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Modular ideality for systematic segmentation

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Abstract. In modern developing world, there is a growing significance of the contradiction between versatility and ease of manufacturing. Products should exist in many user-centered variants, that are manufactured with the least resources possible. The purpose of this work was to formulate a novel method of modular design and assessment to improve design of multivariant products that undergo evolution of Main Parameters of Value. The proposed method represents a systematic approach in technical system segmentation, that is one of the 40 inventive principles in TRIZ. It is based on identification of system evolution and optimized selection of modules and connections between them. As a part of the method, a novel modular ideality parameter was defined that quantitatively describes segmentation principle in the scope of increase of the useful function, increasing versatility of a product with no to little harm to ease of manufacturing. This approach makes it possible to design multi-variant products that represent a systematic and structured application of a segmentation principle. The application of the methods was shown on an example of a Mobile Biogas Station. It was shown in the study, that modular ideality has an influence on ease of manufacturing and resources usage of multivariant product design.

Keywords: Modularity, TRIZ, Segmentation, Ideality.

1 Introduction

Rapid development of customers' needs makes it necessary for engineers to constantly develop new products that will satisfy them. In order to meet those evolving needs, technical systems are required to undergo numerous changes that affect its ideality. According to [1–3], development of technical systems is based on elimination of system contradictions that exist within that system. This leads to increase of a technical system ideality, that is defined as the ratio of useful to harmful functions. In the context of ever-changing supersystem, engineers struggle to deliver high-quality products at minimum costs that are capable to satisfy wide variety of customers' needs. Growing significance of evolutionary based design and design through analogy [4], developing solutions have to be compatible to previous and future generations, increasing versatility and adaptivity. Taking into consideration a traditional approach in design, decisions about technical system or technological process upgrade are rarely correlated with detailed forecasts,

leading to much lower than desired ideality levels (Traditional Design line on fig. 1). A desired approach is to take into consideration evolving needs as soon as possible, tailoring system and process development to the desired outcome. Because such system or process dynamically adapts to changes originating in supersystem, such an approach is referred to as Adaptive Design for variable customers' needs (fig. 1).

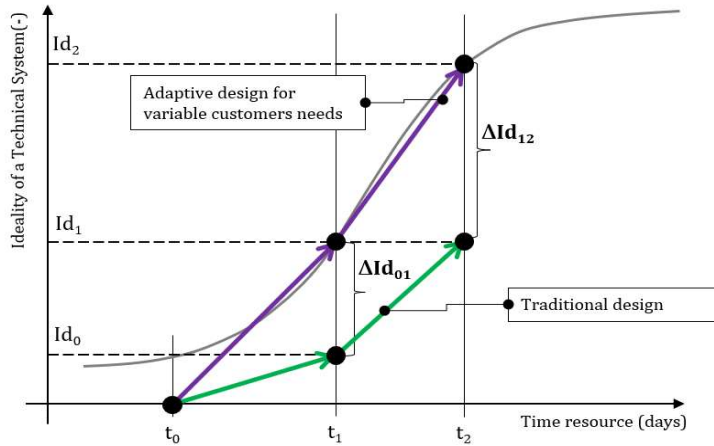


Fig. 1. Ideality in traditional and adaptive design.

Instead of having several technical systems that perform different functions, engineers tend to develop an adaptive technical system that is capable of changing its functionality in exploitation, reducing significantly manufacturing costs. Technical systems that are dedicated to satisfy dynamically changing needs can be often characterized by existence of a pair of conflicting system parameters, that form a system contradiction in the form of:

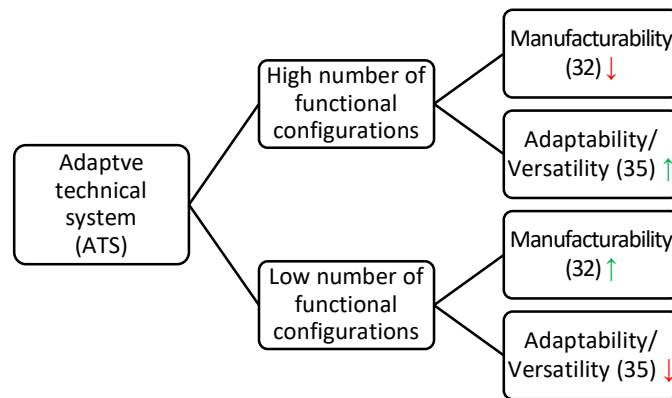


Fig. 2. System contradiction of an adaptive technical system

Two key parameters of a technical system that describe possibility for a change to be implemented are Adaptability and Manufacturability. There are numerous works on how to measure adaptability that are directly connected with identification of MPV's and their variability [5] as well as ideality and innovativeness of a technical system at a given time [6, 7]. Apart from that, technical system deteriorates during their lifecycle, which makes it necessary monitor their critical to quality parameters to make sure it performs as intended[8]. Adaptability can be understood as a change of innovativeness in time or space, depending on if the change is evolution-based (time) or market-based (space). Manufacturability of a technical system is related to its ability to be manufactured, assembled and modified during its lifecycle. Having in mind, that customers' needs often change within a single lifecycle of a technical system, ability of a technical system to adopt to those changes is of a great importance. Using TRIZ Contradiction Matrix to solve the problem, segmentation principle is suggested.

Segmentation in its purest form is the process of division of an object into independent parts. There are many possible methods of such a division, and more efforts are dedicated towards development of novel methods on systematic segmentation. One of the possible solutions for systematic segmentation is to use size ranges, that provide adaptivity of useful function within a given range of size, mass, power, etc. [9]. This approach is effective if the change of needs is related to one single function, changing its intensity. In a different situation, where evolving needs require addition, removal or change in functional model of a technical system, a different rationalization can be implemented, that is referred to as modularity. The concept of modularity is referenced by many researchers all around the globe [10–15] mostly because it provides tools and rationalization techniques to develop highly customizable products with the highest possible manufacturability.

There are many studies on how to measure manufacturability in the context of expected changes in the structure of a technical system. This measure is often referred to as modularity, which is defined as “the relationship between a product's functional and physical structures such that (1) there is a one-to-one correspondence between the functional and physical structures, and (2) unintended interactions between modules are minimized [16]. Modularity is often quantified by means of modules similarity or module-independence, taking into account a number of inter- and intra-module connections. Proposed in literature metrics that makes it possible to assess modularity (and hence manufacturability) are possible to be used during deployment phase of a technical system and are not possible to be implemented at an early design stage, when the only information available is related to components and functions of a technical system. This creates an urgent need to develop a novel metrics that will make it possible to assess manufacturability at an early design stage using available at this point information.

2 Materials and methods

The purpose of this work was to formulate a novel method of modular design and assessment to improve design of multivariant products that undergo evolution of Main Parameters of Value as a part of design-for-change rationalization. Ideal technical system in the context of design-for-change is defined as a system that at any given time is fulfilling customers' needs without a need of redesign and reassembly, thus for all of its configurations is sharing the same set of components and its occurrences. In real technical systems this situation is very often impossible to be achieved which means, that there is always some adaptation work needed to change useful behavior of a technical system. This work is defined as manufacturability, which means the bigger the adaptability of the technical system, the smaller the manufacturability, which is a result of existence of custom-made modules and components that have to be incorporated in product architecture. In this article, a novel measure of manufacturability is proposed that takes into account expected changes in physical structure of a to-be-modified technical system at an early design stage. Similar to [15], proposed metric is dependent on number of non-standard components that are introduced to a technical system as a result of its adaptation to a different need. What is new in this approach is, that apart from change in component itself, a proposed metric takes into account a number of occurrences of standard and unique components, which was not distinguished in earlier works.

For a given set of configurations of an adaptive technical system (hereafter referred to as ATS), a number of changes in components and its occurrences have to be implemented between various configurations of ATS. For a given technical system, one can distinguish a set of components (C1-C7) and its occurrences that constitutes it. This set is presented on fig. 2.

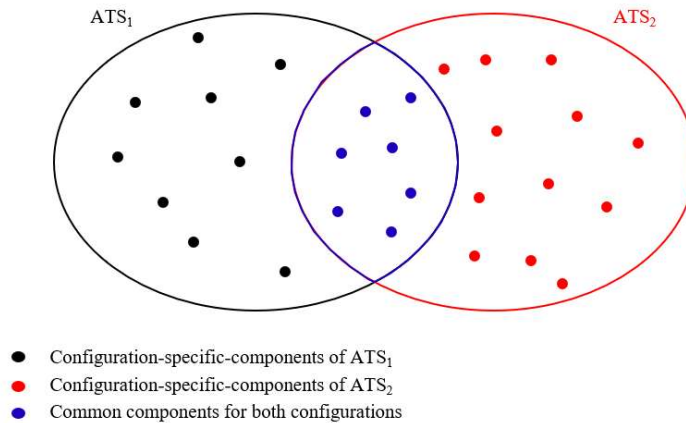


Fig. 3. Scheme of sets of components and its occurrences for two configurations of ATS.

As a result of implemented change in functionality of the ATS, a second configuration was derived (ATS₂) that uses some existing components of ATS₁, referred as common components (CC) and a set of new components, referred to as configuration-specific components (CSC). Ideally adaptive technical system is such, that uses all of its components to provide required functionality, hence for which all configurations contain only common components. Opposite to that, a non-adaptive technical system is such in which all of its configurations contain only configuration-specific-components (CSC). For the purpose of this work it was assumed, that manufacturability decreases with an increase of number of occurrences of configuration-specific components, here and thereafter referred to as n_{CSC} . Increase of manufacturability metric is related to increase of number of occurrences of common components, here and thereafter referred to as n_{CC} . In mathematical form, decrease in manufacturability can be described as:

$$\Delta M = -r \left(\frac{n_{CS}}{n_{CC}} \right) M \Delta \left(\frac{n_{CSC}}{n_{CC}} \right) \quad (1)$$

The rate of manufacturability decrease is dependent on the value of manufacturability at given n_{CSC}/n_{CC} ratio and a proportionality coefficient r , defined as:

$$r = \frac{N_{CSC}}{N_{CC}}$$

In the equation (2), N_{CSC} denotes number of configuration-specific components in ATS and N_{CC} denotes number of common components in ATS. Integrating equation (1) one may obtain the equation for manufacturability metrics of a given ATS:

$$M_{MM} = e^{-\frac{1}{2} \frac{N_{CSC}}{N_{CC}} \left(\frac{n_{CSC}}{n_{CC}} \right)^2} \quad (2)$$

Change in M_{MM} metric is represented on graph:

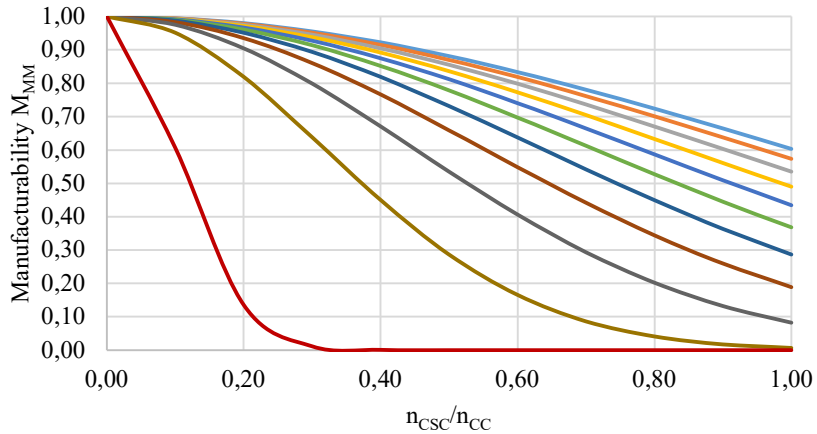


Fig. 4. Manufacturability in a function of component occurrences.

Maximum value of M_{MM} metrics is equal to one and can be achieved only if there are no occurrences of configuration-specific components in a given adaptive technical system (ATS). This represents a situation, when change in functionality is achieved without and need for redesign and/or reassembly of a technical system. Minimum value of M_{MM} tends to zero in the situation where there are only configuration-specific components in a given ATS. This is equivalent to the situation, when for obtaining a new functionality of the product, an entirely new technical system is being created. The latter scenario is the most common if changes of technical system are not anticipated at an early design phase.

When there are n configuration of an adaptive technical system ($ATS_1, ATS_2, \dots, ATS_i, \dots, ATS_n$), manufacturability measure of the entire product family consisting of all those adaptive technical systems can be described as:

$$M_{PF} = \frac{\sum_{i=1}^n M_{MMi}}{n}$$

The above equation means, that manufacturability of a product family can be equal to one if and only if each configuration uses only and all of common components, providing different functionality.

The proposed metric of manufacturability was applied to evaluate two concepts of gas storage unit in order to identify, which solution is more beneficial to be implemented based on customers' needs evolution. Detailed description of the study is presented in the next chapter.

3 Segmentation and Modular Ideality of Gas Delivery Systems

Development of gas delivery systems are of huge interest currently. One of the solutions to meet growing demand on energy obtained from environmentally-friendly sources is connected with utilization of biogas for the purpose of green energy generation [17, 18]. Biogas production is constantly growing, and so are perspectives to use other gases (i.e. Syngas) for energy generation. The evolution of gas supply system from the perspective of a source gas is being shown along with corresponding research in the field. The above means, that technical systems in the area of gas delivery systems should be able to adopt to those changes, and one of the possible solutions to make this process less resource-consuming is to perform its systematic segmentation by modularization.

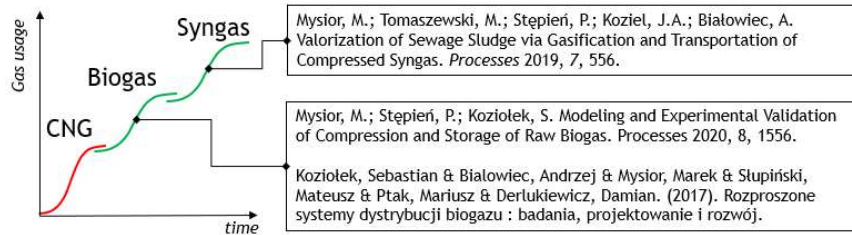


Fig. 5. Evolution of gas energy systems in time

Gas can be transported in dedicated gas storage units, that can store compressed gas at elevated pressure. Transitioning from one gas to another, it is often required to adopt the containers and/or piping of the system to meet conditions and behavior of compressed biogas or syngas. Additionally, due to different energy content of gas taken from various sources, there is a demand for size variability of such systems. Derived in chapter 2 metric was used to assess manufacturability of compressed gas transport container. Based on a required gas capacity, there are two types of gas container needed that differ in size. As a result of TRIZ oriented design [19], two concepts of gas container were developed. The first concept comprises of a frame and 60 gas containers placed horizontally in the transverse direction. The second concept differs in container orientation. Both concepts are shown on fig. 6.

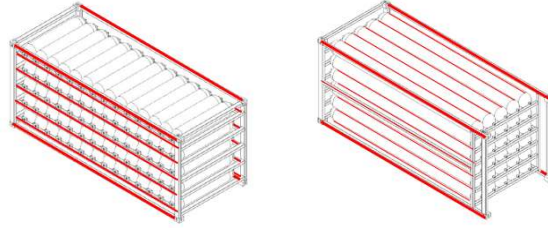


Fig. 6. Gas transport concepts, first concept on the left, second on the right.

Each of two concepts was evaluated in terms of manufacturability using proposed metrics in the scope of size change.

3.1 Concept 1

Basic configuration of gas transport container shown on fig. 4 (concept 1) comprises of 13 components and 100 of their occurrences. Changing size of the container (understood as change in length from 20ft to 40ft) results in 14 occurrences of 2 configuration-specific-components, hence for ATF_{40ft} , $N_{CSC}=2$, $n_{CSC}=14$, $N_{CC}=11$, $n_{CC}=156$. Substituting those values to equation (2) one can obtain:

$$M_{20ft} = M_{40ft} = e^{-\frac{1}{2} \frac{2}{11} \left(\frac{14}{156}\right)^2} \cong 0,99$$

For concept 1, manufacturability M_{PF} (equation 4) equals to 0,499.

3.2 Concept 2

Basic configuration of gas transport container shown on fig. 4 (concept 2) comprises of 13 components and 52 of their occurrences. Changing size of the container results 36 occurrences of 3 configuration-specific-components, hence for ATF_{40ft} , $N_{CSC}=3$, $n_{CSC}=36$, $N_{CC}=10$, $n_{CC}=16$. Substituting those values to equation (2) one can obtain:

$$M_{20ft} = M_{40ft} = e^{-\frac{1}{2} \frac{3}{10} \left(\frac{36}{16}\right)^2} = 0,47$$

For concept 1, manufacturability M_{PF} (equation 4) equals to 0,235.

4 Discussion and summary

In this article, a novel metrics of technical system manufacturability was proposed and demonstrated on an example of gas transport container. It was shown, that manufacturability of a technical system depends on number of components and their occurrences, which can be estimated at an early design phase. This makes it possible to assess manufacturability of an adaptive technical system and all its configurations at the time, when implementation of change is of least expense. This means, that using proposed method of identification of technical system manufacturability makes it easier and more effective to increase its ideality with respect to evolving customers' needs, increasing innovativeness of the product.

The influence of product architecture and the way physical connections and components are arranged within technical system are proven to be sufficient to describe potential of the product to change. This makes it possible to choose an optimal design with respect to planned changes in early development stages, reducing costs and time-to-market.

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