Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 31 (2019) 148–154

Procedia MANUFACTURING

www.elsevier.com/locate/procedia

9th Conference on Learning Factories 2019

# Augmented Go & See: An approach for improved bottleneck identification in production lines

Constantin Hofmann[a,*], Tom Staehr[a], Samuel Cohen[a], Nicole Stricker[a], Benjamin Haefner[a], Gisela Lanza[a]

[a]*Karlsruhe Institute of Technology, Kaiserstrasse 12, Karlsruhe, 76131, Germany*

**Abstract**

Bottlenecks in production lines are often shifting and thus hard to identify. They lead to decreased output, longer throughput times and higher work in progress. Go & See is a well-established Lean practice where managers go to the shop floor to see the problems first hand. Mixed reality is a promising technology to improve transparency in complex production environments. Until recently, mixed reality applications have been very demanding in terms of computing power requiring high performance hardware. This paper presents an approach for real-time KPI visualization using mixed reality for bottleneck identification in production lines relying on the bring-your-own device principle. The developed application uses image recognition to identify work stations and visualizes cycle times and work in progress in augmented reality. With this additional information, it is possible to discern different root causes for bottlenecks, for example systematically higher or varying cycle times due to breakdowns. This solution can be classified according to the acatech industry 4.0 maturity model as a level 3 – transparency – application. It could be shown that the identification of bottlenecks and underlying reasons has been improved compared to standard Go & See.


Peer review under the responsibility of the scientific committee of the 9th Conference on Learning Factories.

*Keywords:* Mixed reality; Learning factory; bottlenecks

## 1. Introduction

The Lean philosophy brought a substantial boost of productivity to many companies. Short improvement cycles and working on processes directly on the shop floor are key to these improvements. Important tools are Go and See and Shop Floor Management enabling leadership exactly at the point of value creation. The concepts of Industry 4.0 contradict the direct, haptic experience of the Lean Philosophy, as data is not acquired manually, but rather automatically through decentralized sensors. On the one hand, this leads to data which is more accurate and comprehensive. On the other hand, it disconnects the information from its source, delivering it in the office, rather than the shop floor. Hence, the approach of this paper shows a way of connecting the direct feedback of Lean with the comprehensive information of Industry 4.0. The developed application displays information right at the point of creation relying on

* Corresponding author. Tel.: +49-721-608-46166 ; fax: +49-721-608-45005.
*E-mail address:* constantin.hofmann@kit.edu

2351-9789 
Peer review under the responsibility of the scientific committee of the 9th Conference on Learning Factories.
10.1016/j.promfg.2019.03.023

mixed reality. Due to the bring-your-own-device approach, decision makers in companies can seamlessly interact with the production environment using the devices they already carry.

## 2. Literature Review

The bottleneck of a production line is the machine that impedes the performance of the overall system. In production lines, bottlenecks are often shifting depending on the current system conditions and thus hard to identify [7]. Improving the bottleneck of a production system leads to an increase in output and is therefore an objective of production optimization. To identify bottlenecks, analytical methods, simulation and indicators can be used. In practice, indicator-based methods such as the Active Period Method have the advantage that they are easy to apply and therefore well-suited for production [10].

Key Performance Indicators, KPIs, are commonly used to identify deviations. Added value is created once the appropriate actions are taken in response to the detected deviation. An optimal set of KPIs should be minimal but still reflecting the behavior of the system [14]. Lean and especially Shopfloor Management focus on KPIs as a means to provide transparency over performance [15], [9]. At the same time, a fundamental principle of Lean is the focus on the shop floor as location where the value adding processes take place. These principles manifest in the method *Go & See* which propagates that managers should go and inspect the reality on the shop floor rather then trusting reports [11]. Digitization offers the possibility to access KPIs from everywhere. A downside of the ubiquitous availability of data is that it undermines the fundamental lean principle of Go & See [3]. The introduced digital Go & See respects the underlying lean principles and fosters the presence of managers on the shop floor.

The Mixed Reality Continuum can be traced back to Milgram and Kishino [8] describing the continuum when merging reality and virtual reality. "Mixed reality is defined as experience that seamlessly blends the user's real-world environment and digitally-created content, where both environments coexist and interact with each other" [2]. In retail, mixed reality is already employed to improve customer engagement [12]. First applications of mixed reality in productions circle around visualization of KPIs and worker assistance [5], e.g. in SCADA systems [13] or for knowledge sharing [1].

The success of Lean Management is driven by a high sense of responsibility of workers and managers for their work [15]. Even though the revised norm ISO 9241-210 provides guidelines for human-centered design [4], a design framework focusing on user engagement has been adopted, to maintain the high sense of responsibility that is important to the success of Lean. When focusing on visualization and user interfaces it is vital to design that touch point of humans with technology in an engaging way improving the underlying objectives [16]. Werbach and Hunter have contributed a six-step development framework originally designed for gamification applications that places its focus on a thorough analysis of the users to generate a high level of engagement, see figure 1.

- **Define business objectives** The first phase consists of the definition of the underlying business objectives, e.g. increase in output or improve quality. The collection of points or badges is not a business objective.
- **Delineate target behavior** Based on the business objectives the intended behaviour should be derived.
- **Describe users** Objective of the third phase is a precise description of the user groups using personas.
- **Devise activity loops** Activity loops consist of the three elements motivation, action and feedback. Activity loops engage the user in an action and provide instant gratification through immediate feedback.
- **Describe fun** Fun can be classified in four categories. *Hard Fun* describes the excitement when solving a particularly difficult problem, *Easy Fun* is caused when the user fully emerges and is guided by the game environment, *Altered State* arises as response to changing emotions, *People factor* arises due to social interactions, competitions and companionship.
- **Deduction of components** Based on the previous analysis, visual components and user flows can be designed to create the desired effects. [6]

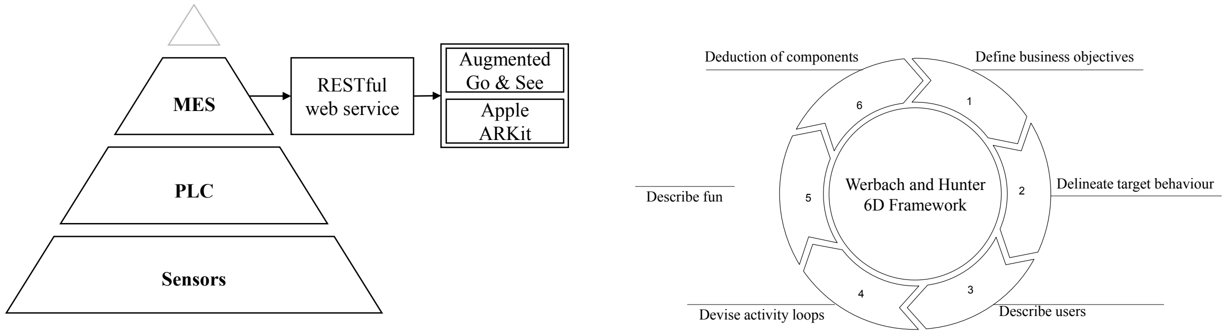


Fig. 1. (a) IT architecture; (b) 6D design framework [16].

Mixed reality provides a means to bridge the gap between digitization and fundamental lean principles such as Go & See. KPI visualization for bottleneck identification is a relevant task of production optimization, ideal to evaluate how mixed reality can be put to use in production.

## 3. Augmented Go & See

The introduced mixed reality Go & See application is based on Apple ARKit. The AR framework allows the development of powerful mixed reality applications that run on common devices such as Apples smartphones and tablets. This opens new possibilities to create powerful AR applications in the context of production that rely on the bring-your-own-device principle. The developed Go & See application uses natural feature tracking to recognize the work station and blend in the last eight cycle times and current buffer levels, as shown in Figure 2. The data to calculate the cycle times is collected using RFID tags on each product. The system records the time stamps when entering and leaving a work station as basis for cycle time calculation. The real-time buffer levels can be deduced as difference between entries and exits of two subsequent work stations. The calculated cycle times for each station and buffer levels can be accessed via a RESTful API. The overall IT infrastructure surrounding the application is shown in Figure 1a. The mixed reality Go & See application has been developed according to the 6D framework of Werbach and Hunter, as shown in Figure 1b.

### *3.1. Step 1: Define business objectives*

Production systems are complex systems with non-linear interactions. As a consequence, it is difficult to detect root causes behind symptomatic deviations. The underlying business objective for Augmented Go & See is the improvement of performance, measured by KPIs in a complex and volatile production environment. The implementation aims to reduce the throughput time, increase output and overall production effectiveness (OEE).

### *3.2. Step 2: Delineate target behavior*

In order to reach the business objective the key users need to behave in a certain way. In a volatile and complex production environment it is challenging to detect dynamic bottlenecks by classic Go & See. Accordingly, the users should regularly inspect and evaluate the production KPIs. The application should invite the user to view the KPIs on a regular basis and help to focus the users attention on the out-of-norm indicators. In a dynamic environment it is important that KPIs are up-to-date, since the point of interest might shift very quickly. Real-time KPIs that help to detect bottlenecks are live cycle times and live buffer levels. The user should regularly check for single, unusually long cycle times at a workstation indicating technical problems or missing parts. Varying cycle times at a workstation indicate an unstable process. Poor line balancing shows in varying cycle times across the different workstations and high buffer levels in between stations.

### *3.3. Step 3: Description of users*

Key user for Augmented Go & See are production planners and Lean managers. This group is used to interpreting charts and has often received special training on lean and efficient production design.

A different user group are the workers. An important tool of Lean production is shopfloor management which includes the worker in the continuous improvement of the production system. For the same reason it is important to include the worker in Augmented Go & See in order to enable them to engage in the continuous improvement cycle of the production line. In contrast to the first user group, they are less used to working with charts and figures. An adapted and intuitive design is thus key to engage this user group as well.

Within a learning factory, the process observers belong to the user group of production planners. Their objective is to identify the reasons for the current performance of the production system as input for to the next continuous improvement cycle. The visualization of KPIs at the point of value creation enables a unique learning experience that is difficult to match by separate consideration of KPIs and the production environment.

### *3.4. Step 4: Activity Loops*

The fast identification of problem hot spots reduces time-consuming search and helps to efficiently allocate efforts. The designed user interface highlights indicators that deviate from the desired value and thus gives a motivation to focus on these (motivation). The users respond to this stimuli by going to the affected work station (action). Having solved a problem, they receive immediate feedback by a change in color of the bar chart (feedback).

The transfer of knowledge in a realistic but safe environment is a main concern of learning factories. A teaching mode based on simulation is an appropriate way to provide a realistic learning experience. The application thus provides a simulation mode, generating, realistic data. To make sure that the users do not loose their attention (motivation), the simulation generates data superior to the regular production pace. However, to provide enough time to thoroughly grasp the situation, the simulation can be paused, users can move around in the facility and analyze the current situation in-depth (action). As the simulation cannot be influenced by the users, feedback has to be provided by a coach accompanying the learning participants (feedback).

### *3.5. Step 5: Analysis of fun*

The user should be attracted by intriguing visual effects and motivated to have a close look on the indicators. The fast change of KPI values causes excitement and a high level of attention. This interplay triggers *altered state* and *easy fun*. Solving the difficult problem of bottleneck identification and seeing the immediate response of buffer levels and cycle times activates *hard fun*.

### *3.6. Step 6: Deduction of components*

The cycle times are visualized using bar charts. These are well suited to compare the cycle times relative to each other and to identify drifts and trends. Additional labels showing the cycle time in seconds provide detailed information.

To attract the user's attention, color coding is applied. If the cycle time is less or equal to its planned cycle time, the bar is colored in green. Yellow indicates actual cycle times between the planned cycle time and the takt time. Yellow bars thus indicate insufficient line balancing. In case the actual cycle time exceeds the takt time, the bar is colored in red. In these cases, the work station causes a decrease in output. This visualization helps the users to focus their attention on urgent problems (red) and potential for optimization by levelling (yellow). Unstable processes are easily identified as the bars show different heights. Machine breakdowns manifest in very high cycle times. To

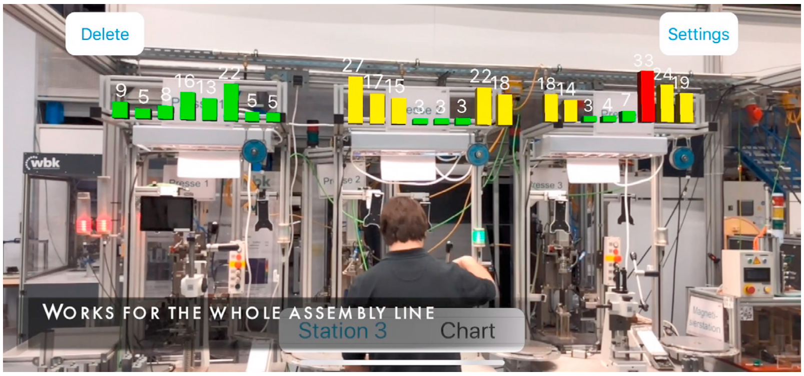


Fig. 2. Augmented Go & See.

identify bottlenecks, the current buffer levels between the work stations are visualized. High buffers in front of a work station in combination with an empty buffer and long waiting times at the following work station indicate a bottleneck.

Augmented reality and the 3D effect of the charts hovering over the work stations are still new to most users generating additional interest in the topic. This temporary effect leads to longer usage times and an intense engagement with the displayed KPIs. To increase the interest even more, new cycle times are continuously polled.

## 4. Case Study

wbk Institute of Production Science runs a Learning Factory on global production to demonstrate how different location factors influence design of a production. To show the effects of the location on quality and efficiency, not only layout and process organization can be varied, but also the automation degree of work stations can be adapted. In workshops the participants carry out the final assembly of an electrical drive for automotive applications.
One exemplary training focuses on the application of Lean and Industry 4.0 tools. One goal is to demonstrate Lean and Industry 4.0 tools and their impact on production KPIs to the participating production planners. Accordingly, the integration of Augmented Go & See in the Learning Factory Global Production serves two goals. Firstly, it shows the participant the relation between production KPIs and actual events occurring in the assembly line in real time. This approach serves the goal of teaching the participants a deeper understanding of critical production KPIs. Secondly, the participants get to see an application of Augmented Go & See, which they might adapt to their specific production context. Based on the experience of carrying out traditional Go & See as well as Augmented Go & See the participants directly experience the effects of these methods.

In order to quantify the difference in impact of traditional Go & See and Augmented Go & See a case study has been carried out among participants of the Lean & Industry 4.0 training in the Learning Factory Global Production. The participants were separated into two groups. Group A received stopwatch, pen and pencil for traditional Go & See. Group B received a tablet computer with the Augmented Go & See application. Both groups were asked to accomplish four tasks during a production cycle:

- Identify the Bottleneck of the line
- Identify a station with technical problems
- Identify an unstable process
- Identify a station with insufficient line balancing

The participants where given four minutes to complete the task. If they could not find the correct solution in time, the completion time was set to four minutes.

## 5. Critical Review and Conclusion

The results show that the participants using the AR App outperformed the traditional lean observers significantly, see table 1. The detection of bottlenecks and stations with technical problems was also possible without access to the cycle times just be observing unusual movement and high buffers. Nonetheless the participants of group A could not match the times of the group using the AR application. The identification of unstable processes and insufficient line balancing require knowledge about the cycle times. Whereas the users of the augmented Go & See are provided with the last eight cycle times, the Pen & Paper group needs to collect the data themselves. As the data collection is time consuming, the time until the members of this group find the correct solution largely depends on their intuition to pick the right station to collect the data.

Table 1. Experiment results: Time until correct identification for both groups.

| Task | Pen & Paper $\mu, \sigma[sec.]$ | AR Go & See $\mu, \sigma[sec.]$ |
|---|---|---|
| Identify the Bottleneck of the line* | $\mu = 103.3, \sigma = 57.10$ | $\mu = 55.2, \sigma = 18.06$ |
| Identify a station with technical problems* | $\mu = 110.1, \sigma = 68.15$ | $\mu = 54.6, \sigma = 34.69$ |
| Identify an unstable process** | $\mu = 170.0, \sigma = 79.49$ | $\mu = 33.3, \sigma = 10.13$ |
| Identify a station with insufficient line balancing** | $\mu = 178.0, \sigma = 84.55$ | $\mu = 38.5, \sigma = 12.87$ |

* significant with 95% ** significant with 99%

The results are based on a sample of ten participants in each group. The choice of the participants in which order to answer the questions impacts the results. Further research could focus on the design of an experiment to independently examine the four aspects.

The introduced mixed reality application gives an example how mixed reality can be put to use in production. Furthermore it demonstrates that digitization not necessarily undermines Lean principles. If designed well and in a user-centred way, it is possible to improve widely-spread and established lean tools even further.

## Acknowledgements

We are indebted to the Baden-Württemberg Stiftung for the financial support of this research project by the Eliteprogramme for Postdocs.

## References

[1] , . Wie Mensch und Maschine zusammenarbeiten: Einsatz von KI und AR. URL: https://www.dfki.de/web/news/detail/News/wie-mensch-und-maschine-zusammenarbeiten-einsatz-von-ki-und-ar/.

[2] Cassagnol, D., . CTA - AR/VR Will Open Eyes in 2018: Record-Setting U.S. Sales Projected, Says CTA. URL: https://www.cta.tech/News/Press-Releases/2018/January/AR-VR-Will-Open-Eyes-in-2018-Record-Setting-U-S.aspx.

[3] Houy, T., 2005. ICT and lean management: Will they ever get along? Communication and Strategies , 53–75URL: http://mpra.ub.uni-muenchen.de/2502/.

[4] ISO, 2011. DIN EN ISO 9241-210 : 2011-01 Titel (deutsch): Ergonomie der Mensch-System-Interaktion - Teil 210: Prozess zur Gestaltung gebrauchstauglicher interaktiver Systeme (ISO 9241-210:2010) 01, 1. URL: http://www.beuth.de/de/norm/din-en-iso-9241-210/135399380.

[5] Juraschek, M., Büth, L., Posselt, G., Herrmann, C., 2018. Mixed Reality in Learning Factories. Procedia Manufacturing 23, 153–158. URL: https://www.sciencedirect.com/science/article/pii/S2351978918304815.

[6] Lazzaro, N., 2004. Why We Play Games: Four Keys to More Emotion Without Story. Game Developer Conference (GDC) , 1–8URL: http://www.citeulike.org/group/596/article/436449%5Cnhttp://www.xeodesign.com/xeodesign_whyweplaygames.pdf.

[7] Li, L., Chang, Q., Ni, J., 2009. Data driven bottleneck detection of manufacturing systems. International Journal of Production Research 47, 5019–5036. URL: https://www.tandfonline.com/doi/full/10.1080/00207540701881860.

[8] Milgram, P., Kishino, F., 1994. A taxonomy of mixed reality visual displays. IEICE TRANSACTIONS on Information and Systems 77, 1321–1329.

[9] Peters, R., 2016. Shopfloor-Management. LOGX.

[10] Roser, C., Nakano, M., Tanaka, M., 2001. A Practical Bottleneck Detection Method, in: Proceedings of the 33Nd Conference on Winter Simulation, IEEE Computer Society, Washington, DC, USA. pp. 949–953. URL: http://dl.acm.org/citation.cfm?id=564124.564259.

[11] Rother, M., 2013. Die Kata des Weltmarktführers: Toyotas Erfolgsmethoden. campus Verlag.

[12] Scholz, J., Smith, A.N., 2016. Augmented reality: Designing immersive experiences that maximize consumer engagement. Business Horizons 59, 149–161. URL: https://www.sciencedirect.com/science/article/pii/S0007681315001421.

[13] Soete, N., Claeys, A., Hoedt, S., Mahy, B., Cottyn, J., 2015. Towards Mixed Reality in SCADA Applications. IFAC-PapersOnLine 48, 2417–2422. URL: https://www.sciencedirect.com/science/article/pii/S2405896315006898.

[14] Stricker, N., Pfeiffer, A., Moser, E., Kádár, B., Lanza, G., 2016. Performance measurement in flow lines–Key to performance improvement. CIRP Annals-Manufacturing Technology 65, 463–466.

[15] Suzaki, K., 1993. New shop floor management: empowering people for continuous improvement. Simon and Schuster.

[16] Werbach, K., Hunter, D., 2014. For the win. Wharton Digital Press, Philadelphia. URL: https://www.lynda.com/Higher-Education-tutorials/Game-thinking/173211/197007-4.html.