The Role of Machine Learning in Managing Uncertainty in Projects – A View on Early Warning Systems

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Abstract: Machine learning techniques deals with, among other things, pattern recognition in large amounts of data to identify trends and possible events in the future regarding a given topic of interest. Machine learning methods are useful for addressing challenges in and creating new benefits for organisations. This paper looks at how machine learning can contribute to manage projects effectively. Many organisations apply the concept of project. A part of them are purely project-based organisations, and a part of them carry out projects in addition to their mass-production activities and permanent operations. Within the realm of project management, this paper sets its focus on studying the role of machine learning in handling unexpected events and uncertainty in projects. One of the ways to deal with unexpected events and uncertainty is to capture early warning signs that can predict unexpected events. A major failure of projects can be seen as a combined effect of a series of small failures, negative results or problems that have occurred over a period of time. Project teams may not notice or just ignore early warning signs of these problems and choose to work further in the project. This could finally lead to a major failure, at which point no preventive actions could save the project from the major failure. Several researchers have researched on early warning signs and systems within the context of projects. Early warning signs can be seen as some kind of a pattern recognition from a pool of relevant data. This paper aims to answer the following two interrelated research questions: (1) What role does machine learning have in early warnings in projects? (2) How can machine learning contribute to effective project management (for example, handling uncertainty in projects)? This is a conceptual paper, based on literature study.

Keywords: Uncertainty management, Machine learning, Project Management, Early warning signs, Learning in organisations

1. Introduction

Projects are one-time activities that has time and resource limitations. They are aimed at achieving specific objectives. Projects are a popular work-form, and several industries conduct their businesses by carrying out projects. Projects are per definition unique. However, the degree of uniqueness can vary from project to project. Uniqueness associated with other characteristics of the project concept – such as, time and resource limitations, involvement of various stakeholders (their needs, requirements, expectations, worldviews, interests, and influence), and being generally susceptible to changes in the internal and external environments – contribute to create uncertainty in projects. Managing uncertainty is important to make sure effective conduct of projects. Hillson (2004, page 3-4) says,

> *"Much of the typical project management process seems to be like trying to drive a car by looking in the rearview mirror, with the concentration on reporting, review, control, and monitoring. Instead projects and businesses need a forward-looking radar, scanning the murky and unclear future to identify the outlines of possible obstacles or shortcuts, allowing the driver to make necessary course corrections in time to avoid disaster and steer toward the desired destination".*

Other researchers, such as Perminova et al. (2008) and Olsson (2007) also point out the significance of managing uncertainty in the discipline of project management.

One of the ways to deal with uncertainty and unexpected events is to capture and address early warning signs that can predict unexpected events. A major failure of projects can be seen as a combined effect of a series of small failures, negative results or problems that have occurred over a period of time. Project teams may not notice or just ignore early warning signs of these problems and choose to work further in the project. This could finally lead to a major failure, at which point no preventive actions could save the project from the major failure. Several researchers have studied on early warning signs and systems within the context of projects (HajiKazemi et al., 2015; Klakegg et al., 2010).

Early warning signs can be seen as a pattern recognition from a pool of relevant data. This paper sets its focus on studying the role of machine learning – which deals with large amount of data to find patterns / trends and predict a possible future – in handling unexpected events and uncertainty in projects.

This paper aims to answer the following two interrelated research questions: (1) What role does machine learning have in early warnings in projects? (2) How can machine learning contribute to effective project management (for example, handling uncertainty in projects)? This is a conceptual paper, based on literature study.

As followed by the introduction, the paper provides relevant concepts / theories and then a brief description of the research method that is applied in the study associated with this paper. After that, a discussion on how machine learning can improve managing uncertainty in projects is presented. Finally, concluding remarks winds up the whole discussion.

2. Relevant concepts / theories

2.1 Uncertainty management in projects

Uncertainty within the context of projects can be described in several ways. Perminova et al. (2008, page 76) define "uncertainty as a context for risks as events having a negative impact on the project's outcomes, or opportunities, as events that have beneficial impact on project performance". Ward & Chapman (2004) and Olsson (2007) also view the term uncertainty as a kind of an umbrella-term to include risk management (threats) and opportunity management (opportunities) – that is, both the negative and positive sides of uncertainty in projects respectively. Ward & Chapman (2004, page 857) further say that uncertainty management "is also about identifying and managing all the sources of uncertainty that give rise to and shape our perceptions of threats and opportunities".

Nobre and Tobias (2008) provide the following definition of uncertainty, which reflects the theory of bounded rationality (Nobre, 2005):

- Insufficient information: Uncertainty is the difference between available information and needed information
- Insufficient cognitive capacity to process information: Uncertainty is the difference between the cognitive capacity that the organisation has and the cognitive capacity that the organisation needs to have

Bounded rationality is the idea that people make decisions that are satisfactory for them, but not the optimal, since their understanding of the situation is shaped by limited information and limited cognitive capacity.

The above description points out that there are greater benefits that organisations can obtain by using some kind of a means to process all possible information (that can be a huge amount of data / information that human brain cannot process it effectively) regarding a given situation, make sense of the information, acquire better understanding of the situation, and act accordingly. One such means can be machine learning.

2.2 Machine learning

2.2.1 What is machine learning?

Historically there have been two ways to approach statistical modelling. In what was up until recently the most used method, the analyst would apply assumptions regarding how the data were generated. In the other method, the underlying data mechanism were treated as unknown (Breiman, 2001). The first method is sometimes referred to as the classical method, while the last approach is commonly known as ML. This technique applies two elements when constructing a relationship between a dependent and independent variable: One algorithm which models the relationship between input data and the variable to be examined, and another algorithm that learns which input variables gives the best fit.

Baduge et al. (2022, page 2) describe machine learning (ML) as follows:

> *"Machine learning is a subfield of artificial intelligence where a computer observes a given set of data and generates a model based on the input data which can be used to solve problems. ML is different from traditional programming. In traditional programming, rules are coded in a computer language without*

> *explicit learning from the data. In contrast to traditional programming, ML uses data to generate predictive models which are then used for predictions with the unseen data. For some problems, it is extremely difficult to develop a rule-based program due to the complexity of the code and ML can be used in these instances provided sufficient data is available relevant to the considered problem".*

Machine learning techniques can broadly be categorised into three subgroups: Supervised learning, unsupervised learning, and reinforcement learning. Unsupervised learning includes algorithms tasked with recognizing patterns in data and determining output classification categories, while algorithms in the supervised learning class rely on clearly defined independent variables which is then related to a dependent variable (Hastie et al., 2009). Reinforcement learning, unlike the others, do not require training data, but instead iteratively try to maximize a mathematical "reward" and through that reach an optimal allocation of input (Sutton & Barto, 2018).

Relevant datasets can be constructed based on other research and expert knowledge within the domain. The data is used for training the model, a process which is typically supported by testing and validation techniques such as K-fold Cross Validation and Rolling Forecast Origin (Hyndman & Koehler, 2006). Both methods measure the algorithms systematic performance when predicting out of sample data.

Today, ML methods are being used broadly. ML-applications can be seen in self-driving cars Shreyas et al., 2020), chatbots (Rahman et al., 2017), financial analysis and risk assessment (Guerra & Castelli, 2021; Samitaset al., 2020), healthcare patient assessment (Aydoseli et al., 2022; Romero-Brufau et al., 2021) and more.

One of the topics that is closely associated with ML is "big data". Referring to earlier studies, Olsson & Bull-Berg (2015) describe big data as a large amount of data that require a new way to process them. Traditional ways (databases) do not have the ability to deal adequately with collecting, storing, processing or analysing big data.

The major purpose of big data is to utilize a large amount of data to obtain new knowledge / understanding and improve decision making. Data analytics play an important role here. According to L'heureux et al. (2017, page 7777), "the ability to extract value from Big Data depends on data analytics. […]. Data analytics involves various approaches, technologies, and tools such as those from text analytics, business intelligence, data visualization, and statistical analysis". The authors further suggests that ML can be considered as a fundamental component of data analytics. Wang & Alexander (2016) also point out that ML has been applied on big data.

2.2.2 Benefits of machine learning / artificial intelligence in projects

ML can be seen as one of the central elements of artificial intelligence (AI). The new wave of digital transformation, in which artificial intelligence (AI) plays a key role, has been making its impact on several industries. One of those industries is the construction industry. When describing AI and ML methods and applications in the construction industry, Baduge et al. (2022, page 1) say:

> *"Due to this digital transformation, massive amounts of data are generated, and systematic analysis of these data and predictive modelling can be used to generate innovative architectural and structural designs, improve construction and operational safety, reduce the embodied and operational energy requirements, reduced construction and operational costs, increased construction speeds, improved payback periods and enhance sustainability. However, analysing massive amounts of data and recognizing patterns by human or conventional computer programs using rule-based approaches is not realistic. Therefore, the capability of AI [artificial intelligence] to process massive amounts of data, recognize the pattern, and ability to build large-scale statistical models is a key facilitator of the building and construction industry 4.0 to process its digitized data".*

A concrete example of AI's benefits is its role in transforming current practices of offsite manufacturing used in prefabricated buildings – where factory-made components of the buildings are transported to and assembled onsite – to an industrial construction system. Integrated analysis for manufacturing's big data (which is a part of AI) is useful for all aspects of automation in offsite manufacturing (Baduge et al., 2022). It is to be noted that prefabrication can reduce uncertainty associated with building something onsite where the building process is susceptible to deal with weather changes.

Other concrete examples of AI's benefits include the following (ibid.): Construction management is currently done by using experiences from the professionals and commercially available software. Progress monitoring is currently carried out by manual extraction of information from construction sites. At present, manual supervision methods are generally applied in safety related activities onsite. Gathering and extracting relevant information, and automation by using AI can improve quality of construction management, progress, and safety. Uncertainty in projects can be reduced by availability of right information at right time at right place. The authors also mention how ML can be used to improve key activities in the construction industry – For instance, architectural design, material design and optimisation. As their conclusion, Baduge et al. (2022) say that the use of AI / ML applications can remove uncertainty in one or several segments of the projects (for example, material design and optimisation) and can contribute to a better-quality assurance, more efficient processes and/or reaching the chosen project goals with a greater ease and more certainty.

Digital twins generate a digital replica of a building that can evolve over the time by using the data that emerge during the lifecycle of the building. AI can contribute to develop digital twin models by processing large amount of data that are gathered during the construction and remaining lifecycle of the project. Pan & Zhang (2021) mention that a data-driven digital twin framework, integrated with Building Information Modelling (BIM), Internet of Things (IoT), and data mining for advanced project management, can enhance data communication and exploration to better understand, predict, and optimize the physical construction operations.

3. Research method

This paper adopts narrative literature review as its research method. According to Gregory & Denniss (2018), narrative literature reviews present "a (non-systematic) summation and analysis of available literature on a specific topic of interest" (page 893). Baumeister & Leary (1997, page 312) say that a narrative literature review is useful "when one is attempting to link together many studies on different topics, either for purposes of reinterpretation or interconnection". This paper focuses one specific major topic (that is, application of machine learning in uncertainty management in projects), and studies, among other things, the interconnection between two sub-topics (that is, machine learning and uncertainty management in projects). Narrative literature reviews incorporate various studies to enable the researcher to understand different views and characteristics of the chosen topic and generate a holistic understanding of the study (Campbell Collaboration, 2001; Kirkevold, 1997). As the authors (ibid.) point out, gaining of this understanding is generally supported by the researcher's experience, and existing theories and models. In this paper, we use existing theories, studies and our experience to acquire more knowledge on the chosen topic.

4. How machine learning can improve uncertainty management in projects – a look at early warning systems

4.1 "Black swans" and early warning signs

One of the aspects in managing uncertainty in project is to capture early warning signs of unexpected events and find out ways to deal with those events. In this regard, we will refer a term called "black swan". Taleb (2007) describe a black swan event as an outlier, since it exists outside of the usual expectations. Experience of the past may seem inadequate to predict the possible occurrence of black swan events.

Different approaches for managing black swan events have been suggested by researchers. The KPMG white paper (2013) suggests proper flow of independent and transparent information within the project. Murphy & Conner (2012) point out that black swan events have warning signs. Their suggestion is to identify early warning signs for minor negative events and deal with them effectively, so that a black swan event can be avoided in the future, or at least its effect can be reduced. Kenett (2013) suggests that obtaining and merging data, and data-based uncertainty analysis can enhance traditional methods that are currently used in uncertainty management.

The description mentioned above points out that black swan events can be predicted, at least to a certain extent, if adequate amount of relevant data can be obtained and studied / structured to provide a better understanding of the situation.

4.2 Machine learning and early warning systems (EWS) for project management

We recommend adaptation of ML driven solutions for EWS within project management. A ML-based EWS can provide project managers with assistance regarding risks and opportunities relevant for their project by estimating impacts of specific events relevant for the expected project performance. In addition, a ML-based

EWS would be able to gather, process, classify and analyse data at a speed otherwise not attainable, thus opening the possibility of almost instant uncertainty-assessment as the project manager logs project-relevant data.

Several studies say that the adaption of ML provides a substantial improvement for contemporary EWS within domains such as economics, health and construction, for example:

- Guerra & Castelli (2021) looks at, among other things, ML and risk / EWS in Banking domain, artificial neural networks (ANN), and recent trends including developing early warning systems (EWS) for bankruptcy and refining stress testing.
- Samitas et al. (2020) describe EWS for predicting financial crisis. In this regard, it establishes a framework for quantifying and determining contagion through the system after a (black swan) event occurred. It uses support vector machine for prediction. Its prediction is very accurate out of sample performance (98.8%).
- Nguyen (2021) focuses on construction management. Based on previous research, the study assumes that Construction Price Index is important, and then use K-nearest Neighbours to predict future Construction Price Index. Out of sample performance indicates an improvement relative to contemporary methods.
- Romero-Brufau et al. (2021) describe EWS in health. It uses gradient boosting to improve contemporary EWS.

To look at uncertainty management in projects using ML, we must first identify what mechanics are behind the change in uncertainty. However, before that, we need to find or define a factor that captures project uncertainty – for instance, what is the best variable or set of variables to capture our definition of negative or positive results within a project? What central factors determine that we consider a project failure or success? This can vary from project to project, so we will call this variable *Y*. One example of *Y* can be budget overruns. Project governance imply that budget restrictions should be adhered to, thus a large budget overrun could for some imply a large project failure.

The potential predictors for *Y* can be assumed to vary between domains and over time as both projects and society change. Therefore, detailed assumptions regarding how the data is generated should be avoided. Thus, a ML approach to statistical modelling is warranted.

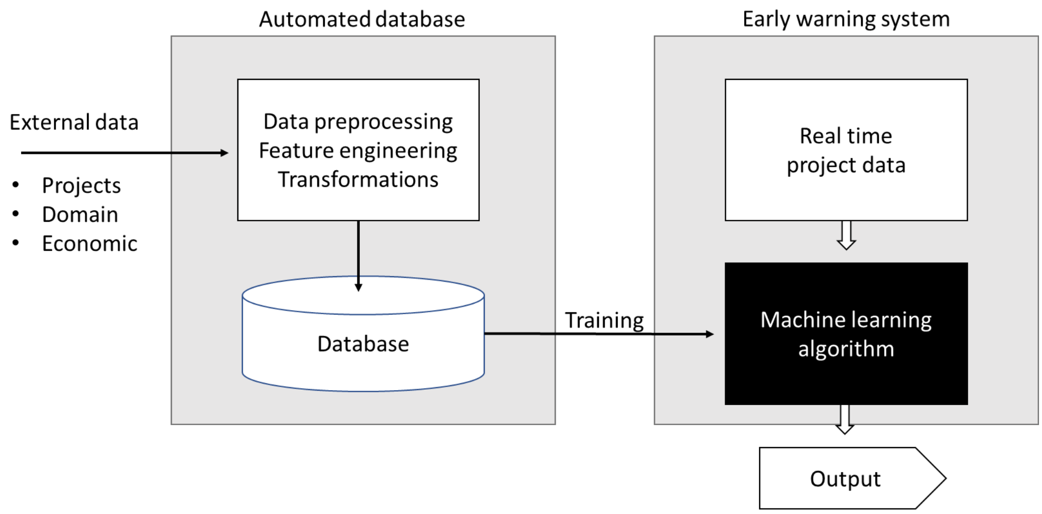

Figure 1: A suggested solution for real time project management system

A suggested solution for real time project management system can be seen in Figure 1. By connecting a database to various online data sources through application programming interfaces, a scripted system can autonomously download, prepare and store large amounts of diverse data. Feature engineering, which includes tasks such as deciding which tests should be executed and which external data should be downloaded, can be an iterative process where end-user experience and knowledge is taken into account. Pre-processed data would be used to train a machine learning algorithm to assess which factors were relevant for the observed change within a given Y-variable. By integrating the trained ML-system with the enterprise software that the organisation uses for its project management, project data can be seamlessly and instantly accessed by the ML-algorithm. This allows for the events from within the project to immediately be put in relation with all the internal and external data the ML-algorithms have access to, and an output be generated regarding the effect of the most central uncertainty parameters involved. Thus, the project manager will get almost instant feedback of the project information. The proposed system thus becomes an integral part of the project managers sensemaking.

The quality of the uncertainty-assessment from an ML-framework for project management such as the one suggested in Figure 1 will be heavily dependent on the quality, type and amount of the training data that are accessed through external databases.

Once the early warnings are identified, then that information is shared in the project / organisation so that the involved actors can interpret, understand, and make sense of the information, and collectively reflect upon their understanding. This collective reflection by the actors, who generally represent different disciplines and functions, can lead to a holistic / systemic understanding of the situation; including the warnings, the context in which the warned events can occur and affect, and possible consequences of the effect. This knowledge can provide a base for designing or developing solutions as a response to deal effectively with the warning signs. As a result, appropriate actions can be taken. The experience and knowledge acquired through this process can then be utilised in the whole process again if necessary to identify and address early warning signs in the future. Figure 2 illustrates the process.

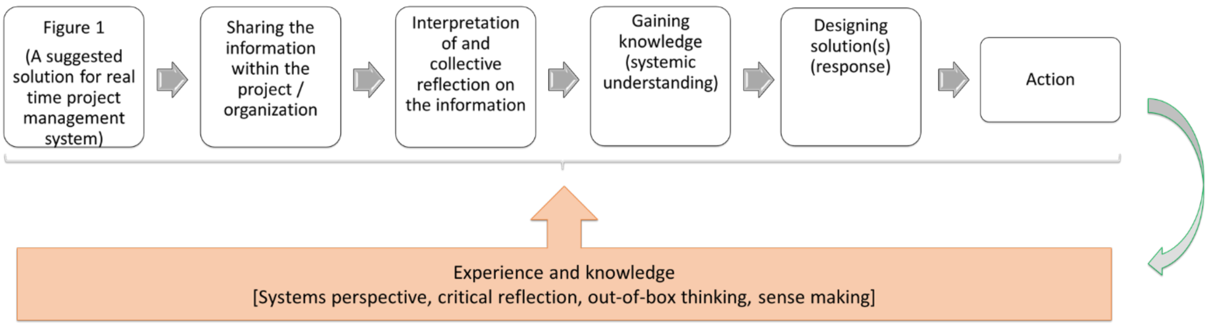

Figure 2: Addressing early warning signs (developed from Hajikazemi et al. (2016))

Collective reflection and discussion around the identified early warning signs mentioned in the above process can also lead to find out other early warning signs that the ML algorithm (in Figure 1) may not find, and / or provide valuable nuances and additional information to the early warning signs that are identified by the ML algorithm.

Referring to other studies, Li & Mo (2020) present three stages of an early warning process: Identification, estimation and evaluation, processing and post-evaluation. Figure 2 incorporates / reflects on these three stages.

Though the application of ML seems very promising, there are several challenges. Some of them are:

- Cost: There is a significant amount of cost connected to dealing with / structuring unstructured and various forms of data. How much effort organisations are willing to put into the effort is a question.
- Effective application: When describing application of BIM in construction projects, Zabin et al. (2022) say "the rapid development of ML applications, the growing generation of BIM-related data in projects, and the different needs for use of this data present serious challenges to adopt and effectively apply ML techniques to BIM-based projects in the Architecture, Engineering, Construction and Operations (AECO) industry". This statement suggests, among other things, a need for learning to make sure an effective adoption and application of ML.

5. Concluding remarks

This paper attempts to answer the following two interrelated research questions:

1. What role does machine learning have in early warnings in projects?

2. How can machine learning contribute to effective project management (for example, handling uncertainty in projects)?

We have addressed these two questions based on narrative literature study. In chapter 2, we have presented some key benefits of ML in the construction industry that applies projects as its prominent work-form. In chapter 4, we have addressed the two research questions by using relevant theory and illustrations (Figure 1 & 2).

Dealing effectively with uncertainty is a significant challenge in projects. One of the main parts of this challenge is to capture, process and try to make sense of a relatively vast amount of information / data that can contribute to eliminate or reduce uncertainty. ML can play a key role in this regard: Identify and describe early warning signs of potentially unforeseeable or unpredictable future events that can affect the project. This contribution can then enable organisational actors to make appropriate efforts to face the uncertainties of the future effectively.

Our study shows that knowledge sharing and learning play an important role in addressing early warning signs in projects by applying ML. We believe that both the technological aspects (such as ML) and organisational and people-related aspects (such as collective reflection and knowledge sharing) should be taken into consideration jointly in order to harvest greater benefits. Project-based organisations that have a process – like the one that we have presented in Figure 2 – can apply the process (and the related ML application) to learn continuously in an effective manner. They can become learning organisations. Learning organisations have the ability to deal effectively with, among other things, changes, uncertainty and efficient use of resources. In this regard, it is relevant to mention a quote from Charles Darwin: "It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is most adaptable to change".

We believe that our study contributes to illustrate the connection between ML, uncertainty management in projects, knowledge sharing and learning. Hence, it can also contribute to develop and test a theoretical framework for the application of ML in managing uncertainty in projects. We also believe that out paper contributes to facilitate further discussion on this topic and to create more knowledge. As further research, we suggest studies on measuring the effect of ML in addressing uncertainty (early warning signs) in projects. It can also be useful to study closely how structural and cultural / social aspects of organisations affect the application of ML in managing uncertainty in projects.

References

Aydoseli, A.; Unal, T. C.; Kardes, O.; Doguc, O.; Dolas, I.; Adiyaman, A. E.; Ortahisar, E.; Silahtaroglu, G.; Aras, Y.; Sabanci, P. A. (2022): An Early Warning System Using Machine Learning for the Detection of Intracranial Hematomas in the Emergency Trauma Setting. Turkish Neurosurgery, 32 (3).

Baduge, S. K.; Thilakarathna, S.; Perera, J. S.; Arashpour, M.; Sharafi, P.; Teodosio, B.; Shringi, A.; Mendis, P. (2022): Artificial intelligence and smart vision for building and construction 4.0: Machine and deep learning methods and applications, Automation in Construction, Volume 141, September, 104440.

Baumeister, R. & Leary, M. (1997): Writing Narrative Literature Reviews, Review of General Psychology, September 1997.

Breiman, L. (2001): Random Forests, Machine Learning 45, Page 5–32.

Campbell Collaboration (2001): https://www.huidziekten.nl/diversen/opleiding/CATDatabase/guidetowritingreviews.pdf, Referred 23rd September 2020.

Gregory, A. T. & Denniss, A. R. (2018): An Introduction to Writing Narrative and Systematic Reviews — Tasks, Tips and Traps for Aspiring Authors, Heart, Lung and Circulation, Vol. 27, Page 893–898.

Guerra, P. & Castelli, M. (2021): Machine Learning Applied to Banking Supervision a Literature Review, Risks, 9 (7), 136.

Hajikazemi, S.; Ekambaram, A.; Andersen, B. S.; Zidane, Y-T. (2016): The Black Swan – Knowing the unknown in projects. Procedia - Social and Behavioral Sciences, Volume 226, page 184-192.

Hastie, T.; Tibshirani, R.; Friedman, J. H.; Friedman, J. H. (2009): The Elements of Statistical Learning: Data Mining, Inference, and Prediction; Springer, Volume 2.

Hillson, David (2004): Effective opportunity management for projects – Exploiting positive risk, Marcel Dekker, Inc.

Hyndman, R. J.; Koehler, A. B. (2006): Another Look at Measures of Forecast Accuracy. International journal of forecasting, 22 (4), page 679–688.

Kenett, R.S. (2013), Managing Risks with Data, Available at SSRN: http://ssrn.com/abstract=2355474 or http://dx.doi.org/10.2139/ssrn.2355474, Referred 20th June 2022.

Kirkevold, M. (1997) Integrative nursing research – An important strategy to further the development of nursing science and practice, Journal of Advanced Nursing, Volume 25, Page 977-984.

Klakegg, O. J.; Williams, T.; Walker, D.; Andersen, B.; Magnussen, O. M. (2010): Early Warning Signs in Complex Projects. Project Management Institute.

KPMG (2013): Avoid major project failure – turning black swans white [White paper], retrieved from http://www.kpmg.com/global/en/issuesandinsights/articlespublications/pages/avoiding-major-project- failure.aspx, Referred 12th March 2015.

L'heureux, A.; Grolinger, K.; Capretz, M.A. M. (2017): Machine learning with big data: Challenges and approaches, IEEE ACCESS, Volume 5.

Li, Z. & Mo, T. (2020): Early warning of engineering project knowledge management risk based on artificial intelligence, Knowledge Management Research & Practice, DOI: 10.1080/14778238.2020.1834885.

Murphy, J. F. & Conner, J. (2012): Beware of the black swan: the limitations of risk analysis for predicting the extreme impact of rare process safety incidents, Process Safety Progress, 31(4), page 330-333.

Nguyen, P. T. (2021): Application machine learning in construction management, TEM Journal, Volume 10, Issue 3.

Nobre F. S. (2005): On cognitive machines in organizations. Ph.D. thesis. Control number: M0266887BU. Birmingham (UK): University of Birmingham, Birmingham.

Nobre, F. S. & Tobias, A. M. (2008): The pursuit of cognition in manufacturing organizations, Journal of Manufactioring systems, October.

Olsson, N. O. E. & Bull-Berg, H. (2015): Use of big data in project evaluations, International Journal of Managing Projects in Business, Vol. 8 No. 3, pp. 491-512.

Olsson, Rolf (2007): In search of opportunity management: Is the risk management process enough?, International Journal of Project Management, 25.

Pan, Y. & Zhang, L. (2021): A BIM-Data mining integrated digital twin framework for advanced project management, Automation in Construction, Volume 124, April, 103564.

Perminova, Olga; Gustafsson, Magnus; and Wikström, Kim (2008): Defining uncertainty in projects – a new perspective, International Journal of Project Management, Volume 26.

Rahman, A.; Al Mamun, A.; Islam, A. (2017): Programming Challenges of Chatbot: Current and Future Prospective; IEEE, page 75–78.

Romero-Brufau, S.; Whitford, D.; Johnson, M. G.; Hickman, J.; Morlan, B. W.; Therneau, T.; Naessens, J.; Huddleston, J. M. (2021): Using Machine Learning to Improve the Accuracy of Patient Deterioration Predictions: Mayo Clinic Early Warning Score (MC-EWS). Journal of the American Medical Informatics Association, 28 (6), page 1207–1215.

Samitas, A.; Kampouris, E.; Kenourgios, D. (2020): Machine Learning as an Early Warning System to Predict Financial Crisis. International Review of Financial Analysis, 71, 101507.

Shreyas, V.; Bharadwaj, S. N.; Srinidhi, S.; Ankith, K.; Rajendra, A. Self-Driving Cars: An Overview of Various Autonomous Driving Systems (2020): Advances in Data and Information Sciences, page 361–371.

Sutton, R. S.; Barto, A. G. (2018): Reinforcement Learning: An Introduction; MIT press.

Taleb, N. N. (2007): The black swan: the impact of the highly improbable, Random House Publishing Group, USA.

Wang, L. & Alexander, C. A. (2016): Machine Learning in Big Data, International Journal of Mathematical, Engineering and Management Sciences, Volume 1, No. 2.

Ward, S. and Chapman, C. (2004): Making Risk Management More Effective. In: Morris, P. and Pinto, J., Eds., Wiley Guide to Managing Projects, John Wiley & Sons, Chichester, 852-875.

Zabin, A.; González, V. A.; Zoua, Y.; Amor, R. (2022): Applications of machine learning to BIM: A systematic literature review, Advanced Engineering Informatics, Volume 51, January, 101474.