A Methodology for Assessing the Cost Effectiveness of Assembly Processes

Kwabena Agyapong-Kodua, Svetan Ratchev

A methodology for assessing the cost effectiveness of assembly processes

K. Agyapong-Kodua* and Svetan Ratchev

Precision Manufacturing Centre, University of Nottingham, NG7 2RD, UK

{k.akodua, svetan.ratchev} @nottingham.ac.uk

Abstract. Assembly processes are undergoing frequent changes as a result of the current drive for agility and rapid product solutions. These changes induce complexities and dynamics in the survival of most Manufacturing Enterprises (MEs). To remain competitive, MEs have to continuously and flexibly adjust through the redesign and organisation of their manufacturing and assembly processes as well as resource elements, with the aim to improve 'cost' and 'values' generated. Cost and values are part of key performance indicators necessary for determining the economic viability of assembly processes. The paper therefore presents a methodology capable of capturing, modelling and using information related to cost and value generation for in-depth assembly process analysis. This form of analysis can help determine assembly process efficiency and therefore support the selection or redesign of assembly processes for maximum value realisation at minimal cost.

Keywords: Assembly processes, Enterprise Modelling (EM), Simulation Modelling (SM), Manufacturing Enterprises (MEs)

1 Introduction

In most assembly processes, different component types are required to flow through networks of resourced activities to enable final (or semi-finished) outputs of various forms to be achieved [1]. This means that assembly processes and their associated resource elements must be designed and organised such that value is added to components along well defined process threads to obtain outputs meeting customer requirements. Best industrial practices recommend that competitive assembly processes should have less cost consumption and high value generation [2] . It is also necessary that values so attained are translated into equivalent monetary 'regard' in the form of prices customers are willing to pay. Currently, many MEs in view of the above reason, design their assembly processes to compete on the basis of their ability to realise economies of scope; by deploying a constrained set of people and technical resources to realise one or more product families [3]. This is not simple to achieve because most MEs are composed of complex interrelated processes such that changes made to one process thread induce dynamics in the ME by having causal and temporal effects on other process threads [4].

Many methods for modelling cost and values have been provided in literature but clearly, none of these methods fully capture the dynamics that impact on cost and value generation in assembly processes. The paper therefore takes an initial look at current best methods for modelling cost and values associated with assembly processes and based on the strengths and weaknesses of existing methods, proposes an innovative modelling methodology capable of capturing aspects of dynamics impacting on processes. This methodology is applied in modelling the product realisation processes of an air-conditioning manufacturing plant based in China.

2 Modelling cost and values generated by assembly processes

Literature has shown that in broad terms, current best modelling techniques with potential to define, measure and utilise aspects of value and cost information in assembly processes can be classified into:

1. Process Mapping techniques (PMs) [5, 6]
2. Enterprise Modelling (EM) techniques [7, 8].
3. Cost Modelling (CM) techniques [9, 10]
4. System Dynamics (SD) Modelling techniques [11, 12]
5. Business Process Simulation Modelling (SM) techniques [13, 14]

PMs (for example: value stream mapping, process activity mapping, overall lead time mapping, product variety funnel, etc.) are not suitable for capturing aspects of complexities and dynamics in assembly processes [15, 16]. This is because most of the PM tools were designed for single product flows and do not reflect real-time dynamic instances of multiple assembly processes. It has also been reported that PM tools do not possess the ability to reflect causal impacts of activities on processes [1]. EM tools (for example: ARIS, CIMOSA, GIM, PERA, GERAM, TOGAF, etc) relative to PM tools offer additional modelling concepts that enable the capture of semantically rich models of various aspects of processes [17-19]. In theory enterprise modelling approaches facilitate the design and development of better assembly processes and systems, and can improve the timeliness and cost effectiveness of change projects in MEs, but full and industry-wide benefit in practice is yet to be realised [8, 15, 20]. Also EM tools generate models which are static and demand appropriate transformations into 'real-time' dynamic simulation models. Business Process Simulation Modelling techniques (SMs) on the other hand generate useful dynamic representations of discrete processes in MEs. They are therefore suitable for 'what-if' analysis of assembly processes and supports virtual process design technologies. However, SMs do not suitably model 'cause and effect' structures of assembly processes and are therefore not suitable for detailed 'process dynamics and complexities' modelling. Cost modelling techniques on the other hand provide a framework for estimating cost based on mathematical algorithms derived from observations and analysis of historic data. They can provide support to any of the modelling techniques explained above in estimating assembly process cost. Literature however shows that SD techniques offer a unique approach towards the modelling of complexities and dynamics in systems [12, 21, 22]. Later attempts have been made to use these techniques in support of the design of assembly systems [17, 23]. Little successes have been reported though and this may be due to the inability of these techniques to critically model processes at the elementary level.

3 A methodology for assessing the cost effectiveness of assembly processes

Observing the strengths and weaknesses of current best modelling methodologies for assessing the cost effectiveness of assembly processes, the authors are of the view that the synergistic application and stage wise integration of enhanced aspects of the 5 modelling techniques would be appropriate. Through the integration, the weaknesses of the individual techniques will be marginalised. Figure 1 shows the various process stages involved in the proposed modelling methodology. At each process stage, the needed inputs are described. For example, to generate enterprise models of MEs, key ME information will be required. This can be derived through interviewing key knowledge holders in the ME and a complementary use of ME data sheets.

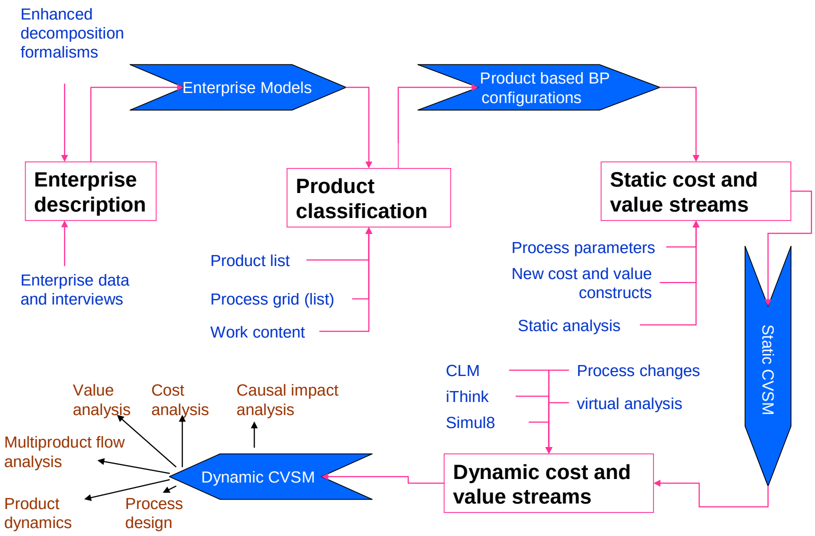

Fig 1: Proposed modelling methodology

The outcome of the Enterprise Model is transferred to the next stage of the modelling exercise together with other data sets on product types and assembly operation times to generate what in this paper is termed as a product-based 'Process-Oriented Configuration' (POC). The derived POC is supported with value and cost constructs together with various process parameters to form an enhanced static cost and value stream model capable of being used for various forms of static cost and value stream analysis. The end result of this first stage of 'static modelling' can readily be translated into 'fit for purpose' simulation models which can underpin various forms of dynamic cost and value stream analysis. The finally derived model is useful for multi-product flow dynamic analysis, causal impact demonstrations, dynamic cost and value analysis as well as providing a tool and specific case models for assembly process improvement and redesign.

4 Case application of modelling methodology

The case study relates to an engineer-to-order air-condition manufacturing company based in China, herein, referred to as AirCon China. AirCon China specialises in the customised design, manufacture and assembly of air conditioners used at power stations, airports, hospitals, in trains and special environments. The major challenges related to their assembly processes included:

1. The high cost of realising assembly processes
2. Improper planning of assembly processes because of the random nature of their production orders

4.1 Modelling the assembly processes for cost and value analysis

Based on the modelling methodology presented in section 3, enterprise models were created to facilitate understanding and provide a basis for in-depth analysis of operations in AirCon China. Based on the Open Systems Architecture for Computer Integrated Manufacturing (CIMOSA) template, several context, interaction, structure and activity diagrams were created to show how Domain Processes (DPs), Business Processes (BPs) and resources interacted. This was considered necessary because the interconnections of activities in the company needed to be understood so that their causal impacts on the assembly process could be adequately modelled. This was considered novel because best literature understanding of process modelling, models in isolation and thus the implication of other activities on the segment of interest cannot be adequately visualised and controlled for ongoing management of businesses. To help reduce the complexities impacting on the assembly processes and to conveniently model the processes, a product-based 'Process-Oriented Configuration' (POC) was used to classification the products. This was based on routing the different products through the different sets of assembly processes and calculating their work content. Based on this exercise, 5 main product types were observed: mostly assemble air cooled A/Cs, mostly assemble water cooled A/Cs, mostly make small sized A/Cs, mostly make large sized A/Cs, and mostly assemble large sized A/Cs. Based on this classification, an initial top level cost and value stream model was created for first-off cost and value analysis (see figure 2). This has been reported in [2]. At the next stage, systems dynamics models were created to capture all the various factors which induced dynamics into the assembly processes. These models reported in [2] were achieved through the use of the causal loop and iThink simulation modelling techniques. Further to this, a discrete event simulation model was created to perform various experiments related to cost and value realisation. A snapshot of the simulation model created with Simul8 is shown in figure 3.

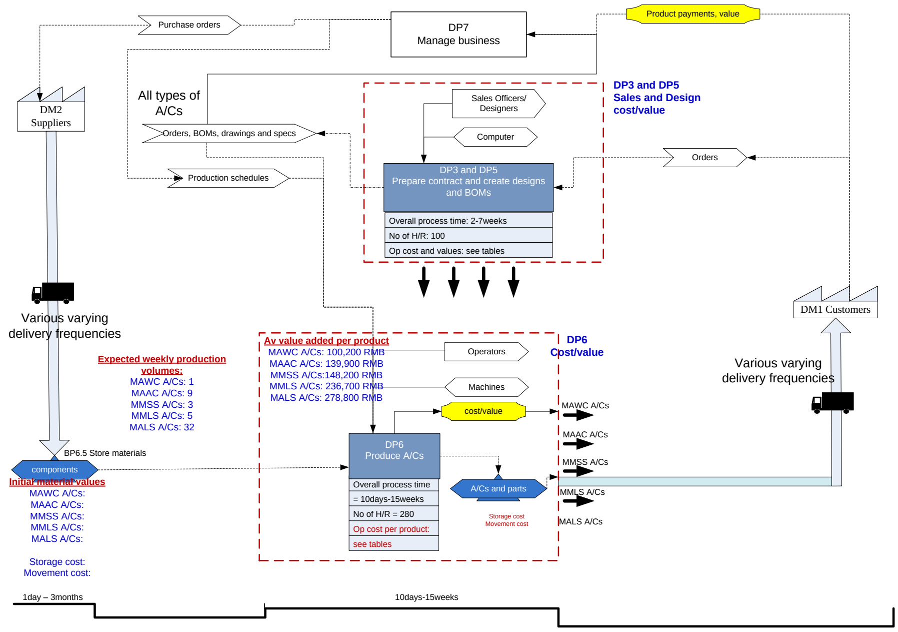

Fig 2: A top level static cost and value stream model

The operating assumption in this modelling methodology is that value is added to materials when introduced into production and assembly processes. During the value addition process, resources are consumed and therefore cost is incurred in the process. The model shown in figure 3 is a top level cost and value stream model consisting of sub models representing the elementary activities in the various processes as depicted in the enterprise model.

Several results were obtained through running experiments with the model. For example in the as-is assembly process, the results shown in Table 1 was obtained. A set of key performance indicators such as inventory cost, operation cost, queue sizes, average queuing time and values generated were chosen to benchmark one experimental result against the others leading to the choosing of the best configuration of assembly processes and resources.

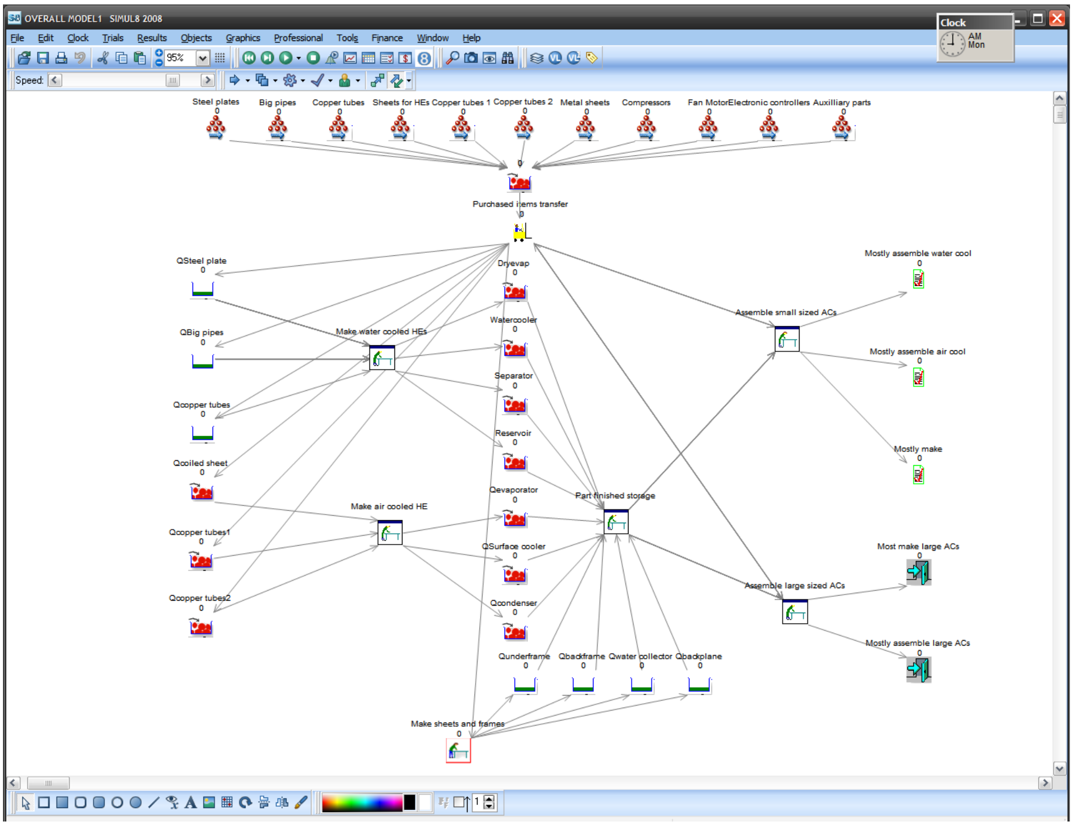

Figure 3: Top level dynamic cost and value stream model

Table 1: Sample result for as-is air conditioners' manufacturing

BP No.	Top level BPs	Total number of operators	Average utilization	
BP6.1	Fabricate metal sheet (Metal sheet shop)	83	40%	
BP6.2.1	Make air cooled heat exchangers	40	42%	
BP6.2.2	Make water cooled heat exchangers	26	65%	
BP6.3	Assemble small sized A/Cs	66	80%	
BP6.4	Assemble large sized A/Cs	60	81%	
BP6.5	Store materials	5	40%	
	Total	280	58%	
	Actual throughput	**Expected throughput**	**Actual value realized (RMB)**	**Expected value (RMB)**
Mostly assemble water cool A/C	5	13	501,000.00	1,302,600.00
Mostly assemble air cool A/Cs	50	118	6,995,000.00	16,508,200.00
Mostly make small size A/Cs	12	42	1,778,400.00	6,224,400.00
Mostly make large size A/Cs	50	78	11,835,000.00	18,462,600.00
Mostly assemble large A/Cs	120	485	33,456,000.00	135,218,000.00
			54,565,400.00	177,715,800.00

The authors conducted a number of experiments with the verified model of figure 3 to observe which combinations of resources and organisation of processes best generate high values and low process cost. In principle, many parameters can be used as levers to manipulate the behaviour of virtual production models, but the following were chosen as useful parameters in the context of the research:

1. The cost and values realised during the execution of as-is assembly processes
2. Changes related to product variance and their effects on cost and value generation
3. Changes related to mechanical and human resources and their impacts on cost and values

Through the experiments, it was observed that when orders related to the production of mostly assemble A/Cs was prioritised over the others, AirCon China achieved very high values. Another relevant observation was that when materials were assumed to be readily available, assembly was harnessed and overall throughput increased as shown in figure 4.

.

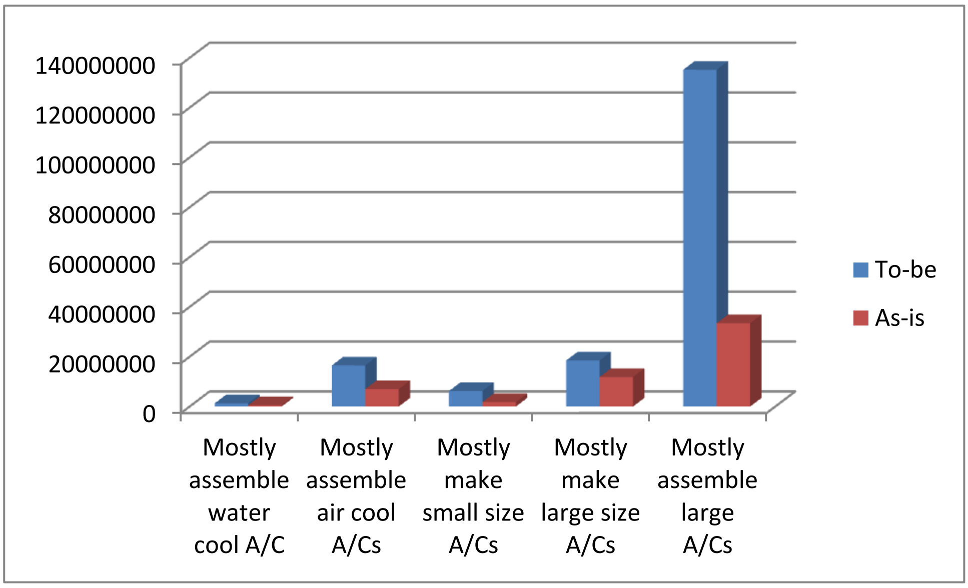

Figure 4: Value indications of 'to-be' and 'as-is' models

Also observed was that when production schedules were aligned with assembly shop models, inventories were minimised and production cost reduced. These observations from the results of the models were considered very useful and were used as basis for recommending specific operational solutions about AirCon China assembly processes

5 Conclusions and future work

The paper has presented a methodology for modelling assembly processes and performing various process improvement analyses related to cost improvement and value addition. This consists of the integration of techniques within the domains of enterprise modelling, cost modelling, process modelling, systems dynamics and business process simulation modelling. The case application of these methodology showed that assembly processes can be captured and analysed and based on specified performance indicators, processes can be redesigned and resourced to meet company requirements.

Further research is ongoing to establish how the transformation from one stage of the modelling process to the other can be automated to reduce the effort and rigour required in each of the modelling tools.

Acknowledgement

The authors will like to thank colleagues of the Precision Manufacturing Centre, University of Nottingham, who supported in various ways to achieve the objectives of this research.

References

1. Agyapong-Kodua, K., W. Bilal, and R.H. Weston. *Process cost modelling in Manufacturing Enterprises*. in *4th International Conference on Digital Enterprise Technology*. 2007. Bath, United Kingdom.
2. Agyapong-Kodua, K., *Multi-product cost and value stream modelling in support of business process analysis*, 2009, PhD Thesis, Wolfson School of Mechanical and Manufacturing Engineering, Loughborough University: , Loughborough. p. 437.
3. Weston, R., et al., *On Modelling Reusable Components of Change Capable Manufacturing Systems.* Proceedings of Institution of Mechanical Engineers Part B: Journal of Engineering Manufacture., 2009. **223**(3): p. 313-336.

4. Agyapong-Kodua, K., *Cost and value stream modelling*. 2010, Saarbrucken, Deutschland: VDM Verlag Dr. Muller GmbH & Co.
5. Bicheno, J., *The Lean Toolbox*. 2000, Buckingham, England: PICSIE Books.
6. Womack, J.P. and D.T. Jones, *Lean thinking - Banish Waste and Create Wealth in Your Corporation*. 2003, New York: Free press.
7. CEN/ISO, *Enterprise integration - Constructs for modelling.* 19440.
8. Vernadat, F.B., *Enterprise modelling and integration; Principles and Applications*. First edition ed. 1996: Chapman & Hall, London.
9. Humphreys, K., *Project and Cost Engineers Handbook*. 1987, New York and Basel: Marrel Dekker.
10. Akintoye, A. and E. Fitzgerald, *A survey of current cost estimating practices in the UK.* Construction Management Economics 2000. **18**(2): p. 161-172.
11. Forrester, J.W., *Industrial Dynamics*. 1961: MIT Press, Cambridge, MA.
12. Sterman, J., *Business Dynamics: Systems thinking and modeling for a complex world*. 2000: McGraw Hill.
13. Kosanke, K., *Process oriented presentation of modelling methodologies.* Proceedings of the IFIP TC5 Working conference on models and methodologies for Enterprise Integration, 1996: p. 45-55.
14. Carrie, A., *Simulation of Manufacturing Systems*. 1988, USA: John Wiley & Sons.
15. Agyapong-Kodua, K., *Multi-product cost and value stream modelling in support of Business Process Analysis*, in *Wolfson School of Mechanical and Manufacturing Engineering*2009, Loughborough University: Loughborough, UK.
16. Scholz-Reiter, B., M. Freitag, and A. Schnieder, *Modelling and control of production systems based on nonlinear dynamics theory.* int. J. of Production Research, 2004.
17. Ajaefobi, J.O., *Human Systems Modelling in support of Enhanced Process Realisation.* PhD Thesis, Loughborough University, UK, 2004.
18. Weston, R., *A model-driven, component-based approach to reconfiguring manufacturing software systems.* Int. J. of Operations and Production Management, Responsiveness in Manufacturing, 1999. **19**(8): p. 834-855.
19. Vernadat, F.B., *UEML: towards a unified enterprise modelling language.* Int. J. of Production Research, 2002. **40**(17): p. 4309-4321.
20. Bernus, P. and L. Nemes, *Enterprise integration-engineering tools for designing enterprises*. IFIP TC5 Working Conference on Models and Methodologies for Enterprise Integration. 1996, Australia: Chapman & Hall.
21. Richardson, G.P., *Reflections for the future of system dynamics.* Journal of Operational Research Society, 1999. **50**: p. 440-449.
22. Wolstenholme, E.F., *Qualitative verses quantitative modelling: the evolving balance.* Journal of Operational Research Society, 1999. **50**: p. 422-428.
23. Chatha, K.A., *Multi-process modelling approach to complex organisation design, PhD. Thesis.* Loughborough University, 2004,.