BUILDING AN INTERPRETIVE STRUCTURAL MODEL FOR FACTORS DEFINING CO-PARTICIPATION LEVEL IN AN INDUSTRY 4.0 ENVIRONMENT

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Abstract: *This publication addresses the factors that support the process of developing an individual approach to customers, which is one of the main tasks of the so-called Fourth Industrial Revolution or Industry 4.0. The emphasis is on the study of the interrelationships and the interaction between these factors and their integration in a structured way, with the help of the so-called Interpretive Structural Modeling (ISM) to help integrate them into a comprehensive conceptual framework that represents producer-customer interactions under Industry 4.0 conditions and, as a result, increase the efficiency of the process of creating value according to the individual requirements and expectations of the customer.*

KEYWORDS*: ISM, INDIVIDUAL APPROACH TO CUSTOMERS, INDUSTRY 4.0, SUPPORTING FACTORS, CO-PARTICIPATION, DIGRAPH, INTERRELATIONSHIP*

1. *Introduction*

Individual approach to the customer finds its way even in the time before the first industrial revolution, when there also have been a number of customized/individual products or so-called One-of-a-Kind Products. This has not been causing a serious disturbance for manufacturers due to the significantly limited scale of the activity, geographically isolated markets and insignificant competition.

However, with the growing industrialization, the scale of manufacturing has been gradually expanding, the number of customers grew incredibly, and the satisfaction of their individual requirements and expectations become impossible. In an effort to meet the demand, manufacturers rely on standardization and uniformity of production and take advantage of the opportunity to realize economies of scale.

In the late 1960s and early 1970s, however, the tendency to individualize (customize) the production, but on a much wider scale than the old ones, began to imply, until it came to its full manifestation today.

Given that almost all products nowadays have alternative substitutes and market supply significantly exceeds market demand, it is becoming more and more difficult to satisfy the preferences of customers who are constantly changing and growing in quantity. Every one of them expect to receive a unique product as well as one-to-one marketing. The "typical" customer no longer exists. Given this, the achievement of the corresponding degree of product capitalization, which corresponds to the expectations of the clients, becomes an increasingly difficult task for the producers.

Various approaches are considered in the literature to help producers perform an efficient customized production through customer engagement in the process of creating and manufacturing the product, such as Customer Order Decoupling Point / CODP, Mass Customization, Co-Production, Order Penetration Point, Point of Postponement, etc.

The technological potential of Industry 4.0 makes operations system of the enterprise more efficient in adjusting to the individual and specific requirements of each individual customer in terms of design (the physical structure) and functional features (functional structure) of the end item (the final product) [1,2,3,4,5,6]. Thanks to Industry 4.0, even manufacturing of individual components (batch of one component) can be profitable [2,5,7,8,9]

The purpose of this publication is to investigate the interrelationships and interactions between the factors that underpin the process of product customization according to the expectations of each individual customer. Building a model describing the connections and interaction between these factors will help to integrate them into a comprehensive conceptual framework, presenting the *producer-customer* interaction in the conditions of Industry 4.0 and, as a result, will lead to an increase in the efficiency of the process of creating value tailored to the individual requirements and expectations of the customer.

2. *Building an Interpretive Structural Model for Factors Defining Co-Participation Level*

To investigate and structure the interrelationships and the interaction between the factors that determine the level of customer involvement in the value creation process, the use of the so-called Interpretive Structural Modeling (ISM) hereby is proposed. ISM was created by J. N. Worfiled as a computer-added methodology to study complex issues and to structure them in terms of words and directed graphs which can be easily understood [10].

2.1. *Interpretive Structural Modeling Methodology*

The ISM application is based on the methodological order presented below [10,11,12,13,14] .

Step 1: Problem Identification

One of the main areas in which Industry 4.0 enables improving operations is the achievement of an efficient product customization, considering individual and customer-specific requirements in the value creation process. With the help of the Cyber-physical systems (CPS), Internet of Things (IoT), Internet of Services (IoS) etc., Industry 4.0 allows for a major change in the way of implementing and managing a customer-to-customer interaction [1,2,5,7]. Thanks to them, it the so-called “Smart Factory” is possible to build, in which physical processes are performed and monitored by CPS maintaining a digital duplicate of the entire operations system and, correspondingly – of the processes performed by it, taking decentralized decisions. Through IoT, CPS interact with each other and with people in real time, and this makes the operations system more adaptable, efficient, and more customer-oriented, e.g. – agile.

To achieve a high degree of operations system responsiveness and comprehensive flexibility, a great degree of contribution is brought by the new capabilities of 3D-printing (Additive Manufacturing). Based on CAD data, components of metal, ply or ceramics are produced that up to now would be very difficult manufactured or with high cost. This method allows small-volume and less-weight manufacturing, as well as achieving higher product strength and reliability. Another very important advantage of 3D-printing is the ability to react quickly when changing product structure and design.

To summarize, technological change can provide a more flexible way to serve the customer’s individual needs through a comprehensive digitalization of the operations system performance. This way, with the help of ISM, it is necessary to establish the dependencies between the factors influencing the customer's degree of co-operation in the value creation process and their presentation in a structured manner so as to assist their integrating into one complete digital model for an effective customization.

Step 2: Identification of the Factors

Based on a deeper analysis of the literature [15,16,17,18, 19,20,21,22,23] factors, defining the opportunities for customers' co-participation could be classified in three main groups:

(F_1) Factors, characterizing Market Demand

- *Customer Attitude (**$f_{1.1}$**)* – this factor is related to the customer's expectations regarding the delivery time for the item ordered (product or service). Two scenarios are mainly discussed [25,26]: (1) "*Immediate purchase*" – limited customer intervention is presumed and (2) "*Ready-to-wait*" – most often the customer's attitude for waiting is connected with his/her requirements to the end item in terms of brand, quality etc. The more specific these requirements are, the higher the degree of customer's intervention in the process of value creating.

- *End Item Price (**$f_{1.2}$**)* – it a complex economic category in which the interests of both the producers and the customers reflect. When the focus of producer's attention is on proving a competitive price, the tendency is to reduce the degree of customization. On the other hand, when the aim is to meet the specific requirements of the customers, then the higher the price is acceptable and the tendency is to increase the degree of customer engagement (it could vary from "Distribution-to-order" to "Design-to-order").

- *Type of Market Demand (**$f_{1.3}$**)* – three situations are considered to have an impact on the degree of customer engagement: *(1) Independent Demand, (2) Dependent Demand, and (3) a Combination of Dependent & Independent Demand.* In the first case, the customer's role is depersonalized – he/she don't participate in the end item forming. In the second case, the end item is formed entirely by his/her specific preferences – in terms of raw materials, the manufacturing technology, product design etc. As to the third case, it implies an intermediate degree of customer engagement, which sometimes means sub-assembly to order of some of the components, or assembly to order of the end item.

- *Demand Volume (**$f_{1.4}$**)* – (1) Large-volume, (2) Medium-volume and (3) Low-volume market demand. In order to be adequate to the current market situation, the producers should focus on the search for opportunities, regardless of the volume of demand, to ensure such a degree of customer involvement that meets their requirements. This is one of the most serious challenges facing modern businesses, which Industry 4.0 promises to overcome.

- *Demand variability (**$f_{1.5}$**)* – the following types of market demand nature exist: *(1) uniform, (2) variable and (3) seasonal/ cyclical*. In all three cases, the aim is to ensure the greatest possible involvement of the customer for the particular situation, up to the degree to which it is profitable for the enterprise. However, this consideration is true of any of the factors relevant to the problem discussed.

(F_2) Factors, Characterizing the Product

- *Product Architecture (**$f_{2.1}$**)* – this is one of the factors with the most important significance, as far as the opportunities for the product variance are considered, therefore it is a basic indicator for the product complexity. Given the architecture specificity of the product, the company must be very cautious in determining the point (operation) up to which the customer should be "allowed to penetrate" the process of end item determining, because in some cases this may lead to deterioration of product qualitative and functional characteristics. The aim is to design/construct products with a high degree of architecture *modularity*, as it is an opportunity to "control" the diversity and to some extent makes the task of the manufacturers easier. In addition, as far as the degree of customer involvement is concerned, it has the potential to vary from "make-to-order" up to "sub-assembly/assembly on order". Also, the more modular structure of the final product, the greater the possibilities for product customization, which enables a higher degree of customer involvement (up to "design-to-order"). Otherwise, a good strategy would be to allow the customer to penetrate up to "sub-assembly/assembly on order".

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(F_3) Factors, characterizing Operations Processes

- *Delivery Time (**$f_{3.1}$**)* – the time period between the moment of receiving the order and the moment of delivery of the product to the customer.

- *Process Flexibility/Agility (**$f_{3.2}$**)* – the higher the degree of flexibility and dynamism of the production process, the greater the possibilities for a higher degree of customer involvement.

- *Process Modularity (**$f_{3.3}$**)* – one of the main prerequisites for assisting the producers' pursuit of product customization [27,28,29,30]. In fact, through modularity, some degree of unification of the manufacturing processes for the various components and/or end items from the product mix of the enterprise. This reduces the variety of operations and/or processes that could potentially be affected by a customer's intervention, which in turn favors their effective organization and management.

The factors discussed so far could be combined in a single model with the help of ISM to present the interrelationships and interactions between them and to take into account their complex influence in deciding on the level of customer involvement in the value creation process. They will be grouped as follows:

Step 3: Defining the Relationships between the Factors

According to the ISM methodology, it is necessary to define the dependencies between the observed factors. Table 1 lists all possible dependencies that may occur among the factors presented in step 2. The table also shows the assumed conditional indications of the individual dependencies to be used in the following steps:

Table 1. Relationships between any two factors (*i* and *j*)

F:	Forward relationship from factor f_i to factor f_j i.e. factor f_i helps to achieve or influences factor f_j;
R:	Reverse relationship from factor f_i to factor f_j i.e. factor f_j helps to achieve or influences factor f_i;
FR:	Dual directional relationship i.e. factor f_i and factor fj helps to achieve or influences each other;
X:	No relationship exist between factor f_i and factor f_j.

Step 4: Developing Structural Self-Interaction Matrix

In this step, the so-called Structural Self-Interaction Matrix (SSIM) is developed, in which the dependences between each two factors are expertly defined. The SSIM case presented in this publication is shown in Figure 1.

X axis		F_1					F_2	F_3		
Y axis		$f_{1.1}$	$f_{1.2}$	$f_{1.3}$	$f_{1.4}$	$f_{1.5}$	$f_{2.1}$	$f_{3.1}$	$f_{3.2}$	$f_{3.3}$
F_1	$f_{1.1}$		F	R	R	R	R	FR	FR	FR
	$f_{1.2}$			R	FR	X	R	R	R	R
	$f_{1.3}$				R	R	X	R	R	FR
	$f_{1.4}$					FR	F	F	F	F
	$f_{1.5}$						F	F	F	F
F_2	$f_{2.1}$							FR	FR	FR
F_3	$f_{3.1}$								R	FR
	$f_{3.2}$									FR
	$f_{3.3}$									

Figure 1. *Structural Self-Interaction Matrix*

Step 5: Developing Initial Reachability Matrix

The SSIM developed in step 4 should be transformed into the Reachability Matrix, which shows the dependencies between the pairs of factors in a binary format.

Based on the indications in Table 2, SSIM is converted to the Initial Reachability Matrix, which is shown in Figure 2.

Table 2. *Binary format conversion*

Relationship	f_{ij}	f_{ji}
X	0	0
F	1	0
R	0	1
FR	1	1

The matrix has been named Reachability Matrix because it shows whether any variable is reachable from the remaining variables.

X axis / Y axis		**F1**					**F2**	**F3**		
		$f_{1.1}$	$f_{1.2}$	$f_{1.3}$	$f_{1.4}$	$f_{1.5}$	$f_{2.1}$	$f_{3.1}$	$f_{3.2}$	$f_{3.3}$
F1	$f_{1.1}$	**1**	1	0	0	0	0	1	1	1
	$f_{1.2}$	0	**1**	0	1	0	0	0	0	0
	$f_{1.3}$	1	1	**1**	0	0	0	0	0	1
	$f_{1.4}$	1	1	1	**1**	1	1	1	1	1
	$f_{1.5}$	1	0	1	1	**1**	1	1	1	1
F2	$f_{2.1}$	1	1	0	0	0	**1**	1	1	1
F3	$f_{3.1}$	1	1	1	0	0	1	**1**	0	1
	$f_{3.2}$	1	1	1	0	0	1	1	**1**	1
	$f_{3.3}$	1	1	1	0	0	1	1	1	**1**

Figure 2. Initial Reachability Matrix

Step 6: Incorporating Transitivity and Developing final Reachability Matrix

Euclid [10] had stated that "*Things which are equal to the same things are also equal to one another"*. This is the concept of Transitivity, which is an important feature of ISM.

X axis / Y axis		**F1**					**F2**	**F3**		
		$f_{1.1}$	$f_{1.2}$	$f_{1.3}$	$f_{1.4}$	$f_{1.5}$	$f_{2.1}$	$f_{3.1}$	$f_{3.2}$	$f_{3.3}$
F1	$f_{1.1}$	**1**	1	1*	1*	1*	1*	1	1	1
	$f_{1.2}$	1*	**1**	1*	1	1*	1*	1*	1*	1*
	$f_{1.3}$	1	1	**1**	1*	1*	1*	1*	1*	1
	$f_{1.4}$	1	1	1	**1**	1	1	1	1	1
	$f_{1.5}$	1	1*	1	1	**1**	1	1	1	1
F2	$f_{2.1}$	1	1	1*	1*	1*	**1**	1	1	1
F3	$f_{3.1}$	1	1	1	1*	1*	1	**1**	1*	1
	$f_{3.2}$	1	1	1	1*	1*	1	1	**1**	1
	$f_{3.3}$	1	1	1	1*	1*	1	1	1	**1**

Figure 3. *Final Reachability Matrix*

Step 7: Developing Reachability and Antecedent Sets

The utility of the Reachability Matrix is that it can be used to develop hierarchical restructuring [13]. For this, we have to first define reachability and antecedent sets. A ***reachability set*** is defined for each factor as a set containing factors, which can be reached from that particular factor. In other words, the set for each factor contains factors whose cells in the row pertaining to the variable are allotted "1" in the Reachability Matrix.

An ***antecedent set*** is defined for each factor as a set containing factors, which can reach that particular factor. In other words, the set for each factor contains factors whose cells in the column pertaining to the factor are allotted "1" in the Reachability Matrix. For our example the reachability, antecedent and intersection set for the final Reachability Matrix is given below in table 3.

Table 3. *Reachability, antecedent and intersection sets for final reachability matrix*

Factors	***Reachability Set***	***Antecedent Set***	***Intersection Set***
$f_{1.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$
$f_{1.2}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$
$f_{1.3}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$
$f_{1.4}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$
$f_{1.5}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$
$f_{2.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$
$f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$
$f_{3.2}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$
$f_{3.3}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$	$f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$

Step 8: Developing Level Partitions

The reachability, antecedent and intersection sets for initial Reachability Matrix are defined for informative and instructive purpose only. It is the final Reachability Matrix that we are interested in for building the digraph. For this, level partitions i.e. different levels based on a series of iterations, are to be developed. Levels starting with the top level contain the variables for which the Reachability and Intersection sets are the same (meaning that both the sets contain the same variables) in each iteration. The top level (***Level 1***) is identified by checking the variables in the final Reachability Matrix for which the reachability and intersection sets are the same [10]. In our case, each factors occupy Level 1. The factors for which the reachability and the intersection sets are the same occupy the top level in the ISM hierarchy and the top level factors are those factors that will not lead the other factors above their own level in the hierarchy [12].

Step 9: Developing Conical Matrix

The Conical Matrix is the step just before building the digraph. It is developed by clubbing together the factors in the same level, across rows and columns of the final Reachability Matrix [12]. What is done here is that on the X-axis and Y-axis, the factors are written down based on their levels starting from Level-1. In our example, the factors in Level-1 being $f_{1.1}$, $f_{1.2}$, $f_{1.3}$, $f_{1.4}$ $f_{1.5}$, $f_{2.1}$, $f_{3.1}$, $f_{3.2}$ $f_{3.1}$, these factors are first written down on the X and Y axes. The Conical Matrix is similar to the Reachability Matrix with the exception that the factors in the Conical Matrix are written on the X- and Y-axes based on their levels. The relationships between the factors are taken from the Reachability Matrix. The Conical Matrix for our case is the same as final Reachability Matrix (figure 3).

Step 10: Building Digraph

Based on the Conical Matrix, the initial Digraph is built. A Digraph is defined as set of nodes (representing the variables in the Conical Matrix) which are interlinked together as per the relationship in the matrix (F, R, FR or X) and all the links are shown as arrows indicating the direction from one node to the other [10].

The final Digraph as shown in Figure 4 is developed after removing the Transitivity Links.

Thus developed Digraph is the structural model of the interrelationships and the interaction between factors that support the process of developing an individual approach to customers.

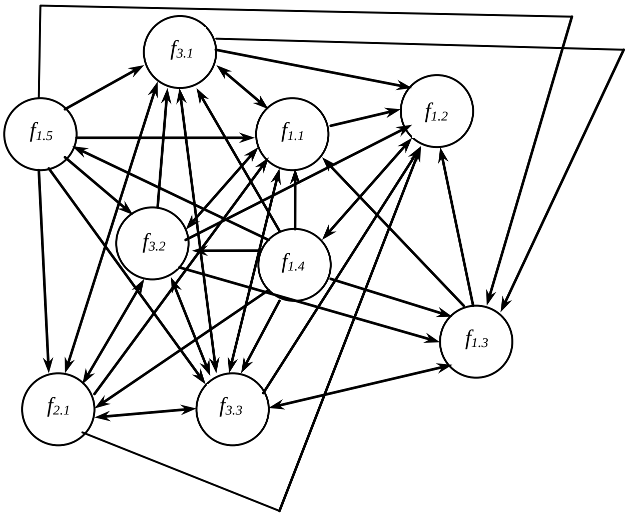

Figure 4. Final Digraph

As can be seen from figure 4 there is a lot of interaction between the factors that help building an individual approach to customers. With the technical support of Industry 4.0 the reporting of the interactions between the factors can be done in real time and thus to build an effective integration of the clients in the process of creating value.

3. Conclusion

In this paper discuses the interrelationships and the interaction between factors, affecting the level of customers Co-Participation, and their integration in a structured way, with the help of the so-called Interpretive Structural Modeling (ISM) to help integrate them into a comprehensive conceptual framework that represents producer-customer interactions under Industry 4.0 conditions and, as a result, increase the efficiency of the process of creating value according to the individual requirements and expectations of the customer.

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