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A granularity model for balancing the structural complexity of manufacturing systems equipment and layout

S.N. Samy [a], T. AlGeddawy [b], H. ElMaraghy [a,*]

[a] Intelligent Manufacturing Systems (IMS) Center, Department of Industrial and Manufacturing Systems Engineering, University of Windsor, Windsor, ON, Canada
[b] Mechanical and Industrial Engineering, University of Minnesota Duluth, Duluth, MN, USA

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ABSTRACT

The structural complexity of a manufacturing system results primarily from the complexity of its equipment and their layout. The balance between both complexity sources can be achieved by searching for the best system granularity level, which yields a manufacturing system with the least overall structural complexity. A new system granularity complexity index is developed to sum up and normalize the complexity resulting from the system layout complexity and the equipment structural complexity. A previously developed layout complexity index together with a code-based structural complexity assessment are used to determine the structural complexity of standalone pieces of equipment and to arrive at a balance between the two sources of complexity. Cladistics analysis is used to hierarchically cluster required pieces of equipment and bundle them into more integrated equipment and machines and demonstrate the possible different system granularity levels. The new developed model is a useful tool to create specific system configuration and layout alternatives based on system components adjacency, and then select the system design with the least overall structural complexity among those alternatives. The results of the presented case study clearly demonstrated this trade-off where decomposing manufacturing systems into a highly granular configuration with standalone machines maximizes system layout complexity and minimizes equipment complexity, while at a low level of granularity pieces of equipment are bundled into complex integrated machines, lines or cells but with a very simple system layout.

1. Introduction

Manufacturing companies often operate in a dynamic environment driven by fluctuations in market conditions, demands, design, technology, and introduction of new manufacturing systems paradigms. Variety creation and innovation has become a constant [1]. Managing the increased products variety is becoming a major concern in manufacturing [2–6]. Manufacturers respond to such variations by controlling product customization and personalization, production volume, manufacturing lead-time and product cost and quality. Many manufacturing technologies and enablers emerged to cope with the spread of product variety and changes in their manufacturing systems [7]. Logical entities such as controls, programs, communication protocols as well as human resources form an important part of the manufacturing enterprise planning strategies. Manufacturing systems combine hardware, software, and people resources. The complexity of modern manufacturing systems is growing [8–10]. More agile and responsive methods and strategies are needed to meet the dynamic requirements of customers and the shortened product lifecycle. Complexity affects the performance of a manufacturing system at both operation and management levels, which negatively affects the productivity and products quality (Fig. 1). The increase of product variety negatively impacts the performance of manufacturing systems in terms of quality and productivity, which has been shown through empirical data and simulations [11,12]. A complex product usually results in complicated and costly product design and development processes, leading to inefficiencies in the product realization phase. Increased complexity increases the life cycle cost of the product. Manufacturing complex products involves higher setup costs; the need for more raw material, work in process and finished goods inventory; reduced economies of scale; higher quality control requirements; complex product scheduling; and difficulty in balancing assembly lines and other managerial and logistical problems in the supply

* Corresponding author. Tel.: +1 519 253 3000; fax: +1 519 973 7053.
E-mail address: hae@uwindsor.ca (H. ElMaraghy).

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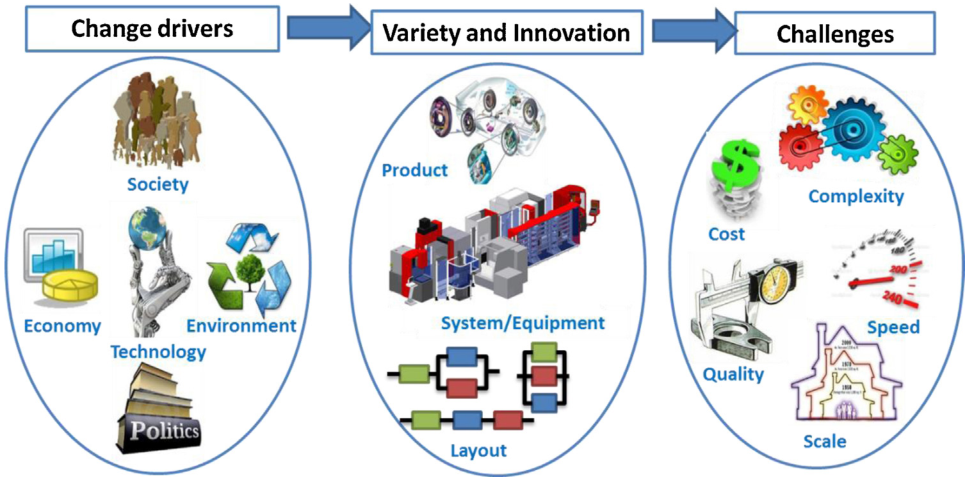

Fig. 1. Challenges related to increased variety.

chain system [13]. The increase in complexity by design is only acceptable if it improves system capabilities and performance, but should otherwise be eliminated or reduced [14]. Hence, the optimum level of variety and the induced complexity costs should be identified.

It is necessary to assess and manage systems complexity. More efficient manufacturing systems should be designed in order to remain profitable and competitive [13,15,16], and respond quickly to the volatile markets and the rising products variety.

Machine tools are used in manufacturing systems either as individuals/standalone machines as in job shops where material flow between the machines is known to be complex; or integrated into lines, cells or systems with pre-defined flow between the operations. An automobile engine cylinder block machining line or engine assembly cells are just few examples of clustered and tightly integrated production systems. The complexity of both the machines and systems featuring these types of equipment arrangements varies depending on the degree of machines integration and clustering. The trade-off between the two extremes of total integration into large and complex systems and using individual standalone machinery and material handling is the balance that any system designer seeks. Finding that balance is the objective of this paper for which some innovative methodologies are employed.

2. Terminology and definitions

The structural complexity of a manufacturing system is related to the architecture of its components (Fig. 2). This type of complexity doesn't change with time – it is static and depends only on structure. Dynamic complexity changes with time. It is attributed to the operational aspects of the system including scheduling, bottleneck, throughput, and production capacity [17]. Structural complexity is primarily due to: (1) complexity of equipment, and (2) system layout complexity [18]. Having clustered and integrated equipment would reduce layout structural complexity, but it will increase the equipment structural complexity. On the other hand, decomposing that set of equipment into individual standalone pieces would lower equipment complexity; however, layout complexity will increase as a result [18,19]. The right balance between number of clusters and equipment combinations within those clusters would minimize the overall structural complexity of both layout and equipment. This can be achieved by searching for the best system granularity level, which defines the degree of equipment integration and details at each system granularity level. Layout granularity is characterized by the number of decision points (nodes) connecting various manufacturing operations. Increased number of decision points and branching at these points in order to implement the required material flow patterns, achieve

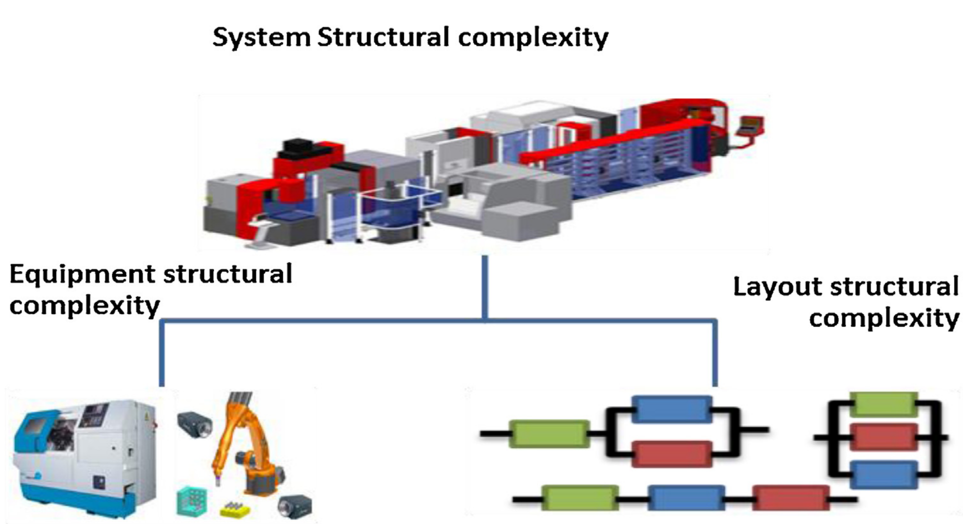

Fig. 2. Manufacturing system structure.