Mapping work content allocation on an assembly cell

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Abstract: Work content allocation influences manpower utilisation and reachable output of a production cell. Usually, process maps show the order of precedence of technology steps, and workstations are defined so that neighbouring steps are performed on a bench, as far as constraints allow. The need of balancing operator work load might result in having one person serving neighbouring stations or benches.

This study aims to use graph theory and introduce bipartite graphs as a new approach to analyse work content allocation to work benches and workers. In this study, a set of nodes represents workers on the cell, and another set consists of the job elements; and edges connecting the nodes in the two distinct sets are representing a job element being completed by a worker. A projection of such a bigraph draws the backbone of the process flow chart, whereas another projection might indicate the connection and handover points between workers. A very similar projection is definable for the connection of workstations with valuable insights of potential layout improvements of a cell.

A possible application of drawing bipartite graphs of a manufacturing cell is to find out alternative ways of allocating work content, and harvesting ideas for brainstorming the layout improvements of the cell.

Keywords: assembly cell; process map; standardized work; work content; allocation; balancing; bipartite graphs

1 Introduction

Efficient use of resources is of major interest in electronics manufacturing, however, the high costs of clean room manufacturing also brings layout and floorspace requirements into focus. Lean manufacturing techniques help identifying losses such as interruptions of flow of production, for example buffers and supermarkets, idle times of machines, inefficient allocation of work contents, non-value-adding motions, and many more. However, waist majority of implemented process improvements are spot kaizens – workplace organization, parts presentation, simple tooling improvements, which rely on intuitive ideas of engineers, managers, and, most importantly, workers on the line.

Implementation of standardized work focuses on safe operation and predictable output by improving motions of operators to a more balanced work content allocation. It is often said in an implementation workshop that the team is seeking the best reachable combination of man, machine, material and information; poorly defining what “best” in this sentence means. It is hardly examined if a standardized work scenario introduces a critical job position into a cell, nor is if there are better options than the one implemented.

This study aims to introduce an analysis of the network of operators and machines in a final assembly cell of an electronics manufacturing company. The questions raised in the research study are:

- How can a bipartite graph represent the work content allocation of machines and operators of a manufacturing cell?
- What aspects of safe operation through allocation can be examined by using bipartite graphs, in addition to the traditional balancing of a manufacturing cell?

2 Literature review

2.1 Standardized work: capturing work content and balance

A key concept in the lean journey of a manufacturing company is the standardization of work, which extends far beyond the content of work instructions. In addition to mapping work contents and improving motions to reduce waste, training and job relations are key elements of standardized work (Misiurek, 2016). Improvement teams are seeking the best combination of man-machine-material and information, though it is poorly defined what “best” means in this context. In lean, this generally means less in-process stock, better repeatability of work resulting in better quality, better utilization of resources at an improved efficiency. The effectiveness of standardized work is measured on balance charts and capacity utilization metrics.

Capturing job elements, the method and key points of an element is crucial to create a proper work instruction (Dinero, 2005). However, allocation of jobs is more of an intuitive process of engineering experience. In our study, we used the precedence charts and already existing work instructions as a starting point for time measurements, and in situ observations to capture handoffs of material flow.

2.2 Graphs and their application in process mapping

Though graphs and networks are widely used nowadays to describe and analyse interconnectedness and features of networks (Barabási, 2016), hardly any examples of production networks are found where work content allocation is examined in detail.

The simplest process models, i.e., the process flow chart (Gilberth, 1921) are requested by the industry-wide quality standards. A typical process flow chart is shown on Figure 1. Flow charts are usually more complex than a simple linear series of steps, however industrial practice just captures the precedence of process steps.

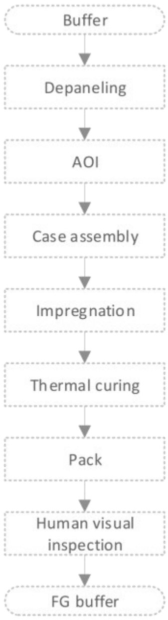

Figure 1

A section of the process flow chart of the area under study

A more detailed graph of the process flow is a value stream map were not only process steps but buffers and logistics connections are also highlighted. The aim of value stream maps is to provide common understanding of the manufacturing process to those who take responsibilities in running the production (Rother-Shook, 1999.)

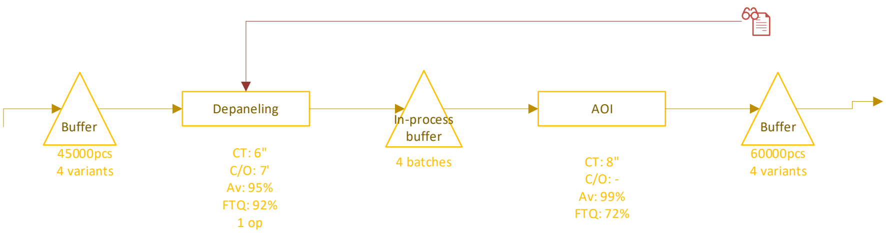

Figure 2

A section of the value stream map of the studied area

3 Methods

The manufacturing cell under study is one of the final assembly cells of an international electronics manufacturer company located in central Hungary. As the process is making a concurrent product in a competitive environment, claiming to be unidentifiable, neither the name nor the details of the product are unveiled in the study, and the job elements are grouped to a generic level without losing any important detail.

Job elements of an existing production process were observed and listed from various sources available in the industry:

- the technological order of manual and machine process steps,
- work instructions of operators of the manufacturing areas,
- observations, time studies and video analyses of work contents of the respective manufacturing areas in serial production conditions,
- motion counts of mock-up simulations.

Constructing a bipartite graph required manual job elements to be grouped into work contents performed outside a machine cycle. With the groups of work contents, I have reconstructed the flowchart so that a manual work content is always followed by a machine work, and a machine work is always followed by a manual operation. Typical details of manual work contents of a position can be:

- Before machine cycle
    - grab a piece
    - align into tool
    - do some manual assembly steps
    - close tool
    - send tool with parts into machine
- After machine cycle
    - remove tool from machine
    - open tool
    - remove part and place into in-process container
    - return tool to previous position
    - repeat from beginning with next piece

After improvements, in-process containers and trays were eliminated as handling and storing them added no value to the product. Thus, buffers were eliminated and manual work contents got reduced, without affecting the completion of value-adding job elements. As a result of improvements, the “after” state contains less work contents and requires less time to complete a product.

A flowcharting and graph drawing software, Microsoft Visio Standard 2016 was used to represent graphs of allocation.

4 Results

4.1 Constructing bipartite graphs

Bipartite graphs require adjacent nodes to be elements of disjunct sets of nodes. In the study, a manual work content is constructed so that it is always followed by a machine job, and a machine job is always followed by a manual work content, as shown in Figure 3. Direction of arrows shows the flow of material between stations and operators.

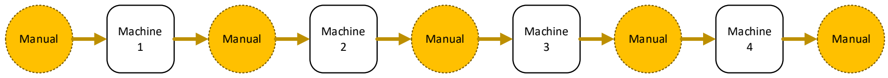

Figure 3
Precedence order of manual and machine process steps

By rearranging the above segment of the process flow diagram, I have constructed the two sets of work contents, as illustrated in Figure 4:

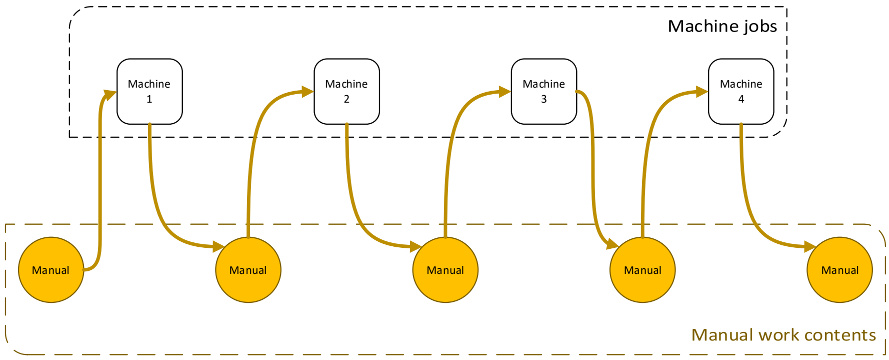

Figure 4
Precedence order of manual and machine process steps, grouped by type of job

As in the existing setup the manufacturing area followed a functional layout (Slack – Brandon-Jones – Johnston, 2013), the work contents were allocated to distinct operators of the functional units, making it impossible to combine work contents and thus reduce headcount, resulting in far underefficient operators.

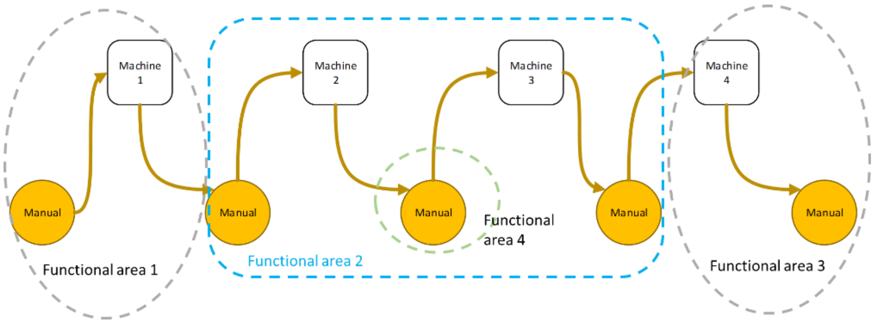

Figure 5
Illustration of functional units that limited manpower efficiency and flow

The lack of cooperation of areas resulted in extremely fluctuating buffer levels, causing overstock a day and insufficient material another day, and in parallel the operator efficiency remained far under target. The initial business problem, allocation and balance are illustrated on Figure 5 and 6, that is where improvements started from.

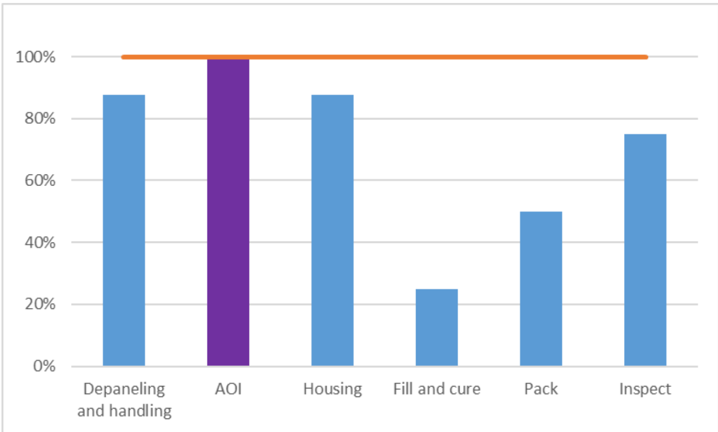

Figure 6
Balance chart of the affected workers, in % of the pace maker process.
Machine jobs apart from the pace maker process are not shown

4.2 Reallocating work contents

With the need of reducing in-process buffers and reducing headcounts, the management of the area turned ready to investigate if the equipments and workstations can be brought into a cell layout, thus enabling elimination of redundant job elements – i.e. place into tray, move and store trays, pick from tray in next job. The rearrangement of layout also enabled reducing walking distances.

Summing up the value-adding work contents and the remainder of handling activities, it turned that 3 people can cover work contents at design takt time.

Figures 7 and 8 show the allocation of work after the improvements, and the bipartite graph of the improved allocation. An arrow pointing from an operator to a machine means an operator serves the machine; an an edge directed from a machine to an operator indicates that machine is unloaded by the operator. As the work contents performed by the operators are indicated on Figure 7, the respective work instructions are also derivable.

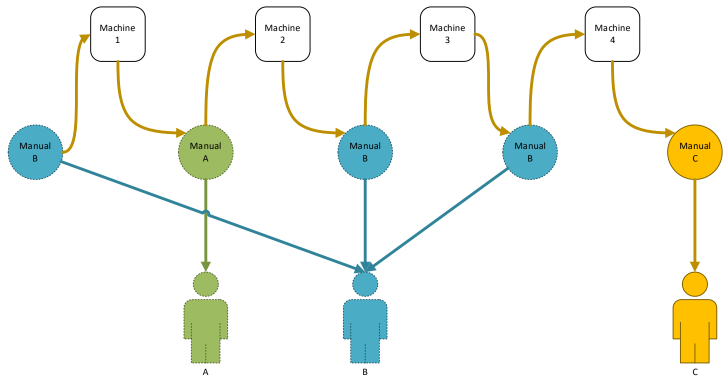

Figure 7
Allocating the work elements after improvements

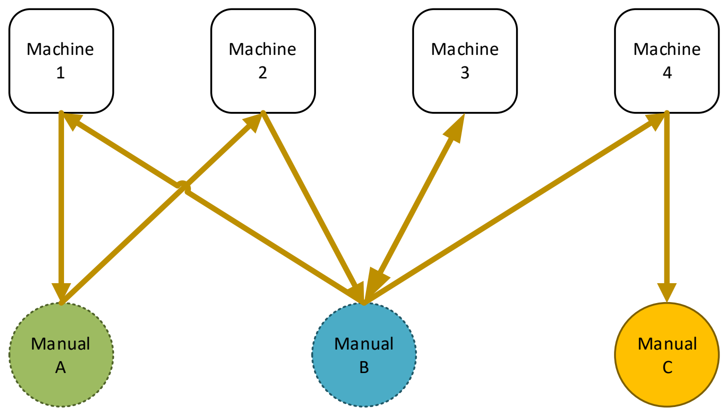

Figure 8
Bipartite graph of allocation after improvements

Breaking with the simple order of job elements, a contraintuitive grouping of non-neighbouring work contents of the precedence chart builds up the job sequence of Operator B of Figure 8. The sum of work contents added up to a better balance, compare Figures 6 and 9. Knowing that Operator B has the highest number of connections, i.e. serving four machines of different speeds and reliabilities, his/her duty is responsiveness, thus, the load must be lower. The team has decided to centralize noncyclical and off-cell activities to Operator B of Figure 8.

The proposed work content allocation has been tested on a mock-up simulation for a significant production run (AIAG PPAP, 2006).

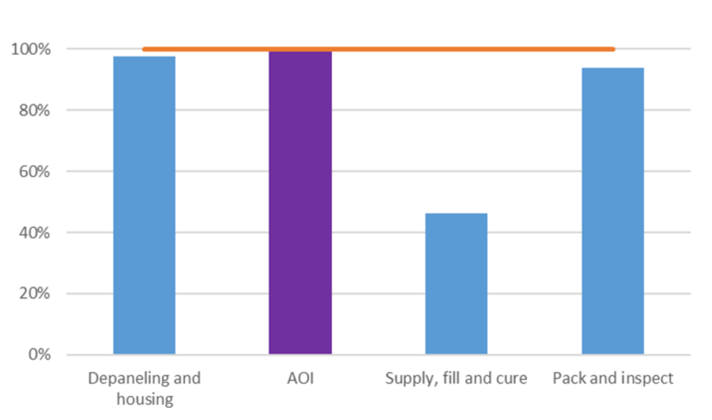

Figure 9
Balance chart of the reallocation of work contents

5 Discussion

Implementing standardized work brings better balancing of the work content allocation which is demonstrated by plotting yamazumi charts. The equivalent information content can be represented by adding weights to the edges: the weight of an edge could represent the time needed to complete the work content by the operator. The sum of weights of edges pointing to or from a node of an operator equals the load of work performed by the operator.

There are considerations so that in a case of a production break, i.e. lunch break of operators, the whole line shall stay in balance, with having the same in-process stocks steady, and having every station stop at the same time, and every operator go on break simultaneously. In spite of that intention, our team has observed that operators A and B behaved more interlinked, whereas operator C worked asynchronously to them, and no supervisorial attention was sufficient to keep the team together.

With the use of projections of the bipartite graph shown on Figure 6, we can find a feature of the cell that is in accordance with the observed behaviour of operators.

Projection to operators is constructed as explained in Figure 10. A directed edge between two operators exists on the projection only if there was a sequence of unidirectional edges between the operators through a machine. In the example below, Operator B serves Machine 1, then Machine 1 is unloaded by Operator A, thus, the section of the projection of the bipartite graph to operators would contain an edge from Operator B to Operator A. From Operator A to Operator B, one can also find an edge, as Operator A is loading Machine 2, and Operator B is unloading Machine 2. Thus, on the projection graph, between operators A and B, there will be a bidirectional edge.

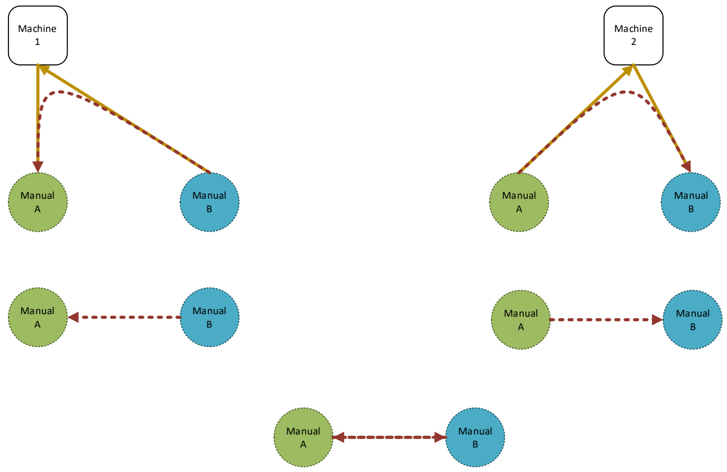

Figure 10
Explaining how the operator projection is constructed

The same procedure is then repeated between every operator, until there are no more machines left on the graph. Figure 11 shows the result of projection: Operator A and B are connected with a bidirectional edge, whereas there is an unidirectional edge from the node of operator B to C. The structure of the projection is in accordance with our observations of the behaviour of operators of the cell setup. Further studies are needed to examine the effect of inter-relatedness of operators and the meaning of the weights of edges to the safe operation of the cell.

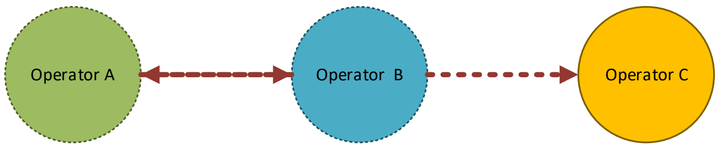

Figure 11
The operator projection of the bipartite graph of work allocation

A very similar series of steps is needed to project the bipartite graph to the set of machines, with the outcome shown on Figure 12. The machine projection of the allocation graph will not necessarily match the order of precedence of process steps; thus, its meaning is out of common sense of process engineers. The weights of edges to a machine compared to the machine cycle time determines whether the machine is a local bottleneck. The practical interpretation turned the attention of the engineers to workplace organization in that particular case: if a machine's cycle time turned longer than the weight of an edge, i.e., the sum of manual element times serving the machine, then a one piece in-process buffer seemed sufficient on the output side of the respective operator. Further studies are needed to examine the effect of reliability and other factors of variance on the safe operation of such a manufacturing cell.

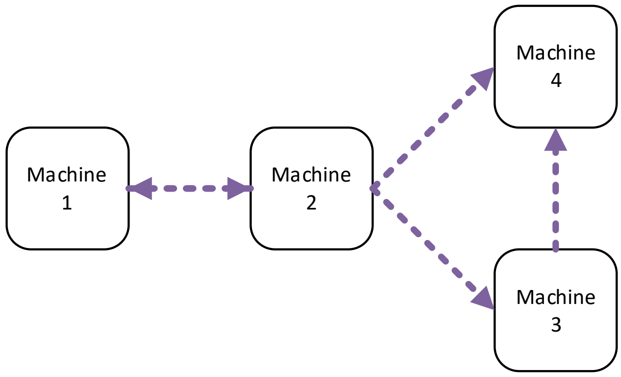

Figure 12
The machine projection of the bipartite graph of work allocation

6 Conclusion

Applying a bipartite graph for visualizing and analysing the machine and manual work content allocation enables analysing man-man and machine-machine connections separately.

The interrelatedness of operators discovered by projecting the allocation graph to the set of nodes representing operators turns our attention to job relations, and raises the question if some common-sense managerial considerations are worth to be studied deeper. In the manufacturing cell studied, it turned that the intuitive behaviour of operators during the breaks are in accordance with the projection, thus, it seems acceptable to split the team of cell workers during the break. The sum of weights of edges is a good indication of balance of operators.

Connection of machines shown on the projection might result in discovering the propagation of machine capacity losses, e.g. breakdowns. Machine balance chart and capacity utilisation chart can also be constructed similarly to the same of operator balance, which can serve as an input for right-sizing machines. Further studies are however needed to discover the potential of applying bipartite graphs on operational safety of manufacturing cells.

Acknowledgement

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