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A system approach for modelling additive manufacturing in defence acquisition programs

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Abstract

Defence Contractors and NATO – Ministry of Defences (MoDs) are currently exploiting Additive Manufacturing (AM) Technology to improve availability of defence platforms and support soldiers deployed in remote Area of Operations (AO). Additive Manufacturing is considered a disruptive technology when employed in a military context to reduce the reliance on supply chains and improve the responsiveness to Operation Tempo (OT). This papers aims at presenting a novel system approach to model the end-to-end process of delivering a product printed with AM and estimate accurately the time and costs of AM. Understanding better the time and costs of AM will allow the MoDs and Defence Contractors to perform comparison with current practices and support their decision making in AM technology acquisition.

Keywords: Defence Acquisition; Additive Manufacturing; Systems Engineering

1. Introduction

AM has been extensively investigated in the military environment due to its ability to provide rapid, delocalized and flexible manufacturing of plastic and metal components. Deploying AM in AO's provides major advantages to the NATO – MoD's. Nevertheless, it is important to estimate the time and cost of AM to quantify the Key Performance Indicators (KPI) and make a comparison with current practices. This will allow key decision makers to adopt a data driven approach when considering AM in their technology acquisition programs. This paper presents both a novel system approach and an exhaustive AM Cost Model for estimation.

2. Literature Review

Hopkinson and Dicknes (2003) developed a cost model to provide direct comparison between "Additive Manufacturing" (AM) and injection moulding. The AM process has been broken down into machine cots, labour cost and material cost. The cost model developed is based on expert judgement, extended and educated assumption and fed by a wide range of data. Ruffo et al. (2006) advances the cost modelling on AM with the development of a cost model which considers the high impact of investment and overheads of modern manufacturing processes. The cost model considers activities associated with AM and divides them into direct and indirect costs. These activities have been translated into hourly rates (£/hour) providing evidence of the application of "Activity Based Costing" (ABC) technique. The developed "Cost Breakdown Structure" (CBS) included labour, material, machine absorption and production/administrative overheads. Moreover, the authors were able to model the costs associated with the alteration of the orientation of the part within the build chamber. Lindemann et al. (2012) Provided a further development into cost modelling for AM introducing a more consistent way of applying "Activity Based Costing" (ABC)

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and "Event Driven Process Chains" (EDPC) for costing AM. The cost model has been developed to estimate the life-cycle costs of AM including the costs occurring from the conceptualisation of the design till the disposal of the product. Lindemann's approach is based on process analysis, cost drivers analysis and product life-cycle analysis. The cost model implements "Time Driven Activity Based Costing" (TDABC) as a computation technique. According to Lindemann et al. (2012) geometrical complexity is a strong influencing factors on the product cost estimate as this has an impact on the cycle time of the machine. Moreover, the need for more accurate deposition time estimation is required. Zhai and Lockett (2012) developed an early stage cost model to compare the costs of "Wire + Arc Additive Manufacturing" (WAAM) technology and CNC. As WAAM technology is featured with high deposition rates, medium design freedom, it is applied to large aerospace structural components and the focus of their cost model is to provide an accurate product cost estimation but mostly outline a comparison

3. Methodology

In Fig.1 the followed methodology is presented. The methodology is made of 7 phases.

As follow a description of the phases:

Phase – 1 "Literature Review" A literature review has been carried out on Additive Manufacturing costing. To do this an analysis of publications on SCOPUS and Sciencedirect databases has been done with the keywords "Additive Manufacturing" and "Cost Modelling" and "Cost Estimation". A total of 4 relevant publications have been identified.

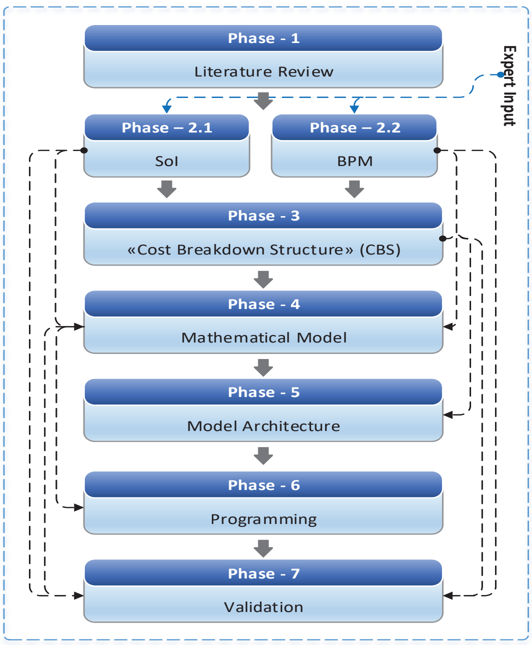

Fig. 1. Methodology.

Phase – 2.1 "System of Interest" (SoI): this represents a conceptual modelling activity which seeks to define the boundaries of the investigated system (the AM organisation), its elements, sequences, links, triggering events and dynamics.

Phase – 2.2 "Business Process Mapping" (BPM): this is the sequential conceptual modelling activity which provides a further level of information on the AM organisation and how it delivers value through its processes.

Phase – 3 "Cost Breakdown Structure" (CBS): fed by the SoI and BPM, this phase looks at defining at a conceptual level the CBS. The CBS represents also the desired Model output which needs to be as detailed as possible on the FDM system.

Phase – 4 "Mathematical Model": fed by the SoI, BPM and CBS, this phase aims at developing the equations which represents the occurrence of costs during the process of delivering value within the AM organisation. This phase is based on the work of Zhai and Lockett (2012).

Phase – 5 "Model Architecture": this phase aims at studying and defining the logic of the cost model, how the code should be written, what are the inputs/outputs, how to display them to make them significant and how to keep the model flexible in order to make it functional and adaptable to various organisations.

Phase – 7 "Validation": this phase aims at validating the cost model in both ways, through the validation of the process to develop it and through case studies with real organisation in order to compare the results and verify the accuracy and reliability of the model.

Table 1 – List of Experts

Years of Experience	Position	Organisation
20	Managing Director	R&D Company
7	Project Engineer	R&D Company
20	Head of Manufacturing	R&D Company
15	Senior Lecturer	Academia

In order to develop the SoI and BPM, relevant experts have been identified and presented in Table 1and four unstructured interviews have been carried out to elicit and capture expert judgement.