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Aggregate analysis of manufacturing systems using system dynamics and ANP

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Abstract

Aggregate analysis in manufacturing system design is a useful approach to relegate the non-feasible alternatives at earlier stages. A reusable System Dynamics model and the Analytic Network Process is proposed for a rapid and strategically consistent decision-making. The SD model captures the causal relationships and interdependence of the factors that can be simulated while the ANP provides the preferences towards the performance objectives consistent to the strategic objectives. The basis for the SD and ANP is the Causal Loop Diagram (CLD) that shows the relevant relationships and feedbacks among the model parameters. The approach is exemplified via a case to select the best among competing system configurations.

Keywords: Aggregate analysis; Manufacturing system design; System dynamics; ANP; Production layout

1. Introduction

Three design stages can be recognised in manufacturing system development: Conceptual Design, System or Configuration Design and Detail Design. The conceptual design stage starts with a top-down analysis of the design requirement where transformation to a functional and then physical description are made (Paul & Beitz, 1988). The physical description includes technology selection and process planning from which a Master Flow Diagram or Technology Diagram is developed. Alternative possible routes of production can be realised by possibly multiple resource types and arrangements. The total design space of the system is thus formed as a set of all these alternatives. Given the requirements and the design

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space, selecting the best alternative out of the feasible alternatives is a typical design decision task. The scope and complexity of the alternatives vary depending on the requirement they are meant to address.

When the complexity of the system makes analytical methods impractical for performance evaluation, simulation based tools with a rigorous experimental design and statistical output analysis are used. Evidently the time and budgetary resources required to assess multiple alternatives may be high that can be beyond limit for highly complex and/or several alternatives. On this backdrop rapid and aggregate analysis are necessary to relegate the unfeasible alternatives at earlier stage before proceeding to a more elaborate analysis.

Though the methods and tools used for such an aggregate analysis vary depending on the underlying system complexity, it is generally desirable for the method to have the following properties:

- Less time of analysis.
- Reusability of the model for multiple alternative systems.
- Capability of the model to evolve into a more detailed model that can be useful throughout the system life cycle.

The use and research work on aggregate such as queuing networks is extensive and well established. Notable to these literatures include (Dijk, 1993; Kleinrock, 1976). However, the use of queuing networks is limited to steady state analysis and to certain types of production systems that can be modelled as a product form—the solution for the state of the system is dependent on the product of the utilization factor and the number of jobs. This is based on such assumptions as exponential service times, FIFO discipline, zero or negligible transport times, no scrap, etc. Even with some extensions or relaxations to these fundamental assumptions, for instance, processing time distribution be any type as long as it has a rational Laplace transform non-product form models can not satisfactorily be applied.

In this paper, an aggregate performance analysis of MS based on a reusable System Dynamics model and the Analytic Network Process is proposed for a rapid and strategically consistent decision-making. The SD model is based on system thinking and captures the causal relationships of the factors and their interdependence that can be simulated to reveal the dynamic behaviour of the system (Sterman, 2000). Hence the SD simulation provides the system performance while the ANP provides the preferences/ weights of the lower level performance criteria consistent to the strategic objectives. The basis for the SD model and ANP is the Causal Loop Diagram (CLD) that captures the relevant relationships and feedbacks among the model parameters and performance variables. The SD model is developed by mathematically establishing the relations and transforming the factors in the CLD to rates, stocks (levels) and auxiliary variables that can be simulated with time.

The reusability of the model is due to its generic structure from which the different competing alternative can be represented. The use of a generic model greatly decreases the model building time—a highly desirable advantage for aggregate analysis. Furthermore, the model can evolve into a more detailed model for a comprehensive performance analysis by integrating the different aspects of the manufacturing system to suit subsequent design or operational tasks.

Due to their long term effects, design decision need to be consistent with the manufacturing strategy. Therefore mechanisms should be in place to ensure accurate interpretation of the strategic objectives at every level of the decision making process. One such mechanism is the assignment of preferences to the design criteria when there exist conflicting or competing objectives—which is often the case. Due to its ability to accommodate complex interdependencies and feed backs in the performance parameters,