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Validation of the complexity index method at three manufacturing companies

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Abstract. In order to manage increasing numbers of product variants, tools that can reduce or manage production complexity are vital. The paper describes CompleX-ity Index (CXI), an index-based method and tool that assess the complexity and difficulty of work at an industrial workstation. CXI was validated at three Swedish manufacturing companies studying the correctness of the calculation, usage as a prediction tool and the view of different roles. In all three cases, CXI was seen as a useful tool to evaluate the operator-perceived complexity of a workstation.
Keywords: Production complexity; station work; continuous improvements; production planning; industrial competitiveness.

1 Complexity Index

Today increased complexity is still one of the biggest challenges in manufacturing [1]. Manufacturing industry experience an increasing number of product variants, components, product mix, and frequent changes in volume, process, product, and organisation. In order to manage these challenges, it is vital for industry to be able to reduce or manage production complexity. People working with production engineering, operation, or introducing changes need to better understand and visualize what level of *production complexity* they experience. Further, industry needs to have tools to identify what type of improvements that can be made to reduce complexity.

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To meet the apparent need to measure production complexity, a CompleXity Index (CXI) was developed within the project COMPLEX. CXI is a questionnaire-based method and complexity assessment tool that includes 23 statements addressing the following identified problem areas: *Product variants, Work content, Layout, Tools and support tools, Work instructions* and *General* (general view of the station). The problem areas are based on empirical work by Fässberg et al., [2] and Gullander et al., [3] (the development of CXI is further explained in Mattsson et al., [4]) The questionnaire statements in CXI are of Likert-type, and evaluated as part of a formula (see Mattsson et al., [4]). The output of the formula is a complexity index that establishes a measurement for the complexity of a station (see score boundaries in Table 1).

The objective of CXI is to assess whether a station has a low, middle, or high complexity (green, yellow or red) focusing on the perceived view of complexity. Scores are given for separate problem areas and presented in a colour-carpet, which indicate the urgency of action (see scores for CXI in Table 1). This can be used in several ways e.g. to improve stations and plan production.

Table 1. Score boundaries for CXI

CXI	Complexity	Colour	Action
<2	Low	g (Green)	No action needed
2 and <3	Middle	**y** (Yellow)	Need change
≥3	High	R (Red)	Need urgent change

The aim of this paper is to investigate the usefulness of CXI and to test its validity.

2 Validation through triangulation

In this paper an applied research methodology is used, which means that empirical data from industrial case studies are a major part of the research results. To validate the proposed CXI method, a triangulation approach [5] was used. In this paper investigator and data triangulation was used suggested Deniz [6] (Deniz also suggested two other types of triangulations). The validation of CXI includes three cases where the feasibility and outcome of the method is tested and investigated. The case study contained semi-structured interviews and discussions with affected personnel regarding the outcome of CXI (both the measurement index and visualization using the colour-carpet). In all cases, the respondents completed their questionnaire in their own time. Afterwards, to be able to evaluate the CXI usage, their opinion was captured in an interview.

Investigator triangulation means that several researchers gather and/or analyses the same type of data. In the presented studies, multiple researchers and in some cases master students, were involved in collecting the data and the information (see Table 2). Investigator triangulation was used to reduce experiment bias, i.e. data-collection dependency on individual researchers' views and interests.

Table 2. Types of users in the investigator triangulation

Company	**Gathering CXI questionnaires**	**Performing analysis**
A	Novice users	Expert users
B	Novice users	Expert users
C	Novice users	Users

Data triangulation is the use of multiple sources, i.e. different participants are asked the same thing. In these studies different types of data sources were used: operators, logistical personnel, trainers, a production supervisor, the head of competence-assurance and higher official and heads (see Table 3). In this table the types of companies, Company A-C, are also presented.

Table 3. Data sources: the respondents and personnel part of discussing the results of CXI

Company	**Type of company**	**Respondents**	**Part of analysing results**
A	Large automotive company	4 operators (2 stations)	4 operators and 1 production supervisor separately
B	Large automotive company	12 operators and 3 trainers (3 stations)	Head of competence-assurance
C	Medium sized company making electronic components	4 kit operators and 10 logistics personnel (11 stations)	An operator representative, higher officials and department heads.

3 Correctness of calculation, usage as a prediction tool and the view of different roles

The validation was made at three manufacturing Companies A-C with different study focuses: *Correctness of the calculation, usage as a prediction tool* and *the view of different roles*. In this chapter the result and discussion is presented.

Whether the CXI *calculation was performed correctly* or not was investigated at Company A, by interviewing the respondents. Two specific stations were chosen for CXI testing at Company A, based on an previous assessment of CXI indicating that the stations had high complexity (see stations F and H in Mattsson et al., [7]). In the new assessment, the stations were rated as complex due to two problem areas: *Product variants* and *Layout.* The respondents stated that the station should be given a red complexity index. Although the operators thought that the station was acceptable to work at, they said that a new person would have difficulty to learn the work and other stations were more difficult for them. The production supervisor also believed the CXI calculation was correct. He however stated that the measurement did not give him new information (in addition he was not given resources to perform any big changes). Instead, he thought the method could be useful on a higher management level.

At Company B, the CXI tool was used to *predict problems* in future stations by studying similar already existing stations. 26 respondents assessed three stations and the main problem area, indicated by CXI, was *Production variants.* Almost all personnel perceived the tools and support tools to be green, but some improvement suggestions were given. Improvement suggestions included work instructions (station 1), sequencing, pre-work and handling of material (station 2), lifting and narrow work place (station 3). The results were considered useful to the company, since it reflected previously unknown facts.

The *view of different roles* was investigated at both Company B and Company C by studying differences between operators and trainers and the views of kit assembly personnel and logistics personnel respectively. The trainers' role at Company B was to teach new trainers how to educate their personnel on the lines i.e. had deeper knowledge of the station but had not worked there for some years. Results indicate that trainers rated the stations as more complex than the actual operators did. However, stations A and C had values close to red values (CXI_A=2.96 and CXI_C= 2.90, see score boundaries in Table 1), see Fig. 1. The difference could however be due to that they had not worked on the station for some time. In order to further understand the problems identified, a discussion with the associated operators is needed. CXI was considered useful as a first step in that discussion.

	Station A		Station B		Station C	
Problem area	Trainers	Operators	Trainers	Operators	Trainers	Operators
Product variants	R	R	R	y	R	y
Work content	y	g	g	y	y	g
Layout	y	y	y	y	R	y
Tools and support tools	g	g	g	g	y	g
Work instructions	g	y	g	y	y	y
General	y	y	g	y	y	y
CXI	R 3.58	y 2.96	y 2.63	R 3.38	R 3.67	y 2.90

Fig. 1. Colour-carpet for trainers and operators at Company B

At Company C, eleven stations were assessed. Studies were made in order to reduce and understand time and work carried out that was not included in the balance, i.e. unbalanced time at the stations. Both operators and logistics personnel were included in the study to get a more holistic view of the stations. Three types of stations were studied: a kitting station, the assembly train, and four assembly stations. It was indicated that perceived complexity was proportional to the unbalanced work and the stations were mainly complex in the following problem areas: *Product variants, Work content* and *Layout*. The station that had the highest index had unbalanced work ranging from 56-61% [8] and the common unbalanced work was listed as: rework, repeated movement of the operators from station to material rack, and waiting time. Results were presented to Company C's operator representative, higher officials, and department heads who thought that the results were useful, since it gave detailed insight on where there are problems with unbalanced work. In addition the colour-carpet was seen as a good basis for discussion since it helped their view of how to improve the process and quality of the system and how to prioritize future actions. The index also coincided with their perceived view of the station.

4 Conclusions

The method, CompleXity Index (CXI), was in all industrial cases seen as a useful tool for evaluating perceived production complexity at a station. It was found that CXI measures what it was intended to measure. Furthermore, the CXI questions, grouping of problem areas and calculation were considered correct. In addition, the use of CXI as a prediction tools and the view of different roles was supported. The method was seen as useful in the context of three Swedish manufacturing companies:

- At Company A the operators were satisfied with the assessment and its usefulness, but that the production supervisor did not have the resources to perform changes according to the known problem areas.
- At Company B, CXI provided a view of complexity that could be used for continuous improvements.
- At Company C a correlation between unbalanced work and complexity was found.

In addition it was seen that the results from different roles should be interpreted together with the personnel. The results cannot be generalized, since three different types of cases were used. However, results indicate if the method measures what it is intended to. Future work includes further studying the benefits of using the method.

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6 References

[1] W. ElMaraghy, H. ElMaraghy, T. Tomiyama, and L. Monostori, "Complexity in engineering design and manufacturing," *CIRP Annals - Manufacturing Technolocy*, pp. 793-814, 2012.

[2] T. Fässberg, U. Harlin, K. Garmer, P. Gullander, Å. Fasth, S. Mattsson, K. Dencker, A. Davidsson, and J. Stahre, "An Empirical Study Towards a Definition of Production Complexity," in *21st International Conference on Production Research (ISAM)*, Stuttgart, Germany, 2011.

[3] P. Gullander, A. Davidsson, K. Dencker, Å. Fasth, U. Harlin, and J. Stahre, "Towards a Production Complexity Model that Supports Operation, Re-balancing and Man-hour Planning," in *4th Swedish Production Symposium (SPS)*, Lund, Sweden, 2011.

[4] S. Mattsson, P. Gullander, and A. Davidsson, "Method for Measuring Production Complexity " presented at the International Manufacturing Conference IMC 28 - Manufacturing Sustainability, Dublin City University, Ireland, 2011.

[5] W. Olsen, *Developments in sociology (Ch. 4 Triangulation in social research: Qualitative and quantitative methods could really be mixed)*, 2004.

[6] N. K. Dezin, *The researh act: A theoretical introduction to sociological methods*. Chicago: Aldine, 1970.

[7] S. Mattsson, P. Gullander, U. Harlin, G. Bäckstrand, Å. Fasth, and A. Davidsson, "Testing Complexity Index - a Method for Measuring Perceived Production Complexity," in *45th Conference on Manufacturing Systems 2012*, Athens Greece, 2012, pp. 394-399.

[8] K. Lokhande and M. Gopalakrishnan, "Analysis of the impact of process complexity on unbalanced work in assembly process and methods to reduce it," Master of Science Thesis, Royal Institute of Technology, Stockholm, 2012.