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METHOD FOR MEASURING PRODUCTION COMPLEXITY

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ABSTRACT

Many companies today struggle with fierce demands on efficiency, flexibility and sustainability connected to customization and the introduction of new sustainable products. This increases production complexity, which should be managed through a holistic approach in order to avoid sub-optimization, focus usage and support relevant changes in the production set-up. This paper presents a first step approaching such a framework, a method for measuring production complexity specifically on a station level in a line re-balancing scenario. A Complexity Index was developed in analogy with, and as a compliment to, Robustness Index (RI) a calculation method used at Volvo Cars. The RI involves parameters that are ranked by a multifunctional group during several days. Complexity Index should in comparison, be used by one person at a time evaluating four parameters: *Product and variants, Method, Layout and Equipment* and *Organisation and Environment*. The method should be validated empirically through in-depth studies at Volvo Cars Corporation.

KEYWORDS: Complexity, flexibility, sustainability

1. INTRODUCTION

For many years there has been a development towards shorter product life cycles, frequent changes in products, processes and volumes, which increases production complexity. Volvo Cars Corporation (VCC) reports that in a couple of years the number of components will increase by 50-100%, mainly because of the introduction of new sustainable products i.e. electric and hybrid engines. The variants are also expected to be more differentiated e.g. fuel tank or batteries instead of a number of fuel tanks variants. Changing products in production inevitably introduce certain amounts of ramp-up losses and disturbances in running production, which introduces problems related to balancing.

The term “complex” is often used in everyday language to refer to the difficulty of understanding or analyzing a system. When modelling a system’s complexity, there seems to be a common understanding in literature to separate “structural complexity” - which is related to fixed nature of products, structures, processes, and “dynamic complexity” - variations in dates and amounts due to material shortness, breakdowns, insufficient supplier reliability [1-3]. However, since humans may consider the same system and situation differently it is important to consider how the system is perceived. Li & Wieringa [4] presented a conceptual framework for perceived complexity in supervisory control systems, consisting of three factors: a systems technical complexity (machine and equipment), task complexity (volume variety and link dependencies) and perceived complexity in terms of personal factors (knowledge, training, personal type, background, willingness) and operation and management strategy. In handling complexity a theoretical framework was first suggested handling static and dynamic complexity [5]. This model was expanded with empirical data and it was seen that a missing piece of understanding complexity was perceived or subjective complexity seen from different roles in production [6]. In this paper a method, used by different roles connected to production for measuring complexity, is presented.

1.1 Aim and delimitations

In this paper the research question, first stated in Gullander et al. [5] will be followed: *What should be included in a definition and description of "production complexity" to support measurement and development work of efficient, highly flexible and sustainable production?* This paper will focus on analysing existing methods for measuring complexity and concepts similar to it and to suggest a method for measuring complexity at a work-station-level. The research work reported in this paper is conducted within the project "Support for Operation and Man-hour Planning in Complex Production" (COMPLEX) where a holistic standpoint is aimed for.

The main aim of the method under development is to be used for continuous improvements, to suggest a degree of complexity and ways of managing it. In order to develop the method iteratively the method, in this step, will consider how the degree of complexity is measured, specifically for a re-balancing situation. Effects and ways of handling complexity are not considered. The focus of the method lies in subjective or perceived complexity, filling the gap in previous complexity frameworks.

The work is conducted in collaboration with the Belgian Complex project**.**

2. RESEARCH METHOD

Previously used methods or measurements of complexity are investigated to see if they fill theoretical and empirical gaps. In identifying requirements of a company, VCC is considered as a specific example.

In the empirical framework for complexity, by Fässberg et al. [6], the theoretical framework for complexity was updated and the complexity parameters were extended to *Regulations*, *Market requirements*, *Product*, *Changes*, *Layout*, *Routing*, *Planning*, *Organization*, *Process steps*, *Information* and *Work environment.* These parameters will be analysed further in connection to existing literature and methods.

The complexity method will be formed so that it can, after this step, be tested by different roles in order to get their feedback on parameters, the method as a whole and the manual for how to use the method. A request, from VCC, was that the method would result in a complexity number or degree that would say how low or high complexity a station has in order to better choose a way to handle complexity at that specific station. In addition the tool should be easy to grasp and used by people with different roles connected to the direct production.

3. EXISTING METHODS

In literature a number of different complexity models and corresponding methods for calculating complexity measures are presented. These concentrate on the emerging behaviour resulting from a system having a number, variety, strength of interactions and a certain structure. Generally it can be stated that the methods identified are difficult to grasp, requires detailed data on the system to be measured, and are time consuming. Despite the effort required, they do not cover all aspects of complexity, such as the subjective aspects of complexity. The most relevant methods found are seen in Table 1, see full literature review in Gullander et al. [5].

Both the entropy model [2] and the information diversity model [7] have been seen hard to understand and to use; the entropy model has been hard to use by people working on shop floor level. Calinescu et al. [8] compared Frizelle's entropic and the MFC method [9], concluding that the methods complement each other since they differ regarding what types of complexity they show, requirements, and methodology. The entropic method, was much more time consuming and data requiring, but provided more information of the system. However, the MFC method provided more information of the decision-making process, and was faster and easier to use.

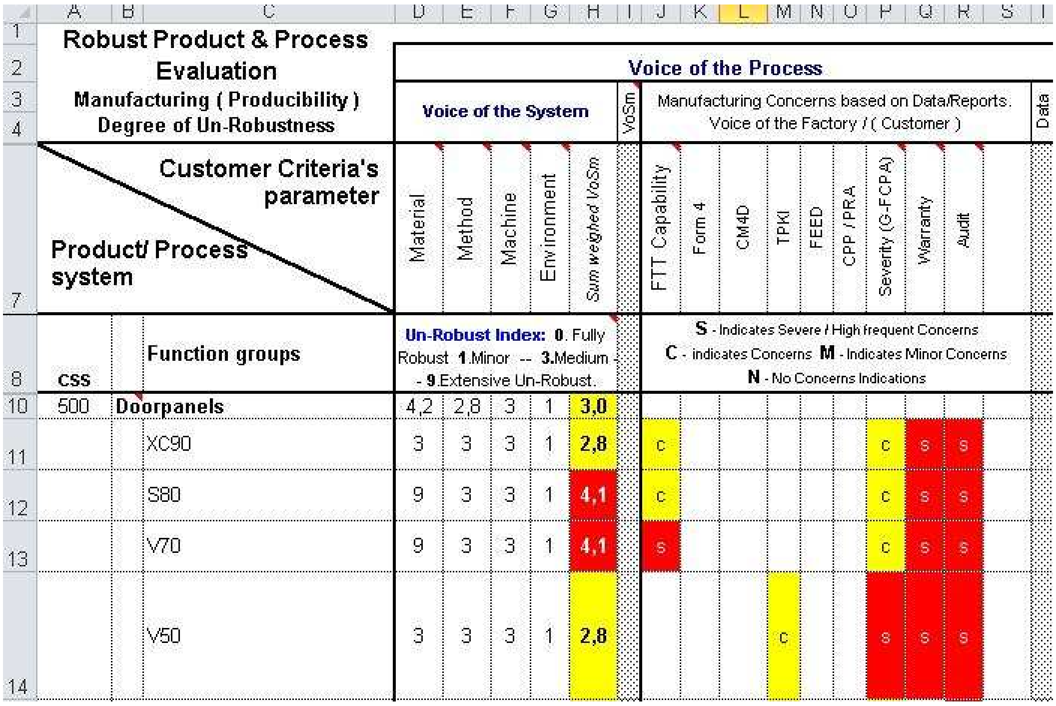
Table 1: Summary of complexity methods and measurements found in literature

Name	**Developed by**	**Focus**	**Method**
Complexity Entropy model	Frizelle and Woodcock [2]	Static and dynamic complexity	Formula that calculates the probability of a state to occur
Information diversity, content and quality	ElMaraghy and Urbanic [7, 10]	Complexity of products, process and operations	Ratio of diversity, content and quantity
Management of software development (MFC)	Meyer and Foley Curley [9]	Knowledge and technology complexity	Interviews and questionnaires on seven scores concerning decision-making and information at hand

Another related method found at VCC was the internally developed Robust Product & Process Evaluation called Robustness Index (RI). The method is based on FMEA methodology and is used in early development phases. RI is useful since it provides a number that you can work on a long-term basis with. The purpose of RI is to secure the producability of a part (system) of the product and to evaluate if the new product has a more or less robust system, see Figure 2.

Each product system is evaluated in a spreadsheet from 3 different aspects; Voice of System, Voice of Production and Voice of Customer. The main parameters: Material, Method, Machine, and Environment, are the same for each of the voices but has its own criteria for evaluation. The robustness is evaluated by every part for one product and then summarized. The parts are judged as, 0 = Fully robust, 1 = Minor robust, 3 = Medium robust and 9 = Extensive un-robust. The method is during ongoing changes where one suggestion is to insert also a 5 in the robustness scale in order to make the gap between 3 and 9 smaller.

The evaluation is made in cross-functional teams in order to gather the total picture.



Robust Product & Process Evaluation
Manufacturing (Producibility)
Degree of Un-Robustness

Voice of the Process: Voice of the System | VoSm | Manufacturing Concerns based on Data/Reports. Voice of the Factory / (Customer) | Data

Un-Robust Index: 0. Fully Robust 1.Minor -- 3.Medium - 9.Extensive Un-Robust.

S - Indicates Severe / High frequent Concerns
C - indicates Concerns M - Indicates Minor Concerns
N - No Concerns Indications

CSS	Function groups (Product/ Process system \ Customer Criteria's parameter)	Material	Method	Machine	Environment	Sum weighed VoSm	FTT Capability	Form 4	CM4D	TPKI	FEED	CPP / PRA	Severity (G-FCPA)	Warranty	Audit
500	Doorpanels	4,2	2,8	3	1	3,0									
	XC90	3	3	3	1	2,8	C						C	S	S
	S80	9	3	3	1	4,1	C						C	S	S
	V70	9	3	3	1	4,1	S						C	S	S
	V50	3	3	3	1	2,8				C			S	S	S

Figure 1: Robustness Index

The sister project in Belgium is developing a method for measuring the objective complexity by collecting a number of parameters for each assembly station. The method is under development and aims at capturing the complexity of direct operator time and focuses on data that can be gathered automatically as it exists today (from computer systems). This method produces a number/degree of the objective complexity and is not yet included in any work procedure or any management concept.

4. METHOD PROPOSED - COMPLEXITY INDEX

The CompleXity Index (CXI) was built on the same principle as RI. In comparison to RI, CXI is simplified in order to be used continuously and by fewer people and focuses on a station or line instead of the product. This means that instead of evaluating every parameter by every part of for example XC90, see Figure 1 and the RI = 2.8, CXI will consider a station or line and all parts/products produced there. CXI has otherwise the same features that RI has; that people should evaluate parts on a scale of 1, 3, 5 and 9 on how complex a certain object is (see Figure 2) and that a manual should be used for explaining the important parameter criteria. The number of parameters used in CXI should be as many, or fewer than for RI.

In this first step it is suggested that people close to production should use the method. In this way three or more people assigned to the same station or line, within different roles, could give their view of how complex a certain station or line is. The index given by all roles are summarized and a final index will be given the station/line so that complexity can be handled accordingly. If there is a big difference in indexes between different roles a further discussion is suggested. Two roles suggested for using the method are internal logistics and production personnel, see Figure 2.

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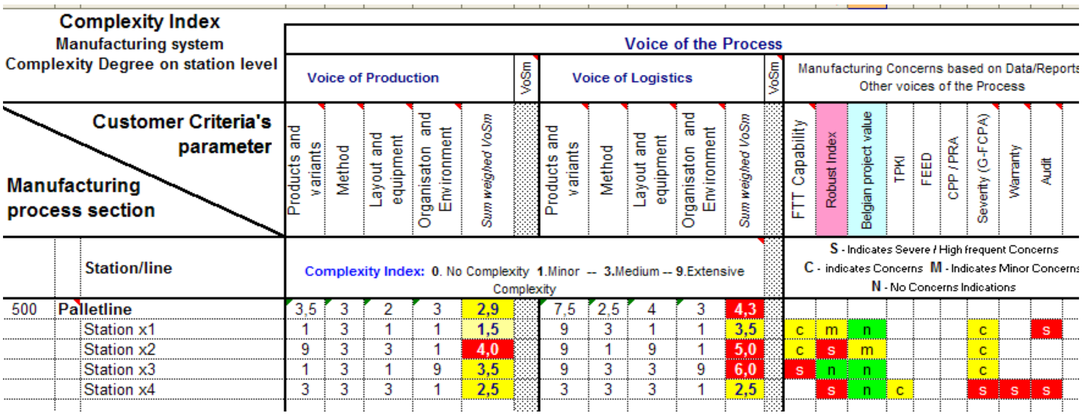

Complexity Index — Manufacturing system — Complexity Degree on station level

Complexity Index: 0. No Complexity 1.Minor -- 3.Medium -- 9.Extensive Complexity

S - Indicates Severe / High frequent Concerns; C - indicates Concerns; M - Indicates Minor Concerns; N - No Concerns Indications

	Station/line	Voice of Production: Products and variants	Method	Layout and equipment	Organisaton and Environment	Sum weighed VoSm	Voice of Logistics: Products and variants	Method	Layout and equipment	Organisaton and Environment	Sum weighed VoSm	FTT Capability	Robust Index	Belgian project value	TPKI	FEED	CPP / PRA	Severity (G-FCPA)	Warranty	Audit
500	Palletline	3,5	3	2	3	2,9	7,5	2,5	4	3	4,3									
	Station x1	1	3	1	1	1,5	9	3	1	1	3,5	c	m	n				c		s
	Station x2	9	3	3	1	4,0	9	1	9	1	5,0	c	s	m				c		
	Station x3	1	3	1	9	3,5	9	3	3	9	6,0	s	n	n				c		
	Station x4	3	3	3	1	2,5	3	3	3	1	2,5		s	n	c			s	s	s

Figure 2: Complexity Index, as suggested

4.1 Parameters for measuring complexity

The subjective parameters found in previous case studies were grouped into higher-level parameters, Figure 3. *Product/variants*, *Method*, *Layout and Equipment* and *Organisation and Environment* were formed using data from the empirical studies and framework, see research method.

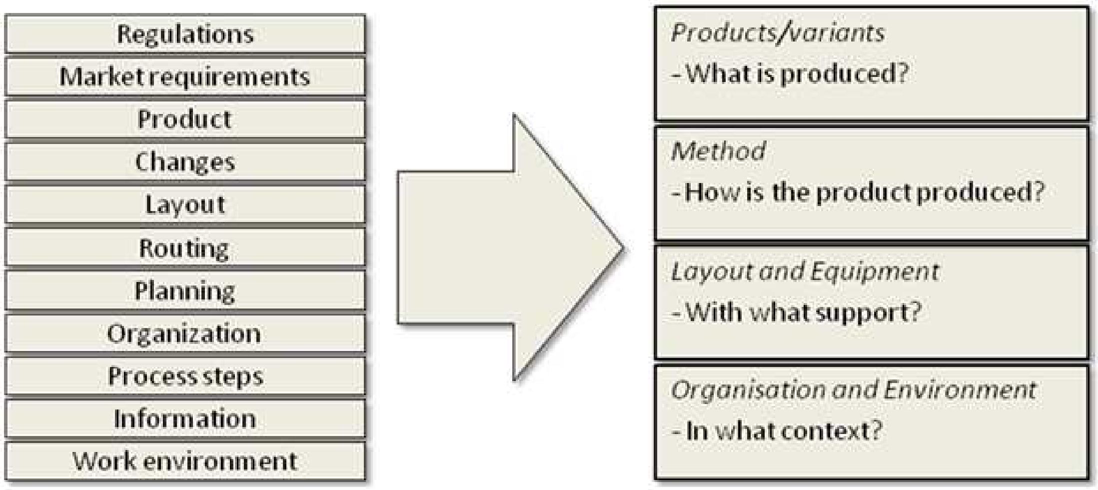

Figure 3: Complexity parameters

The implication of each parameter will differ between the different roles, required to evaluate a station. As an example, product/variant for internal logistics includes consideration about; How does the products and number of variants affect storage, package (repackaging) and the information system used? How does the change in volume/deviations affect the packaging, organization, support systems used for internal and external communication? How does this effect the sequence regulations?

While for a production personnel, the same parameter includes consideration about; how do the products and number of variants affect information handling i.e. work instruction and method of working? How does the change in volume/deviations affect control, time pressure and metal workload? How does this affect maintenance?

4.2 Manual

For each of the parameters a manual, similar as for RI, stating what criteria should be considered when judging the degree of complexity was made. The manual should be read "To what extent is the line complex in terms of the *Parameter*?" see Table 2, specifically considering the *Main question* and the *Aspects* connected to is.

Table 2: Manual for Complexity Index

Parameter	**Main question**	**Aspects to consider**
Product and variants	What is produced?	Number of products, models, variants, variance between variants, frequency of same parts, frequency of changes etc
Method	How is the product produced?	Information support, number of work instructions, type of instructions, information system for both machine and humans, number of components to pick, similarities/differences between components, pick to handle, type of assembly, number of methods
Layout and Equipment	With what support?	Layout, equipment, tools, fixtures, number of programs, material facade,
Organisation and Environment	In what context?	Organisation, man-hour planning, communication, leadership, rules, time pressure, competence, ergonomics, different work tasks, improvement work

5. DISCUSSION

Existing methods together with data from an industrial case show that there is a need for methods that can include more production aspects than analysis methods, which are based on the product and components. Methods identified in the literature study have disadvantages of being hard to understand and use, as well as not being sufficiently holistic. The entropy model is hard to understand by shop floor people [2, 11] but is good since it discusses both static and dynamic complexity. This can be connected to structural complexity as well as dynamic complexity, which have been used for modeling complexity [1-3]. However the model does not consider subjective complexity, which also was considered important [4, 6]. The information diversity model was also seen hard to use and considers dynamic complexity. It was seen that the entropy and MFC model complimented one another and focuses on different kinds of complexity [8]. The MFC model was based on subjective complexity (Ibid.). Nevertheless the methods provide a guide for choosing measurable parameters, relations and the conceptual models should be included in a holistic complexity model.

We propose that users should assess complexity subjectively using the parameters for defining production complexity. In this way, we can include the relevant parameters and ideas that generate complexity.

The parameters chosen for complexity consider static, dynamic and subjective parameters. The main parameters are *Product/variants* which covers the dynamical changes also seen in the entropy and information diversity model and *Method* which covers the process and instruction process similar to the task complexity in Li & Wieringa's conceptual framework [4]. *Layout and Equipment* is similar to the systems technical complexity seen in the same framework and perceived complexity (also from Li &Wieringa) is connected to the last parameter *Organisation and Environment*. The second parameter *Method* is also connected to the MFC model and content seen in the information model is seen in the last parameter *Organisation and Environment.*

At VCC a method RI has had an implementation process of 3 years and is now part of normal working procedure. Many of the evaluation criteria used are highly relevant for a complexity method, and the procedure has the advantage of being established. However, it is made from a product perspective and does not include enough production or logistics relevant parameters. It can also be understood that it was difficult to gather people from different units at the same time.

Since one of the demands for the method was that the method should be easy to use a CXI was formed using the same principle as RI. One of the improvement suggestions for RI, that the scale should also consider 5, was suggested for CXI. Also, instead of having a group of people sitting together for several days, the CXI-method is designed for one person at the time (for different roles). This could be more efficient in a production setting, but could also have its disadvantages since two or three people with different roles could have very different views of the complexity. Also if the roles in the company are not well defined it could be hard to find a person with a specific role for example internal logistics. The method, its parameters and manual need empirical testing to reduce such problems.

The Swedish project has focused on qualitative parameters in terms of subjective or perceived complexity in order to bring many aspects together. Since the Belgian project has focused on objective parameters they should act as a complement to one another.

5.1 Future work

The method suggested will be part of an iterative in-depth study made at VCC. First stations or lines, good for both internal logistics and production technicians to study will be chosen together with the company. Second, the method and manual will be tested and commented separately by key people at VCC, without consideration of a specific line or station. Third, the stations and the revised method will be tested for validation.

6. CONCLUSIONS

Gullander et al. [5] and Fässberg et al. [6] stated that a more perceptive view of complexity, especially connected to a role perspective is needed to define production complexity. In reaching this, existing methods, parameters for complexity and company requirements were investigated, in order to give a first draft of the method and to prepare for an in-depth study at VCC. A complexity method, CXI, was based on a literature review, an analysis of parameters found in previous case studies and the RI used by VCC. In comparison the CXI was developed to act as a continuous tool at a station level. This method should act as a compliment to the Belgian complexity method and will be tested further to develop a practical and useful guide for companies to calculate the degree of production complexity.

7. ACKNOWLEDGEMENTS

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