

HYBRID FLEXIBLE APPROACH FOR SIX SIGMA IMPLEMENTATION IN CONSTRUCTIONAL SME

Jerzy PASLAWSKI

*Division of Construction Engineering and Management, Faculty of Civil and Environmental Engineering,
Institute of Structural Engineering, Poznan University of Technology, Poznan, Poland*

Received 11 Jan. 2013; accepted 7 May 2013

Abstract. Possibility of Six Sigma implementation in small/medium enterprise (SME) in construction industry is the goal of this paper. Robust conception of Six Sigma is taken as one option of flexible approach used in construction industry for risk management. High level of risk on the operations management is very important feature in comparison between construction industry and other economy branches. This problem is connected with very restricted level of automation and robotics, influenced environment, etc. Hierarchical culture with fragmentation of activity and low cost preferences as typical approach in construction industry seems to be important reasons of problems in Six Sigma implementation process. Presented conception is based on hybrid approach for flexibility implementation: robustness (Six Sigma), adaptation, simplification (Japan flexibility school) and modification of organizational culture. All four elements were fitted together for achievement of synergy effect.

Keywords: Six Sigma; hybrid approach; flexibility; organization culture.

Reference to this paper should be made as follows: Paslawski, J. 2013. Hybrid flexible approach for Six Sigma implementation in constructional SME, *Journal of Civil Engineering and Management* 19(5): 718–727.
<http://dx.doi.org/10.3846/13923730.2013.804433>

Introduction

The specific character of the construction industry is characterized by the presence of much higher risk and uncertainty at the operational level than in enterprises of other branches of the economy. Problems in achieving conformity between actual stages of construction process in progress with their planned course are an essential result of that situation. Dynamic changes of the environment resulting in variable results of the operations are one of the crucial causes of the problem. The purpose of robustness in this approach is to guarantee the desired results irrespective of the changes occurring in the environment. With the definitions of flexibility (Paslawski 2011) as the basis, we can assume that robustness is one of the two principal options of flexibility (adaptability, the complementing one, can be understood as possibility of relatively quick adjustment on the basis of e.g. monitoring of the relevant parameters of the process and environment).

If we consider the general trends in the development of management three basic directions come to the fore:

- In the sphere of quality management – Six Sigma;

- In the sphere of production management – Lean Management;
- In the sphere of IT – application of Supply Chain Management approach.

The present article focuses primarily on implementation of Six Sigma concept which, in view of common occurrence of quality problems in construction industry, merits particular attention.

The purpose of the presented concept, therefore, is to find a formula of Six Sigma concept implementation in Construction Management using the hybrid approach. A typical hybrid approach (Six Sigma + Lean Management + Supply Chain Management) need not be the only possible solution. We have shown through the analysis of examples from the literature, as well as our own Case Study that it is very unlikely to expect positive results from application of the Six Sigma approach alone.

1. The role of Six Sigma in management development

When analysing activities of a construction enterprise in the twenty-first century against the background of development trends of organizations operating in other fields of the economy, we can indicate several management concepts aimed at the success of an

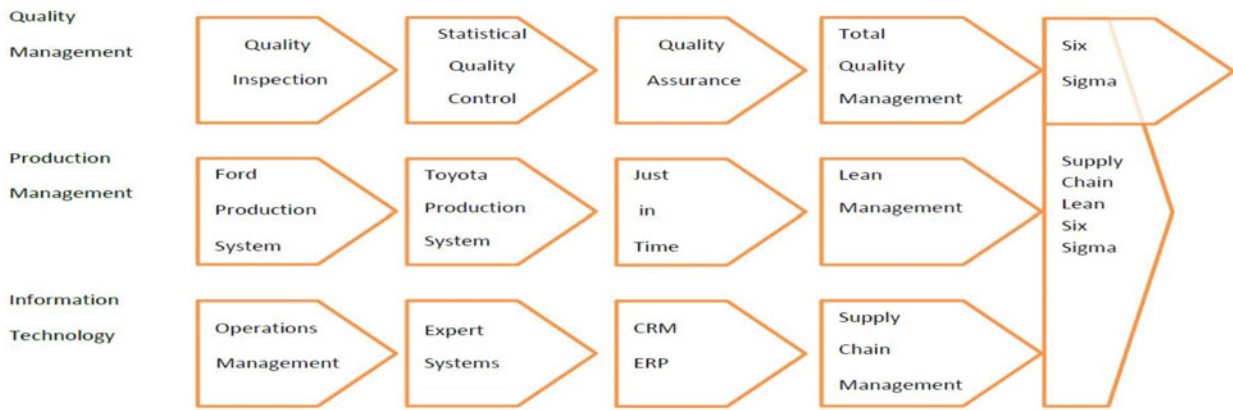


Fig. 1. Key topics in management development

organization which has to operate within the dynamically changing environment. The examples of directions of development (Fig. 1) include (Furterer 2009a, b; Sullivan 2011):

- Just-in-Time;
- Total Quality Management;
- Lean Management;
- Six Sigma;
- Supply Chain Management.

It seems that the above directions seeking to reduce waiting time, restrict time or storage space reserves, create standard operating procedures or restrict losses and unnecessary operations reveal considerable advantages, which enable construction enterprises to develop and survive in the competitive markets at both regional and global levels. Six Sigma plays an important role in the development of management methods for ensuring the practical effect of production reliability (“zero defects”). The main objective of the Six Sigma methodology is the implementation of a measurement-based strategy that focuses on process improvement and variation reduction.

Client’s satisfaction with the product/service offered is a typical goal of quality management. This satisfaction is based to a considerable degree on product reliability, which means absence of defects, and not only during takeover and initial operation. It also means client’s satisfaction over the relatively long period of use without defects, which in certain sectors of construction industry may go up to 100 years or more (church buildings, etc.). Returning to the history of quality management, we may point out a period (the seventies are often mentioned in that context, although it will depend on the branch of industry and the geographical location, naturally) when a certain level of defects was acceptable (e.g. about 40% in the production of color kinescopes in Poland in mid 1990s). The end of such approach and shifting of emphasis from passive quality management (based on detection of errors and correcting them after they occur) to proactive approach (forecasting and preven-

tion of quality problems) worldwide is dated to the 1950s, and the beginnings of TQM are often assumed to have taken place in the 1980s. The slogans of one of the precursors of the Total Quality Management, “Zero defects” and “Quality is Free” (Crosby 1979), seem to be difficult to achieve in the construction industry despite all the time that has passed, and rather considerable involvement of the construction sector in popularization, publishing and maintenance of certified quality management systems.

Against this background the opinions about declining interest of scientific workers in quality management come as no wonder. On the other hand, when we look at the slow pace of change in the sphere of quality management in Poland and the neighboring countries, the importance of cultural differences for the success of this action becomes clearly visible. Of course the involvement of the operational level employees is crucial there, since implementation of the idea of Total Quality Management stirs up no reservations at the strategic level.

The limited interest of scientific workers (defined by the share of quality management in the subject matter of scientific papers in the sphere of the Construction Management) in Six Sigma during the last decade (Abudayyeh *et al.* 2004; Crawford *et al.* 2006; Hua 2008; Kaplinski 2009; Kwak, Anbari 2009; Pietroforte, Stefani 2004; Tamošaitiene *et al.* 2010; Xue *et al.* 2012) rises certain concerns. At the same time, problems with exceeding project execution time and budget are frequent not only in construction industries of Poland or the Eastern Europe, but also of the USA as well (Sullivan 2011). The simplicity of the Six Sigma method and the divergence between the interests of scientific workers and those engaged in practical work confirmed by Kaplinski (2009) may be the potential causes of this state of affairs.

From the point of view of practical management of building production the critical opinion on the possibility of achieving Six Sigma level by improvement of the process can be substantiated. It has been confirmed by the examples discussed in the literature

as well (Pheng, Hui 2004; Koziok, Derlukiewicz 2012; Stewart, Spencer 2006). However, when we compare it with the market requirements, it is precisely this direction which has to be pointed out as the one needing practical support, without going in deep into current trends in the sphere of the Construction Management. The approach aimed at finding a formula confirming the possibility of effective utilization of the new ideas seems to be correct, since finding examples against it looks much easier. If we acknowledge inconsiderable interest in implementation of Six Sigma in production processes in the construction industry, the following question should be put forward: is it possible to find an approach facilitating positive effects of implementation of Six Sigma in Construction Management?

Idea of Six Sigma as a business management strategy had been invented and developed many years ago. During 20–30 years had been introduced in many sectors of economy as a set of practices designated to improve manufacturing process and eliminate defects.

The Six Sigma approach comes from the notion that having six standard deviations between the process mean and the nearest specification limit practically no items will fail to meet specifications. The process variation seems that empirically based 1.5 sigma shift is introduced in the calculation. This shift was estimated from practice by Motorola and others and finally, the number of defects per million for long-term sigma quality is 3.4. Two goals in designing for Six Sigma are (Koch *et al.* 2004): (1) improvement of reliability (shifting the performance distribution relative to the constraints or specifications limits) and (2) improvement of robustness (shrinking in performance distribution to reduce the variability and sensitivity of the design). When analyzing improvement of production process based on changing level of six sigma (Fig. 2), one can find 66800 parts per million defective (PPM) for traditional three sigma level. Process Capability Index (C_p) is calculated taking into account the ratio of the difference between the upper (USL) and lower (LSL) specification limits and Six Sigma.

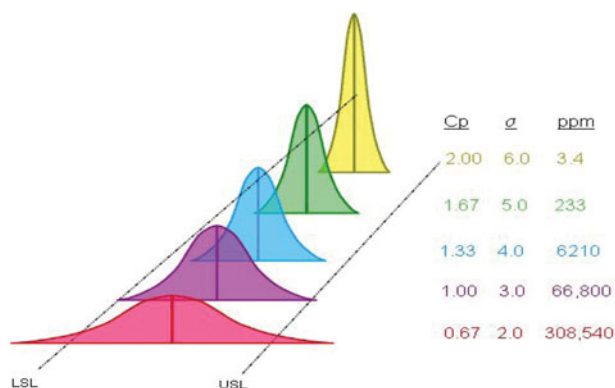


Fig. 2. General idea of Six Sigma approach (Produlog 2013)

Pande *et al.* (2000) formulated a definition of Six Sigma as follows: “Comprehensive and flexible system for achieving, maintaining and maximizing the success of Six Sigma is uniquely driven by close understanding of customer needs, disciplined use of facts, data and statistical analysis, and turning special attention to the management, improvement and discovery of business processes”. In this context, Six Sigma as a strategy of flexible manufacturing process ensures its robustness. The second strategy of flexibility is a strategy of adaptation, which is based on adjusting to a changing environment (Paslawski 2011).

2. Examples of Six Sigma application in the construction industry

First application of Six Sigma idea in construction industry had been dated during the first decade of the twenty-first century. Buggie (2000) has given as an example of application in construction industry by Han *et al.* (2008). Six Sigma defined by Buggie (2000) is an approach that focuses on intensive data collection, measurement and statistical analysis of operations. For new product/process this idea seems very difficult to implement. Buggie’s (2000) proposal was based on three-step procedure: (1) establish criteria, (2) generate solutions given by group of experts, and (3) adapt the best concepts to company operations. Six Sigma method was found as a procedure started out slow and expensive, especially for new product/process. Improvement of the overall quality of the product/service was given as the end result of six sigma procedure based on reduction of the product defect rate. The DMIAC (Define – Measure – Analyze – Improve – Control) and Performance Information Procurement System (PIPS) were methods of Six Sigma introduction in construction process elaborated by Kashiwagi (2004). Strong aspirations to implement Six Sigma in the construction industry were found by Kashiwagi as inconsequential, due to a price-based environment.

Very interesting applications of Six Sigma in the construction industry were given by Pheng and Hui (2004). This pioneered implementation in building organization (Housing and Development Board) in Singapore had been prepared for improving quality of internal finishes for public housing projects. This case study showed that the initial Six Sigma (2.66σ) had been transformed to 3.95σ (a goal had been lower – 3.8σ). The final suggestions were as follows: (1) underline role of management support, (2) relevant training, (3) appropriate selection of projects, and (4) commitment by team members. It seems interesting final sigma level achieved after 10-months training period (about 4σ).

An example of introduction of Six Sigma in Process Improvement Project (PIP) for production of concrete elements had been presented by Stewart and

Spencer (2006). This analysis was concentrated on productivity improvement in case study concerning construction of concrete longitudinal beams. Key element was late delivery of platform beams (forecasted delay was 8 weeks). Poor communication between different participants of production process was the main reason for this problem. General outcome of the Six Sigma PIP was the improvement of production process due to coordination between project's participants.

A method for Six Sigma implementation in construction operations had been presented by Han *et al.* (2008). For reaching a synergy effect based on combination of different techniques, the Six Sigma and Lean Management was taken into consideration. This conception had been proposed by Ballard (2000), Abdelhamid (2003) and others. In inventory management, lean management with near zero resource buffers seems inadequate for construction operations which have many discontinuous processes due to high level of uncertainty and risk (Horman, Thomas 2005). Finally proposed procedure is based on two phases: (1) improvement process through minimizing wastes and reducing variability, and so on, (2) modification of construction process by DMAIC to fit the construction operations. In the first case study concerning iron-reinforced bar assembling process, sigma level in the beginning was 1.41 with initial resource level 8.2 t. After process modification without modifying the buffer size the sigma level reached 1.72 only. Modification of the buffer size (using special software for simulation) increasing from 8.4 to 19.2 t (nearly maximum capacity) the sigma level improved from 1.72 to 6.0. But estimated cost of this change was extremely high and finally option with 3.64σ had been recommended. In the second case study (deck plate installation process) the sigma level was 1.41σ in the beginning. After first phase of process improvement it was changed to 1.72σ , and finally to 3.64σ .

An example of Six Sigma application in design process of construction equipment using design for Six Sigma (DFSS) approach was presented by Koziolok and Derlukiewicz 2012. "Five sigma" limit as a problem of stopping improvement by six sigma methodology was defined. A redesign of production process was given as a way to further improve the quality. This option could be very complicated and expensive. Implementation of DFSS was based on small set of critical requirements, for example:

- Critical to delivery – CTD;
- Critical to process – CTP;
- Critical to operation – CTO.

All critical to quality (CTQ) characteristics could be defined (especially in construction) using different tools (check list, Ishikawa diagram) and methods (Quality Function Deployment – QFD, Failure Mode and Effect Analysis – FMEA). The methodol-

ogy using more than one tool/method could be very useful. For improvement of construction process one can use Ishikawa diagram and FMEA analysis. Quality function deployment (House of Quality) is very useful to help in the identification of customer's requirements and translate them into controlled technical parameters. An analysis of different sources of non-conformances in designing and fabrication of construction vehicles and machines was presented by Koziolok and Derlukiewicz (2012). It was based on importance weights for different design requirements: safety, ecology, operation and economy, ergonomics and esthetics, mass, reliability, and manufacturability. Proposed DFSS methodology aids managers in decision-making concerning corrective actions and adopting new solutions for prevention of defects. Presented maximal value of Six Sigma level obtained was near 3σ .

Practical solutions for quality improvement in construction process of prefabricated composite structure using Six Sigma method was presented by Tchidi *et al.* (2012). The proposed approach is composed of three steps. First one is documentation of the process, productivity and quality based on data given by company staff, Six Sigma consultants, construction managers, engineers, clients and architects. Composed of five steps DMAIC procedure is a key element of the second phase. If Sigma level is not reaching 6, then phase three (Define – Characterize – Optimize – Verify approach) will be initiated. The DCOV method goal is to prevent defects and/or to redesign process. In Optimize step (third element of DCOV procedure) could be implemented some special tools like: Monte Carlo simulation, risk analysis software and finite element software. During 12 months of improvement quality Six Sigma level evolution from 2.2 to 5.0 is very significant but not sufficient. The redesign process and steel-concrete beam to surpass five sigma quality level had been proposed. This proposal is based on implementation of two chemical anchors in structure of steel-concrete beams. Three optional solutions for this conception had been verified using finite element analysis and on specimens with crush test. Combination of different tools and method helps to find and eliminate critical defects and failure before starting the production process.

3. Hybrid flexible approach in Six Sigma implementation in construction industry

Taking into consideration examples of application of Six Sigma approach in construction industry we can point out the following potential problems:

- The statistics of decision-making based on collected reliable data is the key to Six Sigma. The assumed possible drift by ca 1.5σ results

- from practical observations, not from theoretical calculations (Eckes 2001a), and in case of e.g. the construction industry may not be sufficient.
- As shown by the studies of working time losses the following (Eckes 2001a) such losses by operational employees reach as much as 50% of the total. After a period of such a situation being tolerated, employees begin to consider it as acceptable losses. They should be made aware that the improvement belongs to their scope of duties.
 - The dynamics of working teams has considerable importance. The principal problems in that field which have to be mentioned include inappropriate selection of personnel, and insufficient assistance from the leaders.
 - Combining both technical skills and the question of organizational culture change in Six Sigma process is a significant problem.
 - Treating Six Sigma implementation like a project (which has its end). Of course it is possible to undertake projects connected with implementation of Six Sigma at the initial stages. Following two–three years of working with Six Sigma, it is discipline as a daily practice in all the processes of an organization which should play the most important part.
 - Undertaking the activities typical for elimination of special causes when dealing with chance variations (Fig. 3). This cause of failure seems to be particularly important in relation to construction processes. As a rule construction processes are characterized by high variability.

- Absence of defined targets in the sphere of organizational culture change accompanying Six Sigma implementation and their efficient execution. The formulation of Eckes (2001b), who defined the effect of implementation as the product of advancement in the field of quality management and adjustment of the organizational culture to those changes, is symptomatic. It seems to be particularly important in the sphere of team-work and general committal (particularly in the construction industry).
- A large number of potential sources of disruptions of construction processes (people, methods, materials, environment, management, etc.), which makes it difficult to anticipate and prevent problems of quality.

Described issue due to the typical practice of designing of construction processes based on the average value. Commonly designers adopt the hypothesis that acceptance of the average values of the specification gives the correct result. However, this assumption is incorrect in many cases, because:

- Focusing on the average or most probable value involves the omission of the importance of the stress that can generate risks and opportunities;
- The production system does not take into account changes depending on the results of the surrounding environment can lead to significant losses (weather, road conditions, soil and water conditions, etc.);
- Assuming a normal distribution as the typical production processes in the construction industry often has no basis in reality (dominated by asymmetrical distributions);
- Construction processes are characterized by high complexity – problem lies not in the optimization of one process, but on the harmonization of several interdependent processes.

Analyzing the possibilities of application of Six Sigma in the management of construction processes it is necessary to point out the significance of process resistance to disturbances, as important in an open system as the dominant option of production execution conditions in construction industry.

However, the benefits of Six Sigma approach can be achieved only on the condition of stability in the construction process. This requires the simultaneous use of different process approaches (a hybrid approach). One example is the approach of Lean Six Sigma. In the hybrid approach, different problems could be taken into consideration– multicriteria analysis (Zavadskas *et al.* 2011; Zavadskas, Turskis 2011), risk management (Kashiwagi *et al.* 2009; Turskis *et al.* 2012), and, technological development (Slowik 2012; Ustinovichius *et al.* 2012).

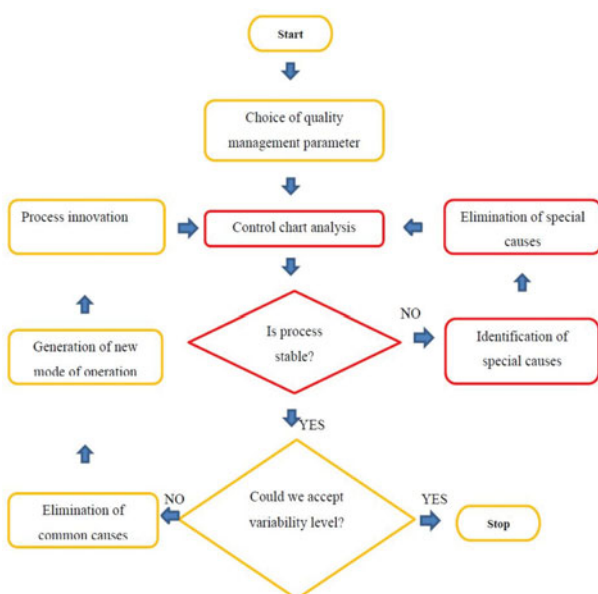


Fig. 3. Stabilization as a key element in quality management of construction process

In the integrated approach to Lean Six Sigma (Han *et al.* 2008) the typical activities resulting from the Lean Management concept, like:

- effective resources management (zero reserves);
- planning reliability;
- elimination of waste,

are supplemented by Six Sigma with:

- identification of critical factors;
- improvement process basing on the level of standard deviation of the analyzed results (achieved results);
- DMAIC procedure as the improvement standard.

Synergy between Lean Management and Six Sigma works in many areas of production.

However, the construction management that requires an ability to accommodate to changing environment (internal and external) is not this case. Examples of changes in the environment may be variable performance teams and machines (the internal environment), or changing weather conditions (the external environment).

These changes are the source of displacement distribution (drift), which can be countered by assuming the transition from aleatory approach (based on the unpredictability) to epistemic approach (based on the lack of information) in the management of risks and uncertainties. The source of missed information may be management support system based on the environmental monitoring and construction process in progress monitoring. Immediate adjustment of real-time system can reduce the drift to the limit values.

Analyzing developmental tendencies in the sphere of management we can indicate several trends aimed at application of flexibility both as dominating robustness and adaptability. Considering the above-mentioned problems, which appear very important aspect of efforts to stabilize the production process of construction should be indicated on the applicability of a flexible approach. It is based on robustness (which in this case is achieved by an approach of Six Sigma and Lean Management) and adaptability, which gives the ability to adapt to the current situation (in real time). It may mean, for example, the ability to connect the emergency power supply in case of failure or correction of a typical vehicle travel time providing for the construction of such mixed concrete through a system of GSM location of the current position and the advancement of truck mixer in progress.

4. Case studies

The aim of presenting case study analysis is monitoring of problems occurring in Six Sigma application in production process in construction industry. Ready Mix Concrete delivery for pavement of runway is the

first case presented. Problems in Six Sigma implementation in fabrication of concrete modifiers is analysed in the second one. In this case production seems quite similar to typical production in other economy branches. But evident limitations for Six Sigma conception were shown when all environmental factors for this case were taken into consideration.

First case study was concerning ready mix concrete delivery from the mixing center distance 7.1 km. Capacity of RMC Trucks – 6.0 m³, and capacity of paving equipment – 600 m³/16 h. Working time per day – 16 hours.

Model (Fig. 4), ready to modification, had been based on 72 cycles measured in reality in one month. Finding rational parameters of analyzed processes for maximization of that efficiency was the aim of this study. At starting point it had been stabilized at 31.1 m³/h with 8 RMC trucks used. Alteration on RMC trucks number was the first option for rationalization. For 9 RMC trucks production capacity was increasing to 32.56 m³/h, but for 10 RMC trucks to 32.63 m³/h, only. The loading and unloading time modification was the second option in this analysis.

The best results were found for reduction of loading time from 10 to 9 minutes and unloading time from 15 to 12 minutes (based on technical changes). Production capacity increasing to 37.1 m³/h was the final result including last proposal of changes. The distance reduction (delocalization of mixing center) from 7.1 to 4.3 km and after from 4.3 to 0.0 km were given non interesting results at all (33.3 and 34.4 m³/h, accordingly). Analysis of presented case study and building site observations gives a basis to draw out following conclusions:

- 1) A sociotechnical system modeling is a typical situation for construction production. A human role must be taken into consideration in this analysis. Important obstacles for automation and robotics implementation in construction processes were found: commitment of RMC trucks drivers is a key element of presented model efficiency and effectiveness; traffic fluctuations are really important and indispensable.

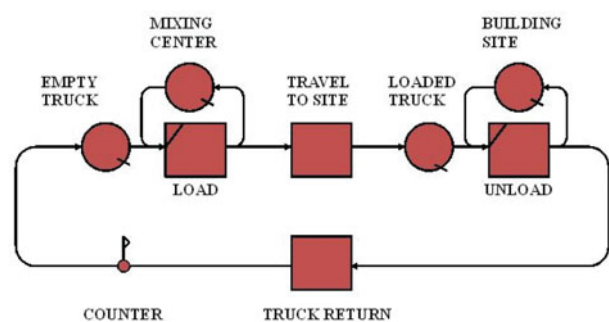


Fig. 4. General idea of simulation of concrete mix production and delivery process

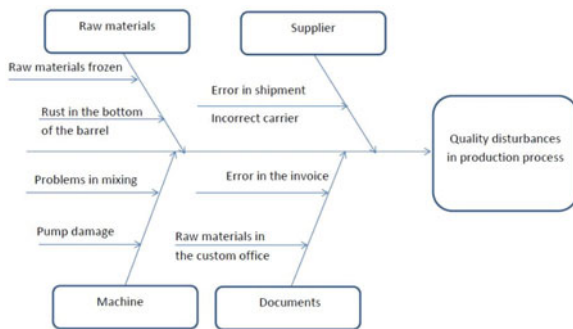


Fig. 5. Ishikawa diagram for concrete modifiers production in SME

- 2) Contradiction of decision criteria for different participants of this simple model is significant: mixing plant owner, RMC trucks owner, paving aggregate owner and RMC truck driver.
- 3) High variability in presented model could be compensated by flexibility (differentiation of trucks number depending on traffic fluctuation, etc.).
- 4) Striving to achieve the required level of Six Sigma in the studied model (e.g. for RMC truck journey times of transporting fresh concrete from the factory to the construction site) seems to be not only very expensive task, but also impractical. High variability resulting from the individual characteristics of the driver (fluctuations in journey times up to 25%) even in the case of deliveries at night must be taken into consideration. Some additional difficulties associated with, for example, changes in weather conditions must be also expected.

A small enterprise fabricating modifiers for cement concrete had been taken as an object of the second case study. This SME is concentrated on innovation technologies in the field of concrete additives and admixtures. From the Six Sigma idea point of view the most interesting is operational level of management. Production disturbances analysis had been taken using Ishikawa diagram (Fig. 5).

All types of disturbances in production of one type of modifier (modifier A) with frequency of

appearance in one-year period and solutions proposed are given in Table 1.

It is clear that in majority of cases the problem is so important that one (first) appearance of any type of disturbance could be critical to SME. One significant error could be a reason to be late in delivery and at nowadays market our product could be replaced by another.

The sigma level for the production process of modifier A is estimated in Table 2.

Sigma level 4.45σ seems adequate to production line taken into consideration. During all analysed period of production process (three years) only one unit had been found as inadequate.

Looking for Tables 1 and 2 one can find clear that a general problem in SME is not a problem of production process but other processes helping this process. For example once it was a problem with invoice error. Time passed for demanding a new one and presenting it at the customs office was 10 days generating delay in raw material delivery and special cost for customs storage.

The calculation in Table 2 was carried out according to the procedure proposed by Eckes (2001a). After determining the type of the analyzed process, the performance indicators are calculated based on the number of defects of the total cycles completed and properly executed. The potential number of critical factors of quality was then established (for the production process – 1, along with auxiliary processes – 7) and the ratio of defects and DPMO (defects per million opportunities).

Very similar situation had been created in case of error in shipment procedure (incorrect carrier). One week delay in raw material delivery and special costs for: (1) a new customs office, (2) customs storage abroad and (3) special payment for another carrier were given as results of this problem.

Looking for other problems in Table 1 one can find that it was very difficult to forecast these types of disturbances and prevent them.

Analysis of data from Tables 1 and 2 shows wide range of interference and relatively low frequency of their occurrence.

As shown in the case study, the basic problem consists in difficulties of overcoming the causes of

Table 1. Observed disturbances and proposals to eliminate them

Number	Type of disturbance	Frequency [per year]	Solutions
1	Rust at the bottom of the barrel	7	Plastic drums
2	Raw materials frozen	5	Heated truck
3	Raw materials stopped at the customs office	2	Change customs office
4	Mistakes in mixing – not dissolved rest	4	Automation
5	Error in invoice – (CHF/EUR)	1	Change supplier
6	Error in shipment – incorrect carrier	1	Change supplier
7	Pump damage	2	Second pump

Table 2. Estimation of Six Sigma coefficient

Number	Estimated element	Result
1	Production process for SIX SIGMA estimation	Modifier A
2	How many units had been fabricated?	435
3	How many units had been fabricated successful?	434
4	Productivity factor for production process	0.99
5	Defect factor for production process	0.01
6	Number of potential critical quality attributes	1
7	Defect coefficient for critical attribute	0.001429
8	Number of defect per million	1429
9	Six sigma coefficient	4.45
10	Proposals for quality	OK

disturbance, the sources of which are numerous, and which are characterized by a considerable scope of variability. Meanwhile the success of Six Sigma approach is based on guaranteeing correct process results despite the process parameters being shifted by 1.5σ . It has to be emphasized that the case under consideration referred to a company engaged in production of building materials. In this case the production resembles factory production much more closely than execution of production processes on a building site, which may involve far more serious problems. Simplification of production procedures obtained due to mechanization and automation is one of the ways for avoiding production disturbances, as shown in the case study. Implementation of flexibility in the form of raw material buffers, alternative sources of supply (optional suppliers), alternative power sources (power generators), alternative production equipment, etc. is the second direction of activity.

Conclusions

Theoretical assumptions, examples from scientific papers, and case studies were given as basis for following conclusions:

- The traditional hierarchical culture of quality management principles resulting from Six Sigma seems to be in opposition to the particular culture of a small company operating in the construction sector (focusing on flexibility and environment variables).
- Six Sigma is focused on technical rationality, not including: organizational culture, humanizing the workplace, workforce creativity, etc.
- Six Sigma concept seems to be difficult to implement in the construction industry due to the process stability required. Similarly the assumed distribution shift by 1.5σ may be too

small for typical construction processes dependent on the changing environment.

- The system approach makes it possible to consider a production system in the construction industry as a sociotechnical system encompassing both the organizational culture and improvement of the technical subsystem due to Six Sigma concept. The hierarchical structure of the construction sector and connected organizational culture are important there as well.
- The construction industry is that sphere of economy which presents enormous possibilities of improvement in quality management. Such activities should take into account the specifics of the sector, i.e. handicraft character of many construction processes (high manual labor input), restrictions on automation and robotics, strong impact of the environment, and fragmentation of processes, as well as the predominant criterion of costs minimization in contracting construction works.
- The problems connected with the high input of handicraft work can be solved by prefabrication (automation and robotization of processes and limiting the environmental influence). Similarly the stability of production processes can be achieved more readily in the conditions of a prefabrication shop.
- Proposed hybrid approach composed of buffer management, automation and Six Sigma seems quite effective for second case study including typical production process in SME.

Summing up the possibilities of utilization of Six Sigma concept in construction production it should be noted that reaching Six Sigma level is a very difficult task. The analysis of examples from literature and two case studies shows that the level between 4σ and 5σ seems to correspond to the limit of capabilities of production systems in the construction industry. A considerable potential of implementation can be found in introduction of the hybrid approach based on:

- Robustness provided by application of Six Sigma concept;
- Introduction of flexibility in the scope necessary for proper functioning of the organization in a dynamically changing environment (adaptation);
- Simplification of production procedures (Japanese school of flexibility);
- And modification of the organizational culture toward general commitment.

Adjustment of production capabilities (e.g. adjustment of process and organizational options) to the dynamically changing environment may be a considerable asset. It is precisely the adaptability as active flexibility based on the monitoring of the environment

and production processes in real time which supplements Six Sigma (robustness).

The fact that generation of excessive flexibility (in relation to the existing risk and uncertainty) may lead to additional complications (increase of the costs as well as aggravation of uncertainty in the system) also needs to be emphasized. It points out to the need for flexibility management in a production system, which requires flexibility measurement and appropriate adjustment to the situation (current and expected).

Acknowledgments

The author would like to thank the Institute of Structural Engineering of the Poznan University of Technology for the support from its statutory activities fund.

References

- Abdelhamid, T. S. 2003. Six-Sigma in lean construction systems: opportunities and challenges, in *Proc. of the 11th Annual Conference for Lean Construction*, Blacksburg, VA, 65–83.
- Abudayyeh, O.; Dibert-De Young, A.; Jaselskis, E. 2004. Analysis of trends in construction research: 1985–2002, *Journal of Construction Engineering and Management* ASCE 130(3): 433–439. [http://dx.doi.org/10.1061/\(ASCE\)0733-9364\(2004\)130:3\(433\)](http://dx.doi.org/10.1061/(ASCE)0733-9364(2004)130:3(433))
- Ballard, G. 2000. *The last planner system of production control*: PhD thesis, School of Civil Engineering, University of Birmingham.
- Buggie, F. D. 2000. Beyond Six Sigma, *Journal of Management in Engineering* ASCE 16(4): 28–31. [http://dx.doi.org/10.1061/\(ASCE\)0742-597X\(2000\)16:4\(28\)](http://dx.doi.org/10.1061/(ASCE)0742-597X(2000)16:4(28))
- Crawford, L.; Pollack, J.; England, D. 2006. Uncovering the trends in project management: journal emphases over the last 10 years, *International Journal of Project Management* 24(2): 175–184. <http://dx.doi.org/10.1016/j.ijproman.2005.10.005>
- Crosby, P. 1979. *Quality is free: the art of making quality certain*. New York: McGraw-Hill. 270 p.
- Eckes, G. 2001a. *The Six Sigma revolution: how general electric and others turned process into profits*. New York, NY: Wiley. 124 p.
- Eckes, G. 2001b. *Making Six Sigma last. Managing the balance between cultural and technical change*. New York, NY: Wiley. 256 p.
- Furterer, S. 2009a. Secure operational excellence, *Industrial Engineering* 41(4): 43–47.
- Furterer, S. 2009b. Enabling enterprise Six Sigma through business process architecture modeling techniques, *Quality Management Forum* 35(3): 7–10.
- Han, S. H.; Chae, M. J.; Im, K. S.; Ryu, A. D. 2008. Six Sigma-based approach to improve performance in construction operations, *Journal of Management in Engineering* ASCE 24(1): 21–31. [http://dx.doi.org/10.1061/\(ASCE\)0742-597X\(2008\)24:1\(21\)](http://dx.doi.org/10.1061/(ASCE)0742-597X(2008)24:1(21))
- Horman, M. J.; Thomas, H. R. 2005. Role of inventory buffers in construction labour performance, *Journal of Construction Engineering and Management* ASCE 131(7): 834–843. [http://dx.doi.org/10.1061/\(ASCE\)0733-9364\(2005\)131:7\(834\)](http://dx.doi.org/10.1061/(ASCE)0733-9364(2005)131:7(834))
- Hua, G. B. 2008. The state of applications of quantitative analysis techniques to construction economics and management (1983 to 2006), *Construction Management and Economics* 26(5): 485–497. <http://dx.doi.org/10.1080/01446190801998716>
- Kaplinski, O. 2009. Information technology in the development of the Polish construction industry, *Technological and Economic Development of Economy* 15(3): 437–452. <http://dx.doi.org/10.3846/1392-8619.2009.15.437-452>
- Kashiwagi, D. T. 2004. Six Sigma applications in construction, in *ASC Proc. on the 40th Annual Conference*, Brigham Young University, Utah [online], [cited 12 May 2012]. Available from Internet: <http://ascpro0.ascweb.org/archives/cd/2004/2004prof/2003>.
- Kashiwagi, J.; Sullivan, J. K.; Kashiwagi, D. T. 2009. Risk management system implemented at the US army medical command, *Journal of Facilities Management* 7(3): 224–245. <http://dx.doi.org/10.1108/14725960910971496>
- Koch, P. N.; Yang, R.-J.; Gu, L. 2004. Design for Six Sigma through robust optimization, *Journal of Structural Multidisciplinary Optimization* 26(3–4): 235–248. <http://dx.doi.org/10.1007/s00158-003-0337-0>
- Koziolek, S.; Derlukiewicz, D. 2012. Method of assessing the quality of the design process of construction equipment with the use of DFSS (design for Six Sigma), *Automation in Construction* 22: 223–232. <http://dx.doi.org/10.1016/j.autcon.2011.07.006>
- Kwak, Y. H.; Anbari, F. T. 2009. Analyzing project management research: perspectives from top management journals, *International Journal of Project Management* 27(5): 435–446. <http://dx.doi.org/10.1016/j.ijproman.2008.08.004>
- Pande, P. S.; Neuman, R. P.; Cavanach, R. R. 2000. *The Six Sigma way: how GE, Motorola, and other top companies are honing their performance*. New York: McGraw-Hill. 448 p.
- Paslawski, J. 2011. Flexibility as risk management option implemented in the bridge repair, *The Baltic Journal of Road and Bridge Engineering* 6(4): 258–266. <http://dx.doi.org/10.3846/bjrbe.2011.33>
- Pietroforte, R.; Stefani, T. P. 2004. ASCE Journal of Construction Engineering and Management: review of the years 1983–2000, *Journal of Construction Engineering and Management* ASCE 130(3): 440–448. [http://dx.doi.org/10.1061/\(ASCE\)0733-9364\(2004\)130:3\(440\)](http://dx.doi.org/10.1061/(ASCE)0733-9364(2004)130:3(440))
- Pheng, L. S.; Hui, M. S. 2004. Implementing and applying Six Sigma in construction, *Journal of Construction Engineering and Management* ASCE 130(4): 482–489. [http://dx.doi.org/10.1061/\(ASCE\)0733-9364\(2004\)130:4\(482\)](http://dx.doi.org/10.1061/(ASCE)0733-9364(2004)130:4(482))
- Produlog. 2013. Improvement techniques Six Sigma [online], [cited 23 April 2013]. Available from Internet: <http://www.produlog.nl/Lean-Sigma/Six-Sigma-Lean>.
- Slowik, M. 2012. Modelling of the inverse creep of road bitumen modified with SBS copolymer, *The Baltic*

- Journal of Road and Bridge Engineering* 7(1): 68–75.
<http://dx.doi.org/10.3846/bjrbe.2012.10>
- Stewart, R. A.; Spencer, C. A. 2006. Six-sigma as a strategy for process improvement on construction projects: a case study, *Construction Management and Economics* 24(4): 339–348.
<http://dx.doi.org/10.1080/01446190500521082>
- Sullivan, K. T. 2011. Quality management programs in the construction industry: best value compared with other methodologies, *Journal of Management in Engineering* 27(4): 210–219.
[http://dx.doi.org/10.1061/\(ASCE\)ME.1943-5479.0000054](http://dx.doi.org/10.1061/(ASCE)ME.1943-5479.0000054)
- Ustinovichius, L.; Rasiulis, R.; Ignatavicius, C.; Vilutiene, T. 2012. Analysis of waterproofing defects and technology development for car parking roofs: Lithuanian case, *Journal of Civil Engineering and Management* 18(4): 519–529.
<http://dx.doi.org/10.3846/13923730.2012.701231>
- Tamošaitiene, J.; Bartkiene, L.; Vilutiene, T. 2010. The new development trend of the operational research in civil engineering and sustainable development as result of collaboration between German-Lithuanian-Polish scientific triangle, *Journal of Business Economics and Management* 11(2): 316–340.
<http://dx.doi.org/10.3846/jbem.2010.16>
- Tchidi, M. F.; He, Z.; Li, B. L. 2012. Process and quality improvement using Six Sigma in construction industry, *Journal of Civil Engineering and Management* 18(2): 158–172.
<http://dx.doi.org/10.3846/13923730.2012.657411>
- Turskis, Z.; Gajzler, M.; Dziadosz, A. 2012. Reliability, risk management, and contingency of construction processes and projects, *Journal of Civil Engineering and Management* 18(2): 290–298.
<http://dx.doi.org/10.3846/13923730.2012.672931>
- Xue, X.; Shen, Q.; Fan, H.; Li, H.; Fan, S. 2012. IT supported collaborative work in A/E/C projects: a ten-year review, *Automation in Construction* 21: 1–9.
<http://dx.doi.org/10.1016/j.autcon.2011.05.016>
- Zavadskas, E. K.; Turskis, Z. 2011. Multiple criteria decision making (MCDM) methods in economics: an overview, *Technological and Economic Development of Economy* 17(2): 397–427.
<http://dx.doi.org/10.3846/20294913.2011.593291>
- Zavadskas, E. K.; Turskis, Z.; Tamosaitiene, J. 2011. Selection of construction enterprises management strategy based on the SWOT and multi-criteria analysis, *Archives of Civil and Mechanical Engineering* 11(4): 1063–1082.
[http://dx.doi.org/10.1016/S1644-9665\(12\)60096-X](http://dx.doi.org/10.1016/S1644-9665(12)60096-X)

Jerzy PASLAWSKI. Associate Professor at Institute of Structural Engineering, Poznan University of Technology, Head of Division of Construction Technology and Management Division. His research interests include flexibility applications in construction management, scenario analysis, and hybrid advisory system.