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Using the complexity index method to manage problems related to manufacturing

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ABSTRACT
The Complexity Index method is an approach developed to help manufacturing companies quantify complexity in production. This paper sheds light on the connection between complexity and manufacturing problems and how the Complexity Index method was used to capture the areas in a production line with high levels of complexity to determine the sources of manufacturing problems related to labour time, surplus production, and manufacturing error. The main areas perceived as complex were due to Work Instructions, Work Content, and Product Variants. The perceived complexities were assessed for proper actions to be taken to decrease their level of complexity. The correlations between complexity and manufacturing problems were used for tracking related issues and ways for improvement. This study presents data on the use of workers' perception to uncover the areas of complexity, which could be used by the management team to pragmatically capture difficulties and issues related to manufacturing problems to improve the production system.

KEY WORDS
complexity Index, perceived complexity, complexity drivers, and manufacturing problems

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Introduction

Companies in the competitive market strive to enhance their production by lessening manufacturing problems. Complexity is defined as the quality or state of something that is not fully understood or the lack of ability to perform a task easily. It plays a major role in many manufacturing problems and has a direct effect on quality.

There has been an increase in the complexity of production as the human–machine interface evolved

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in manufacturing industries, along with the change in the workplace environment and the ways tasks are done. The human–machine interface has become essential in today's manufacturing and resulted in many manufacturing problems. A human–machine interface is a complex interface and is not directly data-based, nor does it have a numerical matter. There is a need to find aspects that impact this interface, ways to calculate this impact as a quantitative matter and to understand its influence on the quality of a production line.

The Complexity Index (CXI) method was used in this study to enhance the overall efficiency of the factory and to eliminate or lessen the impact of problems during production by focusing on the human–machine interface, increasing the quality of the production line. Perceived complexity was the main focus of the study to reduce waste. The CXI method was used in this study to find the level of the perceived complexity of the production lines and the areas where complexity was perceived to be highest. Data were collected regarding the difficulty of tasks and manufacturing processes. These data were analysed to measure complexity and find reasons and major aspects that lead to production deficiency, and find ways to relate this measurement to various manufacturing problems for enhancement.

1. Literature review

In any manufacturing system, the understanding of the causes of complexity is challenging. Increased transparency of the complexity within the factory can help to identify problems related to manufacturing. Budde et al. (2015) stated that to gain an understanding of the complexity, the causes of complexity need to be identified first, and their dependency on products and processes will be described subsequently. Sivadasan et al. (2006) defined complexity in a system as something that is "difficult to understand, describe, predict or control". Chryssolouris et al. (2013) stated that to manage and consider a complex system, the system complexity should be quantifiable.

As a reaction to the increasing market variety, methods to manage the product complexity are necessary during product development. Salminen et al. (2000) referred to product complexity as the number of product offerings aiming to meet diverse customer demands. Karlsson et al. (2013) saw that product variants were the main cause of complexity. Experienced operators might not look at instructions when new tasks are introduced; hence, work instructions have to be improved. Even production complexity is created by highly varied and customised products (Soltysova & Bednar, 2015); complexity can either be linked to products or production processes. Similarly, Trattner et al. (2019) reported that product variants and components have a negative effect on operational performance in terms of cost, time, and quality.

Mattsson (2013) defined production complexity as "the interrelations between product variants, work content, layout, tools and support tools, and work instructions". Tarrar et al. (2016) studied the use of the complexity index in an automotive company to discuss work improvements. The finding was related to product variance with high complexity levels pointing to the wide variety of product produced and the high complexity levels in the layout, as well as the absence of ergonomics. Kohr et al. (2017) reported that complexity drivers, such as product structure and dynamics of technology, influenced the discrete manufacturing industry. Li et al. (2018) reported that operator performance in terms of perceived cognitive workload and information quality was affected by the presented content of information in work instructions.

Lean production tools are widely used in manufacturing industries to identify and eliminate problems in production (Sony, 2018). Soliman et al. (2018) indicated that lean production in a complex socio-technical manufacturing system has some impacts that reduce complexity while other impacts imply an increase, suggesting that lean production can be an effective way of balancing complexity attributes. Riesener et al. (2019) presented a methodology for the identification of complexity-relevant information requirements for analysis and visualisation of product and service complexity. Ukala and Sunmola (2020) used a rule-based approach to improve the complexity of product assembly.

Mattsson et al. (2012) and Gullander et al. (2012) used a method called the Complexity Index (CXI) to describe the complexity levels. Furthermore, Mattsson et al. (2012) used the CXI method to identify sources of task complexity and solutions to the problems faced by manufacturing companies in the areas of complexity, anthropometry, the safety of the workstation, expertise, and knowledge of a worker to deal with the task. Similarly, Mattsson et al. (2014) stated that the CXI measurement was based on the definition of production complexity, where focus areas included product variants, work content, layout, tools and support tools, work instructions and the general view of the station. However, studying how the employees perceive their work is crucial to successfully manage and design the system (Grote, 2004; Mavrikios et al., 2007). Mattsson et al. (2018) used CXI to capture the operators' view of a system for managing production complexity in a production system. Johanson et al. (2016) studied manufacturing companies that face vulnerability in quality of production when a variety of a product is being produced. They reported that production variation was directly related to perceived complexity. The manufacturing of product variants in manual assembly was challenging since the operation of product variants tended to increase the perceived complexity for the operator.

2. Research methods

2.1. Case study

The factory used for this study is considered a medium production facility in Lebanon. Their products range from mechanical equipment to power generators. The majority of the production systems are carried out manually, which requires human interaction with machines. The other production is semi-automatic, with workers overseeing the process. Every station has a group of workers assigned to deliver the final product. In this pilot study, problems reported during production were related to the MUDA type of waste (Ohno, 1998) and to waste skills (Liker, 2004). In this study, three problems were the main concern for the production and operator managers. They were classified according to:

- Time: this type of problem resulted from a large number of employees working in the factory. For manual production systems, workers have an excess of idle time waiting for the machines to complete the assigned job. Additionally, for the semi-automatic system, time was wasted as workers who oversaw the production were waiting for the job to end.
- Surplus production: this problem was due to the large number of products the company makes. Each product has its own production technique and finishing process. Even though instructions were available, the employees planned and performed their work mostly based on their experience/know-how. This led to ambiguity in quantifying the number of finishing products produced.
- Manufacturing error. This problem was related to a high number of variants and customised orders. The employees handled special customer orders based on their intuition because, in some cases, they neither had the design nor the knowledge. These customisations led to a complex production, which affected the quality of the final product.

2.2. Methodology

The CXI method gives an index for a production line stating how complex it is regarding a few aspects of the work (focus areas). A set of questions concerning certain focus areas that might be perceived as complex was handed out to the workers for answers. Those answers were used to calculate the complexity index of each focus area (CXIe) using the following equation (Mattsson, 2013):

$$CXI_e = \frac{\sum_{P=1}^{n} M_{ep}}{n} \tag{1}$$

where CXI_e = CXI for focus area e, M_{ep} = median of the questionnaire answers for problem areas e for respondent p, and n = number of respondents. The CXI for each production line was calculated by adding the median for CXI_e to the highest median for all focus areas complexity divided by four. The CXI for each production line was calculated using the following formula (Mattsson, 2013):

$$CXI = med_{e=1\ldots k}\, CXI_e + \frac{max_{e=1\ldots k}\, CXI_e}{4} \tag{2}$$

The second part of the formula makes sure that high values of problem areas are captured, i.e., individual differences are captured in the station CXI. Here, the highest median for all problem areas (the maximum median) is taken and divided by four (the highest median can be five as the statements are rated from 1–5, which means that if a five is the highest median, the second factor will be 1.25) (Mattsson, 2013). To visualise the complexity index, the scores from the statements are divided into three categories:

- $0 < CXI < 2$ (no change needed),
- $2 \le CXI < 3$ (need to change),
- $3 \le CXI$ (urgent need to change).

2.3. Data collection

Data were collected from five different production lines to assess human–machine interactions and the effect of the working environment on the performance of workers. Each of these production lines

Tab. 1. Overview of production lines and the number of workers

Production Line	A	B	C	D	E
Number of Workers	7	5	10	8	8

consists of several stations. The variation in the number of workers provided the study with the variability that may be found in production lines when it comes to the number of workers needed to do a certain task. The number of workers assigned to each production line is presented in Table 1.

A survey of 58 questions was carried out to assess the complexity level in each production line. The survey was distributed to workers to measure the level of complexity of tasks they are assigned to. The survey answers were based on a Likert scale (1=Strongly Agree, 2=Agree, 3=Neutral, 4=Disagree, and 5=Strongly Disagree). The questions were grouped into six focus areas (Fässberg, 2011):

1. Work Instructions. Work instructions are used to help workers in their daily work. They are vital for the measurement of complexity because instructions simplify the task and give direct information on how to perform it efficiently. They are step-by-step guides to perform the job. The absence of work instructions or provided obscure instructions may complicate a task.
2. Product Variants. It relates to the number of product variants and/or customised products during production. The product variability implies a higher complexity for the operators since a higher number of variants has a negative effect on productivity and is challenging to the overall manufacturing performance.
3. Tools and Support Tools. Tools and support tools are related to the type of tools workers have on the production line and if they help the operators in their work. Poor tool design leads to fatigued, frustrated and injured workers, which leads to a more complex workplace.
4. Work Content. The operator must know what to do when they come to the station and the assigned tasks. Experience plays a major role since more experienced workers generate less waste and produce better-quality products. Work knowledge and experience have a major effect on the complexity level of the task.
5. Layout. It relates to the layout of the production line and ergonomics. It involves the allocation of space and the physical arrangement of equipment to achieve the greatest coordination and efficiency of workers and workplace interaction. Layout plays a major role in how workers perceived complexity; it also directly affects the general quality of the production line and the manufacturing process itself.
6. General View. The general view is the broad image of the workplace. It reflects how the workers generally perceive the production line they work at and if it is possible to comment or suggest improvements. It helps to understand the general overview of the level of complexity of the production line.

3. Results and discussions

3.1. Complexity

Table 2 displays the CXI values derived from the surveys. These values show the complexity in each focus area and their contribution to the overall CXI of each production line. The calculated total CXI values show the areas and production line in the factory with higher levels of perceived work complexity and difficulty.

Tab. 2. Complexity level in the production lines

Focus area	Production line				
	A	B	C	D	E
Product Variants	1.9	2.9	3.5	2.1	4.6
Tools and Support Tools	2.7	2.8	2.2	1.3	2.9
Layout	2.4	2.4	1.4	1.3	2.7
Work Content	2.3	4.5	2.1	1.2	3.9
Work Instructions	2.2	3.6	3.5	2.1	4.4
General View	1.7	2.6	2.1	1.6	1.6
Total CXI	**2.93**	**3.98**	**3.03**	**1.98**	**4.55**

The differentiation in the CXI levels of each focus area reflected the general difference in every production line. The results presented in Table 2 show clearly that the complexity level in most of the focus areas is somewhat moderate ($2 \leq CXI < 3$) to high ($CXI \geq 3$). Also, it shows that station E has the highest CXI levels with a total CXI=4.55. This means that station E is the most critical, and actions must be taken immediately. Next in line are stations B and C with CXI=3.98 and CXI=3.03, respectively; this implies that both stations have high complexity levels and need immediate attention as well. Station A has moderate complexity levels with CXI=2.93 that need swift attention and actions to decrease the complexity level before it becomes critical. Station D has low complexity levels with CXI=1.98, which implies that workers do not perceive this station as complex, and it needs little attention to keep the complexity level within the range of being low.

Every production line needs a different approach to reducing waste, enhancing the quality of the production, and improving the factory's overall efficiency. Actions and improvements must start with the production line that has the highest levels of complexity. Actions and improvements must be more specific and must begin with the focus areas that score the highest levels. Table 2 clearly shows that:

- Production line E has remarkably high overall perceived complexity, which has a major effect on production. It has three focus areas with high levels, two with moderate levels, and one with low levels. This production line should focus more on making the workspace simpler and more acceptable for the workers to perform better. A focused improvement to Work Instructions, Product Variants, and Work Content focus areas must start immediately to lower the complexity level. After focusing on the high complexity level areas, the management focuses on the moderate level areas since they are not in the safe zone and might have a major role in the high overall complexity levels. This will be carried out by a gradual improvement in Tools and Tool Supports and Process Layout for an efficient and effective change in the complexity.
- Production line B has the second-highest complexity levels with two focus areas in the high-level zone, four in the moderate and zero in the low zone. This means that production line B has to improve all the aspects of the problem and immediately lower the complexity levels. By having zero problem focus areas in the low CXI levels, it is suggested that intensive adjustments and supervision must be exercised to help workers and to simplify the tasks.
- Production line C has the third-highest CXI levels with two focus areas in the high complexity zone, three in the moderate, and one focus area in the low zone. This means that complexity is unstable. It is suggested to work on the product variants and work instructions immediately to maintain a suitable CXI level.
- Production line A has an overall of moderate complexity levels with four focus areas in the moderate CXI levels and two in the low zone. The production line has moderate complexity levels, needs attention and requires actions to be made to decrease the levels, just not as immediate as with production lines with high overall CXI levels. However, having four focus areas out of six in the moderate area imposes a possible future threat of the levels increasing; therefore, it is suggested that actions should be taken to improve the overall quality of production and decrease the complexity.
- Production line D has the lowest CXI level and requires no actions to be taken. This wasn't surprising as production line D is a mainly semi-automatic system and has minimal human–machine interference. However, some moderate complexities were perceived in two focus areas, which were the result of missing instructions for new or customised products.

3.2. Production deficiency

The complexity levels per focus area show how complex each of them was regarded and their contribution to the overall CXI. Table 3 lists in descending order the focus areas that are the main contributors to the complexity and how these focus areas are correlated to the manufacturing-related problems within the factory.

Table 3 shows that Work Instructions is the main contributor to complexity for all the production lines compared to other focus areas. The answers to the survey on Work Instructions reported unclear instructions, lack of support, and difficulty understanding and obtaining work instructions.

This is vital considering that production is facing the challenge of delivering several variant models on time. The outcomes of this study show clearly that the main contributor to many manufacturing problems for all production lines is the absence of clear work instructions.

Tab. 3. Complexity levels of focus areas and their effect on problems related to manufacturing

Focus area	Complexity level			Production-related problem		
	High	Moderate	Low	Time	Surplus Production	Manufacturing Error
Work Instructions	3	2	0	✓	✓	✓
Product Variants	2	2	1	✓		✓
Work Content	2	2	1	✓		✓
Tools and Support Tools	0	4	1	✓	✓	
Layout	0	3	2	✓		✓
General View	0	2	3			✓

The results of Product Variants and Work Content are similar to Work Instructions, where both focus areas have a high level of complexity. This is a drawback considering that all production lines have complexity problems related to product variants and work content. It is believed that the lack of experience and the demand for customised products contribute to the high complexity. In many cases, customised products are considered variants even if they are similar to each other and consist of similar components since they require different manufacturing techniques. The factory faces the challenge of delivering an increasing number of variants and models. Operation managers must be aware that variants require different strategies for production and are challenging to manufacture; additionally, they require highly skilful and experienced workers. Complexity in product variants and experience can magnify issues related to many manufacturing problems as the tasks the operators perform take a relatively long time, and errors in production are irrepressible.

Four production lines showed moderate complexity driven by the focus area Tools and Support Tools. There was a lack of effort to ensure all needed tools and items were available at each production line. The respondents stated that the production line was acceptable for work; however, in some cases, the needed tools to complete a work process were removed from the work area and used at another production line. This contributes to problems related to time wastage. In other cases, workers might increase the volume of production to compensate for any manufacturing error before returning the shared tools to another production line. This also contributes to problems related to surplus in production.

The complexity result of the focus area Layout was similar to the focus area Tools and Support Tools, where both focus areas showed some concern level of moderate complexity. The respondents stated that the production line was well designed for work. Nonetheless, problems were reported in relation to inadequate work preparation and ineffective removal of unnecessary tools and materials from the work area. Insufficient clearing and cleaning can increase problems as tasks performed by operators become lengthy, and errors in production start to creep up.

The focus area General View has the lowest complexity level and the least effect on the waste-related problem. Even though worker feedbacks were perceived as good, two production lines encountered manufacturing errors. The workers' responses to the questions related to this focus area showed workplace contentment and satisfaction but also reported the absence of engagement in decisions related to improvements and the opportunities to resolve work-related problems. This clearly contributes to manufacturing errors.

This section discusses the possible use of CXI results to improve production. Improvements should focus on workers, workplaces, and managers. Based on CXI results, the most important areas of complexity in all production lines are Work Instructions, Work Content, and Product Variants. This is important considering that production faces the challenge to reduce problems related to labour time, surplus production, and manufacturing error. The lack of experience and the introduction of more variants and customised models have been major contributors to complexity. To be more precise, production lines that have the highest complexity index revealed problems related to rework, repeated movement of the operators from machines to the materials rack and waiting time. Operation managers must give valuable information and instructions to workers regarding possible difficulties imposed by such actions on manufacturing. Poor communication and training within the factory were important contributors to poor results in complexity.

The focus area Tools and Tool Supports addresses issues of labour time and inventory. The surveys stressed problems related to the availability of tools and parts. Operation managers must ensure that workers have everything to accomplish the task efficiently. Workers must be provided with needed information and adequate time to finish their job. Additionally, planners must make the station free of unplanned changes or uncertainties, and if not possible, they must provide workers with time to adjust and offer technical assistance if needed.

The complexity in the focus area Layout contributes to the increase in production time and manufacturing error. The issues with Layout resulted from the lack of efforts on material preparations for production and housekeeping concerning the work areas. The survey provided sufficiently detailed information regarding reasons or causes of time-wasting and manufacturing errors. The situation is purely logistic and needs improvement. To reduce problems related to manufacturing, the job design phase should consider information on organising the movement, preparing the work areas, and ergonomic aspects.

The results of the focus area General View outlines how operators feel about their work. It concerns the wellbeing (physical or mental) of staff. Managers must consider the involvement of workers in evaluating the current situation and finding issues in need of improvement. This involvement makes the tasks less stressful and provides workers with the technical information needed to minimise defected, reworked, or recycled products.

Conclusions

This study aimed to investigate how perceived complexity could be used in the manufacturing industry with serious production issues. Using CXI as a complexity measurement tool to reveal complexity drivers and resulting complexity effects, this study presented data on workers' perception to uncover the areas of complexity. The CXI method was found to be extremely useful for seeking workers' feedback and effective in showing their insight into work conditions. The staff contribution helped to point out operation and layout problems of a production line.

The complexity measures of the six focus areas were good predictors for the impact made by inadequate complexity on workers, products and production. The results of the evaluation of these focus areas on production deficiency allowed the management team to define the focus areas that were the main contributors to complexity in production and how these focus areas were correlated to the problems related to manufacturing. The main areas perceived as complex were due to Work Instructions, Work Content, and Product Variants. Consequently, the management team must ensure that workers have everything (instructions, training, etc.) to accomplish the task efficiently. The results of this research can be used to provide improvements and reduce and/or handle production problems. Also, they allow the management team to ascertain an adequate complexity for workers, the workplace and the process.

The outcomes of this study showed significant correlations between complexity, ergonomics, and experience of workers and provided quantitative methods for tracking the quality-related issues and ways for enhancements. The correlation used in this study can aid the management team in pragmatically capturing difficulties and issues related to manufacturing problems. Poor communication was a key variable that led to poor results in complexity. The management team must consider involving workers in the process of evaluating and anticipating problems and determining actions that lead to the desired outcomes or objectives.

In summary, the CXI method can help in the assessment of suitable actions to enhance the issues faced by the factory. This method gives a better insight into the direct relationship between the efficiency of the process and the aspects of human interaction with machines (Complexity, Ergonomics and Experience).

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