A DECISION MAKING TOOL FOR RECONFIGURABLE ASSEMBLY LINES - EUPASS PROJECT

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Abstract A decision making tool is proposed to evaluate assembly costs of micro-products (< 1 dm^3) and to compare different assembly strategies for a given product or product family. The tool takes into account equipment costs as well as running costs, for manual and automatic assembly. Its specificity lies in its ability to deal with different production mixes and production volumes over the life cycle of the product family. The underlying concept of the tool is that the cost of a given assembly function (or process) is constant for different technical solutions. This paper describes a cost evaluation for reconfigurable, manual, automatic or semi-automatic assembly lines, and shows its easiness of use through a simple test case.

1 Introduction

Assembly is a crucial issue in production, and a main cost driver for the total production cost (up to 80%) [1, 2]. Assembly is often more expensive than predicted, due to the lack of quality of components, production stops, and a lower than expected productivity. Companies are furthermore faced with the problem of short product life cycles, and uncertainty in the evolution of the demand. Industrials hesitate to invest in expensive assembly equipment that takes too much time to reach full productivity, and is too expensive for a pay-back within the product life cycle. The risks are too high. They would prefer to start with manual assembly for low production volumes, and be able to upgrade their assembly system to a more automated one very quickly when needed [3].

The purpose of the EUPASS project is to respond to this demand by offering a set of (re)configurable generic assembly modules that can very quickly be set up together to form a functional assembly system. The challenge of reconfigurable assembly systems is to offer economic profitable solutions. The aim is to keep

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Please use the following format when citing this chapter:

Wehrli, F., Dufey, S., Koelemeijer Chollet, S., Jacot, J., 2008, in IFIP International Federation for Information Processing, Volume 260, *Micro-Assembly Technologies and Applications*, eds. Ratchev, S., Koelemeijer, S., (Boston: Springer), pp. 345-352.

manufacturing industries in Europe by providing flexible solutions that can compete with the low wages in some countries such as China [3]. Keeping manufacturing in Europe is not only important from a workforce and employment point of view, but is essential to keep the know-how and the added value to products. It is thus important to also consider logistics, and specific costs related to outsourcing (such as costs due to quality problems and a less trained workforce) to get a complete picture of the productions costs. Cost modelling and evaluation is thus an important task during the development and planning process of a new product and its manufacturing environment.

One task of the EUPASS project is to propose a configuration tool for reconfigurable assembly systems, and the cost evaluation tool is part of this. The specificities of fast evolving demand and the possibility of fast changing physical configuration of the equipment have to be taken into account.

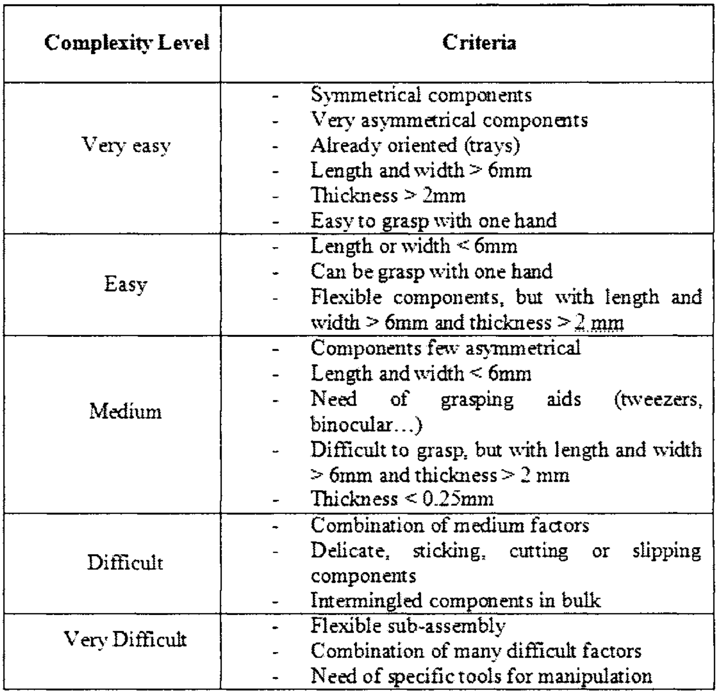
2 State of the art

There are very few ready to use cost models on the market. Most of the time, engineers do cost calculations by their own estimations and by adding different parts of equipment cost. Often, costs are underestimated by a lack on data on significant parameters such as yield, idle times and real productivity values. Existing cost models such as the model for automated assembly lines proposed by Oulevey et al. [4], do not take into account evolving or reconfigurable assembly systems or equipment during the product life cycle. They simply consider a fixed cost calculated on the total units produced by the equipment during the life cycle of the product. Furthermore, the possibility to mix manual and automated assembly is not integrated in the model. There is a need for a simple to use cost evaluation tool, which handles changing demand over the product life cycle, as well as evolving a mix of manual and automated assembly, and evolving equipment.

3 The cost evaluation tool

3.1 Concept for process cost

The concept lying behind this tool is that a set of standard parameters responsible for the assembly cost of a product can be defined for each generic assembly process. Those parameters are typically the manual assembly time, the equipment cost, the assembly yield, the time an operator is needed to watch an automatic process, etc. Those parameters are mean values, and thus not related to a particular technical solution that may be chosen. They are stored in an internal database of the tool. On the shop-floor, a given process will be more or less complex or tricky, depending on the design of the components. This has a direct influence on the set of parameters. To estimate the assembly cost of a product, one has thus to define the required generic processes, and their complexity level. Major factors are the precision required and the geometric dimensions. This information can either be found in the product specifications, or by analyzing the components to assemble. A set of guidelines is provided to the user of the cost tool to help him/her in defining the complexity level related to each process and to each component. The user of the tool should be an expert, which means that he should have strong assembly skills.



Complexity Level	**Criteria**
Very easy	- Symmetrical components - Very asymmetrical components - Already oriented (trays) - Length and width > 6mm - Thickness > 2mm - Easy to grasp with one hand
Easy	- Length or width < 6mm - Can be grasp with one hand - Flexible components, but with length and width > 6mm and thickness > 2 mm
Medium	- Components few asymmetrical - Length and width < 6mm - Need of grasping aids (tweezers, binocular...) - Difficult to grasp, but with length and width > 6mm and thickness > 2 mm - Thickness < 0.25mm
Difficult	- Combination of medium factors - Delicate, sticking, cutting or slipping components - Intermingled components in bulk
Very Difficult	- Flexible sub-assembly - Combination of many difficult factors - Need of specific tools for manipulation

Table 1. Complexity level evaluation for manual feeding and orientation

An important parameter is the manual assembly times for small and precision products. The method used is adapted from Design for Assembly of Boothroyd [1]. As Boothroyd's method covers the assembly of macro-products, it was important to ensure that both the parameters and the values were valid for the assembly of small parts. Times have been adapted, re-estimated and then tested in a company assembling micro-switches. An extract can be found in Tables 1 and 2. Furthermore, the presentation of the tables has been simplified, so that they are easier to use.

Another point behind the concept is that a few generic assembly processes cover most of the requirements. Other processes can be related to one of those generic processes, and there is thus no need to handle an exhaustive list and database. The most common processes will be proposed as standard EUPASS modules, or exist as internal standards of equipment providers.

Operation	Complexity Level	Time [s]
Feeding (manipulation + orientation)	Very easy	1.5
	Easy	3
	Medium	4.5
	Difficult	6
	Very difficult	8
Insertion	Very easy	2
	Easy	4
	Medium	6
	Difficult	8
	Very difficult	10
Screwing	Easy	5
	Medium	8
	Difficult	10
Measurement	Easy	2
	Medium	5
	Difficult	8

Table 2. Manual assembly times for a set of relevant processes

3.2 Business related parameters

Other significant parameters for the cost are related to the production volume over the time, the number of variants, the batch size, the productivity, and the cost of manual labour. This information is typically related to the market demand and the business strategy, and can be found in the business specifications. One of the objectives of the EUPASS project is to be very reactive, and thus to respond very closely to the production changes. Variations in product mix and production volume are two of the major and most frequent changes. The cost tool handles this by calculating the costs per period, a period being a duration during which there are no major changes in the production mix or volume, or in the physical configuration of the line.

The set of standard values thus also includes parameters such as mean setup time, mean configuration time, mean intervention time, or mean maintenance time.

The tool provides a set of pre-selected outputs that helps the expert user in the choice of a configuration. One of the outputs is an indication of the most cost effective solution between automation and manual assembly for each process and each period. Other outputs are the total cost per period, the unit cost per period, the productivity per period. The user may also be interested in other data, such as the set-up cost, the operator intervention cost, etc, which he may directly consult in the tool. The evolution of the cost over the different periods helps the designer of the assembly line to choose the most interesting solution in a cost point of view. If, for example, the tool indicates that a manual process is more suitable for a pick and place, and an automatic process more profitable for a control on a given period, he will chose a semi-automatic system. If for a later period with a higher production volume, the tool indicates that the automatic solution becomes more interesting also for the pick and place, he can plan the reconfiguration of his assembly system at the right moment.

4 Case study

In order to validate the cost evaluation tool and to show its working, an example is illustrated. The case study handles with the insertion of an inner nut in a cog wheel. As shown below (Figure 1), there are three kinds of material for the cog wheel (PVC, steel, brass), all of them are the same size.

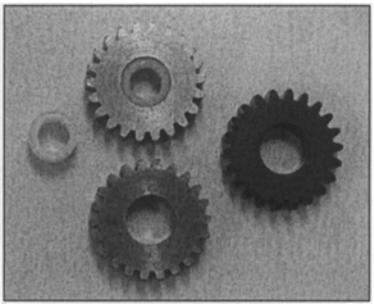


Fig. 1. Case study: three types of cog wheels with one type inner nut

The assembly sequence is the following:

1. Feed cog wheel from bulk
2. Place cog wheel on a support
3. Vision test
4. Transfer
5. Feed nut from bulk
6. Place nut in the centre of the cog wheel
7. Insert the nut into the cog wheel
8. Transfer of the assembly
9. Evacuation of the assembly

4.1 Scenario

The life cycle is presented in Figure 2 and Table 3, which contains the production volume and the batch size for the three variants (PVC, steel and brass) and for each period. The production duration being 2 years and 6 months and the period duration being 3 month, the whole production is divided into 8 periods.

The batch size is more or less proportional to the production volume, except for period 5 and 6. The production volume remains constant, but batch size 1'000 in period 5 and 10'000 in period 6.

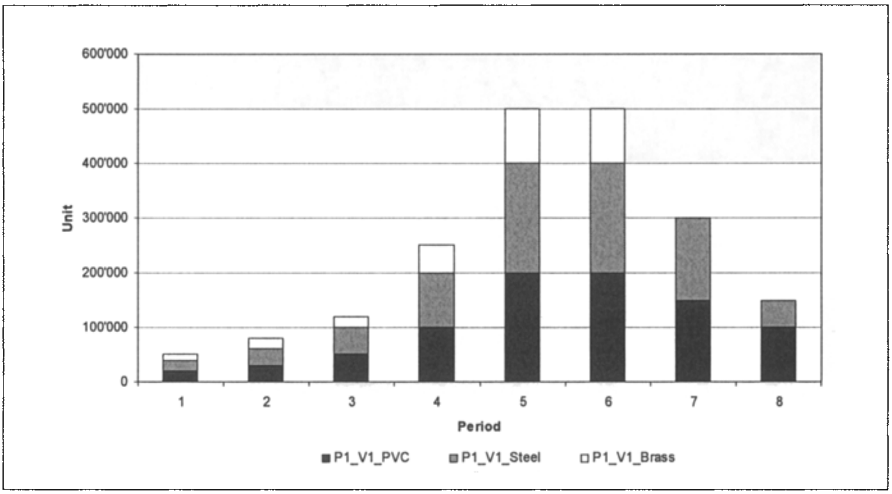


Fig. 2. Production volume for each product and each period

Product to be assembled	Batch size P1	Batch size P2	Batch size P3	Batch size P4	Batch size P5	Batch size P6	Batch size P7	Batch size P8
PVC-variant	200	200	500	1'000	1'000	10'000	500	500
Steel-variant	200	200	500	1'000	1'000	10'000	500	500
Brass-variant	50	50	100	200	1'000	10'000	0	0

Table 3. Batch size for each product and each period

4.2 Production mode comparison

The tool provides the assembly cost for the recommended optimal mode (mix of manual and automatic), as well as for full automatic and for manual production (Figure 3). The optimal solution is not necessary the cheapest way to assemble in one period, but the cheapest global solution, because configuration costs have to be taken into account.

Process list	Period 1	Period 2	Period 3	Period 4	Period 5	Period 6	Period 7	Period 8
Cog wheel feeding	M	M	M	A	A	A	A	M
Positionning cog wheel	M	M	M	M	A	A	M	M
Vision test	M	M	M	A	A	A	A	M
Transfert	M	M	M	M	A	A	A	M
Feed nut	M	M	A	A	A	A	A	A
Positionning nut	M	A	A	A	A	A	A	A
Insert nut	M	A	A	A	A	A	A	A
Transfert	M	A	A	A	A	A	A	A
Evacuation	M	M	M	M	A	A	M	M

Table 4. Optimal production mode recommended by the tool for each process and each period

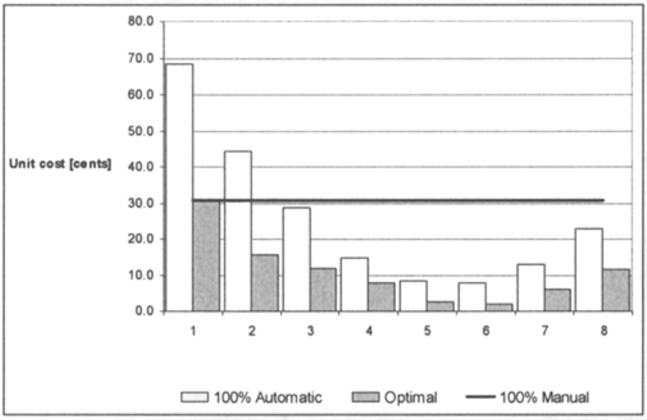


Fig. 3. Costs comparison between a full automated line, a full manual line and the optimal solution proposed by the tool

5 Conclusion and further work

The specificity of this tool is that all costs are calculated for each production period during which the production volume, the production mix and thus the configuration of the line is fixed. This allows taking into account the product life cycle, which is the main added value of this tool. Furthermore, the tool allows comparing the cost of automatic and manual assembly.

Further work to improve the tool will be to complete the internal database, and to check the tool on a real case. The integration of shipping cost, which is another logistics aspects that will help to compare the cost in different countries (mainly European or occidental versus low wage countries).

Acknowledgements

The manual assembly times and parameters have been elaborated and tested with M. Vito Carrea of the company MICROPRECISION ELECTRONICS SA, in Vouvry, Switzerland.

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