time. We should remember that assembly rotating system is mostly effective in case when product demand is equal to the total number of stations.

7 CONCLUSIONS

In the paper two assembly systems were considered. First assembly lines were presented. Next assembly rotating round table was shown. The problems seems interesting for low product demand. Known procedures of solving balance of line structures allow to get very easy optimal or near optimal solution for two stations line. Investigated assembly rotating round table allows to quick changes of assembling different product. Heuristic procedure improves the result of average cycle time from 70 to 53. This kind of assembly table takes benefits from layout described in section 4 dealing with their disadvantages such as monotony, boredom, operators overload and communication. Different measures of final result (smoothness index, line efficiency, line time or average cycle time) simplify the choice of the most appropriate solution. We should underline that assembly rotating round table system don’t need additional sequencing procedure. Mixed product assembly deals with many precedence relations but we choose only this one with maximal number of tasks and connection. Therefore we calculated the balance of whole model with maximal task time operations. It allows to choice appropriate cycle time of turn. In serial lines we need to sequence the mix product model and sometimes to stop the line (different model cycle time) or to add additional parallel station.

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