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Approaches for handling wicked manufacturing system design problems

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Abstract

Due to complex interdependencies, incomplete information and uncertainty in the manufacturing requirements, manufacturing system design can be described as a wicked problem. A wicked problem is an ill-defined problem, which makes it difficult to determine if a solution has been found and cannot be solved with traditional optimization approaches. This research will present arguments to justify why such manufacturing system design problems can be considered to fall under the definition of wicked problems especially when customer requirements, hence products, evolve over time. Paradigms such as changeable manufacturing, cyber physical and evolvable production systems have emerged to deal with these issues. A critical analysis of these approaches is then presented, which exposes a gap which exists in the design stages of manufacturing systems to adequately support manufacturing system designers in handling the wicked aspect of manufacturing system design problems. This research therefore argues for the importance of developing integrated approaches which consider both business and product evolution aspects when designing manufacturing systems. Finally an integrated approach is contributed which leverages artificial intelligence to support manufacturing system design decision making whilst considering business and product evolutionary aspects.

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Keywords: Evolution; Industry 4.0; Manufacturing system design.

1. Introduction

Wiendahl et al. [1] defines a set of change drivers, which lead to the need for the dynamic adaptation of manufacturing structures. These drivers vary significantly, from social and political factors, which are forcing new legislation and concepts of sustainable development, to new and cutting edge developments in production technology, such as micro and nano-manufacturing techniques.

ElMaraghy [2] et al., and other authors such as Koren [3] described one such change driver as the evolution of manufacturing. This evolution has transformed manufacturing from the Taylor paradigm that led to the industrial revolution in the 1920s, to mass customisation and then to the new paradigm of personalised products and production.

1.1. Product Evolution

Due to this shift in customer needs highly competitive markets and technological advances, product ranges are constantly evolving over time. ElMaraghy [4] states that product ranges continuously evolve with the addition of new features or parts that may be added or replaced to the current range of products. This paradigm has also resulted in a reduction of the product life cycle with an increase in product variety, and an associated decrease in production volume per variant. This means that the factories and MSs that have been planned to manufacture these products have longer life cycles than the products which they produce. Hence, as argued by Schenk et al. [5], the inherent nature of factories means that they need to be capable of producing different product ranges throughout their life cycle.

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1.2. Manufacturing System Design

Several factory planning approaches can be found in literature such as those described in [6], the "0+5+X" planning model by Schenk et al. [5], classical approaches of Kettner [7], Aggteleky [8] and the VDI 5200 factory planning procedures [6]. As defined in the German standard VDI 5200 [6], traditional MS design can be seen as a design-process of a factory from the first idea to the start of production that is systematic, goal-oriented, structured in successive phases and supported by methods and tools.

Chryssolouris [3] defines MS design as the mapping from performance requirements of the MS onto suitable values of decision variables, which describe the physical design or the manner of operation of the MS.

2. Wicked Manufacturing System Design Problem

2.1. Tame Manufacturing System Design Problems

Typical MS design problems include manufacturing resource requirements, resource layout, material flow and buffer capacity [9]. In these MS design problems detailed MS requirements and constraints are well established [10]. MS solutions are developed and then evaluated based on the MS requirements. These types of resource optimization and traditional factory layout problems are considered to be "tame" or "benign" problems [11], since the objectives are clear, and it is in turn clear whether or not the problem has been solved.

2.2. Wicked Problems

In contrast to "tame" type of problems, Rittel and Webber in their seminal paper [11], present a definition for a new type of problem which they term as "wicked problems". The primary difficulty with wicked problems is that they are ill-defined. Due to this uncertainty in defining the problem, then it is equally difficult to determine if a solution has been found. Chryssolouris [10] in fact argues that the objectives of a MS are often not well defined during the early MS design process, and are subject to change. Chryssolouris states that this vagueness of the inputs to the MS design process makes the optimization in a quantitative fashion difficult. Chryssolouris in fact states that "This uncertainty in defining the MS requirements can therefore render futile efforts to hone solutions to some mathematical optimum [10]."

According to Rittel and Webber it is impossible to find an ultimate solution to wicked problems, but rather these problems are re-solved over and over again [11]. This definition is then applied by Rittel and Webber to urban and societal planning problems.

In defining wicked problems, Rittel and Webber have determined ten distinguishing properties. Other researchers such as Farrell and Hooker [12] have examined each of these ten properties defined by Rittel and Weber and successfully applied these to engineering design.

In order to determine whether MS design represents a wicked problem, the following section similarly examines the ten properties defined by Rittel and Webber with reference to the MS design problem.

2.2.1. [P1] There is no definitive formulation of a wicked problem.

As explained in [12], there is a different cognitive structure to a design process for wicked versus tame problems. In tame problems, the problem is already fully and optimally specified and the relevant information is then applied 'algorithmically' by MS designers to deduce an optimal design.

This is not possible for wicked problems since the information needed to understand the problem depends upon one's *idea* for solving it. In order to describe a wicked problem in sufficient detail, one has to develop an exhaustive inventory of all conceivable solutions ahead of time. This is not possible for MS design problems since it is not possible to determine *all* possible evolutionary paths.

2.2.2. [P2] Wicked problems have no stopping rule.

MSs are continuously being adapted, they do not stop co-evolving with the product range. The MS only stops evolving when it is decommissioned. During MS design it is therefore not possible to predict all the changes that will affect the design.

Moreover an ultimate degree of changeability can never be determined and achieved during MS design, since there is always room for further changeability.

2.2.3. [P3] Solutions to wicked problems are not true-or-false, but good or bad.

MS solutions are evaluated with respect to the MS requirements. That said, a MS design solution, cannot be unambiguously assessed as being correctly designed to cater for future product evolution, since due to customer product requirements, changes in legislation, etc., how product evolution will take place over time cannot be predicted with absolute certainty.

An expert in the field can therefore only assess a MS design solution to be "good" or "bad" at handling future product evolution, based on some values or criteria previously defined. But even the expert has limitations in terms of how long term the future being considered is.

2.2.4. [P4] There is no immediate and no ultimate test of a solution to a wicked problem.

Rittel and Webber state that any solution generates waves of consequences over an extended period of time. During MS design, the decisions made by designers have consequences not only on the current capability and properties of the MS, but also on future MS capability (MCCs) and changeability (FCCs).

Therefore in order to test the MS design solution, one has to compare it to the future product evolution. Since as previously stated, it is impossible to predict with absolute certainty what future product evolution will be, then there is no immediate or ultimate test for a MS design solution.