INTEGRATED REGRESSION AND FUZZY MODEL TO DETERMINE REMAINING PROJECT DURATION

CLEMENT CORNELIUS SCULLY

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Mechanical Engineering)

School of Mechanical Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

FEBRUARY 2022

ACKNOWLEDGEMENT

I wish to give thanks to God for blessing me and countless of opportunities throughout my research journey. The process of completing this thesis is definitely very long and full of challenges and I wish to thank those who had contributed their time and effort along my research journey. I am very thankful to my supervisor Assoc. Prof. Dr. Mohd. Zamani Ahmad and Assoc. Prof. Ir. Ts. Dr. Mohd Khairi Abu Husain for their guidance and supporting my research journey. I would also extend my gratitude to my second supervisor Prof. Dr. Omar Yaakob and Dr. Nik Mohd Ridzuan Shaharuddin for their guidance which had helped me with my thesis submission. I am also grateful for the extra support and motivation from Professor Dr. Astuty Amrin which had helped me during difficult times in this challenging research journey.

This thesis would not be completed without the support and prayers from my beloved wife, Valerie A/P Vincent Thomas, my parents Patrick William Scully and Lee Poh Giek and my in-laws Cecilia Tan Swee Gaik and Vincent Thomas A/L Thomas David.

ABSTRACT

Many attempts have been made by previous researchers to improve the monitoring process in engineering phase of a Floating Production Storage and Offloading (FPSO) conversion project. Earned Value Method (EVM) has been used to monitor the engineering phase progress towards the completion of project with the emphasis on cost monitoring, but it lacks the ability to capture the changes of expected project remaining duration based on changes in engineering deliverables and manhours performance. This study aimed to analyse the correlation of engineering phase monitoring variables to provide a visual projection of expected project duration. A model was developed using fuzzy method to produce a surface plot of engineering phase remaining duration. Stepwise regression selection was done on sets of variables combinations of Master Deliverable Register, manhours and progress by comparing the adjusted R2 values for each set. Regression coefficients from the selected set were extracted to form an algorithm to be implemented into fuzzy membership rule. Triangular membership is selected with each variables having seven linguistic terms ranging from 'Minimum' to 'Maximum'. Sensitivity analysis was conducted on the remaining duration plot to determine the impact of linguistic terms towards the extent changes of remaining duration. The model was validated by comparing it with the remaining duration determined using the EVM. It was found that the contour on fuzzy surface plot provides a visual forecast on expected project delays when a plateau is formed where events such as correction of documentations, manhours redundancies, re-work, restriction of manhours, resource levelling, review cycles, delay of Vendor Data Information and clashes with construction site are predicted. The remaining duration from the fuzzy model showed an overall improvement of accuracy when compared with calculated remaining duration from EVM method with 9% lower Mean Absolute Percentage Error and an average of Root Mean Square Error of 18 days as compared to EVM error of 31 days. It can be concluded that fuzzy surface plot enables prediction of the remaining duration and project stagnations from analysis on the surface contours and plateaus. Thus, the proposed model in this study serves as an alternative technique of top-down method for determining the remaining duration.

ABSTRAK

Pelbagai usaha telah diambil oleh penyelidik terdahulu untuk meningkatkan proses pemantauan dalam fasa kejuruteraan projek penukaran Penyimpanan Pemindahan Terapung (FPSO). Kaedah Nilai Terperoleh (EVM) telah digunakan untuk memantau kemajuan fasa kejuruteraan ke arah penyiapan projek dengan penekanan lebih kepada pemantauan kos, tetapi ia tidak berupaya menjangkakan perubahan jangka masa projek berdasarkan perubahan dalam penyampaian kejuruteraan dan prestasi waktu kerja. Kajian ini bertujuan untuk menganalisis korelasi pembolehubah pemantauan fasa kejuruteraan untuk menyediakan unjuran gambaran tempoh projek yang dijangkakan. Model dibangunkan menggunakan dengan kaedah kabur untuk menghasilkan plot permukaan baki tempoh untuk fasa kejuruteraan. Pemilihan regresi langkah demi langkah telah dilakukan pada set gabungan pembolehubah Daftar Serahan Induk, jumlah kerja dan kemajuan dengan membandingkan nilai R2 yang diselaraskan untuk setiap set. Pekali regresi dari set yang dipilih telah diekstrak untuk membentuk algoritma untuk dilaksanakan ke dalam peraturan keahlian kabur. Keahlian segi tiga dipilih dengan setiap pemboleh ubah yang mempunyai tujuh istilah linguistik dari 'Minimum' hingga 'Maksimum'. Analisis sensitiviti dijalankan ke atas plot tempoh yang berbaki untuk menentukan kesan istilah linguistik ke arah perubahan tahap baki tempoh. Model ini disahkan dengan membandingkannya dengan tempoh baki yang ditentukan menggunakan kaedah EVM. Didapati bahawa kontur pada plot permukaan kabur menyediakan ramalan gambaran mengenai kelewatan projek yang dijangkakan apabila dataran tinggi dibentuk yang mana peristiwa seperti pembetulan dokumentasi, kelebihan waktu kerja, kerja semula, sekatan waktu kerja, kerja pelarasan sumber, kitaran semakan, kelewatan Maklumat Data Vendor dan pertembungan dengan tapak pembinaan diramalkan. Tempoh selebihnya dari model kabur menunjukkan peningkatan keseluruhan ketepatan keseluruhan jika dibandingkan dengan tempoh yang dikira menggunakan kaedah EVM dengan 9% Purata Peratusan Mutlak Ralat lebih rendah, dan purata Ralat Segi Empat Kali selama 18 hari berbanding dengan ralat EVM selama 31 hari. Dapat disimpulkan bahawa plot permukaan kabur dapat meramalkan tempoh yang berbaki dan genangan projek dari analisis pada kontur permukaan dan dataran tinggi. Oleh itu, model yang dicadangkan dalam kajian ini berfungsi sebagai kaedah alternatif pendekatan atas ke bawah untuk menentukan tempoh yang berbaki.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AC	-	Actual Cost
AHP	-	Analytic Hierarchy Process
AT	-	Actual Time
BAC	-	Budget at Completion
BCWP	-	Budgeted Cost Work Performed
CCPM	-	Critical Chain Project Management
CI	-	Criticality Index
COG	-	Centre Of Gravity
CPI	-	Cost Performance Index
CPM	-	Critical Path Management
CRI(r)	-	Cruciality Index
CV	-	Cost Variance
DSM	-	Dependency Structure Matrix
ED	-	Earn Duration
ES	-	Earn Schedule
ESM	-	Earn Schedule Method
EV	-	Earn Value
EVM	-	Earn Value Method
FES	-	Fuzzy Expert System
FMCDM	-	Fuzzy multi-criteria decision-making
FPSO	-	Floating Production Storage Offloading
FTPSP	-	Fuzzy Time Dependent Project Scheduling Problem
GERT	-	Graphical Evaluation and Review Technique
IFA	-	Issue for Approval
IFC	-	Issue for Construction
IFR	-	Issue for Review
IT	-	Information Technology
MAPE	-	Mean Absolute Percentage Error
MATLAB	-	Matrix Laboratory
MCDA	-	Multi Criteria Decision Analysis

MCDM	-	Multi Criteria Decision Making
MDR	-	Master Deliverable Register
NWRT	-	Node-Weighted Rooted Tree
PERT	-	Project Evaluation and Review Technique
PV	-	Planned Value
QFD	-	Quality Function Deployment
RCPS	-	Resource Constrained Project Schedule
RMSE	-	Root Mean Square Error
ROF	-	Regular Objective Function
SI	-	Sensitivity Index
SPI	-	Schedule Performance Index
SPSS	-	Statistical Package for the Social Sciences
SRA	-	Schedule Risk Analyses
SSI	-	Schedule Sensitivity Index
WBS	-	Work Breakdown Structure

LIST OF SYMBOLS

μ_A	-	Fuzzy triangular membership
C_i	-	Rating Criteria
w	-	Weightage Criteria
R_{mi}	-	Profile value
ε	-	Regression error
θ	-	Regression constant
$\oplus$	-	Fuzzy number addition
$\otimes$	-	Fuzzy multiplication
$\ominus$	-	Fuzzy number subtraction
$\oslash$	-	Fuzzy number division
t	-	Time instance
$\bar{A}$	-	Fuzzy triangular number
F^{-1}	-	Fuzzy region

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

This current study examines dynamic project scheduling with the application of fuzzy method as well as regression studies. The knowledge application of fuzzy method was applied into scheduling aspect in a dynamic project environment. The term 'dynamism' is used to refer to a sudden transition in the sense of project management. A central unsolved project management problem is the difficulty posed by projects undertaken in complex and unpredictable settings (Collyer and Warren, 2009). The research covers application of dynamic scheduling in detailed engineering of Floating Production Storage and Offloading (FPSO) project.

The background and problems associated with the dynamic nature of project scheduling as well as the purpose and clarifications on the implementation of fuzzy method in this study are presented in this chapter. Subsequently, the research background, the problem of which this research is based, the overall research objective, explanation of the significance of the study, and finally the outline of the overall thesis structure is elaborated.

1.2 Research Background

Project planning and scheduling is a crucial part of project management where scope of work, costing and schedule baseline are managed while considering management of risk, resources and communications. From the planning point of view, the aim is for each project to be completed as scheduled and under the budget, with the desired features and an appropriate level of quality. In a perfect environment, projects meet early finishes and early completions, float is not absorbed, deadlines are

fulfilled, time delay charges are never filed by the employer, and liquidated losses are never evaluated by the owner.

The project manager uses the project schedule to assist with the preparation, execution, and management of project tasks and to track and monitor project progress. Therefore, project control and tracking are necessary to measure the project progress and performance throughout the project. In this study, dynamic project scheduling refers to project tracking at each time interval, with corrective rescheduling required if the targeted dateline is not longer realistic.

The application of the research focuses primarily on engineering phase of an FPSO project. An FPSO is a vessel that facilitates with crude oil processing by allowing separation, storage, and offloading from subsea oil wells or other platforms through risers. The processed hydrocarbon will be delivered to ships through offloading hoses from the FPSO's crude oil tanks. The construction of the FPSO allows for hydrocarbon extraction from remote oil and gas fields in deeper water, as well as a more cost-effective solution for subsea oil pipelines to land.

This research considers fuzzy method as well as linear regression to develop a tool with FPSO CENDOR project as a base case for future project monitoring. In an FPSO conversion project, engineering is the first phase to start before procurement and construction activities. Therefore, any delay in engineering will significantly cause over delays to both procurement and construction phases in the project.

FPSO CENDOR is a Floating Production Storage and Offloading unit which operates in the CENDOR field in Terengganu waters. The FPSO will stabilize crude received from well head and store it into cargo tanks. The crude in cargo tanks will then be offloaded into shuttle tanker using floating hoses. Gas from well head will either be used as fuel gas or gas injection via fuel gas compressor skid and gas injection skid respectively. FPSO project consists of engineering work on vessel demolition, hull conversion, topside design, and integration works.

1.3 Problem Statement

Uncertainty and risk frequently result in project delays and cost overruns. As a result, project forecasting is a critical component of the project control phase since it allows for the prediction of the final project duration and cost (Andrade et al., 2019). Numerous projects deviate from their estimated durations, taking longer or requiring more resources than anticipated, because of poor estimation and unforeseeable occurrences encountered during execution (Hazir and Ulusoy, 2020).

In real world applications, project scheduling problem under a dynamic environment comes from unstable resource availability, time varying resource demands and stochastic activity durations for each of the project activities (Chakrabortty et al.,2020). Gondia et. al (2022) highlighted that project performance targets are inextricably linked and execution errors, quality deficiencies, and approval delays are likely to proliferate, resulting in multiple rework, disrupted resource allocation, and cost overruns.

A well-known technique to monitor the progress of projects and to forecast project cost and duration is Earned Value Method (EVM). While EVM provides performance metrics for both the cost performance and schedule performance of projects, all EVM metrics are cost based. As a result, it is known that the EVM schedule performance indicators are less reliable towards the end of a project (Andrade et al., 2019).

In an FPSO engineering phase, engineering changes are considered unavoidable as the project progresses. The changes are required to satisfy new requirements and error correction. These adjustments will impact the overall project's progress and schedule, particularly in terms of the Master Deliverable Register (MDR), manhours, and progress percentage, which will eventually affect the project's estimated remaining duration. Constraints and events such as document rejection, significant redesign, and late vendor data submission are ambiguous and typically unaccounted for in standard project scheduling methods.

1.4 Objective of Study

The main aim for this research is to develop a scheduling monitoring model for detailed engineering of an FPSO. To achieve this aim, the objectives of this research are as follows:

i. To investigate the correlation of variables linked to detailed engineering phase in FPSO delays by providing a visual projection of project duration expectation.

ii. To analyse and develop a model which determines the estimated remaining duration for FPSO detailed engineering.

These objectives are the foundation of the development of research methodology and subsequently result in the following chapters.

1.5 Scope of Research

This research in general encompasses the features of project management in FPSO construction industry. The scope of the study is contained within the following knowledge boundary:

i. Project scheduling, in particular, the study of dynamism in project scheduling. The element of study in this research is on project duration which is a crucial part of the scheduling procedure. This research analyses on effect of man-hours, project progress percentage and Master Deliverable Register (MDR) towards the remaining duration on FPSO engineering phase. The strategy of top-down method of project monitoring is utilised to acquire projected remaining duration to be applied in schedule revision and updates.

ii. Surface plots were be used to represent the remaining time remaining on the project using a fuzzy method approach. The components of the fuzzy method are implemented, including the membership function, fuzzy inference, fuzzy set aggregation, and defuzzification. The variables' inputs are converted to membership function linguistic terms, and fuzzy inference is the method of converting a given input to an output using fuzzy logic and a set of rules.

iii. Engineering phase of FPSO conversion project. Engineering phase comprises of the execution activities of technical knowledge of the FPSO design. These operations produce documented outputs for drawings, computation, procedures, datasheets, specification and analysis for construction and procurement phase. The technical discipline engaged in the conversion deliverables include Naval Architecture, Marine, Mechanical, Structural, Piping, Electrical, Instrumentation, Telecom, Safety and Process. The list of these deliverables is compiled into a Master Deliverable Register (MDR) where the progress of each deliverable is recorded based on review and approval milestones.

iv. Stepwise regression method were be applied in this research to obtain a set of independent variables from a selection of variables and its multiplication. This method involves adding or removing potential explanatory variables in succession and testing for statistical significance after each iteration.

1.6 Significance of the Study

This research was aimed to develop a better project scheduling method and project control and tracking. Once a schedule is developed, forecast scenario

conditioning and resource planning of the project can be conducted at any particular time of the project.

In project control, project schedule forms the basis for progress monitoring whereby once the baseline schedule is established, the plan progress over the project lifespan is identified. In this research the application of project control was mainly focused on detailed engineering work on FPSO.

This research contribution to the detailed engineering community is focused towards achieving simplicity of obtaining detailed estimation of project completion. With this research model, users can estimate the required completion date of overall detailed engineering work. Fuzzy set theory is applied in this research to solve the decision making problems in which descriptions of observations are imprecise, vague and uncertain during detailed engineering project execution. By managing the vagueness and uncertainties present in detail engineering phase, cascading effect of subsequent delay in procurement, construction and commissioning phases can be minimized which will eventually prevent unexpected project delay and project penalty payment.

1.7 Thesis Outline

This thesis consists of five chapters as follows:

Chapter 1 is the introduction which addresses general introduction of the research comprising of background of the research, problem statement, research objective, scope and significance of the research.

Chapter 2 provides the description on the framework and review of the literature and past researches whose topics are significant for understanding the research details, providing a basis for designing the research methodology and possessing knowledge for discussing the research result and findings. The literature includes theory of project management and project schedule along with fuzzy method

and application. Literature on regression and sensitivity analysis method is also covered in this chapter. Besides, researches on project issues and limitations are further elaborated in this chapter.

Chapter 3 is the research methodology which describes all methods employed in the analytical process towards achieving the research objectives. Methodology system is represented in workflow charts. Details on identification of variable and method on variable correlation are further described in this chapter. Moreover, the application of fuzzy method implementation in correlation with the variable MDR, man-hours and percentage against remaining duration will also be elaborated in this chapter.

In Chapter 4, the results obtained are presented and their salient features are highlighted. The fuzzy surface plot is further explored and explained in this chapter in relation to the regression plot. Plot contour analysis and the sensitivity analysis of the research result model are also discussed.

Chapter 5 concludes this research followed by the explanation of the innovative contributions, areas of application and the limitations of the research. The chapter ends by highlighting several recommendations for further studies and concluding remarks.

REFERENCES

Adilakshmi, S., Shankar, N. (2021). A New Ranking in Haxagonal Fuzzy number by centroid of centroids and application in Fuzzy Critical Path. Reliability: Theory & Application, No2 (62).

Aghaeipoor, F., and Javidi, M. M. (2019). On the influence of using fuzzy extensions in linguistic fuzzy rule-based regression systems. *Applied Soft Computing*, *79*, 283-299.

Ahmad, M. Z., Kader, A. S. A., Ahmat, A. N., and Idris, J. (2006). A Fuzzy Application On A Development Planning Model For A Container Terminal. *Jurnal Teknologi*, 13â-29.

Ali, O. A. M., Ali, A. Y., and Sumait, B. S. (2015). Comparison between the effects of different types of membership functions on fuzzy logic controller performance. International Journal, 76, 76-83.

Al-Najjar, B., and Alsyouf, I. (2003). Selecting the most efficient maintenance approach using fuzzy multiple criteria decision making. *International journal of production economics*, *84*(1), 85-100.

Andrade, P. A., Martens, A., and Vanhoucke, M. (2019). Using real project schedule data to compare earned schedule and earned duration management project time forecasting capabilities. Automation in Construction, 99, 68-78.

Ashari, M. (2016). Integrated Fuzzy Analytic Hierarchy Process for River Ranking and Floodplain Managmenet. Universiti Teknologi Malaysia.

Aslani, P. (2007). *Dynamic resource-constrained scheduling* (Doctoral dissertation, Polytechnic University).

Ballestín, F., and Blanco, R. (2011). Theoretical and practical fundamentals for multi-objective optimisation in resource-constrained project scheduling problems. *Computers & Operations Research*, *38*(1), 51-62.

Bocewicz, G., Banaszak, Z., Rudnik, K., Witczak, M., Smutnicki, C., and Wikarek, J. (2020, July). Milk-run routing and scheduling subject to fuzzy pickup and delivery time constraints: An ordered fuzzy numbers approach. In *2020 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE)* (pp. 1-10). IEEE.

Blej, M,. Azizi, M. (2016). Comparison of Mamdani-Type and Sugeno-Type Fuzzy Inference Systems for Fuzzy Real Time Scheduling. International Journal of Applied Engineering Research, ISSN 0973-4562 Volume 11, Number 22, pp. 11071-11075

Clarkson, P. J., Simons, C., & Eckert, C. (2004). Predicting change propagation in complex design. J. Mech. Des., 126(5), 788-797.

Carlsson, C., and Fullér, R. (1996). Fuzzy multiple criteria decision making: Recent developments. *Fuzzy sets and systems*, *78*(2), 139-153.

Carlsson, C., and Fullér, R. (2003). Optimization with linguistic variables. In *Fuzzy Sets Based Heuristics for Optimization* (pp. 113-121). Springer, Berlin, Heidelberg.

Chakrabarti, S. (2005). Handbook of Offshore Engineering. Elsevier Ltd.

Chanas, S., and Zieliński, P. (2001). Critical path analysis in the network with fuzzy activity times. Fuzzy sets and systems, 122(2), 195-204.

Chao, L. C., and Chen, H. T. (2015). Predicting project progress via estimation of S-curve's key geometric feature values. *Automation in Construction*, *57*, 33-41.

Chen, C. T., and Huang, S. F. (2007). Applying fuzzy method for measuring criticality in project network. *Information sciences*, *177*(12), 2448-2458.

Chen, S. J., and Hwang, C. L. (1992). Fuzzy multiple attribute decision making methods. *Fuzzy multiple attribute decision making*, 289-486.

Chen, V. Y., Lien, H. P., Liu, C. H., Liou, J. J., Tzeng, G. H., and Yang, L. S. (2011). Fuzzy MCDM approach for selecting the best environment-watershed plan. *Applied soft computing*, *11*(1), 265-275.

Chakrabortty, R. K., Rahman, H. F., & Ryan, M. J. (2020). Efficient priority rules for project scheduling under dynamic environments: A heuristic approach. *Computers & Industrial Engineering*, *140*, 106287.

Chukhrova, N., and Johannssen, A. (2019). Fuzzy regression analysis: systematic review and bibliography. Applied Soft Computing, 84, 105708.

Collyer, S., and Warren, C. M. (2009). Project management approaches for dynamic environments. *International Journal of Project Management*, *27*(4), 355-364.

Collyer, S., Warren, C., Hemsley, B., and Stevens, C. (2010). Aim, fire, aim—Project planning styles in dynamic environments. *Project Management Journal*, *41*(4), 108-121.

Coppi, R., Gil, M. A., and Kiers, H. A. (2006). The fuzzy approach to statistical analysis. *Computational statistics & data analysis*, *51*(1), 1-14.

Critical Data, M. I. T. (2016). *Secondary analysis of electronic health records* (p. 427). Springer Nature.

Deb, S. K., Bhattacharyya, B., and Sorkhel, S. K. (2002). Material handling equipment selection by fuzzy multi-criteria decision making methods. In *AFSS international conference on fuzzy systems* (pp. 99-105). Springer, Berlin, Heidelberg.

Demeulemeester, E., De Reyck, B., Foubert, B., Herroelen, W., and Vanhoucke, A. M. (1998). New computational results on the discrete time/cost trade-off problem in project networks. *Journal of the operational research society*, *49*(11), 1153-1163.

Dorfeshan, Y., Mousavi, S. M., Vahdani, B., and Siadat, A. (2018). Determining project characteristics and critical path by a new approach based on modified NWRT method and risk assessment under an interval type-2 fuzzy environment.

Duffy, G., Woldesenbet, A., and Oberlender, G. D. (2012). Advanced linear scheduling program with varying production rates for pipeline construction projects. *Automation in construction*, *27*, 99-110.

Eeckhout, M.V.D., Maenhout, B., Vanhoucke, M. (2018). Computer and Operations Research, CAOR 4556.

Elshaer, R. (2013). Impact of sensitivity infation on the prediction of project's duration using earned schedule method. *International Journal of Project Management*, *31*(4), 579-588.

Fallahnejad, M. H. (2013). Delay causes in Iran gas pipeline projects. *International Journal of project management*, *31*(1), 136-146.

Fenton, N., and Wang, W. (2006). Risk and confidence analysis for fuzzy multicriteria decision making. *Knowledge-Based Systems*, *19*(6), 430-437.

Gámez, J. C., García, D., González, A., and Pérez, R. (2019). An approximation to solve regression problems with a genetic fuzzy rule ordinal algorithm. *Applied Soft Computing*, *78*, 13-28.

Gondia, A., Ezzeldin, M., and El-Dakhakhni, W. (2022). Dynamic networks for resilience-driven management of infrastructure projects. Automation in Construction, 136, 104149.

Haji, M. (2011). Modeling Project Scheduling and Management Systems Involving Uncertainties and Disruptions. University of Illinois at Chicago

Hamzeh, A. M., and Mousavi, S. M. (2019). A new fuzzy approach for project time assessment under uncertain conditions. 15th Iran International Industrial Engineering Conference.

Hao, Q., Shen, W., Xue, Y., and Wang, S. (2010). Task network-based project dynamic scheduling and schedule coordination. *Advanced Engineering Informatics*, *24*(4), 417-427.

Hartmann, S., and Briskorn, D. (2010). A survey of variants and extensions of the resource-constrained project scheduling problem. *European Journal of operational research*, *207*(1), 1-14.

Hazır, Ö., and Ulusoy, G. (2020). A classification and review of approaches and methods for modeling uncertainty in projects. International Journal of Production Economics, 223, 107522.

Hong, T. P., and Lee, C. Y. (1996). Induction of fuzzy rules and membership functions from training examples. *Fuzzy sets and Systems*, *84*(1), 33-47.

Huang, W., Oh, S. K., and Pedrycz, W. (2013). A fuzzy time-dependent project scheduling problem. *Information Sciences*, *246*, 100-114.

İçen, D., and Günay, S. (2019). Design and implementation of the fuzzy expert system in Monte Carlo methods for fuzzy linear regression. *Applied Soft Computing*, *77*, 399-411.

Jayanthi, S. E., Karthigeyan S., and Anusuya S. (2017). Minimizing Earliness and Tardiness Cost with Fuzzy Processing Times and Fuzzy Due Dates in Single Machine Scheduling Using QPSO. Internaltional Journal of Pure and Applied Mathematics. Volume 115, 437-442.

Jiang, H., Kwong, C. K., Chan, C. Y., and Yung, K. L. (2019). A multi-objective evolutionary approach for fuzzy regression analysis. *Expert Systems with Applications*, *130*, 225-235.

Kaka, A. P., and Price, A. D. F. (1993). Modelling standard cost commitment curves for contractors' cash flow forecasting. *Construction management and economics*, *11*(4), 271-283.

Kaneyoshi, M., Tanaka, H., Kamei, M., and Furuta, H. (1990). New system identification technique using fuzzy regression analysis. In *[1990]*

Proceedings. First International Symposium on Uncertainty Modeling and Analysis (pp. 528-533). IEEE.

Kao, H. P., Wang, B., Dong, J., and Ku, K. C. (2006). An event-driven approach with makespan/cost tradeoff analysis for project portfolio scheduling. *Computers in industry*, *57*(5), 379-397.

Karsak, E. E., and Tolga, E. (2001). Fuzzy multi-criteria decision-making procedure for evaluating advanced manufacturing system investments. *International journal of production economics*, *69*(1), 49-64.

Katsigiannis, F. A., Zografos, K. G., Fairbrother, J. (2021).Modelling and solving the airport slot-scheduling problem with multi-objective multi-level considerations.*Transportation Research Part C*, 124, 102914.

Kaur, S., and Bharti, G. (2012). Two inputs two output fuzzy controller system design using MATLAB. *Int. J. Adv. Eng. Sci. Technol.(IJAEST)*, *2*(3).

Khalid, A., Abhary, K., Marian, R. (2016). Multi-objective optimisation of dynamic scheduling in robotic flexible assembly cells via fuzzy-based Taguchi approach. Computers & Industrial Engineering, 99, 250-259.

Kim, J., Kang, C., and Hwang, I. (2012). A practical approach to project scheduling: considering the potential quality loss cost in the time–cost tradeoff problem. *International Journal of Project Management*, *30*(2), 264-272.

Kolisch, R., and Hartmann, S. (2006). Experimental investigation of heuristics for resource-constrained project scheduling: An update. European journal of operational research, 174(1), 23-37.

Kwang, H. L., and Lee, J. H. (1999). A method for ranking fuzzy numbers and its application to decision making. *IEEE Transactions on Fuzzy Systems*, 7(6), 677-685.

Kwok, R. C. W., Ma, J., and Zhou, D. (2002). Improving group decision making: a fuzzy GSS approach. *IEEE Transactions on Systems, Man, and Cybernetics, Part C (Applications and Reviews)*, *32*(1), 54-63.

Larson, E. W., and Gray, C. F. (2006). *Project Management: The Managerial Process (Special Indian Edition)*. Tata McGraw-Hill Education.

Laslo, Z. (2010). Project portfolio management: An integrated method for resource planning and scheduling to minimize planning/scheduling-dependent expenses. *International journal of project management*, *28*(6), 609-618.

Lazarova-Molnar, S., and Mizouni, R. (2010, June). Modeling human decision behaviors for accurate prediction of project schedule duration. In *Workshop on Enterprise and Organizational Modeling and Simulation* (pp. 179-195). Springer, Berlin, Heidelberg.

Lee, J., and Ruy, W. S. (2021). Multi-objective parametric optimization of FPSO hull dimensions. International Journal of Naval Architecture and Ocean Engineering, 13, 734-745.

Leelavathy, T., Padmadevi, S. (2019). Fuzzy project planning and scheduling using critical path techique. Journal of Physics, 1377 012044.

Li, W. (2005). Adaptive Production Scheduling and Control in One of a Kind Production. University of Calgary

Lin, M. C., Tserng, H. P., Ho, S. P., and Young, D. L. (2012). A novel dynamic progress forecasting approach for construction projects. *Expert Systems with Applications*, *39*(3), 2247-2255.

Lipke, W., Zwikael, O., Henderson, K., Anbari, F. (2009). Prediction of project outcome The application of statistical methods to earned value management and earned schedule performance indexes. International Journal of Project Management, 27, 400–407.

Liu, S., Wenqi, H., (2021). Forecasting the scheduling issues in engineering project management: Applications of deep learning models. Future Generation Computer System, 85-93

Long, L. D., and Ohsato, A. (2008). Fuzzy critical chain method for project scheduling under resource constraints and uncertainty. *International journal of project management*, *26*(6), 688-698.

Lu, W., Peng, Y., Chen, X., Skitmore, M., and Zhang, X. (2016). The S-curve for forecasting waste generation in construction projects. *Waste Management*, *56*, 23-34.

Lukas, M. J. A., and Cce, P. (2008). EVM. 01 Earned Value Analysis–Why it Doesn't Work. *AACE International Transactions*, 240-243.

Mansour, A. E., and Ertekin, R. C. (Eds.). (2003). Proceedings of the 15th International Ship and Offshore Structures Congress: 3-volume set. Elsevier.

Mohanty, S., and Codell, R. (2002). Sensitivity analysis methods for identifying influential parameters in a problem with a large number of random variables. *WIT Transactions on Modelling and Simulation*, *31*.

Möhring, R. H., Schulz, A. S., Stork, F., and Uetz, M. (2003). Solving project scheduling problems by minimum cut computations. *Management science*, *49*(3), 330-350.

Morais, C., Estrada-Lugo, H.D., Tolo, S., Jacques, T., Moura, R., Beer, M., Petelli, E. (2021). Robust data-driven human reliability analysis using credal networks. Reliability Engineering and System Safety, 218, 107990.

Ohnishi, S. I., Yamanoi, T., and Imai, H. (2009). A Fuzzy Weight Representation for Inner Dependence Method AHP. In *IFSA/EUSFLAT Conf* (pp. 1612-1617).

Ohnishi, S. I., Yamanoi, T., and Imai, H. (2011). A fuzzy representation for non-additive weights of AHP. In *2011 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE 2011)* (pp. 672-675). IEEE.

Patwal, R. S., Narang, N. (2020). Multi-objective generation scheduling of integrated energy systemusing fuzzy based surrogate worth trade-off approach. *Renewable Energy*, 156, 864-882.

Perez, P.B., Elamrousy, K.M., Gonzalez-Cruz, M.C. (2019). Non-linear time-cost trade-off models of activity crashing: Application toConstruction scheduling and project compression with fast-tracking. Automation in Construction, 97, 229-240.

Peteghem V.V., Vanhoucke, M. (2010).A genetic algorithm for the preemptive and non-preemptive multi-mode resource-constrained project scheduling problem. European Journal of Operational Research, 201, 409-418.

Polat, G., Bingol, BN. (2013). "A comparison of fuzzy logic and multiple regression analysis model in determining contingency in construction", *Construction Innovation*,13.

Ramli, N., and Mohamad, D. (2009). A comparative analysis of centroid methods in ranking fuzzy numbers. *European Journal of Scientific Research*, *28*(3), 492-501.

Rose, K. H. (2013). A guide to the project management body of knowledge (PMBOK® Guide)—Fifth Edition. *Project management journal*, *3*(44), e1-e1.

Sackey S., Lee, D.E., Kim, B.S. (2020). Duration Estimate at Completion: Improving Earned Value Management Forecasting Accuracy. KSCE Journal of Civil Engineering 24(3), 693-702.

Salciccioli, J.D., Curtain Y., Komorowski, M., Marshall, D.C. (2016). Sensitivity Analysis and Model Validation. Secondary Analysis of Electronic Health Records, MIT Critical Data, Springer Open.

Sathish, S., and Ganesan, K. (2011). A simple approach to fuzzy critical path analysis in project networks. *a=(a, a, a, a)*, *1*(2), 3-4.

Servranckx, T., Vanhoucke, M. (2019). A tabu search procedure for the resource-constrained project scheduling problem with alternative subgraphs. European Journal of Operational Research, 273, 841-860.

Sia, L., and Wenqi, H. (2021). Forecasting the scheduling issues in engineering project management: Applications of deep learning models. Future Generation Computer Systems, 123, 85-93.

Shafiee, M., Animah, I., Alkali B., and Baglee D. (2019). Decision support methods and applications in the upstream oil and gas sector. Journal of Petrolium Science and Engineering, 173, 1173-1186.

Shi, Q., and Blomquist, T. (2012). A new approach for project scheduling using fuzzy dependency structure matrix. International Journal of Project Management, 30(4), 503-510.

Shimamura, Y. (2002). FPSO/FSO: State of the art. Journal of Marine Science and Technology 7, 59-70.

Smith, G. (2018). Step away from Stepwise. Journal of Big Data, 32.

Scully, C. C., and Zamani, M. (2019). Dynamic project scheduling and progress monitoring of engineering phase in FPSO conversion project with fuzzy method. *Open International Journal of Informatics (OIJI)*, *7*(1), 113-122.

Shapiro, A. F., and Koissi, M. C. (2015). Risk assessment applications of fuzzy logic. Casualty Actuarial Society, Canadian Institute of Actuaries, Society of Actuaries: Ottawa, ON, Canada, 390.

Soltani, A., and Haji, R. (2007). A project scheduling method based on fuzzy theory. *Journal of Industrial and Systems Engineering*, *1*(1), 70-80.

Sreekumar, and Mahapatra, S. S. (2011). Supplier selection in supply chain management: a fuzzy multi-criteria decision-making approach. *International Journal of Services and Operations Management*, *8*(1), 108-126.

Sun, L. (2008). Comparing Dynamic Risk Based Scheduling Methods with MRP. University of Louisville.

Sunarsih (2013). Profiling and Ranking of Marine Propulsion Plant Based on Fuzzy Multi Criteria Decision Making Method. Universiti Teknologi Malaysia.

Suresh, V., and Chaudhuri, D. (1993). Dynamic scheduling—a survey of research. *International journal of production economics*, *32*(1), 53-63.

Tam V. H. Y. (2020). Inherently safer design in offshore oil and gas projects. Journal of Loss Prevention in the Process Industries, 68, 104329.

Totin, C. M. (2013). Effective Construction Schedule Management: Construction Project Monitoring With Project performance indicators & The project status Report.

Ulusoy, G., and Cebelli, S. (2000). An equitable approach to the payment scheduling problem in project management. *European Journal of Operational Research*, *127*(2), 262-278.

Vanhoucke, M. (2010). Using activity sensitivity and network topology information to monitor project time performance. *Omega*, *38*(5), 359-370.

Vanhoucke, M. (2011). On the dynamic use of project performance and schedule risk information during projecttracking. *Omega*, *39*(4), 416-426.

Vanhoucke, M. (2012). *Project management with dynamic scheduling* (p. 4). Springer Berlin Heidelberg.

Vanhoucke, M., and Vandevoorde, S. (2007). A simulation and evaluation of earned value metrics to forecast the project duration. *Journal of the Operational Research Society*, *58*(10), 1361-1374.

Vinnem, J. E. (2014). Uncertainties in a risk management context in early phases of offshore petroleum field development. *Journal of Loss Prevention in the Process Industries*, *32*, 367-376.

Vlachopoulou, M., Ferryman, T., Zhou, N. (2013). A Stepwise Regression Method for Forecasting Net Interchange Schedule. IEEE Power & Energy Society General Meeting, 1932-5517.

Wang B., Wang Y., and Wang S. (2021).Improved water pollution index for determining spatiotemporal water quality dynamics: Case study in the Erdao Songhua River Basin, China. Ecological Indicators 129, 107931.

Wang Y., He, Z., Kerkhove, L., Vanhoucke, M. (2017). On the performance of priority rules for the stochastic resource constrained multi-project scheduling problem. Computers & Industrial Engineering, 114, 223-234.

Wang, Y., Estefen, S. F., Lourenço, M. I., and Hong, C. (2019). Optimal design and scheduling for offshore oil-field development. *Computers & Chemical Engineering*, *123*, 300-316.

Watada, J., and Yabuuchi, Y. (1994, June). Fuzzy robust regression analysis. In *Proceedings of 1994 IEEE 3rd International Fuzzy Systems Conference* (pp. 1370-1376). IEEE.

Wood, D. A. (2018). A critical-path focus for earned duration increases its sensitivity for project-duration monitoring and forecasting in deterministic, fuzzy and stochastic network analysis. Journal of Computational Methods in Sciences and Engineering, 18(2), 359–386.

Wyrozębski, P., and Wyrozębska, A. (2013). Challenges of project planning in the probabilistic approach using PERT, GERT and Monte Carlo.

Yang, S. M., Liu, Y. C., and Yen, T. Y. (2018, June). Integration of Fuzzy Logic and QFD for Critical Chain in Project Scheduling with Uncertainties. In *2018 International Conference on System Science and Engineering (ICSSE)* (pp. 1-6). IEEE.

Yao, S., Jiang, Z., Li, N., Zhang, H., Geng, N. (2011). A multi-objective dynamic scheduling approach using multiple attribute decision making in semiconductor manufacturing, International Journal of Production Economics, 130, 125–133.

Yasseri, S. F., Bahai, H. (2019). Interface and integration management for FPSOs. Ocean Engineering, 191, 106441.

Zadeh, L. A. (1965). Information and control. *Fuzzy sets*, *8*(3), 338-353.

Zadeh, L. A. (1988). Fuzzy logic.-IEEE Transactions on Computers, vol. 21, no. 4.

Zadeh, L. A. (1999). Fuzzy logic= computing with words. In *Computing with Words in Information/Intelligent Systems 1* (pp. 3-23). Physica, Heidelberg.

Zareei, A., Zaerpour, F., Bagherpour, M., Noora, A. A., & Vencheh, A. H. (2011). A new approach for solving fuzzy critical path problem using analysis of events. *Expert Systems with Applications*, *38*(1), 87-93.

Zeng, J., An, M., and Smith, N. J. (2007). Application of a fuzzy based decision making methodology to construction project risk assessment. *International journal of project management*, *25*(6), 589-600.

Zimmermann, H. J. (2011). *Fuzzy set theory—and its applications*. Springer Science & Business Media.

LIST OF PUBLICATIONS

Scully, C. C., and Zamani, M. (2019). Dynamic project scheduling and progress monitoring of engineering phase in FPSO conversion project with fuzzy method. *Open International Journal of Informatics (OIJI)*, *7*(1), 113-122.