CYBER-PHYSICAL SYSTEM FOR SELF-ORGANISED AND FLEXIBLE LABOUR UTILISATION

D. Spath, S. Gerlach, M. Hämmerle, S. Schlund, T. Strölin

Fraunhofer-Institut for Industrial Engineering IAO, Nobelstr. 12, 70569 Stuttgart, Germany.
E-Mail of corresponding author: stefan.gerlach@iao.fraunhofer.de

Abstract
Within this paper the approach of a self-organised and highly flexible labour utilisation will be presented. It displays the on-going German research project 'KapaflexCy", which comprises ten industrial and science partners. Target of the research project is to define and investigate specific applications of Cyber-Physical Systems (CPS) in a production environment. The approach of the project 'KapaflexCy" is to involve employees in the personnel planning and scheduling. A CPS will be developed, which permanently monitors the order backlog, the production environment and the actual workload. According to these conditions the CPS schedules necessary work duties. The immediate assignment of persons is self-organised by the employees by means of a matching process. Mobile communication devices together with social media elements will provide support. The described approach offers a new way to a flexible mode of labour.

Keywords:
Cyber-Physical-Systems, Lean Production, Personnel Planning, Human-Resource-Allocation

1 INTRODUCTION

1.1 Demand for Flexibility

The sales quantities of manufacturing companies follow the product lifecycles and the world-wide economic activity. Additional effects may result from seasonal demands, campaigns, or overlaid, very large, singular orders. These effects in combination with the globalisation of the markets and upcoming international competitors make it difficult to estimate the sales forecast [1]. It especially seems to be impossible to predict the world-wide economic activity reliably [2]. Nevertheless it is agreed in practice, that there will be regular economic cycles.

So far, manufacturing companies are challenged by volatile markets and unreliable sales forecasts. As a consequence they cannot predict and plan their production quantity and workload in advance. Nevertheless they have to meet high requirements in terms of short delivery times, low stock quantities and competitive costs [3, 4]. They have to fulfil customer demands for products of high quality faster and more reliably as the competitors [5].

The still used approach of a centralized planning and scheduling of production demands and orders [6] is too slow and to inefficient to meet new requirements of dynamic and volatile markets. The typical effects of a centralized planning usually are slow delivery times, high security stock levels and, in general, a high 'wasting'.

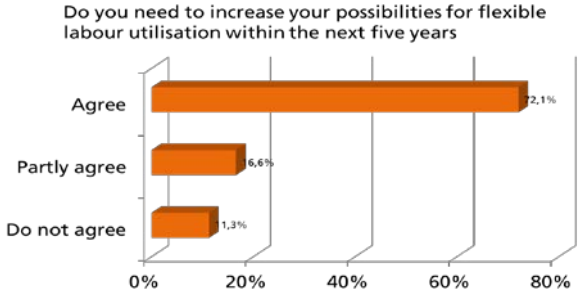

Figure 1: Demand for flexibility [10].

The concept of lean production is proved to be more successful [7]. It avoids every kind of 'waste' in production processes and is strongly dedicated to customer demands and high efficiency. Unnecessary production of unused material is strictly forbidden. Only goods ordered by the customer will be produced very quickly. This concept desires a high degree of flexibility – from the technical equipment as well as from the high skilled production employees [8].

Companies with a substantial amount of manual production activities are forced to utilise flexible forms of labour [9]. In a current survey of the Fraunhofer IAO, 72% of the participating companies have agreed to the demand for increased possibilities of flexible labour utilisation within the next five years [10], see figure 1. In countries with high average wages, for example Germany, the flexible utilisation of labour is an essential success factor for companies' competitiveness.

1.2 Research Project 'KapaflexCy'

Task of the German research project 'KapaflexCy' is the development of strategies, methods, and tools to implement, support, and operate a self-organised scheduling of labour times [11].

It is expected, that the results of the project will increase the degree of flexibility of labour utilisation in production. The companies will be able to react efficiently, immediately and in short times to unbalanced and fluctuating workloads. Thus they will be better prepared for volatile markets. At the same time they can reduce the effort for their capacity management. For employees it is expected, that they will be involved in the process of the personnel planning and scheduling. Groups of employees use mobile communication devices together with social media functions to agree upon their work assignments. Thus they will experience a transparent, independent personnel planning and they can better combine the concerns of business demands with their private and familiar interests.

The core of the research approach of the project is a so called Cyber-physical-system (CPS). The application of

CPS in production environments is a new research topic in Germany. The impacts are expected as so tremendous, that they will be designated as the '4th industrial revolution' [12]. To stimulate this important future vision, the German government has started a large national research program in 2012. Three 'early bird' projects have to investigate and establish the recent field of research. KapaflexCy is one of them.

Within the following paper, the application of CPS in production environments and the expected effects will be introduced. Afterwards the approach and preconditions of a self-organised labour utilisation will be explained. The 4th chapter shows the general structure of a supporting CPS. It will be concluded by a preview of the research activities.

2 CYBER-PHYSICAL-PRODUCTION SYSTEMS

Cyber-physical systems connect the virtual cyber world with the real, physical world to an Internet of things, data and services [13], see figure 2. They capture data of the real world via sensors, process them with software from embedded controllers, use the Internet and cloud computing for mutual communication between the connectors and interact with real world by means of mechatronic actuators [14, 15]. First application fields include e.g. robotics, car navigation, health care or energy distribution [16]. Meanwhile, CPS will be regarded as a new key technology even for production processes. To remain successful, it will be crucial to develop and operate autonomous, self-managing, knowledge-based and sensor-based production systems [12].

The list of possible applications of CPS in the industrial production is manifold [17, 18, 19]. Mobile and real-time assistance systems with context-sensitive user interfaces control and monitor production processes constantly. Self-organising and networked production equipment detects and configures their components and tools. In case of missing process parameters they ask independently for them over the Internet. Therefore they communicate with comparable production equipment or other users. Decentralised local memories in production equipment or products collect, store, review and distribute detailed information about the product and production processes. They collect data regarding e.g. the energy management, life cycle controlling, or preventive maintenance. Autonomous cooperating logistic processes and production orders plan their steps across the entire value chain, reserve the materials required and allocate plant capacity. In case of foreseeable delays and unavoidable deviations they organize additional capacity and inform the customer.

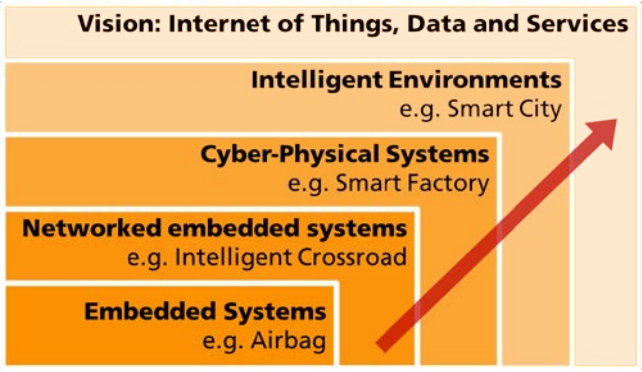

Figure 2: Evolution of the Internet of things [19].

These examples are all visions of future applications of CPS in an industrial production, the so called Cyber-physical production systems (CPPS). They give an impression, how CPPS will shift production technology, processes and equipment towards flexibility and self-control of the production facilities. The desired benefits are evident. Intelligent, networked objects and autonomous control systems are able to reflect customer demands in real-time. The flexible utilisation of production facilities with short throughput-times and zero-stock are the answer to the increasing demand of customised products and the trend of more volatile markets. Therefore a paradigm shift is expected, from centralised production planning to a decentralised coordination of self-controlled and autonomous processes.

3 SELF-ORGANISED LABOUR UTILISATION

As introduced in the first chapter, volatile markets demand flexibility. Lean production and flexible labour utilisation are the appropriate organisational measure. CPPS and the paradigm shift towards decentralised coordination and autonomous processes are a proposed technical measure to meet the flexibility demand as well.

Obviously the target for both measures is the same. CPPS will give a significant boost to flexibility. To meet increasing demands for individuality, productivity and process complexity in shortest lead times, people and networked objects will decide cooperatively. Intelligent assistance systems and human decision-making competence find each other in mobile communication devices. Together they implement a self-organised labour utilisation, which will be described throughout this chapter.

3.1 Flexible Labour Utilisation

Labour utilisation has to follow the facility utilisation closely. The daily working hours must not longer be fixed and equal. They still have to reflect the fulfilment of customer demands in real-time.

An overview of common measures to implement a flexible labour utilisation is presented in table 1. These measures will often be called 'flexibility instruments'. Table 1 also shows and proves their dissemination and exploitation through German companies [20]. The figures are based on a nationwide business survey in 2011, which was conducted within a German research project [21]. An overview and brief introduction of the common flexibility instruments is given e.g. in [22, 23].

Table 1: Flexibility Instruments

	Companies, that the measure …	
Measure	**Uses**	**Often uses**
Overtime	**99%**	**55%**
Overtime reduction	**93%**	**57%**
Partial time	**84%**	**11%**
Gliding time	**75%**	**31%**
Annual working time	**50%**	**22%**
Personnel grant	**94%**	**28%**
Terminated contracts	**67%**	**6%**
Homework	**20%**	**1%**
Students	**66%**	**7%**
Freelancer	**60%**	**9%**
Temporary workers	**53%**	**11%**

3.2 Actual Scheduling of Labour Times

A flexible labour utilisation requires a short-term control of flexibility instruments and the use of staff. In practice this is done always manually. Team leaders and shift managers coordinate the arrival and absence of staff, requesting support by part-timers and freelancers and plan the use of temporary workers. For this purpose they communicate daily with their workers, the human resources department, additional shift managers and temporary employment agencies - usually orally, rarely, and with sufficient time by E-Mail. This kind of short-term staff usage is also reactive. Occurring capacity gaps have to be closed by daily trouble shooting, in which usually established patterns will be used. That denotes, that always the same flexibility instruments are used and the same staff will be requested. A coordinated use of flexibility instruments in regard to volatile markets is hardly possible.

The amount of overtime worked annually in Germany [24] stresses the need for capacity flexibility and conveys an impression of which effort is needed for the coordination of the use of staff, see figure 3. The manual and oral coordination of flexible capacity utilisation and the use of short-term staff are therefore subject to a number of serious drawbacks [25]:

- High communication overhead due to oral coordination;
- Short-term adjustments of capacity use does not succeed
- Uneven distribution of lucrative activities or unlikely high loads on staff;
- False and cost-driving use of flexibility instruments.

The concept of a self-organised labour utilisation to be developed within the project ‘KapaflexCy’ promises, to overcome the identified drawbacks. The approach is based on the following three linked items, which will be introduced briefly in the rest of this chapter.

- Mechanisms for a decentralised coordination of the work assignments in working groups. For this purpose the groups take advantage of mobile devices.
- Priority rules that guide and limit the decentralised coordination within an economical justified corridor for the utilisation of flexibility instruments.
- Preconditions and requirements for the implementation and usage of self-organizing capacity flexibility, which are preliminary for the acceptance of the process by all stakeholders.

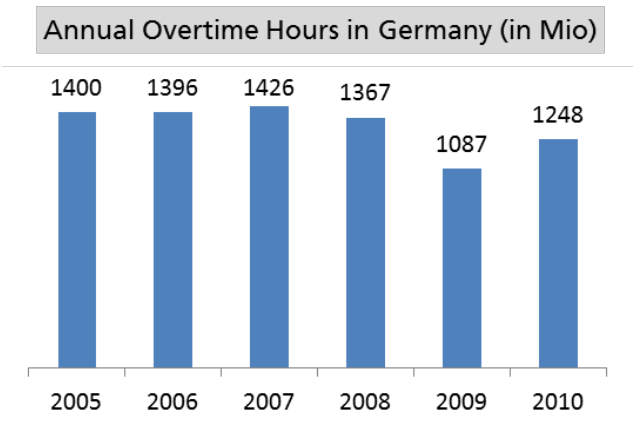

Figure 3: Annual Overtime in Germany [24].

3.3 Decentralized Coordination

Horizontal decisions within and between working groups will replace the conventional vertical directives 'from top to bottom'. Mobile devices and a central coordination instance provide a platform for staff employees to agree self-organised upon their work assignments.

The central coordination instance processes in real time information regarding the production environment. A kind of agent-based 'capacity broker' will learn typical situations and conditions of customer orders and workloads. It will indicate necessary capacity requirements and matches for this purpose suitable capacity profiles. Mobile communication features support the employees to agree upon their assignments. They have to decide, which persons take over the additional work assignments.

The use of mobile devices accelerates the assignment process between employees who are more accessible in this manner. Moreover they ease the horizontal oral communication between the employees, which may be helpful in specific situations. In addition, the use of 'Social Media' decouples decision-making from a spatial and temporal availability.

3.4 Priority Rules for Flexible Labour Utilisation

A systematic framework for action must be created for the efficient and economical use of a self-organizing labour utilisation. Figure 4 shows the corresponding model. It depicts three essential steps for the framework for action. First step is the definition of capacity corridors. The second step comprises the selection of a group of employees in a situation with changing capacity demands. The third and last step is the process of agreement between the employees as described in the last paragraph.

Step 1: Setting capacity corridors. Today a wide range of flexible instruments for labour utilisation are known, which allow companies to adapt the capacity of their staff to the needs required by the market. First, it is to determine what flexibility instruments in general should be provided. For example increased demands for capacity can be covered by the core employees in additional shifts. Alternatively, the increased demands can also be handled through the use of temporary workers. Whereas both flexibility instruments can cover the additional demand, they are different in terms of cost, time to utilise and coverable amount of capacity [14].

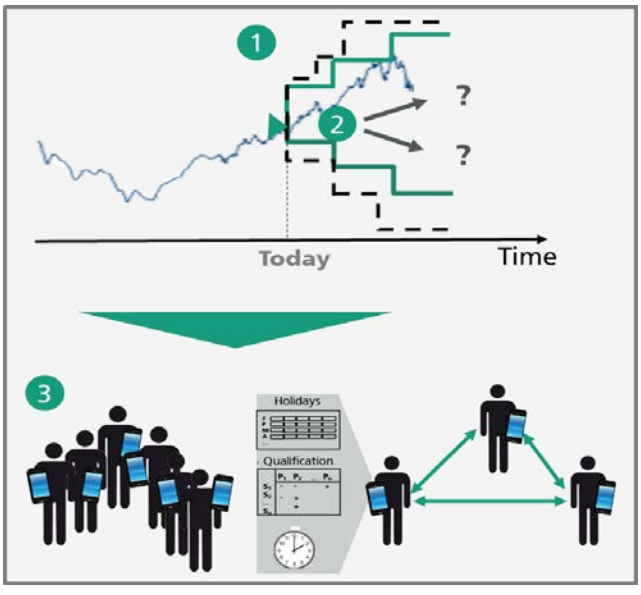

Figure 4: Framework for Action.

Usually a company provides a mix of different overlaid flexibility instruments. The mix has to meet the unsteady demand for capacity which may be caused by different market conditions and stages, as introduced in chapter 1. Therefore upcoming business and product life cycles must be taken into account as well as pursued market trends and sales forecasts of the specific company. Restrictions by the product or company, such as long training periods or high qualifying requirements may further restrict the mix of available instruments. Obviously the determination of the mix of provided flexibility instruments is a multi-criteria decision. To support this non-trivial decision, a tool will be developed in this project, to calculate the total benefit of a given mix of flexibility instruments and to compare it with the financial budget needed.

An exemplary outcome of an instrument determination and sizing could be the selection of the instruments 'Use of temporary workers in the context of 0-10% of the core workforce' as well as 'Use of working time accounts from -200 h to + 200 h per employee'. The size of the overlaid flexibility instruments can be visualised in a ‘capacity corridor’, see figure 5 for an example.

Step 2: In a particular case of capacity alignment, it has to be decided, which of the provided flexibility instruments should be used currently. Therefore a comprehensive set of priority rules has to be developed. The priority rules specify for each instrument at what time or what market stage it is used. For example, if a company has a particular seasonal demand, it is probable to need overtime in the peak season. Hence overtime has to be reduced in the low season. An according set of priority rules may advice in low season to utilise part time workers to reduce the overtime of core employees.

A further set of priority rules is needed to select a group of employees, which are eligible for work assignment. This personnel priority rules are addressing personal parameters such as the required qualifications of the personnel, the level of the individual working time account, personal preferences, and exclusion periods for applications. With these two sets of priority rules, the employees eligible for the alignment of the capacity to a specific demand can be determined.

Step 3 is the agreement of eligible employees upon their work assignments. They use mobile devices for that, as described in section 3.3.

3.5 Preconditions

There are also some more general preconditions for the vision of a self-organizing labour utilisation to become reality. In addition to the above described technical and organisational requirements, the particular qualification and acceptance aspects are taken into account as well.

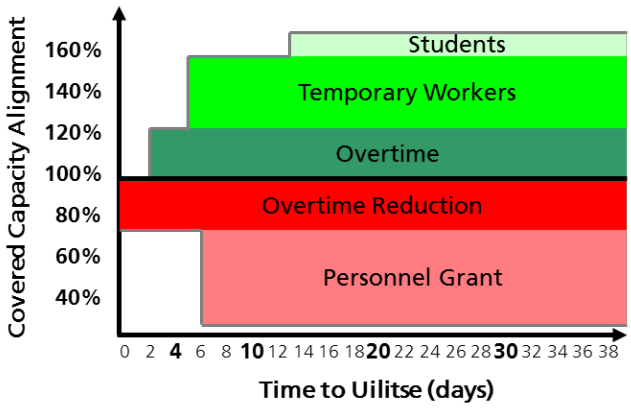

Figure 5: Example of a capacity corridor.

Qualification: The use of decentralised and self-organizing control and the possibilities of CPS require new forms of qualification, which go beyond mere explanation of technical systems. For the use of voting processes and self-organization, stakeholders must have sufficient knowledge and insight to the underlying principles. So the principle of self-organised labour utilisation relies on the idea that events are taken over quickly and reliably by the employee. Still, the consequences of possible non-actions must be known to the involved players. Another necessary condition is the extension of skilling of the staff involved. The approach relies on the existence of a pool of employees eligible for work assignments. A large number of employees, who can vote for requests, increase the potential of the application.

Acceptance: A comprehensive usage requires the acceptance of the actors involved. The importance of this condition can exemplarily be pinned down to the social partners. The employer has to accept, support and to transfer the responsibility of the work assignments to the actors and the executing staff. This is overlaid by the required guarantee that the necessary work is executed in time, and that responsibility for the work assignment is partly transferred to automated systems. In these structures it will be difficult to answer the question who is in the end responsible for the work. Closely related is the requirement of new leadership behaviour, which must be more oriented on cooperative elements. On staff, the gained higher level on flexibility will lead directly to solutions concerning new forms of compensation. Only if the added value of a better accessibility for the staff is clearly implemented, the acceptance in all levels of the workforce can be guaranteed.

All of these aspects require a close coordination of the social partners. The realisation of technology and the introduction of voting processes alone will not be sufficient to implement a self-organising labour utilisation successfully.

4 CPPS FOR LABOUR UTILISATION

The last chapter described the organisational, logical, and social aspects of the concept of a self-organised labour utilisation. The concept is based on a CPPS with mobile devices for purposes of communication and voting for flexible work assignments. This chapter gives a brief introduction of the general technical structure of the CPPS, which will be developed within this project.

The system architecture comprises the typical elements of a web based assistance application, see figure 6. The front end is built with HTML-Components, which can be presented on desktop browsers as well as on mobile clients, tablet-PCs or smartphones for example. The layout of the web pages has to take care for the different screen sizes of the devices used. Therefore distinct templates will be needed to present the same information in device-specific layouts. This will be handled by the web server. It is the central control instance for all interactions with the end user. The dialogs and elements for navigation, voting upon work assignments, reporting of the labour utilisation and for the customising of the system are in responsibility of the web server. The content presented by the web server is stored in a central database, which itself is connected to backend systems of the company, for example ERP applications.

A web application is always limited to dialogs initiated by the user. He has to request for new information. The

application itself is passive. In a web application there is no reliable way to inform the user immediately about events and new information. One target of the new concept of a flexible labour utilisation is to reduce the time for short term work assignments. Hence the provision of new information to the user is crucial for this concept. For this reason a push notification of the user is planned. A native mobile client informs the user, i.e. the employee, in case of new work assignments he has to vote for. The push client may use typical means to attract attention. For example the telephone rings or the smartphone vibrates.

The elements seen so far, are all addressing interactions with users. In particular they are necessary for the decentralised coordination, described in the last chapter. Further essential parts of the concept of flexible labour utilisation are priority rules and the observation of business activities. The latter signalises situations, which cause an alignment of capacity. The most important origin of capacity alignments are fluctuating workload introduced by unsteady customer orders. Both business activities are stored in the ERP systems of the company, A so called 'condition handler' monitors these activities in the backend database and throws events to signalise a demand to align the capacity. The element which is responsible for priority rules catches this event, and determines the group of employees eligible for the alignment of the capacity. The condition handler and the priority rules have to be adapted, customized, and trained to the business environment and market behaviour of the company, which uses the CPPS for flexible labour utilisation. Thus they will be implemented as separate modules which offer strong means to adapt to business environments.

The illustration in figure 6 is the first, rough sketch of the system architecture. Many details have to be discussed and detailed. Especially the mechanism for priority rules have to be stressed by the on-going research work.

5 CONCLUSION

The research project 'KapaflexCy' explores new ways of use of CPPS and mobile communication technologies to increase the flexibility of labour utilisation in the production. The focus of the research is the development of information technology and a supporting CPPS. The solution will use in particular mobile devices, to include persons acting as leading authorities in CPPS control logic.

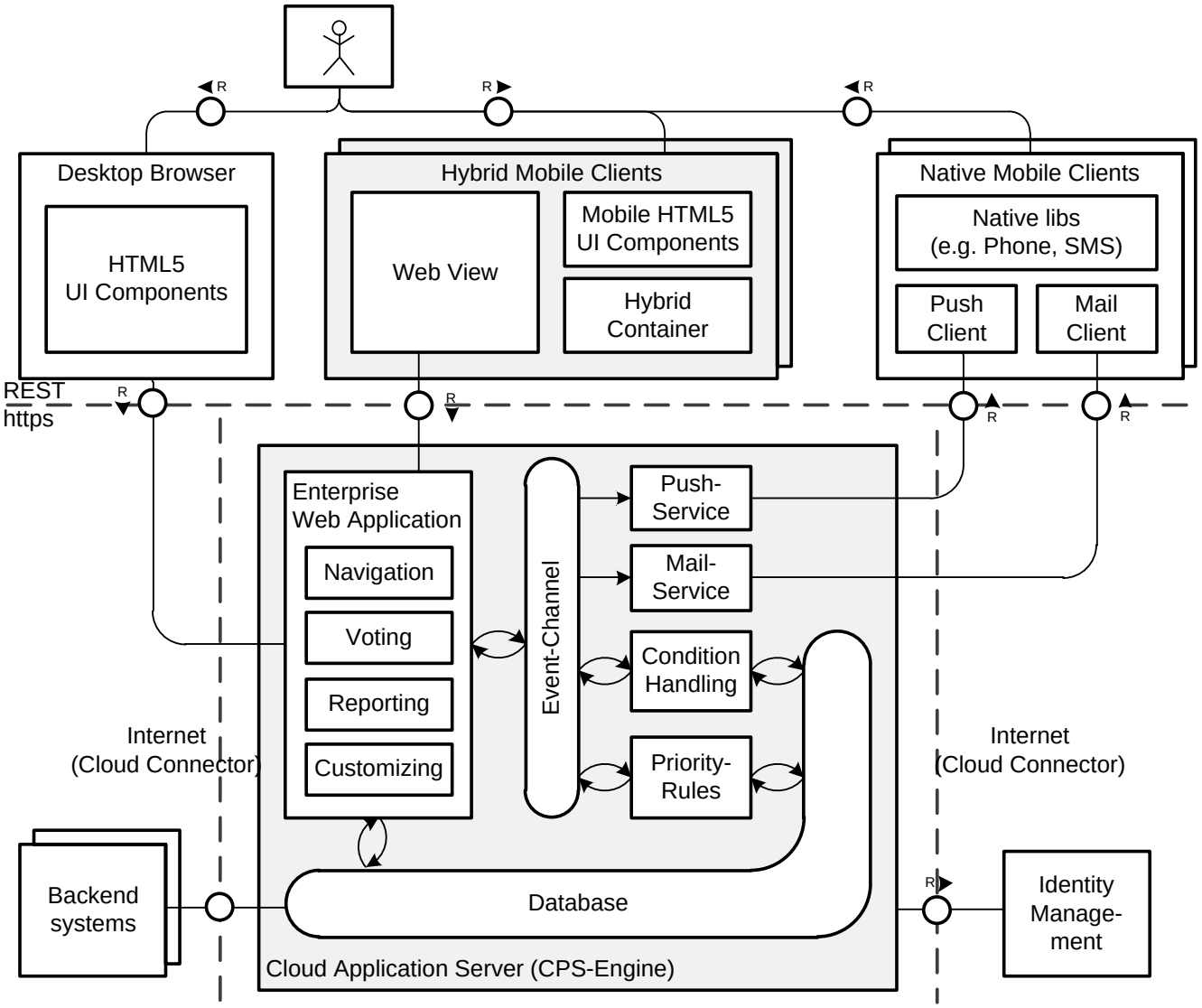

Figure 6: System Architecture of the CPPS.

Another focus of research activities is designing methods and heuristics for a quantitative assessment and the prioritization of the use of the flexibility instrument. The quantitative assessment is the key to the priority rules in the central coordination instance for the work assignments.

At the end of the project, three pilot applications of developed tools and methods are planned by the industrial application partners in the project. The pilot applications will gain valuable insights about conditions, requirements, applicability and acceptance of the developed tools, and about the economic benefits of a self-organizing labour utilization.

If the expectations in this form of highly flexible work come true, the findings could be transferred to content and spatially distributed work. New forms of work identity and employment could emerge in an industry 4.0, which includes the membership of an employee to several teams and employers in a 'Multi-job employment'. Especially in a urban context of production a highly flexible 'PatchWork'-employment may be possible.

6 ACKNOWLEDGMENTS

The research and development project ‘KapaflexCy” is funded by the German Federal Ministry of Education and Research (BMBF) within the Framework Concept ”Research for Tomorrow’s Production” and managed by the Project Management Agency Karlsruhe (PTKA).

More information about the ongoing research project is provided via the website http://www.kapaflexcy.de. Please apologize, that the website is in German language.

7 REFERENCES

[1] Tolio T., Design of Flexible Production Systems: Methodologies and Tools, Springer, 2009.

[2] Bullinger H.-J., Spath D., Warnecke H.-J., Westkämper E., Handbuch Unternehmens-organisation – Strategien, Planung, Umsetzung, Springer, Berlin, 2009.

[3] Salvendy G., Handbook of Industrial Engineering: Technology and Operations Management, Wiley, NewYork, 2001.

[4] Hopp, W.J., Spearman M.L., Factory physics, 3. ed. McGraw-Hill, Boston, 2008.

[5] Spath, D.: Global Challenges and the Need for Enhanced Performance. Presentation, Professional Training Facts, Stuttgart, 11. Nov. 2008.

[6] Artiba A, Elmaghraby S., The Planning and Scheduling of Production Systems: Methodologies and applications, Springer, 1996.

[7] Spath, D. (Hrsg.): Ganzheitlich produzieren - Innovative Organisation und Führung. Stuttgart: LOG_X Verlag, 2003

[8] Takeda, H.: Das synchrone Produktionssystem: Just-in-time für das ganze Unternehmen. Frankfurt: Redline, 2004.

[9] Oechsler W. A., Personal und Arbeit – Grundlagen des Human Resource Management und der Arbeitgeber – Arbeitnehmer-Beziehungen, Verlag Oldenbourg, Munich, 2011.

[10] Spath, D. (edt.): Zukunft der Produktionsarbeit. Stuttgart: Studie Fraunhofer IAO im Zeitraum 1.08.2012 bis 30.09.2012. http://www.produktionsarbeit.de/.

[11] N.N.: Homepage of Projeck “KapaflexCy”. Stuttgart: Fraunhofer IAO 2012.: http://www.kapaflexcy.de/.

[12] Promotorengruppe Kommunikation der Forschungsunion Wirtschaft – Wissenschaft (Hrsg.): Bericht der Promotorengruppe Kommunikation: Im Fokus: Das Zukunftsprojekt Industrie 4.0 – Handlungsempfehlungen zur Umsetzung. Berlin. 2012.

[13] Uckelmann, D. et al.: Architecting the Internet of Things. Heidelberg: Springer Verlag 2011.

[14] Lee, E.: Cyber Physical Systems: Design Challenges. Technical report. Berkeley: University of California, 2008

[15] National Science Foundation: Cyber-Physical Systems. http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503286, called 21.11.2011.

[16] acatech (Hrsg.): Cyber-Physical Systems. Innovationsmotor für Mobilität, Gesundheit, Energie und Produktion. Acatech Position 2011. http://www.acatech.de/de/publikationen/stellungnahmen/acatech/detail/artikel/cyber-physical-systems-innovationsmotor-fuer-mobilitaet-gesundheit-energie-und-produktion.html

[17] Broy, M. (Hrsg.): Cyber-Physical Systems. Innovation durch Software-intensive eingebettete Systeme. Heidelberg: Springer, 2010.

[18] Glotzbach, U. (2009). Intelligente Objekte - klein, vernetzt, sensitiv: eine neue Technologie verändert die Gesellschaft und fordert zur Gestaltung heraus. acatech - Deutsche Akademie der Technikwissenschaften. Berlin; Heidelberg: Springer

[19] Geisberger, E.; Broy, M. (Hrsg.): AgendaCPS: integrierte Forschungsagenda Cyber-Physical Systems. Berlin, Heidelberg [u.a.] Springer. 2012.

[20] Sende, C. et.al.: Flexibler Mitarbeitereinsatz – Ergebnisse einer deutschlandweiten Unternehmensbefragung. Industrie Management 27 (2011) 4, S. 52-56.

[21] Starke, J.: Homepage oft he project „Flexpro“. Bonn: ALROUND e.V. 2012. Internet: http://www.flexpro.info/. Called 16.01.2012.

[22] Spath, D.; Bauer, W.; Hämmerle M.: Requirements for an Evaluation Model for the Proactive Management of Human Resource Capacity in Volatile Markets. In: Proceedings of the 22nd International Conference on Production Research ICPR – 22, 28th July – 1st August 203, Iguasso Falls, 2013.

[23] Reilly P., Balancing Flexibility – Meeting the Interests of Employer an Employee, Burlington, Gower, 2001.

[24] N.N.: Überstunden der Arbeitnehmer in Deutschland von 2000 bis 2011 (in Millionen). Hamburg: Statista GmbH. http://de.statista.com/statistik/daten/studie/76945/umfrage/ ueberstunden-der-arbeitnehmer-in-deutschland-seit-2000/. Called 16.01.2012.

[25] Witte, K.-W.; Vielhaber, W. (Hrsg.): Flexible und wirtschaftliche Serienmontage – Wege zu zukunftsstabilen Montagesystemen (MORATIO). Shaker Verlag, Aachen 2003.

[26] Breithaupt, J.-W.: Rückstandsorientierte Produktionsregelung von Fertigungsbereichen: Grundlagen und Anwendung. Düsseldorf: VDI-Verlag, 2001. (Fortschritt-Berichte VDI: Reihe 2; 571) Zugl. Hannover, Univ., Diss., 2000.