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Technical paper

# A model for assessing the layout structural complexity of manufacturing systems

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ABSTRACT

The layout of a manufacturing facility/system not only shapes its material flow pattern and influence transportation and operation cost, but also affects logistics and parts/machine assignment decisions. The layout of manufacturing systems determines its structural complexity by virtue of its design configuration characteristics. This paper introduces a new model and indices for assessing the structural complexity of manufacturing systems layout in the physical domain. Six complexity indices, based on the physical structural characteristics of the layout, have been introduced and formulated. They are layout density, path, cycle, decision points, redundancy distribution and magnitude indices. An overall Layout Complexity Index (LCI) which combines all indices is developed using a novel method based on radar plots which is insensitive to the order of plotting the individual indices. The use of the developed LCI is demonstrated using six typical types of manufacturing systems layouts and relevant guidelines are presented. The developed model and complexity indices help design system layouts for least complexity and compare layout alternatives that meet the specifications, at early design stages. It supports making trade-off decisions regarding manufacturing systems flexibility and complexity and their associated costs.


## 1. Introduction

Manufacturing companies often operate in a dynamic environment driven by changes in market conditions, customer demands, product design and processing technology. Complexity and uncertainty limit the effectiveness of conventional production control and scheduling approaches. The scope of complexity is categorized into: part, product, system, and system of systems. Many disciplines, such as mathematics, statistical physics, biology, medicine and social sciences as well as computer science and engineering face the challenge of quantitatively measuring complexity of a system and defining its limits. The sources of complexity may include: (i) size, (ii) coupling, (iii) variety, and (iv) multi-disciplinarity. Complexity may be static (structural) or dynamic (operational). Static complexity is time-independent and is inherent in the structure of an engineered system. Dynamic complexity is time-dependent and is concerned with the operational behavior of the system [1].

Manufacturing systems layout generation and evaluation is challenging and time consuming due to its multi-objective nature and requires extensive data collection, analysis and synthesis. Systems layout has been an active research area for many decades. Layout complexity has a significant impact on the operation and performance of manufacturing systems. A good layout contributes to the overall efficiency of operations and can reduce by up to 50% the total operating expenses [2]. However, despite the attention given by researchers to measuring structural complexity in many fields [3–5], systems layout complexity has not been given much consideration. Manufacturers need to introduce new products regularly and with minimum disruption of operations. Managers often cope with the inefficiencies of existing layouts with limited and localized fixes rather than undergo expensive and time consuming layout redesign. Emerging trends in industry which influence systems layout include: delayed product differentiation, scalable machines, movable machines, and distributed and modular layouts [6].

The objective of this research is to introduce metrics for assessing the structural complexity of manufacturing systems layout by defining its characteristics and flow patterns that contribute to the complexity of decisions made during system operation related to its layout.

A manufacturing system layout is defined by the arrangement of machines, areas or departments, their locations and connections between them [7]. A manufacturing system configuration is the set of constituent components, such as machines, workstations, transporters and controllers, etc., and the number and type of each module that make up a manufacturing system and their relationships which define the flow of work pieces between them [8].

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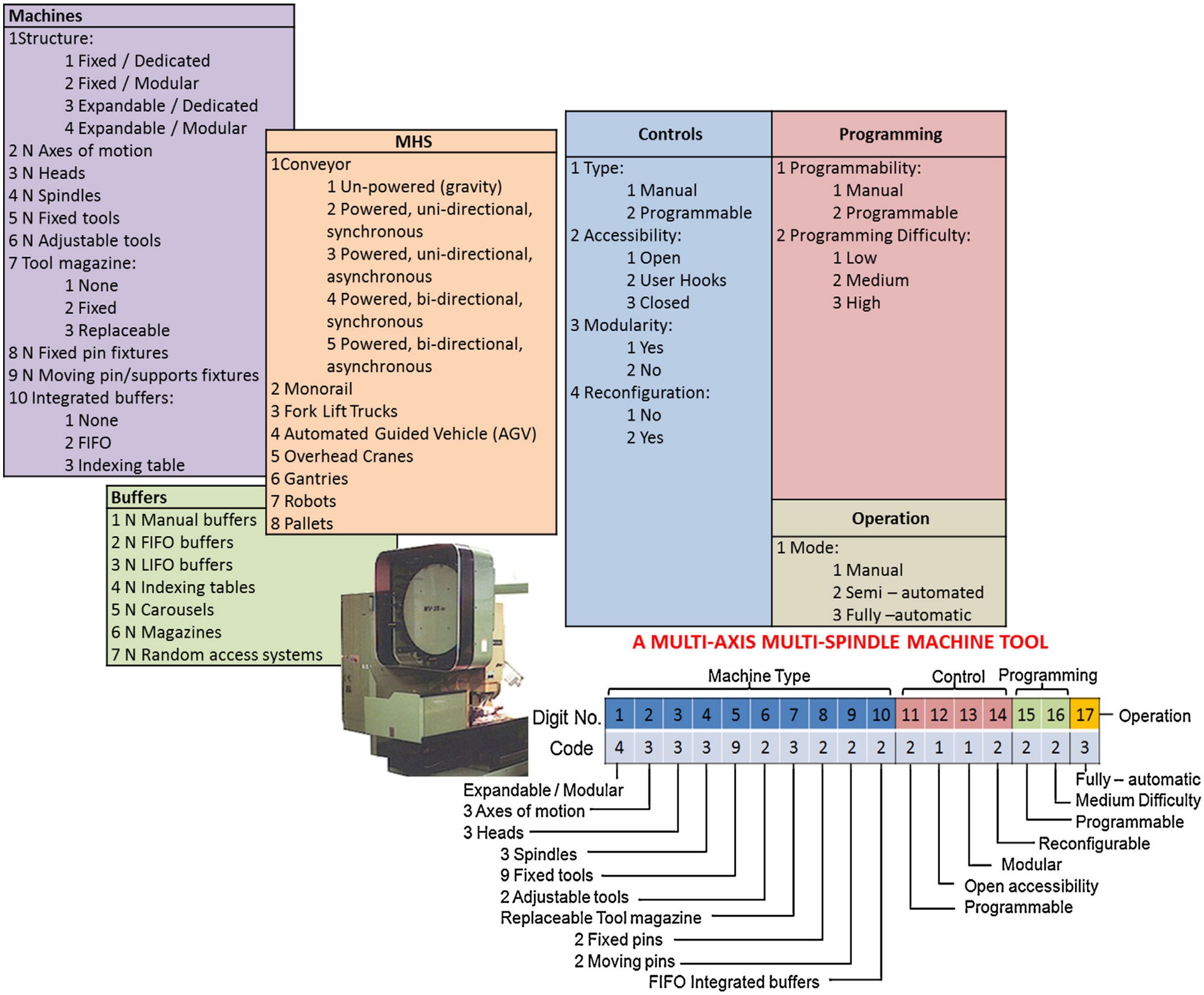


**Fig. 1.** Manufacturing system Structural Classification Code (SCC) developed by ElMaraghy [11].

A new methodology is proposed which develops a graphical representation of the physical manufacturing system layout and produces measurable complexity indices, based on the number, locations and connections of decision points within the system layout. These indices are used to evaluate the structural complexity of layout alternatives and identify potential structural layout problems at an early design stage.

## 2. Complexity in manufacturing systems

Measures for static (structural) [9] or dynamic (operational) manufacturing systems complexity have been proposed in literature [3]. Frizelle [9] defined static complexity as the expected amount of information necessary to describe the state of a manufacturing system and is based on the probability of resources being in a certain state. Dynamic complexity was defined as the expected amount of information necessary to describe the state of system deviation from schedule due to uncertainty [10,3] by measuring the difference between the actual and scheduled system performance.

Kim [4] proposed a heuristic approach to quantify the structural and operational system complexity based a series of system complexity metrics which measure the relationships between system components, number of elements and the complexity of each element. However, neither the relative importance of the individual metrics was discussed nor were they combined into a single system complexity index. ElMaraghy [11] developed a manufacturing system Structural Classification and Coding system (SCC) that captures its structural complexity in the physical domain which is inherent in various types of equipment found in manufacturing systems as well as those used for storage and material handling (Fig. 1). This chain type structural classification code has been extended to include assembly specific structural features of equipment used in assembly systems, such as dedicated assembly machines, parts grippers, feeders, orienting devices and handling equipment [12]. The SCC code uses attributes of the system machinery and their physical structure and their operation and control characteristics to assess the system overall structural complexity of the system configuration. It also proposed means for measuring the layout complexity. The SCC was applied to many industrial examples including comparing the layout complexity of three suggested systems for machining the same surfaces of an automobile engine block [13].

Gabriel [5] investigated the internal static manufacturing complexity, based on product line complexity, product structure and process complexity components. However, this complexity measure did not consider layout, arguing that it was difficult to assess