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Understanding disturbance handling in complex assembly: analysis of complexity index method results

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Abstract

Disturbance handling is crucial for managing production complexity in final assembly. Due to that complexity in a system causes uncertainties and assembly errors, it is important to further investigate what causes disturbance handling and how it can be managed to support operators working with complexity. Production complexity was assessed through the method CompleXity Index (CXI), which captures operators' view of a station. A statistical analysis of the CXI data was performed and relations between available time and use of work instructions and also seniority and empowerment were found. In addition no relation between empowerment and stress was seen which indicates that perceived empowerment and its relation to stress should be studied further.

Peer-review under responsibility of the scientific committee of the 8th Swedish Production Symposium.

Keywords: production complexity; empowerment, stress, work instructions, organizational management.

1. Background

It is believed that digitalization will transform operators work environment so that complexity will increase due to new work tasks and new collaborations with high level of automation [1-7]. An increased need for understanding the operator in this context is therefore needed [5,6,8]. In addition, since stress and psycho-social health are emerging problems in Sweden and Europe [Swedish Work Environment Authority9,European Agency for Safety and Health at Work10], it is important to further investigate how complex assembly affect the operator, and how operator wellbeing and performance can be increased [11,12].

One of the characteristics of complex systems is that the system is unpredictable [13]. Complexity in a system means something that is "difficult to understand, describe, predict or control" [14]. A complex problem has no formula that could be used since every problem is unique [15], expertise can be needed but does not ensure success and is not sufficient for the task i.e. to solve a complex problem no formula is available and competence might not

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increase the probability of solving the problem. This is due to that the problem relies on variables that are interrelated and that the variables by themselves rely on each other. As a consequence a definition of complexity in assembly systems were derived (based on empirical results e.g. in [16,17]). *Production complexity* is defined as the interrelations between product variants, work content, layout, tools and support tools, and work instructions [18].

Methods are needed to decrease complexity which in turn can increase predictability and productivity [19]. The effects of having complex systems is connected to an overall decrease in ergonomics [20], quality [21,22], production reliability and uncertainty [13], performance [23,24] and production time [25,26]. A method called CompleXity Index method (CXI) was developed in 2011 and has been used by over 460 participants to assess how operators perceived work at their workstations. *Complex assembly* was defined, according to results from the CXI, as stations that are perceived as complex by the operators working there, as assessed through the CXI method. When using the CXI method it was found that station design, work variance and disturbance handling caused complex assembly [27]. Due to that work variance depends on product variants, which cannot be reduced (due to marked demands), disturbance handling is investigated further in this paper.

Disturbance handling regards handling disturbances i.e. product variants that does not occur frequently and disturbances connected to material loss etc. This also includes to what extent the operators' are part of planning and improving their work and the way information is presented i.e. through paper, screens, mobile devices etcetera and how it is presented. Disturbance handling is relevant due to that routines and competence is needed to be able to manage unknown events [28].

1.1. Scope

To support operators working in complex assembly, it is crucial to further investigate how disturbance handling could be managed better. Disturbance handling is relevant since it was identified as one of the main causes of production complexity. The scope of this paper is therefore to investigate and discuss what aspects of disturbance handling as defined in CXI that are important when supporting operator work. This is investigated by studying CXI data previously captured at four different production companies.

2. CXI

CXI is a method that gives an index for the perceived complexity at a production station [29]; presented in Appendix A (current version). CXI includes 22 statements, one tick-box and 1 comment field and includes Likers scales (scale from 1-5). CXI was developed in 2011 and has been used as a current state analysis tool e.g. in Johansson, et al. [30], Mattsson and Fast-Berglund [31] and Tarrar, et al. [32]. 464 participants at 14 different companies have been part of the studies. Most studies have been carried out in the automotive industry (43%) but a number of studies in other industries have also been performed (pharmacy 14%, machining 29%). CXI is currently also used to assess complexity in de-assembly[*] (2 companies, 14%). Disturbance handling is one of the three areas of CXI (the areas Station design and Work variance is not included in the scope of this paper) and has been identified as one of the causes of perceived complexity (for automotive, pharmacy and machining) [27].

CXI is calculated through a formula where a higher score indicates a higher complexity. The score is divided into three complexity levels and colours: Low complexity; Green < 2, Moderate complexity; Yellow equal to or larger than 2 and smaller than 3.5, High complexity; Red larger or equal to 3.5. The output of the method is a colour carpet, which visualises the areas and statements contributing to increased complexity at a station.

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3. Work environment: empowerment and perceived stress

To manage complex systems, a company culture where everyone is part of constantly adapting to new changes is needed [33]. One way to achieve this is through empowerment (Ibid.). *Empowerment* is defined by the following features: Sharing information on the organization's performance, Base rewards on that performance, Provide knowledge that make it possible for employees to contribute to that performance and Give the employees power to make decisions that influence the organization performance directly [34]. Similarly, Wilkinson suggested the following features: information sharing, upward problem solving (to both work and to choose which problems needs solving), task autonomy, attitudinal shaping and self-management [35]. Another description of empowerment is connected to Lean Manufacturing, as stated by Liker and Hoseus [33].

To implement empowerment and understanding its effects are difficult [34] and sometimes the implementation of good organizational examples have been associated with stress [36]. As an example, when trying to implement empowerment according to the Lean concept, the organizational culture have been disregarded (along with long-term thinking and personnel respect) [33,37]. Instead, many companies focused on tools (more than the company culture) [33]. In a case study where both CXI and empowerment were assessed it was seen that operators often lack the power to make decisions that influence the organization [38]. The implementation of new organizational principles has however been connected to stress and other psycho-social demands [39]. In a study by Koukoulaki the introduction of Lean production principles had a positive correlation between implementation and stress for some tools [39]. However, many differences between companies and context could be seen. Another review of Lean implementations stated that the implementation will not lead to stress or bad ergonomics [40]. In the CXI aspects of empowerment and stress are included, therefore an investigation of their relationships is interesting.

4. Method

CXI data were collected during the years of 2015 and 2016 at four different Swedish companies. The CXI is available both in paper and a digital version and two companies used the digital version. The survey was distributed through participant's team leader and operators were instructed to fill in the survey when they could (to not interrupt production time). 167 operators filled in the CXI survey at 73 stations. The sample data is seen in Table 1. On average more than 2 participants filled in the survey per station (for Company D it was 2.1, Company C and A 2.7 and for Company B it was 4.0).

Table 1. Sample data

Participant characteristics	Data
Number of participants in percentage (no.)	80% Company D (133), 11% Company C (19), 7% Company A (11), 2% Company B (4)
Experience level	M = 8.43, SD = 7.8
Worked on that station	M = 3.46, SD = 3.59

4.1. Analysis

In this paper statements from the Disturbance handling area were transformed into new variables using averages. This way 5 new variables were constructed, as described in Table 2. The variables were: 1, Available Time, 2 Instructions, 3. Empowerment, 4. Stress, 5. Years at current station.

Table 2. Variables for data analysis

Variables	CXI statements	Comment regarding data
1: Available time	"The tact time at this station is generally enough for me to perform my work tasks" and "During unplanned changes/uncertainties there is enough time for me to perform my work tasks"	2 responses to the first question and 7 responses to the second question were missing but the indexed variable still consisted of 167 values since it was calculated from average values and the missing responses overlapped.
2: Instructions	"During unplanned changes/uncertainties (for instance change of plans, new instructions/variants, or machine disturbances), it is easy to find the information I need to perform the tasks at this station", "The work instructions are easy to understand" and "The work instructions at this station simplify my work"	3 responses to the second question and 5 responses to the third question were missing but the indexed variable still consisted of 167 values due to overlapping.
3: Empowerment	"I am part of the planning for the changes on this station"	Responses from 10 out of the 167 participants were missing.
4: Stress	"During my work at this station I often feel stressed and/or frustrated"	No responses from the 167 participants were missing.
5: Years at current station	-	Responses from 8 out of the 167 participants were missing.

The first variable, *Available Time* was derived from two CXI statements (6 and 8, see Appendix for all statements), with Cronbach's Alpha equal to .57. The second, Instructions was derived from three CXI statements (9, 20 and 21), with Cronbach's Alpha equal to .66. The third and fourth variables were found through using just one of the CXI statements (10 and 11) and the fifth was taken from the background data (qualitative question with the possibility to answer freely). To test the variables a pilot study was carried out. Data was captured by adopting the CXI statements to a university context, which were used to ask students to consider their most recent course, and the results gave positive indications as to using the variables for analysis.

SPSS was used for analysis and ANOVA calculations were performed. For the independent variables a three interval variable was used (instead of the original 1-5 scale). For variables 1-4 the score three was set as "Average", and scores above or below three as either "High" or "Low". The last variable were constructed according to three groups: (1) One year or less, (2) One to Five years and (3) Five or more years of experience.

5. Results

The hypothesis and results for the main Pearson correlations and one-way ANOVA are presented in Table 3.

Table 3. Variables for data analysis

Hypothesis	Pearson correlation (H1-H3) and one-way ANOVA (H4)	Hypothesis
H1: operators who perceive the available time as insufficient also perceive higher levels of stress	*Significant,* $r(167) = .271, p = .000$	kept
H2: operators who perceive themselves to be empowered at work have a lower level of perceived stress	*Not significant,* $r(157) = -.056, p = .487$	rejected
H3: operators who perceive the work instructions as supportive also have a lower level of perceived stress	*Not significant* $r(167) = .115, p = .140$	rejected
H4: seniority moderates the relation between empowerment and stress	*Not significant* $F(8, 141) = .519, p = .722, \eta^2 = .015$.	rejected

One of the hypotheses was kept. no 1: operators who perceive the available time as insufficient also perceive higher levels of stress. This means that the perceived stress is higher when the takt time is not enough. Although the second hypothesis was rejected a significant Pearson correlation was found between Instructions and Available Time r(167)

= .508; p = .000. Since both variables were reversed, the result implicates that operators who perceive their work instructions as supportive also perceived that they had enough time to perform the work tasks. This indicates that work instructions act as supportive organizational resources for the operators. For H4 an interaction effect could not be found, however a plot of the average values showed a tendency of interaction effect could be seen. It seemed as that operators with more than five years of experience at their current station perceived lower levels of stress with high empowerment, but for operators with less than five years of experience the relationship was the opposite i.e. higher levels of stress with high empowerment. Although the fourth hypothesis was rejected a significant negative correlation was found for Empowerment and Years at Current Station, $r(150) = -.216, p = .008$. A one-way independent ANOVA showed that there was a significant difference in Perceived Empowerment between the groups of One year or less (M = 3.53, SD = 1.30), One to Five years (M = 2.95, SD = 1,15) and More than Five years (M = 2.72, SD = 1.25) at the current station $F(2, 147) = 5.68, p = .004, \eta^2 = .072$. Bonferroni's Post Hoc test showed that operators with One year or less of experience perceived significantly higher levels of Empowerment compared to both operators with One to Five years *(p = .036)* and operators with More than Five years of experience *(p = .007)*. No significant difference could be found between operators with More than five years of experience and Between one and five years of experience. In addition, Levene's Test of Equality of Error Variances was not found to be significant, $F(2, 147) = 1.221, p = .298$. The result implicates that operators with longer experience perceive themselves as less empowered than newer operators.

6. Discussion

It was seen that operators who perceive the available time as insufficient also perceive higher levels of stress (H1). This is an important results since Available time is based on the statements concerning if the operators feels as there is enough takt time to carry out the work (both during work in general and during unplanned changes). This means that the perception of takt time is important for operator stress. This was also seen in a previous experiment, where operators perceived stations as difficult and stressful when they had a short cycle time [41]. This is also in line with Karasek's Job Demand Control Support model, as described by Eklöf (2017), in which stress is the result of imbalance between the aspects of demand, control and support.

Operators who perceive themselves to be empowered at work have a lower level of perceived stress (H3) was rejected. This is in line with previous research [39,40]. The results does not contradict the findings by Eklöf et al. [36] who found reduced stress levels from participation, since those findings were limited to white-collar workers. In the present study, only data from blue-collar workers were used.

No significant correlation between good work instructions and stress was seen (H3). However, since it was found that good work instructions correlates with higher levels of Available time an implication can be that work instructions instead affect the perceived takt time. This is an important aspect of increasing productivity and was also seen in a recent experiment where different instructions were tested [42]. The results were that information content did not affect product results but the takt time was longer with paper instructions. All types of instructions were perceived as good or very good.

Although seniority was not seen to moderate the relation between empowerment and stress (H4), a significant correlation between Empowerment and Years at Current Station was found. This was confirmed by the ANOVA and the post-hoc test from which it was indicated that all operators with more than one year of experience differed in their perception of empowerment from operators with up to one year of experience. This implicates that seniority at a station might have a negative impact on the perceived level of empowerment, already after the first year, which in itself might be something to consider when working as a manager of operators in complex assembly. In a previous study however, operators were seen as empowered working at complex stations (by the authors) [38]. In that study more aspects of empowerment were studied than here where only one statement covered one of the aspects of empowerment.

6.1. Limitations and reflections

The gathering of the data was done during a long time period and also different versions of the CXI questionnaire were used (some statements were not added until later versions). Therefore some answers were lacking. Empowerment lacked 10 responses (6 %). also Years at station had some falling-off, 8 responses (5 %) lacked. In addition, no number of how many participants that did not complete the survey is seen (response rate). This is due to that surveys were given to the team leaders and control of the actual number of distributed questionnaires was thus lacking. Also, it was not possible to check if they filled in the survey when sitting alone or if they sat together. The number of participants that filled in the survey for each station varied from 2 to 4. Company D had the most respondents but had the lowest average of respondents per station. With two respondents per station the anonymity of the respondents are preserved. However, it is preferable that all operators working on a station are included in the survey to ensure a representation of the perceived complexity [32]. Previous studies show that operators agree with the CXI results [27] in addition to the method's indicated high reproducibility [43].

The most interesting result might be that operators with more than one year of experience from a specific work station differs from newer operators in their perception of empowerment. This relatively short period of time, one year, compared to the average years of experience of the participants (about 8 years in assembly and about 3.5 years at the current station) puts new focus on how quickly the perceived level of empowerment is affected to the worse. No evidence has been found on why this relationship might have occurred. Instead, the authors recommend future research on this aspect in order to further understand how to build the sustainable human organizations of the future.

7. Conclusions

This study highlights some important issues in studying operators in complex assembly. One of those highlights are that available time is important from a stress perspective and that having good work instructions is not connected to low stress. Being empowered is also not related to having a lower degree of stress. Further, more research is needed on why perceived empowerment may change fast and how operators can be better supported to manage complex assembly work. In addition, the perceived empowerment needs further investigation in a complex production context.

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Appendix A. CXI statements

The statements are ordered into themes according to causes of complexity, first column, as reported in literature *product variants, work content, layout, tools & support tools, work instructions* and the *general view* of the station. These themes supposedly make it easier for the participants to answer the survey. The last column presents the statements relation to the CXI calculations, where the overall CXI index depends on the complexity level for respective complexity area: *A-station design*, *B- work variance and competence* and *C-unexpected events and information* (see formula 1-3).

Causes of complexity	**Statements (1 = Not complex, 5 = Very complex)** *** (1 = Very complex, 5 = Not complex)**	**Area of complexity**
Product variants	1. There are many different variants on this station	B Work variance (all below)
	2. Many variants are similar to one another regarding function and/or external surface at this station	
	3. There are many variants that are seldom assembled at this station	
	4. The variants at this station require different strategies to assemble	

	(for instance order, difficulty, different amount of operations)	
Work content	5. I have many other work tasks, except for the assembly work at this station (for instance material handling, 5S, documentation etcetera)	B Work variance
	6. The tact time at this station is generally enough for me to perform my work tasks	C Disturbance handling and instructions
	7. My work at this station is often affected by unplanned changes/uncertainties (for instance change of plans, new instructions/variants, or machine disturbances)	Not used in calculation
	8. During unplanned changes/uncertainties there is enough time for me to perform my work tasks	C Disturbance handling and instructions
	*9. During unplanned changes/uncertainties (for instance change of plans, new instructions/variants, or machine disturbances), it is easy to find the information I need to perform the tasks at this station	C Disturbance handling and instructions
	*10. I am part of the planning for the changes on this station	C Disturbance handling and instructions
	11.Durring my work at this station I often feel stressed and/or frustrated	B Work variance
Layout	*12. This station is well designed regarding reachability	A Station design (all below)
	*13. This station is well designed regarding heavy lifts in the assembly work	
	*14. This station is well defined regarding ergonomics in the assembly work (for instance stretching, bending down)	
	*15. This station is well designed regarding the material façade (for example type of packaging, placement, simple to pick and sequence material)	
	*16. The placement of tools, fixtures and components on this station is generally good	
Tools & support tools	*17. The tools/fixtures that are used on this station are well adjusted for the tasks performed there	A Station design
	18. Which support tools are found at this station? ☐ Pick-by-light (lights are lid for a specific part) ☐ Barcodes and scanners ☐ RFID system ☐ Feedback from screens ☐ Feedback from tools (for example the correct force and correct bit) ☐ Checkpoints (feedback in the assembly work) ☐ Other __________________	Not used in calculation; leading to statement #19.
	*19. The above mentioned support tools helps me to carry out my work on this station	A Station design
Work instructions	*20. The work instructions are easy to understand	C Disturbance handling and instructions (all below)
	*21. The work instructions at this station simplify my work	
The general view of the station	22. It takes a long time to learn the work on this station (compared to other stations in my team area)	B Work variance
	*23. In general I think this station is well designed	A Station design

	24. Comment (for example a possible improvement, change of the station, work content, support or other)	Not used in calculation; used to match CXI result

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