KNOWLEDGE IN PRODUCTION: TOWARDS A QUANTIFYING MODEL

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Abstract: Many concepts related to knowledge sharing and knowledge creation impact to the overall efficiency and competitiveness of production systems. From a socio-technical system perspective a model is presented combining focus concepts derived from the three areas: efficiency, empowerment and automation. The contribution is a first step towards a quantifying model of the overall production system in relation to knowledge.

Keywords: knowledge sharing, knowledge creation, cognitive automation, role allotment, production metrics

1. INTRODUCTION

Automation like for instance machines and robots have provided gain in terms of production efficiency in the past century. Because of increased product complexity, mass customisation, and higher demand for sustainable products (Colledani et al., 2014), more flexible manufacturing strategies are required. This need for flexibility puts more emphasis on the human workers and their role in the manufacturing environment. Further, technology advancement in the factories leads to a more complex production system where the importance of knowledge and information is very high. This suggests that human workers need to interact more with both machines and each other (Schuh et al., 2014).

The processes of sharing and creating knowledge (Nonaka, 1994) are very important in complex and flexible manufacturing systems. Workers need to be educated and empowered; they need adequate knowledge to properly handle the high complexity. They also need to be connected to enable sharing of knowledge within and between teams (Malone, 1997). Requirement of connectivity drives the need of communication and information technology and this further adds to the overall complexity. Maskell (2001) argue that efficient manufacturing methods include technologies but they do not need to be high-tech methods, rather highly capable. To fully understand how knowledge among operators in a production system is shared and created, it is important to understand how the entire system behaves.

Human workers in production systems behave, as in any other context, as individuals. How they share information can depend to their individual characteristics, the team structure or more production specific areas. In socio-technical systems it is required to recognise both people and technology (Trist, 1981). From this perspective, the aim is to conceptualise a model that can describe how knowledge is created and transferred among operators in a manufacturing system. The model is derived from the main areas production efficiency, empowerment and automation.

1.1. Scope

The scope is to combine the three main areas and choose focus concepts including how to measure them. Since the perspective is holistic, a more generic view is presented and discussed but not further examined. The criteria of the model are that it needs to be simple and quantifiable. Simplicity is important because for the model to be useful, to include every aspect of knowledge would be deemed to fail. A quantifying model is important to enable measurements, simulation and validation.

2. KNOWLEDGE THEORY

This section describes general theories about knowledge and how it can be described and structured. It includes: the hierarchy model, where knowledge is related to data, information and wisdom; tacit knowledge; knowledge sharing and knowledge extraction.

The wisdom hierarchy is the most common way to structure how data, information, knowledge and wisdom relate to each other. The concept of data, information and knowledge was presented by Henry (Henry, 1974), but then the hierarchal model was only implied. Ackoff is often credited as the first to explicitly express this in a scientific journal, then also including understanding located between knowledge and wisdom (Ackoff, 1989). This is an hierarchal model because one level is described in terms of the one below; information is described in terms of data, knowledge is described in terms of information, and wisdom in terms of knowledge (Rowley, 2007).

The distinction between information and knowledge is seldom clear and many models overlap. A way of dealing with this overlap of definitions is to divide knowledge into different parts. Michael Polanyi (1966) was the first to use the term tacit knowledge as opposed to explicit knowledge. This distinction has been widely accepted and discussed. Tacit knowledge is something that cannot be easily expressed. Tacit knowledge itself could then be divided further, that which have not been expressed yet and that which inheritably is not expressible (Blair, 2002).

Knowledge management evolves around sharing knowledge and strategies of supporting this process. Within an organisation, knowledge sharing can be expressed with the knowledge spiral (Nonaka, 1991). It starts with tacit to tacit knowledge transfer, also known as socialisation. Then the tacit knowledge becomes explicit through externalisation, explicit knowledge is combined and turns into new tacit knowledge in the organisation, which is called internalisation. Externalisation is of course a very useful transformation since it would allow tacit knowledge to be stored, transferred and presented by information systems.

Looking at knowledge as a resource in the company suggests that it would be possible to gather this resource for later use (Wernfelt, 1984). This is where the knowledge management strategies and information technology meet. The two main engineering strategies for general knowledge extraction are codification and personalisation (Hansen et al., 1999). Codification is where you attempt to collect knowledge into documents and store it for future use. Personalisation focuses on connecting people by knowledge links so that also tacit information may be shared.

When looking at the knowledge as a resource, for the purpose of measuring knowledge sharing, the knowledge must be shared (as information) in a structured way. Further, there is no way to measure tacit knowledge. It becomes clear that the presented theory regarding knowledge do not provide a good base for a quantifying model of operator's knowledge in production.

3. QUANTIFIABLE CONCEPTS

This section describes concepts that are connected to quantifiable methods related to human workers in the production context. It includes discussions regarding knowledge sharing and examples using scenarios from industry. The scenarios derives from case studies that have been conducted through observations and semi-structured interviews. In the first scenario, A, a milling machine is being utilized during the night without personnel to monitor it. If problems occur during the night the machine will stop and the production halt will not be noticed until the next morning. Therefore it is important that the machine is loaded with the optimal product batch that allows for a full night steady run. The problem in scenario B is situated around set-up of machines between different product types. Switching between different types of products require reconfiguration of machines to deal with new sizes and tolerances. This specific task is done in several different shifts and every shift has one or several experts that usually do the reconfiguration work. Since the knowledge of how to do this task is different depending on shift and available personnel the speed and quality of the reconfigurations varies significantly.

3.1. Production efficiency

Production systems efficiency is closely connected to the workers level of skill. As an example, someone could be skilled at one task and can e.g. assemble something very fast, but does not have the knowledge about in what order work should be handled. Therefore it is important understand what skill is measured so that the impact is correctly valued. Table 1 lists common production metrics in no particular order (Groover, 2008).

Table 1, production metrics.

Measure	**Description**
Production rate	How many pieces are produced per time unit.
Production capacity	Maximum production rate.
Utilization	Actual production related to the capacity.
Availability	Reliability of equipment. *Mean Time Between Failure (MTBF)* *Mean Time To Repair (MTTR)*
Manufacturing lead time	Total time of processing a given part through the entire plant.
Work-in-Process	The quantity of all the parts currently being processed.

3.2. Empowerment

Empowerment is a generic term that does not have one clear and uniform definition. One way to describe empowerment is that it's a set of rules or schemes, and these schemes are, according to Wilkinson, "*united by sharing a common assumption that employees' and employers' interests are inextricably connected"* (1998). Another example are the concepts decentralising of decision making authority and motivation of workers (Psoinos and Smithson, 2002). The first part, regarding decentralised decision making, is closely related to flexibility. Workers that can perform many different tasks can be said to be more flexible.

Flexibility and knowledge sharing
In the second scenario, B, five shifts work in the same production line. The machine set-up process is sometimes complex and time consuming. Because of this, not everyone is comfortable dealing with this to full extent. Some have been working at the same place for years but do still not consider themselves experts. Someone must be the first to learn a complex task before they can take on the role of teaching others. Tasks, roles and workers are all connected to each other in various ways. By measuring who does the actual set-up, and more importantly, who does not, can give a lot of information regarding the ability of the organisation to share complicated work over time.

Measuring flexibility
For employees flexibility depend both on their skills, that they can perform a certain task, but also on their level of freedom. Some organisations do not allow people to step out of their roles, and this could be because of outspoken rules or embedded in the culture. Sheridan (Sheridan, 1992) classify five different roles; plan, teach, monitor, intervene & perform. Measuring what roles workers actually takes on (called role allotment) could be done by conducting interviews, as exemplified by Mattsson et al. (2014). It is important to note that the interview method can only be useful for general empowerment assessment, if all roles are evenly spread within a team. It would be more difficult to precisely measure if e.g. some information tool allowed someone to enter the teaching role more often. The first thing to understand when considering measure role allotment in any context is what tasks exists and how these relate to selected roles. The tasks used in the example reference, presented by Stahre (Stahre, 1995), consist of 17 tasks identified in production.

3.3. Automation

Automation is automatic control with the aim to reduce the need of human work. Sometimes it is defines as technology that completely removes human involvement (Groover, 2008, p. 3). What is perceived as automation will constantly change (Parasuraman and Riley, 1997) and there are different types of automatic control that can be applied with different levels ranging from none to full.

Cognitive automation

There are several ways to divide types of automation. One way is to separate physical automation from cognitive automation (Fasth, 2012). Cognition is the word for mental processes such as perception, attention, memory, language, problem solving, creativity, reasoning, judgement and decision-making. Parasuraman et al. (2000) discusses four types of cognitive processes: Information acquisition, information analysis, decision and action selection, and action implementation. If physical automation is automatic control over physical work e.g. using an impact wrench, cognitive automation is automatic control over cognitive work. Hence, cognitive automation is means to support mental processes. It can be an instruction of how to assembly a specific part or a warning system that detects and informs when a process is not followed correctly (Fasth-Berglund and Stahre, 2013).

Automation and knowledge sharing

It is not clear if automation affects sharing of knowledge in a system, but it does change how human perceive the overall process. All types of automation, full or partly implemented, are types of abstraction from a human operator's point of view. This abstraction will naturally affect the overall understanding of the process, called out-of-the-loop problem (Endsley & Kiris, 1995). This can have both a short term and long term effect. In the present situation, if the abstraction is too high, the awareness of what is actually going on might too low for the operator to be able to take appropriate action when a problem arises (Endsley, 1997). There are also some tasks that are complicated and/or discouraging. Some people would then need the cognitive support to be able to get started in learning that task. Learning and understanding is therefore optimised when the cognitive automation is at the correct level and type. What is correct depends on who is concerned.

The problem of planning from scenario A can be used as an example. In the observed scenario, there was in large a consensus among the operators that the planning work was actually quite simple and there was no spoken demand of a support tool to help with this task. The perceived awareness was high. However, the managers were not convinced that the planning was always done in an optimal way. According to them, the complexity of this task was hidden behind unspoken rules and an out-dated information system. The operators wasn't discouraged from doing this task and that might suggest that to partly automate would only reduce the overall understanding. In this specific scenario the information needed to make a proper decision was obscured. Cognitive automation should probably be at a level where it highlights the information but still allows the operators to do the planning.

Measuring cognitive automation

DYNAMO is a qualitative method with the aim to visualise automation strategies (Granell et al., 2007). This method have been transformed into a quantitative method called DYNAMO++ (Fasth, 2012). The actual method deals with both physical and cognitive automation. It consists of four phases where the aim is to align the levels of automation (LoA) in a system to a certain predefined goal. The actual representation of the automation uses seven levels for each type of automation developed by Frohm et al (Frohm et al., 2008). The list below show the automation levels related to cognitive support.

1. **Totally manual**: The user creates his/her own understanding for the situation, and develops his/her course of action based on his/her earlier experience and knowledge e.g. the users earlier experience and knowledge.
2. **Decision giving**: The user gets information on what to do, or proposal on how the task can be achieved e.g. work order.
3. **Teaching**: The user gets instruction on how the task can be achieved e.g. checklists, manuals.
4. **Questioning**: The technology questions the execution, if the execution deviate from what the technology consider being suitable e.g. verification before action.
5. **Supervision**: The technology calls for the users' attention, and direct it to the present task e.g. alarms.
6. **Intervene**: The technology takes over and corrects the action, if the executions deviate from what the technology considers being suitable e.g. thermostat.
7. **Totally automatic**: All information and control is handled by the technology. The user is never involved e.g. autonomous systems.

4. DISCUSSION

The aim is to find focus concepts for a quantifiable model of operator's knowledge in production. Level of cognitive automation should be included since cognitive processes are directly related to understanding and decision-making. Using the LoA method is powerful because it is simple. It is possible to do the measurement just by knowing about the technology and preferably observe how it is used. However, LoA does not inform in any way if the implementation of the automation is correct or that it highlights the truly important information. Production metrics could provide some hint but not the complete picture. To further specify at what type of cognitive automation that is actually used, it could be possible to include whom is actually supported by it e.g. experts and novices. Other consideration about using automation in the model is if it should include both physical and cognitive automation. All types of automation change awareness (out-of-the-loop problem).

There are empirical studies suggesting that empowered teams are more productive and proactive (Kirkman and Rosen, 1999). Empowerment, in this context, could be described as decentralisation of decision-making. The process of teaching takes time and usually there are short-term gains in letting the same people keep on doing the tasks they are more experienced in. This is naturally a vulnerability of the system, people can get sick, injured or simply quit. In this sense, it would be more valuable if everyone could do most of the tasks. Therefore, as described for scenario B, measuring role allotment could prove very useable to identify vulnerability and to validate knowledge sharing.

For workers to evenly share the work tasks require both the skills and knowledge to perform the tasks and incitement for motivation to do them. The example from scenario A highlighted the planning task in relation to cognitive automation. Cognitive automation supports workers when performing complex tasks. Scenario B showed the relations between tasks, roles and workers. This connects automation and empowerment (Fig. 1).

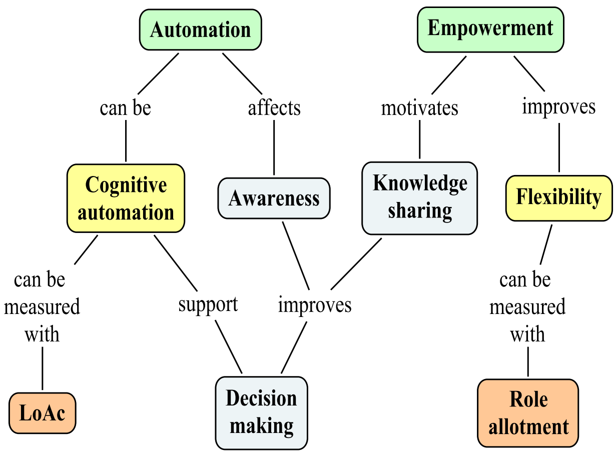

Fig. 1. Connecting automation and empowerment.

There are more connections between human behaviours in terms of knowledge sharing and how the organisation is managed. Knowledge sharing can be facilitated by technology, like ICT tools, and by motivation. To introduce technology that support connecting workers to facilitate knowledge sharing may, but not necessarily, be fruitful. "If individuals are not motivated to share knowledge, it is not likely that they are motivated to use tools facilitating knowledge sharing" (Hendriks, 1999). Hendricks refer to Herzberg's (1987) six positive motivational factors: achievement, responsibility, recognition, operational autonomy, promotional opportunities and challenge of work. Motivated workers that share knowledge form efficient teams. Individual operators in those teams should perform well.

Time is the first measurement that comes to mind when thinking of measuring operator performance. And cycle time is the base of production rate, production capacity and availability. When it comes to work skills like assembly of parts or set-up machines, the skills can be measured with the time it takes doing the task. Many basic forms of cognitive automation, like work instructions, directly affects cycle time and number of errors (Fast-Berglund et al., 2013). The most basic relation to connect the system to performance metrics is to simply state that skills affect the production metrics in various ways. The last picture (Fig. 2) shows the overview where all three areas are included.

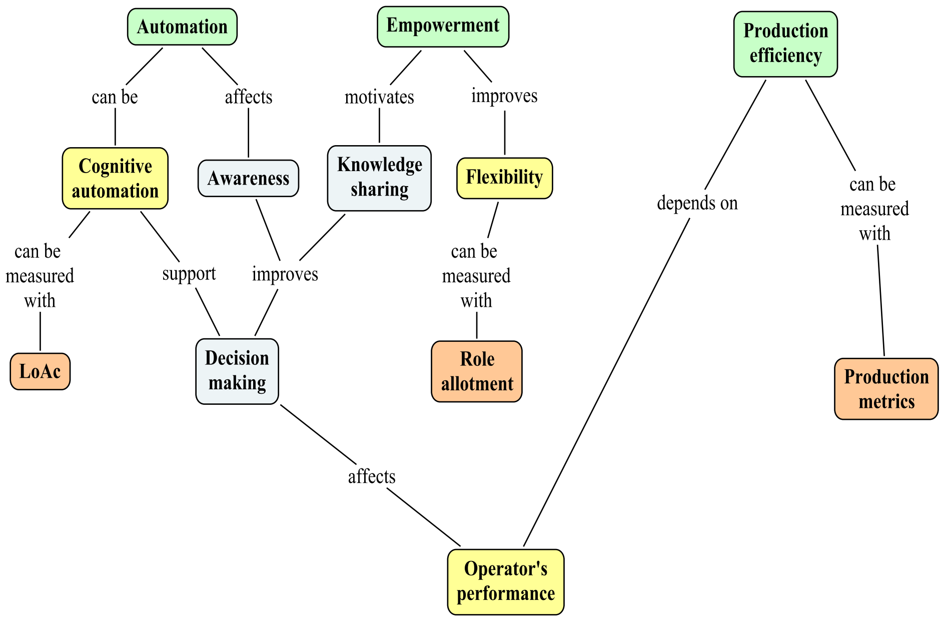

Fig. 2. Overview of operator's knowledge in the production system.

In the end, in a manufacturing context, what matters is sustainable efficient production. Efficiency is measured with the production metrics. When it comes to knowledge sharing, interesting metrics are the ones directly connected to human work in the system, the *operator's performance*. Work-in-process and manufacturing lead-time may, at first glance, seem less interesting metrics in this context. They are more cost related useful for total plant optimisation. However, cognitive challenges can be tightly related to planning, shown from scenario A. In scenario B, it was the set-up time that was the underlying problem.

Table 2, the three focus concepts with measurements related to the holistic view.

Holistic perspective	**Production efficiency**	**Empowerment**	**Automation**
Concept in focus	**Operator performance**	**Flexibility**	**Cognitive automation**
Example of *measurement*	Production metrics (Groover, 2008)	Role allotment (Stahre, 1995)	LoAc (Fasth, 2012)
Gaps Holistic view focus concept	Other production metrics e.g. number of errors.	Group dynamics, communication tools etc.	Physical automation, awareness, implementation, experts and novices etc.

5. CONCLUSION

Examining theory of knowledge does not give a clear way of measuring or simulate knowledge, or how sharing of knowledge relate to a production system. From the three areas: production efficiency, empowerment and automation it is possible to identify focus concepts including measurements that could be quantified.

Several new questions arise, that need to be considered, when examining the areas further. The level of automation is a relevant measure but does not paint the full picture. Role allotment reveals flexibility but does not include all aspects about empowerment. Different production metrics measures efficiency but it need to be connected to specific tasks and people to get actual operator performance. The focus concepts; operator performance, flexibility and cognitive automation have all shown to be relevant when building a holistic model of operators knowledge in production systems.

ACKNOWLEDGEMENT

The authors like to thank the academia and companies involved in the research. The work has been carried out within the Production Area of Advance at Chalmers and sponsored by VINNOVA. This support is gratefully acknowledged.

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