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A SCIENTOMETRIC ANALYSIS OF PROJECT MONITORING LITERATURE

Earned Value Management (EVM) is an approach used to measure and analyze the schedule and cost performance of projects. This study reviews the progress of academic knowledge in EVM by conducting a scientometric analysis of the field and aims to provide an overview of the current state of research and main trends. The research methodology comprises a 4-step framework: search, appraisal, synthesis, and analysis. The science mapping software CiteSpace® and VOSViewer® were used to construct and visualize scientometric maps. The findings show that the EVM literature has grown and become popular in the last decade. The findings also suggest that the studies shifted their focus from simple EVM applications to the ones proposing advanced models, mostly for time and cost forecasting, under uncertainty. The paper summarizes and discusses the main findings from the literature and highlights the perspectives for future research in the field. The findings of the study will be helpful to project managers to get necessary insights regarding the management of their projects by the EVM technique.

Key words: scientometrics, Project Management, project monitoring, Earned Value Management.

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Жоба мониторингі бойынша әдебиеттерді ғылыми-метриялық талдау

Игерілген құнды басқару (EVM) – жобалардың мерзімі мен құнының тиімділігін бағалау үшін қолданылатын әдіс.

Бұл ғылыми жұмыс зерттелетін аумақта ғылыми-метриялық талдау жүргізу арқылы EVM саласындағы академиялық білімнің ілгерілеуін зерттейді және осы бағыттағы ғылыми еңбектердің ерекшеліктері мен трендтеріне шолу жасауды мақсат етеді. Зерттеу әдістемесі келесідей төрт кезеңнен тұрады: іздеу, бағалау, синтез және талдау. CiteSpace® және VOSViewer® бағдарламалық жасақтамалары ғылымиометриялық карталарды құру және визуализациялау үшін пайдаланылды. Зерттеу нәтижелері соңғы онжылдықта EVM әдебиеті айтарлықтай байытылғанын және танымал бола бастағанын көрсетеді. Сонымен қатар қазіргі таңда осы саладағы зерттеулердің басым көпшілігі қарапайым EVM қолданбаларынан белгісіздік жағдайында жоба мерзімі мен оның құнын болжау үшін кеңейтілген үлгілерді ұсынатын зерттеулерге ауысқанын көрсетеді. Жұмыста зерттеу тақырыбына сай әдебиеттерден алынған негізгі қорытындылар жинақталып, талқыланды және осы саладағы болашақ зерттеулердің перспективалы бағыттары белгіленді. Зерттеу нәтижелері жоба менеджерлеріне EVM әдісі арқылы жобаларын басқару туралы қажетті ақпаратты алу үшін пайдалы болады. Сонымен қатар зерттеу жүргізу үшін осы саладағы өзекті тақырыптар мен мәселелерді айқындауға мүмкіндік береді.

Түйін сөздер: ғылыми-метрия, жобаны басқару, жоба мониторингі**,** игерілген құнды басқару.

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Наукометрический анализ литературы по мониторингу проектов

Управление освоенной стоимостью (EVM) – это подход, используемый для оценки сроков и эффективности стоимости проектов. В этом исследовании рассматривается прогресс академических знаний в области EVM посредством проведения наукометрического анализа в исследуемой области.

Целью исследования является анализ существующих научных исследований и выявление основных трендов в данной области. Методология исследования состоит из четырех этапов: поиск, оценка, синтез и анализ. Программное обеспечение CiteSpace®, а также VOSViewer® были использованы для построения и визуализации наукометрических карт. Результаты показывают, что литература по EVM была существенно обогащена и стала популярной за последнее десятилетие.

Результаты также показывают, что исследования сместили акцент с простых приложений EVM на те, которые предлагают расширенные модели, в основном для прогнозирования сроков и стоимости проектов в условиях неопределенности. В исследовании обобщаются и обсуждаются основные выводы из литературы, а также освещаются перспективы будущих исследований в этой области. Результаты исследования будут полезны для руководителей проектов с целью получения необходимой информации об управлении проектами с помощью метода EVM. К тому же, результаты и выводы помогут выявить актуальные и перспективные направления в данной области для проведения новых исследований.

Ключевые слова: наукометрия, управление проектами, мониторинг проекта, управление освоенной стоимостью.

Introduction

Project performance management remains problematic despite many decades of practice and academic research. Empirical evidence suggests that projects do not generally achieve the required scope, are often late, and perform poorly on the quality of deliverables and cost budgets (Padalkar and Gopinath, 2015). This research is focused on Earned Value Management (EVM) system since project professionals accept it as one of the most valuable performance measurement and feedback tools. The tool reveals deviations in project cost and schedule plan throughout the project execution phases. According to Project Management Institute (PMI), EVM is a management methodology for integrating scope, schedule, and resources to objectively measure project performance and progress and forecast project outcomes (Practice Standard for Earned Value Management, 2011).

This study provides a scientometric analysis of the EVM academic literature. The study answers questions about how the EVM research field has been evolving since it was adapted as a practical tool in project control and monitoring in the 1990s. It also provides an overview of the current state of research and main trends using scientometric analysis. Notably, it focuses on citations, keywords, and clusters analysis to further study the most cited articles.

According to Willems (2015), the last comprehensive scientometric review in EVM was done by Christensen et al. (1995). This research aims to update the progress of academic knowledge in EVM up to the 2020 year and answer the following research questions:

1) What are the main research clusters in the EVM field?

2) What are the main research focus and trends in the field of EVM?

3) What are the top-cited studies by citation analysis?

The findings of the study will be helpful to project managers to get necessary insights regarding the management of projects.

This study is organized in the following way. The background research section provides short information about the basic concepts of EVM and past studies. The materials and methods section describes the steps used to search and analyze the scientometric data and the software used to build networks and visualize the literature. The results and discussion section presents the results of the research work and interprets the findings in the analysis. The last part is the conclusion, which summarizes the

main findings and outlines recommendations for researchers.

Background research

The concept of EVM in project monitoring and control has been widely studied globally for the last decades and has become a subject of interest for many project managers. Furthermore, as mentioned before, EVM is recognized by organizations and project professionals as an essential and valuable tool for efficient project control and monitoring. However, according to research work on identifying the maturity level of Kazakhstani organizations, performed by Narbaev (2015), most companies still have a massive number of failed projects in their portfolio. The research results say that PM tools and methodologies have not been effectively used in Kazakhstan. This leads to the situation when organizations are let each project run with its procedures and processes without unified standards set in an organization. Consequently, it leads to poor performance during the project control and monitoring stage (Ziyash, 2018).

The importance of retrieving accurate and meaningful project performance indicators like cost and schedule for support decision making in project management and forecast project results is one of the main topics considered in the literature. Regarding the fact that EVM can also be used to forecast the resulting project outcomes, Vandevoorde and Vanhoucke (2006, 2007) developed three forecasting methods based on EVA metrics and compared them in terms of prediction accuracy. Narbaev and De Marco (2014b), in their research, integrate statistical methods into analysis to enhance the prediction performance of EVM.

As for risk management, Pajares and Lopez-Paredes (2011) developed two metrics that assist project managers in differentiating project over-runs, whether they are structural or normal deviations. As stated above, the main advantage of applying the EVM tool for project monitoring is in support of decisions that need to be taken by project managers in case of deviations. Aliverdi et al. (2013) and Acebe et al. (2014) used simulation and statistical control charts to enhance decision-making. To achieve project targets, hedging uncertainty is equally essential with risk analysis. With regards to this, Naeni and Salehipour (2011) described percent completions as fuzzy numbers and used fuzzy set theory for estimating project performance. As stated by De Marco et al. (2016) in their research work, forecasting costs with EVM and managing contingency budget, as a rule, are considered two different paths in project management research. They attempted to highlight risk impact on cost forecast by CEAC methodology adjusted with risk contingency.

Regarding the popularity of EVM in various industries, Naderpour (2011) found out that project control tools are commonly used in the construction area. De Marco and Narbaev (2013) contributed to the diffusion of EVM as a practicable methodology to control and monitor construction projects. They revealed that the European construction industry is lagging behind other developed countries, even though EVM in construction projects was found to be applicable, adaptable, and predictive of integrated final cost and schedule. They outlined that CEAC is forecasted by only CPI, while the earned schedule concept is revealed as an accurate predictor for the TEAC.

Despite the evident fact of the advantages of application of EVM methodology in project control and monitoring process, Besner and Hobbs (2006), in their research work, wrote there is a lack of use of the EVM though being intensively studied (Ziyash, 2018). This can be explained by the fact that project managers are faced with several constraints in applying EVM in real work. Hall (2012), in his research, attempted to summarize the main factors that caused it. According to him, one of the problems is ignorance of behavioral aspects of management. Another factor is that critical and non-critical activities are not differentiated and are assumed as independent activities.

The importance and effectiveness of EVM in application to project control and monitoring are mentioned in most research articles. For example, in his book, Solanki (2009) says that to provide the management with valuable information required by program management for effective control contact of project, EVMS should be implemented. Giammalvo (2007) shared his experience and observations in PM World Today journal of the interrelation of countries perceived as not being corrupt and the adoption by that country of EVM. The result shows that those countries that adopted EVM as the methodology in project control and monitoring early show “clean” project management. Further in his studies Giammalvo (2013) concludes that EVM, used appropriately in the execution stage of project management as a project measurement tool, can provide us a solution to ensure that the project is “successful” – without cost overruns, delays in schedule, and according to quality and contractual requirements. But most important, Giammalvo

says, EVM help to identify problems when there is a sufficient timeframe to resolve them, and if addressed actions have not been applied to resolve these issues, EVM provides a clear audit trail to identify those contractors who should be legally and financially accountable for the failure (Ziyash, 2018)

Materials and methods

The scientometric method for quantitative analysis of academic publications' content has been applied to achieve the study's objectives. The science mapping software CiteSpace® and VOSViewer® were used to construct and visualize scientometric maps.

The research design is depicted below in Figure 1.

As shown in Figure 1, the analysis consists of four sections. The first section evaluates the status of the EVM research and knowledge by an overview of the extracted data set. Then, the paper provided a cluster analysis created a citation network of scientific publications relevant to EVM. The work also provides an overview of the research front and focuses on analyzing keywords. Finally, the study assesses the most cited works in EVM research.

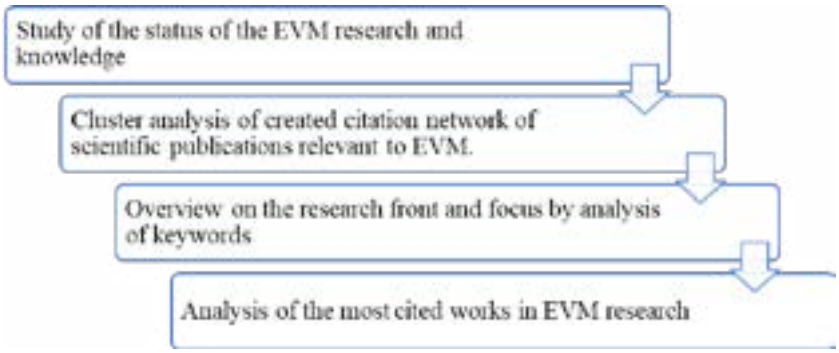

Figure 1 – Research design of the current study
Note – designed by authors

The research methodology is based on Rezende et al. (2018) approach, depicted in Figure 2. The method implies proceeding with data analysis through 4 step framework: search, appraisal, synthesis, and analysis, abbreviated as SALSA and suggested by Booth et al. (2013).

Data collection and appraisal

The Scopus database was used in the first stage of this research. It was compared to another frequently used scientific source – Web of Science. During the comparison, it was found that the Scopus database found more topic-related papers rather than Web of Science by using the same keywords in a search query, 316 against 185. According to Booth et al. (2013), every search has the potential risk of missing relevant articles or papers if wrong search parameters were used. Therefore, to minimize this risk in the search for relevant articles in the project control and monitoring area, the following combination of words have been used: "earned value management" OR "earned value technique" OR "earned value analysis" OR "earned value method*". The search covers the title, abstracts, and keywords, and only article and review document types have been chosen. Books, conference papers, and other types of sources were withdrawn from the search. As a result, 316 documents for October 25, 2019, published from 1985 to 2019, were extracted for further analysis.

Data synthesis and analysis

The data set extracted in the previous step is used as input data for the CiteSpace® software in the next stage. Chen develops the tool. The VOSviewer® software is a tool created for establishing and examining scientometric network maps like a scientific network of authors or studies based on cited references data or establishing a network of keywords based on co-occurrence information (Eck, N. J., Waltman, L, 2009). CiteSpace® is a software developed to help in scientometric research work with visual explorations of patterns and trends transmitted by the body of literature. During this step, all 316 articles and cited references are linked together

with the help of mentioned software to form a citation network. Creating a citation network with further visualization allows identifying main patterns in the research field during the years, forming EVM studies intellectual base by citations examination, and creating EVM research clusters with visualization. The co-occurrence of key terms chosen by authors and published journals form clusters of research focuses and trends during the years in the network. As for citation bounds, the network helps to reveal to most cited works, thereby forming the foundation of the EVM study. The citation network itself was examined according to structural metrics: modularity and silhouette. According to Chen, modularity is a quantitative characteristic of a network that has ranged from 0 to 1, and it shows the strength between blocks which form a network (Chen et al., 2010). With greater modularity, a better structure of the network. The silhouette is an indicator that varies between -1 to 1, and it shows uncertainty in forming clusters (Chen et al., 2010).

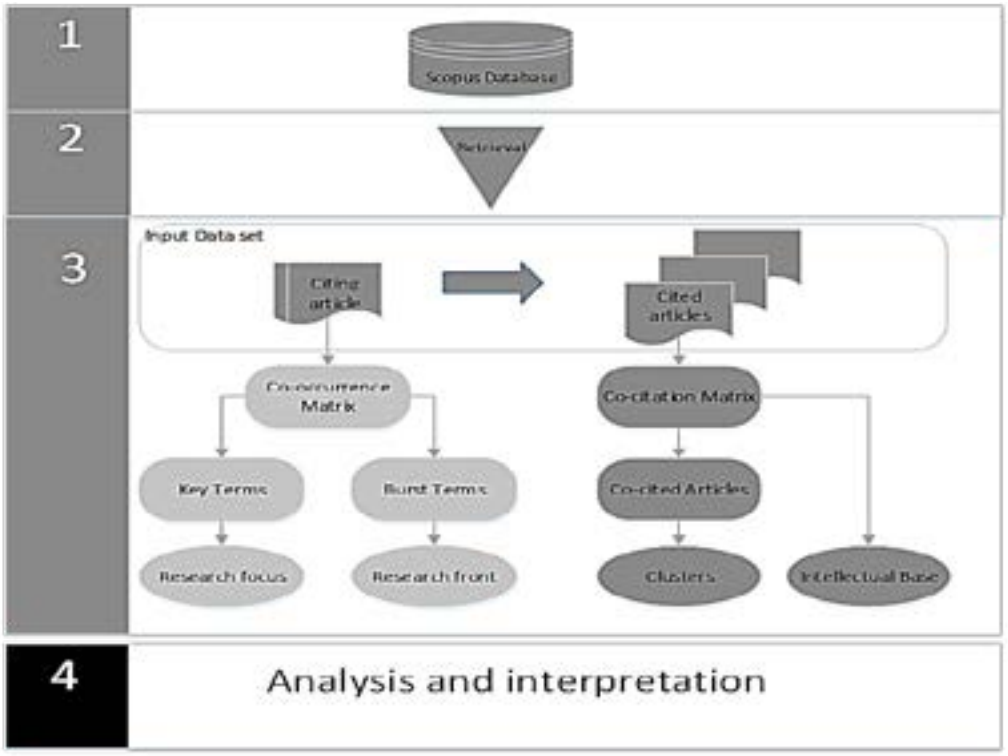

Figure 2 – The SALSA methodology approach (adapted from Rezende et al. 2018)

Along with the structural metrics, the created network is also characterized by temporal metrics such as burst detection and betweenness centrality. It shows when a citation or keyword in *n* article has a considerable score, evidence of a change of interest in the particular work. The betweenness centrality metric measures "the extent to which the node is in the middle of a path that connects other nodes in the network" (Chen et al., 2010, p.8). The visualized data network and its structural and temporal metrics reveal characteristics and patterns in the EVM research field.

The last stage was the analysis of the created networks. It describes the meaning of patterns and information elicited from the synthesis stage with mentioned above software. The whole analysis helps to understand how project control and monitoring, earned value management field evolved during the years and set up a direction for future research trends.

Results and discussion

General findings from the data set

The data set extracted from the Scopus database on October 25, 2019, contains 316 articles and review papers from well-recognized published journals. With further analysis in Scopus, it has

been found that 1659 documents cite selected 316 articles. Document sets represent research works in the range of date from 1985 to 2019 from various subject areas, where the top three are *Engineering (181), Business, Management and Accounting (129), and Computer Science (78).* The last three subject areas are *Energy (10), Arts and Humanities (6), and Economics, Economy (6).* The other areas contain a substantially small number of research works, and as shown below in Figure 3 overall index does not exceed 5% of the total amount of EVM research works.

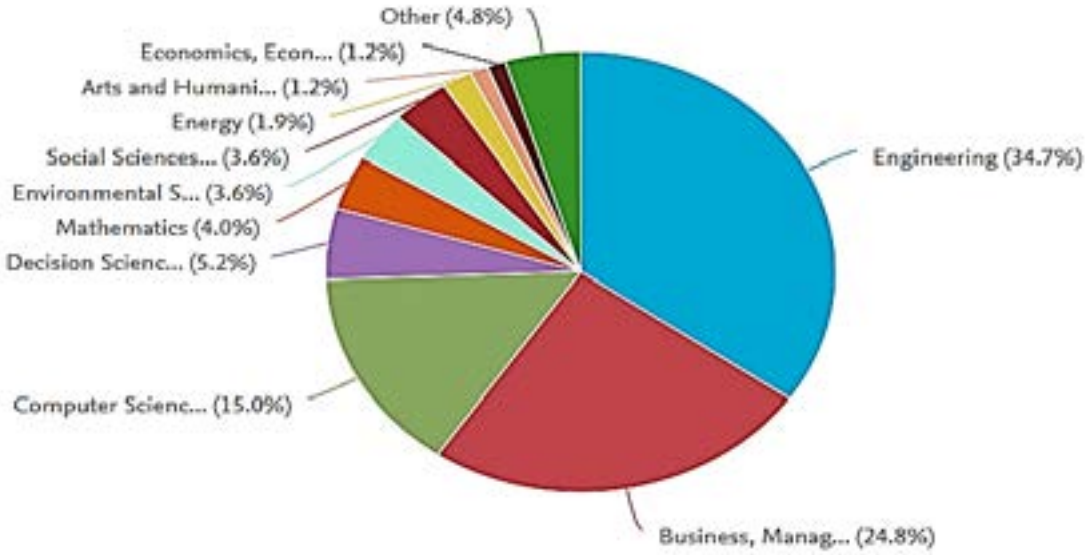

Figure 3 – Distribution of EVM articles by Scopus-defined subject areas
Note – designed by authors

Figure 3 illustrates how EVM has become a subject of interest to researchers over the years. As mentioned in part 2 of this research work, EVM was developed further from the 90s, and Figure 4 reflects its progress. It is an interesting remark that after the first work in this research domain published in the Journal of Management and Engineering, "Earned value technic for performance measurement" (McConnel, 1985) was a period of silence until the mid-90s when several works continued study. In the period until 2001, not many articles were published by researchers. However, after 2002, the number gradually rose until 2006 and fluctuated slightly by 2012. The last years in the graph show that the EVM research field has become a popular subject of interest among researchers.

The infographic below shows the most productive authors of articles extracted from the data set. It has been revealed that Vanhoucke, M. has published 27 articles in the EVM research field, which is the greatest number compared to other authors. The next follows Bagherpour, M with 15, Kim B.C, and Lipke W. with ten research works accordingly. Four authors Colin J., Martens A., Narbaev T., and Salari M., have the same number of published works – 5.

The most popular journals where authors published their works are presented in Table 1. As can be seen from the table, "International Journal of Project Management" published 30 EVM research filed related articles, the highest score among all. The "Journal of Construction Engineering and Management" is less below the number of 27 works, which is understandable given that the construction field is one of the industries that incorporated EVM at an early stage.

Findings from the EVM research clusters analysis (RQ1)

The citation network presented in Figure 6 provides information about citation links between research works in the earned value management field. The links establish 6 clusters by the main focuses in the articles with a modularity Q=0.55, which index of a well-structured network, and the mean silhouette score of 0.35, which indicates a low uncertainty level involved in identifying the nature of its clusters.

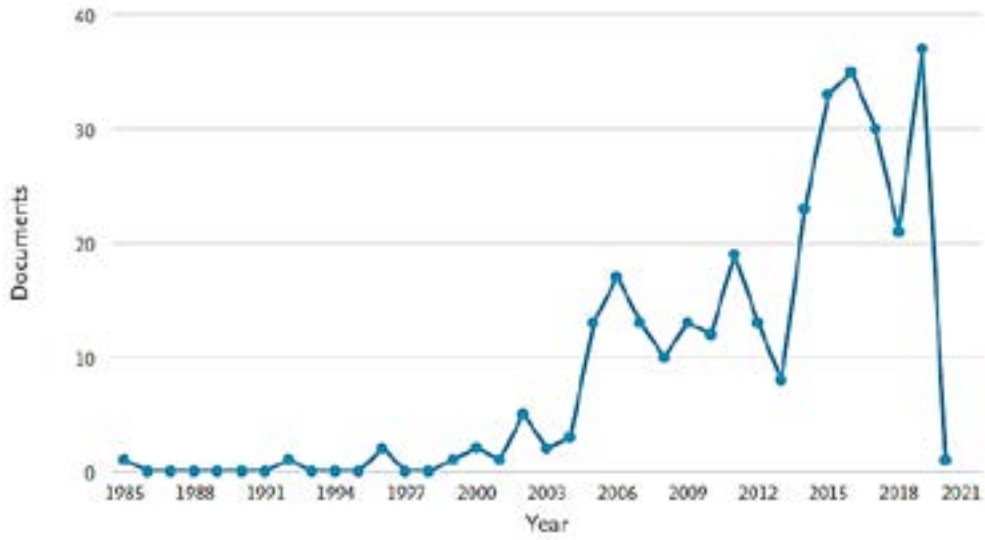

Figure 4 – Distribution of EVM articles over 1985-2019

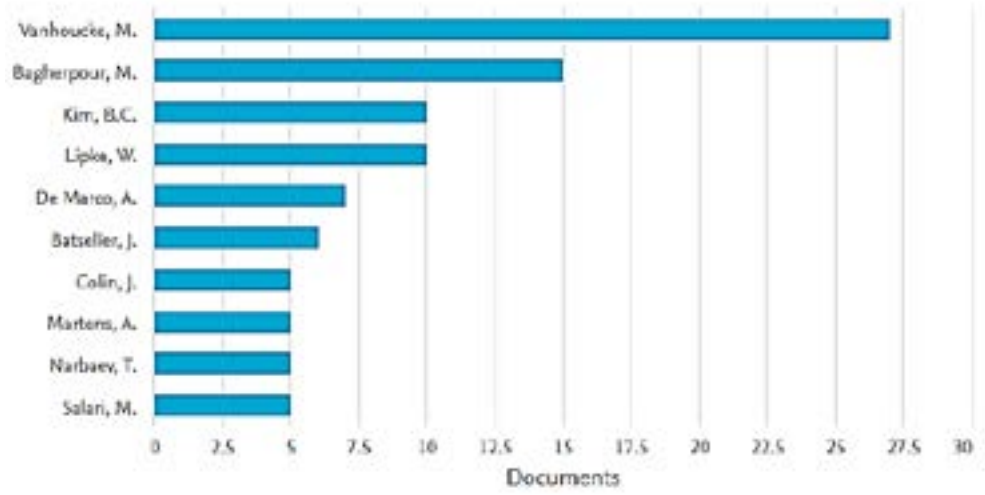

Figure 5 – Top 10 authors in the EVM field

Table 1 – Top 5 journals that publish EVM articles

No.	Source title	Number of articles
1	International Journal of Project Management	30
2	Journal of Construction Engineering and Management	27
3	Crosstalk	18
4	Journal of Management in Engineering	9
5	Automation in Construction	8

The network and formed clusters are presented in Figure 6. Circles can vary in size, depending on the number of citations they received. The bigger circle is, others more cited the document. The document circles are allocated on different layers, and it depends on the citations represented on a

single timeline, which shows how the document has been analyzed over time. Some of the circles are outlined with a bold pink line indicating the betweenness centrality score.

As can be seen from the picture, the range of the themes covered by the abstract terms, namely: *"#0 project control process", "#1 value technique", "#2 stochastic analysis", "#3 non-deterministic condition,", "#6 forecast-risk compatibility check" and "#9 green building"*. The most discussed topic is *"#0 project control process"* and the cluster explorer shows that the mean year of discussion is 2011 and cover 39 documents with coverage of aspects such: as project, ability, actual performance, tolerance limits, system, actions, project control, baseline schedule, duration, database, project cards, project data, actual performance, project, forecasting methods, approach, variation, warning, and stability. The *"#1 value technique"* cluster has a mean of 2007. It covers 37 documents with a discussion of important topics such as project performance, tracking approach, top-down project, project performance measurement, risk analysis, project managers attention, project tracking, project progress, implementing EVM, working flowchart, project performance, construction, fuzzy logic, advantages, scheduling, z-number theory, and top-down project. The cluster *"#2 stochastic analysis"* in the cluster explorer show information about research focuses for mean 2013 year in 30 articles: uncertainty; stochastic analysis; work items; budget; decision-makers; points; critical path; complex projects; work item; to-completion forecasts; completion; cost performance; date; cost projection; prediction; unique features; popular method; prediction accuracy; cost prediction. The most recent mean for the 2015 year *"#3 non-deterministic condition"* revealed the following research focuses: completion; predictive power; cost overrun probability; cost data; approach; objective; future status; review; conceptual framework; critical infrastructure project; project completion time; non-deterministic conditions; approach; purpose; practical implications; EVM method; actual physical completion percentage; cost overrun probability; objective; future status. The last two themes, *"#6 forecast-risk compatibility check"* and *"#9 green building,"* are relatively smaller clusters, as shown in Figure 6, that are allocated along the edges of the main array and have a mean 2011 year for research focuses. *"#6 forecast-risk compatibility check"* cluster's key terms are research; implementation; NASA; future; government; application; management; programs; effectiveness; forecast sensitivity; effectiveness; compatibility check; forecast-risk compatibility check; forecast-risk compatibility; framework; forecast sensitivity; database; construction. Moreover, for the last *"#9 green building,"* the key terms are green buildings; energy; cost deviation; value approach; green building; buildings; individual project; criteria; moment; early cost; procedure; continuous improvements; decision-making; criteria; organization; organizations; early cost; green buildings; green building.

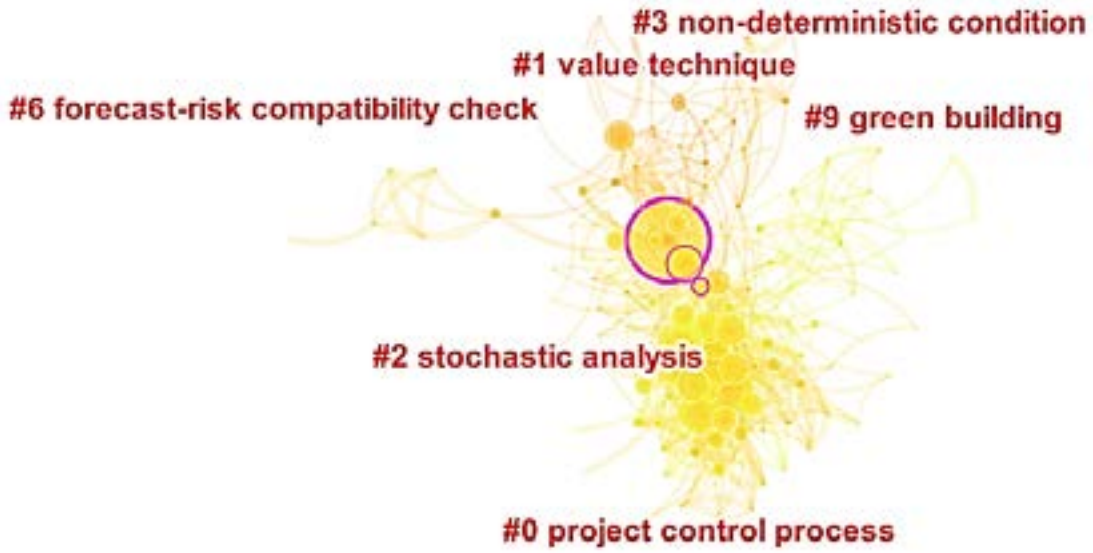

Figure 6 – Main clusters of the EVM literature

The further analysis of the network presented in Figure 6 with additional data from Figure 4 indicates three periods in the life of the EVM research field. The first can be described as early works in the EVM research field from 2003 to 2009. Those articles introduced some important ideas related to EVM methodology and implementation in the project monitoring process as a beneficial tool that project managers should approach. The second period of EVM research is in the range of 2009 – 2015 years characterized by further development of EVM research and contains discussion about project control process, implementation of statistical analysis in the forecasting of project performance and risks. The last and current period from 2015 to 2019 revealed discussions about improving time and cost prediction in projects with uncertain environments, which can be complex infrastructure projects.

Findings from the analysis of the main research foci and trends (RQ2)

This research work aims to answer the next question: what are the main research focus and trends in the EVM field? The change of the focus in the research field can be distinguished by analysis chosen by authors or publishing journals keywords. As can be seen from Table 2 below, CiteSpace software distinguished the most cited over the three decades' keywords. The keywords *project management, value engineering, earned value management,* and *budget control* has been most mentioned in research works in the EVM field. They revealed concern about the importance of control measurements in project management, especially the earned cost. The keyword *cost,* in general, is trendy among chosen authors front term is used to describe the value of EVM application. Other keywords such as *forecasting, estimating,* and *analysis* are used to describe EVM as a tool that helps to plan the financial aspect of the project and help to predict any deviations from planned estimations. The following most occurred keyword is the *schedule. Risk assessment* and *management* were associated with a research focus on project risk management and how EVM can be helpful in risk analysis and measurement. *Construction project* and *construction industry* keywords gave sensemaking about the most popular industry among researchers to apply EVM methodology.

Table 2 – Top keywords representing the EVM field

Keyword	Occurrence	Keyword	Occurrence	Keyword	Occurrence
project management	164	project control	30	construction project	18
value engineering	162	earned value analysis	27	construction industry	17
budget control	158	scheduling	23	risk management	15
earned value management	139	cost and schedule	21	simulation	13
cost	55	decision making	21	cost estimating	11
earned value	52	earned schedule	21	estimate at completion	11
forecasting	38	project performance	20	project manager	11
cost-benefit analysis	30	risk assessment	20	schedule control	11

Some of the keywords from Table 3 received more attention from researchers during the specified time range. The identification of keywords frequency made by a special option in the CiteSpace software and algorithm was calibrated to present all keywords trending over the whole period. Figure 7 presents 19 keywords with burstiness strength scores and time range with the greatest attention as we can see the last trending keywords highlighted research topics such as *life cycle, cost analysis, risk perception,* and

schedule control. The keyword *life cycle* introduced the general attention to EVM application in the project control and monitoring field. Enhanced quantitative analysis methods in EVM methodology are leading interest in *cost analysis, risk management,* and *schedule control.* The revealed discussion from research works and the recently from the 2015 year burst terms draw the trends of the research front in the EVM research field, shed light on the research that is being done now and what can be anticipated shortly. Recent trends show that attention has been raised to enhancing methodology in cost and schedule control and scrutiny of EVM from risk management.

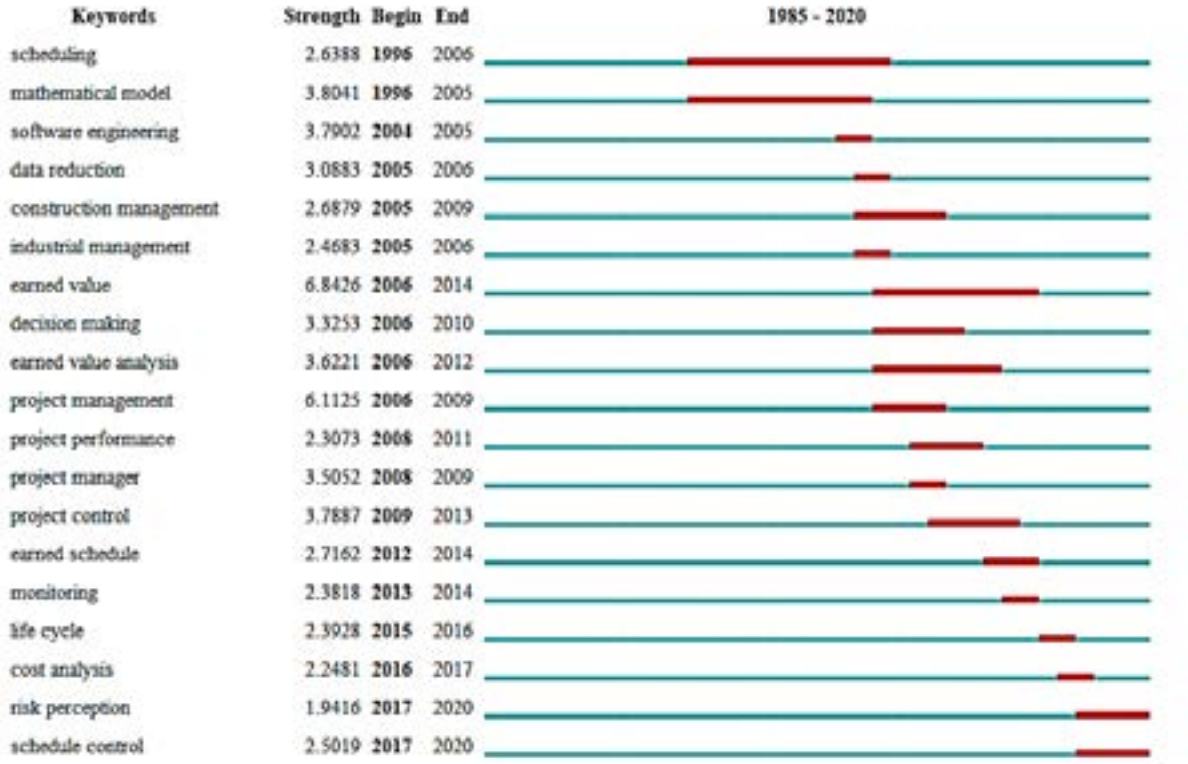

Figure 7 – Keywords citation burst during 1996-2020

Findings from the analysis of the top-cited studies (RQ3)

This part of the analysis is aimed to answer the third question of thesis work by identifying the most cited research works by citation analysis.

While the research front cover state-of-the-art in the field, the intellectual base is composed of the most frequently cited research works and, according to it, represents the foundation of this research field (Chen, 2006). The composed citation network in the CiteSpace application graphically highlights the interrelation of research works in the EVM field. The importance of each article in the foundation of the intellectual database can be determined from the citation count in the composed network. As shown from Figure 6 of part 4.2 in this research work, the most cited articles have larger circles on the map, and Table 3 reflects them in a list with details of citations count, authors, the title of research works, and date of publications. The list represents the top 17 cited articles ranging from the highest number of citations to fewer. In order to highlight the studies that significantly contributed to the development EVM research field and to understand how researchers used others' findings to elaborate them further, articles will be summarized from the oldest to the newest.

The seminal work of Vandervoorde and Vanhoucke (2006), as one of the earliest works in the EVM research field, contributed to the development of duration forecasting. They argued that traditionally EVM was focused only on cost management. They also noted that EVM was little applied to project duration control using classic SV and SPI performance indicators and presented newly developed indicators SV(t) and SPI(t). They

were used for forecasting duration applicable in different project situations. Following this research, Vanhoucke and Vandervoode (2007) published an extensive study simulation using their indicators for enhanced project forecasting. Their research demonstrated careful control of the project uncertainty, dependency on the accuracy of the forecasts from the project network structure, and the timeframe where the EV-based measures provide accurate and reliable results.

Table 3 – Most cited articles in the EVM field (the articles that received at least 10 citations are shown)

Rank	Citations	Reference	Title
1	41	Lipke (2009)	Prediction of the project outcome. The application of statistical methods to earned value management and earned schedule performance indexes
2	27	Vanhoucke (2011)	On the dynamic use of project performance and schedule risk information during project tracking
3	25	Khamooshi (2014)	EDM: Earned Duration Management, a new approach to schedule performance management and measurement
		Elshaer (2013)	Impact of sensitivity information on the prediction of project's duration using earned schedule method
4	23	Colin (2014)	Setting tolerance limits for statistical project control using earned value management
5	19	Pajares (2011)	An extension of the EVM analysis for project monitoring: The Cost Control Index and the Schedule Control Index
		Vandervoorde (2006)	A comparison of different project duration forecasting methods using earned value metrics
6	17	Narbaev (2014a)	An Earned Schedule-based regression model to improve cost estimate at completion
7	16	Aliverdi (2013)	Monitoring project duration and cost in a construction project by applying statistical quality control charts
8	15	Vanhoucke (2010)	Using activity sensitivity and network topology information
		Vanhoucke (2007)	A simulation and evaluation of earned value metrics to forecast the project duration
9	13	Batselier (2015)	Construction and evaluation framework for a real-life project database
		Acebes (2015)	Stochastic earned value analysis using Monte Carlo simulation and statistical learning techniques
10	12	Naeni (2011)	A fuzzy approach for the earned value management
11	11	Wauters (2014)	Support Vector Machine Regression for project control forecasting
12	10	Colin (2015)	A comparison of the performance of various project control methods using earned value management systems
		Chen (2016)	Earned value project management

Alongside the recent technique proposed by Vanhocuke and Vandervood, Lipke (2009), in his research work on improvement in the prediction of project outcomes, proposed mathematics of statistics in the methods of predictions and testing. His research work aimed to provide a reliable forecasting method of the final cost and duration. This method was studied and tested using the data of 12 projects. Vanhoucke (2010), in his article "Using activity sensitivity and network topology information to monitor project time performance," performed a simulation study to measure the ability of sensitivity metrics to improve the time performance during the project execution dynamically. In the following year Vanhoucke (2011) studied two alternative project tracking methods how they are efficient in early problem detection and the quality of corrective actions. Notably, he reviewed bottom-up and top-down project tracking approaches and, as a result of computational analysis, concluded that the top-down project tracking method is effective for project networks with a serial activity structure.

In contrast, a bottom-up approach performs better in a parallel structured project network. Pajares (2011) introduced new indexes Cost Control Index (CCI) and schedule control index (SCI), that combine EVM and Project Risk Management in project control and monitoring. Naeni (2011), in

the same year, developed a new fuzzy-based earned value model with the advantage of developing the EVM indices and the time and cost estimates at completion under uncertainty. Elshaer (2013) continued the analysis of activity sensitivity proposed by Vanhoucke (2011) and, in his research work, studied the impact of the activities' sensitivity information on the forecasting accuracy of the Earned Schedule Management method. Aliverdi (2013,) to uncover the capability of reporting accepted cost and time deviations in EVM, applied statistical quality control charts to monitor earned value indices in real construction projects. Narbaev and De Marco (2014a) proposed a new CEAC method based on a modified index-based formula predicting expected cost for remaining work, the Gompertz growth model with nonlinear regression curve fitting.

Khamooshi and Golafshani (2014) stated about the dominance of EVM with recently extended technique to track the schedule and developed new Earned Duration Management in their research work. Colin (2014), likewise Aliverdi (2013), studied the accepted level of deviations in his research work and presented a new statistical project control procedure that sets tolerance limits, which improves the ability to trigger actions when deviations in project progress exceed certain predefined thresholds. Wauters and Vanhocke (2014) compared the Support Vector Regression (SVR) model with the best-performed EV and ES methods in the analysis of project forecasting. They found that SVR outperforms available forecasting methods. Batselier and Vanhoucke (2015), for their research work, created a real-life project database.

Furthermore, to ensure the quality of the project data, the database construction and evaluation framework was developed. Acebes et al. (2014), in their research work, proposed several refinements to previous EVM and risk analysis methodologies using refinements in previous methodologies. A new project control approach is likewise presented by Colin and Vanhoucke (2015) in their research, where they combine elements of top-down and bottom-up control. For this purpose, they integrated EVM/ES method with multiple control points affiliated with critical chain/buffer management. Chen (2016), in his research, suggested using a straightforward modeling method for improving the predictive power of PV before executing a project.

Some research works received considerable attention from authors during specific periods, notwithstanding the highest citation scores received. Those works presented in Figure 8 are obtained from burstiness analysis in the CiteSpace application.

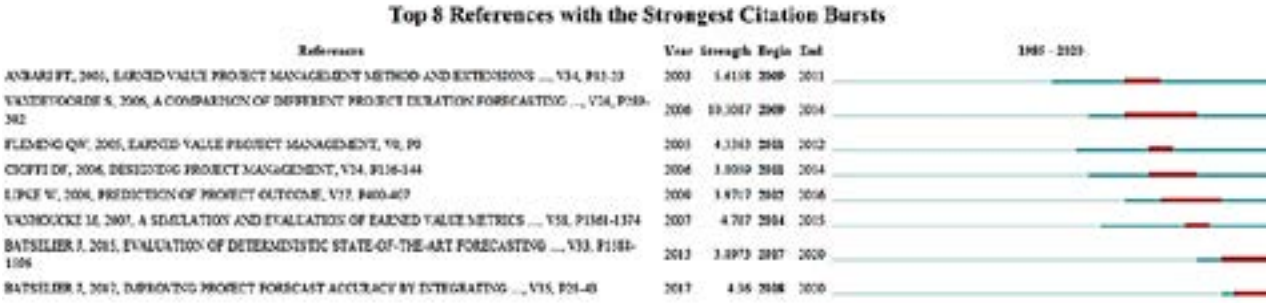

Figure 8 – Document citation burst between 2009 and 2020

Several documents from Figure 8 with strong burstiness scores were also ranked as the most cited references in the network, such as Vandervoorde (2006), Lipke (2009), Vanhoucke (2007), and Batselier (2015). The earliest work of Anbari (2003) was famous in cited references between 2009 and 2011. It provided an overview of major aspects of EVM and showed graphical tools for assessing project performance trends. The research work of Fleming (2006) also became the most cited article in the 2011-2012 years, focusing on the application of EVM in software projects. Cioffi (2006) introduced in his research work scientific notation and improved formalism for EV calculations transparently and flexibly. His work received the greatest attention from researchers from 2011-to 2014 years. Batselier and Vanhoucke (2017), in the most recent research work, integrated EVM methodology with the exponential smoothing forecasting approach. This

new technique, called XSM and currently under great attention for further research.

Discussion of the main findings

Combining the results and findings from the previous sections provides us with information that helps us see a holistic picture in EVM. It also shows how the field has evolved over the last years. For reference, it is founded that the earliest work is "Earned Value Technique for Project Performance" by McConnell (1985), and then the research field was developed most since 2006. Construction engineering was a considerably popular industry area among researchers for applying EVM methodology in real projects, both standard techniques and newly developed for test purposes. This thesis work emphasized the most productive authors, and it has been revealed a significant contribution of efforts made by Vanhoucke M. in the development of the research field.

As for the first research questions, the results tell us that considerable research works belonged to "project control process", "value technic", and "stochastic analysis". Most of the works were highlighted attention on improvement in measurement for project duration forecasting by developing methods in Earned Schedule and introducing new indices. Alongside risk management and analysis of activities, sensitivity was received attention from researchers. It can be noticed in the footprint in another cluster, "forecast risk-compatibility check," and "non-deterministic condition".

The research question #2 was put forward to investigate the focus and trends in the research field by keywords. The central focus was on cost management, budget control, earned schedule, and project duration forecasting. We see from the analysis of keywords that the construction industry is the focus of researchers for applying EVM methodology. The burst analysis of keywords helps identify the main trends during the past years. The results tell us that at an early stage of research development, the main trends were usability of EVM methodology in various spheres such as software engineering, industrial management, and construction management. Then the trend was shifted to earned value analysis and cost management. At the last stage, the trend turned to earned schedule and project forecasting in an uncertain environment.

The last research question was put to explore the most cited articles that formed the intellectual base of the research field. As was described in this section of the study, 17 most cited articles can be considered the foundation of the research field. However, the most cited articles are belonged to recent years, starting from 2006, and it is a limitation for this research work and suggested as research agenda for the following works.

Conclusion

The findings of the scientometric analysis revealed that research started developing at the beginning of the 1990s and was evolved significantly during the 2010s. The earliest works were focused on the EVM methodology standard technique and practical application in industrial and construction areas. The analysis of burst citations and keywords showed the shift of focus starting from 2009 to improvement in the calculation of project duration forecasting and developing new techniques in earned schedule metrics. These conclusions are also rooted in the intellectual base findings, suggesting that previous works focused on financial performance aspects in the project control and monitoring area. The analysis of research clusters revealed significant research topics works collated in the clusters of "#0 project control process", "#1 value technique", "#2 stochastic analysis", "#3 non-deterministic condition", "#6 forecast-risk compatibility check" and "#9 green building".

Overall, the findings show that the EVM literature has grown and become popular in the last decade. The findings also suggest that the studies shifted their foci from simple EVM applications to the ones proposing advanced models, mostly for time and cost forecasting, under uncertainty. The findings presented in this work summarize and fill the existing gap in the literature regarding the research focus and trends, main ideas from the most cited articles, and research topics in EVM. The implications to researchers and the wider public are in the ability to use the identified intellectual base to understand the main trends that have been explored thus far.

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