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APPLICATION OF LEAN METHODS – A BUSINESS GAME STUDY IN GERMAN COMPANIES

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Abstract
Production companies face the challenge of choosing a suitable process optimization method from a variety of methods, even though their effect on operational processes is uncertain. This study shows, using a statistical hypothesis test, the impact of the methods Kanban and Standard Worksheet on an autonomous team in comparison to a team that applies these methods. For this purpose, 44 companies – of different size and operating in various industries – across Germany completed a business game and generated data regarding the KPIs adherence to delivery date, number of reworks and inventory costs. Based on these data, the team's performance could be ascertained and compared with each other.

Keywords
Lean methods, business game, process optimization, two proportions test, paired t-test.

Introduction

Production companies operate within a complex environment where various influence factors and circumstances are prevailing [1]. There is constant and progressive change on an economic, political, technical and ecological level [2]. In light of this high volatility and dynamic in various sectors, production companies are exposed to a variety of external and internal challenges [3]. These challenges cause a field of tension, which necessitates the ongoing improvement of the competitiveness of a production company [4]. One big challenge for companies is the selection of suitable process optimization methods and their targeted alignment [5]. The term "process optimization method" means the optimization of existing processes through the application of certain methods, to operate successfully in the market [6].

To examine the performance and behavior of certain teams that apply process optimization methods in contrast to those not applying them, a Germany-wide survey was conducted. The following research question was derived:

Can the improvement of defined KPIs be demonstrated by using "Kanban" and "Standard Worksheet" within a business game in companies?

The usage of the business game methodology allows a statistical hypothesis test [7]. The aim is to derive conclusions about the effectiveness of the method application regarding the team performance mentioned above by evaluating collected data. The used KPIs are the result of literature research and group discussions with experts. This validation was achieved by running statistical hypothesis tests and evaluated using the statistic software Minitab® (V18.1© 2017).

Selected lean methods

Two empirical data collection methods (Online Survey and Literature Research) were used to deter-

mine the process optimization methods. To establish a coherent understanding of the process optimization methods applied and to avoid misunderstandings, they will be further outlined using a brief description.

Standard worksheet (SWS)

Standardization allows a safe, efficient and reliable iteration of processes. Likewise, it is possible to identify deviations and potentials for improvement by way of standardization [8]. This method is considered an operational standard form, which describes details of every single work step of a workstation and is used for academic and training purposes [8]. Figure 1 exemplarily shows the assembly steps of a gear assembly [9].

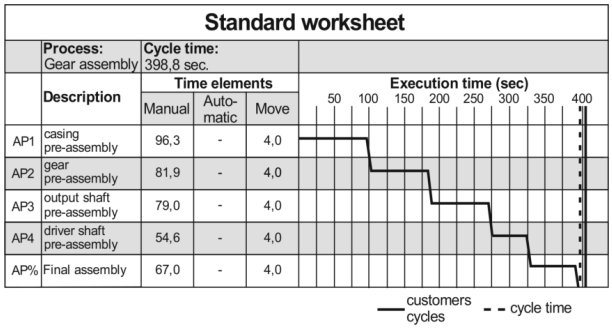

Fig. 1. Standard Worksheet of a gear assembly [9].

Kanban

The development of Kanban goes back to Taiichi Ohno, who adapted the supply of goods of US-American supermarkets to the production facilities of Toyota [10]. The endeavor to avoid overproduction was the key stimulus that led to the implementation of Kanban [11]. A Kanban system essentially consists of customers and suppliers within a closed loop, which regulates the material flow and requirements based on consumption by using information carriers [8]. Ohno uses cards (Japanese 'Kanban') as information carriers [12]. The Kanban card contains all the necessary information for the supply of goods.

The withdrawal of a respective product at the end of the production process triggers the initiation of the Kanban circle [13]. This withdrawal sequence continues through the subsequent production process. The material and information flow run in the opposite direction (see Fig. 2). An empty Kanban container can also be seen as a trigger to induce the refill or exchange it with a filled container within a production facility [14].

The following aims are achievable by a consistent application of the Kanban methodology: minimum inventory, more efficient workstations, better quality utilizing early remedies, transparent processes, short operations [15].

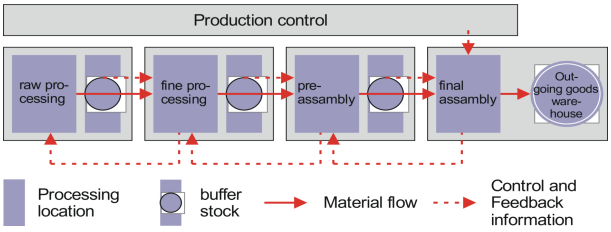

Fig. 2. Kanban control cycle for production control. Reference: author's illustration based on [21].

Business game concept

Blötz [16] calls a business game an instrument that is geared towards making real processes less complex so that they can be transferred into a situational model for the illustration of economic correlations. Adopting this definition, Hitzler et al. [17] describe a business game as a dynamic model, which depicts a real business situation. It is used to analyse and simulate system processes that are too time-consuming, expensive and risky to be run in reality. With this in mind, a model always needs to be described as an abstract image of reality or usually as an excerpt of reality [18]. Models are important objects of economic and technical activities [19]. Furthermore, the potential of business games within social science is not completely used, since they can be used for educational, support-related and research purposes [20].

To conduct the business game, nine subjects are required for each business game round. Three for assembly, two for material supply and one for final inspection. Besides, three subjects are required to make sure that the business game rules are adhered to and to record quality defects and output quantity.

The task is to manufacture as many dump truck models (Fig. 3) as possible within the playing time of 10 minutes.

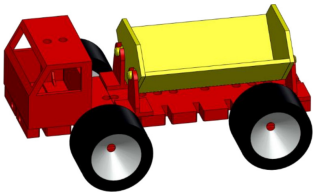

Fig. 3. Dump truck and components.

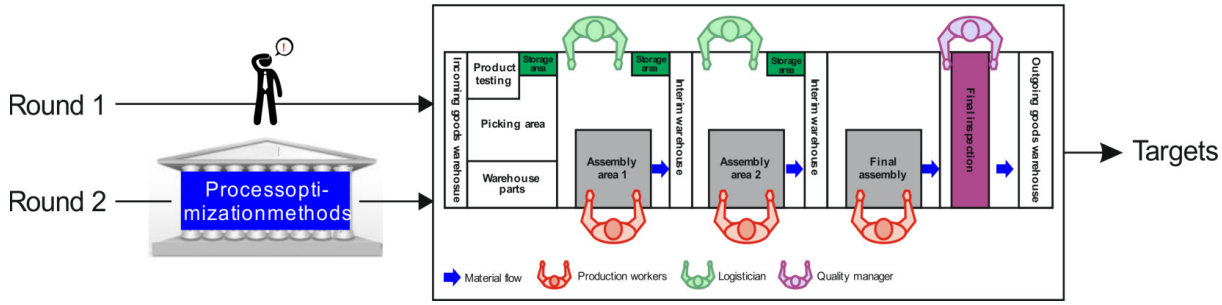

Fig. 4. Structure and play rounds of the business game.

The customer specification demands the first dump truck to be ready at the outgoing warehouse (non-defective) after 2 minutes in flawless condition.

Thereby, the KPI 'adherence to delivery date' is constituted, which has a nominal scale (binary) because the customer specifications are either fulfilled or not. Before sending the dump trucks to the outgoing goods warehouse, they must be checked in the final inspection. If a dump truck does not pass the final inspection, it will undergo remedial work within the respective assembly station and afterward will be sent to the final inspection again. The number of components, which have to be reworked, because they were assembled the wrong way, represents the KPI 'number of reworks'. Lastly, the KPI 'inventory costs' is measured after the playing time of 10 minutes. They include all components and half-finished dump trucks, which still are in the temporary storage upon completion of the playing time.

The business games were conducted with 44 companies in the different Federal States of Germany. The companies of various industries were acquired nationwide via the network of the university.

The companies each provided nine employees, who played the business game. To that, not only production employees but employees of other business units, too, were allocated.

The motivation, both for the companies and the employees, to take part in the business games was above all to get to know new methods, with which their work processes can be improved. Moreover, cooperation in the business game promotes team spirit.

The business games were carried out within five months in 2018. The setting of the business game is mobile. Therefore, the business games were conducted in the 44 companies on site. The exact replication of the business game was possible due to the mobile setting in every company. The same manual time recording with digital timers, pen and paper could always be ensured, because the same scientific assistants always travelled with and recorded the data.

All of the 44 teams played the business games in two rounds. The first round was a reference round, where the subjects got neither instructions nor any optimization method. In round 2, the abovementioned process optimization methods were implemented. By comparing these two rounds, the effectiveness of the process optimization methods can be examined.

In total, 88 data sets resulting from the number of teams and play rounds could be generated. 80 data sets were complete and recorded correctly and, therefore, serve as a foundation for further analysis.

Analysis and results

Hypothesis testing

The statistical hypothesis test provides information about the extent to which the collected data most likely match the abstract assumptions [22]. Hence, this method can validate a hypothesis using population size subset metrics [23]. Since a thorough survey is often too expensive, time-consuming, or almost impossible [24], inductive statistics are used to extrapolate from a random sample to the characteristics of the population [25]. In literature, various processes of a statistical hypothesis test are presented, and tasks are partially summarized or subdivided further. The following six steps were performed: Formulation of the null hypothesis H0 and alternative hypothesis H1 [26], determination of α-significance level [23], specification of the test statistic [26], details of rejection area [27], calculating the test value-based on collected data [28], selecting the corresponding hypothesis [29].

Table 1
Excerpt from the data collected.

Nr/R.	Inventory costs [€]		Shortest lead time [s]		Longest lead time [s]		Number of reworks [piece]		Output [piece]		Adherence to delivery date [Yes/No]	
	1	2	1	2	1	2	1	2	1	2	1	2
10	138.100	111.000	35	80	202	143	1	0	14	20	Yes	Yes
12	119.400	24.600	88	46	130	78	0	0	15	20	No	Yes
13	9.500	0	87	50	167	123	2	1	17	18	Yes	Yes
14	44.200	5.000	48	54	104	97	2	1	29	30	Yes	Yes
15	21.800	17.000	67	75	256	124	0	0	13	15	No	Yes

Formulation of the null hypothesis H0 and alternative hypothesis H1

The first step is to formulate two statistical hypotheses that make a proposition about the characteristic properties of a probability distribution or parameters of a model [30]. These are on the one hand the null hypothesis H0 and on the other hand, the alternative hypothesis H1 (also referred to as HA [31]). They are called difference hypotheses, which typically determine differences in means or frequencies. The verification of a hypothesis is differentiable in a one- or two-sided test [32, 33].

A one-sided test is useful when specific premonitions concerning the differences or the direction of effect are available [34]. Otherwise, a two-sided test should be carried out [35]. Figure 5 shows the confidence interval and the interval limits of the two-sided test.

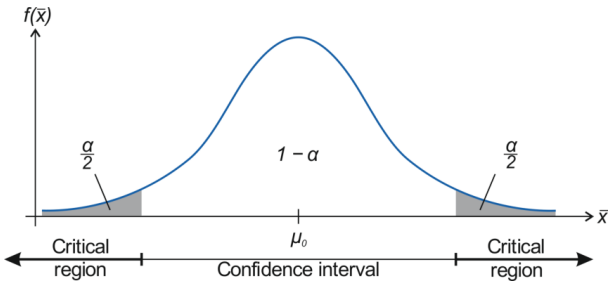

Fig. 5. Illustration of two-sided-test [36].

Based on the described topic of the business game, it is of interest to determine whether deviations in one or two directions are to be identified. In light of this view and the lacking premonition, the hypotheses per KPI have been subjected to a two-sided test.

Model KPI 'Adherence to delivery date'

$$H_{0_T} : H_{0_T} - H_{1_T} = 0.$$

"On average, the use of Kanban and Standard Worksheet leads to the same value of the KPI 'Adherence to delivery date'."

$$H_{1_T} : H_{0_T} - H_{1_T} \neq 0.$$

"On average, the use of Kanban and Standard Worksheet leads to a smaller or larger value of the KPI 'Adherence to delivery date'."

Model KPI 'Inventory Costs'

$$H_{0_C} : \mu_{1_C} = \mu_{0_C}.$$

"On average, the use of Kanban and Standard Worksheet leads to the same value of the KPI 'Inventory Costs'."

$$H_{1_C} : \mu_{1_C} \neq \mu_{0_C}.$$

"On average, the use of Kanban and Standard Worksheet leads to a smaller or larger value of the KPI 'Inventory Costs'."

Model KPI 'Number of Reworks'

$$H_{0_R} : \mu_{1_R} = \mu_{0_R}.$$

"On average, the use of Kanban and Standard Worksheet leads to the same value of the KPI 'Number of reworks'."

$$H_{1_R} : \mu_{1_R} \neq \mu_{0_R}.$$

"On average, the use of Kanban and Standard Worksheet leads to a smaller or larger value of the KPI 'Number of reworks'."

Determination of the α-significance level

The second step is used to determine the α-significance level (error probability) and is often considered by a value of 0.05 (5%) in specialist literature [28, 37]. We use this value for further analysis. According to Hartmann and Lois [28] a significance level of $\alpha = 0.05$ is classified as 'significant'.

Specification of the test statistics and distribution of the null hypothesis

In this study, two test methods are used to analyze the data: first, the two proportions test and second, the paired t-test. The implementation is carried out using the statistical software Minitab®.

Two proportions test

Due to the nominal scaling (binary/dichotomic characteristic [38]) of the KPI 'Adherence to delivery date' (yes/no), the 'two proportions test' is to be conducted. This test method examines whether a difference is likely to be detectable between two readings, taken before and after each use of the method [39] (e.g. within a process improvement) [40]. The prerequisite for this is that the data may merely assume two values (e.g. yes/no) [40].

α-significance level	: 0.05 (5%)
Confidence interval	: 0.95 (95%)

The application of the assay of proportions by Minitab® provides the results shown in Table 2.

Table 2
Results 'two proportion test'.

KPI	Number of on-time delivery without methods	Number of on-time delivery with methods	95%-CI	p-value (by Fisher)
Adherence to delivery date	29	39	−0.429740; −0.109221	0.003

Model KPI 'Adherence to delivery date'

The absolute values of the data used for the KPI 'Adherence to delivery date' provide the result that on-time delivery could be increased by approx. 35%. The two proportions test confirms this improvement in the KPI. According to Held and Bové [41], the output p-value in line with Fisher's exact method can be regarded as 'substantial proof' against the null hypothesis. This test result suggests using optimization methods. It can be interpreted that there is a statistically significant effect of improving the KPI using process optimization methods.

$$p < \alpha = 0.003 < 0.05$$

Based on this, H_{0_T} can be rejected.

$$\text{Reject } H_{0_T}$$

Paired t-test

The t-test verifies that there is a significant difference between the two sample means [42]. The criteria relevant for the application of the 'paired t-test' were taken from literature. The presence of a related sample is a two-sample test, which consists of two cycles. The first cycle represents the preliminary study without the use of measures, the second the re-examination after the use of measures aimed at determining the effectiveness of the action [43].

Another criterion to be considered when specifying the test procedure is the distribution of sample data, with the normal distribution representing the most significant distribution form [30]. However, if the sample size is $\geq$ 30 pairs of measurements, it is unnecessary to use a test method according to Anderson-Darling, Ryan-Joiner, Kolmogorov-Smirnov, and Shapiro-Wilk [44].

Sample number	: two-sided-test
Sample type	: paired
Sample size (n)	: 40
α-Significance level	: 0.05 (5%)
Confidence interval	: 0.95 (95%)

Minitab® generates the values in Table 3 from the collected data for the paired t-test.

Model KPI 'Number of reworks'

The application of the process optimization methods shows an effect on the absolute average values of 'Numbers of reworks'. The number of reworks was reduced by ≈51% – from 33 to 17. Optimizing the number of reworks can be seen as a significant difference. This is substantiated by the determined t- and p-values.

$$t > t_{\text{critical}} = 2.45 > 2.0227$$
$$p < \alpha = 0.019 < 0.05$$

Table 3
Results of paired t-test for matched pairs.

KPI	Method used	$\overline{y}$	s	$s_{\overline{y}}$	$\overline{d}$	s_d	$s_{\overline{d}}$	95%-CI for $\overline{d}$	p	t	t_{critical}
Number of rework	No	0.825	0.931	0.147	0.400	1.033	0.163	0.070; 0.730	0.019	2.45	2.0227
	Yes	0.425	0.594	0.094							
Inventory costs	No	44.250	45.306	7.164	2.723	65.645	10.379	−18.272; 23.717	0.794	0.26	2.0227
	Yes	41.528	54.516	8.620							

The t-value is greater than t_{critical} and the p-value is about 40% less than α. According to the authors Held and Bové [41], the p-value is to be regarded as 'weak proof' against H_{0_R}, however, the null hypothesis H_{0_R} must be refuted.

$$\boxed{\text{Reject } H_{0_R}}$$

Model KPI 'Inventory Costs'

The direct comparison of both averages shows that the use of methods reduces inventory costs from 44.250€ to 41.528€ (about −6%). Accordingly, the total amount of inventory costs will decrease from 1.770.000€ to 1.661.100€. While the absolute values show an improvement in the KPI, the determined t and p values speak for the formulated thesis (H_{0_C}). It can be deduced that the improvement gained by the use of process optimization methods cannot be proved as a statistically significant effect.

$$\boxed{\begin{array}{c} t < t_{\text{critical}} = 0.26 < 2.0227 \\ p > \alpha = 0.794 > 0.05 \end{array}}$$

According to Held and Bové [41], the p-value is to be classified as 'no proof' against H_{0_C}. As a result of these values, a rejection of the null hypothesis H_{0_C} cannot be performed because a significant difference could not be detected.

$$\boxed{\text{Keep } H_{0_C}}$$

Conclusion

This paper reviews the following research question:

Can the improvement of defined KPIs be demonstrated by using "Kanban" and "Standard Worksheet" within a business game in companies?

Comparing autonomous teams with teams using "Kanban" and "Standard Worksheet" leads to diverse results regarding three relevant KPIs.

Two of the three selected KPIs show, that teams using "Kanban" and "Standard Worksheet" gained better results than the autonomous ones: The KPIs 'adherence to delivery date' and 'number of reworks' lead to a better value using "Kanban" and "Standard Worksheet" than not using them. The KPI 'Inventory Costs', on the other hand, cannot be improved by using those two lean methods. There does not exist a statistical difference compared with the autonomous team.

This business game was carried out in various companies with numerous employees. The demonstrated significant effects of the KPIs 'adherence to delivery date' and 'number of reworks' can be attributed to the methods used. Kanban allows a demand-oriented and self-controlling material supply in exact quantities. This primarily ensures the supply of materials and there are no bottlenecks. Kanban respectively the Kanban card also provides a visualization of the required materials. A delivery of wrong and/or defective parts is thus counteracted. Easy and exact filling of the Kanban bins is ensured as well as the provision at the correct place of the requirement (production place).

A Standard Work Sheet also provides this visual support. It standardizes the assembly steps and serves as an assembly instruction for each operation. The subjects thus receive detailed information about each process/assembly step and can clearly see how and where the components have to be put together/assembled. By standardizing the operations and the continuous material supply, it can be assumed that the improvement of the KPIs, 'adherence to delivery date' and 'number of reworks' will, therefore, be achieved.

Nevertheless, there is still uncertainty concerning learning effects and their influence on the test result. These issues should be finally kept in mind when interpreting the results of the statistical hypothesis testing.

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