MODELLING OF ASSEMBLY PROCESS MODULES IN TERMS OF

MASS CUSTOMIZED MANUFACTURING

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1. INTRODUCTION

In today's market, personalized demands of various groups typical for mass customization (MC) phenomena can be satisfied only through the strategy of mass customized manufacturing. Even though mass customization as a strategic tool to satisfy individual requirements of customers is under theoretical exploration for many years, theory of mass customized manufacturing is at the beginning. Therefore, modelling of assembly process modules for mass customized manufacturing will be in this paper a matter of interest. The modules can be then applicable into assembly supply chain models. Commonly for this purpose, graph theory is applied. Assembly supply chains (ASCs) can be represented by tree directed graphs, in which each node in the chain has at most one successor, but may have any number of predecessors. Such supply chain structures are convergent and are divided into two basic types: modular and non-modular. In the modular structure, the intermediate sub-assemblers are understood as assembly modules, while the non-modular structure consists of only original suppliers and a final assembler (root node).

2. RELATED WORK

Mass Customization is understood as the marketing, development and production of affordable goods or providing services with such a sufficient diversity and adaptation that each consumer finds exactly what he wants. In other words, the aim is to give customer what he wants and when he wants it [1]. Another definition of Mass customization was introduced by the authors Tseng and Jiao [2]. They define MC as the technology and systems producing goods and services based on individual customer requirements. MCP as a business strategy of expanding the sphere of influence by particular companies brings attractive opportunities to added value to the precisely addressed customer requirements. In fact, mass customization is still a new manufacturing concept that is rarely applied by companies and requires further research and development [3]. Typical feature for MC is that products consist from several modules and each module can have a certain number of variants. Combinations of these variants contribute to high product variety that triggers high manufacturing complexity [4]. The assembly of the modules creates a network of interconnected workstations that are frequently characterized as mixed-

model assembly systems (MASs). At each station selected components are assembled onto the partially finished product. Finally, end product is finalized at the last station. According to several studies [5, 6, 7], a configuration of assembly stations has a notable impact on the performance of manufacturing systems. Wang [8] therefore adds that „it is necessary to take into account the effect of system configuration when studying the variety induced- manufacturing complexity and its impact on the performance of mixed-model assembly systems".

In our paper, in this context, assembly process modules will be also treated as sub-sources of variety-induced complexity.

3. INITIAL DESCRIPTION OF ASSEMBLY PROCESS MODULE

ASC in terms of MC may be composed of the following two types of modules:
a) Assembly process module without a possibility of component selection, where at least two entry components have a functional (stable) character, and/or
b) Assembly process module with possible selection of components, where at least one component entering a module has optional character.
Our focus will be oriented only on the second type of assembly module. In order to show a contextual view on such assembly module, a simple theoretical ASC model is depicted in Fig. 1.
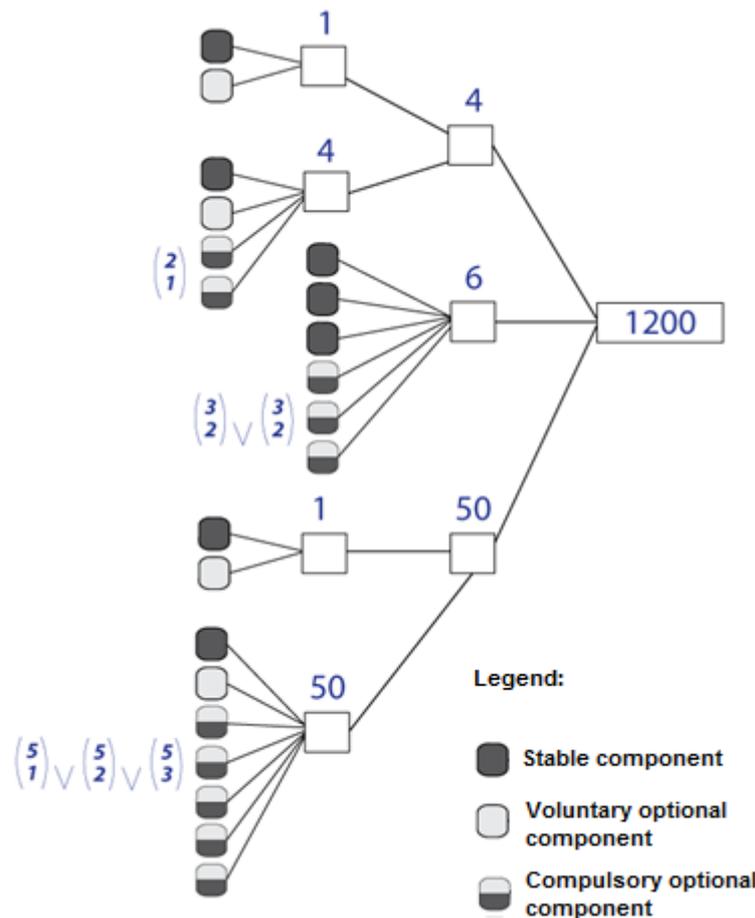

Fig. 1 An example of mass customized assembly supply chain model

This ASC model consists of seven pre-assembly modules and one final assembly module. Initial inputs into pre-assembly process modules include three types of components: stable, voluntary optional and compulsory optional ones. In case of compulsory optional components, there is a need to specify selection rules. These selection rules can be in simple way specified by combinatorial number $\binom{k}{l}$ defining ways of picking all l-combinations from a set of k while $<1 \leq l < k>$. From the Fig. 1, one can see that the total number of product configurations is 1200. Obviously, well-designed ASC usually has to be tailored to the existing manufacturing and ASC resources. As it is emphasized by Jiao et al. [9], the consequence of high product variety introduces significant constraints to production planning and control. At the same time, production planning and control depends on design of ASC. Therefore, collaboration among product design, process planning and the supply chain design plays important role in optimizing effectiveness of ASC. Accordingly, in terms of mass customization, it is purposeful to establish a system of assembly components and rules for determination of product configuration.

4. SPECIFICATION OF ASSEMBLY COMPONENTS

Two of the three types of assembly components, namely stable component (S) and voluntary optional component (VO) do not need a special definition from viewpoint of enumeration of all possible module/product configurations. They are commonly used in various applications including mass customization. Special attention is paid on compulsory optional component (CO).

Number of compulsory optional components is limited in selection. They are optional, but with minimum, maximum or exact requirements for 'l' on a selection by customer. In mass customization environment, practically any number of stable, voluntary and compulsory optional components can be combined. However, the following specific selection rules of the selections for the set of CO components with number k may occur when identifying product configurations. They are:

Rule A: Individual selectivity rule - we may define exact number of 'l' of components to be chosen from all 'k' of CO components, or

Rule B: Maximum selectivity rule - we may define the maximum number 'l' of CO components to combine within an assembly choice of all 'k' of CO components (note that 'l' is max. $k-1$), or finally

Rule C: Minimum selectivity rule – we may choose/combine at least 'l' CO of components from available 'k' of CO components (note that 'l' is min. 1).

Practical situation for using compulsory optional components can be demonstrated by the following example. Let us say, there is an offer of four metallic car colors. If customer chooses voluntary single color of all four available colors, then the whole car is painted in this color. In addition, any combinations of the four colors can be chosen. This offer allows combining all possible colors by specific requirements for different parts of car body. Then, we can clearly model this customized operation case by Fig. 2, where four compulsory optional components and one stable component (represented by the car body) result with 14 product configurations.
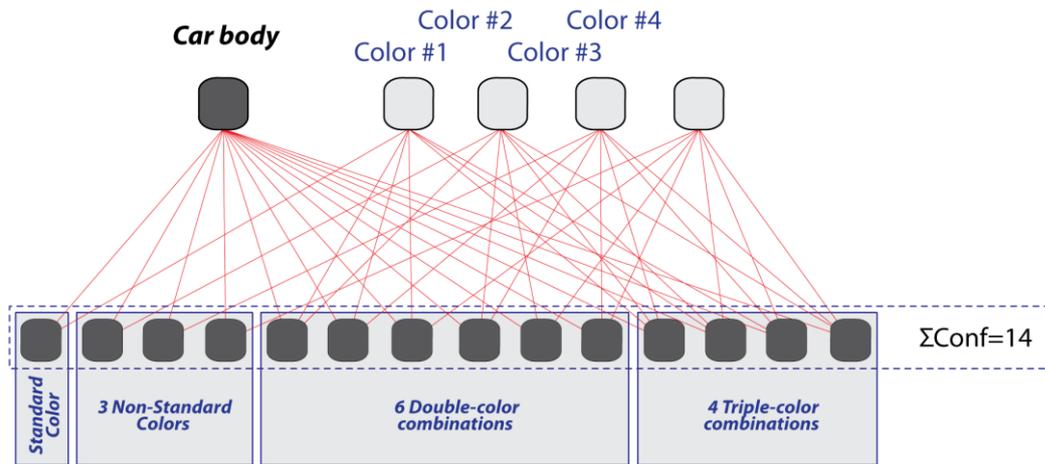
Fig. 2 All available product configurations for the case assembly

To model mass customized operations for any possible realistic situation, it is useful to develop further methodological guidance. Firstly, we will divide assembly operations into two groups. The first of them assumes the existence of only two types of initial assembly components, namely stable and voluntary optional. Assembly operation under this condition will be named as Scenario 1 (S#1). The second group (Scenario 2) assumes the existence of all three assembly component types, namely stable, voluntary and compulsory optional.

5. MODELLING FRAMEWORK FOR SCENARIO 1

Purpose of the following methodological framework is to present in a simple manner all possible categories of MCA operations in single assembly process module for the given scenario. The simplest MCA operation category is considered only with one voluntary optional component *VO* and growing number of stable components *S*. Subsequently, next categories will be determined based on growing number of VO components. Accordingly, it is easy to obtain number of product/module configurations at arbitrary tier of ASC as it is shown in from Fig. 3. For further investigation, it is meaningful to establish the following notation. Each type of MCA operation differing with the number of stable and voluntary optional components will be noted by Component Classes (CL_{1-n}) and Component Subclasses (SCL_{1-d}). Component Classes are determined by the same number of *S* components (i=$1,...,$ *n*) and Component Subclasses by the number of *VO* components (j=$1,...,d$). Then Class and Sub-class of assembly components determine a structure of *S* and *VO* components.
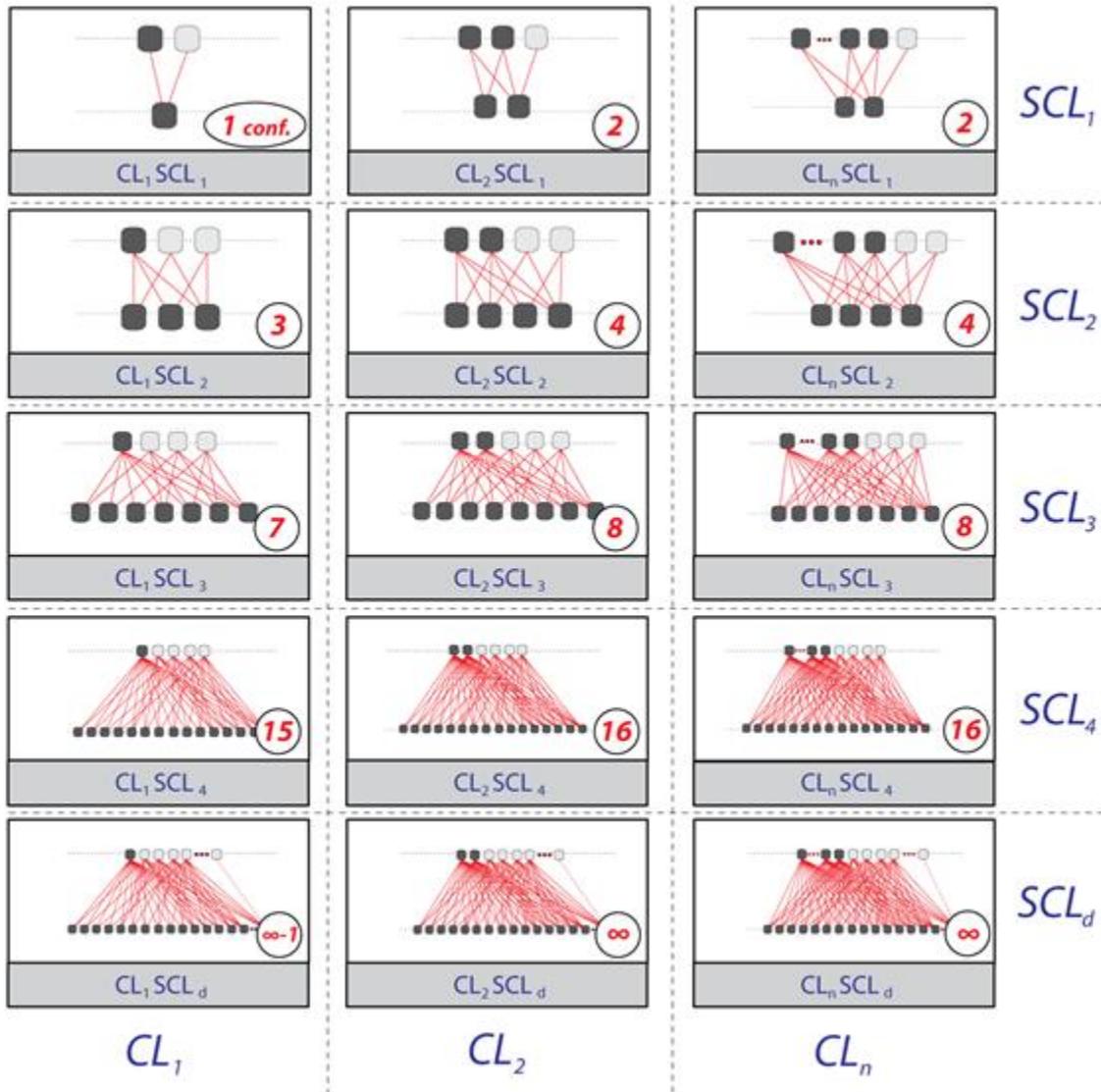
Fig. 3 The basic modeling framework for Scenario 1

Categories of MCA operations can be then analyzed by the classes or subclasses. Accordingly, from Fig. 3 the following finding can be formulated. Identical Component Sub-clases for Classes 2-∞ generate the same number of product/module configurations.

6. MODELLING FRAMEWORK FOR SCENARIO 2

Similarly, as in Scenario 1, here we present a procedure for generating all possible categories of MCA operations for the scenario under assumption the existence of all three assembly component types. In addition to previous scenario#1, Sub-class of assembly components in scenario#2 determines a structure of CO and VO components by notation SCL_{1-d}^{2-r}, where number of compulsory optional components starts from 2 to r. Analogically, it is possible to create pertinent categories of MCA operations by bipartite graphs and enumerate number of all possible product/module configurations, as depicted in Fig. 4.
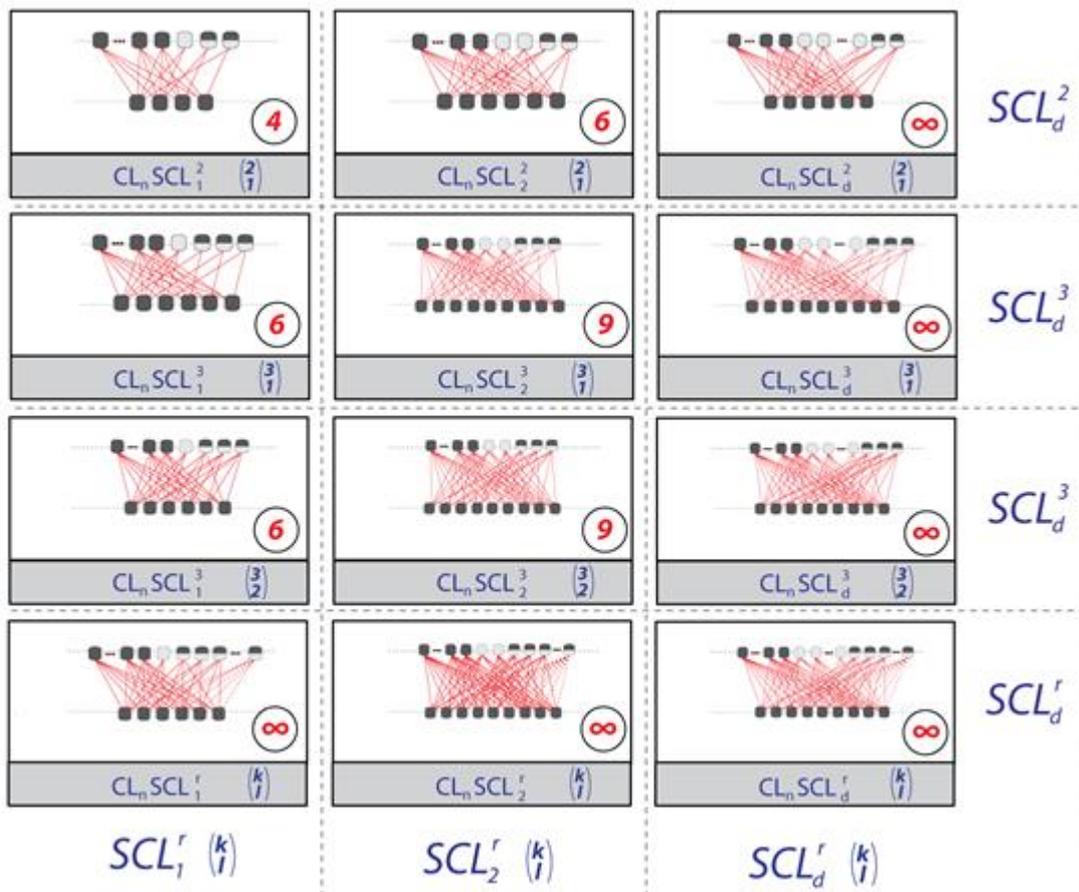
Fig. 4 The basic modeling framework for Scenario 2

However, in this categorization, we presume that the number of stable components is constant. Obviously, number of product configurations for different categories cannot be simply determined as in S#1. In this concept, it is necessary to define selection rules related to CO components. Applying these rules into comprehensive algorithm, a calculator for enumeration of number of product configurations can be developed. Then one can briefly obtain information about size of product configurations.

7. MATHEMATICAL MODEL OF PRODUCT CONFIGURATOR

In the context of previous models of MCA operations, two groups of numerical schemes can be generated. The first group assumes that the number of stable components equals one and the second group assumes that $i \neq 1$.

In the first group, it is pragmatic to identify four different cases. They are:

1. The simplest case is when only one stable component is passing through the operation. This may include for instance visual check operation. Then, initial component composition can be formally written as: $i=1$; $j=0$; $k=0$; $l=0$.

2. In the next case, it is supposed that compulsory components are available and individual selectivity rule is determined for selection from CO components. If, e.g. $k=10$ and $l=(2;8)$, then the number of resulting configurations is 1002.

3. The third case differs from the previous one in presence of both optional component types and in selectivity rule for $\binom{k}{l}$. In this case all possible specific selection rules are applicable. For example if $j=5$, $k=10$, $l=(1\text{-}9)$, then $\Sigma\text{Conf}=31\,682$.

4. The last case involves, except for single stable component also several voluntary optional components. Let us say that $j=15$, then $\Sigma\text{Conf}=32\,767$.

Similarly, in the second group, four cases are considered as pertinent. Cases 1 and 2 generate the same numbers of product configurations. This is because under these specific conditions, the number of stable components does not influence product variety. In the third case, higher number of stable components ($i\neq1$) allows to choose no VO component. Therefore, if number of both optional component types are identical, number of product configurations is higher in case when $i\neq1$ than in case when $i=1$. Case 4 slightly differs from situation in Group 1 when $i=1$. It is because if $i>1$, then stable components generate one extra product configuration.

Based on such stipulations, a comprehensive algorithm of product configuration can be introduced as is shown in Fig. 5. Subsequently, one can easily transform this algorithm into product configuration calculator.
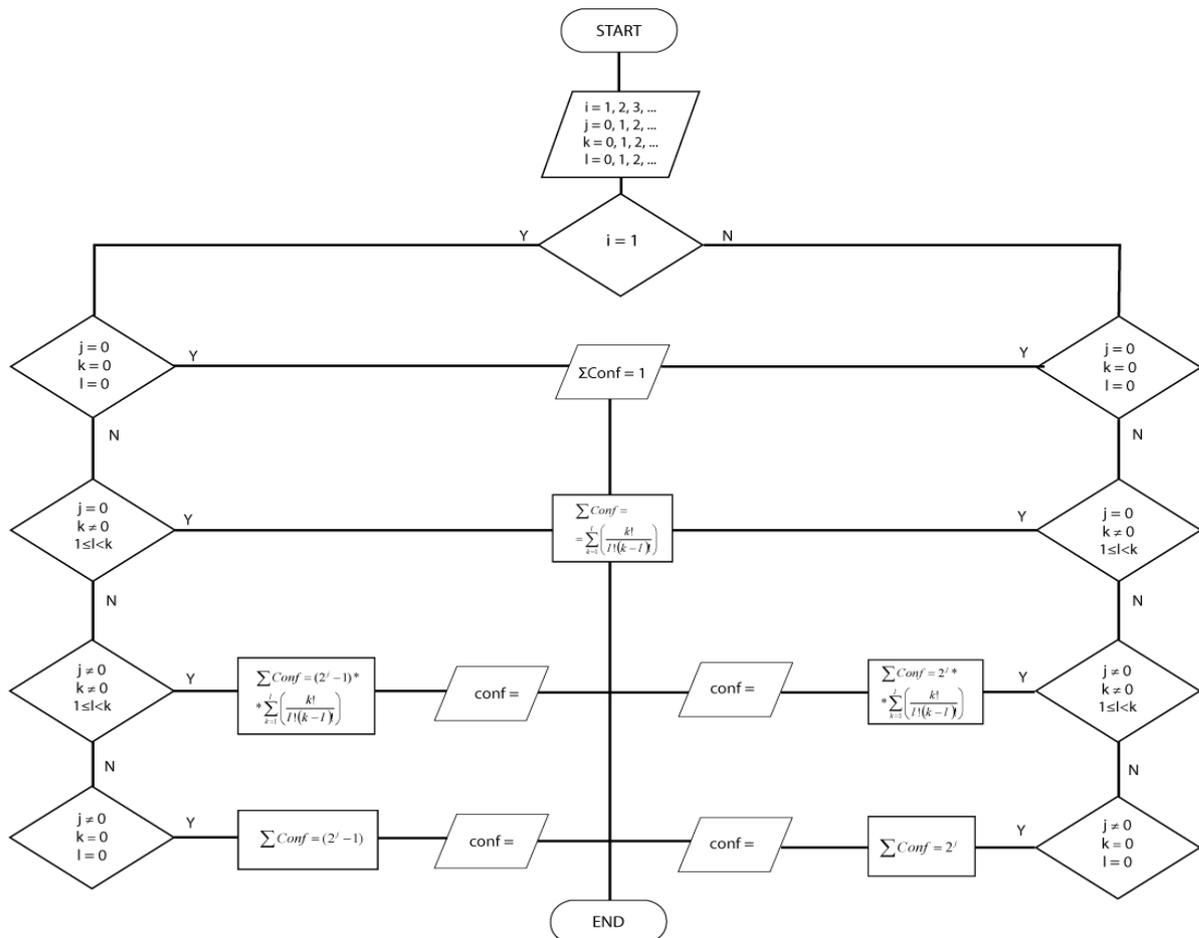

Fig. 5 Product configuration algorithm in terms of MCA

8. CONCLUSIONS

The main objective of this paper is to outline possible framework for quantification of variety-induced complexity based on enumeration of all possible product configurations identified in a single assembly process module. Obviously, one can argue that there are several similar approaches that are dedicated to this problem. However, based on our experiences in this operations research domain [10-12], generic solutions will not totally suit with all possible situations in mass customization environment. For example, mass customized services require another approach than mass customized manufacturing. Accordingly, this research domain opens new research perspectives, especially if we consider restrictions arising when customizing products or services.

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