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MULTI-CRITERIA ASSESSMENT OF LEAN MANAGEMENT TOOLS SELECTION IN CONSTRUCTION

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The situation on the construction market is difficult. One way to improve it can be to implement modern methods and techniques related to the lean management in construction. The article presents an algorithm supporting the selection of appropriate Lean Management tools and techniques for construction companies using AHP method. The efficiency of the proposed algorithm is illustrated by a case study consisting of a small construction company performing insulation works in a multifamily house. The presented approach is part of the broader research work carried out by the authors in the field of improving construction processes and verifying the efficiency and effectiveness of Lean Management methods and techniques construction works..

*Keywords**:** Lean Management, Lean Construction, AHP, SMEs*

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1. INTRODUCTION

The current situation in the construction sector is very difficult. This view is the result of previous experience of the authors' professional work in which they come into contact with:

- Discomfort arising from losses occurring in production processes;
- Problems (permanent) with planning;
- Disturbances in construction processes resulting from operation in a changing environment.

In addition, lower productivity (Figure 1) in construction compared to production significant potential in the possibility of introducing improvements in construction processes are indicated, in many areas and aspects [1] which until now has not been fully utilized. The performance aspect in the construction sector compared to other branches of the economy is not without significance. It should be emphasized that while the productivity in industry has been rising continuously for many years, a similar level or even decrease is observed in construction, which is reflected in the financial results of enterprises involved in construction processes and is caused by many different problems in construction sector [1,2].

One of the way that can improve the described situation, which are proposed by researchers in the field of improving construction production, except for using modern approaches like i.e. Industry 4.0 [3,4], has been and is the use of management methods, e.g. Lean Management (Lean Construction).

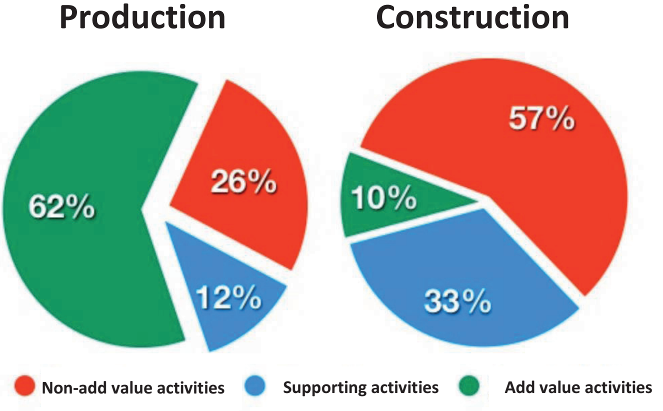


Figure. 1. Productivity in production and construction [5]

Lean Management is a number of methods, techniques and tools, the use of which leads to process improvement by reducing the wide range of wasteful waste and focusing on creating added value for the end customer [6], which is implemented through various methods introduced at the stage of planning and production of a given product. The concept of Lean Management is a MIT term derived from Japan [7]. John Krafcik used it for the first time in an article discussing the results of an international research project on the automotive industry, devoted to finding the reasons for the advantage of the Japanese automotive industry over countries producing cars using traditional management methods [8].

In construction, the term is known as Lean Construction, which is a certain narrowing of the term Lean Management to processes and implementation in the field of construction production, where it is used more and more widely [9], especially when improving processes that are in their a form similar to typical production processes (e.g. in prefabrication) [10].

There are many publications showing the effectiveness of individual Lean Management tools in construction [5,10,11,12,13]. There are known and commonly used groups of tools and techniques to improve the construction process. However, due to the specifics of construction, seasonality of work performed, lack of repeatability of processes and implementation of works for a specific investor's order, the indication of one and the best tools and techniques for the entire industry is, according to the authors, impossible.

An issue that has not been thoroughly analyzed so far is how to select and implement the appropriate tools and techniques in construction companies for specific processes, especially in the SMEs (Small & Medium Enterprises) sector. If company owners want to use tools and techniques whose theoretical benefits are known and at the same time possible to obtain, the question arises about the selection of the right method in terms of expectations and the possibility of introducing changes in the enterprise. It is related to the variable effectiveness of methods used in various environments, with different processes and conditions, both internal and external. What's more, researchers indicate that there is a real need to work on the systematic use of the Lean Management concept in construction (as Lean Construction) clearly indicating that the mere use of the tool is insufficient to fully feel the positive effects of the methodology [14,15].

The aim of this work is to present the algorithm of selecting lean management tools in construction based on multicriteria assessment for choses construction processes in SMEs sector. It is done with the use of AHP method and illustrated based on example related to the construction works. Obtained results showed effectiveness as well as waste reduction potential in presented case.

2. MULTI-CRITERIAL EVALUATION OF LEAN CONSTRUCTION TOOLS AND TECHNIQUES

For the purpose of the publication the scheme of the algorithm for assessing multi-criteria of Lean Management tools used in construction is presented in Figure 2. It takes int account the expectations of entrepreneurs interested in implementing the Lean Management philosophy, as well as their knowledge and ability to perform implementations in the processes.

In general it can be divided into 3 main steps, which relate to subsequent stages of the more general procedure of selection proper methods, i.e. expert, system and directly related to the enterprise, which indicates what information at a given stage should be used and where the data obtained / processed in order to achieve the final result, which is the list of Lean Management tools / methods selected according to the company's expectations.

It has to be noted that the operating diagram presented below is “open”. Using the proposed method of assessment and selection, it is also possible to apply additional criteria if it turns out that they would be required in a given specialized process or enterprise [25].

- **Stage I**

At this stage, all input data necessary to run the algorithm is collected. First of all, it is necessary to obtain data on the basic assessment of individual Lean Management tools and techniques. The data comes from experts who have made the necessary assessment of each tool and technique using detailed scale in 3 categories: knowledge, experience and area of improvement (Fig 3.) The next phase is the collection of data from the company in the similar fields, if the company has the necessary knowledge to define such an areas. Each time company representatives are asked to determine level of awareness in each above mentioned category and provide this information for further analysis.

- **Stage II**

The second stage is designed to implement the initial selection of Lean Management tools and techniques in such a way that from among available tools, techniques to choose only those that are appropriate in a given case in terms of basic criteria, i.e. the level of Lean Management knowledge, experience in application and the area which is supposed to affect the improvement, with the area being defined only in a situation where such a possibility exists. This is done based on the information collected in stage I. Stage II ends with obtaining a list of several tools and techniques that are adequate in the given situation. The resulting list should be subject to additional verification in terms of the appropriateness of the tools and techniques to be used in the given case.

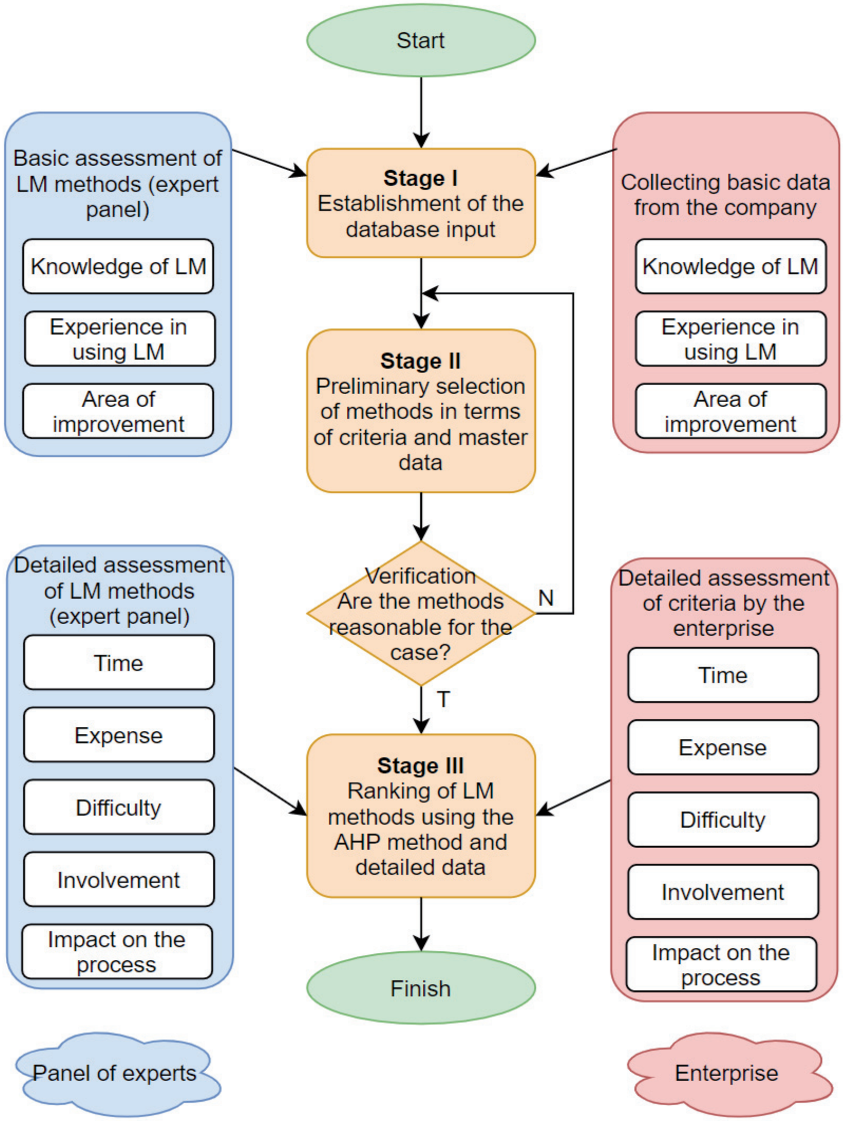


Figure 2. Stages of multi-criteria assessment of Lean Management tools and techniques in terms of enterprise expectations

The assessment of legitimacy is made by an expert or a person conducting the implementation in consultation with the implementation team, whose task is to check whether the obtained list of tools and techniques is suitable for the type of business activity, the process which will be subject to authorization, expected results and expectations. If the tools and techniques obtained are adequate, there is a need to proceed to stage III, otherwise re-selection is required, taking into account additional criteria that critically assess the appropriateness of the tools and techniques.

- **Stage III**

The third stage aims to create the final ranking of Lean Management tools and techniques using the AHP method which provides an objective, mathematical way to process the subjective and personal preferences of an individual or group of people while implementing the decision making process [16]. AHP involves decomposing the problem into its components [17,20,21] and developing priorities for alternative solutions and criteria used to assess possible alternatives [18] after performing needed calculations [22,23, and is commonly used in construction [19,24],

The database in the Stage III is a detailed assessment of the individual Lean Management tools and techniques that were on the list after the initial selection as part of stage II. It is implemented on the basis of pair-wise comparisons consisting of five criteria:

- implementation time,
- implementation cost,
- difficulty in implementation,
- necessary staff involvement,
- and impact / effect on the whole process.

In addition, it is necessary for company representatives to evaluate and compare in pairs according to the AHP all the above-mentioned criteria. On this basis, by performing the necessary mathematical operations and transformations using the SuperDecisions software, the final list is selected with tools and techniques that best meet the expectations of entrepreneurs, and thus which should be introduced first of all when implementing Lean Management implementations in a given process.

It should be noted that in the third stage it is possible to obtain input data in the form of 2 versions:

- lists of several tools and techniques,
- only one tool/ technique.

In the case of obtaining a list, the process of creating a ranking takes place using the AHP method described above, while when only one tool /technique is received at this stage, it is considered suitable for implementation in a given enterprise.

3. EXAMPLE OF IMPLEMENTING THE ALGORITHM

In order to show how the proposed algorithms works, an example of its application is presented below by selecting a tools or technique for a small construction company interested in implementing Lean Management techniques to the installation of secondary vertical water-proof insulation with heat insulation in a multi-family building from mid 50's in Poznan. Implementation was carried our using DMAIC (Define, Measure Analysis, Improve and Control) cycle based on the issues that accrued during performing works at the first weeks of the construction project, mainly: risk of not meeting the deadline and weather conditions that influenced working time. The main drivers for trying proposed approach were possible benefits that were about to minimize above risks on the construction site.

- **PHASE I**

Using basic data on individual Lean Management tools and techniques and data obtained from the enterprise, this is in described example:

- Type of enterprise: An enterprise employing 11 people operating in the general construction industry;
- Level of Lean Management: Awareness of Lean Management;
- Experience in using Lean Management: No experience in implementations;
- Type of processes to improve: installation of waterproof layer into foundations of existing multifamily building.

The necessary input data was collected to carry out the further stages of the proposed algorithm.

- **PHASE II**

With the help of the information obtained, it was decided that the most appropriate in this case, due to the lack of experience in implementing Lean Management, there will be baseline tools and techniques, among which the project team identified 5S, Visual Management and Standardization as key. Therefore, the above 3 tools and techniques will be considered for further evaluation using the AHP method in the following phase of the presented algorithm.

- **PHASE III**

In order to implement the third stage of the algorithm, the SuperDecisions program was used, which supports the performance of necessary calculations to obtain the final ranking of tools and techniques worth entering in a given case. To perform the necessary calculations using the above-mentioned program, it is necessary to collect data that will be processed in this program, i.e.

a) the enterprise preference matrix for the assessment of individual categories according to which the tools and techniques will be assessed;

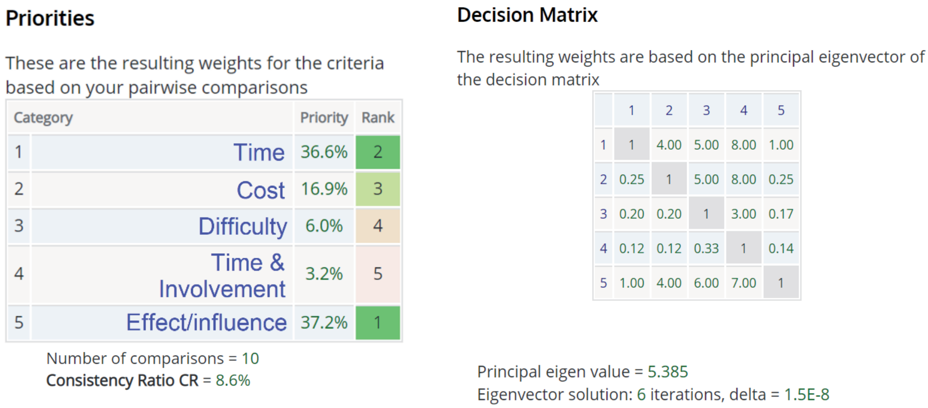
b) a pairwise comparison matrix for tools and techniques in terms of individual categories based on a detailed assessment of tools and techniques performed by experts.

Collecting data on the preferences matrix requires contacting the company and making pairs of individual assessment criteria: implementation time, implementation cost, implementation difficulties, necessary staff involvement, impact (effect) on the entire process.

It was implemented using the online BPSMG calculator (online tool) [26], which allows transparent review of the results in terms of consistency of the assessments made. As a result, it is possible to make the necessary adjustments to achieve the required level of consistency of the preference matrix.

Finally, the BPMSG program calculates the weights of individual criteria and shows their ranking (Figure 3). Additionally, the decision matrix for the introduced criteria is presented (Figure 4), which is used in the next steps in the SuperDecisions program.

As part of the input, there is also need to prepare a matrix of comparisons of the proposed tools and techniques in pairs for individual categories. The proposed algorithm is implemented on the basis of information derived from a detailed assessment carried out by experts, where for each of the tools and techniques an assessment was made on a scale of 1-10, which makes it possible to compare individual tools and techniques in a given criterion with each other. In the currently analyzed example, the detailed assessment for the three analyzed tools and techniques 5S, Visual Management and Standardization is shown in Table 1.



Priorities

These are the resulting weights for the criteria based on your pairwise comparisons

Category		Priority	Rank
1	Time	36.6%	2
2	Cost	16.9%	3
3	Difficulty	6.0%	4
4	Time & Involvement	3.2%	5
5	Effect/influence	37.2%	1

Number of comparisons = 10
Consistency Ratio CR = 8.6%

Decision Matrix

The resulting weights are based on the principal eigenvector of the decision matrix

	1	2	3	4	5
1	1	4.00	5.00	8.00	1.00
2	0.25	1	5.00	8.00	0.25
3	0.20	0.20	1	3.00	0.17
4	0.12	0.12	0.33	1	0.14
5	1.00	4.00	6.00	7.00	1

Principal eigen value = 5.385
Eigenvector solution: 6 iterations, delta = 1.5E-8

Figure. 3. Priorities for comparable criteria and Decision matrix necessary for further calculations

Table 1. Expert assessment - detailed for Lean Management tools and techniques

Tools and techniques	Detailed assessment (expert)				
	Implementation time (1- Short, 10- Lomg)	Implementation cost (1- Low, 10- High)	Difficulty in implementation (1- Low, 10- High)	Commitment to implementation (1- Low, 10- High)	Impact effect. (1- Low, 10- High)
5S	7	3	3	6	6
Visual Management	2	2	2	3	3
Standardization	5	3	3	5	5

At this stage, all necessary input data exists to perform calculations in the SuperDecisions program. Work begins with the introduction of a decision hierarchy to the program including:

- main purpose,
- adopted assessment criteria,
- alternatives between which the choice is made.

The program in this phase requires that the various stages of the hierarchy be linked together in such a way that it is possible to carry out the necessary calculations. It is important to pay attention to the names of individual levels of the hierarchy, as they are important for the correctness of calculations.

After entering all the necessary data, the program is used for performing calculations and for indication which tool or technique is optimal taking into account the indicated criteria. In the analyzed example, the best assessment was obtained by the Visual Management tool. Figure 5 presents the results.

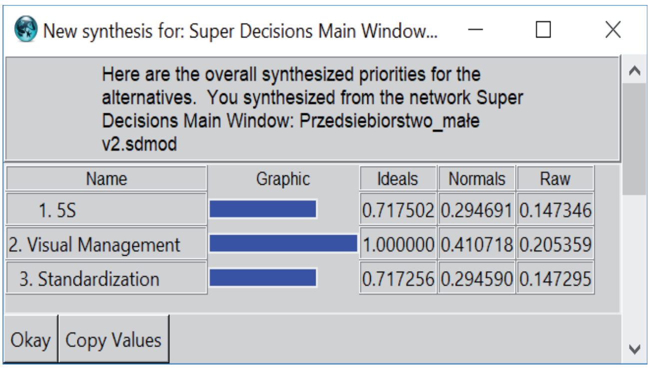


Figure 4. The result of the analysis carried out in the form of a ranking of tools and techniques for the decision problem

In order to check the correctness of entered data and calculations carried out, sensitivity analysis should be performed. The SuperDecisions program allows to carry out this procedure for all entered criteria. An example of sensitivity analysis for time criterion is presented below.

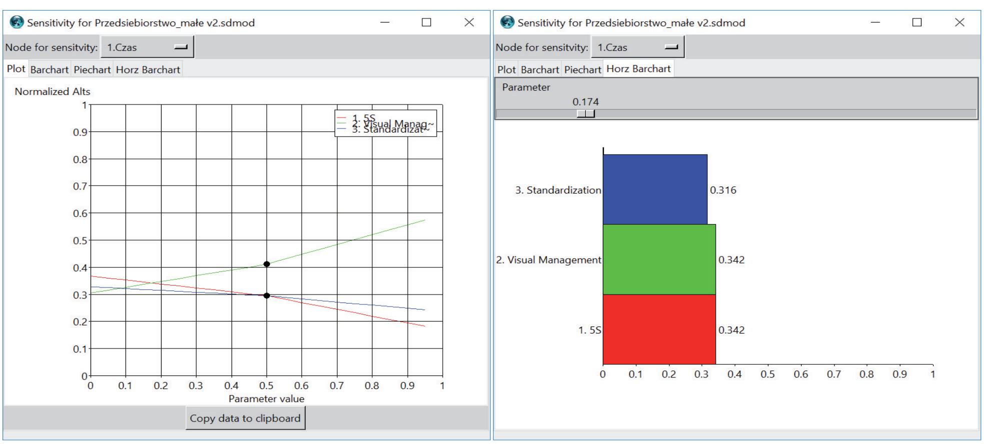


Figure 5. (left) Example of sensitivity analysis of the criterion: implementation time and (right) graph for the criterion: implementation time with sensitivity parameter reduced by 32.6%

4. PRACTICAL EFFECTS OF IMPLEMENTATION

The implementation was carried out proposing Visual Management tool during the process of water and heat insulation installation project. This tool was selected by using proposed and described in the article algorithm. The implementation involved changing the walking routes on the construction site as well as introduction procedure of special marking of the broken tools used by the workers of the company (Figure 6).

The introduction of road signs at the construction site was especially useful for new employees. During the implementation of the work, it turned out that for people performing the simplest activities, there was a very high staff turnover, as well as workers appeared who did not speak local language well. Thanks to the installation of "signposts", they were able to understand the work system prevailing at the investment and the optimal way of moving faster. At the same time, the use of damaged tool markings helped them to be identified more quickly, making testing of the tools unnecessary before use. It was immediately known which tools were in working order.

Finally, the entire implementation of Lean Management was assessed mostly positively, with employees noting that seeing the effect in the form of shorter paths associated with less fatigue would be interested in other tools and techniques that would facilitate their work in the implementation of subsequent investments. The management of the company welcomed the information about how much time could be saved by using the system from the very beginning and will be even more interested in further analyzes in the future. The implementation of the goal for which Lean Management was introduced, that is, saving time so that additional works could be carried out, was limited. Due to the fact that the workload of additional works was too high and did not allow the entire works to be completed within the contractual period - eventually the deadline for completion of works had to be extended. Nevertheless, taking into account other aspects, the whole implementation was assessed as a success.

Figure 6. Marking the direction to the nearest material warehouse (left); Application of the procedure to mark faulty equipment (right).

5. Conclusions

The algorithm for selecting the appropriate Lean Management tools and techniques presented in this article, depending on the entrepreneur's expectations, and the example of application for a small construction company, prove the correctness of the proposed solution. The use of input data in the form of expert opinions in the assessment of individual Lean Management tools and techniques in conjunction with the expectations of entrepreneurs for selected criteria for the implementation of the Lean Management tool or technique, in combination with the use of the AHP method allows to choose a tool and technique consistent with the expectations and capabilities of the construction company.

Moreover, the algorithm described is flexible at the level of possibilities to extend its application with additional tools and techniques, or other criteria that a given company would like to consider at the selection stage. The authors note that due to the use of the AHP method, there are a number of threats related to the correctness of the results indicated, which can be eliminated, among others by improving the credibility of the assessments of the experts involved in the process. However, at this stage, the test carried out for the data of a small construction company showed the effectiveness and appropriate level of opinions used in implementing the proposed algorithm.

In addition, as part of ongoing work it was found that:

- The proposed algorithm proved to be effective significantly eliminating the identified waste of waiting;
- It was possible to improve the result in the amount of time spent on direct work on a business day by 5.7% for the analyzed work;
- An improvement in employees' perception of Lean philosophy has been observed, which has changed from moderate reluctance at the beginning to acceptance at the end;
- Average hourly productivity was increased by 35.8%;
- The proposed algorithm has demonstrated its effectiveness in the described activities, making it possible to use it more widely in other construction companies and in the implementation of other processes.

The authors are planning to continue to work on the improvement of the proposed approach making it suitable for companies form the SME sector.

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Tabela 1. Ocena ekspercka - szczegółowa dla wybranych metod Lean Management

MULTI-CRITERIA WIELOKRYTERIALNA OCENA DOBORU NARZĘDZI LEAN MANAGEMENT W BUDOWNICTWIE

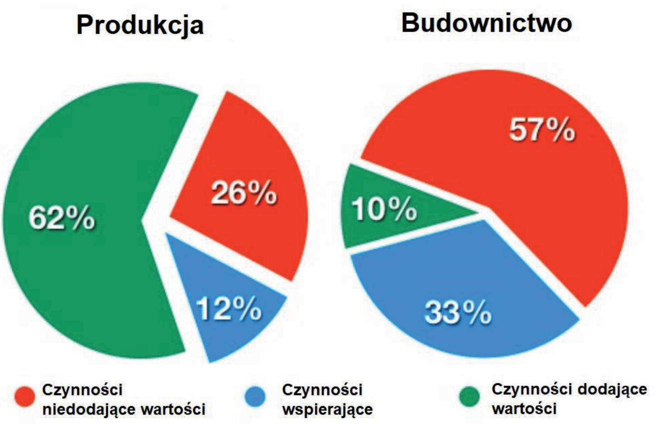
Keywords: Lean Management, Lean Construction, AHP, MŚP

STRESZCZENIE

Obecna sytuacja w sektorze budowlanym jest bardzo trudna. Ten pogląd jest wynikiem wcześniejszych doświadczeń w pracy zawodowej autorów, w których mają oni kontakt z:

- Dyskomfortem wynikającym ze strat występujących w procesach produkcyjnych;
- Problemach (stałych) z planowaniem;
- Zakłóceniami w procesach budowlanych wynikającymi z pracy w zmieniającym się otoczeniu.

Ponadto niższa produktywność (Rysunek 1) w budownictwie w porównaniu do produkcji wskazuje na znaczny potencjał możliwości wprowadzenia ulepszeń w procesach budowlanych, w wielu obszarach i aspektach, które do tej pory nie były w pełni wykorzystane.



Rysunek. 1. Porównanie produktywności w budownictwie i sektorze produkcyjnym

Aspekt wydajności w sektorze budowlanym w porównaniu z innymi gałęziami gospodarki nie jest bez znaczenia. Należy podkreślić, że chociaż produktywność w branży stale rośnie od wielu lat, podobny poziom lub nawet spadek obserwuje się w budownictwie, co znajduje odzwierciedlenie w wynikach finansowych przedsiębiorstw zaangażowanych w procesy budowlane i jest spowodowane wieloma różnymi problemami związanymi z sektorem budowlanym.

Jednym ze sposobów poprawy opisanej sytuacji, zaproponowanym przez badaczy w zakresie poprawy produkcji w budownictwie jest stosowanie nowoczesnych metod zarządzania, np. Lean Management.

Istnieje wiele publikacji pokazujących skuteczność poszczególnych narzędzi Lean Construction. Istnieją znane i powszechnie stosowane grupy metod narzędzi do poprawy procesów produkcji budowlanej. Jednak ze względu na specyfikę budowy, sezonowość wykonywanych prac, brak powtarzalności procesów i realizacji prac na konkretne zamówienie inwestora wskazanie jednej i najlepszej metody dla całej branży jest, zdaniem autorów, niemożliwe.

Problemem, który dotychczas nie został dokładnie przeanalizowany, jest sposób wyboru i wdrożenia odpowiedniej metody lub narzędzia w firmach budowlanych i określonych procesach, szczególnie w sektorze MŚP. Jeżeli właściciele firm chcą zastosować metody, których teoretyczne korzyści są znane i jednocześnie możliwe do uzyskania, pojawia się pytanie o wybór właściwej metody pod względem oczekiwań i możliwości wprowadzenia zmian w przedsiębiorstwie. Jest to związane ze zmienną skutecznością metod stosowanych w różnych środowiskach, z różnymi procesami i warunkami, zarówno wewnętrznymi, jak i zewnętrznymi. Co więcej, badacze wskazują, że istnieje realna potrzeba pracy nad systematycznym wykorzystaniem koncepcji Lean Management w budownictwie (jako Lean Construction), co wyraźnie wskazuje, że samo użycie narzędzia jest niewystarczające, aby w pełni odczuć pozytywne skutki metodologii.

W artykule przedstawiono zagadnienia związane z wyborem odpowiedniej metody i techniki Lean Management, którą można wybrać stosując metodę AHP, a także wskazano możliwe korzyści z stosowania tego podejścia. Wydajność proponowanego algorytmu ilustruje studium przypadku małej firmy budowlanej wykonującej prace izolacyjne w domach wielorodzinnych. Prezentowane podejście jest częścią szerszych prac badawczych prowadzonych przez autorów w zakresie poprawy procesów budowlanych oraz weryfikacji wydajności i skuteczności robót budowlanych.

Przedstawiony w artykule algorytm wyboru odpowiedniej metody Lean Management, w zależności od oczekiwań przedsiębiorcy, oraz przykład aplikacji dla małej firmy budowlanej, potwierdza poprawność proponowanego rozwiązania. Wykorzystanie danych wejściowych w postaci opinii ekspertów w ocenie poszczególnych metod Lean Management w połączeniu z oczekiwaniami kontrahentów dla wybranych kryteriów wdrożenia metody Lean Management w połączeniu z zastosowaniem metody AHP pozwala na wybór metody LM zgodnej z oczekiwaniami i możliwościami firmy budowlanej oraz jej klientów.

Co więcej, opisane algorytmy są elastyczne na poziomie możliwości ich rozszerzenia i zastosowania o dodatkowe metody lub inne kryteria, które dana firma chciałaby rozważyć na etapie selekcji. Autorzy zauważają, że dzięki zastosowaniu metody AHP istnieje szereg zagrożeń związanych z poprawnością wskazanych wyników, które można wyeliminować, między innymi poprzez poprawę wiarygodności ocen ekspertów zaangażowanych w proces. Jednak na tym etapie test przeprowadzony dla danych małej firmy budowlanej wykazał skuteczność i odpowiedni poziom opinii zastosowanych przy wdrażaniu proponowanego algorytmu.

Ponadto w ramach trwających prac stwierdzono, że:

- Zaproponowany algorytm znacznie eliminuje zidentyfikowane straty związane z marnotrawstwem oczekiwania;
- Zaobserwowano wzrost ilości czasu poświęconego na pracę w dniu roboczym o 5,7% dla analizowanego procesu;
- Zaobserwowano poprawę postrzegania przez pracowników filozofii Lean, która zmieniła się od umiarkowanej niechęci na początku do akceptacji na końcu wdrożenia;
- Średnia wydajność godzinowa wzrosła o 35,8%;
- Proponowany algorytm wykazał swoją skuteczność w opisanych działaniach, umożliwiając jego szersze zastosowanie w innych firmach budowlanych oraz we wdrażaniu innych procesów.

Autorzy planują kontynuować prace nad ulepszeniem proponowanego podejścia do wdrażania Lean Management, aby umożliwić firmom z sektora MSP korzystanie i korzystanie z podejścia Lean Management.

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