A New Simulation-Based Approach to Schedule Personnel Deployment Times in Decentrally Controlled Production Systems

The Project Sim4PeP

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Abstract—**The fourth industrial revolution rises new challenges for personnel planning. On the one hand, the decentralization of production control gains a new level of flexibility. Without a fully detailed production schedule in advance, the workforce requirement will be just identified during the current processes. Therefore, it is almost impossible to deduce the concrete times of workforce requirement in advance, but this would be necessary for workforce scheduling. On the other hand, manual activities themselves will change in smart factories, resulting in a reduced deployment continuity. In order to ensure efficient resource planning, including workforce, the project Sim4PeP develops a simulation-based forecasting method to schedule workforce deployment times in a decentrally controlled production system for short- to medium-term planning horizons.**

Keywords-CPPS; simulation-based optimization; workforce requirement planning.

I. Introduction

One main topic of the fourth industrial revolution is the decentralization of production control [1]. The decentralized real-time control will gain a new level of flexibility to achieve a rapid reactivity and a demand-oriented production by handling customer-specific orders, small batches and process disturbances with minimal planning effort [1]. In this concept, orders and resources communicate autonomously and decide at lowest shop floor level (cyber-physical production system) [1]. Thereby, there is no longer a fully detailed production schedule in advance. It is not known in advance which operation of which order on which machine to what time will be processed. This "scheduling gap" also effects the workforce operations and causes a fundamental conflict: Staff schedules have to be determined some weeks in advance [2] – for individual, administrative and regulatory reasons. To enable an efficient staff schedule, that synchronizes personnel supply and demand, the times of personnel requirement times have to be known already during the scheduling of the workforce.

In addition, the changing tasks of the production workers in smart factories intensify the conflict. The scenario of a deserted factory stays still both utopian and not to be aspired [3]. Instead, the human being remains a key factor in the concept of smart factory and will take on a coordinating, controlling and directing role. Thus and due to the complexity of the system, there will be jobs with high qualification requirements and high specialization [3], which presumably arise discretely in time. At the same time, progressive automatization will increasingly eliminate simple work tasks [4], which are often accompanied by a steady deployment continuity. Accordingly, there will be more specific qualification classes and less consistent periods of working time, resulting in a further reduced deployment continuity.

Especially in countries, such as Germany or France, personnel costs are a driving force in manufacturing industry [5] that have to be optimized. Therefore, an efficient resource planning of the workforce is an essential part of Production Planning and Control (PPC) and should be a "first level resource" during the optimization process. To achieve a high workforce capacity utilisation, single tasks have to be bundled, so no (or less) idle times will occur. However, this has an effect on machine allocation and job sequence, too.

In order to solve the resulting time and planning conflict described above, the project develop a simulation-based forecasting method to schedule workforce requirements for decentrally controlled production systems.

Section 2 briefly reviews the state of the art. Section 3 introduces the concept of the new simulation-based approach and the related project. The paper concludes by a short summary and an outlook on long-term goals.

II. State of the Art

The "classic" PPC-process focuses on optimization with regard to orders or resources (in the sense of machines or unspecific form but without care of the specific attributes of workforce) [6]. The production planning creates a central production schedule from which workforce schedules are derived. Accordingly, the workforce is a "second level resource" and a subordinated optimization object in the optimization process, respectively [6]. Regarding to the changed conditions described in Section I, this approach does not work anymore at all or at least not in an efficient way.

 ISBN: 978-1-61208-831-0

Already at the turn of 2000, a direction of research within the PPC has emerged which especially deals with the focus of workforce scheduling and its special features (see for example [6] or [7]). These approaches take up the issues of qualification-related allocation possibilities and resource flexibility of workforce via working hours with seasonal accounts (e.g., flextime). For example in 2002, there was an AiF funded project which dealt with the integration of flexible working time models into PPC [7].

The reason to introduce flexible working hours in production is the short- to medium-term synchronization between capacity supply and demand. Consequently, the PPC is enabled to react to the volatility of the markets [6].

No literature around the millennium 2000 could deal with the later emerging idea of the future fourth industrial revolution (for example in Germany around 2012 – cf. [1][8]). Therefore, they do not deal with the essential core aspect of this research effort: The conflict between decentralized, real-time driven production control and the required lead-time of workforce resource planning.

There are also publications in the recent past developing or improving approaches to personnel planning (see for example [9] or [10]). Due to the constantly changing production requirements and influences of the rapidly changing markets, characterized by global fluctuating supply and demand relationships, more customer-specific products and shortening delivery times, personnel planning is still a current topic within PPC [9][10].

[9], for example, examined strategically as well as operationally opportunities to make personnel planning more flexible. Nevertheless, the approach does not attend to the dilemma of the time conflict of workforce scheduling in decentralized production control.

[10] developed flexibility instruments for medium- to long-term periods that is not within the scope of the presented approach.

[11] contributes an approach to allocate a highly qualified and specialized workforce under the aspects of flextime via seasonal accounts, heterogeneous deployment flexibility with regard to individual qualifications, as well as individual efficiency for the time required to fulfil the duties. However, the method is based on a deterministic production schedule with already known workforce requirement times. The same applies, for example, to [12] and [13].

[14] uses a two-stage procedure, in which the workforce is just a second level resource.

The collaborative project MyCPS [15] focuses on the integration of humans into the cyber-physical world of production. The focus is not on organizational but on technological issues, except for one project: KapaflexCy [2]. KapaflexCy enables small and medium-sized companies to implement innovative forms of working time models for more flexibility with personnel deployment schedules, individually tailored for each company. For example, they developed an app that allows employees to decide whether they want to work additional hours at requested times. In the case of short-term requirements, the employees receive requests on their smartphones. The approach thus focuses on the reactive balancing of short-term fluctuations of the capacity demand in production with the concrete and in advanced fixed allocation of workforce supply. In contrast, the core of the presented research approach involves the proactive derivation of workforce requirements based on variable production programs without a detailed production schedule known in advance. Furthermore, the focus is not only on the scheduling of additional shifts but also on the planning of the base load. The method to be developed for the research project also rejects classic shift systems.

Furthermore, some recent approaches of workforce planning and scheduling use machine-learning techniques. [16], for example, predicts the need of products and services from which it assigns work tasks to employees. In contrast to the approach presented below, [16] is an experience based approach as it mainly use history-based files. In addition, it refers to a public utility service billing company but not to the background of industrial production.

Moreover, there are scientific approaches that integrate a digital twin for employees in a self-controlling production system (see for example [17]). The twin reflects human characteristics, like behavior, skills and preferences, and strives for a better collaboration between human and automated production system, especially on intuitively interaction with technical devices [17]. However, this method does not deal with the creation of personnel deployment plans or the overall deviation of personnel requirement times sufficiently in advance. Therefore, it does not match the research focus of this contribution.

On commercial level, there are also software companies of personnel planning products that take up the changes of the fourth industrial revolution. Their products provide employee self-service portals for, e.g., wishes such as absence days or shift changes, model individual working time arrangements or the matching process of qualification requirements (see for example [18] or [19])). Nevertheless, they do not deal with the planning paradox described at the beginning.

Especially due to the thematic reference to working hours and models, legal framework conditions have to be taken into account; in Germany for example, there are [20] or [21].

To sum up the literature reviewed, the workforce should be considered as a specific resource in the PPC-process. However, none of the approaches was dealing with the dilemma of workforce requirement planning in a decentrally controlled production system.

III. Research Project Sim4PeP

A. Simulation-Based Forecasting Method

The research project Sim4PeP focuses on the described paradox of the lead-time for workforce scheduling and the ad-hoc decisions of the decentrally controlled production system. To solve this issue, the aim of the project is to develop a simulation-based forecasting method for the generation of workforce attendance schedules and validate the functionality of the method.

The forecasting method focuses on a short- to medium-term planning horizon (up to 6 weeks) under stochastic influences. It proceeds according to a rolling wave planning

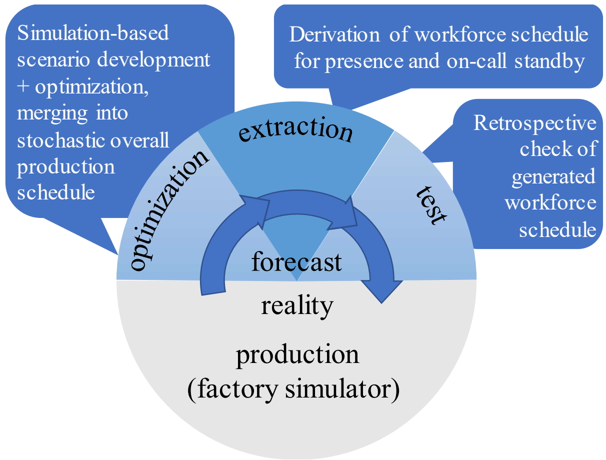

Figure 1. The three steps of the forecasting method

model and successively updates subsequent planning intervals. The method consists of three steps: optimization, extraction and test (see Figure 1).

In the first stage (optimization), a simulation-based optimization model predicts proposals of potential production schedules that consist of a timetable with resource allocations and order sequences. The objective function already includes the optimization objects “order”, “machine” and “employee”. Thus, the “classic” optimization objects “order” (e.g., minimizing makespan) and “machine” (e.g., maximizing capacity utilization) remain in the objective function. However, as described in the second section, the workforce working times should no longer be a subordinated optimization object, but rather a "first-level" resource due to the changed situation. Components of objective function in relation to workforce scheduling are, for example, the minimization of the total attendance time over all employees, which is for example a corporate objective. The method should not only deal with corporate objectives but also with goals of individual employees. For example, they should have the opportunity to contribute wishes of their own working hours. Thereby, the model ensures the legal or even the individually agreed working time specifications by hard model restrictions. This way, the modeling guarantees that there are, e.g., a maximum workload of 8 hours a day and adequate break times. More self-chosen and flexible working time leads to a better work-life balance and finally to a higher motivation at work [20]. Furthermore, it increases the attractiveness of the company for the workers. The forecasting method will work completely with flexible working hours and abandon from rigid shift times. So “work 4.0” is partially also available for employees in the production. In addition, the flexible working hours could enable a better synchronization of capacity supply and demand.

Due to the stochastic disturbances and uncertainty for future forecasts, as well as the autonomy in the variety of decisions of the decentral control the simulation model generates different scenarios. Weighted by the corresponding objective function value, a set of the best scenarios build a general schedule. That schedule is not exact and deterministic but rather a stochastic distribution over preferable scenarios (see Figure 2). Stochastic influences are, for example, process time deviations or machine and personnel failures.

Furthermore, this schedule already contains stochastically distributed demand times for the workforce according to qualification classes. By including the worker in the objective function of the first stage, it already meets the optimization requirement (first level resource). Stage 2 extracts the workforce attendance and when appropriate on-call standby times. However, the general schedule does not yet provide a clear, deterministic statement but the times for the staff schedules have to be deterministic. For this purpose, the method could use variable tolerance limits (see Figure 2). The derived workforce schedules have to leave as much flexibility as possible for the decentral real-time control. Therefore only the attendance times are defined, the exact allocations between work tasks (capacity demand) and the planned working times (capacity offer) are not defined, so the decentral control can still match it.

In the third stage, a retrospective test checks the generated workforce schedule by feeding the attendance times back into the simulation model. The objective function value decides whether the schedules can be released for the reality or whether it must be returned to stage 2. In the latter case, a variance of the tolerance limits can readjust the schedules.

In the research project, an extended factory simulator will replace the real production process. It incorporates further stochastic influencing variables and broader stochastic scenarios. There is not yet an adequate benchmark for the problem described in the introduction which can be applied for comparison. Using a factory simulator, the validation of

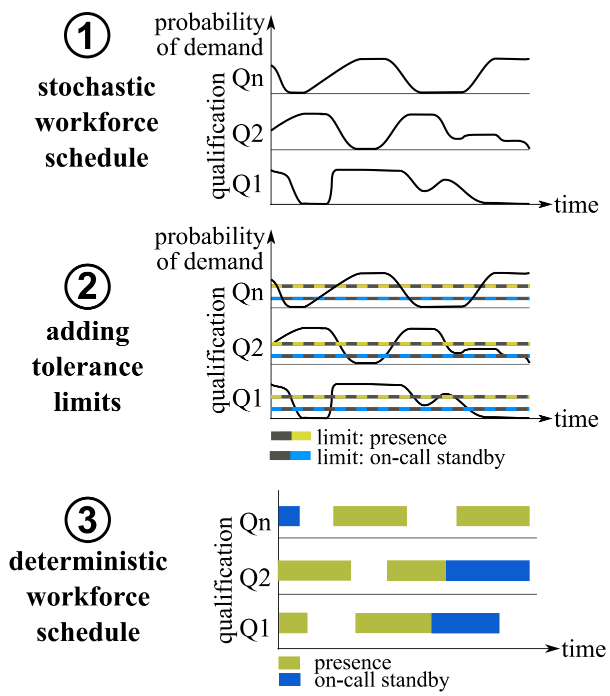

Figure 2. Derivation of the workforce schedule

 ISBN: 978-1-61208-831-0

the method, as well as a quality analysis of the generated plans is possible. Especially due to the stochastic problem modelling, deviations between the created personnel plans and the factory simulator are to be expected. Even in real systems application, the generated plans will not correspond one hundred percent with the actual implementation, as the forecast is still uncertain. However, it is the aim of the project to enable the method to keep these differences as small as possible by reasonable computing effort.

If the results are promising, a test on a real system can be carried out at a later project stage or in a subsequent project.

B. Research Focus

Besides the development of the forecasting method itself, it is a goal of the research project to determine feasibility, requirements and limits of this methodology. There are three main categories of research questions in the project:

- Deterministic derivation in the stochastic field: Above all, the questions arise: To what extent do the deterministic specification of the forecasted attendance requirements limit the degree of self-optimization of decentralized planning? In this context, is it feasible to achieve optimal results in terms of the overall objective? Moreover, is it feasible to achieve an optimized process for the overall system at all by determining deterministic workforce times from the stochastic forecast?
- Working time models and task bundling: What would a working time model have to look like in order to support the flexibility of decentralized control and at the same time implement a humane workforce planning? Which components of existing working time models lead to which influences within the method (e.g., flextime, overtime or division of the daily working time into parts)? How can the method match requirements from the production system (that means 24-hour operation) with the requirements regarding to the workers (e.g., 8 hours preferably during the day)? Is there a compromise? To what extent can employees contribute their preferred working hours (may possibly in different priority levels) or are core working hours necessary to ensure the basic supply of workforce? Is it possible to bundle tasks that there are no or less idle times? Does it have strong effects on the other optimization objects? Are there synergetic or antagonistic effects between working hours and task bundling?
- Computing time and method initiation: Computational efficiency is a central challenge within the project, because it can become the limiting factor of the model size. Due to the focus on the creation of the workforce schedule and not on the concrete assignment of workers to tasks, the model does not have to work on a real-time basis. Instead, it is executed cyclically (e.g. weekly). However, with regard to the later usability of the method in practice, the runtime of the models is very important. How can the models achieve a runtime improvement? May machine-learning strategies improve the metaheuristics of the simulation-based optimization? What type of triggering points will start the forecasting method (fixed time intervals vs. specific or unexpected events). How responsive are these trigger points with regard to already fixed personnel plans (e.g. drastic market changes in the occurrence of Covid19)? In which frequency do the method have to start in general? What model-internal time pattern for workforce scheduling is adequate (e.g., half-hourly)?

IV. Conclusions

The research project Sim4PeP focuses on the paradox of the creation of workforce schedules in smart factories. Therefore, the project is developing a forecasting method that contains a simulation-based optimization approach. A further goal of the research project is to determine feasibility, requirements and limits of this methodology in general.

The research approach pursues long-term goals. It brings benefits for the employees. They should have the chance to have an impact on their own individual organization of working hours. This will increase the work-life-balance, which – especially for younger employees at present time – plays a more important role than the salary [20]. The increased self-determination also leads to higher motivation and thus to higher productivity. This in turn is a corporate benefit. In addition to the companies' benefits, an efficient workforce deployment is encouraged. This results in a lean staff, which nevertheless ensures maximum flexibility and maximum production capacity. Therefore, it leads to cost advantages.

Last, the strategy "Industry 4.0" is moving forward. The research project addresses the need for novel planning and control mechanisms inside the fourth industrial revolution.

Acknowledgment

The Deutsche Forschungsgemeinschaft DFG is funding the project with the title "A simulation-based and flexi-time applying prediction model for scheduling personnel deployment times in the production planning process of cyber-physical systems" (project-id: 439188616).

References

[1] German Federal Ministry of Education and Research, "Industrie 4.0. Innovationen für die Produktion von morgen (Industry 4.0. Innovations for the production of tomorrow)", Publikationsverband der Bundesregierung, Berlin, August, 2017.

[2] W. Bauer and S. Gerlach, "Selbstorganisierte Kapazitätsflexibilität in Cyber-Physical Systems: KapaflexCy. Abschlussbericht. (Self-organized flexibility of capacity in Cyber-Physical Systems: KapaflexCy. Final Report.)", Fraunhofer Verlag, Stuttgart, 2015, ISBN: 978-3-8396-0932-3.

[3] D. Spath, O. Ganschar, S. Geralch, and M. Hämmerle, "Produktionsarbeit der Zukunft (Production work of the future)", Fraunhofer Verlag, Stuttgart, 2013, ISBN: 978-3-8396-0570-7.

[4] P. Ittermann, J. Niehaus, and H. Hirsch-Kreinsen "Arbeiten in der Industrie 4.0: Trendbestimmungen und arbeitspolitische Handlungsfelder (Working in industry 4.0: Determining

trends and labour policy fields of action)", Study of Hans-Böckler-Stiftung, vol. 308, Düsseldorf, June, 2015.

[5] C. Schröder, "Industrielle Arbeitskosten im internationalen Vergleich (Industrial labour costs in international comparison)", in IW-Trends, vol. 43 (3/2016), Institut der deutschen Wirtschaft Köln, Cologne, 2016, doi: 10.2373/1864-810X.16-03-03.

[6] B. Grabot and A. Letouzey; "Short-term manpower management in manufacturing systems: new requirements and DSS prototyping", In: Computers in Industry, vol. 43, pp. 11-29, 2000.

[7] R. Schieferdecker and C. Schmidt, "Produktionsplanung und -steuerung bei flexiblen Arbeitszeiten: Arbeitszeitspezifische Planungsmodelle für eine integrierte Personalressourcen-planung (Production planning and control with flexible working hours: Working time specific planning models for integrated personnel resource planning)" AiF-founded project, project-id 12257N, 2002.

[8] German Federal Ministry of Education and Research, "Zukunftsbild „Industrie 4.0" (Vision of the future "Industry 4.0)", Publikationsverband der Bundesregierung, Bonn, July, 2015.

[9] T. Stock, "Ein Verfahren zur Personalplanung und -steuerung und Restrukturierung der Aufbauorganisation für eine bedarfsorientierte und wandlungsfähige Produktion (A method for personnel planning and control and restructuring of the organizational structure for a demand-oriented and adaptable production)", dissertation. In: Stuttgarter Beiträge zur Produktionsforschung, vol. 9, 2013, doi: 10.18419/opus-6817.

[10] M. Hämmerle, „Methoden zur strategischen Dimensionierung der Personalflexibilität in der Produktion: Wirkungsbe-wertung von Instrumenten zur Flexibilisierung der Personal-kapazität im volatilen Marktumfeld (Methods for strategic dimensioning of personnel flexibility in production: Impact assessment of instruments for making personnel capacity more flexible in a volatile market environment)", dissertation, in Schriftenreihe zu Arbeitswissenschaft und Technologie-management, vol. 26. Fraunhoferverlag, Stuttgart, 2015, ISBN 978-3-8396-0899-9.

[11] E.-A. Attia, P. Duquenne, and J. Le-Lann "Considering skills evolutions in multi-skilled workforce allocation with flexible working hours", in International Journal of Production Research, vol. 52(15), pp. 4548-4573, 2014, doi: 10.1080/ 00207543.2013.877613.

[12] G. Gong, R. Chiong, Q. Deng, and X. Gong, "A hybrid artificial bee colony algorithm for flexible job shop scheduling with worker flexibility", in International Journal of Production Research, 2019, doi: 10.1080/00207543.2019. 1653504.

[13] X. Zheng and L. Wang "A Knowledge-Guided Fruit Fly Optimization Algorithm for Dual Resource Constrained Flexible Job-Shop Scheduling Problem". in International Journal of Production Research, vol. 54(18), pp. 5554–5566, 2016.

[14] R. Lin, G. Zhou, A. Liu, H. Lu, and T. Li, "Impact of personnel flexibility on Job Shop Scheduling". In Scientific Programming, Article ID: 3403058, Hindawi Publishing Corporation, 2016, doi: 10.1155/2016/3403058.

[15] Fraunhofer Institute for Industrial Engineering IAO, "MyCPS", available from: www.mycpstoolbox.de, [retrieved: september, 2020].

[16] N. Simeunović, I. Kamenko, V. Bugarski, M. Jovanović, and B. Lalić "Improving workforce scheduling using artificial neural networks model" in Advances in Production Engineering & Management , vol. 12 (4), pp. 337-352, APEM journal, december, 2017, doi: 10.14743/apem2017.4.262.

[17] I. Graesslera and A. Poehler "Intelligent control of an assembly station by integration of a digital twin for employees into the decentralized control system" 4th International Conference on System-Integrated Intelligence, vol. 24, pp. 185-189, Procedia Manufacturing, 2018, doi: 10.1016/j.promfg.2018.06.041.

[18] FASTEC GmbH, "Personnel Planning" available from: https://www.fastec.de/mes-fastec-4-pro/personalplanung, [retrieved: september, 2020].

[19] ATOSS Software AG, "Workforce scheduling" available from: https://www.atoss.com/en-gb/workforce-management/ workforce-scheduling, [retrieved: september, 2020].

[20] German Federal Institute for Occupational Saftey and Health (baua), "Flexible Arbeitszeitmodelle: Überblick und Umsetzung (Flexible working time models: overview and implementation)", 2. edition, Dortmund, October 2019, doi: 10.21934/baua: praxis20170719.

[21] German Federal Ministry of Justice and Consumer Protection: "Arbeitszeitgesetz (law on working time)", available from: www.gesetze-im-internet.de/arbzg/BJNR117100994.html, [retrieved: september, 2020].