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SIMULATION ANALYSIS OF A PRODUCTION PROCESS WITH SELECTED SIX SIGMA RATIOS

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ABSTRACT. Background: Computer technologies allow more and more to model as well as to perform simulation experiments of various processes. The simulation analysis provides a better understanding of the interdependencies between various stages of production processes.

Methods: The results of simulation studies were presented, the aim of them was to show the opportunities of the analysis of the process according to the scenarios and variants developed in connection with the qualitative assessment process. The study was based on simulation models developed and programmed for the processing of parts in an automated production line. The results of the conducted simulation experiments were referred to the primary ratios of the system work like the use of machines and other means of production, capacity, number of defects, etc. The analysis of the process was expanded by the qualitative assessment, based on selected ratios used in Six Sigma methodology.

Results: The significant influence of the identification of so-called "hidden factories" in the production process on the value of sigma level was observed.

Conclusions: The application of Six Sigma methodology and its statistical methods has a significant importance in the estimation and improvement of processes. The identification and the choice of number of inspection points are important for the monitoring and evaluation of the whole process. The obtained results confirmed the earlier assumptions of great importance of "hidden factories". Not revealing them influences significantly the quality of a process.

Key words: production line, manufacturing, modeling, simulation, Six Sigma

INTRODUCTION

The Six Sigma concept is used to improve the product quality and to reduce the amount of defected products, mainly by the changes in the organization of the production process as well as by the continuous monitoring of processes and their parameters. The application of statistical methods for the improvement of processes, where there is a big impact of human factor, proved to be useful also in such areas of activities like researches, development and innovations. The efforts of Six Sigma are directed to strategical improvement of business activities by the use of tools for analytical and design management [Barney, McCarty 2005]. It should be noted, that the improvement of financial results by the improvement of the quality is the main purpose of its application. The increasing interest in the implementation of Six Sigma methodology is shown by most of big companies, as well as small an medium ones. It is a results of the continuos aspirations to improve the quality in time of strong competition and the tendency of reducing costs [Wessel, Burcher 2004, Bratić 2011].

The Six Sigma strategy is based mainly on the measurement of actions' effectiveness, which should be measured at each step of the primary and secondary processes. The sigma level determines the fractions of incompatibilities in processes, which could occur during its implementation. The process of counting of incompatibilities allows comparing processes, which seem to be incomparable and it is the main advantage of this concept.

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To estimate the effectiveness (called sigma level), the following ratios are used: DPU (defects per unit), DPO (defects per opportunity) and DPMO (defects per million opportunities). The above-mentioned sigma level can be determined based on calculated number of defects. In qualitative terms, the higher the sigma level, the lower the probability of the defect. It should be noticed, that an average company operates usually at the sigma level equal to 3-4. In case the sigma level is under 3, the companies are not able to survive on the competitive market and the cost associated with the securing of the quality is equal to 25-40% of incomes from the sale [Wodecka-Hyjek, Walczak 2006; Harry, Schroeder 2001].

Analyzing the process in terms of sigma level, the value of this level can be calculated for any stage of the process as well as for the whole process. The choice of the place of measurement, the measurement methods and methods of processing and handling of data are of great significance in Six Sigma concept. The choice of measurement points should be determined by the steps critical for the quality of a process and its costs. The operations related to measurement and data collection should be conducted fairly and reflect the real process. Only information gathered in such a way can be used in the process of the analysis and the improvement [Hamrol 2005, Shetwan, Vitanov, Tjahjone 2011].

It should be considered that the sigma level at the output of the process could be different, and even lower, than at its various stages. Depending on the characteristics of the process, there can be such cases, that the incompatibility disqualifies a production unit (defect/lack) and/or the incompatibility can be removed and restored in the process (incompatible unit/fixable). Therefore, there is a possibility of a situation that the calculated sigma level do not reflect the actual level of the process quality. It does not take into account the impact of additional activities, so called “hidden factories”. The evaluation of such state can be conducted by the determination of the probabilities of the incompatibility in various stages of the process. The ratio TY (Throughput Yield) is used to determine the probability of no incompatibility in a single production unit in a given operation of the process. The indication RTY (Rolled-Throughput Yield) is used to estimate the whole process. It gives the probability that the individual finished part, leaving the production is without any incompatibility [Pyzdek 2003]. In case, when the ratio RTY is higher than the product of ratios TY of analyzed stages of the process, it should be assumed, that the additional operations (in order to remove incompatibilities) are taken at some stages of the process and they should be taken into account during the evaluation of the quality of a process.

The process of modelling of complex processes and simulations of dynamic analysis of processes play the increasing role in many modern business areas like industry, logistics, telecommunications, services and public sector. The simulations are defined as numerical techniques, used to carry out the experiments on certain types of mathematical models, which describe the behaviour of a complex system in long period by the use of a digital machine. The processes, which already exist as well as these at the design stage, can be modeled and simulated. The computer simulation of the process enables the analysis and the optimization of processes without the need for costly and time-consuming experiments on real objects.

Summary, the aim of the use of simulation models presented in this paper, is to find optimal solutions for the processes analyzed in terms of the performance, finding the critical points or the prediction of the behavior of the production system under certain conditions. In this context, the attention of the research was focused on the simulation of the real industrial case. The aim of both this analysis and this study was to compare the results obtained from computer simulations of the various variants of the production line, whose effectiveness was evaluated by the use of selected ratios used in Six Sigma methodology.

SAMPLE ANALYSIS OF A PROCESS

The model of a system was based on the production line of an automobile company. The line consists of series of workstations, connected by the common transport system. The scheme of this line is presented on the Figure 1. *Workstation 1* and both stands *Inspection 1* and *Inspection 2* consist of homogeneous machines of equal process capabilities (processing, measuring and control ones). The stands *Workstation 2* and *Workstation 3 as* well as *Packager* are a single machine.

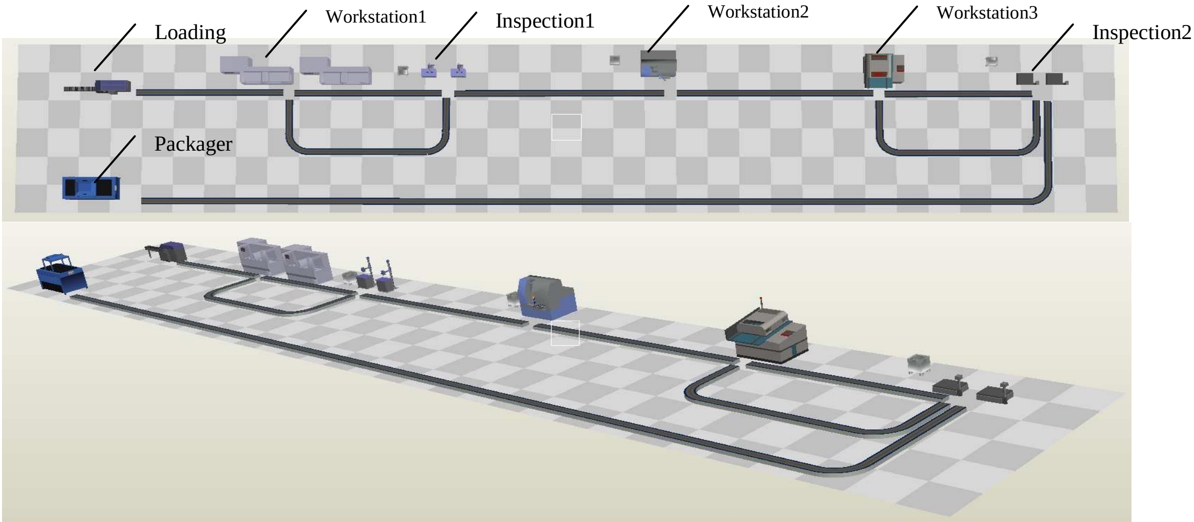

Fig. 1. The layout of workstations of a production line
Rys. 1. Rozmieszczenie stanowisk (layout) linii produkcyjnej

The different workstations work according to parameters related to number of parts processed simultaneously at this workstation, the processing time (specified deterministically or stochastically) and setups, characterized by their duration and number of operations, after which they appear (Table 1).

Table 1. Parameters of workstations in the analyzed production line
Tabela 1. Parametry pracy stanowisk w analizowanej linii produkcyjnej

	Workstation	processing block [pieces]	Processing time [min]	change-over time [min]	number of operations before the change-over [pieces]
1	Workstation 1	6	TRIANGLE (5.5,6.0,7.2,6)	1	10
2	Workstation 2	10	TRIANGLE (2.7,3.0,5.1,7)	0,5	5
3	Workstation 3	5	TRIANGLE (1.8,2.0,2.2,8)	0,3	10
4	Inspection 1	1	1	0,2	1
5	Inspection 2	2	1	0,25	1
6	Packager	60	5	3	1

It can be observed based on the above data, that there is no synchronicity of processing operations in the presented process and therefore the continuity of the production process is disrupted. The tact of the conveyor is 0,1 min, and the maximum number of parts on individual sections are successively 30, 30, 20, 30 15 and 80 pieces in main transport route and 20 pieces in both secondary transport routes of "hidden factories" (Fig. 2).

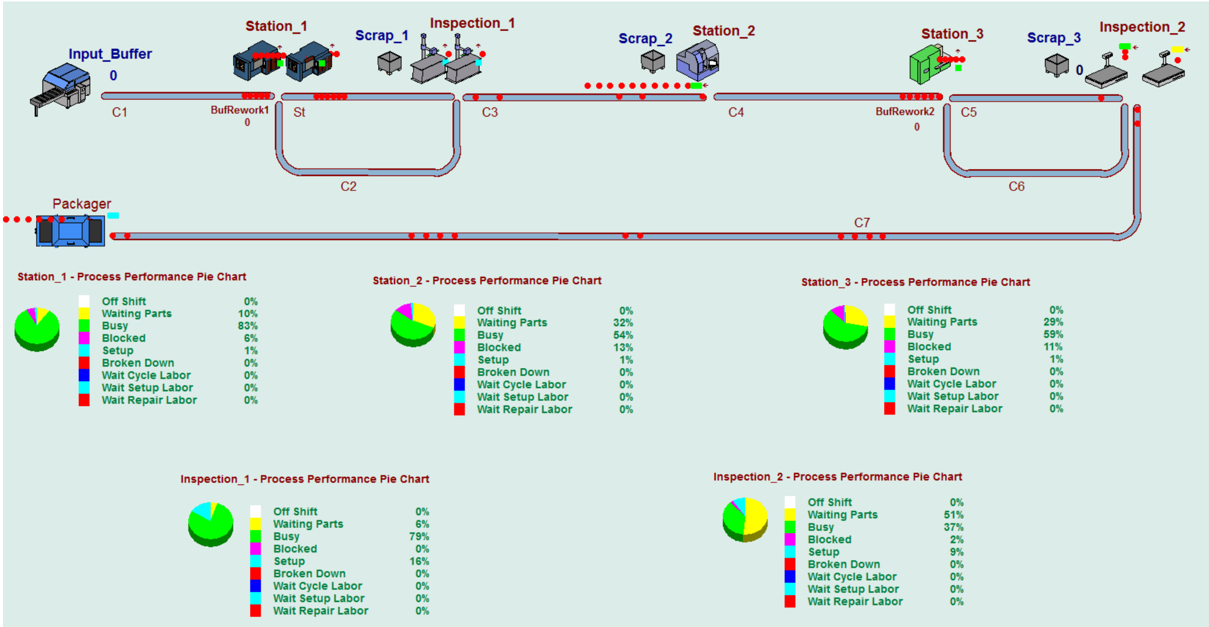

Fig. 2. The analyzed model of the process according to the simulation scenario 1
Rys. 2. Analizowany model procesu po symulacji według scenariusza 1

It was assumed that the defects are generated at the *Workstation 1* and *Workstation 3*. The probability of their appearance was calculated based on historical data obtained in previous implementation of the process using machines now used in these positions. The computer simulations were carried out for these values and they were defined as a scenario 1. The additional operations were assumed to be taken in the scenario 2. Their aim was to reduce the number of defects. The improvement of all stages was assumed to be done by eliminating inconsistencies and focusing on the right organization of the process, using methods and techniques of quality improvement tools, so called TQM. The right organization of processes, training of the technical personnel, investments and implementation of methods to prevent defects (Poka-yoke) are to aim to the total elimination of defects at the workstations *Workstation 1* and *Workstation 2*, and a number of defects are to be reduced significantly. The average percentage values of a good production are presented in the table 2.

Table 2. The average level of a good production for the analyzed scenarios
Tabela 2. Średni poziom dobrej produkcji dla analizowanych scenariuszy

	Workstation 1	Workstation 3
Scenario 1	93%	98%
Scenario 2	98%	99,9%

The experiments were conducted for both scenarios, performing five consecutive replications, each of 2880 min, for each scenario. The time of the initial instability of the process (warm-up period) was set at 960 min. On basis of obtained data, the number of parts made in given period of time increases from 4320 to 4380 pieces. It should be noted that, the increase of the productivity was obtained without any changes in parameters of various workstations of the production line and it was only the result of improvement of the process at the workstations.

The number of irreparable defects decreased by 33.3% in scenario 2 in analyzed period and the number of parts, which had to be reprocessed, decreased significantly. The data are presented in the table 3.

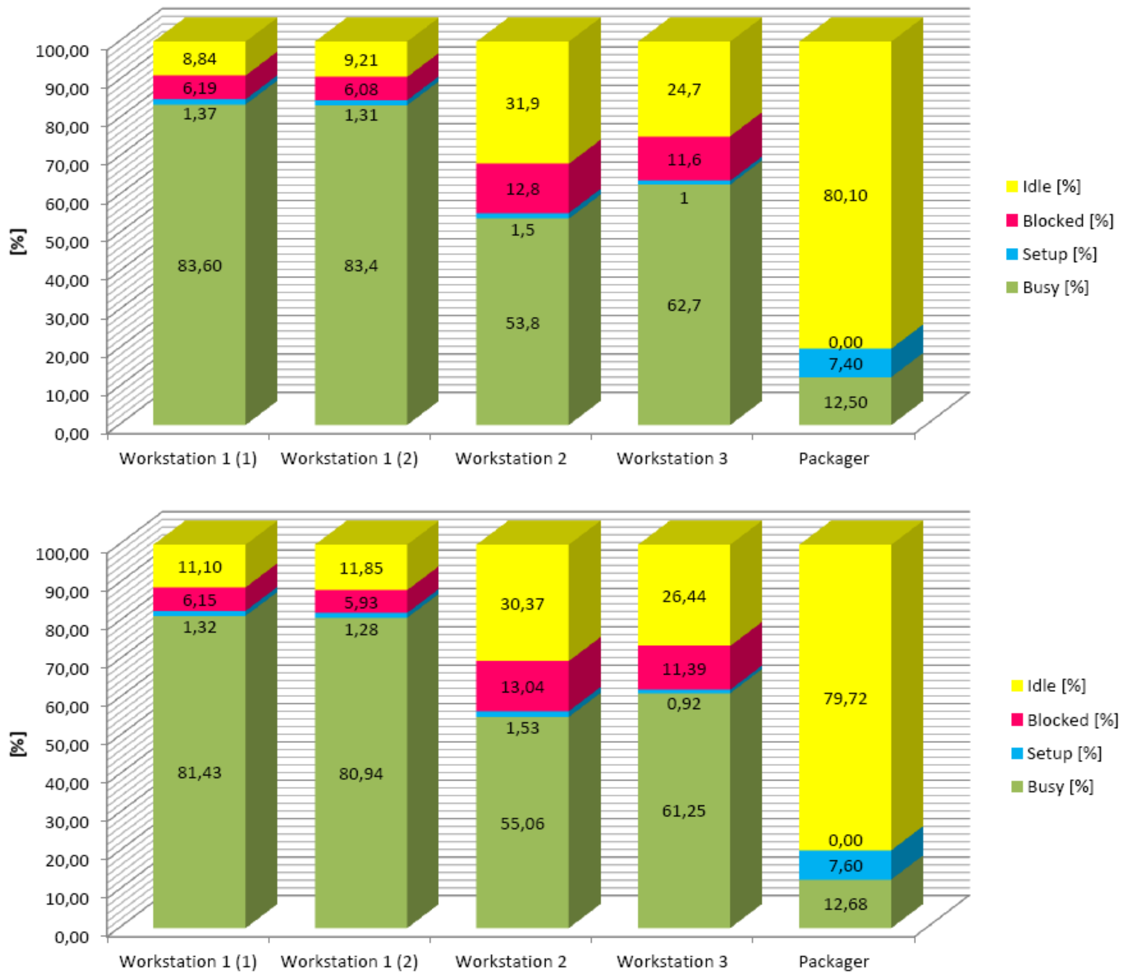

Fig. 3. The average percentage usage of workstations in scenarios 1 (a) and 2 (b)
Rys. 3. Średnie procentowe wartości wykorzystania stanowisk w scenariuszach 1 (a) i 2 (b)

It can be concluded on the basis of the date presented in the figure 3, that the parameters of the use of each particular means of production did not change significantly and the differences were up to 2,5%. The improvement of the organization of a process should be the next step, which will result in the increase of the productivity and better utilization of the system.

Table 3. The average number of defects for the four variants of analyzed scenarios
Tabela 3. Średnie liczby jednostek niezgodnych dla analizowanych scenariuszy z uwzględnieniem czterech wariantów

	Variant 1	Variant 2	Variant 3	Variant 4
Scenario 1	0	413	264	677
Scenario 2	0	125	14	139

In order to show the influence of "hidden factories" on the value of sigma level, a few variants of calculations were conducted. The Variant 1 represents a situation where the steps of restoring the reparable defects at any stage of the process are not taken into account at the determination of sigma level. Therefore, it is assumed in this variant, that no "hidden factories" were identified. The sigma level of 4,11 to 4,45, obtained in this case, does not correspond with the real quality of the process.

After revealing "hidden factories" (respectively workstations 1 and 3 in variants 2 and 3), the value of sigma level was from 2,78 to 4,10 (Fig. 4).

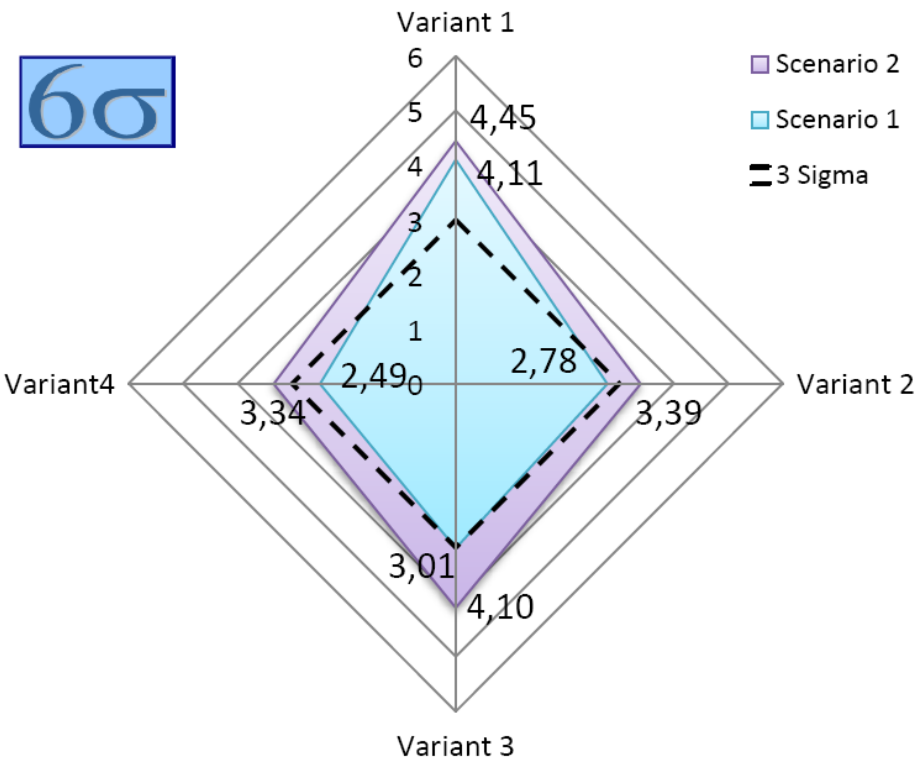

Fig. 4. The average values of sigma level for four variants of analyzed scenarios
Rys. 4. Średnie wartości poziomu sigma dla analizowanych scenariuszy z uwzględnieniem czterech wariantów

The value of sigma level decreased rapidly after revealing „hidden factories" in the production process (Variant 4). It is particularly evident in the scenario 1, where the value was reduced by almost 40%. However, in the scenario, where the activities for the improvement of a process were undertaken, the value was reduced from 4,45 to 3,34 (by 25%). The simulation of a process, which takes into account parameters of the whole process, shows the scale of actions, which should be undertaken to improve the production process or one of its parts in order to obtain the better value of sigma level.

SUMMARY

The application of Six Sigma methodology and its statistical methods has a significant importance in the estimation and the improvement of processes. It allows determining the sigma level for various processes and enables to compare them. The identification and the choice of number of inspection points are important for the monitoring and evaluation of the whole process. The results of the simulation process were presented, which, enriched by the qualitative analysis of the process (based on the calculation of the sigma level), give a comprehensive picture of the conducted system, which does not focus only on its efficiency and its utilization. In the case of the analyzed production line, it was proved to be important to disclose "hidden factories" at different stages of production. The comparison of the values of sigma levels achieved for the developed scenarios and variants allows a complete analysis of the process. The obtained results confirmed the previous assertions of great importance of "hidden factories" as well as the fact that if they are not disclosed, it significantly affects the quality of the process. Summary, the combination of simulation analysis of the system with the simultaneous evaluation of numeric model gives the potential to prepare assumptions and conclusions of the behavior of real systems. It gives, therefore, the possibility of the estimation of scenarios, impossible of difficult to be conducted in real conditions. Therefore, the managers become the option to analyze existing processes in order to improve them.

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ANALIZA SYMULACYJNA PROCESU PRODUKCYJNEGO Z UWZGLĘDNIENIEM WYBRANYCH MIERNIKÓW SIX SIGMA

STRESZCZENIE. **Wstęp**: Obecnie narzędzia komputerowe pozwalają w coraz większym zakresie modelować i przeprowadzać eksperymenty symulacyjne procesów i zjawisk. Analiza symulacyjna umożliwia lepsze zrozumienie współzależności pomiędzy etapami realizacji poszczególnych procesów produkcyjnych.

Metody: Przedstawiono wyniki badań symulacyjnych, których celem było pokazanie możliwości analizy przebiegu procesu wg opracowanych scenariuszy i wariantów w powiązaniu z oceną jakościową procesu. Badania oparto o modele symulacyjne opracowane i oprogramowane dla przetwarzania części w zautomatyzowanej linii produkcyjnej. Wyniki dla przeprowadzonych eksperymentów symulacyjnych odniesiono do podstawowych wskaźników pracy systemu jak wykorzystanie maszyn i innych środków produkcji, wydajności, liczby jednostek niezgodnych itp. Analizę procesu poszerzono o ocenę jakościową, opartą o wybrane mierniki stosowane w metodologii Six Sigma.

Wyniki: Zaobserwowano znaczący wpływ identyfikacji tak zwanych "ukrytych fabryk" w systemie produkcyjnym na wartość poziomu sigma.

Wnioski: Zastosowanie metodologii Six Sigma, wykorzystującej statystyczne metody analizy, ma duże znaczenie w ocenie i usprawnianiu procesów. Identyfikacja, dobór liczby i miejsc inspekcji ma duże znaczenie dla kontroli i oceny całego procesu. Zestawienie uzyskanych poziomów sigma dla opracowanych scenariuszy i wariantów pozwala na pełną analizę przebiegu procesu. Uzyskane wyniki potwierdziły wcześniejsze twierdzenia o dużym znaczeniu "ukrytych fabryk", a fakt ich nieujawnienia znacząco wpływa na jakość procesu.

Słowa kluczowe: linia produkcyjna, wytwarzanie, modelowanie, symulacja, Six Sigma

SIMULATIONSANALYSE DES PRODUKTIONSPROZESSES MIT BERÜCKSICHTIGUNG AUSGEWÄHLTER SIX SIGMA-MESSWERTE

ZUSAMMENFASSUNG. Einleitung: Rechnerunterstützte Werkzeuge ermöglichen heutzutage bei Erkundung von Prozessen und technischen Erscheinungen in einem immer größer werdenden Ausmaße, Simulationsexperimente zu modellieren und durchzuführen. Demzufolge erlaubt die Simulationsanalyse, die Zusammenhänge, welche zwischen den Ausführungsetappen innerhalb von einzelnen Produktionsprozessen vorkommen, besser zu verstehen.
Methoden: Im Rahmen der dargestellten Simulationsversuche wurden Möglichkeiten ausgearbeiteter Szenarien und Varianten, verbunden mit Qualitätsbewertung des jeweiligen Prozesses durchgeführt und dessen Verlauf aufgezeigt. Die Versuche waren auf die Simulationsmodelle gestützt, die für die Zwecke der Verarbeitung von Teilen innerhalb einer vollautomatisierten Fertigungslinie konzipiert und programmiert wurden. Die Ergebnisse der durchgeführten Simulationsexperimente wurden auf die grundlegenden Kennziffern der Arbeit des Systems, wie Auslastung der Maschinen und anderer Produktionsmittel, Produktionsleistung, Anzahl von Ausschuss-Einheiten u. ä. bezogen. Die Prozess-Analyse wurde mit der Six Sigma-Technologie und den angewendeten Messwerten ergänzt.
Ergebnisse: Es wurde ein weitgehender Einfluss der Identifikation der sog. "versteckten Fabriken" im Produktionssystem auf das Niveau des Sigma-Wertes wahrgenommen.
Fazit: Die Anwendung der Six Sigma-Technologie hat eine große Bedeutung bei der Bewertung und Vervollkommnung der Prozesse. Identifikation, Auswahl der Anzahl und Orte der durchzuführenden Inspektionen spielen eine große Rolle bei der Kontrolle und Bewertung des Gesamtprozesses. Die Zusammenstellung des ermittelten Sigma-Niveaus für die ausgearbeiteten Szenarien und Varianten erlaubt eine vollständige Analyse des Verlaufs eines Prozesses. Die gewonnenen Ergebnisse haben frühere Feststellungen bezügl. der großen Bedeutung der "versteckten Fabriken" bestätigt, wobei die Tatsache deren Nichtaufzeigens wesentlich die Qualität des Prozesses beeinflusst.

Codewörter: Produktionslinie, Fertigung, Modellierung, Simulation, Six Sigma.

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