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Development of an IoT-based inventory management solution and training module using smart bins

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Abstract

Flexibility, transparency and changeability of warehouse environments are playing an increasingly important role to achieve a cost-efficient production of small batch sizes. This results in increasing requirements for warehouses in terms of flexibility, scalability, reconfigurability and transparency of material and information flows to deal with large number of different components and variable material and information flows due to small batch sizes. Therefore, an IoT-based inventory management solution and training module has been developed, implemented and validated at Werk150 – the Factory on campus of the ESB Business School. Key elements of the developed solution are smart bins using weight mats to track the bin's content and additional sensors and buttons which are connected to an IoT – Hub to collect data of material consumption and manual handling operations. The use of weight mats for the smart bins offers the possibility to measure the container content independent of the specific component geometry and thus for a variety of components based on the specific component weights. The developed solution enables focusing on key for success elements of the system to provide synchronization of the flow of materials and information resulting an increase of flexibility and significantly higher transparency of the material flow. AI-based algorithms are applied to analyse the gathered data and to initiate process optimizations by providing the logistics decision makers a profound and transparent basis for decision making. In order to provide students and industry visitors of the learning factory with the necessary competences and to support the transfer into practice, a training module on IoT-based inventory management was developed and implemented.

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1. Introduction

Warehouse environments are dominated primarily by manual processes which are proven to be particularly challenging to capture process-related data to create transparency and enable analysis and optimisations of the respective processes and inventory levels. Such manual processes can contribute to a blurring of the material flow. The blurring, in turn, can lead to delays or other disruptions that, in the worst case, hinder material supply at the workplace [1].

In this paper the focus is on the material flow from the warehouse to the production (e.g. assembly station). To ensure smooth production, a constant supply of material is required at the workplace. This is already practised by well-known systems such as Kanban. However, only a few systems show the current consumption due to a lack of transparency [2]. Especially A-parts, which often turn out to be a bottleneck. The Theory of Constraints (TOC) is designed to identify bottlenecks. As soon as a bottleneck is identified, it is counteracted with a suitable buffer.

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Accordingly, care is taken to deliver parts at the right time, thereby increasing the efficiency of inventory management.

Starting with the investigation of the requirements in terms of flexibility, scalability, reconfigurability and transparency of material and information flows of industrial inventory management systems an approach for IoT (Internet of Things) - based inventory management using smart bins has been developed. The developed solution which is also using the TOC approach and AI (Artificial Intelligence) algorithms for analysis and optimisation have been tested and validated at the learning factory Werk150 by user testing.

A limitation of the approach described in this paper is that it is only applicable to warehouse environments that are dominated by manual processes, and may not be effective in other types of warehouse environments. However, the combination of the TOC and the IoT has the potential to greatly improve inventory management by increasing transparency and enabling real-time analysis and optimization of material and information flows. By using sensors and other IoT technology to capture data on the movement of materials in a warehouse, and applying TOC principles to analyze and optimize the data, it is possible to identify bottlenecks and improve the efficiency of inventory management. This can ultimately lead to better utilization of resources, reduced delays and disruptions, and improved supply chain performance.

The objective is the development of an IoT-based inventory management solution and training module using smart bins to capture and analyse process-related data to increase transparency of material flows and improve inventory management. Additionally, by visualising process-related data of manual processes a training module to teach optimisation strategies of inventory management is developed. The Design Science method (DSM) was used to develop the solution. DSM involves a process of systematic and iterative development, testing and refinement of solutions to problems using a set of guiding principles and processes. It is based on the idea that a designed item is a solution to a specific problem and that the design process should be based on a thorough understanding of the problem and its context.

2. Analysis of the state of the science

In the following chapter, the state of the art in the field of methods for the analysis of inefficient material flows, intelligent containers and TOC are presented. This also provides a rationale for the selection of the method chosen here for developing an IoT inventory management solution and the corresponding training module.

2.1 Solutions to analyse inefficient material flows

There are several methods that can be used to analyse inefficient material flows in a factory. Some of these methods include:

Data analysis and visualization: By collecting and organizing data on material flow, it is possible to use data analysis and visualization tools to identify bottlenecks and other areas of inefficiency. This can help factories identify patterns and trends that can help them improve material flow and reduce inefficiencies [3].

Time and motion studies: These studies involve measuring the time it takes to complete a task or process and analysing the movements and actions involved. They can be used to identify inefficiencies and suggest ways to improve the process [4].

Lean manufacturing methods: Adopting a lean manufacturing approach can help reduce excess inventory, improve material flow, and reduce waste and inefficiencies throughout the production process [5].

Process mapping: Using process mapping techniques, factories can visualize and analyse the flow of materials through the production process. This can help identify bottlenecks and other areas of inefficiency, and can be used to develop and implement improvements to the material flow process [6].

Simulation modelling: Simulation modelling can be used to create virtual models of the production process, allowing factories to test different scenarios and evaluate their impact on material flow. This can help factories identify and implement improvements to material flow [7].

Overall, there are many different methods that can be used to analyse and improve inefficient material flows in a factory. By using a combination of these methods, factories can gain a better understanding of their material flow processes, and can develop and implement solutions to improve efficiency and reduce waste. In this paper, the combination includes data analysis and visualisation as well as time and motion study and extends it to TOC. The implementation of this combination requires its own technical infrastructure. This is compiled from various components, which are elaborated and described in the following chapters.

2.2 Smart bins and overlays

There are already intelligent small load carriers, so-called smart bins, which promise automated C-parts management. The technology framework of smart bins is the IoT. The IoT refers to the connectivity of devices, machines, and everyday objects through the internet, enabling them to send and receive data and interact with one another. This connectivity allows devices to be controlled remotely and to automate tasks, improving efficiency and convenience. With the addition of sensors and actuators to monitor and control physical processes, this creates a cyber-physical system (CPS) [8].

The company Würth Industrie Service has developed the "iBin" and put it on sale. The container gets its intelligence from the equipment of two different technologies and their combination. On the one hand, an integrated camera generates the fill level of the bin. On the other hand, RFID technology triggers replenishment orders. The "iBin" aims to manage consumption-controlled C-parts along the value chain [9].

The "DProdLog" research project is pursuing a similar goal. With the help of intelligent small load carriers, challenges in the cross-company procurement process are to be overcome. With the help of intelligent small load carriers, challenges in the cross-company procurement process are to be overcome. For this purpose, the containers are equipped with a fill level sensor and an RFID label. The goods are assigned to the container by scanning the goods and the container. The sensors installed in the container make it possible to check at regular intervals whether the container is full or empty. If the status "empty" is detected, an order is automatically placed with the supplier [10].

The two smart bins presented have similarities. Both are used for automated C-parts management. With the built-in technology, an order is placed with the respective supplier. The "iBin" is only designed for parts from Würth. Thus, these two containers are primarily suitable for cross-company applications. The case examined within this paper strives to improve the intralogistics material flow. To do this, the stock between the assembly station and the warehouse must be monitored. Here, it is primarily desired to measure the current consumption in real time and to replenish it with the right quantity at the right moment. For this purpose, an overlay is to be used that can be placed either under or in a container. Pressure sensors are built into such an overlay, which are able to determine the weight of the contents. The advantage here is that the quantity can be determined independently of the geometry. In order to keep production running without interruptions, the material must be continuously replenished [2]. With the determination of the weight, limits can be set in order to replenish at the right moment. This makes a buffer calculation possible. This means that depending on consumption, the right amount can be added or reduced at the workplace. However, this first requires the collection of data. Although the sole application of the technologies supports the monitoring of the process, algorithms are needed that allow the control of the process. Only through the implementation of algorithms and the use of artificial intelligence does the system become holistic. As already mentioned in the introduction, the TOC is particularly suitable for identifying bottlenecks. Transforming this theory into an algorithm can address the challenges mentioned in the introduction. The mapping of the data can also be used to develop a training module designed to identify short comings, inefficient material flow and material consumption patterns.

2.3 Concept of Theory of Constraints

TOC is a value stream management methodology that ensures the growth of objective function values while focusing efforts on a minimum number of factors. In other words, TOC allows, achieving maximum value with minimal cost.

Theory of Constraints is a management methodology developed by Eliyahu M. Goldratt and described in his book The Goal: The Process of Continuous Improvement [11].

Dr. Goldratt took the epic phrase "Give me a foothold and I will turn the whole world upside down" by adapting it into a fundamental rule of managing organizations. Formulate the key need of your customers and determine what constraints you in the process of its implementation - this will be your foothold. Simply put, Dr. Goldratt suggested that organizations can achieve their goals by identifying and exploiting the constraints of the system.

The Theory of Constraints consists of five key steps [11]:

1. Determine the limitation of the system
2. Use the limit to the maximum
3. Subordinate all other elements of the system to the task of maximizing the use of the constraint
4. Expand the limit
5. Check if the constraint has moved to another element of the system. Avoid inertia and repeat the process.

Instead of looking at individual components and processes, the idea is that it is more efficient to use constraints in the path of a holistic workflow. This holistic concept has been translated into detailed solutions for areas such as: project management, production management and supply chain management [12].

The basis for building detailed solutions for all other industries are the thinking processes developed by Dr. Goldratt: Formalization of managerial dilemmas in the form of diagrams, construction of current and future state trees and construction of transformation logic tree [13].

Using the TOC, by improving one single stage of the workflow you improve the whole system. An independent academic study of 400 international case studies of TOC showed significant results indicating enormous potential [14]. One of the results was an average reduction of 70% in delivery times. Another result was an average 44% reduction in on-time deliveries. In addition, there was a 49% average reduction in inventory. These phenomena have resulted in an average increase in profit of 63%.

3. IoT – based inventory management solution

This chapter describes the applied technology in interaction with the TOC. In addition, the optimisation strategy based on the algorithm is also described and illustrated in this chapter.

3.1 Advin Overlay

Advin is a start-up project (http://advin.pro/) aimed primarily at stock management in stores. The object of control is the "last 100 meters" of the supply chain, namely from the back room to the store shelves. According to expert estimates, more than 70% of empty shelves are the fault of the store. Responsible personnel do not have time to ensure that each shelf is replenished on time. And then a paradoxical situation arises - the goods are in the store, but not on the shelf.

The Advin project provides an informational solution to this problem - an overlay with weight sensors is installed at the entire depth of the shelf and the amount of goods on it is controlled. The received data is wirelessly transmitted to the server online.

The algorithms of the Advin project are based on the principles of supply chain management according to the TOC - auto-order, DBM and replenishment of sold goods. These elements correspond to the components of a CPS, which is described in chapter 2.2. The weight mat is the sensor in this system. The GSM module connects the weight mats with each other and the platform (cloud). The data is collected in the cloud. The visualised data can be monitored via the website. In addition, actions are triggered that are controlled by the TOC algorithm running in the background.

The software generates online reports and analytics in the web user's account and sends alerts when the shelves are close to being empty. Responsible store employees have time to replenish the stock of goods before the shelf is empty.

Conducted pilot projects on the example of beverages have shown that the Advin project can bring income to a retailer from $5 for every $1 invested in the system.

By analogy with managing the "last 100 meters" of the supply chain, the Advin system can also be used for the "first 100 meters", that is, in production. The management of the replenishment of boxes of parts in the "supermarkets" on the assembly line is routinely carried out using the Kanban system. The Advin system can perform the same functions as Kanban, but at the same time automatically analyse flows, as well as fill the artificial intelligence databases with the necessary information.

In addition, the system is very easy to install, which allows you to quickly scale the project.

3.2 TOC – based analysis and optimization

Advin startup was boosted up by merge with the TOC concept. To illustrate the possibilities and practical value of TOC, the Advin project opened up new possibilities. Advin generates regular data, which is then processed by the TOC algorithm - dynamic buffer management. For companies that have participated in pilot projects, this combination of methodology and hardware solutions has yielded promising results.

Simple and straightforward methods for easy comprehension are used and therefore do not follow very sophisticated modules of forecasting. The algorithm dynamically measures the actual usage of the stocks and readjusts the inventory levels accordingly. This method is referred to in current TOC literature as DBM. By monitoring the buffer penetration at each stock location for each product, the right buffer size that can be kept for a product at a stock location can be identified.

The DBM approach argues that by monitoring and adjusting the buffer sizes, the “real” stock required to be kept at the site in order to cover for the demand, taking into consideration the supply side (how fast delivery to the stock location can be made) can be easily arrived at.

One of the goals is to define a level of safety and constantly monitor how the safety is being used. This safety is called a buffer. Figure 1 illustrates an exemplary course of DBM.

The quantity kept at the stock locations including the plant warehouse (PWH) and regional warehouse (RWH) is defined as buffer size, and this is a stock type buffer. The buffer size in this system (Make to stock Buffer Size) is the number of units one would like to keep overall in the supply chain for this stock location from this SKU.

Id	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Quantity	2	0	16	14	14	14	14	13	12	12	11	10	10	10	10	10	10	9	8	7	5
% buffer penetration	83.3	100	0	12.5	12.5	12.5	12.5	18.8	25	25	31.3	37.5	37.5	37.5	37.5	37.5	37.5	43.8	50	56.3	68.8

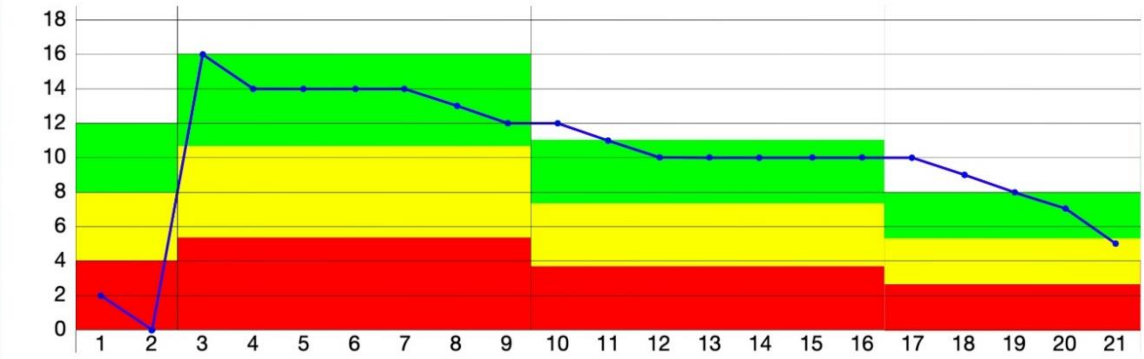

Fig. 1: Dynamic Buffer Management (DBM)

For example – if the stock buffer size is 100 units and currently at the stock location there are 40 units, there are approximately 60 units to order or on the way from the feeding stock location to this one (the feeding stock location for the Plant Warehouse is the plant). If those 60 units are not on the way, a replenishment order of 60 units should be issued immediately.

It is important to note that different stock locations will have different buffers for the same SKU, since the supply and/or demand pattern might be different between them.

The buffer penetration colour gives an indication regarding the urgency of replenishing this stock:

Green – the inventory at the consumption point is high – providing more than enough protection for now

Yellow – the inventory at the consumption point is adequate – there is a need to order more units from the upstream supply chain

Red – the inventory at the consumption point is at risk of depletion – units in transport/ manufacturing (depending on which consumption point it is) should be considered for expediting effort. An urgent replenishment order must be put to the supplying source if nothing is available on the way to the consumption point.

Black – the stock has run out at the consumption point, meaning every hour passed at this stage is lost sales opportunities – this situation must be resolved ASAP as it represents real damage, especially at the most downstream links in the supply chain.

4. Training module for IoT – based inventory management

The applied teaching methods are based on the four-step method following Riffelmacher [15]. The four steps are: Teaching of theoretical content in a lecture, demonstration in the learning factory by the lecturer, application of the learning content by the participants using an example and finally independent application in the learning factory by the participants. For first tests, the learning module described below have been integrated into a graduate lecture. Following Riffelmacher's approach, the basics of TOC are first taught in the lecture. These are backed up with illustrative examples from the current literature on the subject [16]. Further case studies illustrate the principle of the theory.

The basic idea behind TOC is that every system has at least one constraint or bottleneck that determines its performance, and that by identifying and addressing this constraint, an organization can increase its overall performance and achieve its goals more effectively [11]. Nevertheless, it is named “Theory” it is very practical. This can be perfectly illustrated in the Learning Factory environment. For this case the use of TOC for procurement of an assembly line with appropriate parts is considered. The key performance measurements for the procurement of assembly shop are:

1. The required number of parts for assembly, regardless of fluctuations in demand for the final product, is always present on the assembly table.
2. When the demand for the final product changes, the stock level synchronously changes by a proportional amount.

These requirements can be met with the Kanban method, but the use of TOC brings a number of new benefits:

• The operator at the stage of preparing parts for shipment to the assembly line can see on the screen how these parts are consumed on the assembly line and the transition to produce necessary parts is less stressful for him;

• Supply chain management according to the TOC method - Dynamic Buffer Management (DBM) - has become one of the main methods of supply chain management and in the case of external supplier, the DBM rules will not require additional clarifications;

• The continuous flow of data allows the use of various methods for analysing the cause-and-effect relationships of the absence or excess of parts;

• This data can be fed into databases for training AI.

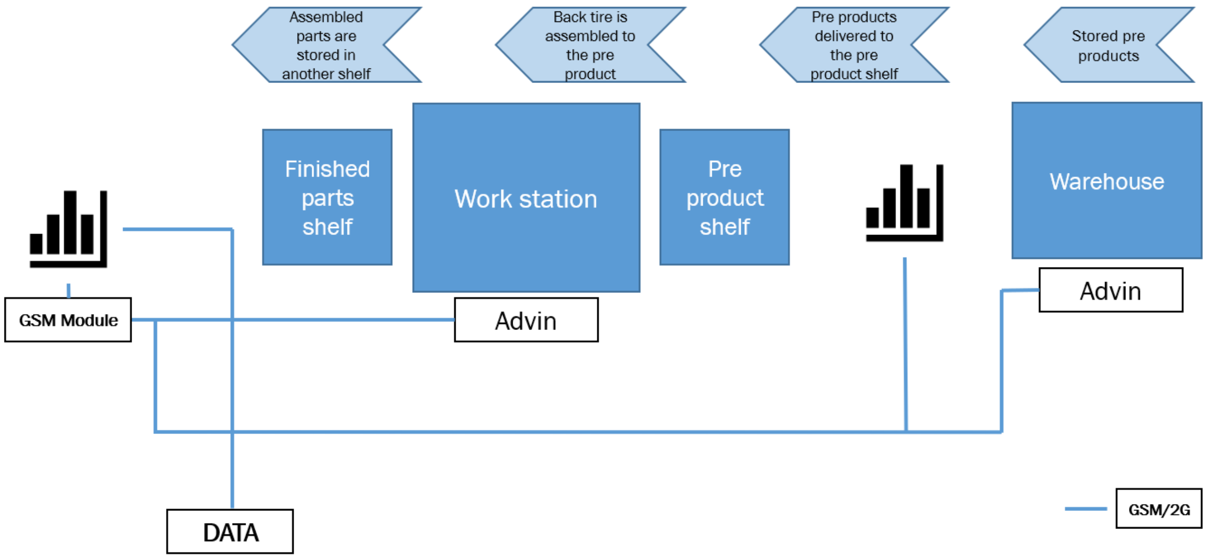

Fig. 2: Architecture of the demonstrator including the information flow

The case studies are also supported by demonstrations in the learning factory. Subsequently, the students are allowed to apply the principle in a business game. Finally, the students are allowed to identify and apply optimisation strategies based on TOC on the production floor at the demonstrator in initial tests. The demonstrator presented in figure 2 is composed of an assembly station and a warehouse. The rear wheel of a scooter is assembled at the assembly station. The associated individual parts are located at the assembly station for this purpose. The parts are replenished from the warehouse. The students assign different roles to each other in the group. One pair is responsible for assembling and resupplying the individual parts, while the others observe the process. The data is displayed in the dashboard so that the students can use it to identify the bottleneck. Once the bottleneck is identified, it is the students' task to apply principles of the Theory of Constraints using the knowledge from the lecture and the business game with appropriate methods. Finally, the success of the measures is analysed and evaluated based on a renewed execution of the process with the introduced measures. In a discussion round, the students finally reflect on the training module.

5. Conclusion

In conclusion, the use of IoT-based inventory management systems, such as smart bins, in combination with the TOC approach can greatly improve transparency and efficiency in warehouse environments. The TOC approach is designed to identify bottlenecks in the material flow and provide a suitable buffer to counteract them, leading to increased efficiency in inventory management. The data captured by smart bins can be used to analyse and optimize inventory management, and can also be fed into databases for training artificial intelligence. These improvements can help ensure a constant supply of material at the workplace, leading to smoother production and higher efficiency in inventory management. With the development of the IoT-based inventory management solution, TOC has been integrated into the learning factory environment in the form of a training module. Additionally, the visualization of process-related data from manual processes can be used to develop a training module that teaches optimization strategies for inventory management. This can help improve the overall efficiency and productivity of warehouse operations. At the same time, the training module is further developed and optimised through iterative implementation.

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