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Testing Complexity Index – a Method for Measuring Perceived Production Complexity

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Abstract

CompleXity Index (CXI) is a method developed to help manufacturing companies to describe complexity as experienced and to assist in reducing the effects it has on operator performance. The method is targeting the perceived complexity and was tested at Volvo Cars Corporation. Reproducibility of the method could be seen between respondents and was considered a valuable tool for visualizing problem-areas at the stations. It is suggested that objective data could be one way to identify which stations should be tested in-depth with the CXI method, and that CXI could be used for suggesting improvements or appropriate support tools.

Keywords: Production complexity; perceived complexity; case study; improvement suggestions; problem areas

1. Introduction

Manufacturing companies face challenges in handling dynamic customer demands, fluctuating material needs and requirements on sustainability regarding economical, environmental and social aspects. These challenges result in increasingly complex production and process systems, especially regarding assembly systems. If these effects on production complexity could be measured, work on reducing complexity would be greatly supported, thus creating advantages for companies working with flexible and complex production lines.

1.1. Perceived complexity governs performance

The ultimate goal of measuring and managing complexity is to improve the end users´ performance – in this context – the operator's performance, i.e. to decrease process errors, achieve high quality, good working conditions, fast processes/work and quick change-overs.

The performance depends on the situation and on individual aspects. For example, an operator without sufficient training or experience can perceive a workstation as highly complex although it generally is seen as a station with low complexity. The level of experience is one of many factors; the behaviour of an operator may vary depending on stress level, specific situation, personality and so on. A high workload can induce stress for an operator that might usually not perceive the station as a difficult matter. In order to achieve a practical and applicable measure of complexity, a definition and measure is required that incorporate individual aspects.

1.2. CompleXity Index

In Gullander et al., [1] a framework was proposed showing different aspects of complexity, including static, dynamic and objective complexity. This

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framework emphasizes the subjective or perceived perspective of the system to ensure that the individual experience is considered. The framework was used as a basis for conducting empirical studies and was further developed in Fässberg et al., [2].

The Complexity Index (CXI) method, presented in Mattsson et al., [3], suggest a complexity index based on perceived production complexity and the problem areas included in the framework. In this paper, the problem areas are further developed and the CXI method is tested in a case study.

1.3. Purpose and scope

The aim of this paper is to investigate the usefulness of the CXI method. This is done through answering the following research questions from the operators' perspective:

- What problem areas could be used to describe and measure perceived production complexity at a station level? *(RQ1)*
- How can CXI be useful in handling and reducing the perceived complexity? *(RQ2)*

This is done at a station level. To visualize complexity at a higher level, e.g. a line, several stations can be measured separately and aggregated.

2. Frame of reference

2.1. Modeling perceived complexity

Many research efforts have been made to model complexity: separating it into static and dynamic [4, 5], elaborating on causes [6, 7] and looking at entropy measures. However, only few complexity models explicitly include individual subjective aspects, e.g. [1, 8-10]. Furthermore, most work concern complexity models, and not the implementation of models into measuring methods. Four frameworks and models are presented:

Li and Wieringa presented a framework for perceived complexity that proposes that perceived complexity depends on the human-machine system complexity, task complexity, personal factors, operation and management strategy [11]. The perceived complexity is indirectly affected via the human-machine system through task complexity, processes, and control system. The personal factors include job training and knowledge, type/personality, intelligence, cultural background, and motivation to work (willingness). The operation and management strategy is based on experience, by the operator or for the operator. A similar model is presented by Guimaraes et al., who propose that there is a basic complexity associated with the system and the tasks [12]. They state that perceived complexity is a moderation of the basic complexity, where the moderation variables are: operator training and man/machine interface.

Some models include information aspects. For instance Urbanic and ElMaraghy put forward a complexity model for products, process, and operations where three elements affect the complexity: the diversity (measuring uniqueness of a task), content of information (measuring effort needed), and the quantity (information needed for a task) [13]. The parameter of information content includes effort needed and difficulty of task. Meyer and Foley Curley [14] defined a framework and method for measuring complexity, targeting management and decisions within software development processes. The model focuses on the knowledge and information needed to make decisions, including estimation of the breadth and depth of knowledge, as well as how much the knowledge has changed.

The presented descriptions can be synthesized in a common model, see Figure 1. In addition to research that explicitly focuses on the concept of *System complexity*, specific relations and areas that affect the perceived complexity are the *Human-machine system, Task complexity* and *Personal Factors*. Human-machine systems affect the way the situation, system, and tasks are perceived by the operator (and thus the perceived complexity) [15].

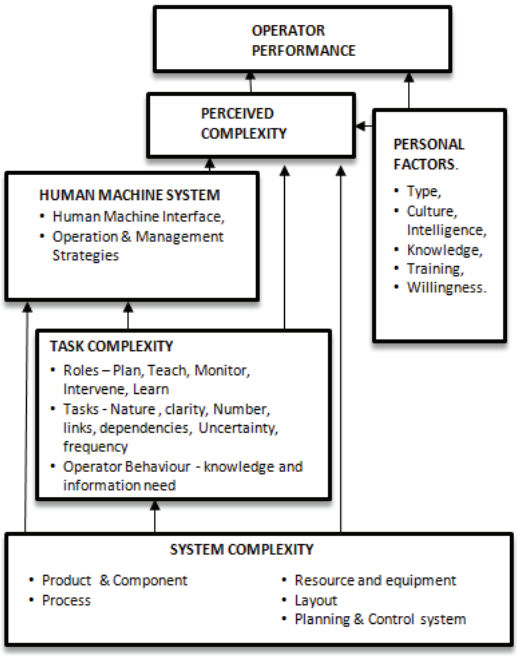

Fig. 1. A common model of perceived complexity, synthesis of models presented in [11] [12] [14].

Also affecting the complexity are the different task roles

that operators have during their work (programming tasks, teaching, monitoring process, intervening, learning) [16], which is related to the level of automation of the system [17]. The importance of roles was also stressed in Gullander et al., [1]. Another important factor is research on what types of behaviour the operator have when performing the tasks, i.e. skilled, rule or knowledge based behaviour [18]. Related to this are studies on information support and training needs appropriate for executing tasks, thus reducing the perceived complexity. Each of these areas may provide knowledge into areas that have a major affect on the *Operator performance*, and the perceived complexity.

The common model of perceived complexity gives an understanding of what effects perceived complexity in a complex working environment.

2.2. Production complexity problem areas

The framework proposed in Fässberg et al., [2] includes the identification of problem areas (called causes of complexity in Fässberg et al.). The problem areas were: Regulations, Market requirements, Product, Changes, Layout, Routing, Planning, Organization, Process steps, Information and work environment. In Mattsson et al., [3] a further development was done suggesting the following areas: *Product and variants, Method, Layout and equipment* and *Organization and environment*. As part of the practical application of the method the problem areas will be further developed (*RQ1*).

3. Methodology

As a further development of the CXI the problem areas were re-evaluated. The following problem areas are suggested:

- Product variants (Area i)
- Work content (Area ii)
- Layout & Tools (Area iii)
- Support tools & Work instructions (Area iv)
- General (Area v)

The re-evaluation was due to that the previous version presented in Mattsson et al., were used as a spreadsheet with an accommodating manual; which meant that they had a bigger descriptive part. The problem areas were re-arranged so that they would match operators, logistical personnel as well as production technicians (see Mattsson et al., [3] for details regarding the development of the method). The fifth area was included to include what the respondents think of the station as a whole.

The new version of CXI is questionnaire with 23 statements. The respondents rated Likert-type scaled statements on each area. A Liker-type scale is an attitude statement [19] ranging from one to five where one was *I do not agree at all* and five was *I fully agree*. Respondents could also answer *I don't know/Not relevant*. The questionnaire included 23 statements (21 closed and 2 open-ended). Most of the questions were stated so that the answer five would mean that the station was complex. Some of the questions were reversed to reduce possibilities of bias.

The problem areas were not ranked, instead they are thought to have the same impact on complexity. If an impact variation is found the calculation of CXI could be changed; differences may be seen for different companies.

3.1. Analysis

The usefulness of the method is tested by looking its reproducibility and then by using objective data to move towards validating the method. Reproducibility means to test the degree of agreement between measurements or observations on more than one respondent [20]. A disagreement could be due to experiment bias, which is the tendency to answer questions according to the researcher's expectation, or that the respondent can have preferences for certain numbers. The reproducibility was determined using Pearson's product-moment correlation coefficient.

Validation of subjective measurement with few samples is very difficult. A first indication of validity will be tested comparing CXI to objective data. The objective data used was the number of variants and components on the station.

4. Case study at VCC

CXI have been developed as part of a current state analysis, which could be used before moving into in-depth studies. The current state analysis gives an overview of the problem by selecting an area of interest *A1*, identifying and measuring complexity *A2* and by visualizing complexity *A3*. The current state analysis will be used to understand how CXI practically can be used in industry (*RQ2*).

An operator and a team leader were chosen from each of the eight team areas. The team leaders at VCC coordinate and plan the work that should be done by the team. They have however no managerial responsibilities and do approximately 50% assembly work at the station. The 16 respondents themselves filled out the questionnaire, when the production schedule allowed them to work with it. The response rate of the questionnaire addressing the perceived complexity was 100%.

4.1. Selecting an area of interest A1

In this case study, eight stations, from eight team areas were chosen, Station A-H. The selection was made in cooperation with the company so that a range of layout and characteristics of VCC could be represented and that some stations that were believed to be complex and some not complex were chosen. Four were pre-assembly stations.

4.2. Identifying and measuring complexity A2

CXI was calculated, station-by-station, by taking the total median of the statements and adding the highest median value for the problem areas divided by a factor, see Formula 1. The highest median is added to the station in order to make sure high scores on statements, i.e. individual differences, will be represented by CXI.

$$CXI_{(per\ station)} = \text{total median}_{(per\ station)} + (\text{highest median}_{(per\ problem\ area)} / 4) \quad (1)$$

The score was divided into three categories: *Green, Yellow and Red*, which would visualize the complexity index, the limit scores for *Yellow* was > 2 and *Red* >3. The CXI calculation is seen in Table 1 where stations A, C, E-F and H show *Red* values *(R)*. Stations D and G show *Yellow (Y)* and station B *Green (G)* values. The highest score is seen for station E (The median N = 6.3).

Table 1. CXI on stations

STATION	A	B	C	D	E	F	G	H
CXI	3	1.3	3	2.3	6.3	4.3	2.8	3.8
	R	*G*	*R*	*Y*	*R*	*R*	*Y*	*R*

The analysis of reproducibility between the two respondents for each of the stations A-B and E-H is presented in Table 2. There was a strong positive correlation between the two respondents, for stations B and G, $r > 0.82$, $p<0.05$. Stations A and F had a low correlation, $r < 0.60$ while for stations E and H the correlation was stronger, $r > 0.60$. Stations C and D did not show significant values for the correlation.

Table 2. Pearson product-moment correlation coefficient for stations A-B and E-H

STATION	A	B	E	F	G	H
Pearson's coefficient *r*	0.54	0.94	0.62	0.57	0.82	0.60

As a first step of validating the method CXI was compared to the objective data, number of variants and components. A new coefficient was defined, *VarComp*, which was calculated as the average of *Var*iants and *Comp*onents for each station. CXI correlated with the coefficient, some differences are noted for stations A, E and G that have a higher CXI than *VarComp* and station H that have a lower CXI than *VarComp* see Figure 2.

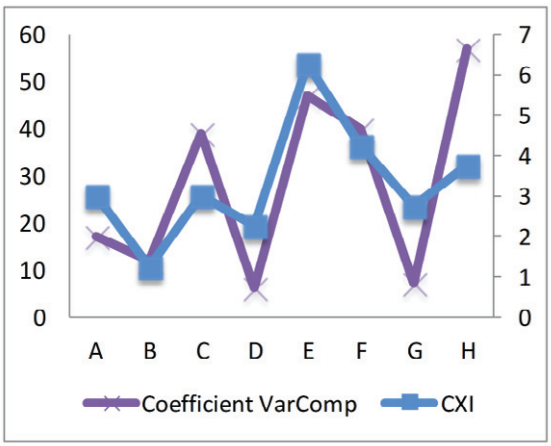

Fig. 2: Graph over the variant and component coefficient and CXI

4.3. A3 Visualizing complexity

In this step the medians for the problem areas are presented in Table 3. The CXI is visualized in Fig 3 with a colour-carpet. A majority of *Red* values were seen for Product/variants (N = 4), Area i. Then came Work content (N =3), Area ii, Support tools & Work instructions (Area iv) and General (Area v) and lastly Layout & tools (Area iii). Looking at the stations, station E and F show the highest values (N = 3 *Red* values). Stations A, D and H, have two *Red* values and station C and G (N = 1 *Red* values) while station B had no *Red* values.

Table 3: The medians on stations

STATION	A	B	C	D	E	F	G	H
Area i	4	1	4	1	5	5	5	5
Area ii	1	1	1	5	5	3	1	1
Area iii	2	1	1	1	2	2	2	3
Area iv	3	1	2	1	1	3	1	1
Area v	2	1	2	3	5	2	1,5	2.5

STATIONS	A	B	C	D	E	F	G	H
Area i	*R*	*G*	*R*	*G*	*R*	*R*	*R*	*R*
Area ii	*G*	*G*	*G*	*R*	*R*	*R*	*G*	*G*
Area iii	*Y*	*G*	*G*	*G*	*Y*	*Y*	*Y*	*R*
Area iv	*R*	*G*	*Y*	*G*	*G*	*R*	*G*	*G*
Area v	*Y*	*G*	*Y*	*R*	*R*	*Y*	*G*	*Y*

Fig. 3: Colour-carpet showing the medians on stations A-H

5. Discussion

As conceived in the common model of perceived complexity, Figure 1, there are a lot of parameters that affects the perceived complexity of a system. Especially the personal factors have a variety, which introduces an individual filter to all parameters. Hence, the approach of asking the operators of their view could thus be an efficient way to comprehend all aspects, including the personal issues. Using CXI as a way to measure the perceived complexity is a way to move closer on what effects operator performance in a complex work environment. Although it does not give the full view of what effects a complex environment the problem areas suggested were valuable for stating why a station was Green, Yellow or Red. Load/ergonomic issues were not part of the statements and could be included in future versions. It was also seen that future studies is needed in order to state the relevance of problem areas and if they should be weighted.

Testing the CXI included reproducibility, to some extent validation and visualization. It was seen that the reproducibility between respondents was high for two stations, and above average for three stations (two stations did not give significant values). Also the comparison between the objective data and CXI showed similar trends, pointing towards that the method gives valid data. It was suggested that objective data, at this company, could be used to state on which personnel the CXI should be given to.

5.1. Using CXI in industry

Since objective data is easy to measure and can sometimes be generated automatically it can be used to practically state which stations that should be further investigated with CXI. The colour-carpets could be used, as an in-depth tool to understand which areas needs urgent changes (A1 from current state analysis). Stating for instance that a *Red* area needs urgent change, *Yellow* needs change and that *Green* would mean that no change is needed (A2 identifying and measuring complexity). This way the perceived complexity can be understood and handled. The team leader could use the colour-carpet together (Figure 3) with the operator in order to discuss what support tools could be used and to prioritize problem area solutions (A3 Visualizing complexity).

5.2. Method implication and future work

The CXI will be developed further to incorporate additional roles when analysing the station. This is due to that different roles perceive stations in different ways according to their specific work tasks and problems.

One of the questions (Question 19: I often (daily) using the work instructions at this station) was removed according to the risk of bias. Question 24: Comments (for instance possibilities for improvements, changes of the station, work content, support or etcetera), was used to further state why high CXI values was given at a station. Four comments were given regarding load/ergonomic issues, which indicates that a statement regarding this could be included.

Furthermore, in the current version of the questionnaire statements about the respondents' background are lacking.

6. Conclusions

The aim of this paper was to investigate how perceived complexity can be measured and in addition how such a method can be tested and used in industry. This paper presents the CXI questionnaire method, as a further development of the conceptual CXI method developed in Mattsson et al. [3]. Results from the examination indicate that CXI can measure perceived production and results confirm the usability and usefulness of the method in terms of visualizing and finding problem areas, where the common model (Figure 1) could be used to understand what is measured. The measurements from CXI correlated with data collected. This represents the systems objective complexity (number of products and variants) and it is suggested that data could be used, to state which stations should be analysed further with CXI.

In summary CXI can help to point out problem areas at a station, which could help companies to pragmatically reduce and handle production complexity at a station level. Also, the visualization of problem areas could be a valuable tool for continuous improvements to handle re-balancing or man-hour planning and to suggest appropriate information support.

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