Comparing methods for redesigning, measuring and analysing Production systems

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ABSTRACT

This paper reviews 10 methods or models that are developed to redesign, measuring or analysing a production system. Furthermore, a comparison is done between the methods and models based on four focus areas with the aim of putting the developed DYNAMO++ and concept model into perspective due to the other methods and models. A literature study is used in order to review the methods and the focus areas. The result shows that the DYNAMO++ and the Concept model could be a golden way between the most socio-cognitive models and the technical-physical models when measuring and analysing a production system. The model also takes into consideration both physical and cognitive Levels of Automation in a more delicate scale than the other methods and models which makes the task allocation more precise.

Keywords: Production, Assembly, Task allocation, Levels of Automation (LoA), methods

1. INTRODUCTION

Current tradition for design and usage of assembly systems may not be adoptable to the future needs and challenges that production companies have to face. When companies adopt automated solutions, they need to determine the correct amount of automation. However, it might be suboptimal to just evaluate the technical part of the system. Completely automated systems almost always have a human operator somewhere, at some level [1] so Chapains' dream in 1970, to automate everything you possible can towards autonomous systems remain a dream, forty years later. Jordan [2] argued that men and machines/technique should be seen as complementary, rather than conflicting, resources when designing a man-machine system. Therefore it is also vital to evaluate the socio-part of the system when changing a production system. Moreover, it is imperative to understand *why* to change the system and, if possible, break down these triggers into measurable goals so a comparison after the change could be executed.

In fifteen case studies [3, 4], conducted in the late 90s, companies often used informal and unstructured evaluations of the current system for why to change the system. According to Fasth et al [5], a majority of ten case studies conducted in 2007-2008, knew why to change their system. However, in line with Säfsten, the evaluations was often informal and unstructured i.e. feelings rather than facts.

Today, a lot of different methodologies and models exist in order to describe and improve production systems. This paper will therefore discuss the following question;

Are DYNAMO++ [6] and the concept model [7] filling any gaps regarding task allocation in a production system?

In order to discuss this question, ten design and measurement methods or models regard to four focus areas connected to redesign, measuring and analysing a production system has been chosen;

Design and measurement methods or models

1. DYNAMO++ [8] and Concept model [7]
2. TUTKA production assessment tool [9]
3. Systematic Production Analysis (SPA) [10]
4. Productivity Potential Assessment (PPA) [11]
5. Lean Customisation Rapid Assessment (LCRA) [M. Comstock, 2004]
6. A model for types and levels of human interaction with automation [12]
7. Complementary Analysis and Design of Production Tasks in Socio-technical Systems (KOMPASS) [13, 14]
8. Cognitive Reliability and Error Analysis Method (CREAM) [15, 16]
9. Task Evaluation and analysis Methodology (TEAM) [13, 17]
10. Taxonomy for Cognitive Work Analysis [18]

Focus areas

1. What assessment scale and level of change within the production system is the main focus?
2. Assessment objectives i.e. what is the methods' main measurement parameters?
3. Assessment methods i.e. qualitative or quantities methods?
4. Where within the dimensions of Socio-Technical and Physical -Cognitive is the methodology's main focus?

Methodology review

The following sections will provide a short summary of each methodology and a summary of focus area 1-3.

DYNAMO++ methodology and concept model

The DYNAMO++ method and the concept model (fig. 1) for task allocation were developed during 2007-2009. The main aim is to evaluate and analyse the current stage of assembly systems due to triggers for change i.e. the company's internal or external demands and Levels of Automation. Further to propose possible improvements for the future in a more structured way by using the LoA matrix, illustrated in figure 2, and the Square of Possible Improvements (SoPI). The LoA analysis is done mainly on a task, station or cell level but from an operator's perspective.

The model also considering the competence of the operator group (LoC) and the information flow to and from the operators (LoI), this is done on a station or cell level. These areas are divided into direct task i.e assembling or value adding tasks and indirect tasks i.e planning, improvement – non value adding tasks.

LoC in the direct tasks in the assembly system could be described according to Rasmussen's Skill-Role-Knowledge (SRK) behaviour levels [19] and as an competence matrix where the tasks and the number of operators are listed and combined, This could also be transformed into the cognitive LoA and showed visually in the SoPI in the LoA matrix. For the indirect tasks in the current system, LoC can be described as the accumulated and combined knowledge of an operator group working in the system. An example of an indirect task is planning of assembling,

LoI can be described as the indirect information needed in the assembly cell in order to handle the indirect tasks i.e other then assembling products. The information flow is divided into carrier (HOW the information is presented, i.e. phone, paper, other operators, PDAs etc) and content (WHAT is presented i.e. orders, alarms etc).

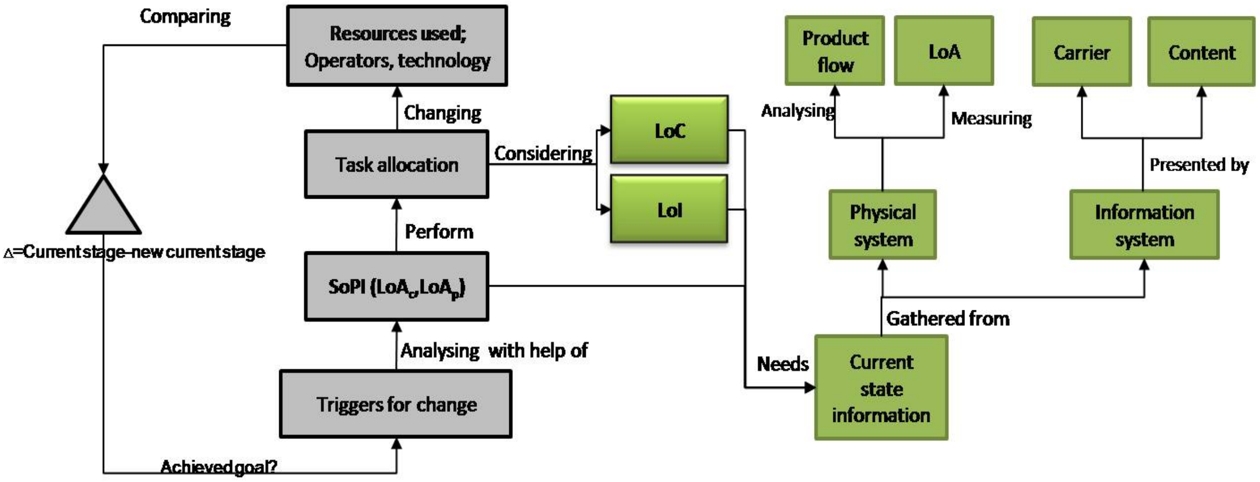

Fig. 1 Concept model, further developed from DYNAMO++[7]

The measurement parameters used for task allocation is a seven by seven matrix [6], seen in figure 2,. This is a further development of a taxonomy described by Frohm [20], considering both cognitive and physical levels of automation. Parasuraman et. al [12] argues that automation design is not an exact science but continuous, however, neither does it belong in the realm of the creative arts, with successful design dependent upon the vision and brilliance of individual creative designers. The Square of Possible Improvements (SoPI) within the LoA matrix is used for the future analysis and could be seen as an attempt to find a balance between facts and feelings (experience) when improving the system.

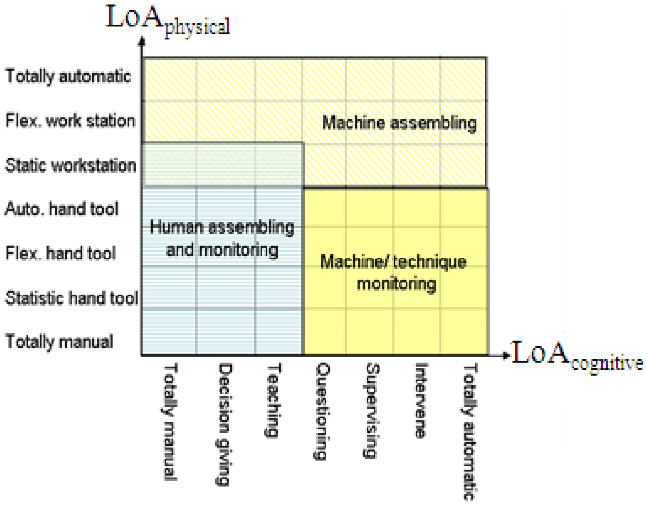

Fig. 2 LoA Matrix

TUTKA production assessment tool [9]

The TUTKA production assessment tool was developed during the end of 2000s. The main aim with the tool is to assess the current state of a production system and to identify potential and means for improvements. The tool is comparing the current state of the system with a desired state i.e. a well performed production system, by using 33 key characteristics, 6 decision areas and 6 production objectives.

Systematic Production Analysis (SPA) [10]

The SPA was developed in 2007-2008 with focus on manufacturing processes such as machining. The main aim is to measure the existing production condition and to simulate [21] different outcomes regarding three main parameters i.e. Quality (Q), Down-time parameters (S) and Production speed/tact (P) in order to reduce cost. The methodology has also been used in assembly operations [22], focusing on capacity flexibility and part cost. Two levels of automation is used to describe the assembly stations (manual/ automatic).

Productivity Potential Assessment (PPA) [11, 23]

The PPA method was developed during 2005-2006. The main aim is to show the improvement potential of productivity in Swedish manufacturing companies.

The parameters forming the PPA Method are divided into different 4 levels;

- Level 1 is the core of the method, constituting two parameters for measuring efficiency in manual work and machine work respectively.
- Level 2 parameters affect productivity at corporate level,
- Level 3 parameters indicate the company's ability to improve the production while maintaining a sound work environment.
- Level 4 treats the potential of improving productivity by improving the "M" factor of equation 1

Four levels of (mechanical) automation are used; 1) Man- Manual, 2) Semi – Semi-automatic 3) Auto – Automatic 4) Proc – Process industry

Lean Customisation Rapid Assessment (LCRA) [24]

This method is a further development of the Rapid Plant Assessment (RPA) method, which was developed to help managers to fast determine if a factory was lean or not and discern the factory's strength and weaknesses were [25]. The main aim with the further develop method, LCRA, is to provide support in the analysis and/or design of a production system or even en entire company for mass customisation [26]. This is done thru three evaluation sheets divided into costumer elicitation, engineering and manufacturing.

A model for types and levels of human interaction with automation [12]

The model is primarily used to analyze ATC (Air Trafic Control) systems with the issue; *Given specific technical capabilities, which system functions should be automated and to what extent?* The human performance consequences of specific types and levels of automation constitute the primary evaluative criteria for automation design using the model. Secondary evaluative criteria include automation reliability and the costs of action consequences. Such a combined approach—distinguishing types and levels of automation and applying evaluative criteria—can allow the designer to determine what should be automated in a particular system. The model does not *prescribe* what should and should not be automated in a particular system. Hence, the model provides a more complete and objective basis for automation design than approaches based purely on technological capability or economic considerations. Ten levels of automation of decision and action selection is used for task allocation.

Complementary Analysis and Design of Production Tasks in Socio-technical Systems (KOMPASS) [13, 14]

The method was developed in the end of the 1990s aiming for designing production systems were human has control over technology i.e. automated systems. Expert analysis of existing systems is done based on three levels of analysis criteria; work system, human work tasks and human machine system. The method is built on the complementary principle [2] when designing a system i.e. humans and machines are fundamentally different and can therefore not be compared on a quantitative basis but complementing each other, performing tasks in a joint cognitive system [27]

Cognitive Reliability and Error Analysis Method (CREAM) [15, 16]

CREAM is a Human Reliability Analysis (HRA) method i.e. modeling cognitive errors and error mechanisms into the risk assessment processes. Results from the development were published in 1996-1998. The basic notion is that of contextual control modeling, i.e., describing human cognition in terms of the competence for actions and the way in which the actions are controlled.

CREAM can be used to identify the most likely cause of an observed event--either an accident or an erroneous action. The method can also be used in a predictive way to derive the likely consequences of specific erroneous actions.

Task Evaluation and analysis Methodology (TEAM) [13, 17]

The method was developed between 1994-1996. The main aim is to evaluate existing advanced manufacturing systems (AMS) from a user perspective in order to pinpoint efficiency problem areas. Further to provide support for humans to better interact with complex technology [13]. Task analysis is presented in an evaluation matrix, developed by Stahre [28], based on a combination between Sheridan's supervisory control and Rasmussen's human behaviour levels.

Four factors are considered; work environment, work tasks, information flow and system performance [17].
The method should ideally be performed by multidimensional system design teams with at least one human factor specialist. Three levels is used for task evaluation; 1) generally difficult, 2) differentially difficult, 3) tasks known by few operators

Taxonomy for Cognitive Work Analysis [18, 29]

This taxonomy was first published in 1980s and should be used for effective support of decision processes to create a work practise that suits the individual users' cognitive resources [18]. A work domain should be represented at five levels of abstraction, representing goals and requirements, general functions, physical processes and activities, as well as material resources [18]. Any of these levels has a work function (*what* should be used) which can be seen both as a goal (*why* it is relevant) for a function at a lower level, and as a means for a function at a higher level (*how* this is realized), [30]. Moving from a lower level to a higher level of abstraction means a change in the representation of system properties.

Focus area 1-3

The following chapter will describe and define focus area 1-3 and show a summary of the focus areas regard to the different methods.

Focus area 1: What assessment scale and level of change within the production system is the main focus?

The assessment scale could be described as the deepness of the methodology in the production system. Figure 3 illustrates seven structuring levels and two views; the resource view proposal by Westkämper [31] and the space view proposal from Nyhuis [32] based on H-P Wiendahl [33]. The *resource view* looks for the technical and human resources, which maintain the processes whereas the *space view* considers the architectural objects which have to be designed in accordance with these resources. The resource view is used in this paper to describe the deepness of the methods and models, seen in table 1.

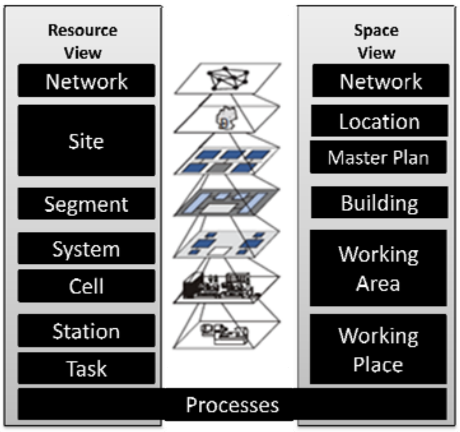

Fig. 3 Structuring levels and views of a factory [34], edited.

Tasks within stations has been added as a level in the model, in figure 3 [31, 33] [32]. This is done to be able to in count task allocation in the model e.g. the assessment scale in this paper is a maximum of seven (not including the processes which are the resources, machines and/or humans working in the different levels [34]) start counting from task level and up.

Level of change

The level of change could be described as a two degree change according to Porras and Robertsson [35]; 1st degree – Changes or improvements in the current system and 2nd degree - Redesigning the system

Focus area 2: Assessment objectives i.e. what is the methods' main measurement parameters?

As been said in the introduction, it is important to know why to change a system and to have parameters to compare the current state and the system after the changes in order to see if the goals with the change have been achieved. In this paper these parameters are divided into two different types;
P_{DM} -Parameters that are direct measurable (quantifiable) i.e. time, cost
P_{IDM} -Parameters that are indirect measurable (qualitative) i.e. Flexibility, Complexity, Proactivity

Focus area 3: Assessment methods i.e. qualitative or quantities methods?

Different assessment methods could be used in order to collect the data needed for analysing the system. IN this paper the methods are divided into qualitative and quantitative approaches. The differences with the approaches could be described as;
Qualitative research is to understand the meaning of a certain phenomenon or discovery, whereas quantitative research dissects the phenomenon to explore its components, which later become the studied variables[36]. These approaches also have a relation due to the different dimensions that will be described in focus area 4. If the method or model is more focused on a socio-dimension tendencies are to used qualitative methods i.e interviews, observations etc, while if the method investigates more of a technical approach it tends to be more quantitative methods i.e. measurements and pre-defined criteria.

A comparison between the ten methods and models due to the focus areas 1-3 is seen in table 1.

Table 1 Comparison between the different models and methods regarding focus area 1-3

Methods /Models	***Assessment Scale**** *Starting from task	***Level of change***	***Assessment Objectives***		***Assessment methods***
			P_{DM}	P_{IDM}	
DYNAMO++ and Concept model [6-8]	**3**	**1st**	**Time, LoA matrix**	**Proactivity, Flexibility and Complexity**	**Qualitative; Semi structured interviews, Observations, HTA, VSM**
TUTKA production assessment tool [9]	4	1st	Cost Quality, Time (lead, delivery time)	Flexibility (volume and product)	Quantitative; 33+6+6 predefined criteria, process maps
Systematic Production Analysis (SPA) [10]	3	1st	Quality (Q), Down-time parameters (S) and Production speed/tact (P) cost.		Quantitative; Measurement in production (machines)
Productivity Potential Assessment (PPA) [11]	5	1st	Performance (Speed)	Method (LoA), Utilization (how well) Productivity	Quantitative; Questionnaire (40 yes or no Q:s), and time study
Lean Customisation Rapid Assessment (LCRA) [M. Comstock, 2004]	5	1st	Cost	Flexibility	Qualitative; 3 different rating sheets
A model for types and levels of human interaction with automation [12]	4	1st		Information processing	Qualitative; Human performance, 2) Cost of decision/ action outcomes
Complementary Analysis and Design of Production Tasks in Socio-technical Systems (KOMPASS) [13, 14]	3	2nd			Qualitative; Semi-structured interviews, work place observations
Cognitive Reliability and Error Analysis Method (CREAM) [15, 16]	1	1st	Probability of a human error occurring		Qualitative
Task Evaluation and analysis Methodology (TEAM) [13, 17]	3	1st		Efficiency	Qualitative; Interviews, questionnaire, observations, evaluation matrixes
Taxonomy/model for Cognitive Work Analysis [18]	5	1st		Cognitive LoA	Qualitative

***Focus area 4:* Where within the dimensions of Socio-Technical and Physical-Cognitive is the methodology's main focus?**

The dimensions seen in figure 4 have been chosen because most production and manufacturing system can be described within these.

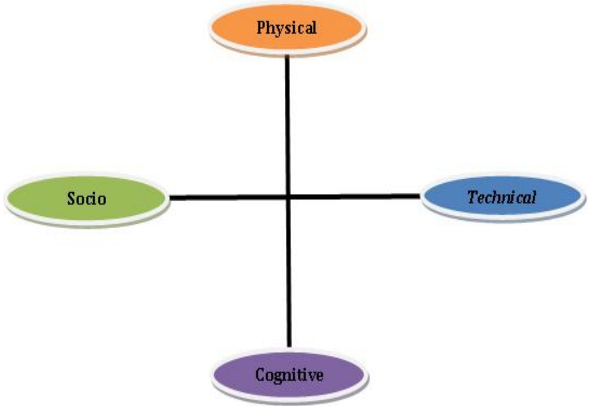

Fig. 4 The dimensions of Socio-Technical and Physical-Cognitive.

Socio-technical dimension

The Socio-Technical viewpoint of manufacturing systems emerged from two different schools with the idea to combine technology, organization and human growth in order to maximise the system performance. The theory was first formed in 1950 at the Tavistock institute of human relations, with the beginning of the well known empirical analysis by Trist and Bamford at the English coal mines [37].

The school of human relation [38] which also could be described as the social sub system handle members of the organisation, individual demands and qualifications and group specific demands [39]. The second school, scientific management [40] – rational production engineering, also described as the technical sub system [39] handle resources, technologies and methods.

These thoughts led to a new paradigm of work with seven principles that differ from the old way of thinking [41];

1. The work system, which comprised a set of activities that made up a functioning whole, now became the basic unit rather than the single jobs into which it was decomposed
2. Correspondingly, the work group became central rather than the individual job-holder
3. Internal regulation of the system by the group was thus rendered possible rather than the external regulation of individuals by supervisors
4. A design principle based on the redundancy of functions rather than the redundancy of parts [42] characterized the underlying organisational philosophy which tended to develop multiple skills in the individual and immensely increase the response repertoire of the group.
5. The socio-technical principle valued the discretionary rather than the prescribed part of work roles [43]
6. The principle treated the individual as complementary to the machine rather than as an extension of it [2]
7. It was variety-increasing for both the individual and the organization rather than a variety in the bureaucratic mode

Out of these two dimensions illustrated in fig. 4, four areas could be discussed. The following sections will bring up some definitions of these areas and position the models and methods in within these areas;

Socio- Physical

A composite class of sciences which intersect in a fundamental way both to the physical and social science could be called socio-physical sciences. Furthermore, socio-physical sciences must be vitally concerned with human behaviour and objectives. An example is industrial engineering.

The eventual extensive use of automation will bring into the class many additional areas now considered components of social or physical sciences. The necessity of considering a technology directly in terms of goals of the social groups involved in or affected by that technology is what ultimately distinguishes this class of sciences [44]. The methodologies or models place in this quadrant are models with the main focus on strategies and organisation theory. None of the chosen methods is put here.

Keywords: Industrial engineering, Industrial sociology, economics and psychology, organization and communication

Socio-Cognitive

Socio-cognitive engineering aims to analyse the complex interaction between people and computer-based technology and then transform this analysis into usable, useful socio-technical systems, a dialectical relationship to user-centred design [45]. Humans developed a unique socio-cognitive ability to cognitively create information that they then store, organize, retrieve and used. There is a critical need to understand and incorporate information behavior into an

evolutionary and life-span understanding of human behavior [46].
The methodologies or models place in this quadrant are models with the main focus on Humans-in-control and human based systems further the assessment methods are often qualitative, i.e. CREAM,TEAM, COMPASS, A model for types and levels of human interaction with automation and Taxonomy for Cognitive Work Analysis

Keywords: Human in control, human-based, human behaviour

Technical - Cognitive

Cognitive Technical Systems differ from other technical systems in that they perform cognitive control and have cognitive capabilities [47, 48]. A cognitive system is goal directed; it uses knowledge about itself and its environment to monitor, plan, and modify its actions in the pursuit of goals; it is both data and concept-driven.
The development and application of Cognitive Technical Systems (CTS) aims at an integrated approach for the planning and execution, as well as the continuous learning and adaptation of processes in technical systems under unpredictable circumstances [48]. Furthermore it could be described as a single, integrated system composed of both human and artificial cognitive systems [49]. Advances in computation AI technology have greatly expanded the potential for the support of human cognitive activities and for the development of artificial cognitive systems--i.e., systems that perform tasks normally associated with human cognition [50].

Methodologies or models place in this quadrant are models with the main focus on autonomous systems. None of the chosen methods are placed here, But one example of such a method or model could be the cognitive factory [48].

Keywords; AI, evolvable systems, autonomous systems, cognitive agents, cognitive engineering

Technical-Physical

This quadrate could be described as the most technical or mechanised way of describing a production system or rational production engineering. The methods often use quantitative methods such as P_{DM}: s or pre-defined criteria which are assessed with the system.
For example; in the PPA method a questionnaire with 40 yes or no questions (or predefined criteria of a productive system) is used to determine the level of productivity within the system (above 35 yeses is seen as a well functional productive system)
Out of the ten methods, the assessment tools (PPA, LCRA and TUTKA) and the SPA method is placed here.

Keywords: Production engineering, System design, Physical automation, scientific management

Figure 5 shows a summary of the chosen methods and models placed in the different areas. One explanation to why none of the methods or models was place in the socio-physical or technical-cognitive is that the methods is chosen due to task allocation and assessments mainly on a shop-floor level, while these two quadrants are on a more strategic level.

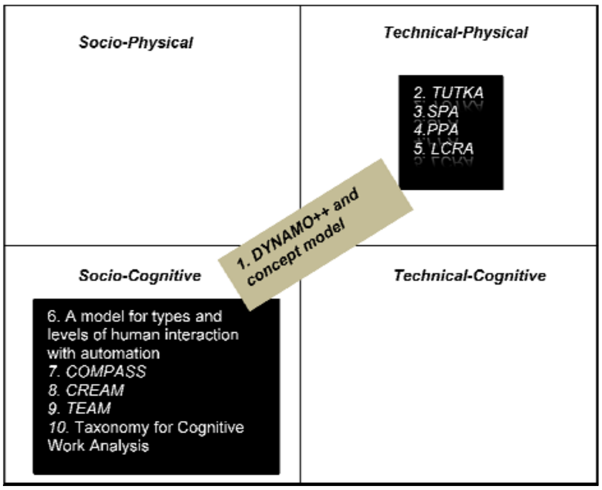

Fig. 5 a summary of the methods and models placed in the different dimensions

CONCLUSIONS

The result shows that the DYNAMO++ and the Concept model could be a golden way between the most socio-cognitive models and the technical-physical models when measuring and analysing a production system based on two main reasons. The model takes into consideration both physical and cognitive Levels of Automation in a more delicate scale than the other methods and models which makes the task allocation measurements and analysis more precise. Furthermore, the model also considers the social aspects in terms of competence within the operator group and the information flow to and from the cell or station.

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