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Human- and Task-Centered Assistance Systems in Production Processes of the Textile Industry: Determination of Operator-Critical Weaving Machine Components for AR-Prototype Development

Marco Saggiomo
Institut fuer Textiltechnik, RWTH Aachen University
Marco.Saggiomo@ita.rwth-aachen.de

Mario Loehrer
Institut fuer Textiltechnik,
RWTH Aachen University
Mario.Loehrer@ita.rwth-aachen.de

Daniel Kerpen
Institute of Sociology,
RWTH Aachen University
dkerpen@soziologie.rwth-aachen.de

Jacqueline Lemm
Institut fuer Textiltechnik,
RWTH Aachen University
jacqueline.lemm@ita.rwth-aachen.de

Yves-Simon Gloy
Institut fuer Textiltechnik, RWTH Aachen University
Yves.Gloy@ita.rwth-aachen.de

Abstract

Smart manufacturing concepts merge modern production machinery and digital technologies in Cyber-Physical Systems (CPS). CPS consist of intelligent real-time-capable and networked sensors and actuators. The operation of such advanced machinery requires new and substantial skills in employees in various qualification phases. Successful implementation strategies take these varying skills of the workforce, which result from diverse cultural, educational, age- or gender-related socio-demographic variables, into account. Thus, the need for a differential-dynamic job design in textile production seems more relevant than ever, especially regarding the increasing number of older employees due to demographic changes in high-wage countries,. An important measure that is intertwined with the implementation of advanced manufacturing concepts in textile production is supporting employees in their development of skills concerning these new production methods. For this purpose, the development of Augmented reality-based assistance systems in connection with up-to-date textile machinery is regarded as a promising step towards the successful implementation of adequate, user-adaptable Cyber-Physical Systems.

Keywords: Industrie 4.0, smart manufacturing, human-machine interaction, human- and task-centered assistance systems, Augmented reality, workforce diversity

1. Introduction

Currently, one of Germany's most frequently discussed topics among industry practitioners and engineering academics is the so-called fourth industrial revolution (Industrie 4.0) [1].The German term *Industrie 4.0* and its discourse is comparable to global scale ideas like the industrial internet, advanced manufacturing, integrated industry, or smart industry/smart manufacturing [2].

Common basic assumptions of these concepts are for instance:

- The merging of physical and virtual environments by so-called Cyber-Physical Systems (CPS) which integrate computational, physical, and social processes in human/nonhuman (software, sensors, and actuators) interaction networks [3,4].
- The interconnection of CPS with the Internet of Things (IoT) interacting with each other through unique addressing schemes. Single CPS upload process solutions and product-related data to cloud-based storage solutions making them available for the entire process chain [5] Thus, CPS communicate via the

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Internet of Things and are able to optimize manufacturing processes as well as internal logistics. CPS are a central element of Industrie 4.0 in the manufacturing environment [6].

Regarding the vast range of possible applications, CPS and the IoT are praised for having "the potential to dwarf the 20th century IT revolution" [7].

Recent developments in advanced manufacturing have furthermore spurred interest in the social sciences and humanities, which deal with questions of e.g. the individual and organizational adaptation of advanced production systems or their ethical, legal, and (macro-)social impacts (ELSI) as well as further educational and socio-economic aspects [8,9,10,11].

Hence, advanced manufacturing/production systems are regarded as socio-technological systems [12] with potentially disruptive impacts on an economic and societal scale.

This paper focuses on how assistance systems in the textile industry can facilitate the development of competence with respect to diversity/demographic aspects such as an increasingly aging workforce. In the next chapter of this paper (Chapter 2), several socio-technical implications like the aforementioned demographic change or increasing technical complexity will be outlined. Afterwards, the concept of human and task-centered assistance systems will be introduced (Chapter 3). Chapter 4 is the core of this paper and shows the results of a survey conducted to identify critical tasks of an operator of a weaving machine. Chapter 5 describes and depicts a potential assistance system in form of a smartphone app. The last chapter (Chapter 6) provides a conclusion to this paper and gives a brief outlook on future work.

2. Socio-technical implications of smart manufacturing in the textile industry

The textile industry is characterized for the mid-sized German industrial landscape. The textile industry is the second largest consumer goods sector in Germany, with a focus on technical textiles. Industrial textile machines are used in the manufacture of various products e.g. clothing, lightweight construction, car interiors, or the field of medical technology. When considering the textile industry, it is likewise observable that the development towards Industrie 4.0 in textile production is primarily based on modern production machines in conjunction with digital technologies. This poses severe implications on different levels of research, as subsequently shown.

2.1. Increasing production complexity

Manufacturing companies in the high-wage country Germany can only persist in the global competition with technologically innovative, custom-made products. The resulting complexity consists of a high product variety with low lot sizes and might be overcome by technological progress. Thus, smart manufacturing concepts provide technological approaches to ensure the competitiveness of high-wage countries.

Current Industrie 4.0 projects focus on rejecting rigid manufacturing structures and supporting a factory of the future that improves its own processes steadily by using technical innovations and adapting to new requirements automatically [13].

2.2. Increasing job complexity

Following the trend towards Industrie 4.0, the operation and development of advanced machinery becomes more complex and requires therefore extended skills of employees in various qualification phases. The requirements of mechanics become more mechatronics-oriented. Industrial electricians work more and more together with computer scientists. At the same time, fundamentals of mechanics and electrics are required which are not necessarily provided by younger employees.

Eventually, basis for successful introduction and implementation of new production technologies and thus the connectivity to new trends are the competencies of the employees. These competencies are inextricably linked with the already described production complexity.

Individual processes in the textile industry, particularly in the field of technical textiles —such as weaving or finishing— are highly automated. Therefore, the handling of modern textile machines is more complex than before and requires increasing skills of the employees in operation and maintenance. Along the textile chain, for example in the processing of fibers to fabrics, a number of different highly complex machines are used. For instance, a loom has about 200 setting parameters.

Finally, another point to be taken into consideration is the increasing personnel diversity in the textile industry, as will be subsequently outlined.

2.3. Increasing workforce diversity

One of the leading factors regarding diversity in the textile industry in high-wage countries is demographic change [14]. In Germany for instance, the group of employees who are older than 60 years of age has been increasing for several years. According to statistics of the German Federal Employment Agency from 2013 the number of employees older than 60 years increased from 2011 to 2012 by 12.5 % [15].

In comparison to 2007, the share of the over 60 years old employees increased by 76.9 % to a total of 1.654.831 people. With regard to the demographic development and the raising of the retirement age to 67 in Germany, further increasing of this age group is assumed.

Considering the growth of the group of older employees, the differential-dynamic job design in textile production seems more relevant than ever. Younger employees who already grew up with digital media have an advantage over their older counterparts. However, older employees have a significant edge in experience. Therefore, textile production is faced with the dilemma between employment of older employees and younger employees, as will be subsequently shown in further detail.

In addition to the mentioned aging distribution of employees, the decline of qualified school leavers leads to non-sufficient skills in the textile industry. New approaches have to be developed in order to acquire qualified young employees.

To sum up, extended skills on socio-economic and socio-technical domains are observed. The interplay between social and technological change highlights the need for an interdisciplinary approach to cope with the challenges of future textile production. Figure 1 illustrates the depicted dilemma between the employment of younger and older employees together with the dilemma of autonomous vs. manual textile production.

By creating and providing diversity equitable workplaces and technical tools companies can provide their employees with individual assistance in the exercise of their activities. These measures will contribute to the large group of older employees also helps to compensate for resulting performance limitations and allow them an adequate participation in professional life. These effects are reduced such as social exclusion or economic competition between employment generations.

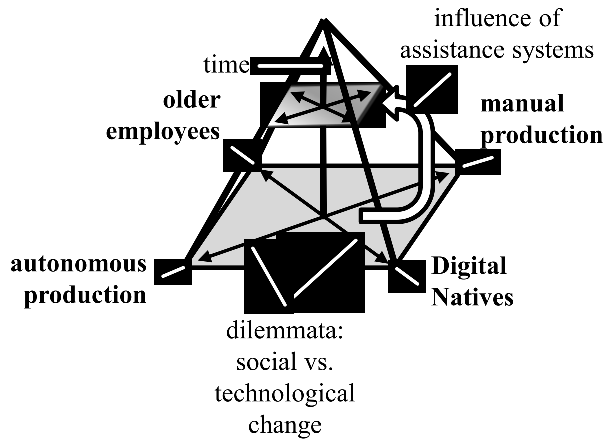

Figure 1: Vision of adjustment of social and technological change through assistance systems [16]

Especially the increasing degree of automation in the context of Industrie 4.0 leads to changes of work structures and tasks of employees at all levels [16]. A higher degree of automation using intelligent CPS in textile production [17,18,19,20] goes along with a more autonomous way of production. A lower degree of automation, thus manual configuration of single production machines represents most parts of the today's textile production.

Since younger employees grew up with new technologies (Digital Natives), it is assumed that they cope with autonomous textile production more easily. Older employees are usually more experienced in setting up complex production processes of the textile industry manually. This means that personnel and organizational issues, such as new organizational and training forms, as so-called 'soft factors' must be considered [21].

Thus, low trained employees need assistance in order to keep the desired high quality level of textile mills in high-wage countries. Experienced employees need to transfer their knowledge to their low trained, for example younger colleagues to ensure a constant level of skills of the workforce.

In the next section it will be outlined in how far human- and task-centered assistance systems can support both low trained and experienced employees.

3. Human- and task-centered assistance systems

By providing

- diversity-driven workplaces,
- technical tools and
- mobile information technologies

companies could be able to provide their employees with individual assistance in the exercise of their activities. These measures will support the group of older workers to compensate performance limitations caused e.g. by new components of smart manufacturing technologies. In particular, the introduction of mobile information technologies in manual processes or handling operations can help to compensate age-related decreases in cognitive processes or declining sense sharpening [22]. The advantages gained by mobile information technologies can reduce effects such as social exclusion or economic competition between employment generations.

The integration of technologies in work processes and environments is called "Ambient Assisted Working" (AAW) [23]. Embedding technologies of the AAW is particularly suited to making significant contributions to the learning-design of such systems.

Human- and task-centered assistance systems, for example a motion capture system, significantly contribute to train employees and promote health and safe systems of work. In order to do this, assistance systems need to adapt to individual problem solving and learning strategies automatically. Due to the ability to adapt to the individual needs of different employees, learning new skills and solving complex tasks is simplified by assistance systems. The use of self-adapting assistance systems allows an age-appropriate work and a skills-specific training of staff. Through this work-integrated training, employees are able to develop their occupational capacity. However, recent research findings suggest that learning can be defined as a multi-level construct [24]. A human- and task-centered assistance system is a tool for the realization of learning supportive structures and processes in a company which covers settings, frameworks and instruments. These assistance systems support learning processes in the context of machine utilization and provide information for occupational education and training as well as for so-called Communities of Practice (CoP) [25].

Technical process analyses of weaving machines provide the empirical base for the subsequent work on assistance systems. Deeper descriptions of an empirical approach to determine operator-critical weaving machine components follow in the next chapter. From the results of empirical investigations, the requirements for the development of an Augmented reality (AR) - based assistance system prototype is derived.

4. Determination of operator-critical weaving machine components for AR-prototype development

The objective of this research consists of providing support to the weaving machine operator in handling the weaving process. After presenting fundamentals of weaving technology, the determination of operator-critical machine components and tasks is described in this paper.

Furthermore, the first results of the development of an AR-based assistance system prototype are presented.

4.1. Fundamentals of weaving technology

In the textile industry, the art of weaving is one of the oldest processes. Weaving employs two distinct sets of yarns and interlaces them at perpendicular angles to obtain a fabric. Figures 2 and 3 visualize the setup of a weaving machine.

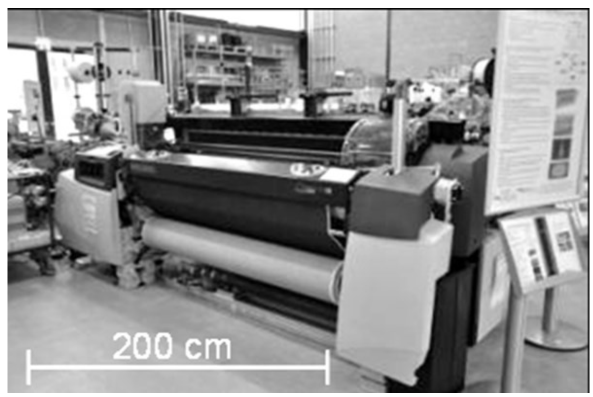

Figure 3: Weaving machine by Picanol NV

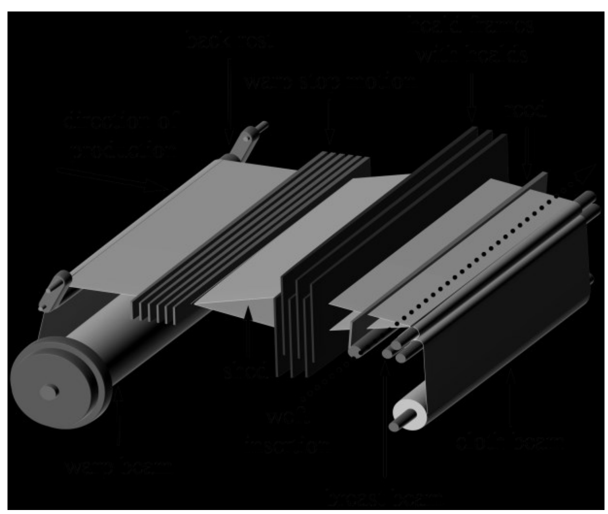

Figure 3: Setup of a weaving machine [26,27]

The warp yarns which are oriented in the direction of production are winded up on the warp beam. The yarns are diverted to the production area by the back rest. Each warp thread is connected with the warp stop motion which interrupts the weaving process in case of warp yarn breakage. After passing the warp stop motion, the warp yarns are led through the healds of the heald frames. These rectangular frames create the shed by distinct vertical motion. The shed is the physical separation of the warp yarns and creates an opening for weft insertion. Finally, the weft yarn is inserted through the shed and tightened to the fabric edge by means of the reed. The fabric is stored on the cloth roll through the breast beam system [26].

4.2. Definition of objective and scope of the survey

The scope of the research is to clarify the distinction between relevant and irrelevant data. To support the operator to handle the increasing complexity of intelligent machinery, which could be realized through an augmented reality-based assistance system, is also an objective. Focus is dedicated to the perspective of the machine operators, who has to reduce the downtime of one or more weaving machines to a minimum.

Furthermore, emphasis is stressed on the weaving machinery and process, not on yarn production and preparation. In detail, only machine components and process parameters, which are directly related to the weaving process, are considered. These elements influence the quality of the fabric straightforward and can be manipulated by the operator.

Consequently, internal machine components like the electric motor, lubrication circuits and gear boxes, which are maintained by expert personnel, are beyond the scope of the practical implementation due to their complexity.

4.3. Approach for identification of critical components and tasks

In order to identify the critical machine components and operator tasks, an empirical survey was conducted. Information is gathered from operators and technicians of eight weaving mills in Belgium and Germany. The critical components of a weaving machine are identified by means of three open questions, focusing on the most maintenance-intensive, time-intensive and most frequent failures. The questions are namely:

1. Which components of your weaving machinery require the most efford regarding maintenance or replacement?
2. Which errors often result in an interruption of the weaving process?
3. Which tasks or preparations on your weaving machines are the most time-consuming ones?

Potential applications of an assistance system can be deduced from the critical part identification (see section 4.6.). The analysis of the collected data is based on the methodology shown in Figure 4.

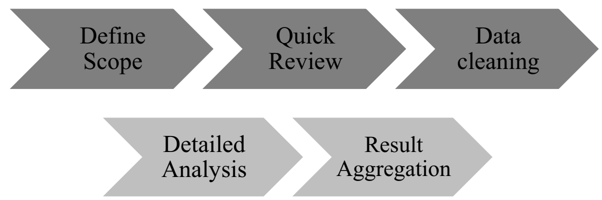

Figure 4: Steps for data analysis of empirical survey [28]

4.4. Quick review of the results

Diagonal reading of the collected data is performed to identify important areas for the detailed analysis [28]. The following areas are considered important when analysing the answers:

- Consider the severity of an error induced by failure of the component or parameter, as well as the time-intensity for repair
- Consider frequency and probability of failure
- Consider the current lack of an assistance system for the focused component or parameter
- Consider factors like increased air consumption and quality consequences instead of only looking at possible failure of components
- Define the importance and reliability of different information sources

4.5. Data cleaning

The raw data is adjusted according to the following actions:

- Remove irrelevant responses on basis of the research's scope;
- Detect and remove duplicate responses;
- Build a list of themes for open-ended questions, allowing to quantify data;

- Mapping of answers with different description, but identical meaning;

4.6 Detailed analysis: Result aggregation and data analysis

Finally, the cleaned data is processed and crucial information is extracted, taking the identified areas from the quick review into account. The results are visualized in histograms or tabular form.

The following results include a total number of n=18 returned and completely filled out questionnaires from which the subsequently presented histograms are derived.

The histogram presented in Figure 5 shows the survey results coming from operators and technicians from eight German and Belgian Weaving Mills.

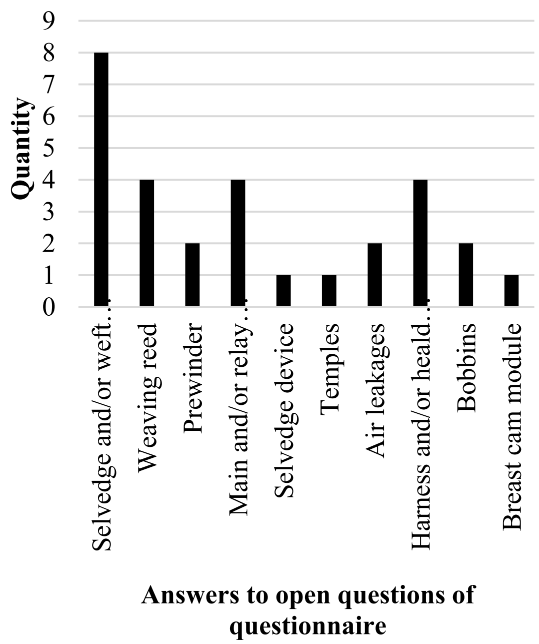

Figure 5: Histogram of survey results (critical components)

From a quantitative perspective, the operators and technicians agree on

- selvedge and weft scissors,
- main and relay nozzles,
- reed and
- harness and heald wires

as critical components of a weaving machine.

Figure 6 shows the survey results regarding machine downtime causes from the perspective of operators and technicians.

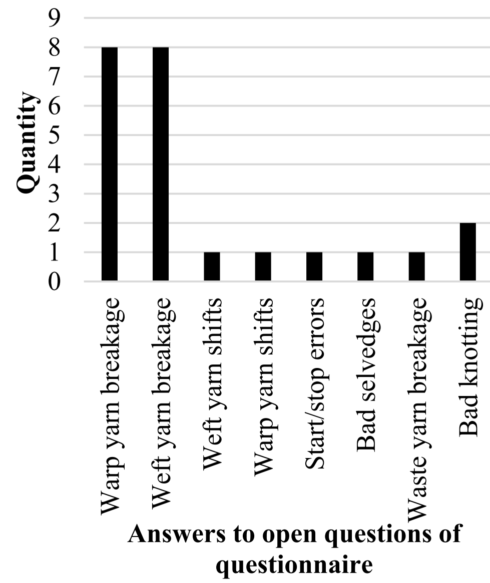

Figure 6: Histogram of survey results (machine downtime causes)

The results in Figure 6 show that weft and warp yarn breakage is a major cause for downtimes of weaving machinery.

Furthermore, the repair of broken yarns and harness elements are identified as time-intensive tasks, see Figure 7.

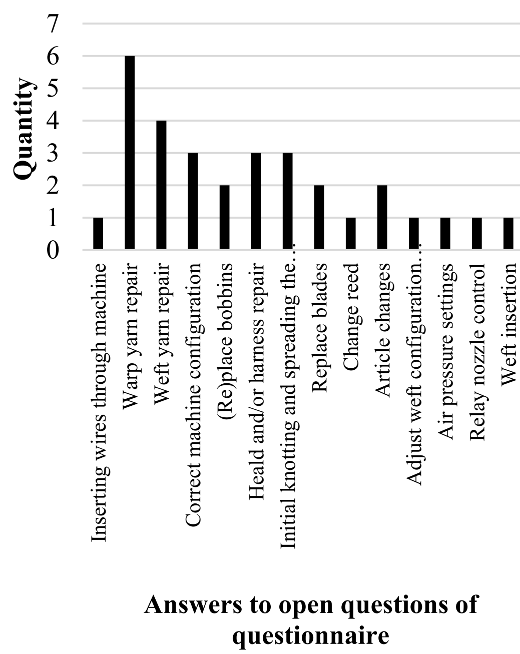

Figure 7: Histogram of survey results (time-critical actions)

Additionally, initial preparation of the machine and finding the correct machine configuration are considered as troublesome, see Figure 7.

Basing on the results shown in Figures 5, 6 and 7, an augmented reality-based application for Smart Mobile Devices is developed. To assist the operator by resolving the machine stops, the assistance systems should know the reasons for these. The frequency of scissor problems is in reality lower than for yarn breakage. Therefore, the repair of weft yarn is suited for the development of an AR prototype with limited but sufficient complexity. The prototype can be used afterwards as an adequate reference for researching the economic potential of AR-based assistance systems.

5. Development of AR-based application for Smart Mobile Devices

The planned mobile application can be used to assist operators to handle problems regarding weft yarn breakages.

A screenshot of the prototype application assisting operators to fix broken weft yarns is shown in Figure 8.

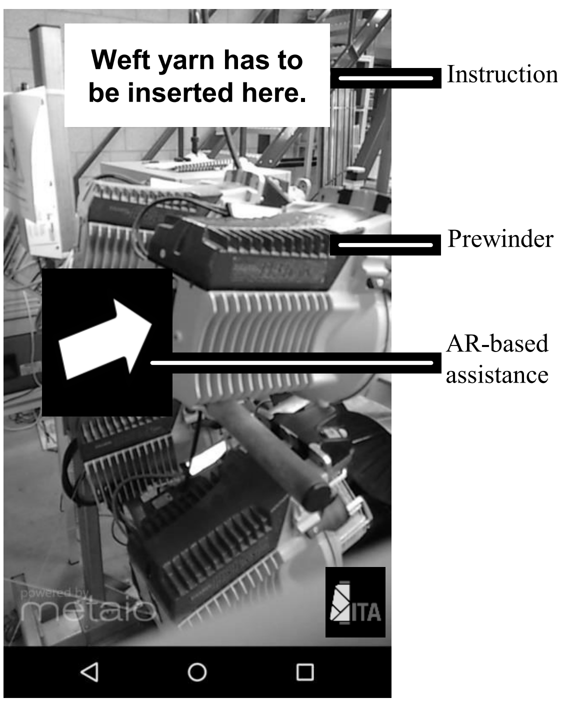

Figure 8: Screenshot of AR-based mobile application

In case an operator needs assistance in order to fix a broken weft yarn, the weft insertion devices (from creel to main nozzles of a weaving machine) have to be focused with the camera of the used device. For the developed application prototype, smartphones, tablet PCs or smart glasses can be used as runtime platforms.

The application detects the position where the weft yarn is broken and provides the operator with individual case-specific AR-based assistance.

For instance, Figure 8 shows the instruction that the weft yarn has to be inserted into the inlet of the prewinder. An AR-based arrow points at the inlet considering the case that the operator has a low experience level.

It is intended to provide further user group-sensitive instructions and layouts. For instance, the font size shall automatically increase if an older operator logs on to the system. Similarly, the interface of employees with language barriers shall show more pictograms to facilitate understanding.

Although the described AR-system is specifically designed for weaving machines, it can easily be transferred to other machines in the textile industry and even to machines in other industries.

6. Conclusion and Outlook

An empirical approach was chosen in order to derive requirements for an Augmented reality (AR)-based assistance system development.

Furthermore, the development of the AR-based assistance system prototype is associated with the greater context of smart manufacturing systems which merge physical and virtual environments through the integration of Cyber-Physical Systems.

In light of the construction of textile machinery, main challenges smart manufacturing poses on the textile industry were outlined. Challenges of future textile production go beyond the scope of solely production technology and reach out in social domains like educational systems and vocational training concepts.

Future work might consider the deeper economic analysis of Industrie 4.0-ready and (AR-based) assistance systems alongside presenting suitable business cases in the textile industry as well as in other industries. Further studies might address the important issue of user-experience in actual textile production implementation as well. Privacy-, security-, and safety-related aspects of assistance systems in the smart manufacturing context of Industrie 4.0 are going to be discussed.

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