Comparing two methods to measure assembly complexity from an operator perspective

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ABSTRACT

As the number of product variants, components, and changes increase manufacturing companies experience a strong need to reduce or handle complexity. Therefore, two research projects, in Sweden and Belgium, have developed methods for measuring the level of complexity in production stations. This paper presents and compares the methods. The Belgian Complexity Calculator, CXC, measures complexity using objective parameters, collected from data systems. The Swedish Complexity index, CXI, focuses on subjective measure of complexity, as experienced by operators in the stations, collecting data using a questionnaire. Both methods overlap in content, and are validated by industrial cases with positive results. CXI is validated towards correlation with objective data, and CXC is validated by correlation with subjective data. Both methods have added value compared to the intuitive view of complexity, by providing more detail, structure, indication of solutions, and by getting involvement to complexity issues. The two methods have merits and by using both methods in conjunction, synergy can be achieved. This synergy would A give a possibility to first automatically and objectively do an overall scan of all the plant's stations, and then subjective in-depth studies could be performed.

Keywords: complexity, flexibility, manufacturing, assembly, work station, product variants, components,

1 INTRODUCTION

1.1 Industrial problem

Future production systems need to be extremely flexible and still remain and excel their efficiency. Mass customization of consumer products increases the number of product variants, shortens product cycles, and frequently results in increasingly complex production systems [1]. Furthermore, they must meet sustainability requirements regarding economical, environmental and social aspects. This means that these systems are in an environment of both change and uncertainty.

Assembly complexity is increased by new product requirements, for example are production of hybrid and electric engines associated with increased regulations on competences and safety. Volvo Cars Corporation in recent years stated that they as an effect of that expect the amount of car components to increase by 50% to 100% within the years to come. This will increase the complexity in the supply chain as well as in the production. In order to handle the challenges related to production complexity, support is needed for development of work towards efficiency, highly flexible and sustainable production. The production complexity in assembly systems therefore needs to be defined, described and broken down into relevant components that can be used for measurements, analyses and support tool for development. Thereby a better understanding of effects of changes on complexity can be achieved, which is a prerequisite for reducing and management of complexity.

Theoretical models of the concept of complexity, has been available for many decades. There has also been a growing interest in the study of complexity models applied to manufacturing processes and systems. Calinescu et al. list drivers or factors causing complexity. The parameters are: products, plant/shop, planning, information flow, other and environment [2]. It is important to differ between dynamic and static complexity, between objective and subjective complexity. Regarding objective production complexity, measurable parameters can capture both dynamic and static aspects of complexity [3,4,5]. The static complexity of a system can be modelled measuring parameters such as number of stations, work tasks, parts, etc. The dynamic complexity is modelled in order to include time and dynamics, like deviations from plans, and uncertainty.

To measure complexity, Urbanic et al put forward a model focusing on the information content, where the quantity, diversity and content of information are used as a function related to complexity [6]. Another frequently adopted approach to model and measure complexity is to use the term "entropy" which measures the uncertainty and randomness of a variable in the system. Entropy shows the rate of variety among possible next states, as a system changes state [4]. Applied to production, the entropy of a production system can be applied to states of a station, the tasks/choices in station, or the line/system. The entropy of an operation reflects how uncertain it is that the operation is the next operation in a station. Frizelle and Woodcook [7] presented a entropy model for static and dynamic complexity of production, which is highly relevant, although theoretical.

Increased automation and more indirect work make more people involved in operations, all with different tasks, and perspectives in production [9]. Regarding subjective production complexity, the same production system or situation may be perceived in a different way depending on a number of different factors such as individuals´ skills, competence and experience. Therefore, it is important to consider not only the system's complexity as it is, but also how it is perceived. Many in literature adopt this categorization of complexity. Li & Wieringa [9] presented a conceptual framework for perceived complexity in supervisory control systems. This fits still with the challenges of innovating and managing complex socio-technical systems [1]. Subjective complexity and perceived complexity represents the same concepts and is seen as synonymous throughout this paper.

1.2 Background

Against this background, two research projects have been initiated. In Sweden a Vinnova-funded National project COMPLEX "Support for Operation and Man-hour Planning in Complex Production", which is conducted from 2010 until 2013. The overall focus is to reduce complexity by developing generic models and methods to support strategies, planning, managing, and optimizing of complex production. Parallel to this, in Belgium, a research project, funded by the national Flander's Drive, has been running 2010-2012 (also acronymed COMPLEX) "Management and control in a complex manufacturing environment". The concurrent research and development work in the two projects has been regularly coordinated for mutual benefit.

As part of the work, methods and tools have been developed in both these projects for analysing and measuring the level of complexity in production stations. In the Swedish project the Complexity Index (CXI) has been developed, and in the Belgian project an Complexity Index Calculator (CXC) has been constructed [15].

1.3 Scope

The conceptual methods that today are available within the projects have both differences and similarities. The research groups see that a comparison of the methods is needed and that there are potential benefits from combining the methods into a common methodology. The scope and purpose of this paper is to present the two methods briefly, to compare the methods in different aspects, and to evaluate whether a combined methodology could be beneficial.

2 METHOD

The comparison of the two measurement methods is made as a joint work between the two research groups behind the methods. First methods are described (Section 3 and 4) and then compared (Section 5). Each method is described regarding its purpose, the historical development, overall description of the method, and the model/formula used for calculation. Also presented are results from industrial case studies where the methods are used. The comparison is made regarding:

- Development of the method,
- Purpose of method,
- Contents of the method (what aspects / parameters are covered),
- Intended usage,
- Method for calculation and for visualising the results,
- Validity of the methods,
- Added value by using the method,
- Prospects for future development.

3 SWEDISH COMPLEXITY INDEX – METHOD AND RESULTS

3.1 Method purpose and usage

CompleXity Index (CXI) is a method developed to help manufacturing companies to describe the complexity of a production system; as the people working within the system experience it. By measuring the subjective view, in an easy way, it is possible to find unknown bottlenecks and to suggest appropriate support tools or other improvements.

CXI is a questionnaire that studies complexity at a station level. Respondents are given statements that they answer individually which take approximately 10-15 minutes. The goal is to give the questionnaire to people with different roles that for instance normally don't speak with each other, which could help improve communication and could act as a discussion tool when solving problems or suggesting improvements.

3.2 Method development

The method is based on a theoretical framework and empirical work done within the Swedish COMPLEX project. In Gullander et al., [10] a framework was proposed showing different aspects of complexity, including static, dynamic and objective complexity. To ensure that the individual experience is considered, this framework emphasizes the subjective or perceived perspective of the system. This framework was used as a basis for conducting empirical studies and was further developed in Fässberg et al. [11]. The empirical studies included workshops and interviews at three industrial companies, including VCC. Thus, theory provided a basic model of complexity, and the empirical studies gave a more concrete view of what aspects are common for different roles and companies (the roles included in the study were operators, logistical personnel and production technicians). The CXI method was first presented in Mattsson et al. [12] and was further developed in Mattson et al. [13] it was further developed.

The method has been tested in case studies at VCC, Electrolux and Volvo Powertrain. The results from VCC is presented in this paper and used to exemplify the usefulness of CXI. CXI is not yet fully validated and future studies will include more roles and company types (in the studies only final assembly was studied).

3.3 *Method description*

CXI includes statements from the following five problem areas (Mattson et al. [13]):

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

Each problem area includes 3-4 statements, which is rated using a Likert-type scale [14]. The answers are rated from one to five, where one is *I do not agree at all* and five is *I fully agree* (respondents can also answer *I don't know/Not relevant)*. In total the questionnaire includes 23 statements (21 closed and 2 open-ended). Most of the questions are stated so that the answer five means that the station was complex, in respect to that statement. Some of the questions are reversed to reduce the risk of bias and one of the open-ended statements is a comment field regarding what generally can be improved at the station.

The problem areas are not ranked among one another; instead they are thought to have the same impact on complexity. In the future, there is a possibility to add ranking/weights to change the significance of each problem area. This could be useful if a company has a specific interest in an area, for instance if an area is determined as more important from an ethical point of view.

3.4 *Complexity model/calculation*

CXI is calculated, station-by-station, by first calculating the median for the statements in each problem area, for each respondents in that station. Then, the medians for each of the problem areas are calculated (one median is calculated for all respondents). In order to account for high values (since a high median point toward a high complexity) given by all respondents the highest median is added to the already calculated factor, see Equation 1. The highest median is divided by a coefficient = 4. The highest median is added to the station complexity value in order to make sure high scores on statements, i.e. individual differences, will be represented by the station CXI.

$$CXI_{station} = \text{median}(M_i, M_{ii}, M_{iii}, M_{iv}, M_v) + \frac{\max(M_i, M_{ii}, M_{iii}, M_{iv}, M_v)}{4} \quad (1)$$

Where $(M_i, M_{ii}, M_{iii}, M_{iv}, M_v)$ is the median of answers for all statements in area *i, ii, iii, iv, v* among responents belonging to the station.

To better visualize the complexity index, the result is divided into three categories: *Green, Yellow and Red.* This is done in order to state that a *Red* area needs urgent change, *Yellow* needs change and that *Green* means no change is needed. The limits for these categories are: Green for CXI < 2, Yellow for 2 ≤ CXI < 3, and Red for CXI ≥ 3. The results are displayed on a colour-carpet i.e. the result is presented in a table which is coloured according category limits. This makes it possible to quickly identify *Red* problem areas.

3.5 *Industrial case*

CXI was been tested at Volvo Cars plant in Gothenburg (VCC). In this case study, eight stations, from eight team areas were chosen, Stations A-H. he chosen stations were believed to represent the various types of stations on VCC where some stations were believed to be complex, and some not complex. This selection was made by cooperation with the company. Stations A-B, D-E and G-H were believed by the company as having a low complexity. Stations C and F were perceived as having a high complexity. Four stations were pre-assembly stations.

As respondents an assembly operator and a team leader were chosen from each of the eight team areas. The 16 respondents themselves filled out the questionnaire (when the production schedule allowed them to work with it). The response rate of the questionnaire was 100%. At VCC team leaders 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. In this study it was interesting to see if this contributed to similar or fundamentally different answers depending on the slight difference in roles.

3.6 *Case results and discussion*

The CXI calculation is seen in Table 1 where stations A, C, E-F and H show *Red* values i.e. were perceived as highly complex stations. The highest score is seen for station E (the median N = 6). However compared to the companies original grouping only stations C and F were believed to be complex. It was seen that the team leader and the operator had similar answers i.e. the trends were similar which could be due to that the team leader also works with assembly on the station. This could be seen as something that helps validate the model, but in a way the model did not capture the different roles.

Tab. 1. CXI complexity measure on stations at VCC

STATION	A	B	C	D	E	F	G	H
CXI	3	1	3	2	6	4	3	4

Together with Table 2, which is a visualization of the problem areas (the colour-carpet) and the Comment field (one of the open-ended statements) it was possible to study the results further. Since the stations A, E and H, which originally was believed to be less complex stations, they are described in detail.

Station A, was given high values for Product/variants (Area i) as well as for Support Tools & Work instructions (Area iv). In the open-ended statements it was seen that although they have a lot of variants they don't have support tools to reduce the cognitive load. One improvement could be to introduce some type of support tool. Station E had high numbers on the general view of the station (Area v) as well as on the Work content (Area ii). In the Comment field the respondents wrote that there were a lot of confusions on the station which also included a lot if indirect work. Station H had a high value on Product/variants but also on Layout & Tools and by studying the ratings it is seen that respondents think that the station is not well designed in terms of material façade or placement for tools.

Stations D and G showed Yellow values, which means that they need changes regarding some of identified the problem areas (for station D: Work content and the General view of the station which was due to that a lot of indirect work was done and for station G high values are given because of Product/variants).

Tab. 2: Colour-carpet showing the medians of the questionnaire answers, indicating complexity for each station and each problem area (◇red, △yellow, ○green).

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	○ 2	△ 3

The results from the case shows that CXI can be used in order to, in a simple way get an understanding of the perceived problems at a station. Here the index should be used in conjunction with the colour-carpet and the statements, which could be useful in order to find improvement suggestions.

In addition, CXI was compared to objective data for the stations as a step of validating the method. The number of variants and components formed a new coefficient, *VarComp*, which was calculated as the average of *Variants* and *Components* for each station. CXI correlated with this coefficient, with 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 1.

It was suggested that since objective data is easy to measure and can sometimes be generated automatically, this measurement can be used to 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. However in this case, which is also true for many automotive companies, the number of product and variants have been seen as a cause of production complexity. This may not be true for companies with other products.

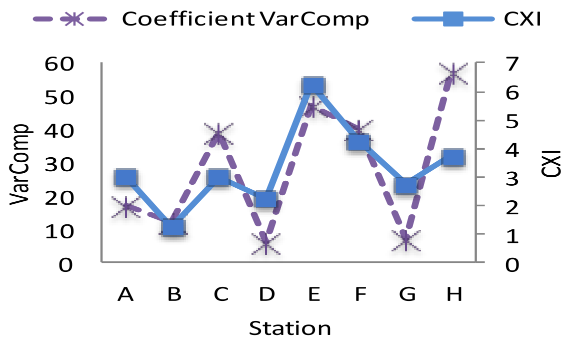

Fig. 1: Graph over the variant and component coefficient and CXI for the stations at VCC

4 BELGIAN COMPLEXITY CALCULATOR – METHOD AND RESULTS

4.1 Method purpose and usage

Within the Belgian Complex project, a complexity measurement method has been developed, Complexity Calculator CXC [15]. The focus and purpose of the method are to characterize workstations complexity. The intended usage is different from CXI – objective data is collected from different data systems and used to calculate complexity for all stations. The operators are thus not involved, and the method can easily cover many stations.

4.2 Method's development

In order to define the main complexity drivers, a set of workshops was done in collaboration with a group of automotive manufactures. Those workshops were a great opportunity to study and explore real manufacturing situations where complexity is present. In order to be able to gather as much useful information as possible, the participants included shop floor employees, production engineers, quality controllers and line management, who deal with complexity in their daily activities. During the workshops brainstorming sessions were organized. From these workshops a lot of relevant information was gathered pertaining to complexity drivers, parameters, impacts, etc. In the next subsection, a set of complexity drivers is presented as an outcome of the investigation of this information.

4.3 Method description

Using the information gathered during the interaction with the automotive manufacturers, complexity drivers were identified [15]. The list of complexity-driving variables is presented in Table 3 together with a concise explanation of each variable. The next question to tackle was to characterize the relation between these variables and complexity, in an attempt to build a model and investigate whether this set of variables is crucial to recognize what increases or decreases complexity.

4.4 Complexity model/calculation

A complexity measurement was developed based on a weighted sum of the 11 variables. This measure determines if workstations have a low or high complexity according to equations 2 and 3:

$$\text{basic complexity}(w) = \sum_{i=1}^{n} \frac{\text{score(i)*weight(i)}}{\sum_{i=1}^{n} weight(i)} \quad (2)$$

$$\text{complexity(w)} = \frac{\text{basic complexity(w)} - \sum_{i=1}^{n} \min i}{\sum_{i=1}^{n} \max i - \sum_{i=1}^{n} \min i} * 10 \quad (3)$$

where:

- basic complexity(w) is the complexity score of a workstation *w*,
- Score(i) is the value of the variable i according to the Likert scale,
- Weight(i) is the weight of the variable i,
- max i is the maximum possible value for variable i,
- min i is the minimum possible value for variable i,
- complexity(w) is the complexity score of a workstation normalized into a scale from 0 to 10.

Because the values of the variables fluctuate widely, in the method each range is transformed into a 4 or 5 point Likert scale (the fifth being zero), as shown in Table 4. The weight of a variable represents its importance for the complexity score. If all weights are set with value 1, all variables have the same impact when calculating the complexity score, to adjust this impact the weight varies. Some variables has a higher significance than others.

4.5 Industrial case

Using the list presented in Table 3, the manufacturing collaborators were asked to select five workstations and define the value for each of these variables (drivers). Moreover, they were asked to classify each workstation as low complex or high complex. The result is a dataset composed of 76 workstations, 41 classified as low complex and 35 classified high complex, and the respective driver values.

4.6 Case results

Figure 2 shows the result of the calculated complexity measure compared to the subjective labels of LOW and HIGH complexity for each of the 76 workstations, with all weights equal to one. The 76 workstations are represented in the x axis and the complexity score in the y axis. First the 41 workstations classified as low complex and then the 35 workstations classified as high complex. If initially a station is classified as low complex, its score is set as zero, and if the station is classified as high complex its score is set as ten.

The score for the LOW complexity workstations averages 4,8 and HIGH averages 7,2. The calculated score seems to distinguish HIGH from LOW complexity workstations, so the variables it is based on do seem to have a relation with the subjective complexity level. However, there is quite some fluctuation in the complexity scores.

Tab. 3: Complexity-Driving Variables.

Complexity-driving variables	Description
Picking technology	*Fixed (F) :* Operator takes part always on the same location from bulk storage. *Signal (S)* : Operator picks part from location indicated by a signal (light, display) *Comparing (C)* :Operator must compare simple information (symbols, colors) *Manual (M)* : Operator must read extensive information from manifest
Bulk / Sequence / Kit	*Sequenced (S)* : Every part is in its package in correct assembly sequence *Kit (K)* : Parts are delivered in kits with exact set for one assembly operation *Bulk (B)* :Parts are by type in their own package
# Packaging types	The total number of different packaging types, a type having a specific layout. So, two identical boxes with different inserts are two different types.
#Tools per workstation	The number of tools that the operator(s) need to handle to perform all possible assembly variants in this station, automatic tools (servants) excluded.
# Machines per workstation	Machines that perform automated tasks without operator assistance, with automatic or manual start.
# Work methods	Every unique set of work methods the operator must master in this workstation. A method contains several small steps.
Distance to parts	The farthest distance between the normal operator position (or the center of the workstations) and the parts at the border of line.
# Variants same model	The highest number of variants belonging to one model, among all models of which parts are assembled in this workstation.
# Variants in this workstation	Total number of variant parts, summed over all models that are assembled in this workstation.
# Different parts in workstation	Total number of unique part references that are assembled in this workstation, including all variants and models that typically occur in one year.
# Assembly directions	The number of different positions the operator must take to complete his workstation cycle, including repositionings of the upper body or the feet, but not small repositionings of the hands.

The model was able to classify 82% of the workstations correctly. The results obtained by the model provide some insight into the complexity-driving variables and their related scores. Off course, some of the subjective labels could be wrong, especially if the calculated score is rather extreme. This seems the case with LOW workstations 18, 19, 32, and with HIGH workstation 57, warranting further research. It does seem from Figure 2 that operators tend to rate workstations lower than the numbers suggest, which highlights the psychological aspect of interpreting complexity.

Tab. 4: Complexity Driving Variables, Likert Scale (crossed alternatives are not used)

Complexity-driving variables	Likert scale value for each alternative			
	0	1	2	3	4
Picking technology		F	S	C	M
Bulk/Sequence Kit		S	K	B	
# Packaging types		1	2-4	5-8	>8
#Tools per workstation		0-1	2-4	5-8	>8
# Machines per workstation	0	1	2	>2	
# Work methods		0-2	3-5	6-8	>8
Distance to parts (in meters)		0-1	1-2	2-4	>4
# Variants same model		1	2-3	4-5	>5
# Variants in this workstation		1	2-4	5-10	>10
# Different parts in workstation		1-4	5-10	11-20	>20
# Assembly directions		1	2-3	4-5	>5

5 COMPARISON AND DISCUSSION

5.1 Development and purpose of the methods

Both CXC and CXI has been developed based on:

- theoretical literature studies of what production complexity includes, and
- industrial workshops capturing industrial view of complexity and drivers for complexity.

CXI have been tested at Volvo Cars (Gothenburg), Electrolux, and Volvo Powertrain (Skövde) in the Swedish consortium. CXC have been tested at Volvo Cars Gent, Ford Genk and SML Genk in the Belgium project consortium. The research groups in Belgium and Sweden have had collaboration during the project work, to make sure results will complement rather than compete. Regarding method development, attention has been given not to affect each other's method development regarding content, methods, calculations, etc. However, one thing was early on realized and decided:

- The Belgian approach was to focus on objective data, striving for automatic capturing and calculations.
- The Swedish approach was to focus on capturing the subjective complexity perceived by the operators.

5.2 Contents of the methods

For a number of problem areas both the CXI and CXC have similar contents, but different means of measuring the parameter:

- *Product variants:* CXC capture the total number of variants and the maximum number for one model. The CXI have subjective measures to reflect if there are many variants in the station, if there are variants that are very uncommon, and if there are variants that *resembles* each other.
- *Assembly work methods:* The CXC identifies the number of positions or directions the assembly requires. Similarly, the CXI captures if the assembly requires different assembly procedure / sequence.
- *Machine and hand tools:* The CXC describe the number of hand held tools and automatic machines. The CXI asks questions regarding how well adapted the tools are to the work and to what extent different assembly requires different tools.
- *Layout and material façade:* The CXC identifies the picking technology/sort, the way material are supplied (bulk, sequence, kit), number of parts, packaging types, and distance to parts. The CXI captures the accessibility of the parts; if the positioning of tools, fixtures, and parts is good; the layout/design of the material façade; and whether heavy lifts occurs.

The major differences for these problem areas between CXI and CXC are (i) objective vs. subjective data, and (ii) level of detail. A few aspects are only covered in the CXI but are not included in the CXC:

- *Work instructions:* The CXI questionnaire includes questions regarding work instructions, if they are easy to understand, if they are used/read, and whether they simplify work.
- *Work content:* The CXI statements concern the working conditions: if the operator knows what to do, have time to finish work, whether work includes non-assembly work (planning, improvement work, quality, etc.). Also included are questions regarding if occurrence of unplanned changes, deviations and disturbances and if the operator has possibility to influence such work station changes.
- *Other aspects*: The CXI gives the operator possibility to give an overall judgement of the design of the

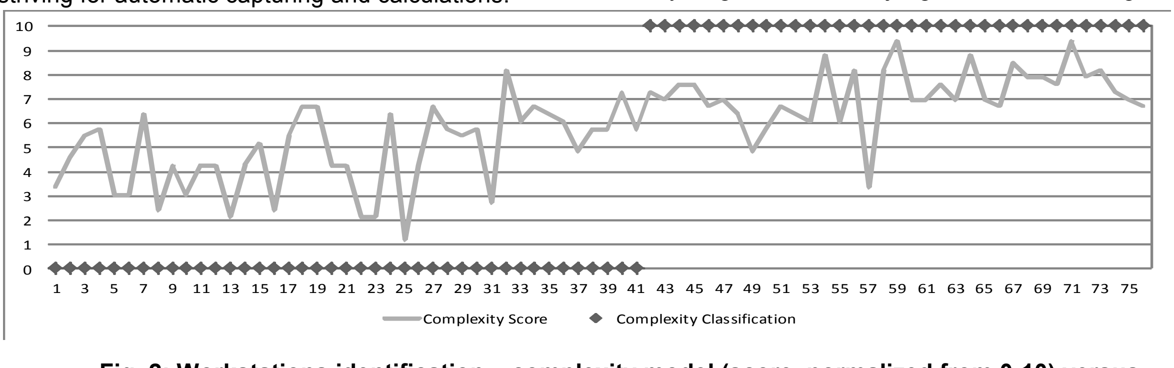

Fig. 2: Workstations identification – complexity model (score, normalized from 0-10) versus the initial classification of complexity (high or low)

work and station. And as an indication of complexity, an assessment of the time needed to learn the work in the station, as compared to other stations.

5.3 Intended usage of the methods

The CXI requires the operators at the stations to fill out the questionnaire. The goal is to make it as easy as possible, in order to reduce time needed for this. However, this is still a problem since operators' time is difficult to get, being required to take part in the assembly. Getting the subjective view of complexity is at the cost of taking time from the assembly work. The CXC is intended to capture the data needed from different data systems. An analyst is needed to study systems and capturing the data. The goal is to be able to easily collect, or even automatically, and thus scan the complexity level in all stations in the plant. This requires all data to be (made) available, and in proper format, which may not always be the case. Both methods have potential of becoming more efficient

5.4 Calculation and visualisation

Both methods capture the complexity for a number of parameters/areas using Likert-scales. This is then for CXI visualised using the "colour-carpet" table to provide understanding of complex stations and/or complex areas. Similar visualisation of the results is possible also for CXC. Both CXC and CXI provide a similar complexity measure for each station. CXC calculate a weighted mean while CXI use the median of scores with a weighted influence of the highest score. This is to better capture high score areas (high complexity) in the station score.

5.5 Validity of the methods

It is difficult to validate the methods and models with certainty. For CXI, correlation with objective data has been checked. Validation is made by comparing the CXI measure with the initial view and believe of station's complexity.

Hard facts of station complexity, like number of variants or components, can be an indication of complexity level. Validation of CXI was supported by the objective complexity parameters (number of components and variants). We argue that since high objective complexity in stations generally will lead to high subjective complexity, objective complexity should on a general level correlate with subjective complexity. A (objectively) highly complex situation generally should be more difficult to manage, thus increasing the subjective complexity. However, individual differences due to personal type, experience, education, etc mean the correlation is less clear and necessarily not true on an individual basis. CXI reflects a subjective aspect and thus must be validated towards personal view of complexity.

CXC have been adjusted to match the subjective understanding of stations, having high or low complexity. Based on this, the weighing factor can be adjusted. Apart from this, validation of both CXI and CXC has been carried out, with positive results. This has been done by application and by using the methods in real cases, with positive feedback. Both methods need however more testing to further validate the results.

5.6 Added value of the methods

Using CXI and CXC is supposed to have an advantage as compared to the intuitive understanding of a station's complexity. We believe that both the methods have advantages:

- A more structured approach, involving more people and data will reduce the sensitivity to individual's opinions. As seen in the CXI case at VCC, also stations not intuitively considered complex, had complexity problems/issues.
- Being more detailed, the CXI and CXC provide knowledge on, not only the complete complexity level, but also what aspects are complex (layout, No of variants, material façade, etc.). Thereby the methods provide indication for how to reduce the complexity in the stations.
- The measurement provides operators, production engineers etc. people involved in the production development work with hard facts of the current situations (as supposed to vague ideas) which makes discussions, easier. For example, engineers can clearly show that a station already is too complex to manage further charges.
- CXI will provide with also an understanding of how different operators have different opinions of complexity levels. This variation is natural and will depend on personal differences, like e.g. experience, education, capacity, or personality. We believe CXI is good for examining the variations among individuals in a workstation.
- Measuring and visualizing using CXI, and for visualization using CXC, the focus of the people involved is set on the complexity issue, which will increase understanding of difficulties and make propositions for changes easier to introduce.
- For pro-activity, i.e. to support production development in making good design of workstations. Both CXC and CXI have a number of areas/issues that may increase design focus on certain aspects and guide the design. Using CXC preliminary measurements could be made. CXI however needs operators and production operation, which obviously limits its pro-active usability.

5.7 Future possible development

The CXI today is only targeted towards operators in assembly workstations. The intention of CXI is also to include more roles in the measurement, to get a holistic view on the complexity. This could include logistics personnel, production engineers, and people working with quality. It would be advantageous to compare the methods by measuring the same set of stations using both methods.

5.8 Methodology including both methods

The research groups see that there are advantages with both methods. CXC being possible to quickly gather complexity data from the whole plant, and CXI that will get more detailed information on complexity situation and causes regarding specific stations.

We suggest that the methods be used in conjunction:

- regular scan using CXC to see trends, problematic stations, on an holistic perspective.
- event-based study using CXI to investigate further the problematic stations, or stations that are in focus of a future change (equipment, variants, layout, variants, etc.)

6 CONCLUSION

The scope of the paper has been to present in a structured manner two methods for measuring complexity that have been developed in two parallel research projects. The method developed by the Belgian research group, Complexity Calculator, CXC, measures complexity using 11 objective parameters, collected from data systems, summed up as a single complexity measure. The method developed by the Swedish research group, Complexity index, CXI, is focusing on capturing a subjective measure of complexity, as experienced by operators in the stations, using a questionnaire with 23 questions. CXI results are visualised using a colourmap identifying areas of problem and improvement potentials.

Both methods overlap in content, have similar use of Likert scale and are validated by industrial cases with positive results. CXI is validated towards correlation with objective data, and CXC is validated by correlation with subjective data. It is concluded that both CXI and CXC is adding value as compared to the intuitive idea of complexity, by providing more detail, structure, indication of solutions, and getting involvement to complexity issues. Also, it is suggested that a combined use of the methods would give possibility for overall scan of plant's stations, and in-depth analysis of specific stations.

7 ACKNOWLEDGEMENTS

The Swedish research project is funded by Vinnova within the programme Production Strategies and Models for Product Realization. The project is carried out in collaboration between Swerea IVF, Chalmers, Volvo Cars, Electrolux, Stoneridge Electronics, and The Volvo Group. Their support is gratefully acknowledged. The authors would also like to thank the industrial collaborators within the Belgian project: Ford Genk, SAS, SML Genk, VCST, Van Hool Industrial Vehicles, Volvo Cars Ghent and Volvo Trucks Ghent. The authors also gratefully acknowledge the support of Flanders' Drive, the innovation center for the vehicle industry in Flanders.

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