Fuzzy Agent-Based Modeling of Construction Crew Motivation and Performance

by

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Abstract

Crew performance is influenced not only by the environment where construction activities occur, but also by crew motivation, which has largely been overlooked in construction research. For many years, construction engineering researchers have observed that motivational differences within construction crews explain meaningful variance in the performance of those crews. However, construction researchers have long had difficulties identifying the motivational factors that affect crew motivation and performance. These difficulties are due to the uniqueness and dynamism of the construction environment and the fact that motivation occurs at both individual and crew levels. Furthermore, previous construction research has not comprehensively investigated situational/contextual factors and their impact on the relationship between crew motivation and performance.

To overcome these difficulties, two methodological approaches, agent-based modeling and fuzzy logic, are applied and integrated to develop a model of construction crew motivation and performance. Agent-based modeling is a good solution for handling complex systems of interacting agents and is therefore suitable for modeling construction crew behaviour. Agent-based modeling can handle system complexities that arise from the interactions of system components; however, many systems—especially those comprising human behaviour and social relationships—also include subjective uncertainties, which are not accounted for in agent-based modeling. Fuzzy logic, on the other hand, is able to deal with subjective uncertainty. Therefore, integrating these two techniques is advantageous for modeling behavioural and social systems, such as those that arise through the interaction of construction crew motivation and performance.

This research presents a review of the literature on motivation in both the construction and non-construction domains, and it uses recent advancements in motivation research from non-construction disciplines to bridge the gaps in construction literature. This research identifies the factors affecting construction crew motivation and performance, defines a comprehensive set of crew performance metrics, analyzes the relationship between motivational factors and crew performance metrics, and identifies the key situational/contextual factors that affect the relationship between crew motivation and performance. Given that motivation is subjective in nature, the research provides a fuzzy agent-based model of construction crew motivation and performance, which is validated based on collected field data.

This research makes seven major contributions. First, it presents a novel methodology for identifying and measuring motivational factors at both the individual and crew levels. Second, it defines a methodology to evaluate and rank critical factors and factors with a high potential for improvement in construction crew motivation and performance and to evaluate the differences between the perspectives of supervisors and craftspeople on the identified critical factors. Third, it develops a comprehensive set of factors affecting crew motivation and performance; and developing a comprehensive set of construction crew performance metrics that relate not only to task performance, but also to contextual performance and counterproductive behaviour. Fourth, it reveals how motivational factors affect crew performance; and provides a comprehensive list of the key moderators of the relationship between construction crew motivation and performance. Fifth, it expands the scope of applicability of ABM by integrating fuzzy logic with ABM to create fuzzy agent-based models, which can handle both probabilistic and subjective uncertainty. Sixth, it provides a novel methodology for developing fuzzy agent-based models, which can be used to develop new models to assess construction processes and practices. Seventh, it develops a fuzzy

agent-based model of construction crew motivation and performance, which improves the assessments of crew performance by considering not only the interactions of crews in the project but also the subjective uncertainties in the model variables such as crew motivation. The findings of this research also directly contribute to the construction industry by helping managers and decision makers improve their workforce practices.

Preface

This thesis is an original work by Mohammad Raoufi. The research project, on which this dissertation is based on, received research ethics approval from the University of Alberta Research Ethics Board, Project Name "Assessing the Effect of Motivation on Construction Crew Performance and Modeling Crew Dynamics Using Fuzzy Agent-Based Modeling", Study ID: Pro00063112, approved on March 31, 2016. This research was funded by the Natural Sciences and Engineering Research Council of Canada Industrial Research Chair in Strategic Construction Modeling and Delivery (NSERC IRCPJ 428226–15), which is held by Dr. A. Robinson Fayek.

Chapter 2 of this thesis has been submitted for publication in the *Journal of Construction Engineering and Management*: Raoufi, M., and Fayek, A. Robinson (2017). "Framework for Identification of Factors Affecting Construction Crew Motivation and Performance." *J. Const. Eng. Manage.*, 37 manuscript pages, submitted Oct. 23, 2017; a decision of revise for re-review was returned on Jan. 15, 2018. Chapter 3 of this thesis has been accepted for publication in the *Journal of Construction Engineering and Management*: Raoufi, M., and Fayek, A. Robinson (2018). "Key Moderators of the Relationship between Construction Crew Motivation and Performance." *J. Const. Eng. Manage.*, 39 manuscript pages, accepted Jan. 3, 2018. Chapter 4 of this thesis has been submitted for publication in the *Journal of Computing in Civil Engineering*: Raoufi, M., and Fayek, A. Robinson (2017). "Fuzzy Agent-based Modeling of Construction Crew Motivation and Performance." *J. Comput. Civil. Eng.*, 38 manuscript pages, submitted Dec. 5, 2017; a decision of revise for re-review was returned on Jan. 15, 2018. I was responsible for the development and implementation of the research methodology including data collection and analysis, as well as, the composition of the three manuscripts. A. Robinson Fayek was the supervisor of the research and was involved with the formation of the research concept, technical review of each stage of the research, and the composition of each of the three manuscripts.

Dedication

To my parents Mitra and AbdolRaouf;

Without your love, I wouldn’t been able to get to this stage.

To my little sister, Dr. Nassim Raoufi;

You encouraged me to start this PhD program.

To my supervisor Dr. Aminah Robinson Fayek;

You patiently helped me through this journey.

To the memory of my grandmother MalekTooran;

You wanted me to have the best education.

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List of Symbols and Abbreviations

Symbols

A	Membership function
AI	Index for agreement-importance
Atr	Attribute of an agent
B	Unstandardized regression coefficient
β	Standardized regression coefficient
CM	Crew motivation
CR	Composite reliability
CRT	Contact rates of agents
DI	Index for disagreement-importance
ΔR^2	R^2 change associated with the interaction term
e	Euler's number
er	Error variance of a measure
F-critical	Critical value of F in statistical F-test
F-test	Statistical test for comparing two population variances
F-value	Calculated value of F in statistical F-test
L	Factor loading
μ	Mean value

p	Probability value that the null hypothesis is true
r	Pearson correlation coefficient
R^2	Coefficient of determination
R_A	Weighted percentage of agreement
R_D	Weighted percentage of disagreement
R_I	Weighted percentage of relative importance
$\mathbb{R}^+$	Positive real numbers
S	Susceptibility
WS	Weighted score of a factor
SD	Standard deviation
σ	Standard deviation
t-critical	Critical value of t in statistical t-test
t-test	Statistical test for comparing two population means
t-value	Calculated t in statistical t-test
w	Weight of a measure
x	Value of a variable in the universe of discourse
Z	Zealot agent
z-scored	Standardized variable which has a mean of 0 and a standard deviation of 1
$\mathbb{Z}^+$	Positive integer numbers

Abbreviations

FA	Factor analysis
HSE	Heath, safety, and environment
KPI	Key performance indicator
QA/QC	Quality assurance or quality control
ABM	Agent-based modeling
FABM	Fuzzy agent-based modeling
UML	Unified modeling language
AUML	Agent unified modeling language
FCM	Fuzzy C-means
MAPE	Mean absolute percentage error
RMSPE	Root mean square percentage error

Chapter 1. Introduction

1.1. Background

Labour is a critical resource in construction and many tasks in construction are performed by construction workers. In construction, it is important to be able to assess worker performance; however, this task involves many challenges. One challenge is how to define and measure the attributes of worker performance, such as productivity. The other challenge is how to define and measure the factors affecting worker performance, such as worker motivation and project situation. However, construction workers complete work in crews—collections of workers that together perform a task—so worker performance comprises workers' interactions with each other and with the environment, and not just individual performance. To understand crew performance, it is crucial to be able to model the interactions that occur among the crews themselves, and between crews and the environment. Thus, it is necessary to implement a suitable modeling technique which is able to capture the internal interactions between the components of the model. Furthermore, to understand crew performance it is important to understand what motivation is and which factors affect construction crew motivation.

Generally speaking workplace motivation refers to the direction of attention, mobilization of effort, and the persistence of effort over time – exhibited by individual employees and aggregated across individuals within a work group (i.e., crew motivation) (cf. Vroom, 1964; Locke et al. 1981). In short, individual and group performance has long been viewed as a function of both capability/ability and motivation (Campbell, 1990; Wildman et al. 2011). Therefore, when studying crew performance, it is important to consider not only situational/contextual factors (i.e., the factors related to the situation in which the tasks are performed) but motivational factors as well. Unfortunately, the construction literature has tended to overlook, assume, or de-emphasize motivational explanations when accounting for variations in labour performance (Cox et al. 2006; Maloney 1986; Maloney and McFillen 1987; Khan 1993; Siriwardana and Ruwanpura 2012; Wang et al. 2016). To the extent that motivation is important, then relevant questions emerge: What factors contribute to individual and crew motivation? How are these motivational factors measured? How do all of these motivational factors impact crew performance? It is these fundamental questions that this research attempted to answer.

Though motivation is a major research focus in many disciplines such as business and psychology, limited research has been devoted to motivation in the construction context. For a review of the broader work-motivation literature, see Diefendorff and Chandler (2011). On the other hand, much of the literature that does exist in construction exhibits shortcomings. For example, most theories of motivation consider the motivation of an individual without taking into account the social context in which activities occur, which limits the conclusions that may be drawn. However, drawing upon non-construction literature must be done carefully, since the nature of construction work imposes constraints that may limit the relevance of well-established, individual-level motivational theories. In short, a motivation model that captures the reality of construction crews should include both individual-level and crew-level factors. Construction projects involve highly interdependent activities performed by crews, and performance in construction is multi-dimensional and is impacted by conditions outside of the scope of control of individuals. Therefore, in addition to the questions raised earlier, this research examines the motivational factors that can be reasonably assessed at both individual and crew levels in order to better capture the reality of construction crew dynamics.

In addition to considering the complexity involved in the interactions between workers in a construction crew, to accurately model construction crew behaviour, models must also consider subjective uncertainties due to the subjective nature of some factors affecting workers' behaviour. A worker's self-efficacy (i.e., perception of his or her ability to transform his or her efforts into a desired outcome) is one such factor. This factor is a variable subjective in nature, and cannot easily be assigned a numerical value. For example, when asked to evaluate his or her self-efficacy, a worker is asked to provide a judgment reflecting his or her perception of his or her own ability. People are usually unable to assign a numerical value for their perception of their own abilities (e.g., "I have 80% self-efficacy" or "My level of commitment is 60%"). Instead, they prefer to use linguistic terms (e.g., "I have *high* self-efficacy" or "My level of commitment is *very low*"). In many other similar situations, in order to define such variables, subjective terms such as *high* and *low* will be used by experts (e.g., a worker's supervisor may provide a judgment about workers' commitment). In order to model construction crew behaviour we should also be able to handle the subjective uncertainty that exists in subjective factors (e.g., linguistic terms of expert judgments). Fuzzy logic is a mathematical tool for dealing with subjective uncertainty (Zadeh 2015).

1.2. Problem Statement

There are numerous gaps in construction research on crew motivation and performance. Not many studies have examined the topic of motivation within a construction context, and even less is known about the relation of workers' motivation to crew performance. The review of literature in construction on crew motivation and performance reveals the major gaps in this research area. The current gaps are summarized in this section.

Construction literature largely considers motivation at the individual level. While previous studies have identified some motivational factors in construction at the individual level, researchers have yet to addresses the sources of motivation at both the individual and crew levels. Thus, the ***first gap*** in construction research on crew motivation and performance is in defining factors affecting crew motivation at both the individual and crew levels in construction.

In construction, a number of situational/contextual factors affect the performance (and productivity) of construction crews. The presence of these situational/contextual factors will help or hinder the effect of crew motivation on crew performance. In construction projects examples of situational/contextual factors can be task-related (e.g. task design; work flow), foreman-related (e.g. leadership skills), labour-related (e.g., functional skills of the crew itself), project-related (e.g., job conditions), management-related (e.g. project management practices), resource-related (e.g., tools; equipment; materials), work setting-related (e.g. weather conditions). In short, in addition to motivational factors it is important to include the situational/contextual factors when studying motivation to crew performance relationships. However, past research on motivation in construction only focused one very limited number of situational/contextual factors. Therefore, the ***second gap*** in construction research on crew motivation and performance is the lack of a comprehensive set of situational/contextual factors affecting crew motivation and performance.

The construction industry is a project-oriented industry; and the focus of performance measurement in construction industry is on the project level rather than the organization level (Love and Holt 2000). Construction projects were usually evaluated in terms of time, cost, and quality (Kagioglou et al. 2001). However, these categories of project performance measures have been shown to be insufficient (ward et al. 1991). Past research show that there are other performance measures related to the success of a project. One of the dominant performance measures is productivity (Mani et al. 2017; Sveikauskas et al. 2016; Tsehayae and Fayek 2016). Some argued that there was overemphasis on productivity and it was not lead to its expected results in measuring performance (Skinner 1986). There are other performance measures (e.g. contextual performance, counterproductive behaviour) involved in project success such as quality of relationships between crew members in a project (Bassioni et al. 2004). Those other aspects of performance (contextual performance and counterproductive performance) are important in defining a performance metrics of a construction crew; as they are at the discretion of workers and thus more likely to be affected by workers' motivation. Thus, the ***third gap*** in construction literature on crew performance is the lack of a comprehensive set of construction crew performance metrics that relate not only to task performance, but also to contextual performance and counterproductive behaviour.

Construction project performance is a function of how efficiently resources, particularly labour, are utilized. Research in this area faces one important challenge that is how to determine the relationships that exist between motivational factors, situational/contextual factors, and crew performance. Therefore, the ***fourth gap*** in construction research on crew motivation and performance is the need to determine the relationship between motivational factors and crew performance. Furthermore, construction projects are executed in a dynamic environment that is influenced by several situational/contextual factors, such as those relating to task, labour, foreman, project characteristics, management, work-setting conditions, and resources. These factors will help or hinder the effect of motivation on crew performance. However, the effect of situational/contextual factors on the relationship between crew motivation and performance has not been comprehensively investigated in previous construction literature. Some researchers have investigated a limited number of situational/contextual factors when studying motivation (Cox et al. 2006; Maloney and McFillen 1987; Šajeva 2007; Siriwardana and Ruwanpura 2012; Wang et al. 2016); however, these studies were not validated with field data and did not investigate the moderating effects of situational/contextual factors on the relationship between crew motivation and performance. Therefore, the ***fifth gap*** in construction research on crew motivation and performance is in defining the key moderators of the relationship of construction crew motivation and performance.

Research on crew behaviour in the construction domain suffers from many gaps and shortcomings related to method of analysis. Some research only uses statistical analysis to find the relationship between factors affecting workers' behaviours (e.g., assigned goals, company norms) and workers' behaviours. For example, Ahn et al. (2013) analyzed the relationship between social norms and construction workers' absence behaviour by using statistical analysis to relate the factors affecting workers' absence behaviour (e.g., perceptions and attitudes toward social rules) to workers' absence behaviour. Researchers have also used different simulation techniques (e.g., discrete event simulation and system dynamics) to solve more sophisticated problems in construction. However, the complexity of crew members' interactions requires more innovative approaches such as agent-based modelling to study employees' behaviour (Ahn and Lee 2014; Macy and Willer, 2002). ABM, a relatively recent modeling technique in construction research, has been used to model complex systems of interacting agents. However, there are some gaps in the research on ABM in the construction domain, especially when the problem under study involves subjective variables such as linguistically expressed attributes of human agents, or when numerical data are not available in sufficient quantity and quality for modeling purposes. ABM traditionally relies on addressing the probabilistic uncertainties in the variables (e.g., probabilistic distributions for agent attributes), as well as, the relationships (e.g., mathematical formulas or regression equations for agent behavioural rules and agent interactions) of the system. However, ABM alone is not able to address subjective uncertainty related to the variables and the relationships of the system that cannot be represented either by mathematical formulas or regression equations. Thus the ***sixth gap*** in construction research on ABM is related to the limitation of current ABM in modeling subjective variables and relationships. In regard to the study of construction crew motivation and performance, there is a need for a modeling methodology that allows us to account for not only the complexity of interactions among construction agents (e.g., construction crews) but also the subjective uncertainties involved in construction variables (e.g., crew motivation) and relationships (e.g., the relationship between crew motivation and performance).

1.3. Research Objectives

The main objectives of this research are to advance the state of the art in construction research on ABM, by integrating fuzzy logic and agent-based modeling to develop a fuzzy agent-based modeling methodology, as well as, developing a fuzzy agent-based model of construction crew motivation and performance. The detailed objectives of this research are grouped under the following three main categories:

1. To advance the state of the art related to the factors affecting construction crew motivation and performance; thereby addressing the *first gap* and the *second gap* in construction research on crew motivation and performance.

    a. To define a methodology to identify the factors affecting construction crew motivation and performance.

    b. To bridge the gap in construction research by exploring more recent motivational concepts that have been introduced and advanced in non-construction domains.

c. To determine a methodology for identifying critical factors affecting construction crew motivation and performance.

d. To determine a methodology for identifying factors with a high potential for improvement in construction crew motivation and performance.

e. To determine a methodology for identifying factors for which there are statistically significant differences between the perspectives of supervisors and craftspeople.

2. To advance the body of knowledge related to crew performance metrics and to investigate the relationship of motivational and situational/contextual factors to crew performance metrics; thereby addressing the *third gap*, the *fourth gap*, and the *fifth gap* in construction research on crew motivation and performance.

   a. To define a comprehensive set of crew performance metrics, including key performance indicators (KPIs) related not only to task performance (i.e., technical and job-specific performance), but also to contextual performance (i.e., discretionary and job-general performance) and counterproductive behaviour.

   b. To study the relationship between motivational factors and crew performance to reveal how motivational factors affect crew performance metrics.

   c. To investigate how situational/contextual factors will affect motivation-performance relationship, and to determine which of those factors have a moderating (i.e., interacting) effect on the relationship between crew motivation and performance.

3. To develop a novel methodology for the development of fuzzy agent-based models in construction and to investigate the application of the developed methodology in modeling construction crew motivation and performance; thereby addressing the *sixth gap* in construction research on ABM.

   a. To advance ABM by integrating fuzzy logic with ABM to handle both probabilistic and subjective uncertainties.

   b. To provide a methodology for developing fuzzy agent-based models in construction to be able to develop new models to assess construction processes and practices.

   c. To develop a fuzzy agent-based model of construction crew motivation and performance to improve the assessments of crew performance.

1.4. Expected Contributions

1.4.1. Academic Contributions

The expected academic contributions of this research are as follows:

1. Presenting a novel methodology for identifying and measuring motivational factors at both the individual and crew levels. Providing a comprehensive set of factors affecting crew motivation and performance; and developing a comprehensive set of construction crew performance metrics that relate not only to task performance, but also to contextual performance and counterproductive behaviour.

2. Defining a methodology to evaluate and rank critical factors and factors with a high

potential for improvement in construction crew motivation and performance and to evaluate the differences between the perspectives of supervisors and craftspeople on the identified critical factors.

3. Revealing how motivational factors affect crew performance; and providing a comprehensive list of the key moderators of the relationship between construction crew motivation and performance.

4. Expanding the scope of applicability of ABM by integrating fuzzy logic with ABM to create fuzzy agent-based models, which can handle both probabilistic and subjective uncertainty. Providing a novel methodology for developing fuzzy agent-based models, which can be used to develop new models to assess construction processes and practices.

5. Developing a fuzzy agent-based model of construction crew motivation and performance, which improves the assessments of crew performance by considering not only the interactions of crews in the project but also the subjective uncertainties in the model variables such as crew motivation.

1.4.2. Industrial Contribution

The expected industrial contributions of this research are as follows:

1. Establishing a comprehensive list of factors affecting crew motivation and performance, which can be implemented in new construction projects and in other construction contexts such as building construction, to identify critical factors and factors with a high potential for improvement in construction crew motivation and performance. Provide a list of factors

with significant differences between the perspectives of supervisors and craftspeople on the critical factors affecting crew motivation and performance.

2. Establishing a comprehensive list of key performance indicators (KPIs) to measure construction crew performance metrics that relate not only to task performance, but also to contextual performance and counterproductive behaviour. The identified KPIs can be used to evaluate the performance of crafts in construction projects.

3. Presenting a data collection protocol which provides detailed guideline for industry practitioners to perform labour motivation and performance improvement studies. The protocol enables the industry practitioner to record the situation in which crews are performing and to measure actual levels of crew motivation and performance in construction projects.

4. Providing a comprehensive list of the key moderators of the relationship between construction crew motivation and performance which can be used to improve crew performance in construction projects by improving the situation in which the crews are performing their tasks.

5. Developing a fuzzy agent-based model of construction crew motivation and performance that enables construction practitioners to assess crew performance in projects, observe the effect of change in model parameters of crew performance, and develop and simulate various scenarios such as a project with different combinations of crew motivation.

1.5. Research Methodology

The research presented in this thesis is carried out in four main stages, which are described in the following sections:

1.5.1. The First Stage

This research began with the identification of factors affecting construction crew motivation and performance. The primary list of factors was derived from existing research in both construction and non-construction domains. First, a motivation expert with 30 years of experience, in business and industrial psychology domains, provided his expertise regarding the initial list of motivational factors. Then, this initial list of factors was presented in a workshop to 10 construction experts involved in projects in Canada. These experts had an average of 15 years of experience, and they represented different types of construction organizations (e.g., owners, contractors, and labour unions); they also held various positions in their organizations, such as senior management, project management, human resources representative, and labour relations representative. The experts reviewed the list and proposed additional factors they thought may affect construction crew motivation and performance and reached consensus on the proposed additional factors; the primary list of factors was then updated to include the proposed factors. The reason for using both motivation and construction experts was to perform face validation on the identified list of factors, because some of them were identified from literature in the non-construction domain and were not considered in past research in construction. This process allowed for the development of a comprehensive list of factors that not only considers the literature in construction and non-construction domains, but that also captures the opinions of both motivation and construction experts.

1.5.2. The Second Stage

The second stage in this research was to design and administer the interview surveys. Two separate interview surveys, the supervisor and craft surveys, were included in the research in order to achieve three design objectives: identify critical factors relevant to supervisors and craftspeople; identify potential areas of improvement in construction crew motivation and performance; and reveal differences between the perspectives of supervisors and craftspeople by comparing respondents' rankings of common factors included in both surveys. In order to identify potential participants, the study methodology and objectives were presented in another workshop to construction companies active in various industrial projects in Canada. A participant company was then selected based on availability of their projects for data collection during the research timeline. Three meetings were held with the survey respondents (i.e., supervisors at the company head office, supervisors in the project field, and craftspeople in the project field) to explain the data collection procedure and the surveys. Sample responses and instructions for completing the surveys were presented to the respondents to ensure respondents understood the surveys. The surveys were performed in the form of structured interview survey where researchers were available for any type of questions and required explanation.

Next, the survey data were analyzed, and the results of the analysis were used to determine the critical factors influencing crew motivation and performance, and to identify the factors with a high potential for improvement. A comparative analysis of supervisor and craft survey results was performed to reveal the differences in perspectives between each group. Statistical tests, including *t*-tests and *F*-tests, were performed to determine if there was a statistically significant difference between the mean and variance of the evaluations of supervisors and craftspeople.

1.5.3. The Third Stage

In the third stage of this research, factor analysis was performed on the survey data to confirm the validity of the identified measures of motivational factors. A model of the relationship between motivational factors, situational/contextual factors, and crew performance was proposed, and each component of the model was described in detail. A novel, comprehensive set of construction crew performance metrics was defined, which includes KPIs related to task performance, contextual performance, and counterproductive behaviour.

Field data were collected on crew motivational factors, situational/contextual factors, and crew performance metrics over the three-month timeline of an industrial construction project. Motivational factors, situational/contextual factors, crew performance metrics were collected for several crews working on different work packages in the project. Field data analysis was performed to investigate the relationship between crew motivational factors and crew performance and to identify key moderators of the relationship between crew motivation and performance.

1.5.4. The Fourth Stage

In the fourth stage of this research, a literature review of the applications of ABM in construction research was performed and the limitations in current ABM research were identified. The integration of fuzzy logic with ABM was investigated; and a methodology of developing fuzzy agent-based models in construction were developed. In the proposed methodology, agents were able to receive and process fuzzy variables and decide based on fuzzy rules. Fuzzy C-means (FCM) clustering, one of the most commonly used methods of fuzzy clustering, was used to construct fuzzy sets for subjective variables and relationships of the model. FCM clustering was used to develop fuzzy sets of agent attributes, as well as, agent behavioural rules. Mathematical formulas based on past research were used to define the interaction of agents. Anylogic®, a simulation software based on Java environment, and MATLAB®, which allows programming in MATLAB®, were connected using Java programming to provide a fuzzy agent-based simulation platform. The application of fuzzy agent-based modeling (FABM) methodology in construction was investigated by developing a fuzzy agent-based model of construction crew motivation and performance. The developed fuzzy agent-based model was then verified and validated. To verify the developed fuzzy agent-based model, four steps were followed: checking the mathematical equations; performing a structured walk-through; checking for replicability of the results; and using runtime graphs and tracing. To validate the fuzzy agent-based model, three methods were used: conceptual validity, data validity, and operational validity.

1.6. Thesis Organization

Chapter 1 provides the background of the research, problem statement including the gaps in construction research that this study aims to fill, research objectives, expected academic and industrial contributions, and research methodology.

Chapter 2 provides a review of current literature on motivation, and applies the most recent advancements in motivation research from non-construction domains to the construction domain. Following the performed literature review, this chapter identifies the factors affecting construction crew motivation and performance. The identified list of factors is then used to design the interview surveys. Finally, the results of survey data collection and analysis are presented.

Chapter 3 presents the factor analysis performed on the data collected by multiple-source interview surveys (i.e., both supervisor and craft surveys) to check for the validity of the identified measures. Filed data collection measures of motivational factors, situational/contextual factors, and crew performance metrics are presented. The identified KPIs related to task performance, contextual performance, and counterproductive behaviour are presented. Correlation analysis is presented to explain the relationship of crew motivational factors and crew performance metrics. The performed hierarchical multiple regression analysis for each of situational/contextual factors is illustrated, and the key moderators of the relationship of crew motivation and performance are listed.

Chapter 4 presents a literature review of the applications of agent-based modeling (ABM) in construction research as well as the limitations in current ABM research. A methodology for developing fuzzy agent-based models in construction is proposed. The proposed methodology is illustrated by developing a fuzzy agent-based model of construction crew motivation and performance. The results of simulation experiments are presented and the developed model is verified and validated.

Chapter 5 presents the conclusions, contributions, and the limitations of this research as well as the recommendations for future research.

Appendix A presents the developed data collection protocol, which includes all data collection procedures and forms.

1.7. References

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Chapter 2. Framework for Identification of Factors Affecting Construction Crew Motivation and Performance[1]

2.1. Introduction

Labour is a critical resource in construction, and being able to effectively predict and improve crew motivation and performance is an important factor in achieving project success. However, predicting crew motivation and performance involves many challenges in areas such as determining the attributes of crew performance (e.g., productivity), and identifying the factors affecting crew performance. Campbell (1990) defines motivation as "the extent to which persistent effort is directed toward a goal". Generally speaking, workplace motivation is defined as the direction of attention, mobilization of effort, and persistence of effort over time, exhibited by individual employees and aggregated across individuals within a work group (Latham and Pinder 2005). Individual and crew performance has long been viewed as a function of both capability and motivation (Campbell 1990). Therefore, when studying crew performance, it is important to

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consider not only situational/contextual factors (i.e., the factors related to the situation in which the tasks are performed) but motivational factors as well.

In construction, workers complete tasks in crews, which means that crew performance is a function of workers' interactions with each other and with their environment, rather than just the performance of individual members. Therefore, in order to assess the performance of a crew, it is essential to assess the motivation of construction crews not only at the individual level but also at the crew level. Unfortunately, the construction literature has tended to overlook, assume, or de-emphasize motivational explanations when accounting for variations in labour productivity and performance (Maloney 1986; Maloney and McFillen 1987; Siriwardana and Ruwanpura 2012). To bridge the gaps in existing construction literature, this chapter attempts to answer the following questions: What factors contribute to individual and crew motivation, and how are these factors identified and measured?

Though motivation is a major research focus in many disciplines such as business and psychology, limited research has been devoted to motivation in the construction context. For a review of the broader work-motivation literature, see Diefendorff and Chandler (2011). On the other hand, much of the literature that does exist in construction exhibits shortcomings. For example, most theories of motivation consider the motivation of an individual without taking into account the social context in which activities occur, which limits the conclusions that may be drawn (Raoufi and Fayek 2015). However, drawing upon non-construction literature must be done carefully, since the nature of construction work imposes constraints that may limit the relevance of well-established, individual-level motivational theories. Construction projects involve highly interdependent activities performed by crews, and performance in construction is multi-dimensional and is impacted by conditions outside of the scope of control of individuals. Therefore, in addition to the questions raised earlier, this chapter examines the motivational factors can be reasonably assessed at both individual and crew levels in order to better capture the reality of construction crew dynamics.

The two main objectives of this chapter are to define a methodology to identify the factors affecting construction crew motivation and performance, and to bridge the gap in construction research by exploring more recent motivational concepts that have been introduced and advanced in non-construction domains. This chapter also aims to determine a methodology for identifying factors with a high potential for improvement in construction crew motivation and performance, as well as the factors for which there are statistically significant differences between the perspectives of supervisors and craftspeople.

This chapter provides a review of current literature on motivation, and applies the most recent advancements in motivation research from non-construction domains to the construction domain. Following a discussion of the research methodology, this chapter identifies the factors affecting construction crew motivation and performance. Next, the design of the interview surveys is explained, and the results of survey data analysis are presented. Finally, conclusions and avenues for future research are proposed.

2.2. Literature Review of Motivation in the Construction Domain

Early work on the topic of motivation within construction contexts has tended to focus on expectancy theory (Maloney 1986), a cognitive theory of motivation, which asserts that individuals will choose to engage in two primary types of activities: activities that they believe they can do well, and activities that will lead to valued outcomes. It became evident from the review of past studies that other motivational factors might be relevant for construction crews, such as the nature of the work, the characteristics and behaviours of the leader/supervisor, and the role of financial incentives (Maloney and McFillen 1987). Maloney and McFillen (1987) collected questionnaire responses from different trades to determine the impact of factors such as general effectiveness and openness on individual worker motivation; they concluded that planning, organizing, staffing, directing, and controlling of work crews would increase worker performance and satisfaction.

More recently, researchers have expanded their view of motivation in the construction context. Shoura and Singh (1999) used need theories to identify the motivational parameters of engineering managers. Goal setting, workforce needs, and workforce incentives/rewards were identified as factors that promote positive motivational behaviour in construction subcontractor crews (Cox et al. 2006). Šajeva (2007) identified work, personal growth and continuous learning, autonomy and personal freedom, status and recognition, and monetary motivators as factors affecting the motivation and loyalty of knowledge workers. Management, supervisor's assessment, motivation based on expectancy theory, and technical skills were also identified as four categories of factors affecting productivity (Siriwardana and Ruwanpura 2012).

In summary, a review of current literature indicates that there are major shortcomings in motivation research for the construction domain. For example, some studies overlooked motivation at the crew level and largely relied on motivation at the individual level, some studies lacked data collection, and many studies based recommendations only on perceptions rather than data analysis. A major gap in construction research is in defining factors affecting crew motivation at both the individual and crew levels. To remedy these limitations, this chapter provides a novel and comprehensive set of factors affecting crew motivation and performance, and identifies factors affecting motivation at both the individual and crew levels.

2.3. Literature Review of Motivation in the Non-Construction Domains

Although numerous individual-level work-motivation concepts have been identified in the literature (Diefendorff and Chandler 2011), there are other possible motivational concepts that might influence crew motivation at both the individual and crew levels. An extensive review of literature outside the construction domain was conducted, and four motivational concepts have been shown to operate at both levels: efficacy (Bandura 1977; Hannah et al. 2016), commitment/engagement (Meyer and Allen 1991; Cesário and Chambel 2017), identification (Ashforth and Mael 1989; Lin et al. 2016), and cohesion (Beal et al. 2003; Chiniara and Bentein 2017). All four motivational concepts (i.e., efficacy, commitment/engagement, identification, and cohesion) have been shown in past research to have strong motivational impacts on both individuals and crews. The following sections provide a discussion and review of research findings for each concept.

2.3.1. Efficacy

Efficacy has been shown to have a potent motivational impact on individuals (Bandura 1977). Self-efficacy (i.e., efficacy at the individual level) refers to an individual's judgment of his or her ability to execute courses of action required to attain a designated outcome (Bandura 1977). Within a construction crew, self-efficacy refers to each individual worker's judgment about his or her capabilities to do a specific task. However, efficacy can also be experienced at a collective (i.e., group, team, or crew) level. Collective efficacy refers to shared beliefs within the group about the collective abilities of members to execute actions required to attain a designated outcome (Bandura 1977). In the context of a construction crew, collective efficacy is the crew's shared judgment of its capabilities to do a specific task. Four sources of efficacy operate at both the individual and crew levels: mastery experience (i.e., the perception that the performance has been successful), vicarious experience (e.g., from observing someone else's success in the same task), social persuasion (e.g., feedback from a supervisor or a colleague), and affective states (e.g., anxiety or excitement) (Goddard et al. 2004; Bandura 1997).

Previous studies analyzed the relationship between self-efficacy and performance, and also collective efficacy and performance. These studies showed that both self-efficacy and collective efficacy have strong relationships to performance, but the relationship between collective efficacy and performance is stronger than the relationship between self-efficacy and performance. Therefore, the relationship between efficacy and performance is strongest at the crew level (Gully et al. 2002).

In order to measure an individual worker's self-efficacy for performing a specific task, it is possible to interview or survey the worker about his or her self-efficacy. A bigger challenge is to measure the collective efficacy of a construction crew. Two crew efficacy assessment methods have been proposed in past research: crew discussion and aggregating each member's belief of the crew's efficacy (Stajkovic et al. 2009). In the first method, crew workers must reach consensus collectively. Because workers in a crew may differ in their levels of competence and roles, a weakness of this method is its vulnerability to potential power influences during crew discussions. In the second, more common method, each crew member provides a private, individual assessment expressing his or her perception of the crew's collective efficacy. The collected data are then aggregated into one assessment of crew's collective efficacy.

In summary, self-efficacy entails an individual worker's judgments about his or her ability to perform a specific task, while collective efficacy refers to the crew's shared judgment of its ability to perform a specific task. Research on non-construction work crews suggests that efficacy, assessed at both the individual and crew levels, is positively associated with crew-level performance outcomes (Gully et al. 2002; Hannah et al. 2016; Tasa et al. 2011).

2.3.2. Commitment/Engagement

Commitment/engagement refers to an individual's emotional attachment to and involvement in the organization and/or to a course of action (Meyer and Allen 1991). These felt emotional bonds, such as emotional attachment to the organization, have been associated with various motivational states (Meyer et al. 2004; Johnson and Yang 2010). In additional to motivational states, emotion-based or desire-based commitment/engagement has been shown to have a positive relationship with technical task performance, a positive relationship with citizenship behaviour/contextual performance, and a negative relationship with counterproductive behaviour, absenteeism, and turnover across jobs and situations (Cesário and Chambel 2017; Gellatly et al. 2006; Meyer et al. 2004). Emotional contagion is the concept that a person's emotional responses trigger similar responses in other people (Hatfield et al. 1994). To the extent that commitment/engagement captures emotional content, it may be assumed that the logic underlying emotional contagion allows for the crew-level conceptualization of commitment/engagement. For instance, a worker with low levels of commitment/engagement working in a crew of highly committed/engaged members will become more committed/engaged due to their interactions with highly committed/engaged crew members.

2.3.3. Identification

Identification has also been shown to impact motivation at both individual and crew levels. Identification has been defined as "the emotional significance that members of a given group attach to their membership in the group" (Ashforth and Mael 1989; Lin et al. 2016; Van de Vegt and Bunderson 2005). To enhance crew identification, it is important to foster two determinants of identification: accepting crew goals and creating goal interdependencies. Crew leaders can create acceptance of crew goals. Goal interdependence is created when the goal attainment of one member of the crew is influenced by goal attainment of other members. Goal interdependence exists when crew members work cooperatively to attain the crew's shared goals (Lee et al. 2011). In short, when attraction is high, members want to work together and are better equipped to communicate and coordinate with each other. In turn, these conditions should increase the crew's level of attention, effort, and persistence in regards to the ongoing task. Identification at the individual level is associated with the motivation of individuals to achieve collective goals, and it has been positively correlated with individual job performance. Identification at this level also increases an individual's self-esteem, elevating his or her performance. In contrast, identification at the crew level generates positive evaluations of crew potency (i.e., the crew's collective belief in its ability to perform well), which elevates performance (Lee et al. 2011). Therefore, identification can be analyzed at both the individual and crew levels.

2.3.4. Cohesion

Cohesion has also been shown to impact motivation at the individual and crew levels. Cohesion reflects the extent to which members want to remain in the crew (Dobbins and Zaccaro 1986); it entails the extent to which the members of a crew are attracted to one another, whether they feel a bond to one another, and/or whether members "stick together" as a unit. Cohesive work crews have been shown to be more productive than non-cohesive crews (Beal et al. 2003; Chiniara and Bentein 2017). Though cohesion can be assessed at both individual and crew levels, the relationship between cohesion and performance appears to be stronger when cohesion is considered at the crew level (Gully et al. 2012). When assessed at the individual level, cohesion is related to an individual's level of attraction or sense of belonging to a crew. When assessed at the crew level, cohesion is related to mutual attraction among crew members. The relationship of cohesion to performance is complex, as it is influenced by other factors (e.g., task type). For example, tasks that involve more interaction among crew members increase the effect of crew cohesion on performance (Beal et al. 2003).

2.4. Research Methodology and Chapter Organization

This research began with the identification of factors affecting construction crew motivation and performance. The primary list of factors was derived from existing research in both construction and non-construction domains. First, this initial list of factors was presented in a workshop to 10 construction experts involved in projects in Canada. These experts had an average of 15 years of experience, and they represented different types of construction organizations (e.g., owners, contractors, and labour unions); they also held various positions in their organizations, such as senior management, project management, human resources representative, and labour relations representative. The experts reviewed the list and proposed additional factors they thought may affect construction crew motivation and performance and reached consensus on the proposed additional factors; the primary list of factors was then updated to include the proposed factors. This process allowed for the development of a comprehensive list of factors that not only considers the literature in construction and non-construction domains, but that also captures the opinions of both motivation and construction experts.

The next step in this research was to design and administer the interview surveys. Two separate interview surveys were included in the research to reveal differences between the perspectives of supervisors and craftspeople. In order to identify potential participants, the study methodology and objectives were presented in another workshop to construction companies active in various industrial projects in Canada. A participant company was then selected based on availability of their projects for data collection during the research timeline. Three meetings were held with the survey respondents (i.e., supervisors at the company head office, supervisors in the project field, and craftspeople in the project field) to explain the data collection procedure and the surveys. Sample responses and instructions for completing the surveys were presented to the respondents to ensure respondents understood the surveys. The surveys were performed in the form of structured interview survey where researcher was available for any type of questions and required explanation.

Next, the collected data was analyzed, and the results of the analysis were used to determine the critical factors influencing crew motivation and performance, and to identify the factors with a high potential for improvement. A comparative analysis of supervisor and craft survey results was performed to reveal the differences in perspectives between each group. Statistical tests, including t-tests and F-tests, were performed to determine if there was a statistically significant difference between the mean and variance of the evaluations of supervisors and craftspeople. Face validation of the results of this chapter was performed with the management team of the company that participated in this study. A report of the results was sent to the company and a discussion meeting was held on the results.

2.4.1. Identification of Factors

Factors influencing construction crew motivation and performance include a wide range of motivational factors at both individual and crew levels, as well as situational/contextual factors at project and crew levels. Figure 2.1 shows a model of the relationships of motivational factors and situational/contextual factors to crew performance: the left-hand side of Figure 2.1 shows motivational concepts, where a number of antecedent factors operate at the individual and crew levels to impact crew motivation; the bottom shows the situational/contextual factors that interact with motivation to affect crew performance; and finally, the right-hand side of the model shows crew performance metrics.

Construction projects are usually evaluated in terms of time, cost, and quality (Kagioglou et al. 2001). However, these categories of project performance measures have been shown to be insufficient (Ward et al. 1991). There are other performance measures involved in project success such as quality of relationships between crew members in a project (Bassioni et al. 2004). These other aspects of performance (contextual performance and counterproductive performance) are important in defining performance metrics of a construction crew, as they are at the discretion of workers and thus more likely to be affected by workers' motivation. Thus, in Figure 2.1, a broader perspective of crew performance can be realized by considering more generic models of job performance developed outside the construction domain. For example, many of these generic models supplement a narrow “technical-task” perspective of performance with behaviours that support technical activities and contribute to overall effectiveness (e.g., helping others; working with enthusiasm; not engaging in counter-productive behaviour). In his seminal paper, Campbell (1990) proposed that the performance domain for any job involves some or all of eight generic dimensions: job-specific technical task proficiency; non-job specific task proficiency; communication proficiency; demonstrating effort; maintaining personal discipline; facilitating peer and team performance; supervision; and management. While the first six dimensions tend to characterize all jobs, the latter two dimensions tend to be emphasized in jobs with leadership or management duties. Borman and Motowido (1997) proposed a model of the performance domain that made a distinction between behaviours that are technical and job-specific in nature and those that tend to be discretionary and job-general; the latter being behaviours that affected the social context in which the technical activities occur (also referred to as organizational citizenship behaviour, Organ, 1988). The notion of job-general, contextual performance is particularly relevant for construction contexts, given the interdependent nature of the work (e.g., crew members persisting to complete technical tasks, volunteering; helping and cooperating with other crew members; following procedures and rules; and supporting crew objectives). Other generic performance taxonomies may also be relevant for defining performance within construction crews (for a review, see Wildman et al., 2011); such performance measures can thus be developed and validated in the construction domain.

As shown in Figure 2.1, a number of situational/contextual factors will affect the performance (and productivity) of construction crews. The presence of these situational/contextual factors will help or hinder the effect of crew motivation on crew performance. In construction projects examples of situational/contextual factors are task-related (e.g., task design; work flow), foreman-related (e.g., leadership skills), labour-related (e.g., functional skills of the crew itself), project-related (e.g., conditions), management-related (e.g., project management practices), resource-related (e.g., tools; equipment; materials), and work setting-related (e.g., weather conditions). In short, in addition to motivational factors, it is important to include the situational/contextual factors when studying motivation to crew performance relationships. In this research, situational/contextual factors up to the project-level are considered in the model. The situational/contextual factors at the organization-level such as company culture can be added to the list of situational/contextual factors in future research.

The left-hand side of Figure 2.1 considers possible concepts that might influence the level of motivation experienced within construction crews. Although numerous individual-level work-motivation concepts have been identified in the literature (Diefendorff and Chandler, 2011), this research focus is limited to predictor concepts believed to exist at both individual and crew levels. In this regard, the selected predictor concepts are efficacy, commitment/engagement, identification, and cohesion. Crew motivational factors at both the individual and crew levels are shown in Table 2.1.

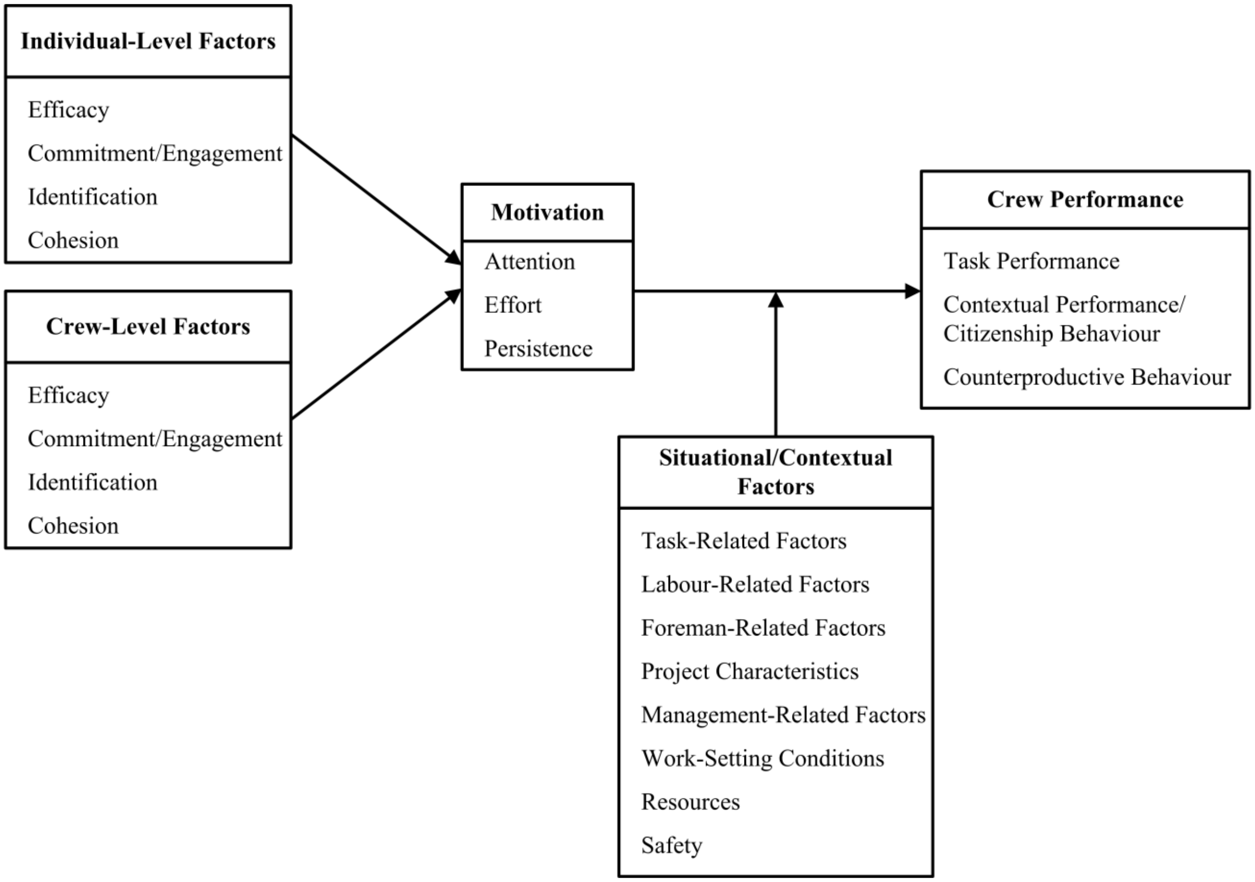


Figure 2.1. Model of the relationship between motivational factors, situational/contextual factors, and crew performance

Table 2.1. Crew motivational factors

Motivational factor category	Number of factor sub-categories	Factor sub-category	Number of factors	Factors
Individual-level motivational factors	4	• Efficacy–individual level	3	Self-confidence in ability to perform tasks effectively, self-confidence in ability to perform difficult tasks, ability to concentrate on performing tasks
		• Commitment/engagement–individual level	6	Being very happy to spend the rest of career with the organization, seeing the organization's problems as own, sense of "belonging" to the organization, emotional attachment to the organization, feeling like "part of the family" at the organization, the organization having a personal meaning
		• Identification–individual level	4	Feeling proud to be part of the crew, identification with the other members of the crew, like to continue working with the crew, emotional attachment to the crew
		• Cohesion–individual level	5	Choose to stay in the crew, feel to be a part of the crew, like to be with crew members, get along with other crew members, enjoy belonging to the crew
Crew-level motivational factors	4	• Efficacy–crew level	3	Crew confidence in ability to perform tasks effectively, crew confidence in ability to perform difficult tasks, crew ability to concentrate on performing tasks
		• Commitment/engagement–crew level	6	Crew members to be very happy to spend the rest of career with the organization, crew members to see the organization's problems as own, crew's sense of "belonging" to the organization, crew's emotional attachment to the organization, crew members to feel like "part of the family" at the organization, the organization having a personal meaning to the crew
		• Identification–crew level	4	Crew members to feel proud to be part of the crew, crew members identification with the other members of the crew, crew members to like to continue working with the crew, Crew members' emotional attachment to the crew
		• Cohesion–crew level	3	Crew members get along well together, defending each other from criticism, crew being a close one
Total	**8**		**34**	

In addition to crew motivational factors, situational/contextual factors also affect the performance of construction crews (AbouRizk et al. 2001; Dai et al. 2009; Fayek and Oduba 2005; Knight and Fayek 2000; Liberda et al. 2003). The presence of these factors will either increase or decrease the effect of crew motivation on crew performance. Table 2.2 shows a complete list of the situational/contextual factor categories, factor sub-categories, and factors in each sub-category.

Table 2.2. Situational/contextual factors

Situational/ contextual factor category	**Number of factor sub-categories**	**Factor sub-category**	**Number of factors**	**Factors**
Task-related	3	• Task characteristics	5	Task type, task size, task complexity, task repetition, task interruption and disruption
		• Task design	7	Skill variety, task identity, task significance, visibility of outcome, flexibility in scheduling, flexibility in procedures, feeling of ownership
		• Rework	5	Rework type, rework frequency, level of rework, rework time requirement, rework source
Labour-related	3	• Crew properties	4	Crew size, crew composition, crew knowledge, crew experience
		• Crew functional skills	5	Job training, safety training, ability to perform, material handling, hazards identification and mitigation
		• Crew behavioural skills	6	Cooperation, teamwork, trust in foreman, participation in decision-making, reliability, adaptability to changes
Foreman-related	3	• Foreman characteristics	4	Foreman age, foreman gender, foreman knowledge, foreman experience
		• Foreman functional skills	7	Planning, scheduling, safety facilitation and implementation, resource management, performance monitoring, communication, team building
		• Foreman behavioural skills	8	Goal setting, feedback, leadership, fairness, decision-making style, teamwork, working relationship, building trust
Project characteristics	3	• Project properties	4	Project type, project size, project duration, project location
		• Work/job conditions	5	Working shifts, daily working hours, camp, work permits, project progress
		• Project engineering	5	Drawings availability, specifications availability, drawing and specs quality, response to inquiries, frequency of revisions
Management-related	4	• Project manager characteristics	4	PM age, PM gender, PM knowledge, PM experience

Situational/ contextual factor category	Number of factor sub-categories	Factor sub-category	Number of factors	Factors
		• Project manager functional skills	7	Project planning, project scheduling, safety management, resource management, performance monitoring & control, change management, communication
		• Project manager behavioural skills	6	Leadership, fairness, goal-setting, feedback, conflict resolution, trust
		• Project and construction management practices	13	Project integration management, project scope management, project time management, project cost management, project quality management, project human resource management, project communication management, project risk management, project procurement management, project safety management, project environmental management, project financial management, project claim management
Work-setting conditions	3	• Site general facilities	5	Office, lunchroom, washrooms, in-site transportation, communication device
		• Working area conditions	7	Cleanness, congestion, noise, pollution, type (covered/ uncovered), ventilation/air conditioning, access points
		• Weather conditions	5	Temperature, humidity, precipitation, wind speed, change in weather conditions
Resources	3	• Material	4	Task material availability, task material quality, consumables availability, consumables quality
		• Equipment	3	Equipment type, equipment availability, equipment quality
		• Tools	3	Type of tools, tools availability, tools quality
Safety	1	• Safety precautions	7	Safety procedures, safety meetings, safety inspections, safety audits, protective safety gears, safety training, recording incidents & corrective actions
Total	**23**		**129**	

2.4.2. Interview Survey Design

Two interview surveys, the supervisor and craft surveys, were developed in order to achieve three design objectives: identify critical factors relevant to supervisors and craftspeople; identify potential areas of improvement in construction crew motivation and performance; and reveal differences between supervisors and craftspeople perspectives by comparing respondents' rankings of common factors included in both surveys. The interview surveys address factors and their effects on crew motivation and performance at the following levels of analysis: micro-level (i.e., individual level), meso-level (i.e., crew level), and macro-level (i.e., project level) factors.

Both interview surveys included three sections: background, motivational factors, and situational/contextual factors. The first section was designed to collect respondent attributes such as age, occupation, experience, and other demographic information. The second section asked survey respondents to evaluate the motivational factors, while the third section involved the evaluation of project situational/contextual factors. In the second and third sections, for each survey question, respondents were asked to provide answers in two different areas: agreement (i.e., the extent to which the respondent agrees that a given factor exists in the project), and importance (i.e., how important a factor is in evaluating its factor sub-category). As proposed by Dai et al. (2009), a seven-point Likert scale was adopted to evaluate agreement and importance. Agreement was measured on a scale ranging from one ("strongly disagree") to seven ("strongly agree"), and importance was measured on a scale ranging from one ("extremely unimportant") to seven ("extremely important").

The supervisor survey included all crew-level motivational factors (i.e., "cohesion", "efficacy", "identification", and "commitment/engagement"), and all situational/contextual factors (i.e., "task-related factors", "labour-related factors", "foreman-related factors, "project management", "work-setting conditions", "resources", "project characteristics", and "safety"), amounting to a total of 137 factors in 9 categories and 26 sub-categories. The craft survey included all individual-level and crew-level motivational factors (i.e., "cohesion", "efficacy", "identification", and "commitment/engagement"), and some situational/contextual factors (i.e., "task-related factors", “labour-related factors”, “foreman-related factors”, “project management”, “work-setting conditions”, and “resources”), amounting to a total of 126 factors in 8 categories and 26 sub-categories (see Table 2.3 for a comprehensive list of these factors).

Table 2.3. Factors in surveys

Factor category	**Number of factors**		
	Supervisor survey	**Craft survey**	**Common to both surveys**
Individual-level motivational factors	-	18	-
Crew-level motivational factors	16	16	16
Task-related	16	16	16
Labour-related	16	16	16
Foreman-related	19	19	19
Project characteristics	10	-	-
Management-related	28	15	15
Work-setting conditions	16	16	16
Resources	10	10	10
Safety	6	-	-
Total	**137**	**126**	**108**

It is important to determine similarities and differences among the rankings of common factors evaluated by both supervisors and craftspeople in order to find and implement effective improvement strategies. While a higher level of agreement on factors between the two groups will help in implementing improvement strategies, a lack of agreement will demand further investigation into the sources of these differences. In order to investigate respondent perspectives, a total of 108 factors in 7 categories and 22 sub-categories were included in both the supervisor survey and the craft survey (Table 2.3).

2.5. Survey Administration and Analysis

The interview surveys were administered to a construction company active in various industrial projects in Canada. Following several meetings with managers of the participating company, the interview survey procedures were finalized, and researchers coordinated with project staff to administer the surveys. For both surveys, participants were identified using a stratified random sampling method. All data were collected in confidence and anonymity was maintained. Participants were also informed of the study goals, and written consent was collected. Each interview was designed to last for approximately 30 minutes, and all interviews were conducted in an environment specifically selected to protect the privacy of participants. All collected interview surveys were then anonymized using a code sheet.

Determination of sample size (i.e., the number of respondents to be surveyed from the population of workers) is essential to ensure the reliability and accuracy of results. Since the interview surveys were designed to address factors from the individual level up to the project level, respondents representing each of these different levels were asked to participate in the study (Dai et al. 2009; Jergeas 2009). The population (i.e., the number of workers in a given project) for the interview survey was assumed to be made up of all construction personnel on the project under study. This population composition ensures that the critical factors identified through the interview survey are applicable to the company's context and its project work force.

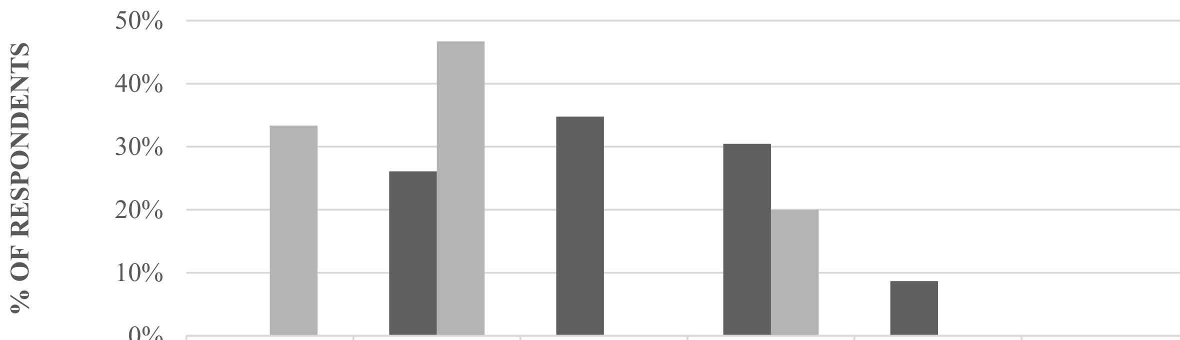
The interview survey population was stratified into the following levels: senior management, project management, construction management, superintendents, project staff (e.g., project controls, site project manager, project coordinator, and safety officer), foremen, and craftspeople. Once the population for each stratum was established, random sampling was applied. Stratified random sampling is an appropriate method in this situation since the structure within the population of each stratum is assumed to be similar in terms of role and function. Additionally, an adequate sample size was used to ensure proper representation of the population as a whole

(Fellows and Liu 2015). Random sampling also ensures that respondents have an equal chance of being selected, which helps to prevent biased selection based on convenience (Robinson 2014).

After defining the population, craft surveys were administered to craftspeople, and supervisor surveys were administered to all other personnel. A construction company with 25 supervisors and 54 craftspeople participated in the study, for a total population of 79 people. From 25 supervisors, 23 responded to the supervisor survey, and from 54 craftspeople, 15 responded to the craft survey. Considering the total population, 37 respondents were required to achieve a 90% confidence level with a 10% margin of error. Since there were 38 respondents for this study, the required 90% confidence level was achieved. However, it should be noted that the response rate of supervisors was higher than that of craftspeople. Considering each survey population separately, 23 of 25 supervisors responded, which provided more than a 99% confidence level with a 10% margin of error. From 54 craftspeople, 15 responded, which provided an 80% confidence level with a 10% margin of error.

2.5.1. Survey Respondents Demographics

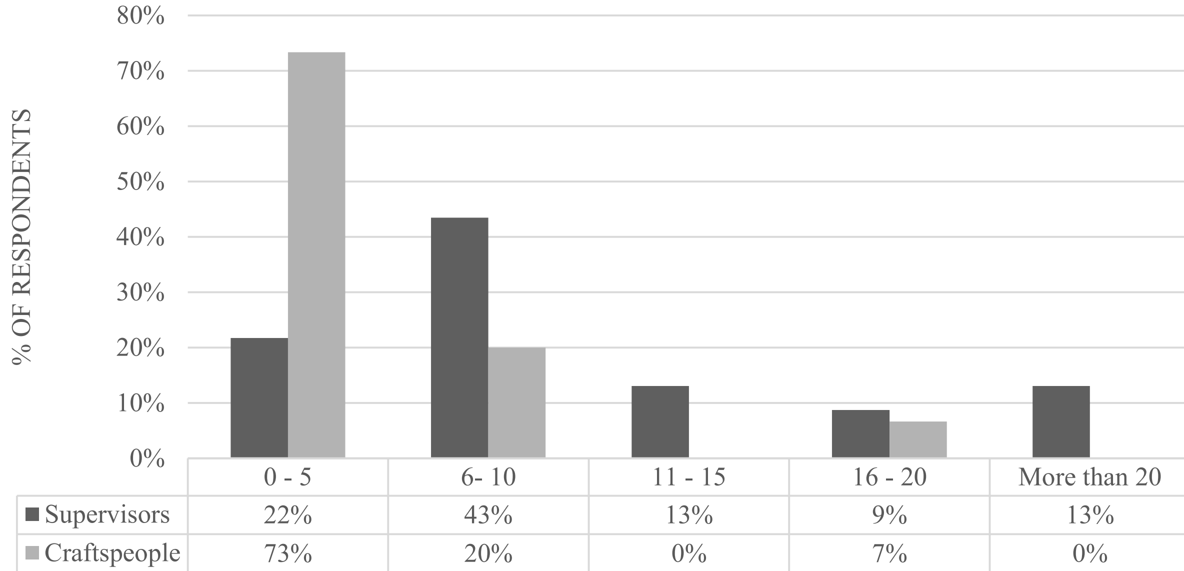
Supervisor survey respondents held the following positions: senior manager, construction manager, project manager, executive manager, superintendent, project controller, field engineer, field supervisor, safety/HSE officer, QA/QC manager, and foreman. Most supervisors were foremen, making up 31% of supervisor survey respondents. Craft survey respondents identified their trades as labourer, pipeliner, welder, sandblaster, pipe coater, and other (e.g., flagger). In terms of trade, most of the craftspeople (i.e., 57% of craft survey respondents) identified their trade as labourer. Figure 2.2 shows the distribution of respondents by age group. Most of the supervisor survey respondents were between 36 and 45 years of age, while most of the craft survey respondents were between 26 and 35 years of age.



	18-25	26-35	36-45	46-55	56-65	over 65
Supervisors	0%	26%	35%	30%	9%	0%
Craftspeople	33%	47%	0%	20%	0%	0%

Figure 2.2. Distribution of respondents by age group

Figure 2.3 shows the distribution of respondents by experience. Supervisor survey respondents had an average of 11 years of experience, while craft survey respondents had an average of 5 years of experience in their trade. As shown in Figures 2.2 and 2.3, supervisors were older and had more experience than craftspeople.



	0 - 5	6- 10	11 - 15	16 - 20	More than 20
Supervisors	22%	43%	13%	9%	13%
Craftspeople	73%	20%	0%	7%	0%

Figure 2.3. Distribution of respondents by years of experience

2.5.2. Critical Factors Influencing Construction Crew Motivation and Performance

To identify the critical factors affecting construction crew motivation and performance, factor rank was calculated based on evaluation scores, the latter of which take into consideration both the agreement and importance of factors. This type of ranking was used previously by Dai et al. (2009) and was expanded by Tsehayae and Fayek (2014) to identify critical factors affecting productivity. In this research, a similar analytical concept was adopted with some differences in formulation. These differences originate from the fact that in the previous works, evaluation scores were based on agreement-impact, while this research bases evaluation scores on agreement-importance.

All factors were analyzed as follows. First, the weighted percentage of agreement (R_A) for a given factor statement is computed using Equation 2.1, where the maximum possible weighted percentage of agreement is 25. The agreement is the extent to which a respondent agrees that a given factor exists in the project. Thus, R_A represents the level of agreement of all the respondents with the existence of a given factor in the project.

$$R_A = \frac{(A\times1+B\times2+C\times3+D\times4+E\times5+F\times6+G\times7)}{(1+2+3+4+5+6+7)}\ x\ 100, \tag{2.1}$$

where A, B, C, D, E, F, and G are the percentage of respondents rating the agreement with the existence of the factor in the project from 1 ("strongly disagree") to 7 ("strongly agree") respectively.

Next, the weighted percentage of relative importance (R_I) of a given factor statement is computed using Equation 2.2, where the maximum possible weighted percentage of relative importance is equal to 25.

$$R_I = \frac{(T\times1+U\times2+V\times3+W\times4+X\times5+Y\times6+Z\times7)}{(1+2+3+4+5+6+7)}\ x\ 100, \tag{2.2}$$

where T, U, V, W, X, Y, and Z are the percentage of respondents rating the importance of the factor from 1 ("extremely unimportant") to 7 ("extremely important") respectively.

Next, the evaluation index and evaluation scores for each factor are computed using Equation 2.3 and Equation 2.4 respectively. The evaluation index, which is the product of the weighted percentage of agreement (R_A) and the weighted percentage of relative importance (R_I), is calculated first. Then, the evaluation score is computed by dividing the evaluation index of a given factor by the maximum possible evaluation index (i.e., 625). The maximum possible evaluation index is the product of the maximum values of the weighted percentage of agreement (i.e., 25) and the relative importance (i.e., 25).

$$Evaluation\ Index_{AI} = R_A \times R_I. \tag{2.3}$$

$$Evaluation\ Score_{AI} = \frac{Evaluation\ Index_{AI}}{625} \times 100. \tag{2.4}$$

After the interview surveys were administered, responses were combined and the evaluation scores were calculated. Each factor's rank was then determined based on its evaluation score. Since the analysis was based on the agreement-importance of each factor, the critical factors influencing crew motivation and performance are the ones that showed high agreement and high importance. Factor category and sub-category rankings are presented in Table 2.4 for both supervisor and craft surveys. These rankings are based on the average evaluation scores of factors in each category and sub-category.

Table 2.4. Factor category and factor sub-category rankings

Factor category	Factor sub-category	Supervisor survey		Craft survey	
		Rank of category	Rank of sub-category	Rank of category	Rank of sub-category
Individual-level motivational factors	• Cohesion–individual level	-	-	5 (88.14)	11 (88.24)
	• Efficacy–individual level		-		**3 (98.38)**
	• Identification–individual level		-		15 (82.18)
	• Commitment/engagement–individual level		-		22 (65.39)
Crew-level motivational factors	• Cohesion–crew level	6 (78.40)	14 (85.03)	6 (88.11)	8 (91.06)
	• Efficacy–crew level		7 (92.22)		**2 (98.71)**
	• Identification–crew level		16 (77.58)		16 (80.49)
	• Commitment/engagement– crew level		25 (58.33)		24 (63.83)
Task-related factors	• Task characteristics	9 (65.80)	23 (68.23)	8(67.72)	20 (71.43)
	• Task design		19 (74.93)		21 (66.81)
	• Rework		26 (53.96)		26 (54.34)
Labour-related factors	• Crew properties	**3 (93.29)**	11 (91.00)	**2 (94.83)**	14 (83.00)
	• Crew functional skills		**5 (95.19)**		7 (91.79)
	• Crew behavioural skills		6 (93.29)		**5 (94.88)**
Foreman-related factors	• Foreman characteristics	4 (91.68)	**3 (96.84)**	**1 (100.00)**	**1 (100.00)**
	• Foreman functional skills		9 (91.40)		6 (93.83)
	• Foreman behavioural skills		13 (86.41)		9 (90.55)
Project characteristics	• Project properties	7 (74.78)	-	-	-
	• Work/job conditions		18 (75.16)		-
	• Project engineering		21 (74.20)		-
Management-related factors	• Project manager characteristics	5 (83.75)	10 (91.04)	**3 (91.75)**	**4 (96.12)**
	• Project manager functional skills		15 (81.92)		17 (79.41)
	• Project manager behavioural skills		12 (87.19)		13 (85.39)
	• Project and construction management practices		20 (74.38)		-
Work-setting conditions	• Site general facilities	8 (72.43)	17 (76.33)	7 (69.57)	19 (72.12)
	• Working area conditions		24 (67.09)		25 (60.89)
	• Weather conditions		22 (73.57)		23 (64.85)
Resources	• Material	**2 (96.20)**	8 (91.57)	4 (89.15)	18 (77.39)
	• Equipment		**1 (100.00)**		12 (87.57)
	• Tools		**4 (96.62)**		10 (88.56)
Safety	• Safety precautions	**1 (100.00)**	**2 (99.86)**	**-**	**-**

[a] The values in brackets indicate the normalized evaluation scores.

The results in Table 2.4 show that supervisors ranked "safety", "resources", and "labour-related factors" as the top three factor categories influencing crew motivation and performance, while they ranked “equipment”, “safety precautions”, “foreman characteristics”, “tools”, and “crew functional skills” as the top five factor sub-categories influencing crew motivation and performance. On the other hand, craftspeople ranked “foreman-related factors”, “labour-related factors”, and “project management factors” as the top three factor categories influencing crew motivation and performance, while they ranked “foreman characteristics”, “collective efficacy”, “self-efficacy”, “project manager characteristics”, and “crew behavioural skills” as the top five factor sub-categories influencing construction crew motivation and performance.

Table 2.5 lists the top 10 critical factors influencing crew motivation and performance, as ranked by the supervisor survey and craft survey respondents. Out of the 137 factors included in the supervisor survey, respondents ranked “using protective safety gears for performing the tasks”, “ability of crew to identify hazards and mitigate the risks associated with them”, “quality of equipment for performing the task”, “cooperation among the members of the crew”, and “team work in the crew” as the top five critical factors influencing crew motivation and performance. On the other hand, out of the 126 factors included in the craft survey, respondents identified “confidence of crew members that they can successfully perform difficult tasks”, “mutual trust between foreman and crew members”, “crew members believe in their ability to perform the tasks”, “foreman has the required knowledge of the work”, and “foreman has the required experience to define procedures for performing the tasks” as the top five factors influencing crew motivation and performance.

Table 2.5. Top 10 critical factors influencing construction crew motivation and performance

Rank	Supervisor survey		Craft survey	
	Factor	**Evaluation score**	**Factor**	**Evaluation score**
1	Protective safety gear is mandatory for performing the tasks.	100.00	The members of this crew feel confident that they can successfully perform difficult tasks.	100.00
2	The members of this crew can identify hazards and mitigate the risk associated with them.	94.88	There is high mutual trust between the foreman and crew members	99.67
3	The quality of equipment is suitable for performing the task.	91.79	The members of this crew believe in their ability to perform the tasks effectively.	99.05
4	Cooperation among the members of this crew is high.	91.17	The foreman has the required knowledge of the work.	99.04
5	Teamwork in this crew is good.	91.17	The foreman has the required experience to define procedures for performing the tasks.	99.04
6	Equipment is available for performing the task.	89.95	I feel confident in my ability to perform my tasks effectively.	99.04
7	The members of this crew have adequate ability to perform the tasks with required quality.	89.92	The foreman has leadership in managing the crew.	98.62
8	The foreman has the required knowledge of the work.	89.92	The foreman has appropriate skills in resource management.	98.08
9	Safety rules and procedures are followed on this project.	89.54	The foreman has effective working relationships with crew members.	97.59
10	Safety procedures are defined appropriately in this project.	89.35	The members of this crew trust in the foreman's judgments and decisions.	97.12

2.5.3. Factors with a High Potential for Improvement in Construction Crew Motivation and Performance

Factors influencing construction crew motivation and performance are important targets for improvement, or if they are already fully satisfied, it is vital to make efforts to keep them at their highest possible agreement level. However, improving a factor that is already close to its highest possible agreement level is very difficult and is sometimes not feasible. Therefore, this section illustrates a method of analysis to identify factors with a high potential for improvement in crew motivation and performance; these are the factors that simultaneously exhibit a low level of agreement and a high level of importance. To determine the lowest possible level of agreement, the weighted percentage of disagreement is calculated using the inverse of the calculations for the weighted percentage of agreement. The potential improvement of each factor is then calculated using the weighted percentage of disagreement and the weighted percentage of relative importance to each factor. All factors have been analyzed using the calculations presented below.

First, the weighted percentage of disagreement (R_D) for a given factor statement by a number of respondents is computed using Equation 2.5, where the maximum possible weighted percentage of disagreement is 25. The calculations for the weighted percentage of disagreement are the inverse of the calculations for the weighted percentage of agreement.

$$R_D = \frac{(A\times7+B\times6+C\times5+D\times4+E\times3+F\times2+G\times1)}{(1+2+3+4+5+6+7)}\ x\ 100, \tag{2.5}$$

where A, B, C, D, E, F, and G are the percentage of respondents rating the agreement of the factor as 1 (“strongly disagree”) to 7 (“strongly agree”) respectively.

The relative importance (R_I) of a given factor statement is computed using Equation 2.2, where the maximum possible weighted percentage of relative importance is 25. Next, the level of potential improvement for each factor is evaluated by calculating the potential improvement index Equation 2.6 and the potential improvement score Equation 2.7. First, the potential improvement index is calculated as the product of the weighted percentage of disagreement (R_D) and the weighted percentage of relative importance (R_I). Next, the potential improvement score is computed by dividing the potential improvement index of a given factor by the maximum possible potential improvement index. The maximum possible potential improvement index is 625, which is the product of the maximum values of the weighted percentage of disagreement (i.e., 25) and the weight percentage of relative importance (i.e., 25):

$$Potential\ Improvement\ Index_{DI} = R_D\ \times\ R_I. \tag{2.6}$$

$$Potential\ Improvement\ Score_{DI} = \frac{Potential\ Improvement\ Index_{DI}}{625} \times 100. \qquad (2.7)$$

The interview survey responses were combined and the calculations for potential improvement scores were performed. Each factor's rank was then determined based on its potential improvement score. Since the analysis was based on the disagreement-importance of each factor, the factors with a high potential for improvement in construction crew motivation and performance are the ones that showed low agreement and high importance. Table 2.6 lists the top 10 factors with a high potential for improvement in construction crew motivation and performance, as ranked by the supervisor survey and craft survey respondents.

Table 2.6. Top 10 factors with a high potential for improvement in construction crew motivation and performance

Rank	Supervisor survey		Craft survey	
	Factor	Evaluation score	Factor	Evaluation score
1	The members of this crew have a high degree of freedom in selecting the procedures to be used in carrying out their tasks.	100.00	The work area is protected from overall weather effects.	100.00
2	Working area is protected from wind effects (e.g. working area is a closed area).	99.83	Working area is protected from precipitation (e.g. working area is a covered area).	94.86
3	The members of this crew have a high degree of freedom in scheduling their tasks.	96.22	Working area is protected from wind effects (e.g. working area is a closed area).	93.67
4	Working area is protected from precipitation (e.g. working area is a covered area).	96.22	The members of this crew have a high degree of freedom in selecting the procedures to be used in carrying out their tasks.	83.32
5	The work area is protected from overall weather effects.	95.09	The goals assigned by the foreman to the crew are difficult.	82.45
6	This company or labour union has a great deal of personal meaning for the members of this crew.	90.85	The members of this crew have a high degree of freedom in scheduling their tasks.	79.15
7	The goals assigned by the foreman to the crew are difficult.	88.60	The members of this crew are very happy to spend the rest of their career with this company or labour union.	65.60
8	Actual progress of the project is based on project estimates.	87.42	Working area is usually not congested.	64.77
9	Types of reworks are very similar in this project.	86.96	On average, the weather conditions (temperature, wind, humidity, precipitation) are normal in the working area.	62.81
10	Working area is usually not congested.	84.59	The members of this crew feel "emotionally attached" to this company or labour union.	62.51

The factors listed in Table 2.6 are the ones that have both a low level of agreement and a high level of importance. For such factors, if the agreement levels are increased (i.e., if respondents display a high level of agreement regarding the existence of these factors on a project), since those factors demonstrate high levels of importance, the motivation and performance of the crew will be improved. Therefore, identifying the factors with a high potential for improvement in construction crew motivation and performance will provide companies with insight into factors that may possibly affect crew performance on future projects. Supervisor survey respondents identified “more freedom should be granted to crew members in selecting work procedures”, “the working area should be protected from the effects of wind”, and “more freedom should be granted to crew members in scheduling their tasks” as the top three factors with a high potential for improvement in crew motivation and performance. On the other hand, craft survey respondents suggested “the work area should be protected from the effects of overall weather effects”, “the work area should be protected from precipitation”, and “the work area should be protected from wind” as the top three factors with a high potential for improvement.

2.5.4. Comparative Analysis of Supervisor and Craft Survey Results

Past productivity research also includes perspective analysis to compare the responses of project managers or foremen with the responses of tradespeople on factors affecting productivity (Dai et al. 2009; Tsehayae and Fayek 2014). In this section, the perspectives of supervisors and craftspeople are compared on three levels: rankings of common factor categories, rankings of common factor subcategories, and rankings of common factors between the two surveys. Between the supervisor and craft surveys, 108 common factors in 7 categories and 22 sub-categories have been evaluated. Rankings for the common factors were derived from the evaluation scores, which were then normalized based on the maximum score. The rankings for the common factor sub-categories are based on the average evaluation scores of factors in each sub-category, while the rankings for the common factor categories are based on the average evaluation scores of factor sub-categories. It should be noted that since these rankings were recalculated to only include the factor categories, sub-categories, and factors that exist in both the supervisor and craft surveys, rankings in this section may differ from those shown in Tables 2.5 and 2.6. The results show strong agreement by the respondent groups on critical factor categories and sub-categories common to both interview surveys. From the top three critical factor categories identified by supervisors, two were also identified as top three critical factor categories by craft survey respondents: "labour-related factors" and "foreman-related factors". Surprisingly, 8 factor sub-categories out of 10 were identified by both respondent groups as the top 10 critical factor sub-categories influencing construction crew motivation and performance.

The differences in evaluation scores between the respondent groups were also calculated. Table 2.7 lists the top 10 factors with the greatest difference in evaluation scores between supervisors and craftspeople. The factors with the greatest difference in evaluations were "task complexity", "participation of crew members in decision-making", and "foreman decision-making style". Statistical tests were performed to investigate if there is a statistically significant difference between each group's evaluations. Previous researchers, such as Tsehayae and Fayek (2014) and Dai et al. (2009), used *F*-tests on the impact scores; in this research, both *t*-tests and *F*-tests were performed. Since the respondents were from different populations, unpaired *t*-test assuming unequal variance was performed to determine if there is a statistically significant difference between the mean values of each respondent group's evaluations scores. The null hypothesis is that there is no statistically significant difference between these means values. A 95% confidence level was assumed and thus a *p*-value (i.e., the probability value that the null hypothesis is true) of 0.05 was considered in the calculations. Table 2.7 shows the *t*-values for each factor. For the items where the *t*-value exceeds *t*-critical (i.e., 2.03), the null hypothesis is rejected, which means that there is a statistically significant difference between the mean values of each respondent group's evaluations. The results in Table 2.7 show that for some factors (i.e., "task complexity", "participation of crew members in decision-making", and "foreman decision-making style"), there is a statistically significant difference between each group's evaluations. However, the results suggest that some factors, such as "the organization having a personal meaning to the crew", do not show a statistically significant difference.

Table 2.7. Top 10 factors with a high difference in evaluation scores

Rank	Factor	Supervisors Evaluation score	Craftspeople Evaluation score	Difference	*t*-value[a]	*F*-value[b]
1	Tasks are very complex in this project.	45.96	70.69	24.73	3.22[c]	3.15[d]
2	The members of this crew try to participate in decision-making process.	68.51	91.42	22.92	2.49[c]	5.27[d]
3	The foreman decision-making style related to work issues is participative rather than autonomous.	75.23	96.57	21.34	2.90[c]	3.92[d]
4	This company or labour union has a great deal of personal meaning for the members of this crew.	46.85	67.92	21.07	1.57	1.26
5	Crew members can participate in goal setting.	71.40	90.40	19.00	2.92[c]	4.05[d]
6	The foreman has appropriate skills in resource management.	79.68	98.08	18.40	2.73[c]	2.88[d]
7	The members of this crew will readily defend each other from criticism by outsiders.	73.08	91.39	18.32	2.60[c]	1.58
8	The members of this crew really feel as if this company or labour union's problems are their own.	45.16	60.84	15.68	1.76	1.41
9	This crew is a close one.	75.26	90.50	15.24	2.88[c]	3.20[d]
10	The foreman treats all crew members equally and fairly.	81.33	96.56	15.23	1.96	2.42[d]

[a] *t*-values are calculated based on importance scale and *t*-critical for *t*-test is 2.03.
[b] *F*-values are calculated based on importance scale and *F*-critical for *F*-test is 2.36.
[c] Indicates that the difference between the mean values of the evaluation scores of supervisors and craftspeople were statistically significant at $p < 0.05$.
[d] Indicates that the difference between the variances of evaluation scores of supervisors and craftspeople were statistically significant at $p < 0.05$.

In addition to the *t*-test, an *F*-test was performed to determine out if there is a statistically significant difference between the variance of the evaluations of supervisors and craftspeople. The null hypothesis is that there is no statistically significant difference between the variance of the evaluations. A 95% confidence level was assumed, and a p-value of 0.05 was considered in the calculations. F-values for each factor are presented in Table 2.7. For the items in which the F-value exceeds F-critical (i.e., 2.36), the null hypothesis is rejected, which means that there is a statistically significant difference between the variance of the evaluations. The results of the F-test are very similar to that of the t-test, indicating that for some factors, there is a statistically significant difference between the evaluations of supervisors and craftspeople. Identifying the factors for which there are differences in evaluations will help to mitigate or eliminate the sources of differences between supervisors and craftspeople, leading to an improved understanding of the work environment and to improved crew performance.

2.6. Discussion

Supervisors considered “equipment”, “safety precautions”, “foreman characteristics”, “tools”, and “crew functional skills” as the major factors influencing construction crew motivation and performance. Three of those factors (i.e., “equipment”, “safety precautions”, and “tools”) can be managed through precise project planning and monitoring, while the other two (i.e., “foreman characteristics” and “crew functional skills”) can be addressed by improving the experience and skills of foreman and craftspeople through training programs. These findings are in line with the study done by Dai et al. (2009), which found that craftspeople identified equipment and tools among their top five factors influencing productivity, and made the recommendation that job site managers focus on control of equipment and tools (Dai et al. 2009). Similar to the results presented in this chapter, “foremen characteristics” and “crew functional skills” were also identified in past research as affecting crew motivation and performance (Maloney and McFillen 1987; Siriwardana and Ruwanpura 2012). However, "safety precautions" were not identified as a critical factor affecting construction crew motivation and performance in previous studies; this may indicate that the company under study had a high safety culture and that supervisors perceive safety precautions as a critical factor.

Craftspeople considered "foreman characteristics", "collective efficacy", "self-efficacy", "project manager characteristics", and "crew behavioural skills" as the major factors influencing construction crew motivation and performance. Two of these factors (i.e., "foreman characteristics" and "project manager characteristics") concur with findings from Maloney (1986), which identified the characteristics and behaviour of the supervisor as one of the factors affecting the motivation of workers. The other two factors related to efficacy were in agreement with the results provided by other researchers on motivation in construction discussed earlier (Siriwardana and Ruwanpura 2012). That being said, previous research studied efficacy only at the individual level, while this research expands motivational concepts to the crew level. Additionally, the results of this study identified crew behavioural skills as a critical factor affecting construction crew motivation and performance, while past research in construction focused only on crew functional skills (Maloney and McFillen 1987; Siriwardana and Ruwanpura 2012).

Supervisors identified the following factors as having a high potential for improvement in construction crew motivation and performance: "freedom of crew members in selecting work procedures and scheduling their tasks" and "the protection of working area from the effects of wind". On the other hand, craftspeople identified the following as factors with a high potential for improvement: "protection of working area from overall weather effects", "precipitation", and "wind". These results indicate that crew performance may improve with favorable weather conditions. Similarly, giving more freedom to crew members in selecting work procedures or scheduling their tasks may increase their motivation and performance. The identification of potential improvement factors are context specific and may vary from project to project. However, awareness of the factors that may contribute to significant improvements in crew motivation and performance might help project managers to improve company policies and procedures.

While the results of the comparative analysis suggest that there is high agreement between the perspectives of supervisors and craftspeople, there are still some areas of disagreement. There were statistically significant differences between each group's perspectives in terms of the mean and variance of the evaluation scores for "task complexity", "crew participation in decision-making", and "foreman decision-making style". The results indicate that craftspeople believed that task complexity was a critical factor affecting their motivation and performance, while supervisors did not see task complexity as a critical factor in the project. The results also indicate that craftspeople would like more involvement in decision-making, while supervisors did not consider the involvement of craftspeople to be a critical factor. Dai et al. (2009) identified a high level of agreement between supervisors and craftspeople, while Tsehayae and Fayek (2014) observed both agreement and disagreement between the perspectives of supervisors and craftspeople. The results of this study are thus in agreement with the research of Tsehayae and Fayek (2014).

2.7. Chapter Summary

Past research on motivation in the construction domain has not only been relatively limited, but it also demonstrates issues in areas such as use of outdated theories of motivation, failure to incorporate recent motivational concepts developed by researchers outside the construction domain, and a tendency to only focus on individual-level motivation. In turn, these gaps in the literature present challenges to researchers in defining crew motivation in construction, as well as in identifying the crew motivational factors and situational/contextual factors affecting crew motivation and performance. This research bridges these gaps by exploring more recent motivational concepts that were introduced and advanced in non-construction domains. Furthermore, to capture the reality of construction crew dynamics, this chapter examined the motivational factors that operate at both individual and crew levels. Four motivational concepts were identified that operate at both levels: efficacy, commitment/engagement, identification, and cohesion.

This chapter provided a methodological approach, which was applied to identify and assess the factors affecting construction crew motivation and performance. A list of 163 factors was identified from existing research in both construction and non-construction domains; this list was validated by both motivation and construction experts and updated based on their recommendations. The methodology of the chapter was then used to analyze the collected survey data. Critical factors, as well as factors with a high potential for improvement in crew motivation and performance, were identified, and the perspective of supervisors and craftspeople on critical factors affecting crew motivation and performance were compared. The results of both the *t*-test and *F*-test indicate that there were some areas of disagreement between supervisors and craftspeople. These statistical tests consider the sample size in calculating the critical values (i.e., *t*-critical and *F*-critical) and are thus able to identify if there is a significant difference between the perspectives of two populations, even if the respondents' sample sizes are small. However, because of the limitation in the sample size of craft survey respondents, craft survey respondents were not completely representative of the overall craft population, and thus the results of the survey analysis associated with this group cannot be generalized; are limited to the given context; and need additional investigation in order to generalize them. Due to the limitations in the craftspeople respondents to surveys, the results of this chapter were not used in the statistical analysis in Chapter 3 nor in the fuzzy agent-based modeling in Chapter 4. Instead, field data collection was performed to collect data on motivational factors, situational/contextual factors, and crew performance metrics for all the crews involved in the project. Then the collected field data were used for the statistical analysis in Chapter 3, as well as the model development in Chapter 4.

This chapter makes three contributions: first, it provides a comprehensive set of factors affecting crew motivation and performance; second, it presents a novel methodology for identifying and measuring motivational factors at both the individual and crew levels; and third, it defines a methodology to evaluate and rank critical factors and factors with a high potential for improvement in construction crew motivation and performance and to evaluate the differences between the perspectives of supervisors and craftspeople on the identified critical factors.

In addition to the data collected through interview surveys, field data were also collected from a Canadian construction project. In the next chapter, data analysis based on the collected field data will be performed to determine the strength of the relationships between motivational factors and crew performance, and to identify factors influencing these relationships. The identified list of factors in this chapter, as well as the results of field data analysis in the next chapter, would be used in the following chapters to develop models that describe the relationship between motivational factors, crew motivation, and crew performance.

2.8. References

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Chapter 3. Key Moderators of the Relationship Between Construction Crew Motivation and Performance[1]

3.1. Introduction

Construction project performance is a function of how efficiently resources, particularly labour, are utilized. Therefore, improving crew performance will significantly enhance project performance. Both crew motivation and the situation or context in which crew tasks are performed affect crew performance. Research in this area faces two challenges. The first is how to measure the factors affecting crew performance, such as motivational and situational/contextual factors. The second is how to determine the relationships that exist between motivational factors, situational/contextual factors, and crew performance.

Construction projects are executed in a dynamic environment that is influenced by several situational/contextual factors, such as those relating to task, labour, foreman, project characteristics, management, work-setting conditions, and resources. These factors will help or hinder the effect of motivation on crew performance. Thus, it is important to take into account situational/contextual factors when studying the impact of motivation on crew performance. The

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effect of situational/contextual factors on the relationship between crew motivation and performance has not been comprehensively investigated in previous construction literature. Some researchers have investigated a limited number of situational/contextual factors when studying motivation (Cox et al. 2006; Maloney and McFillen 1987; Šajeva 2007; Siriwardana and Ruwanpura 2012; Wang et al. 2016); however, these studies were not validated with field data and did not investigate the effects of situational/contextual factors on the relationship between crew motivation and performance.

This chapter has three objectives: (1) to define a comprehensive set of crew performance metrics, including key performance indicators (KPIs) related not only to task performance (i.e., technical and job-specific performance), but also to contextual performance (i.e., discretionary and job-general performance) and counterproductive behaviour; (2) to analyze the relationship between motivational factors and crew performance to reveal how motivational factors affect crew performance metrics; and (3) to investigate situational/contextual factors and to determine which of those factors have a moderating (i.e., interacting) effect on the relationship between crew motivation and performance.

3.2. Research Methodology

In this chapter, motivational factors, their associated measures, and a comprehensive list of situational/contextual factors are identified based on past literature from both the construction and non-construction domains. A model of the relationship between motivational factors, situational/contextual factors, and crew performance is proposed, and each component of the model is described in detail. A novel, comprehensive set of construction crew performance metrics is defined, which includes KPIs related to task performance, contextual performance, and counterproductive behaviour.

Two types of interview surveys, a supervisor survey and a craft survey, were designed and administered to a construction company actively involved in industrial projects in Canada. Factor analysis was performed on the survey data to confirm the validity of the identified measures of motivational factors. The definitions of motivational factors and their associated measures as well as the results of the factor analysis are presented in this chapter. Based on the results of the factor analysis, field data were collected on crew motivational factors, situational/contextual factors, and crew performance metrics over the three-month timeline of an industrial construction project. Out of 11 crews active on the project, nine crews were working on work packages and two crews were involved in logistics and testing. All nine work package crews participated in the data collection. Crew performance metrics were collected for all nine crews and for all 79 work packages of the project. Motivational factors and situational/contextual factors were collected for all nine crews and for 17 work packages out of 79. The collected field data related to the 17 work packages were used for field data analysis because they included the full set of variables (i.e., motivational factors, situational/contextual factors, and crew performance metrics). Field data analysis was performed to investigate the relationship between crew motivational factors and crew performance and to identify key moderators of the relationship between crew motivation and performance. Both sets of analysis results are presented in this chapter. Face validation of the results of this chapter were performed with the management team of the company that participated in this study. A report of the results was sent to the company and a discussion meeting was held on the results.

3.3. Proposed Model of the Relationship Between Motivational Factors, Situational/Contextual Factors, and Crew Performance

Both motivational factors and situational/contextual factors affect crew performance. Figure 3.1 shows the proposed model of the relationship between motivational factors, situational/contextual factors, and crew performance. Motivational factors are antecedent to crew motivation. Crew motivation is the predictor variable in the model. Situational/contextual factors are potential moderators of the relationship between crew motivation and performance. Crew performance is the dependent variable in the model.

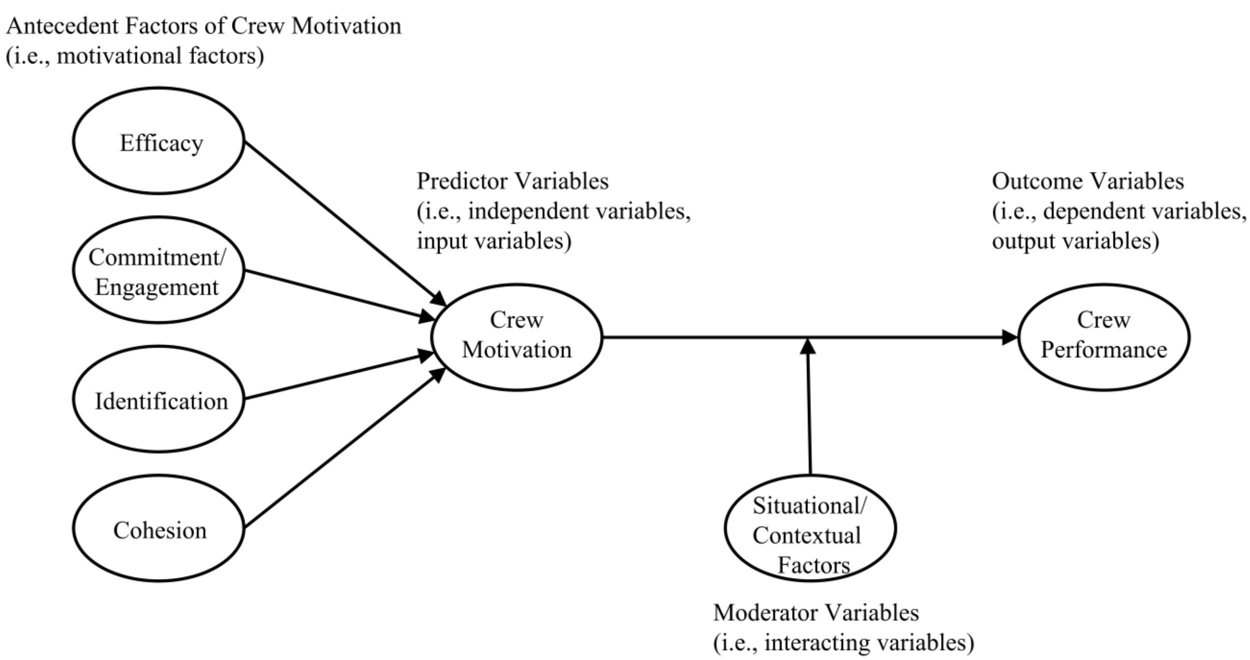

Figure 3.1. The relationship between motivational factors, situational/contextual factors, and crew performance

The motivational factors are efficacy, commitment/engagement, identification, and cohesion, each of which operates at both individual and crew levels. Situational/contextual factors are factors related to the situation or context in which the work is being performed. Crew performance metrics are divided into three categories: task performance, contextual performance, and counterproductive behaviour. The model's components are explained in detail in the following sections.

A moderator (i.e., interacting) variable is a factor that affects the strength or direction of the relationship between a predictor (i.e., an independent or input) variable and an outcome (i.e., a dependent or output) variable (Baron and Kenny 1986). In other words, a moderating effect is the interacting effect of two variables, where the effect of the predictor variable on the outcome variable depends on the level of the moderator variable (Frazier et al. 2004). Figure 3.1 shows the relationship of predictor, moderator, and outcome variables. For example, foreman leadership is a situational/contextual factor, and it has the potential to act as the moderator of the relationship between crew motivation and performance. If the moderating effect of foreman leadership exists, then we anticipate that crews supervised by foremen with better leadership skills will exhibit a stronger motivation-performance relationship. For such crews, increases in motivation lead to higher levels of crew performance compared to crews that are supervised by foremen who lack leadership skills. Therefore, it is important to investigate the moderators of the relationship between crew motivation and performance.

3.4. Defining Model Components

3.4.1. Motivational Factors

Past research on motivation has identified numerous individual-level work-motivation concepts (for a review of this research, see Diefendorff and Chandler 2011). More recent studies suggest there are some motivational concepts that influence crew motivation at both the individual and crew levels (M. Raoufi and A. Robinson Fayek "Factors affecting construction crew motivation and performance: A framework for identification and assessment," submitted, *J. Constr. Eng. Manage.,* 2017). Following a review of literature on motivation in both the construction and non-construction domains, a major gap that exists in construction research on defining factors affecting crew motivation at both the individual and crew levels identified in chapter 2. Research in the non-construction domain identified four motivational concepts that operate at both the individual and group (e.g., crew) levels: efficacy (Bandura 1977), commitment/engagement (Meyer and Allen 1991), identification (Ashforth and Mael 1989), and cohesion (Beal et al. 2003). "Efficacy" is crew members' judgments of their ability to organize and execute the courses of action required to achieve their top performance (Bandura 1977). "Commitment/engagement" is crew members' emotional attachment to and involvement in the organization and/or a course of action (Meyer and Allen 1991). "Identification" is the emotional significance that members of a given group attach to their membership in that group (Ashforth and Mael 1989). "Cohesion" is the extent to which crew members are attracted to one another, whether they feel a bond with one another, and/or whether the crew members "stick together" as a unit (Beal et al. 2003). As a single measure alone cannot perfectly represent a motivational factor, researchers suggest using at least three measures for each motivational factor (Xiong et al. 2015). For example, to measure efficacy at the crew level (a motivational factor), three measures: “crew confidence in ability to perform tasks effectively,” “crew confidence in ability to perform difficult tasks,” and “crew ability to concentrate on performing tasks” have been identified and suggested to be used in this research (see chapter 2). In this research, for each of the motivational factors shown in Figure 3.1, at least three motivational measures are identified based on past research (see chapter 2). Seventeen motivational measures are identified for motivational factors at the individual level and 16 motivational measures are identified for motivational factors at the crew level (see Tables 3.6 and 3.7 in the following sections for the list of identified motivational measures).

Motivational factors and measures were gathered using surveys and during field data collection. The sources of data were two surveys, supervisor and craft surveys, and interviews with foremen and crew members during field data collection. In the surveys, crew members evaluated both the individual-level motivational factors and crew-level motivational factors, and the supervisor of the responding crew evaluated the crew-level motivational factors. Factor analysis was performed on the survey data to check the validity and reliability of the motivational measures. For each motivational factor (i.e., efficacy, commitment/engagement, identification, and cohesion), several measures were identified from past literature. Factor analysis assesses the variations between the identified motivational measures and the motivational factors to check if the identified motivational measures for each motivational factor are representative of that motivational factor.

Following factor analysis, field data were collected. For each day of field data collection, project staff sent the daily plan to the data collector. Based on the daily plan, the data collector randomly selected the crews to be studied from the available crews working that day. For each selected crew, randomly selected members performed a self-evaluation on their individual-level motivational factors. The supervisor of the responding crew evaluated the crew-level motivational factors. For each crew, supervisor evaluation was performed by the foreman of that crew who works closely and constantly in the field with the crew members. The crews in construction consist of several workers and one foreman, all of whom work with each other in the construction field and have constant communication with each other. The results of the survey analysis, which included both foreman and crew members, in evaluating crew-level motivational factors were consistent between the two evaluation sources (crew members and foremen).Thus, in the field self-evaluation was used to determine the values of individual-level motivational factors while supervisor evaluation was used to determine the values of crew-level motivational factors.

3.4.2. Situational/Contextual Factors

Situational/contextual factors might affect the relationship between crew motivation and performance. Therefore, in addition to motivational factors, it is important to take into account situational/contextual factors when studying the impact of motivation on crew performance. On construction projects, for example, situational/contextual factors can be task-related (e.g. task design), labour-related (e.g., the functional skills of the crew), foreman-related (e.g., leadership skills), project characteristics (e.g., work shifts), management-related (e.g., project management practices), work-setting conditions (e.g., weather conditions), and resources (e.g., tools, equipment, material) (AbouRizk et al. 2001; Dai et al. 2009; Fayek and Oduba 2005; Goddard et al. 2004; Knight and Fayek 2000; Liberda et al. 2003; Tsehayae and Fayek 2014). In this research, a total of 129 situational/contextual factors in eight categories are identified (see chapter 2 for the full list of factors). Three categories of situational/contextual factors are at the crew level (i.e., task-related, labour-related, and foreman-related) and five categories of situational/contextual factors are at the project level (i.e., project characteristics, management-related, work-setting conditions, resources, and safety).

Situational/contextual factors from all categories were collected in the field for each participating crew on each day of field data collection. The sources of data collection for situational/contextual factors were interviews with project personnel, including crew members, foremen, field supervisors, and project managers; observations by data collectors on the work packages of the project; project databases and documents such as project safety logs; and external sources such as government databases (e.g., databases for weather data). Table 3.1 shows a sample data collection form for situational/contextual factors.

Table 3.1. Situational/contextual factors: task-related

Situational/contextual factors	Scale of measure	Sub-factors	Range of values
Task type	Categorical		1. Civil 2. Mechanical 3. Electrical 4. Instrumentation
Task size	Real number (Quantity)		$\mathbb{R}^+$
Task complexity	Five-point rating scale	• Number of subtasks • Number of alternatives to do the task • Unknown means	(1) Very low to (5) Very high
Task repetition	Percentage (% of identical tasks in work package over total tasks in work package)		[0%, 100%]
Task interruption and disruption	Integer (Number of interruption and disruption events per day)		$\mathbb{Z}^+$

As the situational/contextual factors collected from one company some of the project-level situational contextual factors did not show variability among the collected data. Thus there is a need for define context variables of this research to be able to investigate those variables in future research. Context is defined as what constrains the main elements of a model without explicitly intervening in the model development process (Bazire and Brézillon 2005). Fayek and Oduba (2005) defined context as a set of factors whose values are fixed in a project scenario. They defined the context variables at the project-level as: project location, year of construction, client, contract type, project type, and season of construction. They also identified the context variables at the activity-level as: type of material and type of welds (for welding activities). In this research context attributes have been generated using the 5W1H questions approach: Who? What? Where? When? Why? and How? (Jang and Woo 2003). This research follows the 5W1H method used by Tsehayae and Fayek (2016a) in defining context variables. From the list of 129 situational/contextual factors in this research, the static factors that provided the best answers to the who, what, where, when, why, and how questions were identified and mapped to the 5W context attributes. Table 3.2 shows the list of context variables of this research.

Table 3.2. Context variables of the research

	Context Variable
Who	**Project engineering** (response to inquiries)
What	**Rework (**rework type, rework source); **Project properties** (project type, project size)
Where	**Project properties (**project location); **Work/job conditions (**working shifts, camp, work permits); **Project engineering (d**rawings availability, specifications availability, frequency of revisions); **Site general facilities (**Office, lunch rooms); **Working area conditions** (work site coverage, working area ventilation/air conditioning, access points)
When	**Project properties (**project duration)
Why	**-**
How	**Project and construction management practices (**project integration management, project scope management, project human resource management, project procurement management**,** project financial management, project claim management); **Safety precautions** (safety meetings, protective safety gear)

3.4.3. Crew Performance Metrics

Construction projects have traditionally been evaluated in terms of time, cost, and quality (Kagioglou et al. 2001). However, these categories of performance measures have been shown to be insufficient (Ward et al. 1991). Past research has demonstrated that other performance measures, such as productivity, are also related to the success of a project (Tsehayae and Fayek 2016b). However, there are other performance measures that impact project success, such as the quality of the relationships between crew members on a project (Bassioni et al. 2004). Other aspects of performance, such as contextual performance and counterproductive behaviour, are important for defining the performance metrics of a construction crew, as they are at the discretion of workers and are thus more likely to be affected by workers' motivation. In this study, a broader perspective on crew performance is employed by taking into consideration more generic models of performance developed outside the construction literature. For example, many of these generic models supplement a narrow "technical-task" perspective of performance with behaviours that support technical activities and contribute to overall effectiveness (e.g., helping others, working with enthusiasm, not engaging in counterproductive behaviour). In his seminal paper, Campbell (1990) proposed that the performance domain for any job involves some or all of eight generic dimensions: job-specific technical task proficiency, non-job-specific task proficiency, communication proficiency, demonstrating effort, maintaining personal discipline, facilitating peer and team performance, supervision, and management. While the first six dimensions tend to characterize all jobs, the latter two dimensions tend to be emphasized in jobs with leadership or management duties. Borman and Motowidlo (1997) proposed a model of performance that made a distinction between behaviours that were technical and job-specific in nature (i.e., task performance), and those that tended to be discretionary and job-general (i.e., contextual performance). Contextual performance includes behaviours that affect the social context in which the technical activities occur (also referred to by Organ [1988] as organizational citizenship behaviour). The notion of contextual performance (e.g., helping, compliance) is particularly relevant for construction contexts given the interdependent nature of the work (e.g., crew members persisting to complete technical tasks, volunteering, helping and cooperating with other crew members, following procedures and rules, and supporting crew objectives).

In this research, the following crew performance metrics were identified: task performance, contextual performance, and counterproductive behaviour. Task performance consists of seven categories: cost performance, schedule performance, change performance, quality performance, safety performance, productivity performance, and satisfaction performance. Contextual performance consists of three categories: personal support, organizational support, and conscientious initiative. Counterproductive behaviour consists of two categories: interpersonal deviance and organizational deviance. Each category of crew performance metrics has several KPIs. A total of 12 different crew performance metrics categories, consisting of 55 KPIs, have been identified from previous research (Bennett and Robinson 2000; Borman et al. 2001; Chan and Chan 2004; Gruys and Sackett 2003; Omar and Fayek 2016; Organ 1988; Podgórski 2015; Rankin et al. 2008; Wildman et al. 2011). Table 3.3 shows the identified crew performance metrics categories and the KPIs in each category. Crew performance data were collected for all crews and for all work packages. For task performance, actual project documents (e.g., time sheets, score cards, safety logs, change order logs, inspection test plans, schedule updates, tender documents, and cost estimates) were used to extract available crew performance data. Then, KPIs related to task performance were calculated for all crews. Table 3.4 shows a sample of some KPIs in the cost performance category. For KPIs related to contextual performance and counterproductive behaviour, multiple-source data collection was utilized, which accounts for both self-evaluation and supervisor evaluation. For each participating crew, self-evaluation forms for contextual performance and counterproductive behaviour were completed by crew members. The mean of the crew members' self-evaluations is equal to the crew members' overall evaluation of crew contextual performance and counterproductive behaviour. For the same crew, supervisor evaluation forms were completed by the foreman to evaluate crew contextual performance and counterproductive behaviour. Following data collection, the mean of the crew members' overall evaluation and the foreman evaluation was calculated. In calculating each KPI for the two crew performance categories (i.e., contextual performance and counterproductive behaviour), equal weight was assumed for the crew members' overall evaluation and for the foreman evaluation.

Table 3.3. Crew performance metrics and KPIs: Fayek and Raoufi taxonomy

Crew performance metrics	Crew performance metrics category	No. of KPIs	KPIs
Task performance	Cost performance indicators	8	Work package cost growth, work package budget factor, work package indirect cost factor, work package direct cost factor, work package cost predictability, work package net variation over final cost, cost per unit at completion, cost for defects warranty
	Schedule performance indicators	5	Work package schedule factor, work package schedule growth, time predictability (work package), time variance (work package), time per unit at completion
	Change performance indicators	6	Total change cost factor, cost for change demand, cost for change supply, time for defects warranty, time for change demand, time for change supply
	Quality performance indicators	4	Work package rework cost factor, work package rework time factor, work package rework index, quality issues-available for use
	Safety performance indicators	5	Lost time rate, lost time frequency, reported incidents rate, first aid frequency rate, near miss incident frequency rate
	Productivity performance indicators	5	Work package productivity factor (physical work), work package productivity factor (cost), work package productivity index, work package absenteeism rate, work package productivity factor (pf)
	Satisfaction performance indicators	1	Overall performance satisfaction
Contextual performance	Personal support	4	Helping, cooperating, courtesy, motivating
	Organizational support	3	Representing, loyalty, compliance
	Conscientious initiative	3	Persistence, initiative, self-development
Counterproductive behaviour	Interpersonal deviance	4	Inappropriate verbal actions, unsafe behaviour, inappropriate physical actions, alcohol consumption or drug use
	Organizational deviance	7	Poor attendance, misuse of time, misuse of resources, misuse of information, poor quality work, destruction of property, theft and related behaviour
	Total	55	

Table 3.4. Task performance: cost performance indicators

KPI No.	KPI name	KPI definition	KPI formula	KPI threshold
1.1.1	Work package cost growth	The variance between the actual total work package cost and total work package estimated cost at tender stage, expressed as a ratio of total work package estimated cost at tender stage	$\frac{(actual\ total\ work\ package\ cost - total\ work\ package\ estimated\ cost\ at\ tender\ stage)}{total\ work\ package\ estimated\ cost\ at\ tender\ stage}$	<0 Desirable Value =0 Planned Value >0 Undesirable Value
1.1.5	Work package cost predictability	The variance between the actual total work package cost and total work package estimated cost at tender stage, expressed as a percentage of the actual total work package cost.	$\frac{(actual\ total\ work\ package\ cost - total\ work\ package\ estimated\ cost\ at\ tender\ stage)}{actual\ total\ work\ package\ cost} \times 100$	<0% Desirable Value =0% Planned Value >0% Undesirable Value
1.1.6	Work package net variation over final cost	The ratio between the net value of variations in work package cost based on original work package scope and the total work package estimated cost at tender stage, expressed as a percentage.	$\frac{net\ value\ of\ variations\ in\ work\ package\ cost}{total\ work\ package\ estimated\ cost\ at\ tender\ stage} \times 100$	=0% Desirable Value >0% Undesirable Value

3.5. Factor Analysis of Motivational Factors at the Individual and Crew Levels

Two types of interview surveys, a supervisor survey and a craft survey, were administered to collect data on the factors affecting crew motivation and performance. Factor analysis was performed for all motivational factors at both the individual and crew levels as well as for their associated measures to check the validity of the identified measures for each factor. Construct validity (i.e., the validity of the measures of a factor) is necessary for reliable theory development (Xiong et al. 2015). Construct validity not only reveals whether the measures within a construct are consistent in measuring the same thing, but it also reveals whether the measures of a construct are distinct from the measures of different constructs (Bagozzi and Yi 2012). There are two common tests for construct validity: convergent validity and discriminant validity. Convergent validity assesses whether the measures of a factor are a good representation of that factor by testing the degree of positive correlation of one measure with other measures within the same factor. Discriminant validity tests whether a factor is truly different from other factors (Xiong et al. 2015). A very common method of testing construct validity, both convergent validity and discriminant validity, is confirmatory factor analysis (CFA). CFA measures the consistency between the measures of a factor and the factor they are measuring, as well as the distinction of the measures of a factor with the measures of other factors.

In this research, CFA is performed to check if the identified motivational measures are valid for measuring the motivational factors they represent. IBM SPSS AMOS® was used to perform CFA. Figure 3.2 shows a sample of CFA for the 4-factor measurement model.

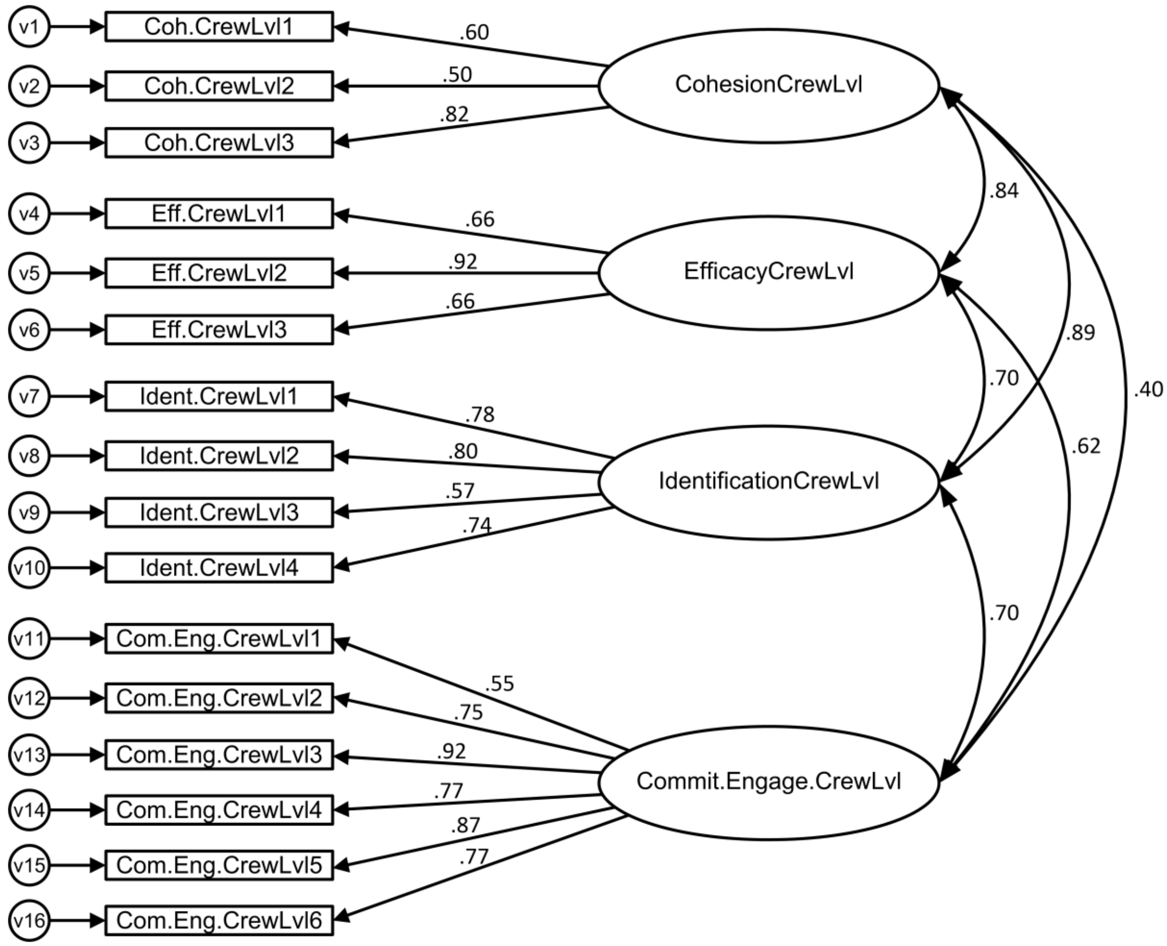

Figure 3.2. Confirmatory factor analysis results (4-factor measurement model)

To assess whether the 4-factor model is the best fit, three measurement models were evaluated using confirmatory factor analysis. The three measurement models are: (1) null model, where all measures are loaded on their own factor; (2) 1-factor model, where all measures are loaded on a single factor; and (3) 4-factor model (as shown in Figure 3.2), where three measures of cohesion are loaded on a factor, three measures of efficacy are loaded on a factor, four measures of identification are loaded on a factor, and six measures of commitment/engagement are loaded on a factor. The fit of each of the three models (null model, 1-factor model, and 4-factor model) was assessed using the comparative fit index (CFI), the incremental fit index (IFI), and the root mean square error of approximation (RMSEA). CFI and IFI fall between 0 and 1, where higher values of CFI and IFI indicate a better fit. For RMSEA, lower values indicate a better fit. Fit indices for the three models are provided in Table 3.5. As shown in Table 3.5, CFI and IFI related to the 4-factor model are higher than CFI and IFI of 1-factor model, indicating that the 4-factor model is a better fit relative to the other measurement models tested. RMSEA for the 4-factor model is also smaller than that of both the 1-factor and null models, indicating that 4-factor model is a better fit relative to the other measurement models tested.

Table 3.5. Goodness of fit indices for confirmatory factor analysis

Model	Model Fit Statistics		
	CFI	IFI	RMSEA
Null model	—	—	0.249
1-factor model	0.673	0.703	0.163
4-factor model	0.873	0.887	0.105

The results of factor loading (i.e., the amount of contribution of each measure to its corresponding factor) of the 4-factor model are presented in Tables 3.6 and 3.7.

Table 3.6. Factor analysis of motivational factors at the crew level

Measure ID	Motivational measures at the crew-level	Standardized factor loadings			
		Factor 1: Efficacy	Factor 2: Commitment/ engagement	Factor 3: Identification	Factor 4: Cohesion
Efficacy 1	Crew confidence in ability to perform tasks effectively	0.662	—	—	—
Efficacy 2	Crew confidence in ability to perform difficult tasks	0.918	—	—	—
Efficacy 3	Crew ability to concentrate on performing tasks	0.664	—	—	—
Commit./Engage. 1	Crew members are very happy to spend rest of career with the organization	—	0.546	—	—
Commit./Engage. 2	Crew members see the organization's problems as own	—	0.748	—	—
Commit./Engage. 3	Crew's sense of "belonging" to the organization	—	0.919	—	—
Commit./Engage. 4	Crew's emotional attachment to the organization	—	0.772	—	—
Commit./Engage. 5	Crew members feel like "part of the family" at the organization	—	0.869	—	—
Commit./Engage. 6	The organization has personal meaning to the crew	—	0.772	—	—
Identification 1	Crew members feel proud to be part of the crew	—	—	0.785	—
Identification 2	Crew members' identification with the other members of the crew	—	—	0.798	—
Identification 3	Crew members would like to continue working with the crew	—	—	0.571	—
Identification 4	Crew members' emotional attachment to the crew	—	—	0.739	—
Cohesion 1	Crew members get along well together	—	—	—	0.596
Cohesion 2	Defending each other from criticism	—	—	—	0.500
Cohesion 3	Crew members are close	—	—	—	0.824

Table 3.7. Factor analysis of motivational factors at the individual level

Measure ID	Motivational measures at the individual-level	Standardized factor loadings			
		Factor 1: Efficacy	Factor 2: Commitment/ engagement	Factor 3: Identification	Factor 4: Cohesion
Efficacy 1	Self-confidence in ability to perform tasks effectively	0.754	—	—	—
Efficacy 2	Self-confidence in ability to perform difficult tasks	0.938	—	—	—
Efficacy 3	Ability to concentrate on performing tasks	0.603	—	—	—
Commit./Engage. 1	Seeing the organization's problems as own	—	0.580	—	—
Commit./Engage. 2	Sense of "belonging" to the organization	—	0.639	—	—
Commit./Engage. 3	Emotional attachment to the organization	—	0.935	—	—
Commit./Engage. 4	Feeling like "part of the family" at the organization	—	0.690	—	—
Commit./Engage. 5	The organization has personal meaning	—	0.965	—	—
Identification 1	Feeling proud to be part of the crew	—	—	0.892	—
Identification 2	Identification with the other members of the crew	—	—	0.836	—
Identification 3	Would like to continue working with the crew	—	—	0.780	—
Identification 4	Emotional attachment to the crew	—	—	0.944	—
Cohesion 1	Choose to stay in the crew	—	—	—	0.636
Cohesion 2	Feel like a part of the crew	—	—	—	0.838
Cohesion 3	Like to be with crew members	—	—	—	0.790
Cohesion 4	Get along with other crew members	—	—	—	0.669
Cohesion 5	Enjoy belonging to the crew	—	—	—	0.901

Researchers suggest that measures with a standardized factor loading of less than 0.5 be deleted (Xiong et al. 2014). The results of the FA suggest a satisfactory construct validity (convergent and discriminant validity). Each factor is loaded just on its own measures (e.g., efficacy is loaded on efficacy measures), and no standardized factor loadings are less than 0.5, indicating a convergent validity. No factor is loaded on the measures of other factors (e.g., efficacy is not loaded on any commitment/engagement measures, identification measures, or cohesion measures), indicating a discriminant validity. After performing FA, the results, such as the loadings shown in Tables 3.6 and 3.7, are used to perform reliability tests to check the reliability of the identified measures of motivational factors. Composite reliability (*CR*) is calculated for each motivational factor using Equation 3.1 (Raykov 1997; Xiong et al. 2015).

$$CR_i = \frac{\left(\sum_{k=1}^{n_i} L_{ik}\right)^2}{\left(\sum_{k=1}^{n_i} L_{ik}\right)^2 + \left(\sum_{k=1}^{n_i} er_{ik}\right)}, \tag{3.1}$$

where i refers to factor i; k refers to measure k; n_i is the number of measures for factor i; L_{ik} refers to the factor loading of measure k of factor i; and er_{ik} refers to the error variance of measure k of factor i. The rule of thumb for reliability in the identified measures of a factor is that a *CR* of 0.7 or higher suggests a satisfactory reliability (Bagozzi and Yi 2012). The calculated *CRs* were as follows: efficacy–individual level was 0.99, commitment/engagement–individual level was 0.76, identification–individual level was 0.93, cohesion–individual level was 0.90, efficacy–crew level was 0.87, commitment/engagement–crew level was 0.83, identification–crew level was 0.81, and cohesion–crew level was 0.72. These results indicate a satisfactory reliability in the identified measures of the motivational factors.

Factor loadings are used to calculate the weighted score of each factor (Wang et al. 2016). In this chapter, the weight (w_{ij}) of each motivational measure for a given motivational factor is computed using Equation 3.2.

$$w_{ij} = \frac{L_{ij}}{\sum_{k=1}^{n_i} L_{ik}}, \tag{3.2}$$

where i refers to factor i; j refers to measure j; n_i is the number of measures for factor i; L_{ik} refers to factor loading of measure k of factor i; and L_{ij} refers to the factor loading of measure j of factor i. For example, using Equation 3.2, the calculated matrix of weights for factor 1 (i.e., efficacy at the crew level) are shown in Equation 3.3.

$$W_1 = [w_{11} \quad w_{12} \quad w_{13}] = [0.295 \quad 0.409 \quad 0.296] \tag{3.3}$$

Next, the weighted score (WS) of each motivational factor i is computed using Equation 3.4.

$$WS_i = \sum_{j=1}^{n_i} w_{ij}.R_j, \tag{3.4}$$

where w_{ij} is the weight of measure j in calculating the weighted score of factor i; R_j is the mean rating value of measure j; and n_i is the number of measures for factor i. For example, using Equation 3.3 for the weights of factor 1 (i.e., efficacy at the crew level) and considering mean rating values of 6.51, 6.49, and 6.32 on a 1 to 7 rating scale for the rating of the existence of each identified efficacy measure, the weighted score of factor 1 is calculated as shown in Equation 3.5.

$$WS_{\text{Efficacy-Crew Lvl}} = [w_{11} \quad w_{12} \quad w_{13}].\begin{bmatrix} R_1 \\ R_2 \\ R_3 \end{bmatrix} = [0.295 \quad 0.409 \quad 0.296].\begin{bmatrix} 6.51 \\ 6.49 \\ 6.32 \end{bmatrix} = 6.45 \tag{3.5}$$

Following factor analysis on the survey data and after the confirmation of the validity and reliability of the measures of motivational factors, field data collection forms were designed using the validated measures. Field data collection was performed to collect crew motivational factors, situational/contextual factors, and crew performance metrics in an actual project setting. For each day of field data collection, project staff sent the daily plan to the data collector. Based on the daily plan, the data collector randomly selected the crews to be studied from the available crews working that day. For each selected crew, randomly selected members of the crew performed a self-evaluation and the supervisor of the crew performed a supervisor evaluation. Self-evaluation is used to determine the values of individual-level motivational factors, while both self-evaluation and supervisor evaluation are used to determine the values of crew-level motivational factors. Each motivational factor was evaluated on a 1 to 5 rating scale for each crew on the project. To produce consistent evaluations among different supervisors, the validated measures of each motivational factor, based on the results of the performed factor analysis, were included in the field data collection forms. For example, to measure efficacy at the crew level, three identified and validated measures, "crew confidence in ability to perform tasks effectively," "crew confidence in ability to perform difficult tasks," and "crew ability to concentrate on performing tasks," were added to the field data collection form as sub-factors of efficacy. Then, the respondents rated efficacy from 1 (least desirable) to 5 (most desirable) with respect to the provided measures in the field data collection form. Based on the collected data, individual-level and crew-level motivational factors were calculated for each crew. The mean values of the motivational factors for all participating crews are shown in Figure 3.2. The values in Figure 3.2 are on a scale of 1 to 5, with 1 representing the least desirable value and 5 representing the most desirable value.

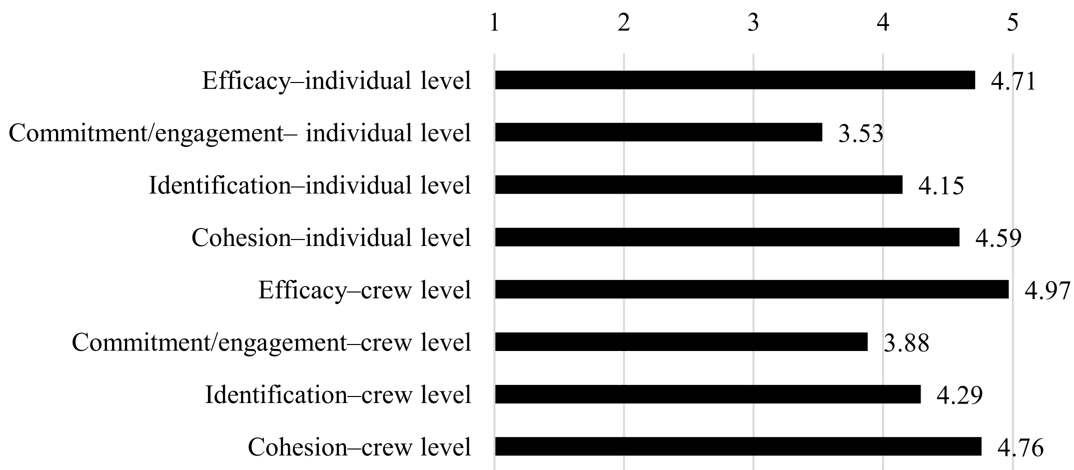

Figure 3.3. Mean values of motivational factors (1–5 rating scale)

The results in Figure 3.2 indicate that the most satisfied motivational factor (i.e., the factor closest to the most desirable value) among participating crew was crew efficacy at the crew level and crew cohesion at the crew level. The least satisfied motivational factor (i.e., the factor farthest from the most desirable value) was commitment/engagement at the individual level. Moreover, the values related to crew-level assessments of motivational factors were higher than the values of individual-level assessments of motivational factors. These findings are in agreement with the results of other studies in non-construction fields, which indicate that when working in a group (e.g., a crew), the overall motivation of the group (i.e., crew-level motivation) is greater than the motivation of its individual members (i.e., the mean value of the individual-level motivation of crew members). This phenomenon may be attributed to the interactions of individuals within the crew. Therefore, policies that promote interactions among crew members (e.g., more interactive site orientations, safety meetings, or daily meetings) may help improve crew motivation.

3.6. Relationship Between Motivational Factors and Crew Performance

Correlation analysis was performed to assess the relationship between motivational factors and crew performance metrics. Pearson correlation analysis is the most common technique for correlation analysis (Bobko 2001). The Pearson correlation coefficient (*r*) is used in correlation analysis to measure the relationship between independent variables (e.g., motivational factors) and dependent variables (e.g., crew performance metrics). The Pearson correlation coefficient determines two characteristics of the relationships between two variables: the direction of the relationship and the strength of the relationship. The direction of the relationship between two variables can be positive or negative. A positive relationship shows that the two variables change in the same direction (i.e., increasing simultaneously or decreasing simultaneously), while a negative relationship shows that the two variables change in opposite directions (i.e., if one variable increases the other variable will decrease). The magnitude of the relationship between the two variables is determined by the value of the Pearson correlation coefficient. The Pearson correlation coefficient varies between -1 and 1. Based on the value of the Pearson correlation coefficient, the magnitude of the relationship between a pair of variables may fall into one of four categories: no correlation for $r < 0.1$, weak correlation for $0.1 \leq r < 0.3$, moderate correlation for $0.3 \leq r < 0.5$, and strong correlation for $r \geq 0.5$ (Cohen et al. 2013).

To calculate crew performance metrics for correlation analysis, each crew performance metric (i.e., task performance, contextual performance, or counterproductive behaviour) is calculated based on the mean of its metrics categories. For example, task performance is calculated as the mean of the following metrics categories: cost performance, schedule performance, change performance, quality performance, safety performance, productivity performance, and satisfaction performance. This approach ensures equal weighting between task performance categories and ensures that the difference in the number of identified KPIs in each task performance category does not affect the mean task performance. Since each metrics category has different KPIs with different ranges of values, the KPIs in that category are first normalized by dividing each KPI by its maximum value, to achieve a value between 0 (undesirable value) and 1 (desirable value). For example, for the KPIs that are evaluated on a 1 to 7 rating scale, the maximum value is 7. For KPIs that are evaluated using mathematical formulations (i.e., KPIs in the task performance category), the maximum value is the maximum of that KPI for all 79 work packages. Then, the mean of the normalized KPIs is calculated for each crew performance metrics category. For example, the crew performance metrics category of schedule performance is calculated based on the mean of the following normalized values: work package schedule factor, work package schedule growth, time predictability (work package), time variance (work package), and time per unit at completion. The results of the correlation analysis between motivational factors and crew performance metrics are presented in Table 3.8, including the means, standard deviations, and intercorrelations among variables.

Table 3.8. Correlation analysis of motivational factors with crew performance metrics

Variables	Mean	Standard deviation	1	2	3	4	5	6	7	8	9	10	11	12
1. Efficacy–individual level	4.706	0.398	1.000											
2. Commitment/engagement–individual level	3.529	0.800	0.127	1.000										
3. Identification–individual level	4.147	0.786	0.647[b]	0.266	1.000									
4. Cohesion–individual level	4.588	0.404	0.463	0.668[b]	0.546[a]	1.000								
5. Efficacy–crew level	4.971	0.121	0.457	0.493[a]	0.048	0.375	1.000							
6. Commitment/engagement–crew level	3.882	0.485	0.457	0.573[a]	0.376	0.375	0.469	1.000						
7. Identification–crew level	4.294	0.751	0.465	0.453	0.610[b]	0.372	0.444	0.701[b]	1.000					
8. Cohesion–crew level	4.765	0.400	0.225	0.707[b]	0.316	0.619[b]	0.493[a]	0.654[b]	0.557[a]	1.000				
9. Crew motivation	4.360	0.386	0.620[b]	0.742[b]	0.729[b]	0.748[b]	0.533[a]	0.784[b]	0.825[b]	0.761[b]	1.000			
10. Task performance	0.828	0.027	0.127	0.143	0.116	0.135	0.166	0.221	0.124	0.167	0.194	1.000		
11. Contextual performance	0.770	0.062	0.469	0.415	0.326	0.540[a]	0.497[a]	0.497[a]	0.434	0.317	0.566[a]	-0.222	1.000	
12. Counterproductive behaviour	0.200	0.074	-0.410	-0.744[b]	-0.309	-0.572[a]	-0.674[b]	-0.674[b]	-0.570[a]	-0.750[b]	-0.768[b]	-0.031	-0.671[b]	1.000

[a] Correlation is significant at $p<0.05$.

[b] Correlation is significant at $p<0.01$.

The means and standard deviations for motivational factors are calculated based on the collected field data. The results shown in Table 3.8 indicate that all motivational factors have a weak positive relationship ($0.1 \leq r < 0.3$) with task performance, a moderate ($0.3 \leq r < 0.5$) to strong ($r \geq 0.5$) positive relationship with contextual performance, and a moderate ($-0.5 \leq r < -0.3$) to strong ($r \leq -0.5$) negative relationship with counterproductive behaviour. For each pair of variables, in addition to the correlation coefficient, the significance of the relationship between the two variables is tested and the *p*-values are calculated. Table 3.8 shows which relationships are significant at $p<0.01$ and $p<0.05$. Cohesion–individual level (r=0.540, p=0.025), efficacy–crew level (r=0.497, p=0.042) and commitment/engagement–crew level (r=0.497, p=0.042) have a significant relationship ($p<0.05$) with contextual performance. Cohesion–individual level (r=-0.572, p=0.016) and identification–crew level (r=-0.570, p=0.017) have a significant relationship ($p<0.05$) with counterproductive behaviour. Commitment/engagement–individual level (r=-0.744, p=0.001), efficacy–crew level (r=-0.674, p=0.003), commitment/engagement–crew level (r=-0.674, p=0.003), and cohesion–crew level (r=-0.750, p=0.001) have a significant relationship ($p<0.01$) with counterproductive behaviour. These findings indicate that increases in cohesion at the individual level and/or efficacy and/or commitment/engagement at the crew level improve crew contextual performance. Increases in efficacy and/or cohesion at the individual level and/or increases in any/all motivational factors at the crew level reduce crew counterproductive behaviour. The results also show a weak positive correlation between motivational factors and task performance, but the correlations are not significant (i.e., there is not enough evidence that motivational factors and task performance are correlated).

As shown in Table 3.8, the correlations of crew-level motivational factors with crew performance metrics are higher than those of individual-level motivational factors with crew performance metrics, indicating that the interactions of individuals with each other in a crew have a greater impact on crew motivation than any one individual. The results of the correlation analysis on the collected field data confirm the findings based on the factor analysis of the survey data that has previously been discussed.

Crew performance is calculated as the mean of the crew performance metrics (i.e., task performance, contextual performance, or counterproductive behaviour). Table 3.9 shows the correlation between motivational factors and crew performance. The results indicate that almost all motivational factors (except identification–individual level) have a strong positive relationship ($r \geq 0.5$) with crew performance. The strongest relationship is related to commitment/engagement (r=0.694 at the crew level and r=0.678 at the individual level), followed by cohesion (r=0.638 at the crew level and r=0.636 at the individual level), and then efficacy (r=0.682 at the crew level and r=0.503 at the individual level). The weakest relationship was observed for identification (r=0.580 at the crew level and r=0.370 at the individual level). The significance of the relationship between variables was tested and the p-values calculated; the results suggest there is a significant relationship between almost all the motivational factors (except identification–individual level) and crew performance ($p<0.05$ for efficacy–individual level and identification–crew level, $p<0.01$ for commitment/engagement–individual level, cohesion–individual level, efficacy–crew level, commitment/engagement–crew level, and cohesion–crew level).

Table 3.9. Correlation analysis of motivational factors with crew performance

Variables	Correlation (r) to crew performance	p-value
1. Efficacy–individual level	0.503[a]	0.040
2. Commitment/engagement–individual level	0.678[b]	0.003
3. Identification–individual level	0.370	0.144
4. Cohesion–individual level	0.636[b]	0.006
5. Efficacy–crew level	0.682[b]	0.003
6. Commitment/engagement–crew level	0.694[b]	0.002
7. Identification–crew level	0.580[a]	0.015
8. Cohesion–crew level	0.638[b]	0.006

[a] Correlation is significant at $p<0.05$.

[b] Correlation is significant at $p<0.01$.

3.7. Identifying Key Moderators of the Relationship Between Crew Motivation and Performance

Situational/contextual factors have the potential to act as moderators of the relationship between crew motivation and performance. However, not all situational/contextual factors are moderators of this relationship; therefore, it is important to identify which situational/contextual factors act as moderators of the relationship between crew motivation and performance. Statistical analysis (i.e., hierarchical multiple regression) was conducted on the field data to test the moderating effect of each of the 129 identified situational/contextual factors on the relationship between crew motivation and performance. Hierarchical multiple regression is commonly used to test moderating effects for both categorical and numerical data (Cohen et al. 2013; Frazier et al. 2004).

IBM SPSS Statistics was used to perform hierarchical regression analysis. To illustrate the analysis, a sample is given of hierarchical regression analysis for investigating the moderating effect of one of the situational/contextual variables (i.e., congestion) on the relationship between crew motivation and performance. Crew motivation is the predictor variable and is calculated as the mean of motivational factors, congestion is the possible moderator variable and is a situational factor, and crew performance is the outcome variable (see Figure 3.1). First, the predictor variable (i.e., crew motivation) and the moderator variable (i.e., congestion) are standardized. Standardization of a variable involves transforming that variable into another variable (called a *z*-scored variable) so that it has a mean of 0 and a standard deviation of 1. Both *z*-scored crew motivation and *z*-scored congestion are calculated. Second, the interaction term, which is the product of the *z*-scored predictor and the *z*-scored moderator, is calculated. The interaction term between crew motivation and congestion is calculated as *z*-scored crew motivation multiplied by *z*-scored congestion. Finally, two regression models are tested. The first model considers crew motivation and congestion as predictors of crew performance. The second model considers crew motivation, congestion, and the interaction term as predictors of crew performance. The moderating effect of congestion on the relationship between crew motivation and performance exists if there are two conditions. First, there must be a significant relationship between the interaction term (crew motivation × congestion) and crew performance. Second, the R^2 of the second model (i.e., the model with the interaction term) must be higher than the R^2 of the first model (i.e., the model without the interaction term). The results of the hierarchical multiple regression analysis are provided in Table 3.10.

Table 3.10. Results of hierarchical multiple regression on the moderating effect of congestion on the relationship between crew motivation and performance

Model No.	Model variables	Unstandardized regression coefficients		Standardized regression coefficients	Significance	Correlation to crew performance	Model fit
		B	Std. Error	*β*	*p*-value	*r*	R^2
1	Crew motivation (*z* score)	0.019	0.005	0.46	0.002	0.78[b]	0.83
	Congestion (*z* score)	-0.025	0.005	-0.59	0.000	-0.84[b]	
2	Crew motivation (*z* score)	0.010	0.004	0.23	0.021	0.78[a]	0.94
	Congestion (*z* score)	-0.021	0.003	-0.51	0.000	-0.84[b]	
	Crew motivation × congestion (*z* score)	0.012	0.003	0.42	0.000	0.82[b]	

[a] Correlation is significant at $p<0.05$.

[b] Correlation is significant at $p<0.01$.

In Table 3.10, *B* is the unstandardized regression coefficient and *β* is the standardized regression coefficient. *β* is the regression coefficient that is standardized so that the predictor variable (i.e., crew motivation), the moderator variable (i.e., congestion), and the outcome variable (i.e., crew performance) have variances of 1. Standardization of regression coefficients helps with the comparison of regression coefficients of variables that have different ranges (i.e., comparing the effects of different moderators). Standard error is the error associated with the calculated *B*. The *p*-value is the significance associated with the regression coefficients (either B or *β*). The *r* is the correlation coefficient of each variable to crew performance. The R^2 is the coefficient of determination representing the fit of each regression model. The adjusted R^2, a modified version of R^2 that considers the number of variables in the model, is used in this chapter.

The unstandardized regression coefficient for crew motivation is 0.019 ($p<0.01$), indicating that there is a significant positive relationship between crew motivation and performance. The unstandardized regression coefficient for congestion is -0.025 ($p<0.01$), meaning that there is a significant negative relationship between congestion and crew performance. The unstandardized regression coefficient for the interaction term (i.e., crew motivation × congestion) is 0.012 (p<0.01), indicating that there is a significant positive relationship between the interaction term and crew performance. The R^2 for the first model (the model without the interaction term) is 0.83, and the R^2 for the second model (the model with the interaction term) is 0.94. Therefore, the R^2 change (ΔR^2) associated with the interaction term is 11%. ΔR^2 indicates the amount of additional variance in crew performance explained by the interaction term over the variance explained by the effects of crew motivation and congestion alone. In other words, ΔR^2 indicates the goodness of fit of the model with the interaction term compared to the model without the interaction term. The interaction between congestion and crew motivation explains an additional 11% of the variance in crew performance over the variance explained by the effects of crew motivation and congestion alone. This means that congestion moderated the effect of crew motivation on crew performance.

To better illustrate the moderating effect, a common practice suggested by Cohen et al. (2003) is to plot the predictor and moderator variables against the outcome variable at four points, for example, *low* crew motivation and *low* congestion, *low* crew motivation and *high* congestion, *high* crew motivation and *low* congestion, and *high* crew motivation and *high* congestion. The *low* is represented by the mean minus 1 *SD* (i.e., standard deviation) and the *high* is represented by the mean plus 1 *SD* for each of the predictor and moderator variables. The moderating effect exists when the slopes of the lines representing the *low* and *high* for the variable, investigated for moderating effect (i.e., congestion), differ from each other in the plot, where the x-axis represents the predictor variable and the y-axis represents the outcome variable (Frazier et al. 2004). Figure 3.3 shows the plot of the interaction of crew motivation and congestion. Crew motivation (the predictor variable) and congestion (the moderator variable) are plotted against crew performance (the outcome variable). As shown in Figure 3.3, the slopes of the lines representing *low* congestion and *high* congestion differ from each other, indicating the moderating effect of congestion on the relationship between crew motivation and performance.

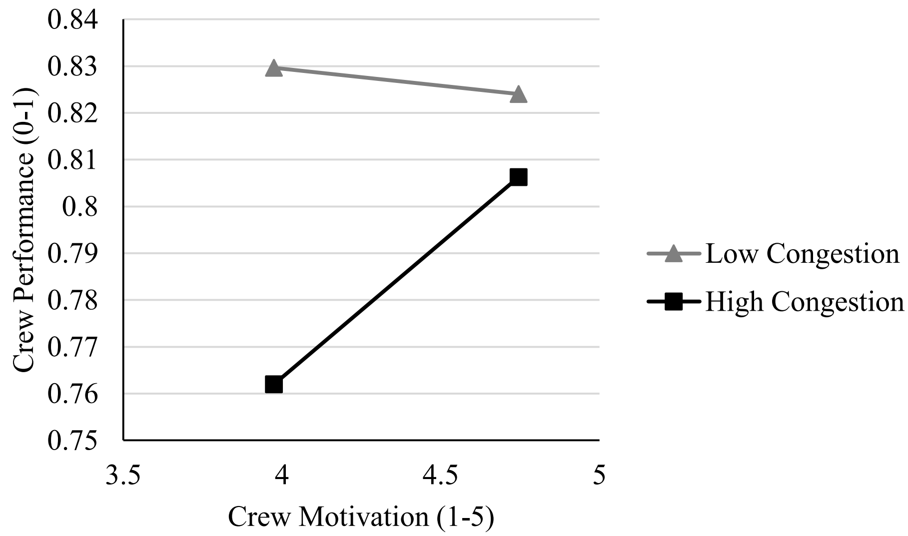

Figure 3.4. Plot of the interaction of crew motivation and congestion

Hierarchical regression analysis was performed for each of the 129 situational/contextual factors and for crew motivation. Then, the moderators of the relationship between motivation and performance were identified. Table 3.11 lists the identified moderators of the relationship between crew motivation and performance. Fourteen moderators were identified, and the standardized regression coefficients, *p*-values, correlations of each moderator with crew performance, and the ΔR^2 associated with the interaction term are presented in Table 3.11. As shown in Table 3.11, 14 situational/contextual factors moderate the effect of crew motivation on crew performance. The first observation from these results is related to the standardized regression coefficients (β). The factors with higher absolute values of β have a stronger moderating effect on the relationship between crew motivation and performance. The highest absolute value of the standardized regression coefficient (β) associated with the interaction term is associated with building trust (-0.88, p=0.040), indicating that building trust has the strongest moderating effect on the relationship between crew motivation and performance compared to other moderators.

Table 3.11. Moderators of the relationship between crew motivation and performance

Situational/ contextual factor category	Factor sub-category	Moderator	Standardized regression coefficients for interaction term	Significance for interaction term	Correlation to crew performance	R^2 change
			β	p-value	r	ΔR^2
Task-related	• Task characteristics	Task type	-0.41	0.019	0.15[a]	14%
		Task repetition	-0.49	0.004	0.43[b]	19%
	• Task design	Visibility of outcome	-0.62	0.000	0.32[b]	34%
Labour-related	• Crew properties	Crew size	0.49	0.012	-0.10[a]	12%
Foreman-related	• Foreman characteristics	Foreman knowledge	-0.36	0.002	0.29[b]	9%
	• Foreman functional skills	Performance monitoring	-0.39	0.046	0.42[b]	10%
		Communication	-0.43	0.024	0.64[a]	12%
	• Foreman behavioural skills	Goal setting	-0.24	0.003	0.33[b]	3%
		Working relationship	-0.64	0.015	0.37[b]	15%
		Building trust	-0.88	0.040	0.48[b]	10%
Management-related	• Project and construction management practices	Project time management	-0.56	0.000	0.55[b]	23%
		Project cost management	-0.57	0.000	0.55[b]	23%
Work-setting conditions	• Site general facilities	Location of facilities	-0.45	0.000	0.14[b]	28%
	• Working area conditions	Congestion	0.42	0.000	-0.84[b]	11%
Total		14				

[a] Correlation is significant at $p<0.05$.

[b] Correlation is significant at $p<0.01$.

The second observation from the results in Table 3.11 is related to ΔR^2, which indicates the amount of additional variance in crew performance explained by the interaction term over the variance explained by the effects of crew motivation and moderator alone. Visibility of outcome has the highest value of ΔR^2 compared to other moderators. The interaction between visibility of outcome and crew motivation explains an additional 34% of the variance in crew performance over the variance explained by the effects of crew motivation and visibility of outcome alone.

The third observation from the results in Table 3.11 is related to the correlations of each moderator to crew performance. Among the identified moderators, task repetition (r=0.43, p<0.01), visibility of outcome (r=0.32, p<0.01), performance monitoring (r=0.42, p<0.01), goal setting (r=0.33, p<0.01), working relationship (r=0.37, p<0.01), and building trust (r=0.48, p<0.01) have a moderate positive relationship with crew performance. Communication (r=0.64, p<0.05), project time management (r=0.55, p<0.01), and project cost management (r=0.55, p<0.01) have a strong positive relationship with crew performance. Congestion (r=-0.84, p<0.01) has a strong negative relationship with crew performance. The two highest absolute correlations are related to congestion (r=-0.84) and communication (r=0.64). Neither of them have the highest amount of either β or ΔR^2, indicating that the situational/contextual factors with the highest absolute correlation may not necessarily have the highest moderating effect.

3.8. Discussion

There are some situational/contextual factors, such as visibility, that have a moderate relationship to crew performance but have a strong moderating effect on the relationship between crew motivation and performance. Therefore, to achieve higher levels of crew performance, it is important to improve the moderators of the relationship between crew motivation and performance, such as visibility of outcome. This suggests that moderation is an important issue to be taken into consideration when the goal is to improve crew performance.

The situational/contextual factors related to the foreman-related category have the highest number of moderators, especially those related to foreman behavioural skills, compared to other situational/contextual factor categories. Out of 14 identified moderators, six are in the foreman-related category, which suggests the importance of foreman-related factors to the relationship between crew motivation and performance. Among the situational/contextual factor sub-categories, foreman behavioural skills has the highest number of moderators, suggesting the importance of foreman behavioural skills on the relationship between crew motivation and performance. Past research in construction focused mainly on foreman functional skills as critical factors affecting crew motivation and overlooked foreman behavioural skills (Siriwardana and Ruwanpura 2012). The findings of this chapter reveal a need for additional research focused on improving foreman behavioural skills.

The moderators of the relationship between crew motivation and performance are from five types of situational/contextual categories: task-related, labour-related, foreman-related, management-related, and work-setting conditions. Three categories of situational/contextual factors did not include any moderators of the relationship between crew motivation and performance: project characteristics, resources, and safety, indicating that the factors in these categories have a direct effect on crew performance without any moderating effects.

3.9. Chapter Summary

In this chapter, motivational factors and their associated measures, situational/contextual factors, and crew performance metrics are identified and analyzed. Factor analysis is performed to check the validity and reliability of the identified motivational measures for each motivational factor. The results of factor analysis show both the validity and reliability of motivational measures. Correlation analysis was performed to investigate the relationship between crew motivational factors and crew performance metrics. The results suggest that all motivational factors have a weak positive relationship with task performance, a moderate to strong positive relationship with contextual performance, and a moderate to strong negative relationship with counterproductive behaviour. Based on these results, the researchers suggest that promoting positive interactions among crew members, such as more interactive site orientations, safety meetings, or daily meetings, will improve crew performance. Among the motivational factors, commitment/engagement was shown to have the strongest relationship to crew performance, followed by cohesion, then efficacy, and finally identification.

Hierarchical regression analysis was performed to identify the key moderators of the relationship between crew motivation and performance. Among the 129 investigated situational/contextual factors, 14 were shown to have a moderating effect: task type, task repetition, visibility of outcome, crew size, foreman knowledge, performance monitoring, communication, goal setting, working relationship, building trust, project time management, project cost management, location of facilities, and congestion. The situational/contextual factor sub-category of foreman behavioural skills has the highest number of moderators, suggesting the importance of foreman behavioural skills on the relationship between crew motivation and performance.

This chapter makes three major contributions: first, it develops a comprehensive set of construction crew performance metrics that relate not only to task performance, but also to contextual performance and counterproductive behaviour; second, it reveals how motivational factors affect crew performance; and third, it provides a comprehensive list of the key moderators of the relationship between construction crew motivation and performance. The key moderators identified in this chapter as well as the motivational factors will be used to develop models of the relationship between crew motivation and performance in construction.

Many of the identified moderators, such as those related to foreman behavioural skills, are subjective variables. Additionally, each project includes different agents, such as crew members and foremen, who not only have different levels of motivation but also interact with each other. Models that are able to incorporate both agent interactions and individual differences in levels of motivation among project agents will help to better assess the impact of crew motivation on performance. Therefore, next chapter will investigate the development of fuzzy agent-based methods to model the subjective variables and relationships between motivational factors, situational/contextual factors, and crew performance metrics, as well as the interactions among project agents.

In Chapter 3, all company data (survey data, project data, and field data) were used. Survey data were used for factor analysis; project and field data were used for correlation analysis and identifying key moderators of the relationship of crew motivation and performance. In the next chapter, the results of project and field data analysis in this chapter, as well as, the identified list of moderators are used to develop models that describe the relationship between motivational factors, crew motivation, and crew performance. Chapter 4 uses the same data set of project and field data used in Chapter 3 to develop the fuzzy agent-based model.

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Chapter 4. Fuzzy Agent-based Modeling of Construction Crew Motivation and Performance[1]

4.1. Introduction

Agent-based modeling (ABM), a relatively recent modeling technique in construction research, has been used to model complex systems of interacting agents. Agents are discrete entities that are classified by type (e.g., crew members), with each type having its own individual attributes (e.g., age, years of experience) and behaviours (e.g., counterproductive behaviour). Each type of agent can have its own unique set of behavioural rules. In ABM, agents are autonomous; they are able to learn from previous experience; they interact, either proactively or reactively, with other agents in an environment; and they act based on their behavioural rules. There are several advantages to using ABM for modeling complex construction systems containing active agents (e.g., construction crews or project units). For example, ABM can predict the overall behaviour of the system by modeling the behaviour of system agents, even when there is no existing information about overall system behaviour (North & Macal 2007); ABM is capable of examining the interactions of agents with each other and with their environment (Reynolds 1999); ABM reveals

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the effect of agents' diversity on the dynamic behaviour of the system (Macal 2010); and ABM models the dynamic properties of a complex system comprised of interacting agents (Scholl 2001).

There are some gaps in the research on the use of ABM in the construction domain, especially when the problem under investigation involves subjective variables or when numerical data are not available in sufficient quantity and quality for modeling purposes. Traditionally, ABM addresses probabilistic uncertainties in variables (e.g., probabilistic distributions for agent attributes) and the system's relationships (e.g., mathematical formulas or regression equations for agent behavioural rules and interactions). However, ABM alone is not able to address variables' subjective uncertainty, nor is it able to account for system relationships that cannot be represented by either mathematical formulas or regression equations (Raoufi et al. 2016). Fuzzy logic techniques, on the other hand, can deal with subjective uncertainty (Zadeh 2015); therefore fuzzy logic can be used to incorporate subjective terms into an agent-based model. To expand ABM's scope of applicability in construction, this research integrates fuzzy logic with ABM and proposes a methodology for developing fuzzy agent-based modeling (FABM). The proposed methodology accounts for the complexity of interactions among construction agents (e.g., construction crews) and the subjective uncertainties involved in construction variables (e.g., crew motivation) and relationships (e.g., the relationship between crew motivation and performance). FABM is capable of modeling the subjective variables of linguistically expressed attributes of human agents; it can be used when sufficient numerical data are not available for probabilistic distribution fitting; and it can define the subjective behavioural rules of agents.

This chapter is structured as follows. First, a literature review of the applications of ABM in construction research is presented and limitations in current ABM research are discussed. Second, an FABM methodology is presented that explains how to integrate fuzzy logic with ABM and how to develop fuzzy agent-based models. Third, a case study is presented that illustrates the proposed methodology and shows the application of FABM in construction by developing a fuzzy agent-based model of construction crew motivation and performance. Finally, the developed model is verified and validated based on the collected field data.

4.2. Literature Review

4.2.1. Applications of Agent-Based Modeling in Construction

Although past applications of ABM in construction were very limited, the trend is changing, and more applications have been introduced in recent literature. Watkins et al. (2009) applied ABM to model space congestion and its effect on labour productivity in construction sites. Kim and Kim (2010) modeled the traffic flow of construction equipment using ABM and assessed the impact of traffic congestion on project duration. ABM was also used to model complex interactions among the components of urban infrastructure management (Osman 2012). Ahn et al. (2013) modeled social interactions among construction personnel using ABM. ABM was also implemented in the development of organizational policies to better manage human resources (Ahn and Lee 2014). The impact of workers' muscle fatigue on construction operations was modeled using ABM (Seo et al. 2016). ABM has also been recently used for simulating the bidding process of contractors with different risk attitudes in determining markups (Asgari et al. 2017). Ben-Alon and Sacks (2017) used ABM to study production control policies in residential building construction. ABM has been used to model earthmoving operations in order to help contractors with planning (Jabri and Zayed 2017). ABM has also been used to simulate crews' workflow in construction sites (Ben-

Alon and Sacks 2017). One of the most recent trends in applications of ABM in construction is modeling the energy-saving potential of commercial buildings (Azar and Ansari 2017; Azar and Menassa 2016).

4.2.2. Limitations of Current ABM Use in Construction

In traditional agent-based models, agents are defined by deterministic or probabilistic attributes. Agents in the real world, however, have subjective attributes and behavioural rules. To better represent the real components of human attributes and behaviours, FABM incorporates fuzzy agents that observe fuzzy variables and then decide how to act based on fuzzy rules. Although ABM research is developing rapidly in the construction domain, there are two major limitations in the current literature on ABM in construction. The first limitation is related to the subjective variables that exist in construction systems. For example, motivation is a subjective variable and assigning a numerical value (e.g., a percentage for crew commitment) is not a good representation of that factor. Instead, subjective variables are better represented with linguistic terms (e.g., *low* motivation).

The second limitation is related to the uncertainty that exists in agent behavioural rules. In a construction system, where the workers are the agents of an agent-based model, the behavioural rules of the workers in the system often include subjective uncertainty. Current agent-based models are limited in their ability to model agent behavioural rules that include subjective terms because they either use mathematical formulas based on past research or statistical regression equations based on collected field data (Papadopoulos 2016). Both mathematical formulas and regression equations can address probabilistic uncertainty using Monte Carlo simulation, but they do not address subjective uncertainty. For example, a rule for a crew agent behaviour expressed by an expert in natural language (e.g., "if the crew motivation is *high* and the work-setting conditions are *good*, then the crew performance is *high*") can be better represented with a fuzzy rule than with a mathematical formula or a regression equation.

Interest in FABM has been increasing in many areas, such as computing science, robotics, manufacturing, control, and the social sciences (Doctor, Hagras & Callaghan 2005; Wang, Yang, Xu & Chin 2006; Hassan, Salgado & Pavon 2008; Ostrosi, Fougères & Ferney 2012; Fougères 2013). In the construction domain, however, there is a gap in the literature about FABM that needs to be addressed. This chapter addresses that gap by presenting a methodology for FABM and implementing the proposed methodology to model construction crew motivation and performance.

4.3. Fuzzy Agent-Based Modeling Methodology

The proposed methodology for developing a fuzzy agent-based model has five steps: (1) determine the fuzzy agent-based model architecture; (2) define the basic structure of agents (i.e., agent attributes and behaviours); (3) define agent interactions; (4) define agent behavioural rules; and (5) perform the simulation experiment. The following sections describe each of these steps.

4.3.1. Determine Fuzzy Agent-Based Model Architecture

The first step is to determine the architecture of the fuzzy agent-based model. The fuzzy agent-based model architecture has two major processing platforms for data analysis: the fuzzy platform and the ABM platform. Figure 4.1 shows the architecture of the fuzzy agent-based model in detail.

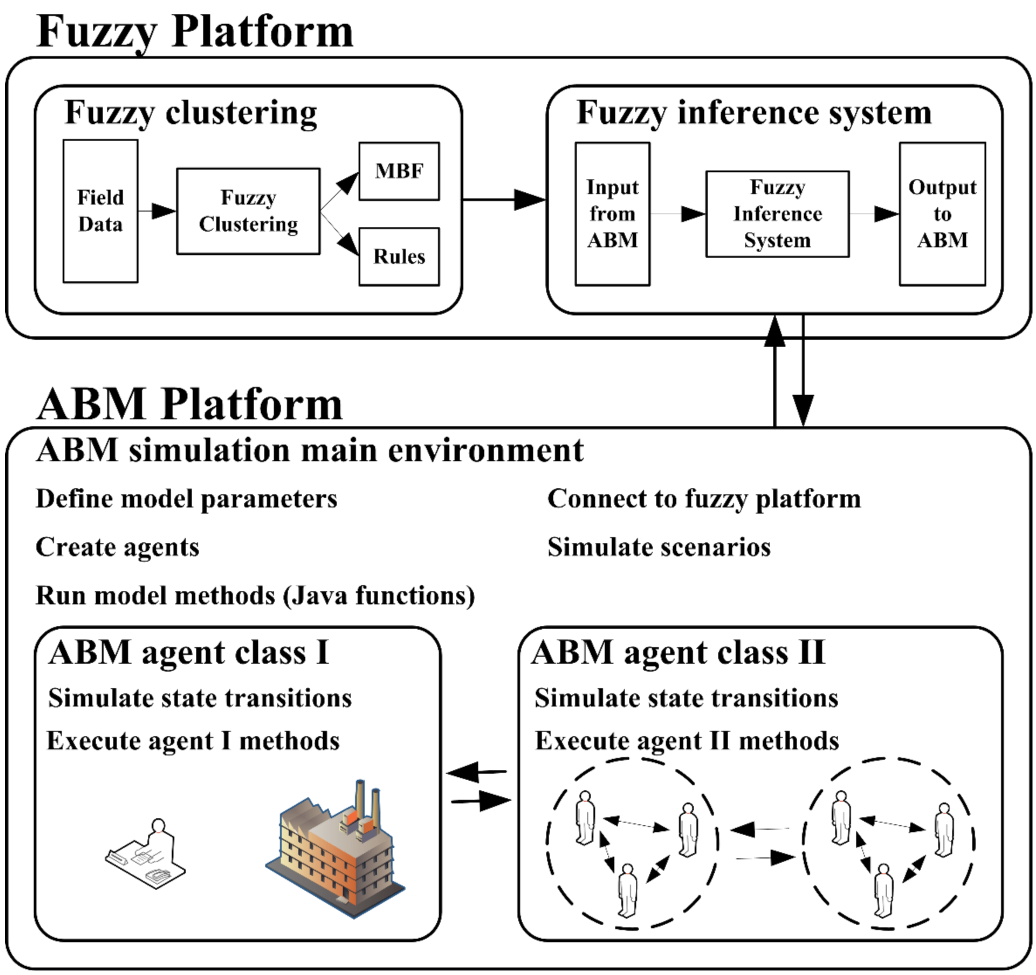

Figure 4.1. Fuzzy agent-based model architecture

The fuzzy platform has two components: fuzzy clustering and a fuzzy inference system. Fuzzy clustering is used to develop fuzzy sets and fuzzy rules based on collected field data. The output of fuzzy clustering is then used for the development of a fuzzy inference system. The fuzzy inference system receives simulation run time input variables from the agent-based model and delivers the predicted output variable. The ABM platform has two components: the simulation main environment and the agent classes. The simulation main environment is responsible for defining the model parameters, creating agents, running the simulation methods (i.e., Java functions), contacting the fuzzy inference system at simulation run time, and simulating defined scenarios. Agent classes are used to define the attributes and behaviours of each agent in the model.

4.3.2. Define the Basic Structure of Agents: Agent Attributes and Behaviours

The second step is to define the basic structure of agents, including the types of attributes and behaviours of each agent in the model. Agent unified modeling language (AUML), an extension of the unified modeling language (UML), is used to represent agents (Azar and Ansari 2017; Huget 2003). Figure 4.2 shows a sample of the basic structure of agents.

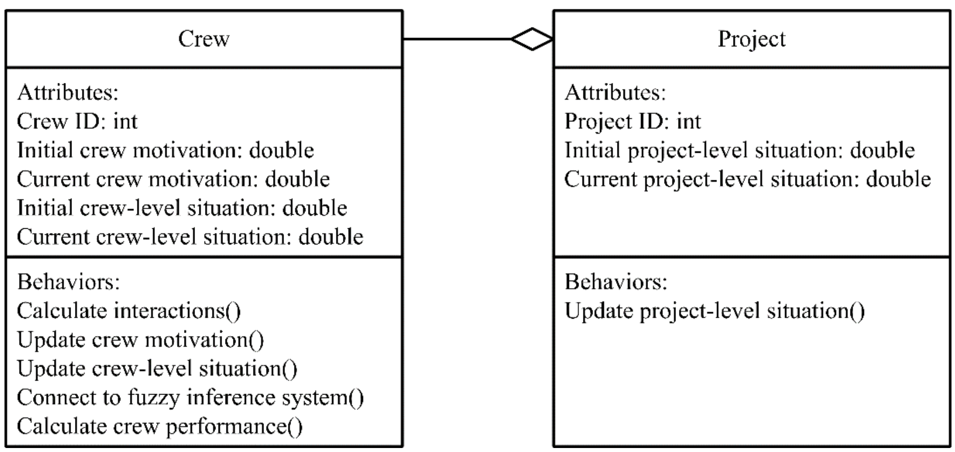

Figure 4.2. AUML diagram for basic structure of agents

Each attribute of each agent needs to be defined. Current agent-based models in construction define agent attributes using probabilistic or deterministic variables. Deterministic variables are either set by the user or defined based on collected field data, while probabilistic variables are determined by curve fitting using statistical distributions based on the available field data (Azar and Ansari 2017). There are, however, subjective variables in the system that also need to be defined.

To model subjective variables, fuzzy sets need to be constructed using one of two available types of methods. The first type includes expert-driven approaches such as horizontal, vertical, pairwise comparison, intuition, inference, and exemplification methods. The second type includes data-driven approaches such as fuzzy machine learning techniques (e.g., fuzzy clustering). Fuzzy C-means (FCM) clustering is one of the most commonly used methods of fuzzy clustering (Bezdek 2013; Pedrycz & Reformat 2006). FCM clustering is a machine learning technique in which each data point belongs to each cluster with a membership ranging from zero to one (Tsehayae and Fayek 2016). In this chapter, FCM clustering is used to develop fuzzy sets of agent attributes. Fuzzy sets representing linguistic terms are defined by membership functions, which represent the degree to which a data point (e.g., motivation score) representing a variable (e.g., crew motivation) belongs to a fuzzy set (e.g., *low* motivation). Gaussian membership functions have been recommended for both the input and output variables in various construction applications (Tsehayae and Fayek 2016; Siraj et al. 2016). They have been used in this research because of their continuity and smoothness, and they are suitable for optimization as they have only two parameters (i.e., the modal value representing the typical value and standard deviation representing the spread). To define fuzzy sets, the Gaussian membership function is defined using Equation 4.1.

$$A = e^{-[\frac{(x-\mu)^2}{2\sigma^2}]}, \tag{4.1}$$

where x represents the value of the variable in the universe of discourse, A represents the membership function for a linguistic term, μ is the mean value, and σ is the standard deviation.

4.3.3. Define Agent Interactions

The third step is to define agent interactions, following similar approaches to those used in ABM. In ABM, agent interaction can be defined as static or dynamic. Static interactions do not depend on other agents or the state of the system, but dynamic interactions depend on the state of the system and other agents' states at each point in time. Past research has shown that human agents have mostly dynamic interactions (Azar and Ansari 2017; Ben-Alon and Sacks 2017). This is due to the fact that agent attributes or behaviours change based on feedback received from observing the behaviour of other agents. However, there are some agents that do not change their attributes or behaviours when interacting with other agents. Such an agent is called a zealot (i.e., an agent with static interaction) in ABM literature. In this research, agents with both static and dynamic interactions are considered in FABM.

Mathematical formulas are often used to define the interactions of agents in ABM. Equation 4.2 is a type of interaction equation commonly used in past research to represent the interactions of agents (Azar and Ansari 2017). This equation is used to calculate the attribute of an agent at a time step based on both the attribute of the agent at previous time step and the attributes of other agents at previous time step.

$$Atr_i^t = (1 - Z \times S) \times Atr_i^{t-1} + (Z \times S) \times \frac{\sum_{j=1}^{N} Atr_j^{t-1}}{N}, \quad (4.2)$$

where *t* and *t-1* refer to current and previous simulation time steps, *i* and *j* are agent indices, *Atr* refers to the attribute of an agent, *Z* refers to the type of agent that changes its attribute based on the observation of the attributes of other agents, *S* refers to susceptibility (i.e., the probability that an interaction leads to a change in the attribute of an agent), and *N* refers to the number of other agents interacting with agent *i*. Similar mathematical formulas can be used in FABM to define the interactions of different agents.

4.3.4. Define Agent Behavioural Rules: Fuzzy Inference System

The fourth step is to define agent behavioural rules, which are how agents decide on their actions based on the history of the system state (i.e., the state of the system at both the current and previous time steps) (Dash, Jennings, & Parkes 2003). Current agent-based models either use mathematical formulas or regression equations to define agent behavioural rules (Papadopoulos 2016). Both these techniques can address probabilistic uncertainty, but they do not address the subjective uncertainty involved in agent behavioural rules. In order to model behavioural rules in FABM, fuzzy rules need to be defined, which can be done using one of three methods. The first method involves using past literature (e.g., theories of human behaviour in literature). This method is useful if there are no data available but there is previous reliable literature regarding the agents' behavioural rules. For example, Ahn and Lee (2014) used social cognitive theory to determine rules for agents' absence behaviour. The second method is an expert-driven approach (i.e., using domain expert judgments). This method is useful if sufficient data about the agent's attributes and behaviour are not available but there is access to sufficient domain expert knowledge regarding the behavioural rules of agents. The third type of method involves data-driven approaches. If sufficient data regarding the agent's attributes and behaviours are available, data-driven approaches (e.g., fuzzy machine learning techniques) can be used to define agent behavioural rules. Pedrycz (2013) showed how to define fuzzy rules from data using fuzzy machine learning techniques such as FCM clustering. FCM clustering minimizes an objective function representing the sum of squared distances of data instances to cluster centers.

In this research, FCM clustering is used to define agent behavioural rules through the following process. In a system with n input variable (x_i, $i=1,\ldots, n$) and one output variable (y), the input-output data set (z) has $n+1$ dimension. Having N sets of data instances, the data instance k is denoted by Equation 4.3.

$$\boldsymbol{z}_k = [x_{k1}, x_{k2}, \dots, x_{kn}, y_k],\ k = 1, \dots, N, \tag{4.3}$$

where k refers to the data instance, x_{kj} represents the j^{th} input variable for the k^{th} data instance, and y_k represents the output variable for the k^{th} data instance.

The optimization process of FCM clustering results in the development of a partition matrix ($\boldsymbol{U}$) that includes the membership degrees of a data point in each cluster (Pedrycz 2013). The partition matrix ($\boldsymbol{U}$) is denoted by Equations 4.4 and 4.5.

$$\boldsymbol{U} = [u_{st}],\ s = 1, \dots, c,\ \ t = 1, \dots, N \tag{4.4}$$

$$u_{st} = \frac{1}{\sum_{j=1}^{c} (\frac{\|z_t - v_s\|}{\|z_t - v_j\|})^{2/m-1}},\ s = 1, \dots, c,\ \ t = 1, \dots, N, \tag{4.5}$$

where s refers to the cluster, t refers to the input-output variable, z_t represents the data instance t, and v_s represents the s^{th} prototype.

Using the input-output dataset, FCM clustering clusters the input-output dataset into c number of clusters. For each cluster, FCM clustering defines a prototype (cluster center), which is denoted by Equations 4.6 and 4.7.

$$\boldsymbol{V} = [v_{ij}],\ i = 1, \dots, c,\ \ j = 1, \dots, N \tag{4.6}$$

$$v_{st} = \frac{\sum_{k=1}^{N} u_{ik}^{m} z_{kt}}{\sum_{k=1}^{N} u_{ik}^{m}},\ s = 1, \dots, c,\ \ t = 1, \dots, N \tag{4.7}$$

Each cluster represent a fuzzy rule; thus, FCM clustering results in the development of *c* number of fuzzy rules in the form of "If X is A_j then y is B_j". In this research, FCM clustering is used to develop fuzzy rules of crew behaviour based on collected field data.

4.3.5. Perform the Simulation Experiment

The final step in the FABM methodology is to perform the simulation experiment. The FABM platform is built by connecting the ABM platform and the fuzzy platform at simulation run time. The ABM platform is Anylogic®, which is a simulation software based on the Java environment that allows the user the flexibility of adding custom Java codes in different parts of the model (e.g., simulation main, object classes). The fuzzy platform is MATLAB®, which allows programming. Java programming in the Anylogic® environment is used to connect the ABM and fuzzy platforms. The FABM platform runs the simulation experiments by executing the simulation methods (i.e., the Java functions) in ABM. Data about agent attributes are sent to the fuzzy inference system in MATLAB® at simulation run time. Next, data about the agent behaviours are calculated using the fuzzy inference system in MATLAB® and sent to the agent-based model in AnyLogic®. The simulation experiments include fuzzy agents who will act in the simulation environment based on their fuzzy behavioural rules. The collective actions of fuzzy agents in the simulation environment will then provide the outputs of the fuzzy agent-based model. In the following sections, a case study is presented to illustrate the proposed FABM methodology.

4.4. Case Study: FABM Model of Construction Crew Motivation and Performance

The construction industry is made up of complex processes that involve many individuals and crews working together and interacting over long periods. In order to effectively manage construction projects, it is important to be able to assess crew performance (e.g., task performance, contextual performance, and counterproductive behaviour). Crew performance is influenced by many factors, including crew motivation and the situations in which crews perform their tasks. Thus one challenge to assessing crew performance is how to model the attributes and behaviours of crews; another challenge is how to model the situation in which the tasks are performed. In addition, the interactions of crew members with each other and with the environment (i.e., the situation in which crew perform their tasks) must also be modeled.

Both motivational factors and situational/contextual factors affect crew performance. Figure 4.3 shows the proposed model of the relationship between motivational factors, situational/contextual factors, and crew performance. Motivational factors are antecedent to crew motivation, which is the predictor variable in the model. Situational/contextual factors are potential moderators of the relationship between crew motivation and performance. Crew performance is the dependent variable in the model. The motivational factors are efficacy (Bandura 1977; Hannah et al. 2016), commitment/engagement (Meyer and Allen 1991; Cesário and Chambel 2017), identification (Ashforth and Mael 1989; Lin et al. 2016), and cohesion (Beal et al. 2003; Chiniara and Bentein 2017), each of which operates at both individual and crew levels. The crew-level situation and the project-level situation represent situational/contextual factors, which might also affect the relationship between crew motivation and performance. It is therefore important to take into account situational/contextual factors when studying the effect of motivation on crew performance. In this research, situational/contextual factors at both the crew level (i.e., the crew-level situation) and the project level (i.e., the project-level situation) are accounted for in the model. The crew-level situation has three categories: task-related (e.g. task design), labour-related (e.g., the functional skills of the crew), and foreman-related (e.g., leadership skills). The project-level situation has five categories: project characteristics (e.g., work shifts), management-related factors (e.g., project management practices), work-setting conditions (e.g., weather conditions), resources (e.g., tools, equipment, material), and safety precautions (e.g., safety training). Crew performance metrics are divided into three categories: task performance, contextual performance, and counterproductive behaviour.

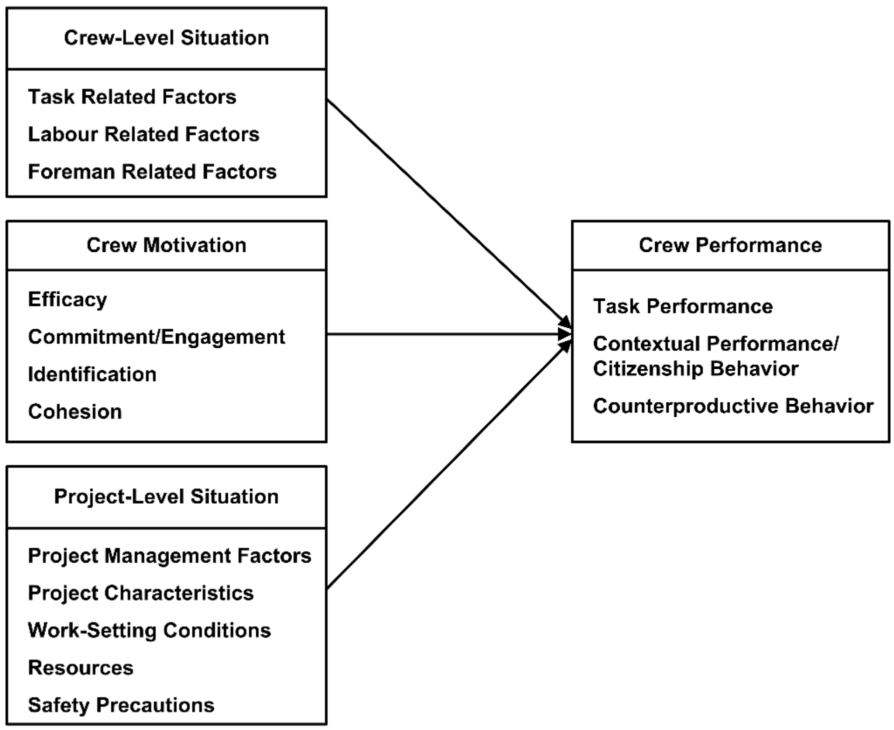

Figure 4.3. Conceptual model of the case study

In the proposed model, the primary list of factors was derived from existing research in both construction and non-construction domains. First, a motivation expert with 30 years of experience in business and industrial psychology provided his expertise regarding the initial list of motivational factors. This initial list of factors was then presented in a workshop to 10 construction experts involved in projects in Canada. These experts had an average of 15 years of experience, and they represented different types of construction organizations (e.g., owners, contractors, and labour unions); they also held various positions in their organizations (e.g., senior management, project management, human resources representative, and labour relations representative). The experts reviewed the list and proposed additional factors they thought might affect construction crew motivation and performance. They reached a consensus on the proposed additional factors, and the primary list of factors was updated to include the additional factors. This process allowed for the development of a comprehensive list of factors that not only takes into account the literature in construction and non-construction domains, but that also captures the opinions of both motivation and construction experts. In this research, 78 situational/contextual factors at the project-level were identified, such as project characteristics—work shifts, management-related—project management practices, work-setting conditions—weather conditions, and resource—material. In addition, 51 situational/contextual factors at the crew level were identified, such as task-related—task design, labour-related—crew functional skills, and foreman-related—leadership skills.

Data collection was performed in a construction company actively involved in industrial projects in Canada. Field data were collected on crew motivational factors, situational/contextual factors, and crew performance metrics over the three-month timeline of an industrial construction project. All nine crews working on the work packages in the project participated in the data collection. Crew performance metrics were collected for all nine crews and for all 79 work packages of the project. Motivational factors and situational/contextual factors were collected for all nine crews and for 17 work packages out of 79. The collected field data related to the 17 work packages were used for field data analysis because they included the full set of variables (i.e., motivational factors, situational/contextual factors, and crew performance metrics).

The sources of data collection for motivational and situational/contextual factors were interviews with project personnel, including crew members, foremen, field supervisors, and project managers; observations by data collectors on the work packages of the project; project databases and documents such as project safety logs; and external sources such as government databases (e.g., databases for weather data). For task performance, actual project documents (e.g., time sheets, score cards, safety logs, change order logs, inspection test plans, schedule updates, tender documents, and cost estimates) were used to extract available crew performance data. Key performance indicators (KPIs) related to task performance were calculated for all crews. For KPIs related to contextual performance and counterproductive behaviour, multiple-source data collection was utilized, which accounts for both self-evaluation and supervisor evaluation (Raoufi and Fayek 2017).

In this case study, a simulation model of crew motivation and performance is developed that describes the relationship between crew motivation, project situation, and crew performance using FABM. The goal is to develop a fuzzy agent-based model that accounts for diversity in the level of crew motivation, the change of crew motivation over time, and changes in the situation in which crews are performing. The model can thus calculate crew performance in a way that reflects the dynamic aspects of crew motivation and the project environment. Furthermore, the model accounts for agent interactions and the variations in agent attributes and behaviours that are based on interactions with other agents.

4.4.1. Construction Crew Motivation and Performance Model Architecture

The fuzzy agent-based model of construction crew motivation and performance includes five components: simulation main environment, project agent class, crew agent class, fuzzy clustering, and the fuzzy inference system. At the simulation run time, the components of the developed FABM send and receive processing information (i.e., agent run time variables and states) to each other and calculate crew performance based on model parameters, agent state history, and the project situation state history. The simulation main environment is responsible for defining model parameters, creating project and crew agents, running the simulation methods (e.g., calculating statistics on crew populations), and contacting the fuzzy inference system at simulation run time. The project agent class is for simulating the situation at the project level, while the crew agent class is for simulating crew motivation and situation at the crew level. The model's inputs are parameters in the simulation main environment, attributes of the project agent (e.g., the situation at the project level), and attributes of the crew agent (e.g., crew motivation, the situation at the crew level). The output of the model is crew performance.

4.4.2. Basic Structure of Agents: Attributes and Behaviours of Crew and Project Agents

To define project and crew agents' attributes and behaviours, fuzzy sets for agent attributes and behaviours are constructed based on FCM clustering, as discussed in the FABM methodology section.

4.4.2.1 Project Agent Class

The project agent class represents construction projects in which construction crews are performing their tasks. The attributes of the project agent class are defined as project ID, initial project-level situation, and current project-level situation. The behaviours of the project agent class are: update the project-level situation, which is defined by Java methods (i.e., Java functions), and state charts in the AnyLogic® agent class template. Figure 4.4 shows the developed project agent class in AnyLogic®.

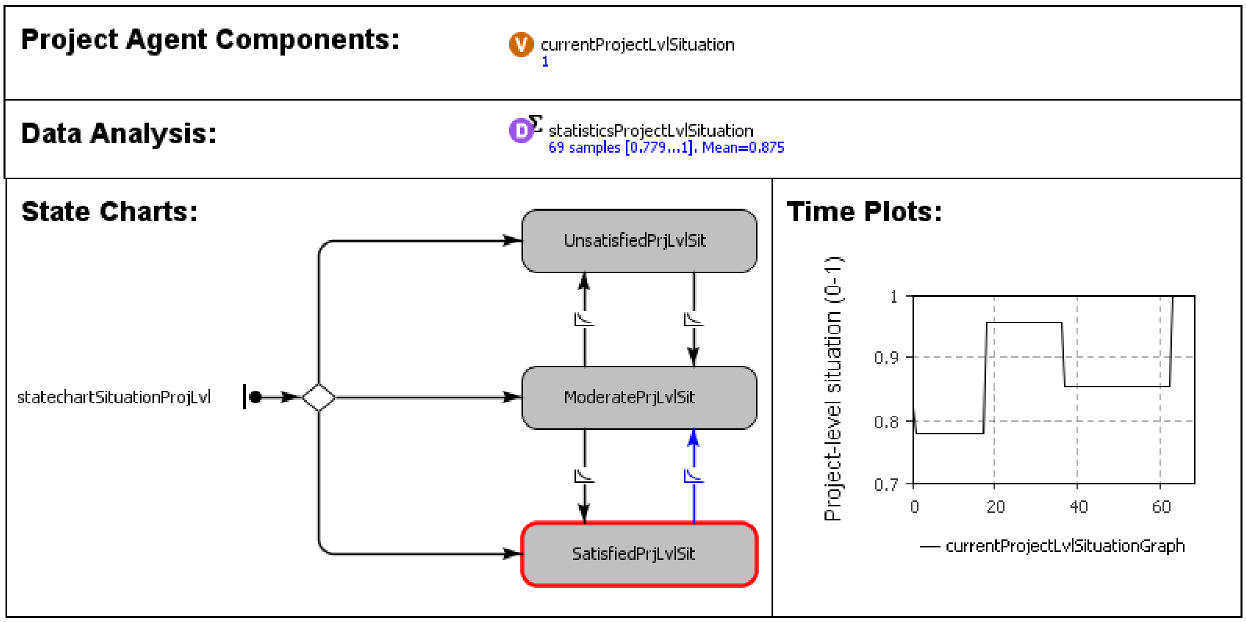

Figure 4.4. Project agent class in AnyLogic®

A project ID is assigned to distinguish different projects in the model. However, in this case study, just one project with several construction crews is simulated, since the goal is to simulate different crews in a project environment rather than the different projects of an organization. Project-level situation attributes are variables representing situational/contextual factors at the project level. In this case study, based on the analysis that was performed on the collected field data, two factors among the situational/contextual factors at the project level were shown to have a significant effect on the relationship between crew motivation and performance: project time management and project cost management (Raoufi and Fayek 2017). The project-level situation attribute is calculated as the mean of the normalized project time management and project cost management to ensure equal weighting between different project-level situational contextual factors and to prevent bias (i.e., the effect of difference in the identified range of values for each situational/contextual factor on the calculated crew-level situation). Normalization was done by dividing each situational/contextual factor by its maximum value, to achieve a value between 0 (undesirable value) and 1 (desirable value).

4.4.2.2 Crew Agent Class

The crew agent class represents construction crews which are performing their tasks in a construction project. The attributes of the crew agent class are crew ID, initial crew motivation, current crew motivation, initial crew-level situation, and current crew-level situation. The behaviours of the crew agent class are: calculate interactions, update crew motivation, update the crew-level situation, connect to the fuzzy inference system, and calculate crew performance. The behaviours are defined either through Java methods or directly through state charts in the AnyLogic® agent class template. Figure 4.5 shows the developed crew agent class in AnyLogic®.

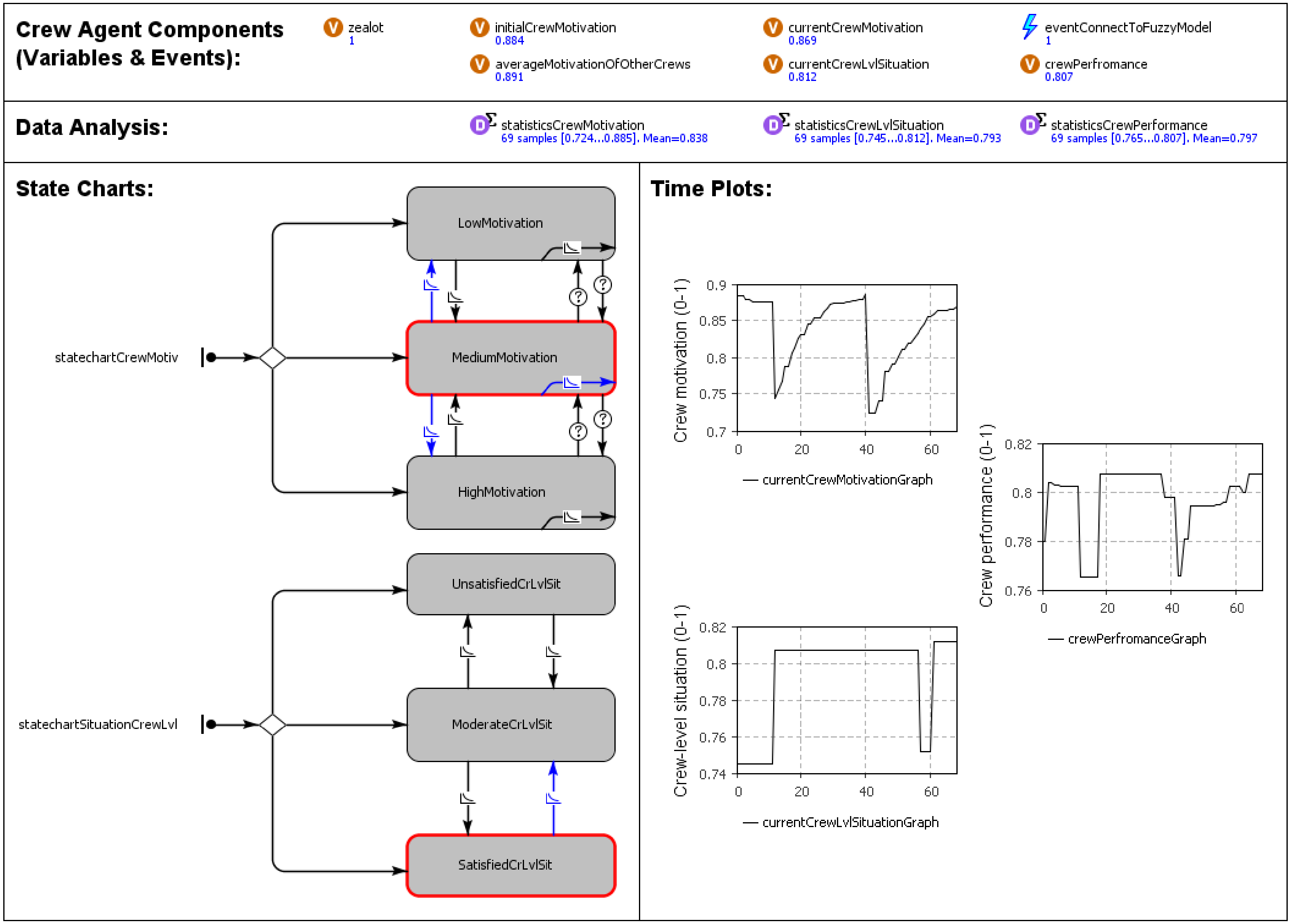

Figure 4.5. Crew agent class in AnyLogic®

A crew ID is assigned to distinguish different crews in the model. Crews are generated in the model based on the initial number of crews that the user defines before each simulation experiment. Crew motivation attributes, either initial or current crew motivation, are variables representing motivational factors (i.e., efficacy, commitment/engagement, identification, and cohesion) at both the individual and crew levels. Crew motivation is calculated as the mean of normalized motivational factors. An equal weight is given to motivational factors in order to avoid any uninformed assumptions about which motivational factor influences crew motivation the most. Crew-level situation attributes, at either the initial or current project-level situation, are variables representing situational/contextual factors at the crew level. Based on the analysis that was performed on the collected field data, 12 of the situational/contextual factors at the crew level were shown to have a significant effect on the relationship between crew motivation and performance: task type, task repetition, visibility of outcome, crew size, foreman knowledge, performance monitoring, communication, goal setting, working relationship, building trust, location of facilities, and congestion (Raoufi and Fayek 2017). The crew-level situation attribute is calculated as the mean of the normalized values of the 12 identified factors to ensure equal weighting between different situational/contextual factors at the crew level and to prevent bias (i.e., the effect of difference in the identified range of values for each situation/contextual factor on the calculated crew-level situation). Normalization was done by dividing each situational/contextual factor by its maximum value, to achieve a value between 0 (undesirable value) and 1 (desirable value).

4.4.3. Crew Interactions

The collected field data suggests that crew motivation changed over time, implying the possibility of dynamic interactions between crew agents. Equation 4.8 is used to represent variations in crew motivation based on the interactions of crew agents. The level of motivation of crew agents is calculated using Equation 4.8 and is based on the level of motivation of that crew and the level of motivation of other crews in the project.

$$CM_i^t = (1 - Z \times S) \times CM_i^{t-1} + (Z \times S) \times \frac{\sum_{j=1}^{N} CM_j^{t-1}}{N}, \quad (4.8)$$

where *t* and *t-1* refer to the current and the previous simulation time steps, *i* and *j* are crew indices, *CM* refers to crew motivation, *Z* refers to the type of crew agent that changes motivation based on observing the motivation of other agents, *S* refers to susceptibility (i.e., the probability that an interaction leads to change of motivation level), and *N* refers to the number of other crew agents that are interacting with crew *i*.

A crew that interacts with other crews may or may not change its motivation based on the motivation of other crews. *Z* has two states: 0 (i.e., the crew agent is a zealot and never changes its motivation when interacting with others) and 1 (i.e., the crew agent is not a zealot and may change its motivation when interacting with others). *S* enables the model to consider the probability that an interaction leads to a change in the level of motivation of a crew agent. *S* takes values between 0 (i.e., no susceptibility) and 1 (i.e., full susceptibility), which indicates how much the interacting crew agents affect the motivation level of crew agent *i*.

Equation 4.8 calculates the motivation level of a crew agent *i* when the interaction of that crew agent with other crew agents happens. However, crews are not always in contact with each other. Therefore, the extension of Equation 4.8, which considers agent contact rates, is developed as Equation 4.9.

$$CM_i^t = (1 - Z \times CRT \times S) \times CM_i^{t-1} + (Z \times CRT \times S) \times \frac{\sum_{j=1}^{N} CM_j^{t-1}}{N}, \quad (4.9)$$

where *CRT* refers to crew agent contact rates (i.e., the rate that crew agents contact each other over the simulation time unit).

It should be noted that the developed model considers the interactions between crews based on the morning toolbox meetings as well as safety meetings. There are also some interactions between the crew members which are not included in the developed model as the agents in the developed model are crew and project agent. Future development of the model can be done by adding crew member agents to the model and member interactions; however, this expansion require observations of crew members' interactions.

4.4.4. Crew Behavioural Rules

Using collected field data, FCM clustering is applied to develop fuzzy rules to represent crew behavioural rules (i.e., how crews perform based on their level of motivation and the project environment). The identified fuzzy rules are then used to construct a fuzzy inference system. A Mamdani fuzzy rule-based model, which is one of the most widely used architectures in fuzzy modeling, is selected to build the fuzzy inference system (Pedrycz 2013). Mamdani fuzzy rule-based models provide an output as fuzzy sets that can be defuzzified to obtain a crisp output and that can be used in the agent-based model at the simulation run time. Gaussian membership functions have been used because of their advantages, which are that they have full coverage (i.e., non-zero values at all points), they possess interpretability, and they are suitable for optimization (Tsehayae and Fayek 2016).

MATLAB® is used to perform FCM clustering and to build a Mamdani fuzzy rule-based model. It is advantageous to limit the number of input variables and the number of linguistic terms in order to have a fuzzy inference system with good interpretability (Tsehayae and Fayek 2016; Gacto et al. 2011). In this chapter, crew motivation and crew-level situation and project-level situation are the three input variables and crew performance is the output variable of the fuzzy inference system. The results of the FCM clustering performed in MATLAB® on the collected field data are the defined fuzzy rules and membership function parameters, which are presented in Table 4.1.

Table 4.1. Fuzzy inference system rules and membership function parameters

Variable	Rule 1		Rule 2		Rule 3		Rule 4		Rule 5	
	σ	μ	σ	μ	σ	μ	σ	μ	σ	μ
Crew motivation	Low		Medium		High		Very High		Very Low	
	0.0349	0.8543	0.0312	0.8806	0.0205	0.9240	0.0325	0.9258	0.0550	0.7192
Crew-level situation	Satisfied		Slightly unsatisfied		Slightly satisfied		Moderate		Unsatisfied	
	0.0252	0.8054	0.0166	0.7322	0.0290	0.7899	0.0199	0.7516	0.0472	0.6426
Project-level situation	Slightly satisfied		Moderate		Slightly unsatisfied		Satisfied		Unsatisfied	
	0.0478	0.9954	0.0618	0.8092	0.0871	0.6021	0.0470	0.9979	0.0849	0.6013
Crew performance	Medium		Low		Very High		High		Very Low	
	0.0106	0.8071	0.0108	0.8055	0.0080	0.8198	0.0168	0.8172	0.0392	0.6957

Table 4.1 shows the parameters for fuzzy membership functions for each input and output variable of the model. For example, *low* motivation is represented by a Gaussian membership function as described in Equation 4.1 where μ=0.8543 and σ=0.0349. Five fuzzy rules are shown in Table 4.1. For example, fuzzy rule 1 is "If crew motivation is *low*, and the crew-level situation is s*atisfied*, and the project-level situation is *slightly satisfied,* then crew performance is *medium*."

4.4.5. Simulation Experiment and Results

After building the fuzzy agent-based model, the next step is to perform the simulation experiment. The initial conditions (e.g., the model parameters) are defined based on the collected field data. Performing the simulation experiment allows for the observation of variations in model variables, such as variations in crew motivation, crew-level situation, project-level situation, and crew performance.

Table 4.2 shows the parameters of the fuzzy agent-based model that need to be defined in order to perform a simulation experiment. In the second column of Table 4.2, the possible range of value for each parameter in the model is presented. The range of value can be used for sensitivity analysis and scenario building. For example, the simulation experiment can be run under new initial conditions (usually hypothetical initial conditions) and the possible outcomes observed. The third column of Table 4.2 shows the initial values for the simulation experiment. These initial values were obtained from the collected field data for the project under study, and they were used in the simulation experiment in the case study.

Table 4.2. Fuzzy agent-based model parameters

Parameter	Range of Value	Initial Value for Simulation Experiment (Based on Collected Field Data)	Description
Number of crews	$\mathbb{Z}^+$	9	Number of crews in the project
Contact rate	$\mathbb{R}^+$	1.00	Number of contacts between crews per simulation time unit
Zealot percentage	[0,1]	0.2857	The percentage of zealots in the project
Susceptibility	[0,1]	0.09419	The probability that an interaction leads to change in motivation
Non-interactive motivation variability	[0,1]	0.01098	The rate of change in motivation-level without contact to other agents
Initial motivation states of crews	[0,1]	0.2857 for "*low*" 0.4286 for "*high*"	Percentages of crews in each motivation state at the start of the simulation. The percentage for "*medium*" is calculated by the model after the user defines percentages for "*low*" and "*high*".
Initial states of crew-level situation	[0,1]	0.1426 for "*unsatisfied* crew-level situation" 0.0000 for "*satisfied* crew-level situation"	Percentages of crews in each crew-level situation state at the start of the simulation. The percentage for "*medium* crew-level situation" is calculated by the model after the user defines percentages for "*unsatisfied* crew-level situation" and "*satisfied* crew-level situation".
Initial state of project-level situation	String	"*medium* project-level situation"	String parameter representing initial states of the project-level situation such as "*unsatisfied*", "*medium*", and "*satisfied*".
Crew-level situation variability	$\mathbb{R}^+$	0.03139	Rate of change in crew-level situation states per simulation time unit
Project-level situation variability	$\mathbb{R}^+$	0.03333	Rate of change in project-level situation states per simulation time unit

There are nine crews in the simulation experiment, each of which has a different level of motivation and performs tasks in different crew-level situations. Field data were collected over 68 days of the project under study; therefore, the simulation finish time is 68 days for the simulation experiment. The behaviour of the system was then observed over the simulation run time and the statistics regarding model variables were collected. Time plots for crew motivation, crew-level situation, and crew performance for all crews are provided in the crew agent class. Time plots for the project-level situation are provided in the project class. In the main simulation environment, time plots for the motivation states of crews, the crew-level situation states of crews, the project-level situation, the average motivation of all crews, the average crew-level situation of all crews, and the average performance of all crews in the project is provided. Figure 4.6 shows a summary of the results of the model experimentation obtained from the simulation main environment for all crews in the project. The results related to each agent are also visible in the agent class, as shown previously in Figures 4 and 5 for the same simulation experiment.

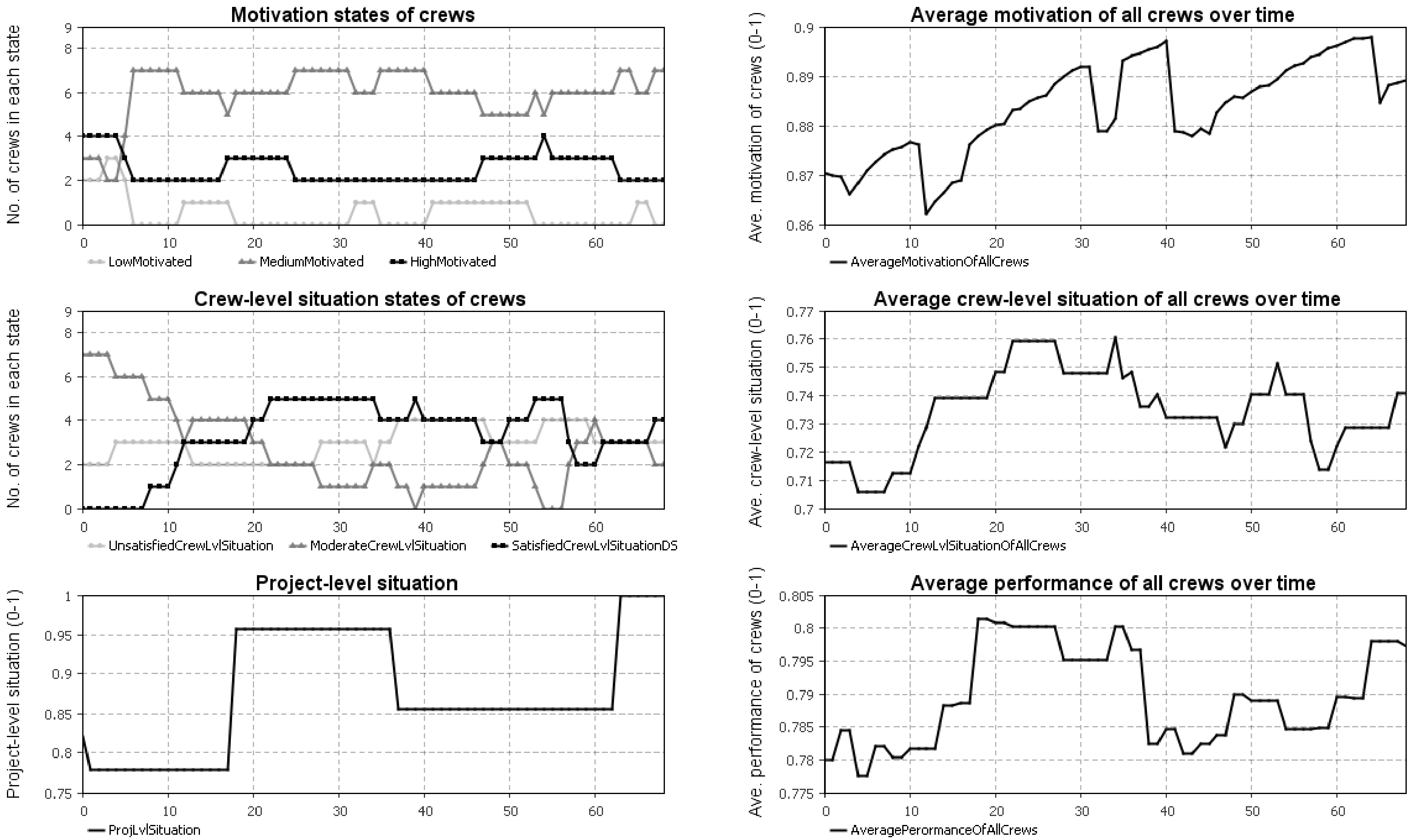

Figure 4.6. FABM simulation experimentation results

In Figure 4.6, the time plot for the motivation states of crews shows the number of crews in each motivation state (*LowMotivated*, *MediumMotivated*, and *HighMotivated*) over the simulation run time. Of the nine crews generated at the start of the simulation, four crews were in a *MediumMotivated* state, three crews were in a *HighMotivated* state, and two crews were in a *LowMotivated* state. Therefore, at the start of the simulation, the number of crews in *HighMotivated* state was more than the number of crews in *LowMotivated* state. Since the initial number of high-motivated crews was more than the initial number of low-motivated crews, the crew interactions were in favor of changing the motivation of low-motivated crews to higher motivation levels (e.g., medium motivated crews). The time plot of motivation states of crews shows that over time, some low-motivated crews changed to medium motivated crews. This is due to the interactions of the crews. The plot of average motivation of all crews over time shows that there was an increasing trend regarding the motivation of crews. As Figure 4.6 presents the aggregated results of all crews, it is also possible to look at this trend regarding the change in motivation of each crew separately in the time plots that exist in crew class. For example, in Figure 4.5 the time plot for crew motivation shows a gradual increase in the overall motivation of a crew over time, demonstrating how the interaction of crews affected the motivation of the crew in the project over time. The areas with a sharp drop or increase in motivation are due to non-interactive motivation variability in crew motivation.

In Figure 4.6, time plots of crew-level situation states of crews, the project-level situation and the average crew-level situation of all crews are presented. The time plot of the average performance of all crews shows the average performance of all crews at each time step. The performance of each crew agent is calculated in the model using a fuzzy inference system based on crew motivation, crew-level situation, and project-level situation. As shown in Figure 4.6, the developed fuzzy agent-based model is able to account for the diversity of crews, crew interactions, variations of crew motivation over time, and variations in the situation in which crews are performing. Thus, the calculated crew performance reflects the dynamic aspects of crew motivation and project situation.

The developed model is based on collected field data from multiple crews in one construction project, but it can be used to assess crew performance in projects with similar contexts. It is also possible to use the model in projects with very different contexts, but the membership functions and fuzzy rules would need to be tuned. To do so, data should be collected from projects in a new context, and the methodology of this chapter regarding the development of fuzzy membership functions and fuzzy rules should be followed. Then the fuzzy inference system could be developed with the new fuzzy membership functions and fuzzy rules for projects in the new context. The ABM part of the model would not change in a new context, but a new project would need to be simulated with new initial conditions.

4.5. Verification and Validation

In construction research, various verification and validation techniques have been developed and used over time, including face validity, internal validity, external validity, and construct validity (Lucko and Rojas 2009). Different methods were implemented in past literature for the verification and validation of simulation models, including agent-based models. Ormerod and Rosewell (2009) defined the methods for verification and validation of agent-based models in the social sciences; Sargent (2013) classified the methods for verification and validation of simulation models; and Lucko and Rojas (2009) reviewed the methods for verification and validation in construction research. In this research, a combination of the methods proposed for verification and validation in construction, the social sciences, and computer science are implemented. The methods applied in this research are the most commonly used according to recent literature on ABM in construction (Azar and Ansari 2017; Azar and Menassa 2014, 2012).

To verify the developed fuzzy agent-based model, four steps are followed. First, all mathematical equations are checked to identify and correct any possible errors in the model (Ormerod and Rosewell 2009). Second, a structured walk-through is performed to examine the components of the model, such as the developed Java methods (Sargent 2013). Third, the model is simulated multiple times to check for the replicability of its results (Ormerod and Rosewell 2009). Fourth, both tracing and runtime graphs are used to track changes in the variables of the model during the simulation experiment and to ensure that model components are working as expected (Sargent 2013).

To validate the fuzzy agent-based model, three steps are followed. First, conceptual validity is performed by basing the model on validated motivational concepts from past literature (Sargent 2013). Motivational factors, situational/contextual factors, and crew performance metrics are defined based on past literature in the construction and non-construction domains. Then the identified list of factors are validated by both motivation experts and construction experts. As suggested by Ormerod and Rosewell (2009), the problem to be modeled is fully described, including all model components such as agents, parameters, and simulation time steps. Second, data validity is performed by developing a data collection protocol and following a structured data collection methodology; testing for construct validity and the reliability of the measures used for data collection must also be done (Sargent 2013). Third, operational validity is performed by both subjective approaches (i.e., methods that do not use actual data) and objective approaches (i.e., methods that use actual data) (Sargent 2013). A subjective approach to operational validity is performed using graphical displays such as time plots at simulation run time. Time plots for model variables are presented in all model agents to observe the behaviour of different elements of the model. An objective approach to operational validity is performed using ten-fold cross-validation, an internal validity technique. A ten-fold cross-validation technique is used to check the accuracy of the developed fuzzy agent-based model in predicting the output. The data were split into ten subsets; then each subset in turn was used for testing, and the remaining 9 subsets were used for training. With the training set, fuzzy culsteing was performed to identify the membership functions and fuzzy rules, and with the testing set the error in the estimation of the crew performance was calculated. To caclulate the error terms, mean absolute percentage error (MAPE) and root mean square percentage error (RMSPE) are used. MAPE is calculated based on Equation 4.10, and it is a measure of the differences between predicted values and actual values. RMSPE is calculated based on Equation 4.11 and provides a quadratic loss function that is similar to the statistical measure of standard deviation of the differences between predicted values and actual values. Both MAPE and RMSPE express errors as a percentage of actual data; thus, they provide a way of judging the differences in the extent of the errors of one model compared to other models developed by different modeling methods and applied in different contexts.

$$MAPE = \frac{\sum_{i=1}^{n}\left|\frac{AP_i - PP_i}{AP_i}\right|}{n} \times 100 \tag{4.10}$$

$$RMSPE = \sqrt{\frac{\sum_{i=1}^{n}\left(\frac{AP_i - PP_i}{AP_i}\right)^2}{n}} \times 100, \tag{4.11}$$

where *AP* refers to the actual crew performance, *PP* refers to performance predicted by the fuzzy agent-based model, and *n* is the number of data.

The ten-fold cross-validation technique was performed, and the calculated MAPE was 2.48% and the calculated RMSPE was 0.79%, indicating a very good prediction of crew performance by the developed fuzzy agent-based model.

4.6. Chapter Summary

ABM has previously been used to model construction processes and practices, which are influenced by the complexities that arise from the interaction of agents. However, the application of ABM in construction research has some limitations, as ABM alone can only deal with probabilistic uncertainty, while construction systems also include subjective uncertainty. For example, construction crew motivation and performance involve subjective uncertainties that exist in human behaviour and social relationships. To address this limitation and improve the effectiveness of ABM, this chapter proposed a methodology for integrating fuzzy logic and ABM. The proposed FABM methodology was then used to develop an FABM model of construction crew motivation and performance that predicts the performance of construction crews using input variables such as crew motivational and situational/contextual variables. The develop FABM methodology was then verified and validated based on collected field data from a company active in various industrial projects in Canada. The developed fuzzy agent-based model is able to account for the diversity of crews, crew interactions, variations in crew motivation over time, and variations in the situation in which crews are performing. The results show that the developed fuzzy agent-based model is able to predict the performance of construction crews in the project by taking into account not only the complexities related to agent interactions, but also the subjective uncertainties involved in the construction system. The model is also able to predict the relative influence of different model parameters. It is also possible to perform scenario analysis to quantify performance gains and analyze cost-benefit associated with changes in each model parameter. Monte Carlo simulation can also be performed to show the effect of probabilistic parameters and probabilistic variables (i.e., parameters and variables having probability distributions functions) on crew performance.

This chapter makes three contributions. First, it expands the scope of applicability of ABM by integrating fuzzy logic with ABM to create fuzzy agent-based modeling (FABM), which can handle both probabilistic and subjective uncertainty; second, it provides a novel methodology for developing fuzzy agent-based models that allows for the development of new models to assess construction processes and practices; and third, it develops a fuzzy agent-based model of construction crew motivation and performance, which improves the assessment of crew performance by accounting for not only the interactions of crews in the project, but also subjective uncertainties in model variables such as crew motivation.

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Chapter 5. Conclusions and Recommendations

This chapter provides the summary of the work conducted in this research, the academic and industrial contributions of the research, limitations of the research, and recommendations for future research and development.

5.1. Research Summary

This research aimed to fill the gaps in construction research on crew motivation and performance. A review of past research in construction domain on crew motivation and performance revealed several gaps: **Firstly**, the construction literature on crew motivation and performance largely considered motivation at the individual level without considering the sources of motivation at both the individual and crew levels. **Secondly**, although there were some studies regarding the effect of situational/contextual factors on crew motivation and performance, all these studies focused on very limited number of situational/contextual factors. There were not studies to investigate a comprehensive set of situational/contextual factors and to assess their effect on the relationship between crew motivation and performance. **Thirdly**, there was a lack of a comprehensive set of construction crew performance metrics that relate not only to task performance, but also to contextual performance and counterproductive behaviour. **Fourthly**, the relationships between crew motivational factors, situational/contextual factors and crew performance were not thoroughly investigated in past research in the construction domain. **Fifthly**, the key moderators of the relationship between crew motivation and performance were not comprehensively studied and determined. **Sixthly**, there were no simulation models for the analysis of crew motivation and performance that are able to capture the complexities involved in the interactions of crews,

Seventhly, available modeling techniques such as agent-based modeling (ABM) had limitations in modeling subjective uncertainties involved in construction variables (e.g., crew motivation) and relationships (e.g., the relationship between crew motivation and performance). Thus, the implementation of ABM in modeling the relationship between crew motivation and performance was very limited. To address the identified gaps in construction on crew motivation and performance, this research was conducted in four stages: (1) identifying factors affecting construction crew motivation and performance; (2) assessing the identified factors by designing, administering, and analyzing the interview surveys; (3) quantifying motivational factors, situational/contextual factors, and crew performance metrics; collecting and analyzing field data; (4) developing FABM methodology and implementing the developed methodology to model construction crew motivation and performance.

In the ***first stage*** of this research, the factors affecting construction crew motivation and performance were identified. The methodological approach, which was applied to identify the factors affecting construction crew motivation and performance were presented in chapter 2. The primary list of factors was identified from existing literature in both construction and non-construction domains. A motivation expert provided his expertise regarding the initial list of motivational factors. To capture the reality of construction crew dynamics, this research examined the motivational factors that operate at both the individual and crew levels. Then, the list of factors was reviewed in a workshop by 10 construction experts. The experts proposed additional factors they thought may affect construction crew motivation and performance and reached consensus on the proposed additional factors; the list of factors was then updated to include the proposed factors. This process allowed for the development of a comprehensive list of factors that not only considers the literature in construction and non-construction domains, but that also captures the opinions of both motivation and construction experts. Four motivational concepts were identified that operate at both individual and crew levels: efficacy, commitment/engagement, identification, and cohesion. Next, a list of 163 factors affecting construction crew motivation and performance was identified, which were presented in chapter 2.

In the *second stage* of this research, the identified factors affecting construction crew motivation and performance were assessed by designing, administering, and analyzing two interview surveys. The methodology for designing, administering and analyzing the interview surveys were provided in chapter 2. Two separate interview surveys, the supervisor survey and the crafts survey, were designed in this research to reveal differences between the perspectives of supervisors and craftspeople. The surveys were administered in the form of structured interview survey in a participant company. Next, Critical factors, as well as factors with a high potential for improvement in crew motivation and performance, were identified, and the perspective of supervisors and craftspeople on critical factors affecting crew motivation and performance were compared. To identify the critical factors affecting construction crew motivation and performance, factor rank was calculated based on evaluation scores, the latter of which take into consideration both the agreement and importance of factors. Then, the potential improvement of each factor was calculated using the weighted percentage of disagreement and the weighted percentage of relative importance to each factor. The result of analysis of critical factors influencing, as well as, the factors with a high potential for improvement in crew motivation and performance were presented in chapter 2. A comparative analysis of supervisor and craft survey results was performed to reveal the differences in perspectives between each group. Statistical tests, including *t*-tests and *F*-tests, were performed to determine if there was a statistically significant difference between the mean and variance of the evaluations of supervisors and craftspeople. The results of both the *t*-test and

F-test indicate that there were some areas of disagreement between supervisors and craftspeople. The areas with the highest difference in evaluation scores of supervisors versus craftspeople were identified and presented in chapter 2.

In the *third stage* of this research, motivational factors, situational/contextual factors, and crew performance metrics were quantified. First, factor analysis was performed on the survey data to check the validity and reliability of the identified motivational measures for each motivational factor. The results of factor analysis showed both the validity and reliability of motivational measures. Following the factor analysis, a novel and comprehensive set of construction crew performance metrics was defined, which included KPIs related to task performance, contextual performance, and counterproductive behaviour. Second, field data were collected on crew motivational factors, situational/contextual factors, and crew performance metrics for several crews working on different work packages, and over the three-month timeline of an industrial construction project. Third, field data analysis was performed to investigate the relationship between crew motivational factors and crew performance and to identify key moderators of the relationship between crew motivation and performance. The results of correlation analysis, which were performed to investigate the relationship between crew motivational factors and crew performance metrics, were presented in chapter 3. The results suggested that all motivational factors had a weak positive relationship with task performance, a moderate to strong positive relationship with contextual performance, and a moderate to strong negative relationship with counterproductive behaviour. Based on these results, the researchers suggested that promoting positive interactions among crew members, such as more interactive site orientations, safety meetings, or daily meetings, would improve crew performance. Among the motivational factors, commitment/engagement was shown to have the strongest relationship to crew performance, followed by cohesion, then efficacy, and finally identification. Fourth, Hierarchical regression analysis was performed to identify the key moderators of the relationship between crew motivation and performance. The results of the performed hierarchical regression analysis were presented in chapter 3. Among the 129 investigated situational/contextual factors, 14 were shown to have a moderating effect: task type, task repetition, visibility of outcome, crew size, foreman knowledge, performance monitoring, communication, goal setting, working relationship, building trust, project time management, project cost management, location of facilities, and congestion. The situational/contextual factor sub-category of foreman behavioural skills was shown to have the highest number of moderators, suggesting the importance of foreman behavioural skills on the relationship between crew motivation and performance.

In the *fourth stage* of this research, FABM methodology was developed, and the developed methodology was implemented to model construction crew motivation and performance. Following a literature review of the applications of ABM in construction research, the limitations in current ABM research were identified. To address the limitations of ABM and to improve the effectiveness of ABM, a methodology was proposed to integrate fuzzy logic with ABM and to develop fuzzy agent-based models in construction. In the proposed methodology, agents were able to receive and process fuzzy variables and decide based on fuzzy rules. Fuzzy C-means (FCM) clustering was used to develop fuzzy sets of agent attributes, as well as, agent behavioural rules. Mathematical formulas based on past research were used to define the interaction of agents. Anylogic® and MATLAB® were connected using Java programming to provide a fuzzy agent-based simulation platform. Then, the proposed methodology of developing FABM was used to develop a fuzzy agent-based model of construction crew motivation and performance. The model was able to predict the performance of construction crews using input variables such as crew motivational and situational/contextual variables. The model was also able to account for the diversity of crews, crew interactions, the variations of crew motivation over time, the variations in the situation in which crews are performing. Based on the simulation experimentation results, which were presented in chapter 5, the developed fuzzy agent-based model was able to predict the performance of construction crews in the project by considering not only the complexities related to agent interactions but the subjective uncertainties involved in the construction system as well. The developed fuzzy agent-based model was then verified and validated using field data collected from a company active in various industrial construction projects in Canada.

5.2. Research Contributions

5.2.1. Academic Contributions

The main academic contributions of this research are as follows:

1. *Presenting a novel methodology for identifying and measuring motivational factors at both the individual and crew levels. Providing a comprehensive set of factors affecting crew motivation and performance; and developing a comprehensive set of construction crew performance metrics that relate not only to task performance, but also to contextual performance and counterproductive behaviour*. The developed methodology explicitly defines each motivational factor, establishes their measures, and defines data sources and data collection cycles. Thus, the developed methodology provides researchers a means for collecting and measuring accurate and valid data on crew motivational factors. The methodology also advances the existing literature on motivation in construction domain by addressing the sources of motivation at both the individual and crew levels. Past research

on motivation in construction only focused on a very limited number of situational/contextual factors. There was also a need for a comprehensive set of construction crew performance metrics, which include contextual performance and counterproductive behaviour. Thus, the identified set of situational/contextual factors and the identified crew performance metrics provide researchers with a more comprehensive means for collecting and analyzing crew motivation and performance data in construction.

2. *Defining a methodology to evaluate and rank critical factors and factors with a high potential for improvement in construction crew motivation and performance and to evaluate the differences between the perspectives of supervisors and craftspeople on the identified critical factors*. The defined methodology can also be used to evaluate the differences between supervisors and craftspeople perspectives on critical factors affecting construction crew motivation and performance; and therefore, to help in mitigating or eliminating the sources of differences between supervisors and craftspeople. The defined methodology can also be used to evaluate and rank the factors in different contexts in construction such as building construction.

3. *Revealing how motivational factors affect crew performance; and providing a comprehensive list of the key moderators of the relationship between construction crew motivation and performance*. Research in construction faced an important challenge of how to determine the relationships that exist between motivational factors, situational/contextual factors, and crew performance. Thus, the results of the analysis of motivational factors and crew performance metrics, as well as, the identified list of the moderators provides researchers in construction the domain with a better understanding of

the relationships that exist between motivational factors, situational/contextual factors, and crew performance.

4. *Expanding the scope of applicability of ABM by integrating fuzzy logic with ABM to create fuzzy agent-based models, which can handle both probabilistic and subjective uncertainty. Providing a novel methodology for developing fuzzy agent-based models, which can be used to develop new models to assess construction processes and practices.* Agent-based models in construction defined agent attributes using probabilistic or deterministic variables; yet, there was a need to define subjective variables which exist in construction systems. This research provided a framework which uses fuzzy C-means (FCM) clustering to construct fuzzy sets for agent attributes and fuzzy rules for agents' behavioural rules. Thus, the developed framework enables ABM in modeling subjective variables and relationships in construction. The developed methodology is a step by step procedure that explains how to develop fuzzy agent-based models in construction. It includes explanations of how to determine a fuzzy agent-based model architecture, the basic structure of agents, agent interactions, and agent behavioural rules, as well as, how to perform FABM simulation experiments. The FABM methodology is useful to construction researchers in modeling construction processes and practices that not only have interactive components (i.e., a capability of ABM) but also involve subjective uncertainty (i.e., a limitation in ABM).

5. *Developing a fuzzy agent-based model of construction crew motivation and performance, which improves the assessments of crew performance by considering not only the interactions of crews in the project but also the subjective uncertainties in the model*

variables such as crew motivation. There were no simulation models in construction for modelilng crew motivation and performance. The developed model enables researchers to assess crew performance in construction projects based on the variations in crew motivation and the situation in which crews are performing their work. The application of the developed model can be generalized to projects in different contexts in construction by tuning the membership functions and fuzzy rules based on collected field data in the new context.

5.2.2. Industrial Contribution

The main industrial contributions of this research are as follows:

1. *Establishing a comprehensive list of factors affecting crew motivation and performance. Providing a list of factors with significant differences between the perspectives of supervisors and craftspeople on the critical factors affecting crew motivation and performance.* The identified list of factors provides construction practitioners with the factors that are critical and require improvement. A similar methodology of factor identification can be implemented in new projects in other construction contexts such as building construction, to identify context-specific list of critical factors and factors with a high potential for improvement in construction crew motivation and performance. The identified factors, with significant differences between the perspectives of supervisors and craftspeople, help construction managers to understand the areas of differences between the perspectives of supervisors and craftspeople in the industrial projects. The provided information can be used to eliminate or mitigate the source of differences in opinions of

the two groups. The methodology used to identify these factors can also be implemented in other project in different contexts in construction.

2. *Establishing a comprehensive list of key performance indicators (KPIs) to measure construction crew performance metrics that relate not only to task performance, but also to contextual performance and counterproductive behaviour.* The identified KPIs can be used by industry practitioners to evaluate the performance of crafts in construction projects. They can also be used to identify how close each KPI is to its desired values and thus provide useful information for construction managers to be used to improve crew performance.

3. *Presenting a data collection protocol that provides detailed guidelines for industry practitioners to perform labour motivation and performance improvement studies.* Data collection cycle are defined for various types of work packages in construction projects. The sources of data collection for each factor are also identified in the protocol. The protocol enables the industry practitioner to record the situation in which crews are performing and to measure actual levels of crew motivation and performance in construction projects.

4. *Providing a comprehensive list of the key moderators of the relationship between construction crew motivation and performance,* which can be used to improve crew performance in construction projects by improving the situational/contextual factors which have a stronger moderating effect on the motivation-performance relationship.

5. *Developing a fuzzy agent-based model of construction crew motivation and performance* that enables construction practitioners to assess crew performance based on the variations

in motivational factors and situational/contextual factors, and to develop and simulate new scenarios to identify and assess the effect of different combinations of crew motivation of overall crew performance in the project.

5.3. Suggested Practices to Improve Crew Motivation and Performance

Several suggestions are presented based on the results of this research to improve crew motivation and performance. These suggestions need to be examined across more companies and projects in order to be claimed as a best practice. Yet, they provide a base for future research studies.

Suggested practices to improve crew motivation and performance are as follows:

1. Precise project planning and monitoring should be performed in construction projects to improve management-related factors such as project time management and project cost management.
2. The skills of craftspeople should be improved by training programs.
3. The functional and behavioural skills of foremen should be improved, with a particular focus on behavioural skills.
4. Areas of disagreement between the perspectives of supervisors and craftspeople related to the factors affecting crew motivation and performance should be identified in each project, and the difference in perspectives should be mitigated.
5. All motivational factors (i.e., efficacy, commitment/engagement, identification, and cohesion) need to be improved, particularly those with stronger relationships to crew performance such as commitment/engagement and cohesion.

6. To achieve higher levels of crew performance, it is important to improve the moderators of the relationship between crew motivation and performance, such as visibility of outcome, location of site facilities, and congestion in working area.

7. To improve crew performance, positive interactions among crew members need to be promoted by more interactive site orientations, safety meetings, or daily meetings.

5.4. Research Limitations and Recommendations for Future Research

Research limitations and the recommendations for future research are presented in this section.

1. *Identifying factors affecting construction crew motivation and performance*. In this research, 129 situational/contextual factors had been identified at the crew and projects levels. Situational/contextual factors at the organization-level such as company culture were not included in this research. Situational/contextual factors at the organization-level may affect crew motivation and performance. It is also possible that organization-level factors, such as company culture or company regulations, affect other situational/contextual factors at the project or crew levels, such as resources or safety. In future, the situational/contextual factors at the organization level should be added to the list of factors and various organizations should be studied to observe the effect of organization-level factors on crew motivation and performance.

2. *Designing, administering, and analyzing the interview surveys*. In this research, the interview surveys were administered in one construction company. There is a limitation

related to the confidence level of the results of the interview surveys. The participating supervisors provided a 99% confidence level with a 10% margin of error for the results of survey analysis. However, it should be noted that the response rate of craftspeople was lower than that of supervisors, and the participating craftspeople provided an 80% confidence level with a 10% margin of error for the results of survey analysis. Thus, this limitation only applies to the result of crafts survey analysis. In future research, the surveys should be administered in other projects to increase the confidence level of the survey analysis results.

3. *Quantifying motivational factors, situational/contextual factors, and crew performance metrics; collecting and analyzing field data*. In this research, field data were collected from one company active in industrial projects in Canada; therefore, the context that the study covers is limited and there is a need to collect data from other projects to be able to generalize the results to a broader context. In this research, the results of field data analysis especially regarding the situational/contextual factors, are limited to the context of industrial projects. For example, the statistically significant results such as the correlations discussed in Chapter 3 can be generalized to the industrial context, but they are not valid in the building construction context. In future, data from projects in other contexts such as building construction should be collected to investigate the effect of situational/contextual factors in other contexts in construction on the relationship of crew motivation and performance.

4. *Integrating fuzzy logic and ABM*. Fuzzy sets for agent attributes and fuzzy rules for agents' behavioural rules were constructed using fuzzy C-means (FCM) clustering. FCM clustering is a well-known data-driven approach, which is one of the most commonly used methods of fuzzy clustering. Using FCM clustering, the fuzzy sets representing the linguistic terms, as well as, fuzzy rules representing crew behavioural rules are defined. One of the limitations regarding the use of FCM clustering is the fact that in the FCM clustering algorithm, the input and output variables are equality weighted for the calculation of the distances of data instances to each cluster center. The ability of introduce different weights to input and output variables, and also different weights to different input variables in the FCM clustering algorithm is an area for future research.

5. *Developing FABM methodology and implementing the developed methodology to model construction crew motivation and performance*. In this research, the developed model is based on the collected field data from multiple crews in one construction project. The developed model can be used to assess crew performance in projects with similar context. The application of the developed model can be generalized to projects in different contexts in construction by tuning the membership functions and fuzzy rules based on collected field data in the new context. To do so, data should be collected from projects in a new context, and the methodology of this research to develop new fuzzy membership functions and new fuzzy rules should be followed. The newly developed fuzzy inference system would be used in the new context. However, the ABM part of the model would not change in the new context except that a new project needs to be simulated with new initial conditions.

6. *Further analysis of the developed model*. In the future, face validation of the results of the developed fuzzy agent-based model needs to be performed. Sensitivity analysis should also be performed to check the effect of variations in model parameters on the results of the developed fuzzy agent-based model. Various scenarios should be developed and simulated, such as a project with different combinations of crew motivation, to compare the performance of crews in different scenarios. Monte Carlo simulation can also be performed in the developed fuzzy agent-based model in order to observe the effect of probabilistic uncertainty that exists in a construction system. By performing Monte Carlo simulation, it is possible to show the effect of variability in the model parameters (i.e., parameters having probability distributions) on the output of the model (crew performance) leading to analysis of gains and losses in crew performance.

7. *Further expansion of the developed model*. The model should be expanded to the organization level by adding the organization class to the model to be able to simulate different projects of an organization. Furthermore, the developed model considers the interactions between crews, but the interactions between the crew members are not included. Future development of the model can be done by adding crew member agents to the model and crew member interactions. Another expansion of the model can be done by modeling situational/contextual factors at the lower levels of analysis (i.e., adding more details in the agent classes) to be able to see the effect of each lower-level factor on crew performance. To do so, there is a need to introduce sub-variables for situational/contextual factors in the fuzzy inference system to predict situational/contextual factors from sub-variables. It is also possible to introduce various types of crew agents (e.g., welding crew agent, excavation crew agent, sandblasting crew agent) with different crew interactions to

model task interdependence between different tasks. Further analysis can be performed in order to investigate the applicability of introducing feedback loops to the model, for example the effect of feedback on task performance on the efficacy of crews can be investigated. Future research should also investigate the applicability of using fuzzy rule-based system for defining agent interactions to address the subjective uncertainties that exist in the interactions among model agents. The developed fuzzy inference system can also be advanced by introducing different weights to input variables and by experimenting with different t-norms in fuzzy rules such as product t-norm. Current agent-based models treat moderator variables as input variables, and they assume independence of all variables. By using FABM, it is possible to not only introduce weights to input variables but also to use different t-norms in the fuzzy inference system. Introducing weights to input variables enables the model to consider the relative importance of input variables; and using different t-norms in the fuzzy inference systems enables the model to account for the interaction of variables, possibly accounting for moderator effect of variables on the relationship between input and output variables. Thus, input variable weights and experimentation with different t-norms may improve the ability of the FABM technique to process the subjective uncertainties in the system by selecting the most appropriate method for the implementation of fuzzy inference in FABM.

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Appendices

Appendix A. Data Collection Procedure

Appendix A discusses the data collection procedure which had been followed to collect filed data from an industrial project in Alberta, Canada. As the first step of data collection, two interview surveys were administered on the project in 2016. In the second step, field data were collected. This report presents the details of data collection (e.g., frequency of data collection and sources of data collection) and the field data collection forms.

The following types of data were collected for the project under study: crew motivational factors, situational/contextual factors, and crew performance metrics. These groups of collected factors are the variables for construction crew motivation and performance that were used in this research. This report describes in detail each type of data that was collected, as well as the sources and methods for data collection. This report is organized as follows: Section A.1 describes the frequency of data collection; Section A.2 presents the details of data collection participants; Section A.3 presents the field data collection forms.

Appendix A.1. Data Collection Frequency

Field data for this study were collected over the three-month timeline of the project. Table A.1 shows the data collection frequency for work packages with a duration of two weeks or more. It should be noted that a five-day work week is used in Table A.1, and the selected dates were chosen randomly. The data collection dates could be different from one project to the next if there is a different number of working days in a week. However, the frequency of data collection for each week kept equal to or higher than the values presented in Table A.1.

Table A.1. Data collection frequency for work packages with a duration of two weeks or more

Week No.	Bi-Weekly Work Packages							
	Frequency of Data Collection (% of working days in each week)	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Week 1	100%	√	√	√	√	√		
Week 2	40%		√			√		
Week 3	40%	√		√				
Week 4	40%		√			√		
Week 5	40%	√		√				
Week 6	40%			√	√			
Week 7	40%		√			√		
Week 8	40%		√		√			
Week 9	40%	√				√		
Week 10	40%			√	√			
Week 11	40%		√			√		
Week 12	40%			√	√			

Appendix A.2. Data Collection Participants

Participants in the data collection were crew members, foremen, and project managers. For each participating crew, the project manager, the direct foreman of the crew, and randomly selected members of the crew provided data. For small crews of three members or less, all crew members had been selected to participate in data collection. For larger crews, at least three crew members had been randomly selected to participate in data collection. Data were collected using the data collection forms that were provided in the appendices of this report. An explanation of the data collection forms and the respondents to each form are presented in the following sections. Figure A.1 shows the data collection participants.

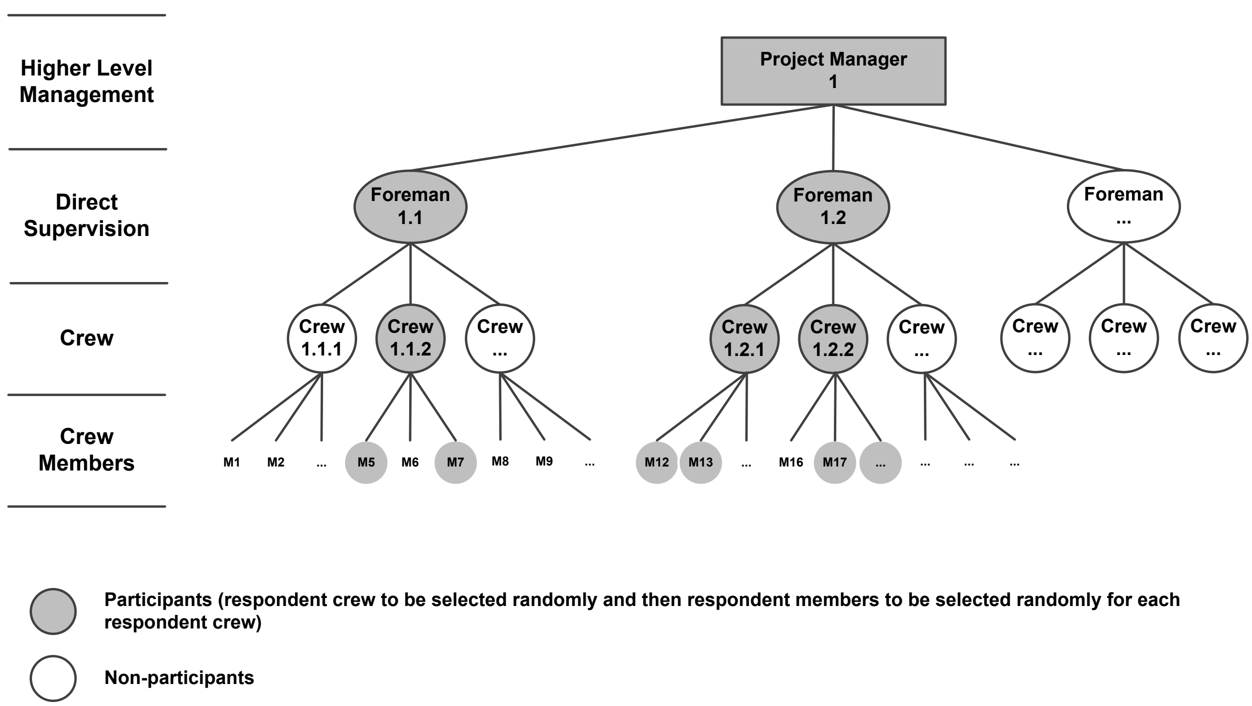

Figure A. 1. Data collection participants

Appendix A.3. Data Collection of Crew Motivational Factors

For each day of field data collection, the daily plan was sent by project staff to the data collector. Based on the daily plan, the data collector randomly selected the crews to be studied from the available crews working that day. For each selected crew, randomly selected members performed a self-evaluation on their individual-level motivational factors. Then, the supervisor of the responding crew evaluated the crew-level motivational factors. Self-evaluation was used to determine the values of individual-level motivational factors, while supervisor evaluation was used to determine the values of crew-level motivational factors. The forms for data collection of motivational factors from foremen and crew members are shown in Appendices B.1 and B.2, respectively.

Appendix A.4. Data Collection of Situational/Contextual Factors

As with motivational factors, situational/contextual factors were collected from foremen, the project manager, and project staff for each participating crew on each day of field data collection (see Appendix A.1 for data collection frequency). The form for data collection of situational/contextual factors of the study, including the data collection source for each factor, is shown in Appendix C.

Appendix A.5. Data Collection of crew Performance Metrics

Crew performance metrics include task performance, contextual performance, and counterproductive behaviour. For task performance, actual project documents (e.g., time sheets, score cards, change order logs, inspection test plans, schedule updates, tender documents, and cost estimates) were used to extract available construction crew performance data. the project under study had a complete set of project documentation regarding task performance. However, for the cases that task performance data would not be available from the mentioned sources, the task performance form, shown in Appendix D, was designed to be completed by project staff. For contextual performance and counterproductive behaviour, evaluation forms were distributed to participating crew members (self-evaluation) and foremen (supervisor evaluation). Appendix E shows the data collection form for supervisor evaluation of contextual performance and counterproductive behaviour, which were completed by foremen. Appendix F shows the data collection form for self-evaluation of contextual performance and counterproductive behaviour, which were completed by crew members.

Appendix B. Data Collection Forms for Crew Motivational Factors

Appendix B.1. Supervisor Evaluation Form (Completed by Foreman)

Supervisor Evaluation Form for Crew Motivational Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
1.2	**Crew-level Motivational Factors**					
1.2.1	**Crew Cohesion**					
1.2.1.1	Crew cohesion – assessed at the crew level	1 - 5 Predetermined rating	Foreman		Crew members: Get along well together; Defending each other from criticism; Crew being a close one	1. Crew members VERY RARELY Getting along well together; Crew members VERY RARELY Defending each other from criticism; Crew NOT being a CLOSE one 2. Crew members RARELY Getting along well together; Crew members RARELY Defending each other from criticism; Crew NOT being a CLOSE one 3. Crew members SOMEWHAT Getting along well together; Crew members SOMEWHAT Defending each other from criticism; Crew NEITHER being a CLOSE one NOR NOT being a CLOSE one 4. Crew members OFTEN Getting along well together; Crew members OFTEN Defending each other from criticism; Crew being a CLOSE one 5. Crew members VERY OFTEN Getting along well together; Crew members VERY OFTEN Defending each other from criticism; Crew being a CLOSE one
1.2.2	**Collective efficacy**					
1.2.2.1	Collective efficacy – assessed at the crew level	1 - 5 Predetermined rating	Foreman		Crew confidence in ability to perform tasks effectively; Crew confidence in ability to perform difficult tasks; and Crew ability to concentrate on performing tasks	1. Crew having VERY LOW Confidence in ability to perform tasks effectively; VERY LOW Confidence in successfully performing difficult tasks effectively; VERY LOW ability to concentrate on performing tasks 2. Crew having LOW Confidence in ability to perform tasks effectively; LOW Confidence in successfully performing difficult tasks effectively; LOW ability to concentrate on performing tasks 3. Crew having AVERAGE Confidence in ability to perform tasks effectively; AVERAGE Confidence in successfully performing difficult tasks effectively; AVERAGE ability to concentrate on performing tasks 4. Crew having HIGH Confidence in ability to perform tasks effectively; HIGH Confidence in successfully performing difficult tasks effectively; HIGH ability to concentrate on performing tasks 5. Crew having VERY HIGH Confidence in ability to perform tasks effectively; VERY HIGH Confidence in successfully performing difficult tasks effectively; VERY HIGH ability to concentrate on performing tasks

Supervisor Evaluation Form for Crew Motivational Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
1.2.3	**Crew Identification**					
1.2.3.1	Crew identification – assessed at the crew level	1 - 5 Predetermined rating	Foreman		Crew members: Feeling proud to be part of the crew; Identify with the other members of the crew; like to continue working with the crew	1. Crew members: have VERY WEAK Sense of being proud to be part of the crew; VERY WEAKLY Identify with the other members of the crew; DISLIKE A LOT To continue working with the crew 2. Crew members: have WEAK Sense of being proud to be part of the crew; WEAKLY Identify with the other members of the crew; DISLIKE To continue working with the crew 3. Crew members: have AVERAGE Sense of being proud to be part of the crew; Identify with the other members of the crew; NEITHER LIKE NOR DISLIKE To continue working with the crew 4. Crew members: have STRONG Sense of being proud to be part of the crew; STRONGLY Identify with the other members of the crew; LIKE To continue working with the crew 5. Crew members: have VERY STRONG Sense of being proud to be part of the crew; VERY STRONGLY Identify with the other members of the crew; LIKE A LOT To continue working with the crew
1.2.4	**Crew Commitment/ Engagement**					
1.2.4.1	Crew commitment/engagement –assessed at the crew level	1 - 5 Predetermined rating	Foreman		Crew members: Being very happy to spend the rest of career with the organization; Sense of "belonging" to the organization; Feeling like "part of the family" at the organization	1.VERY UNHAPPY To spend the rest of career with the organization; VERY WEAK Sense of "belonging" to the organization; VERY WEAK Feeling like "part of the family" at the organization 2. UNHAPPY To spend the rest of career with the organization; WEAK Sense of "belonging" to the organization; WEAK Feeling like "part of the family" at the organization 3. NEITHER HAPPY NOR UNHAPPY To spend the rest of career with the organization; AVERAGE Sense of "belonging" to the organization; AVERAGE Feeling like "part of the family" at the organization 4. HAPPY To spend the rest of career with the organization; STRONG Sense of "belonging" to the organization; STRONG Feeling like "part of the family" at the organization 5. VERY HAPPY To spend the rest of career with the organization; VERY STRONG Sense of "belonging" to the organization; VERY STRONG Feeling like "part of the family" at the organization

Appendix B.2. Self-Evaluation Form (Completed by Crew Members)

Self-Evaluation Form for Crew Motivational Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
1.1	**Individual-level Motivational Factors**					
1.1.1	**Crew Cohesion**					
1.1.1.1	Crew cohesion – assessed at the individual level	1 - 5 Predetermined rating	Crew Member		Feel to be a part of the crew; Like to be with crew members; Get along with other crew members	1. VERY WEAK Feeling to be a part of the crew; VERY LOW Interest in being with crew members; VERY RARELY Getting along with other crew members 2. WEAK Feeling to be a part of the crew; LOW Interest in being with crew members; RARELY Getting along with other crew members 3. SOMEWHAT Feeling to be a part of the crew; AVERAGE Interest in being with crew members; SOMEWHAT Getting along with other crew members 4. STRONG Feeling to be a part of the crew; HIGH Interest in being with crew members; OFTEN Getting along with other crew members 5. VERY STRONG Feeling to be a part of the crew; VERY HIGH Interest in being with crew members; VERY OFTEN Getting along with other crew members
1.1.2	**Self-Efficacy**					
1.1.2.1	Self-efficacy –assessed at the individual level	1 - 5 Predetermined rating	Crew Member		Self-confidence in ability to perform tasks effectively; Self-confidence in ability to perform difficult tasks; Ability to concentrate on performing tasks	1. VERY LOW Self-confidence in ability to perform tasks effectively; VERY LOW Self-confidence in successfully performing difficult tasks effectively; VERY LOW Ability to concentrate on performing tasks 2. LOW Self-confidence in ability to perform tasks effectively; LOW Self-confidence in successfully performing difficult tasks; LOW Ability to concentrate on performing tasks 3. AVERAGE Self-confidence in ability to perform tasks effectively; AVERAGE Self-confidence in successfully performing difficult tasks; AVERAGE Ability to concentrate on performing tasks 4. HIGH Self-confidence in ability to perform tasks effectively; HIGH Self-confidence in successfully performing difficult tasks; HIGH Ability to concentrate on performing tasks 5. VERY HIGH Self-confidence in ability to perform tasks effectively; VERY HIGH Self-confidence in successfully performing difficult tasks; VERY HIGH Ability to concentrate on performing tasks

Self-Evaluation Form for Crew Motivational Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
1.1.3	**Crew Identification**					
1.1.3.1	Crew identification – assessed at the individual level	1 - 5 Predetermined rating	Crew Member		Feeling proud to be part of the crew; Identification with the other members of the crew; Like to continue working with the crew	1.VERY WEAK Sense of being proud to be part of the crew; VERY LOW Identification with the other members of the crew; DISLIKE A LOT To continue working with the crew 2. WEAK Sense of being proud to be part of the crew; LOW Identification with the other members of the crew; DISLIKE To continue working with the crew 3. AVERAGE Sense of being proud to be part of the crew; AVERAGE Identification with the other members of the crew; NEITHER LIKE NOR DISLIKE To continue working with the crew 4. STRONG Sense of being proud to be part of the crew; HIGH Identification with the other members of the crew; LIKE To continue working with the crew 5. VERY STRONG Sense of being proud to be part of the crew; VERY HIGH Identification with the other members of the crew; LIKE A LOT To continue working with the crew
1.1.4	**Crew Commitment/ Engagement**					
1.1.4.1	Crew commitment/engagement –assessed at the individual level	1 - 5 Predetermined rating	Crew Member		Being very happy to spend the rest of career with the organization; Sense of "belonging" to the organization; Feeling like "part of the family" at the organization	1.VERY UNHAPPY To spend the rest of career with the organization; VERY WEAK Sense of "belonging" to the organization VERY WEAK Feeling like "part of the family" at the organization 2. UNHAPPY To spend the rest of career with the organization; WEAK Sense of "belonging" to the organization; WEAK Feeling like "part of the family" at the organization 3. NEITHER HAPPY NOR UNHAPPY To spend the rest of career with the organization; AVERAGE Sense of "belonging" to the organization; AVERAGE Feeling like "part of the family" at the organization 4. HAPPY To spend the rest of career with the organization; STRONG Sense of "belonging" to the organization; STRONG Feeling like "part of the family" at the organization 5. VERY HAPPY To spend the rest of career with the organization; VERY STRONG Sense of "belonging" to the organization; VERY STRONG Feeling like "part of the family" at the organization

Appendix C. Data Collection Forms for Situational/Contextual Factors

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
2.1	**Task Related Factors**					
2.1.1	**Task Characteristics**					
2.1.1.1	Task type	Categorical	Foreman		1. Civil; 2. Mechanical; 3. Electrical; 4. Instrument	
2.1.1.2	Task size	Real number (Quantity)	Foreman			Total quantity in work package
2.1.1.3	Task complexity	1 - 5 Predetermined rating	Foreman		Number of subtasks; Number of alternatives to do the task; Unknown means	1. VERY FEW No. of subtasks; MANY Alternatives; WELL KNOWN Means 2. FEW No. of subtasks; SOME Alternatives, WELL KNOWN Means 3. AVERAGE No. of subtasks; FEW Alternatives, KNOWN Means 4. HIGH No. of subtasks; FEW Alternatives, UNKNOWN Means 5. VERY HIGH No. of subtasks; VERY FEW Alternatives; UNKNOWN Means
2.1.1.4	Task repetition	Percentage (% No. of identical tasks in work package to total No. of tasks in work package)	Foreman		Range (0 -100)	
2.1.1.5	Task interruption and disruption	Integer (Average number of interruption and disruption events per day)	Foreman		Range (0 - 20)	
2.1.2	**Task Design**					
2.1.2.1	Skill variety	1 - 5 Predetermined rating	Foreman			1. VERY LOW variety in skills required to do the tasks 2. LOW variety in skills required to do the tasks 3. AVERAGE variety in skills required to do the tasks 4. HIGH variety in skills required to do the tasks 5. VERY HIGH variety in skills required to do the tasks
2.1.2.2	Task identity	Percentage (% volume of work in work package to total volume of work in the whole project)	Foreman		Range (0 -100)	

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
2.1.2.3	Task significance	1 - 5 Predetermined rating	Foreman			1. Tasks have VERY LOW impact on the work of others 2. Tasks have LOW impact on the work of others 3. Tasks have AVERAGE impact on the work of others 4. Tasks have HIGH impact on the work of others 5. Tasks have VERY HIGH impact on the work of others
2.1.2.4	Visibility of outcome	1 - 5 Predetermined rating	Crew Member			1. Performing the tasks provides crew members VERY LOW visibility of the outcomes of the work 2. Performing the tasks provides crew members LOW visibility of the outcomes of the work 3. Performing the tasks provides crew members AVERAGE visibility of the outcomes of the work 4. Performing the tasks provides crew members HIGH visibility of the outcomes of the work 5. Performing the tasks provides crew members VERY HIGH visibility of the outcomes of the work
2.1.2.5	Flexibility in scheduling	1 - 5 Predetermined rating	Foreman			1. Crew members have a VERY LOW degree of freedom in scheduling their tasks. 2. Crew members have a LOW degree of freedom in scheduling their tasks. 3. Crew members have an AVERAGE degree of freedom in scheduling their tasks. 4. Crew members have a HIGH degree of freedom in scheduling their tasks. 5. Crew members have a VERY HIGH degree of freedom in scheduling their tasks.
2.1.2.6	Flexibility in procedures	1 - 5 Predetermined rating	Foreman			1. Crew members have a VERY LOW degree of freedom in selecting the procedures to carry out the tasks. 2. Crew members have a LOW degree of freedom in selecting the procedures to carry out the tasks. 3. Crew members have an AVERAGE degree of freedom in selecting the procedures to carry out the tasks. 4. Crew members have a HIGH degree of freedom in selecting the procedures to carry out the tasks. 5. Crew members have a VERY HIGH degree of freedom in selecting the procedures to carry out the tasks.

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
2.1.2.7	Feeling of ownership	1 - 5 Predetermined rating	Crew Member			1. Crew members have a VERY WEAK feeling of ownership of the performed work. 2. Crew members have a WEAK feeling of ownership of the performed work. 3. Crew members have an AVERAGE feeling of ownership of the performed work. 4. Crew members have a STRONG feeling of ownership of the performed work. 5. Crew members have a VERY STRONG feeling of ownership of the performed work.
2.1.3	**Rework**					
2.1.3.1	Rework type	Categorical	Foreman		1. Minor, High similarity; 2. Minor, Low similarity; 3. Major, High similarity; 4. Major, Low similarity	
2.1.3.2	Rework frequency	1 - 5 Predetermined rating	Foreman			1. Rework is VERY RARELY required for the task at hand 2. Rework is RARELY required for the task at hand 3. Rework is SOMETIMES required for the task at hand 4. Rework is OFTEN required for the task at hand 5. Rework is VERY OFTEN required for the task at hand
2.1.3.3	Level of rework	Percentage (% of activity total volume of rework to total activity work volume)	Foreman		Range (0 - 100)	Activity Construction Filed Rework Index (CFRI) in terms of Activity total volume of rework to total work volume
2.1.3.4	Rework time requirement	Real number	Foreman		Range (0 - 1)	Rework Time factor as the ratio between total duration of work package rework, and the actual work package duration
2.1.3.5	Rework source	Categorical	Foreman		1. Poor quality of work; 2. Client-initiated change orders; 3. Contractor-initiated change orders	
2.2	**Labour Related Factors**					
2.2.1	**Crew Properties**					
2.2.1.1	Crew size	Integer	Foreman		Range (1 - 20)	

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
2.2.1.2	Crew composition	Integer: No. of journeymen; No. of apprentice (year 4); No. of apprentice (year 3); No. of apprentice (year 2); No. of apprentice (year 1)	Foreman			Note: Record each separately (e.g 2 journeymen, 1 apprentice year 2).
2.2.1.3	Crew knowledge	1 - 5 Predetermined rating	Crew Member & Foreman			1. VERY POOR Knowledge of work methods, procedures, and requirements 2. POOR Knowledge of work methods, procedures, and requirements 3. FAIR Knowledge of work methods, procedures, and requirements 4. GOOD Knowledge of work methods, procedures, and requirements 5. VERY GOOD Knowledge of work methods, procedures, and requirements
2.2.1.4	Crew experience	Number (Average years of experience in current position)	Crew Member & Foreman		Range (1-40)	
2.2.2	**Crew Functional Skills**					
2.2.2.1	Job training	1 - 5 Predetermined rating	Crew Member & Foreman		Effectiveness of participation in job trainings; Sufficiency of job training;	1. VERY INEFFECTIVE Participation of crew members in job trainings; INSUFFICIENT Job trainings are given to crew members 2. INEFFECTIVE Participation of crew members in job trainings; INSUFFICIENT Job trainings are given to crew members 3. SOMEWHAT EFFECTIVE Participation of crew members in job trainings; SUFFICIENT Job trainings are given to crew members 4. EFFECTIVE Participation of crew members in job trainings; SUFFICIENT Job trainings are given to crew members 5. VERY EFFECTIVE Participation of crew members in job trainings; SUFFICIENT Job trainings are given to crew members

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
2.2.2.2	Safety training	1 - 5 Predetermined rating	Crew Member & Foreman		Understanding, communicating and ensuring compliance with safety regulation; Participation in safety trainings; Using PPE	1. VERY POOR in Understanding, communicating and ensuring compliance with safety regulation; VERY INEFFECTIVE participation of crew members in safety trainings; VERY RARELY Using personnel protective equipment (PPE) 2. POOR in Understanding, communicating and ensuring compliance with safety regulation; INEFFECTIVE participation of crew members in safety trainings; RARELY Using personnel protective equipment (PPE) 3. FAIR in Understanding, communicating and ensuring compliance with safety regulation; EFFECTIVE participation of crew members in safety trainings; SOMETIMES Using personnel protective equipment (PPE) 4. GOOD in Understanding, communicating and ensuring compliance with safety regulation; EFFECTIVE participation of crew members in safety trainings; OFTEN Using personnel protective equipment (PPE) 5. VERY GOOD in Understanding, communicating and ensuring compliance with safety regulation; VERY EFFECTIVE participation of crew members in safety trainings; VERY OFTEN personnel protective equipment (PPE)
2.2.2.3	Ability to perform	1 - 5 Predetermined rating	Crew Member & Foreman			1. VERY LOW Ability to perform tasks 2. LOW Ability to perform tasks 3. AVERAGE Ability to perform tasks 4. HIGH Ability to perform tasks 5. VERY HIGH Ability to perform tasks
2.2.2.4	Material handling	1 - 5 Predetermined rating	Crew Member & Foreman			1. VERY INEFFECTIVE 2. INEFFECTIVE 3. SOMEWHAT EFFECTIVE 4. EFFECTIVE 5. VERY EFFECTIVE
2.2.2.5	Hazards identification & mitigation	1 - 5 Predetermined rating	Crew Member & Foreman			1. VERY RARELY Using daily job Hazard assessment forms; VERY INEFFECTIVE in mitigation of identified hazard 2. RARELY Using daily job Hazard assessment forms; INEFFECTIVE in mitigation of identified hazard 3. SOMEWHAT Using daily job Hazard assessment forms; EFFECTIVE in mitigation of identified hazard 4. OFTEN Using daily job Hazard assessment forms; VERY OFTEN in mitigation of identified hazard 5. VERY OFTEN Using daily job Hazard assessment forms; VERY EFFECTIVE in mitigation of identified hazard

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
2.2.3	**Crew Behavioural Skills**					
2.2.3.1	Cooperation	1 - 5 Predetermined rating	Crew Member & Foreman		Accepting others' suggestions; Informing others of work events or requirements	1.VERY RARELY accept other crew members' suggestions; VERY RARELY inform other crew members of work events or requirements 2.RARELY accept other crew members' suggestions; RARELY inform other crew members of work events or requirements 3. SOMEWHAT accept other crew members' suggestions; SOMEWHAT inform other crew members of work events or requirements 4. OFTEN accept other crew members' suggestions; OFTEN inform other crew members of work events or requirements 5. VERY OFTEN accept other crew members' suggestions; VERY OFTEN inform other crew members of work events or requirements
2.2.3.2	Teamwork	1 - 5 Predetermined rating	Crew Member & Foreman			1. VERY RARELY put team objectives over own personal interests 2. RARELY put team objectives over own personal interests 3. SOMEWHAT put team objectives over own personal interests 4. OFTEN put team objectives over own personal interests 5. VERY OFTEN put team objectives over own personal interests
2.2.3.3	Trust in foreman	1 - 5 Predetermined rating	Crew Member			1. VERY LOW Trust 2. LOW Trust 3. AVERAGE Trust 4. HIGH Trust 5. VERY HIGH Trust
2.2.3.4	Crew member participation in foreman decision making	Categorical (Decision Type)	Crew Member & Foreman		1. Not presenting opinions; 2. Just presenting opinions; 3. Joint decision making	
2.2.3.5	Reliability	1 - 5 Predetermined rating	Crew Member & Foreman			1. VERY LOW Reliability on crew member 2. LOW Reliability on crew member 3. AVERAGE Reliability on crew member 4. HIGH Reliability on crew member 5. VERY HIGH Reliability on crew member
2.2.3.6	Adaptability to changes	1 - 5 Predetermined rating	Crew Member & Foreman			1. VERY LOW Adaptability to changes in work package scope and work procedures 2. LOW Adaptability to changes in work package scope and work procedures 3. AVERAGE Adaptability to changes in work package scope and work procedures 4. HIGH Adaptability to changes in work package scope and work procedures 5. VERY HIGH Adaptability to changes in work package scope and work procedures

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
2.3	**Foreman Related Factors**					
2.3.1	**Foreman characteristics**					
2.3.1.1	Foreman age	Number	Foreman			
2.3.1.2	Foreman gender	Categorical	Foreman		1. Female; 2. Male	
2.3.1.3	Foreman knowledge	1 - 5 Predetermined rating	Project Manager			1. VERY POOR Knowledge of work methods, procedures, and requirements 2. POOR Knowledge of work methods, procedures, and requirements 3. FAIR Knowledge of work methods, procedures, and requirements 4. GOOD Knowledge of work methods, procedures, and requirements 5. VERY GOOD Knowledge of work methods, procedures, and requirements
2.3.1.4	Foreman experience	Number (years of experience in current position)	Foreman		Range (1-40)	
2.3.2	**Foreman functional skills**					
2.3.2.1	Planning	1 - 5 Predetermined rating	Project Manager			1. VERY POOR in Planning and Assigning tasks to individuals and crew 2. POOR in Planning and Assigning tasks to individuals and crew 3. FAIR in Planning and Assigning tasks to individuals and crew 4. GOOD in Planning and Assigning tasks to individuals and crew 5. VERY GOOD in Planning and Assigning tasks to individuals and crew
2.3.2.2	Scheduling	1 - 5 Predetermined rating	Project Manager			1. VERY POOR in scheduling of tasks 2. POOR in scheduling of tasks 3. FAIR in scheduling of tasks 4. GOOD in scheduling of tasks 5. VERY GOOD in scheduling of tasks

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
2.3.2.3	Safety facilitation and implementation	1 - 5 Predetermined rating	Project Manager		Knowing, understanding, communicating and ensuring compliance with safety regulation; Providing answers to safety related questions; Participating and completing safety incident reports	1. VERY POOR in Knowing, understanding, communicating and ensuring compliance with safety regulation; ALWAYS NOT Providing answers to safety related questions; VERY POOR in Participating and completing safety incident reports 2. POOR in Knowing, understanding, communicating and ensuring compliance with safety regulation; SOMETIMES NOT Providing answers to safety related questions; POOR in Participating and completing safety incident reports 3. FAIR in Knowing, understanding, communicating and ensuring compliance with safety regulation; ADEQUATE in Providing answers to safety related questions; FAIR in Participating and completing safety incident reports 4. GOOD in Knowing, understanding, communicating and ensuring compliance with safety regulation; ALWAYS Providing answers to safety related questions; GOOD in Participating and completing safety incident reports 5. VERY GOOD in Knowing, understanding, communicating and ensuring compliance with safety regulation; ALWAYS Providing answers to safety related questions; VERY GOOD in Participating and completing safety incident reports
2.3.2.4	Resource management	1 - 5 Predetermined rating	Project Manager		Identifying and Verifying resource requirement and availability; Resource allocation; Skill in resolving resource problems	1. VERY POOR in Identifying & Verifying resource requirement and availability; VERY POOR resource allocation; VERY POOR Skill in resolving resource problems 2. POOR in Identifying & Verifying resource requirement and availability; POOR resource allocation; POOR Skill in resolving resource problems 3. FAIR in Identifying & Verifying resource requirement and availability; FAIR resource allocation; FAIR Skill in resolving resource problems 4. GOOD in Identifying & Verifying resource requirement and availability; GOOD resource allocation; GOOD Skill in resolving resource problems 5. VERY GOOD in Identifying & Verifying resource requirement and availability; VERY GOOD resource allocation; VERY GOOD Skill in resolving resource problems
2.3.2.5	Performance monitoring	1 - 5 Predetermined rating	Project Manager			1. VERY POOR in Assessing competency and capability of crew members to meet quality requirements 2. POOR in Assessing competency and capability of crew members to meet quality requirements 3. FAIR in Assessing competency and capability of crew members to meet quality requirements 4. GOOD in Assessing competency and capability of crew members to meet quality requirements 5. VERY GOOD in Assessing competency and capability of crew members to meet quality requirements

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
2.3.2.6	Communication	1 - 5 Predetermined rating	Project Manager			1. VERY POOR in Communicating to and with the crew 2. POOR in Communicating to and with the crew 3. FAIR in Communicating to and with the crew 4. GOOD in Communicating to and with the crew 5. VERY GOOD in Communicating to and with the crew
2.3.2.7	Team building	1 - 5 Predetermined rating	Project Manager		Use of sport contests, Holiday outings, Picnics, Barbeque events	1. Team building events NOT DONE 2. Team building events DONE, Frequency ATLEAST once a year 3. Team building events DONE, Frequency ATLEAST twice a year 4. Team building events DONE, Frequency ATLEAST six times per year 5. Team building events DONE, Frequency ATLEAST twelve times per year
2.3.3	**Foreman behavioural skills**					
2.3.3.1	Goal-setting	1 - 5 Predetermined rating	Crew Member		Goal clarity; Goal specificity; Goal difficulty	1. VERY POOR Clarity in assignment of goals; VERY LOW Specificity in assignment of goals; VERY EASY Goals are assigned 2. POOR Clarity in assignment of goals; LOW Specificity in assignment of goals; EASY Goals are assigned 3. AVERAGE Clarity in assignment of goals; AVERAGE Specificity in assignment of goals; AVERAGE Difficulty in assignment of goals 4. GOOD Clarity in assignment of goals; HIGH Specificity in assignment of goals; Difficult goals are assigned 5. VERY GOOD Clarity in assignment of goals; VERY HIGH Specificity in assignment of goals; VERY Difficult goals are assigned
2.3.3.2	Feedback	Categorical	Foreman		Yes, No	Provision of feedback on crew members' performance
2.3.3.3	Foreman leadership style	Categorical	Project Manager		1. Transactional; 2. Transformational	
2.3.3.4	Fairness	1 - 5 Predetermined rating	Crew Member		Consistency (same policy), Reasonableness (use of common sense)	1. VERY INCONSISTENT Work assignment among crew members, Unreasonable work assignment among crew members 2. INCONSISTENT Work assignment among crew members, Unreasonable work assignment among crew members 3. SOMEWHAT Consistent work assignment among crew members, Reasonable work assignment among crew members 4. CONSISTENT Work assignment among crew members, Reasonable work assignment among crew members 5. VERY CONSISTENT Work assignment among crew members, Reasonable work assignment among crew members
2.3.3.5	Foreman decision making style	Categorical	Project Manager		1. Autocratic; 2. Democratic; 3. Participative; 4. Goal-oriented; 5. Situational	Definition- Situational (foreman applying any one of them depending on the situation)

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
2.3.3.6	Teamwork	1 - 5 Predetermined rating	Crew Member			1. VERY POOR in Promoting, supporting and facilitating teamwork and harmony 2. POOR in Promoting, supporting and facilitating teamwork and harmony 3. FAIR in Promoting, supporting and facilitating teamwork and harmony 4. GOOD in Promoting, supporting and facilitating teamwork and harmony 5. VERY GOOD in Promoting, supporting and facilitating teamwork and harmony
2.3.3.7	Working relationship	1 - 5 Predetermined rating	Crew Member			1. EXTREMELY INEFFECTIVE working relationships 2. INEFFECTIVE working relationships 3. AVERAGE working relationships 4. EFFECTIVE working relationships 5. EXTREMELY EFFECTIVE working relationships
2.3.3.8	Building trust	1 - 5 Predetermined rating	Crew Member			1. VERY LOW mutual respect, reciprocal trust, and interacting obligations between foreman and crew members 2. LOW mutual respect, reciprocal trust, and interacting obligations between foreman and crew members 3. AVERAGE mutual respect, reciprocal trust, and interacting obligations between foreman and crew members 4. HIGH mutual respect, reciprocal trust, and interacting obligations between foreman and crew members 5. VERY HIGH mutual respect, reciprocal trust, and interacting obligations between foreman and crew members
3.1	**Project Characteristics**					
3.1.1	**Project properties**					
3.1.1.1	Project type	Categorical	Project Manager		1. Commercial; 2. Residential; 3. Industrial; 4. Institutional	
3.1.1.2	Project size	Real number (Project contract value,$ Million)	Project Manager			
3.1.1.3	Project duration	Real number (years)	Foreman			
3.1.1.4	Project location	Categorical	Foreman		1. Edmonton; 2. Calgary; 3. Fort MacMurray	

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
3.1.2	**Work/Job conditions**					
3.1.2.1	Working shifts	Number (Number of consecutive days worked per working cycle)	Foreman		Range (5-14)	
3.1.2.2	Daily working hours	Number	Foreman		Range (8-12)	
3.1.2.3	Camp	Categorical	Foreman		1. Camp; 2. Non-camp	
3.1.2.4	Work permits	Categorical	Foreman		1. Permitted 2. Non-permitted	Permitted: Work permit is required to enter working area; Non-permitted: Work permit is not required to enter working area
3.1.2.5	Project progress	Real Number (% complete of approved construction project cost)	Project Manager		Range (0 -100)	
3.1.3	**Project engineering**					
3.1.3.1	Drawings availability	1 - 5 Predetermined rating	Foreman			1. NEVER Available when needed 2. RARELY Available when needed 3. SOMETIMES Available when needed 4. OFTEN Available when needed 5. ALWAYS Available when needed
3.1.3.2	Specifications availability	1 - 5 Predetermined rating	Foreman			1. NEVER Available when needed 2. RARELY Available when needed 3. SOMETIMES Available when needed 4. OFTEN Available when needed 5. ALWAYS Available when needed
3.1.3.3	Drawings and specifications quality	1 - 5 Predetermined rating	Foreman		Completeness; Readability; Clear information	1. Incomplete; VERY POOR Readability; TOO MANY Unclear information 2. Incomplete; POOR Readability; SOME Unclear information 3. Incomplete; AVERAGE Readability; FEW Unclear information 4. Complete; GOOD Readability; FEW Unclear information 5. Complete; VERY GOOD Readability; VERY FEW Unclear information
3.1.3.4	Response to inquiries (e.g. RFIs, NCRs)	Real number (Avergae response time, hours)	Project Manager		Range (0 - 48)	RFI: request for information; NCR: Non-conformity report
3.1.3.5	Frequency of revisions	Integer (Number of drawing and specification revisions per week)	Project Manager		Range (0-10)	

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
3.2	**Management Related factors**					
3.2.1	**Project manager characteristics**					
3.2.1.1	Project manager age	Number	Project Manager			
3.2.1.2	Project manager gender	Categorical	Project Manager		1. Female; 2. Male	
3.2.1.3	Project manager knowledge	1 - 5 Predetermined rating	Project Manager			1. VERY POOR Knowledge of work methods, procedures, and requirements 2. POOR Knowledge of work methods, procedures, and requirements 3. FAIR Knowledge of work methods, procedures, and requirements 4. GOOD Knowledge of work methods, procedures, and requirements 5. VERY GOOD Knowledge of work methods, procedures, and requirements
3.2.1.4	Project manager experience	Number (years of experience in current position)	Foreman		Range (1-40)	
3.2.2	**Project manager functional skills**					
3.2.2.1	Project planning	1 - 5 Predetermined rating	Foreman		Construction activities; Work packages requirements	1. VERY POOR in Planning construction activities and Identifying work packages requirements 2. POOR in Planning construction activities and Identifying work packages requirements 3. FAIR in Planning construction activities and Identifying work packages requirements 4. GOOD in Planning construction activities and Identifying work packages requirements 5. VERY GOOD in Planning construction activities and Identifying work packages requirements
3.2.2.2	Project scheduling	1 - 5 Predetermined rating	Foreman			1. VERY POOR in scheduling of work packages 2. POOR in scheduling of work packages 3. FAIR in scheduling of work packages 4. GOOD in scheduling of work packages 5. VERY GOOD in scheduling of work packages

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
3.2.2.3	Safety management	1 - 5 Predetermined rating	Foreman		Knowing, understanding, communicating and ensuring compliance with safety regulation; Providing answers to safety related questions	1. VERY POOR in Knowing, understanding, communicating and ensuring compliance with safety regulation; ALWAYS NOT Providing answers to safety related questions 2. POOR in Knowing, understanding, communicating and ensuring compliance with safety regulation; SOMETIMES NOT Providing answers to safety related questions 3. FAIR in Knowing, understanding, communicating and ensuring compliance with safety regulation; ADEQUATE in Providing answers to safety related questions 4. GOOD in Knowing, understanding, communicating and ensuring compliance with safety regulation; ALWAYS in Providing answers to safety related questions 5. VERY GOOD in Knowing, understanding, communicating and ensuring compliance with safety regulation; ALWAYS in Providing answers to safety related questions
3.2.2.4	Resource management	1 - 5 Predetermined rating	Foreman		Identifying and Verifying resource requirement and availability; Assigning resource; Skill in resolving resource problems	1. VERY POOR in Identifying & Verifying resource requirement and availability; VERY POOR assignment of resource; VERY POOR Skill in resolving resource problems 2. POOR in Identifying & Verifying resource requirement and availability; POOR assignment of resource; POOR Skill in resolving resource problems 3. FAIR in Identifying & Verifying resource requirement and availability; FAIR assignment of resource; FAIR Skill in resolving resource problems 4. GOOD in Identifying & Verifying resource requirement and availability; GOOD assignment of resource; GOOD Skill in resolving resource problems 5. VERY GOOD in Identifying & Verifying resource requirement and availability; VERY GOOD assignment of resource; VERY GOOD Skill in resolving resource problems
3.2.2.5	Performance monitoring & control	1 - 5 Predetermined rating	Foreman			1. VERY POOR in Assessing competency and capability of foreman and crew members to meet quality requirements 2. POOR in Assessing competency and capability of foreman and crew members to meet quality requirements 3. FAIR in Assessing competency and capability of foreman and crew members to meet quality requirements 4. GOOD in Assessing competency and capability of foreman and crew members to meet quality requirements 5. VERY GOOD in Assessing competency and capability of foreman and crew members to meet quality requirements

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
3.2.2.6	Change management	1 - 5 Predetermined rating	Foreman		Determining changes; Updating project plan; Corrective actions; Lessons learned	1. VERY POOR in determining changes and updating Project Plan and/or Project Scope; VERY POOR in taking Corrective Actions; VERY POOR in determining lessons learned and updating historical database 2. POOR in determining changes and updating Project Plan and/or Project Scope; POOR in taking Corrective Actions; POOR in determining lessons learned and updating historical database 3. FAIR in determining changes and updating Project Plan and/or Project Scope; FAIR in taking Corrective Actions; FAIR in determining lessons learned and updating historical database 4. GOOD in determining changes and updating Project Plan and/or Project Scope; GOOD in taking Corrective Actions; GOOD in determining lessons learned and updating historical database 5. VERY GOOD in determining changes and updating Project Plan and/or Project Scope; VERY GOOD in taking Corrective Actions; VERY GOOD in determining lessons learned and updating historical database
3.2.2.7	Communication	1 - 5 Predetermined rating	Foreman			1. VERY POOR in Communicating to and with foreman 2. POOR in Communicating to and with foreman 3. FAIR in Communicating to and with foreman 4. GOOD in Communicating to and with foreman 5. VERY GOOD in Communicating to and with foreman
3.2.3	**Project manager behavioural skills**					
3.2.3.1	Project manager leadership style	Categorical	Foreman		1. Transactional; 2. Transformational	
3.2.3.2	Fairness	1 - 5 Predetermined rating	Foreman		Consistency (same policy), Reasonableness (use of common sense)	1. VERY INCONSISTENT Work assignment to crew, Unreasonable work assignment to crew 2. INCONSISTENT Work assignment to crew, Unreasonable work assignment to crew 3. SOMEWHAT CONSISTENT Work assignment to crew, Reasonable work assignment to crew 4. CONSISTENT Work assignment to crew, Reasonable work assignment to crew 5. VERY CONSISTENT Work assignment to crew, Reasonable work assignment to crew

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
3.2.3.3	Goal-setting		Foreman		Goal clarity; Goal specificity; Goal difficulty	1. VERY POOR Clarity in assignment of goals; VERY LOW Specificity in assignment of goals; VERY EASY Goals are assigned 2. POOR Clarity in assignment of goals; LOW Specificity in assignment of goals; EASY Goals are assigned 3. AVERAGE Clarity in assignment of goals; AVERAGE Specificity in assignment of goals; AVERAGE Difficulty in assignment of goals 4. GOOD Clarity in assignment of goals; HIGH Specificity in assignment of goals; Difficult goals are assigned 5. VERY GOOD Clarity in assignment of goals; VERY HIGH Specificity in assignment of goals; VERY Difficult goals are assigned
3.2.3.4	Feedback	Categorical	Foreman		Yes, No	Provision of feedback on foreman and crew performance
3.2.3.5	Conflict resolution	1 - 5 Predetermined rating	Foreman			1. VERY INEFFECTIVE 2. INEFFECTIVE 3. SOMEWHAT EFFECTIVE 4. EFFECTIVE 5. VERY EFFECTIVE
3.2.3.6	Trust	1 - 5 Predetermined rating	Foreman			1. VERY LOW Mutual respect, reciprocal trust, and interacting obligations between foreman and project manager 2. LOW Mutual respect, reciprocal trust, and interacting obligations between foreman and project manager 3. AVERAGE Mutual respect, reciprocal trust, and interacting obligations between foreman and project manager 4. HIGH Mutual respect, reciprocal trust, and interacting obligations between foreman and project manager 5. VERY HIGH Mutual respect, reciprocal trust, and interacting obligations between foreman and project manager
3.2.4	**Project & construction management practices**					
3.2.4.1	Project integration management	1 - 5 Predetermined rating	Project Manager		Project plan	1. VERY POOR in development, execution, and monitoring of Project Plan; VERY POOR in determining and controlling changes and updating Project Plan 2. POOR in development, execution, and monitoring of Project Plan; POOR in determining and controlling changes and updating Project Plan 3. FAIR in development, execution, and monitoring of Project Plan; FAIR in determining and controlling changes and updating Project Plan 4. GOOD in development, execution, and monitoring of Project Plan; GOOD in determining and controlling changes and updating Project Plan 5. VERY GOOD in development, execution, and monitoring of Project Plan; VERY GOOD in determining and controlling changes and updating Project Plan

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
3.2.4.2	Project scope management	2 - 5 Predetermined rating	Project Manager		Project scope; Project charter; Constructability principles	1. VERY POOR in planning, definition, verification, and control of Project Scope; VERY POOR in development of Project Charter; VERY POOR in implementing Constructability Principles 2. POOR in planning, definition, verification, and control of Project Scope; POOR in development of Project Charter; POOR in implementing Constructability Principles 3. FAIR in planning, definition, verification, and control of Project Scope; FAIR in development of Project Charter; FAIR in implementing Constructability Principles 4. GOOD in planning, definition, verification, and control of Project Scope; GOOD in development of Project Charter; GOOD in implementing Constructability Principles 5. VERY GOOD in planning, definition, verification, and control of Project Scope; VERY GOOD in development of Project Charter; VERY GOOD in implementing Constructability Principles
3.2.4.3	Project time management	2 - 5 Predetermined rating	Project Manager		Work breakdown structure (WBS); Project schedule;Resource requirements	1. VERY POOR in development of WBS; VERY POOR in development, execution, and monitoring of Project Schedule; VERY POOR in identifying Resource Requirements 2. POOR in development of WBS; POOR in development, execution, and monitoring of Project Schedule; POOR in identifying Resource Requirements 3. FAIR in development of WBS; FAIR in development, execution, and monitoring of Project Schedule; FAIR in identifying Resource Requirements 4. GOOD in development of WBS; GOOD in development, execution, and monitoring of Project Schedule; GOOD in identifying Resource Requirements 5. VERY GOOD in development of WBS; VERY GOOD in development, execution, and monitoring of Project Schedule; VERY GOOD in identifying Resource Requirements

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
3.2.4.4	Project cost management	2 - 5 Predetermined rating	Project Manager		Project cost estimates; Project budget; Project cash flow	1. VERY POOR in development and monitoring of Project Cost Estimates; VERY POOR in identification of Project Budget; VERY POOR in development and monitoring of Project Cash Flow 2. POOR in development and monitoring of Project Cost Estimates; POOR in identification of Project Budget; POOR in development and monitoring of Project Cash Flow 3. FAIR in development and monitoring of Project Cost Estimates; FAIR in identification of Project Budget; FAIR in development and monitoring of Project Cash Flow 4. GOOD in development and monitoring of Project Cost Estimates; GOOD in identification of Project Budget; GOOD in development and monitoring of Project Cash Flow 5. VERY GOOD in development and monitoring of Project Cost Estimates; VERY GOOD in identification of Project Budget; VERY GOOD in development and monitoring of Project Cash Flow
3.2.4.5	Project quality management	2 - 5 Predetermined rating	Project Manager		Quality management system; Quality management plan	1. VERY POOR in development of Quality Management System; VERY POOR in development, execution, and monitoring of Quality Management Plan 2. POOR in development of Quality Management System; POOR in development, execution, and monitoring of Quality Management Plan 3. FAIR in development of Quality Management System; FAIR in development, execution, and monitoring of Quality Management Plan 4. GOOD in development of Quality Management System; GOOD in development, execution, and monitoring of Quality Management Plan 5. VERY GOOD in development of Quality Management System; VERY GOOD in development, execution, and monitoring of Quality Management Plan
3.2.4.6	Project human resource management	2 - 5 Predetermined rating	Project Manager		Human resource plan; Project team development; Recruitment policies	1. VERY POOR in development, execution, and monitoring of Human Resource Plan; VERY POOR in development of Project Teams; VERY POOR in determining Recruitment Policies 2. POOR in development, execution, and monitoring of Human Resource Plan; POOR in development of Project Teams; POOR in determining Recruitment Policies 3. FAIR in development, execution, and monitoring of Human Resource Plan; FAIR in development of Project Teams; FAIR in determining Recruitment Policies 4. GOOD in development, execution, and monitoring of Human Resource Plan; GOOD in development of Project Teams; GOOD in determining Recruitment Policies 5. VERY GOOD in development, execution, and monitoring of Human Resource Plan; VERY GOOD in development of Project Teams; VERY GOOD in determining Recruitment Policies

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
3.2.4.7	Project communication management	2 - 5 Predetermined rating	Project Manager		Communication plan, Stakeholders identification; Project reporting	1. VERY POOR in development, execution, and monitoring of Communication Plan; VERY POOR in identification of Project Stakeholders; VERY POOR in development of Project Reports 2. POOR in development, execution, and monitoring of Communication Plan; POOR in identification of Project Stakeholders; POOR in development of Project Reports 3. FAIR in development, execution, and monitoring of Communication Plan; FAIR in identification of Project Stakeholders; FAIR in development of Project Reports 4. GOOD in development, execution, and monitoring of Communication Plan; GOOD in identification of Project Stakeholders; GOOD in development of Project Reports 5. VERY GOOD in development, execution, and monitoring of Communication Plan; VERY GOOD in identification of Project Stakeholders; VERY GOOD in development of Project Reports
3.2.4.8	Project risk management	2 - 5 Predetermined rating	Project Manager		Risk identification; Risk analysis; Risk mitigation; Risk registry	1. VERY POOR in identification, analysis, and mitigation of Project Risks; VERY POOR development of Project Risk Registry 2. POOR in identification, analysis, and mitigation of Project Risks; POOR development of Project Risk Registry 3. FAIR in identification, analysis, and mitigation of Project Risks; FAIR development of Project Risk Registry 4. GOOD in identification, analysis, and mitigation of Project Risks; GOOD development of Project Risk Registry 5. VERY GOOD in identification, analysis, and mitigation of Project Risks; VERY GOOD development of Project Risk Registry
3.2.4.9	Project procurement management	2 - 5 Predetermined rating	Project Manager		Vendors list; Tender documents;Purchase orders;Warranties	1. VERY POOR in determining Vendors List; VERY POOR in development of Tender Documents, and Purchase Orders; VERY POOR in determining Warranties 2. POOR in determining Vendors List; POOR in development of Tender Documents, and Purchase Orders; POOR in determining Warranties 3. FAIR in determining Vendors List; FAIR in development of Tender Documents, and Purchase Orders; FAIR in determining Warranties 4. GOOD in determining Vendors List; GOOD in development of Tender Documents, and Purchase Orders; GOOD in determining Warranties 5. VERY GOOD in determining Vendors List; VERY GOOD in development of Tender Documents, and Purchase Orders; VERY GOOD in determining Warranties

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
3.2.4.10	Project safety management	1 - 5 Predetermined rating	Project Manager		Safety plan; Safety requirements; Safety trainings	1. VERY POOR in development, execution, and monitoring of safety plan; VERY POOR in identifying safety requirements; VERY POOR in conducting safety trainings 2.POOR in development, execution, and monitoring of safety plan; POOR in identifying safety requirements; POOR in conducting safety trainings 3. FAIR in development, execution, and monitoring of safety plan; FAIR in identifying safety requirements; FAIR in conducting safety trainings 4. GOOD in development, execution, and monitoring of safety plan; GOOD in identifying safety requirements; GOOD in conducting safety trainings 5. VERY GOOD in development, execution, and monitoring of safety plan; VERY GOOD in identifying safety requirements; VERY GOOD in conducting safety trainings
3.2.4.11	Project environmental management	2 - 5 Predetermined rating	Project Manager		Environmental management system; Required legal permits; Environmental impact assessment	1. VERY POOR in development, execution, and monitoring of Environmental Management System; VERY POOR in providing Required Legal Permits; VERY POOR in Environmental Impact Assessment 2. POOR in development, execution, and monitoring of Environmental Management System; POOR in providing Required Legal Permits; POOR in Environmental Impact Assessment 3. FAIR in development, execution, and monitoring of Environmental Management System; FAIR in providing Required Legal Permits; FAIR in Environmental Impact Assessment 4. GOOD in development, execution, and monitoring of Environmental Management System; GOOD in providing Required Legal Permits; GOOD in Environmental Impact Assessment 5. VERY GOOD in development, execution, and monitoring of Environmental Management System; VERY GOOD in providing Required Legal Permits; VERY GOOD in Environmental Impact Assessment
3.2.4.12	Project financial management	2 - 5 Predetermined rating	Project Manager		Financial plan; Financial administration;Financial control	1. VERY POOR in development, execution, and monitoring of Project Financial Plan; VERY POOR in development of Financial Administration; VERY POOR in Financial Control 2. POOR in development, execution, and monitoring of Project Financial Plan; POOR in development of Financial Administration; POOR in Financial Control 3. FAIR in development, execution, and monitoring of Project Financial Plan; FAIR in development of Financial Administration; FAIR in Financial Control 4. GOOD in development, execution, and monitoring of Project Financial Plan; GOOD in development of Financial Administration; GOOD in Financial Control 5. VERY GOOD in development, execution, and monitoring of Project Financial Plan; VERY GOOD in development of Financial Administration; VERY GOOD in Financial Control

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
3.2.4.13	Project claim management	2 - 5 Predetermined rating	Project Manager		Claim identification, quantification, prevention, and resolution	1. VERY POOR in identification, quantification, prevention, and resolution of Project Claims 2. POOR in identification, quantification, prevention, and resolution of Project Claims 3. FAIR in identification, quantification, prevention, and resolution of Project Claims 4. GOOD in identification, quantification, prevention, and resolution of Project Claims 5. VERY GOOD in identification, quantification, prevention, and resolution of Project Claims
3.3	**Work-Setting Conditions**					
3.3.1	**Site general facilities**					
3.3.1.1	Office (for crew to rest during shift breaks)	Categorical	Researcher		1. Not provided 2. Provided	
3.3.1.2	Location of lunch rooms	Real number (average distance, m)	Researcher		Range (0 - 500)	From crew's site main trailer.
3.3.1.3	Location of washrooms	Real number (average distance, m)	Researcher		Range (0 - 500)	From crew's site main trailer.
3.3.1.4	In-site transportation	Integer (Number of transportation vehicle on site)	Foreman		Range (0 - 10)	
3.3.1.5	Communication device	Integer (Number of Comunication devices on site)	Foreman		Range (0 - 20)	
3.3.2	**Working area conditions**					
3.3.2.1	Cleanness	Integer (Number of cleaning operations per week)	Foreman			
3.3.2.2	Congestion	Real Number (number of people per 100 square meter in working area)	Foreman		Range (1-20)	

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
3.3.2.3	Noise	1 - 5 Predetermined rating	Foreman		Noise sources (equipment's); Intrusiveness of noise; Voice levels in normal conversation	1. NO Noisy Equipment; VERY LOW Intrusiveness; VERY NORMAL Voice Level in Conversation 2. FEW Noisy Equipment; VERY LOW Intrusiveness; NORMAL Voice Level in Conversation 3. SOME Noisy Equipment; AVERAGE Intrusiveness; NORMAL Voice Level in Conversation 4. MANY Noisy Equipment; HIGH Intrusiveness; HIGH Voice Level in Conversation 5. TOO MANY Noisy Equipment; VERY HIGH Intrusiveness; VERY HIGH Voice Level in Conversation
3.3.2.4	Pollution	1 - 5 Predetermined rating	Foreman		Dust and fume source; Level of exposure; Length of exposure	1. NO Source of dust and fume; VERY LOW Level of Exposure; VERY NORMAL Length of Exposure 2. FEW Sources of dust and fume; VERY LOW Level of Exposure; NORMAL Length of Exposure 3. SOME Sources of dust and fume; AVERAGE Level of Exposure; NORMAL Length of Exposure 4. MANY Sources of dust and fume; HIGH Level of Exposure; HIGH Length of Exposure 5. TOO MANY Sources of dust and fume; VERY HIGH Level of Exposure; VERY HIGH Length of Exposure
3.3.2.5	Type (covered/uncovered)	Categorical	Foreman		1. Covered; 2. Uncovered	
3.3.2.6	Working area Ventilation/Air conditioning	Categorical	Foreman		1. Open space; 2. Non-ventilated closed space; 3. Ventilated closed space; 4. Air-conditioned closed space	
3.3.2.7	Access points	Integer (number of acess points to working area)	Foreman		Range (1, 10)	
3.3.3	**Weather conditions**					
2.3.3.1	Temperature	Real number (˚C)	Researcher		Range (-40, 40)	Source: http://climate.weatheroffice.gc.ca
2.3.3.2	Humidity	Real number (%)	Researcher		Range (20, 120)	Source: http://climate.weatheroffice.gc.ca
2.3.3.3	Precipitation	Real number (mm)	Researcher		Range (0, 50)	Source: http://climate.weatheroffice.gc.ca

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
2.3.3.4	Wind speed	Real number (km/hr)	Researcher		Range (0, 100)	Source: http://climate.weatheroffice.gc.ca
2.3.3.5	Change in weather conditions	1 - 5 Predetermined rating	Foreman			1. VERY SLOW changes in weather conditions during daily work 2. SLOW changes in weather conditions during daily work 3. MEDIUM changes in weather conditions during daily work 4. RAPID changes in weather conditions during daily work 5. VERY PARID changes in weather conditions during daily work
3.4	**Resources**					
3.4.1	**Material**					
3.4.1.1	Task material availability	Real number (Average waiting time for getting materials at site, min)	Foreman		Range (0 - 60)	
3.4.1.2	Task material quality	1 - 5 Predetermined rating	Foreman		Level of defects; Level of material adjustment on site	1. VERY HIGH Level of material defects; VERY FREQUENT Material adjustment on site 2. HIGH Level of material defects; FREQUENT Material adjustment on site 3. MEDIUM Level of material defects; SOMEWHAT Material adjustment on site 4. LOW Level of material defects; RARE Material adjustment on site 5. VERY LOW Level of material defects; VERY RARE Material adjustment on site
3.4.1.3	Consumables availability	Real number (Average waiting time for getting consumables site, min)	Foreman		Range (0 - 60)	
3.4.1.4	Consumables quality	1 - 5 Predetermined rating	Foreman		Level of defects	1. VERY HIGH Level of consumables defects 2. HIGH Level of material defects 3. MEDIUM Level of material defects 4. LOW Level of material defects 5. VERY LOW Level of material defects
3.4.2	**Equipment**					
3.4.2.1	Equipment type	Categorical	Foreman		1. Suitable for the task 2. Not suitable for the task	
3.4.2.2	Equipment availability	Real number (Average waiting time for getting equipment at site, min)	Foreman		Range (0 - 60)	

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
3.4.2.3	Equipment quality	Integer (Average number of breakdown occurrence per week)	Foreman		Range (1 - 20)	
3.4.3	**Tools**					
2.4.3.1	Type of tools	Categorical	Foreman		1. Suitable for the task 2. Not suitable for the task	
2.4.3.2	Tools availability	Real number (Average waiting time for getting tools at site, min)	Foreman		Range (0 - 60)	
2.4.3.3	Tools quality	Integer (Average no. of tool breakdown per week)	Foreman		Range (1 - 20)	
3.5	**Safety**					
3.5.1	**Safety Precautions**					
3.5.1.1	Safety procedures	1 - 5 Predetermined rating	Foreman		Development and implementation of safety procedures	1. VERY POOR in Development and Implementation of safety procedures; 2. POOR in Development and Implementation of safety procedures; 3. FAIR in Development and Implementation of safety procedures; 4. GOOD in Development and Implementation of safety procedures; 5. VERY GOOD in Development and Implementation of safety procedures
3.5.1.2	Safety meetings	1 - 5 Predetermined rating	Foreman		Conducting regular safety meetings; Effectiveness of safety meetings	1. NO Safety meeting conducted; 2. Safety Meetings RARELY conducted ; POOR Effectiveness of safety meetings; 3. Safety Meetings SOMEWHAT conducted; FAIR Effectiveness of safety meetings; 4. Safety Meetings OFTEN conducted ; GOOD Effectiveness of safety meetings; 5. Safety Meetings REGULARLY conducted ; VERY GOOD Effectiveness of safety meetings;
3.5.1.3	Safety Inspections	Real number (Number of inspections per month)	Project Manager		Range (0 - 30)	
3.5.1.4	Safety Audits	Real number (Number of audits per month)	Project Manager		Range (0 - 30)	

Data Collection Form for Situational/Contextual Factors

Factor ID	Factors / Sub - Factors	Scale of Measure	Data Source	Data Value	Sub-factor / Range of Value	Predetermined Ratings (1 - 5) / Description
3.5.1.5	Protective safety gears	1 - 5 Predetermined rating	Foreman			1. NOT Mandatory; VERY RARELY Used 2. Mandatory; RARELY Used 3. Mandatory; SOMEWHAT Used 4. Mandatory; OFTEN Used 5. Mandatory; REGULARLY Used
3.5.1.6	Safety trainings	1 - 5 Predetermined rating	Foreman			1. VERY POOR in conducting safety trainings 2. POOR in conducting safety trainings 3. FAIR in conducting safety trainings 4. GOOD in conducting safety trainings 5. VERY GOOD in conducting safety trainings
3.5.1.7	Recording Incidents and taking corrective actions	1 - 5 Predetermined rating	Project Manager			1. VERY POOR in record keeping; VERY POOR in taking corrective actions 2. POOR in record keeping; POOR in taking corrective actions 3. FAIR in record keeping; FAIR in taking corrective actions 4. GOOD in record keeping; GOOD in taking corrective actions 5. VERY GOOD in record keeping; VERY GOOD in taking corrective actions

Appendix D. Data Collection Forms for Task Performance

Data Collection Form for Task Performance

UNIVERSITY OF ALBERTA

STUDY ON CRITICAL FACTORS FOR CRAFT PERFORMANCE IMPROVEMENT ON ALBERTA CONSTRUCTION PROJECTS

Task Performance - Supervisor Evalulation

Date:	
Data Collector:	
Project Name:	
Project Location:	
Supervisor Tag/Position:	
Crew Tag/Trade:	
Crew Members Tag/Trade:	
Crew Size (No.):	

Crew Composition:	**Journeyman (No.)**	**Apprentice (No.)**	**Other (No.)**

Task Type:	

Form Page 1

Data Collection Form for Task Performance

1. Task Performance

1.1 Task Performance - Cost

ID	Performance Measures	Unit	Value
1.1.1	Actual total work package cost (to date)	Cost in Canadian Dollars	
1.1.2	Total work package estimated cost at tender stage (to date)		
1.1.3	Actual work package indirect cost (to date)		
1.1.4	Actual work package direct cost (to date)		
1.1.5	Cost of approved changes to work package (to date)		
1.1.6	Net value of variations in work package cost (to date)		
1.1.7	Construction cost of rectifying all work package defects (to date)		
1.1.8	Quantity of completed work in work package (to date)	QTY (Number/Real Number)	

1.2 Task Performance - Time

ID	Performance Measures	Unit	Value
1.2.1	Actual work package duration (to date)	Duration in Days	
1.2.2	Estimated work package duration at tender stage (to date)		
1.2.3	Approved changes to work package duration (to date)		
1.2.4	Increase/decrease in actual work package duration (to date)		

1.3 Task Performance - Change

ID	Performance Measures	Unit	Value
1.3.1	Total cost of scope changes in work package (to date)	Cost in Canadian Dollars	
1.3.2	Approved cost of change orders in work package originating from client (to date)	Cost in Canadian Dollars	
1.3.3	Approved cost of change orders in work package originating from contractor (to date)	Cost in Canadian Dollars	
1.3.4	Time taken to rectify all defects in work package by the contractor, expressed in hours (to date)	Duration in Hours	
1.3.5	Approved time of client-initiated change orders in work package (to date)	Duration in Days	
1.3.6	Approved time of contractor-initiated change orders in work package (to date)	Duration in Days	

1.4 Task Performance - Quality

ID	Performance Measures	Unit	Value						
1.4.1	Total direct cost of work package rework (to date)	Cost in Canadian Dollars							
1.4.2	Total direct and indirect cost for work package rework (to date)	Cost in Canadian Dollars							
1.4.3	Total duration of work package rework (to date)	Duration in Days							
1.4.4	Quality issues - Available for use rating	Rating (1-7) / Level of client satisfaction with the quality of completed work package	Extremely Dissatisfied	Dissatisfied	Slightly Dissatisfied	Neither Satisfied Nor Dissatisfied	Slightly Satisfied	Satisfied	Extremely Satisfied
			1	2	3	4	5	6	7

1.5 Task Performance - Safety

ID	Performance Measures	Unit	Value
1.5.1	Total actual man-hours worked in work package (to date)	Man-Hours	
1.5.2	Amount of lost time to incidents in work package (to date)	Duration in Hours	
1.5.3	Total number of lost time cases reported in work package (to date)	Number of Cases	
1.5.4	Number of reported incidents in work package (to date)	Number of Cases	
1.5.5	Number of reported first aid cases in work package (to date)	Number of Cases	
1.5.6	Number of reported near miss incidents in work package (to date)	Number of Cases	

1.6 Task Performance - Productivity

ID	Performance Measures	Unit	Value
1.6.1	Actual direct man-hours worked in work package (to date)	Man-Hours	
1.6.2	Total actual man-hours worked in work package (to date)	Man-Hours	
1.6.3	Estimated man-hours in work package (to date)	Man-Hours	
1.6.4	Actual installed quantity in work package (to date)	QTY (Number/Real Number)	
1.6.5	Estimated quantity in work package (to date)	QTY (Number/Real Number)	
1.6.6	Man-hours lost due to unplanned absenteeism in work package (to date)	Man-Hours	

1.7 Task Performance - Satisfaction

ID	Performance Measures	Unit	Extremely Dissatisfied	Dissatisfied	Slightly Dissatisfied	Neither Satisfied Nor Dissatisfied	Slightly Satisfied	Satisfied	Extremely Satisfied
1.7.1	Overall performance satisfaction	Rating (1-7) / Level of client satisfaction with the overall performance of the crew in completing the work package	1	2	3	4	5	6	7

Appendix E. Supervisor Evaluation Form for Contextual Performance and Counterproductive Behaviour

UNIVERSITY OF ALBERTA

STUDY ON CRITICAL FACTORS FOR CRAFT PERFORMANCE IMPROVEMENT ON ALBERTA CONSTRUCTION PROJECTS

Contextual Performance and Counterproductive Behaviour - Supervisor Evaluation

Date:	

Supervisor Position:	

Crew Trades:	

Crew Size (No.):	

Crew Composition:	**Journeyman (No.)**	**Apprentice (No.)**	**Other (No.)**

Supervisor Evaluation Form for Contextual Performance and Counterproductive Behaviour

2. Contextual Performance

2.1 Contextual Performance - Personal Support

ID	Performance Measures	Unit	Never	Very Rarely	Rarely	Sometimes	Often	Very Often	Consistently
2.1.1	**Helping**								
2.1.1.1	The members of this crew offer suggestions to other crew members about their work.	Rating (1-7)	1	2	3	4	5	6	7
2.1.1.2	The members of this crew show other crew members how to accomplish difficult tasks.	Rating (1-7)	1	2	3	4	5	6	7
2.1.1.3	The members of this crew teach other crew members useful knowledge or skills.	Rating (1-7)	1	2	3	4	5	6	7
2.1.1.4	The members of this crew provide emotional support for other crew members' personal problems	Rating (1-7)	1	2	3	4	5	6	7
2.1.2	**Cooperating**								
2.1.2.1	The members of this crew accept other crew members' suggestions and following their leads.	Rating (1-7)	1	2	3	4	5	6	7
2.1.2.2	The members of this crew put team objectives over own personal interests.	Rating (1-7)	1	2	3	4	5	6	7
2.1.2.3	The members of this crew inform other crew members of events or requirements that are likely to affect them.	Rating (1-7)	1	2	3	4	5	6	7
2.1.3	**Courtesy**								
2.1.3.1	The members of this crew show consideration, courtesy, and tact in relations with other crew members.	Rating (1-7)	1	2	3	4	5	6	7
2.1.4	**Motivating**								
2.1.4.1	The members of this crew applaud other crew members' achievements.	Rating (1-7)	1	2	3	4	5	6	7
2.1.4.2	The members of this crew cheer on other crew members in times of adversity.	Rating (1-7)	1	2	3	4	5	6	7
2.1.4.3	The members of this crew show confidence in crew members' ability to succeed.	Rating (1-7)	1	2	3	4	5	6	7
2.1.4.4	The members of this crew help other crew members to overcome setbacks.	Rating (1-7)	1	2	3	4	5	6	7

Supervisor Evaluation Form for Contextual Performance and Counterproductive Behaviour

2.2 Contextual Performance - Organizational Support

ID	Performance Measures	Scale of measure	Never	Very Rarely	Rarely	Sometimes	Often	Very Often	Consistently
2.2.1	**Representing**								
2.2.1.1	The members of this crew defend the organization when others criticize it.	Rating (1-7)	1	2	3	4	5	6	7
2.2.1.2	The members of this crew promote the organization's achievements and positive attributes.	Rating (1-7)	1	2	3	4	5	6	7
2.2.1.3	The members of this crew express own satisfaction with the organization.	Rating (1-7)	1	2	3	4	5	6	7
2.2.2	**Loyalty**								
2.2.2.1	The members of this crew stay with the organization despite temporary hardships.	Rating (1-7)	1	2	3	4	5	6	7
2.2.2.2	The members of this crew tolerate occasional difficulties and adversity cheerfully and without complaining.	Rating (1-7)	1	2	3	4	5	6	7
2.2.2.3	The members of this crew publicly endorse and supporting the organization's mission and objectives.	Rating (1-7)	1	2	3	4	5	6	7
2.2.3	**Compliance**								
2.2.3.1	The members of this crew comply with organizational rules and procedures.	Rating (1-7)	1	2	3	4	5	6	7
2.2.3.2	The members of this crew encourage others to comply with organizational rules and procedures.	Rating (1-7)	1	2	3	4	5	6	7
2.2.3.3	The members of this crew suggest procedural, administrative, or organizational improvements.	Rating (1-7)	1	2	3	4	5	6	7

Supervisor Evaluation Form for Contextual Performance and Counterproductive Behaviour

2.3 Contextual Performance - Conscientious Initiative

ID	Performance Measures	Scale of measure	Never	Very Rarely	Rarely	Sometimes	Often	Very Often	Consistently
2.3.1	**Persistence**								
2.3.1.1	The members of this crew persist with extra effort to complete work tasks successfully despite difficult conditions and setbacks.	Rating (1-7)	1	2	3	4	5	6	7
2.3.1.2	The members of this crew accomplish goals that are more difficult and challenging than normal.	Rating (1-7)	1	2	3	4	5	6	7
2.3.1.3	The members of this crew complete work on time despite unusually short deadlines.	Rating (1-7)	1	2	3	4	5	6	7
2.3.1.4	The members of this crew perform at a level of excellence that is significantly beyond normal expectations.	Rating (1-7)	1	2	3	4	5	6	7
2.3.2	**Initiative**								
2.3.2.1	The members of this crew take the initiative to do all that is necessary to accomplish crew objectives even if not typically a part of own duties.	Rating (1-7)	1	2	3	4	5	6	7
2.3.2.2	The members of this crew correct conditions that are not compliant to project standards whenever encountered.	Rating (1-7)	1	2	3	4	5	6	7
2.3.2.3	The members of this crew find additional work to perform when own duties are completed.	Rating (1-7)	1	2	3	4	5	6	7
2.3.3	**Self-Development**								
2.3.3.1	The members of this crew develop their knowledge and skills by taking courses on own time.	Rating (1-7)	1	2	3	4	5	6	7
2.3.3.2	The members of this crew volunteer for training and development opportunities offered within the organization.	Rating (1-7)	1	2	3	4	5	6	7
2.3.3.3	The members of this crew try to learn new knowledge and skills on the job from others or through new job assignments.	Rating (1-7)	1	2	3	4	5	6	7

Supervisor Evaluation Form for Contextual Performance and Counterproductive Behaviour

3. Counterproductive Behaviour

3.1 Counterproductive Behaviour - Interpersonal Deviance

ID	Performance Measures	Scale of measure	Never	Very Rarely	Rarely	Sometimes	Often	Very Often	Consistently
3.1.1	**Inappropriate Verbal Actions**								
3.1.1.1	The members of this crew make fun of other crew members.	Rating (1-7)	1	2	3	4	5	6	7
3.1.1.2	The members of this crew say hurtful things to other crew members.	Rating (1-7)	1	2	3	4	5	6	7
3.1.1.3	The members of this crew argue or fight with other crew members.	Rating (1-7)	1	2	3	4	5	6	7
3.1.1.4	The members of this crew gossip about other crew members.	Rating (1-7)	1	2	3	4	5	6	7
3.1.1.5	The members of this crew blame other crew members for mistakes.	Rating (1-7)	1	2	3	4	5	6	7
3.1.2	**Unsafe Behaviour**								
3.1.2.1	The members of this crew endanger themselves by not following safety procedures.	Rating (1-7)	1	2	3	4	5	6	7
3.1.2.2	The members of this crew endanger other crew members by reckless behaviour.	Rating (1-7)	1	2	3	4	5	6	7
3.1.3	**Inappropriate Physical Actions**								
3.1.3.1	The members of this crew attack (e.g., pushing, shoving, hitting) other crew members physically.	Rating (1-7)	1	2	3	4	5	6	7
3.1.3.2	The members of this crew sexually harass other crew members.	Rating (1-7)	1	2	3	4	5	6	7
3.1.4	**Alcohol Consumption or Drug Use**								
3.1.4.1	The members of this crew come to work under the influence of alcohol or drugs.	Rating (1-7)	1	2	3	4	5	6	7
3.1.4.2	The members of this crew have crew performance affected due to a hangover from alcohol or drugs.	Rating (1-7)	1	2	3	4	5	6	7
3.1.4.3	The members of this crew engage in alcohol consumption or drug use on the job.	Rating (1-7)	1	2	3	4	5	6	7

Supervisor Evaluation Form for Contextual Performance and Counterproductive Behaviour

3.2 Counterproductive Behaviour - Organizational Deviance

ID	Performance Measures	Scale of measure	Never	Very Rarely	Rarely	Sometimes	Often	Very Often	Consistently
3.2.1	**Poor Attendance**								
3.2.1.1	The members of this crew come to work late or leaves early without permission.	Rating (1-7)	1	2	3	4	5	6	7
3.2.1.2	The members of this crew are absent from work without a legitimate excuse.	Rating (1-7)	1	2	3	4	5	6	7
3.2.1.3	The members of this crew leave progressing work for personal matters unexcused.	Rating (1-7)	1	2	3	4	5	6	7
3.2.2	**Misuse of Time**								
3.2.2.1	The members of this crew take additional or longer breaks than is acceptable at the workplace.	Rating (1-7)	1	2	3	4	5	6	7
3.2.2.2	The members of this crew intentionally work slowly.	Rating (1-7)	1	2	3	4	5	6	7
3.2.2.3	The members of this crew make personal calls or emailing at work.	Rating (1-7)	1	2	3	4	5	6	7
3.2.2.4	The members of this crew drag out work in order to get overtime.	Rating (1-7)	1	2	3	4	5	6	7
3.2.3	**Misuse of Resources**								
3.2.3.1	The members of this crew waste the organization's resources (i.e., materials, energy).	Rating (1-7)	1	2	3	4	5	6	7
3.2.3.2	The members of this crew use the organization's resources (i.e., equipment) he/she is not authorized to use.	Rating (1-7)	1	2	3	4	5	6	7
3.2.4	**Misuse of Information**								
3.2.4.1	The members of this crew discuss confidential matters with unauthorized personnel within or outside the organization.	Rating (1-7)	1	2	3	4	5	6	7
3.2.4.2	The members of this crew intentionally fail to give necessary information to supervisor or other crew members.	Rating (1-7)	1	2	3	4	5	6	7
3.2.4.3	The members of this crew cover up mistakes.	Rating (1-7)	1	2	3	4	5	6	7
3.2.5	**Poor Quality Work**								
3.2.5.1	The members of this crew perform tasks intentionally below acceptable standards.	Rating (1-7)	1	2	3	4	5	6	7
3.2.5.2	The members of this crew intentionally do work badly or incorrectly.	Rating (1-7)	1	2	3	4	5	6	7
3.2.5.3	The members of this crew intentionally do sloppy work.	Rating (1-7)	1	2	3	4	5	6	7
3.2.6	**Destruction of Property**								
3.2.6.1	The members of this crew deface, damage, or destroy property belonging to the organization.	Rating (1-7)	1	2	3	4	5	6	7
3.2.6.2	The members of this crew deliberately sabotage equipment in the organization.	Rating (1-7)	1	2	3	4	5	6	7
3.2.7	**Theft and Related Behaviour**								
3.2.7.1	The members of this crew take tools from work without permission.	Rating (1-7)	1	2	3	4	5	6	7
3.2.7.2	The members of this crew falsify a receipt to get reimbursed for more money than spent.	Rating (1-7)	1	2	3	4	5	6	7
3.2.7.3	The members of this crew take consumables from the organization.	Rating (1-7)	1	2	3	4	5	6	7

Appendix F. Self-Evaluation Form for Contextual Performance and Counterproductive Behaviour

UNIVERSITY OF ALBERTA

STUDY ON CRITICAL FACTORS FOR CRAFT PERFORMANCE IMPROVEMENT ON ALBERTA CONSTRUCTION PROJECTS

Contextual Performance and Counterproductive Behaviour - Self Evaluation

Date:	

Supervisor Position:	

Crew Trades:	

Crew Size (No.):	

Crew Composition:	**Journeyman (No.)**	**Apprentice (No.)**	**Other (No.)**

Self-Evaluation Form for Contextual Performance and Counterproductive Behaviour

2. Contextual Performance

2.1 Contextual Performance - Personal Support

ID	Performance Measures	Unit	Never	Very Rarely	Rarely	Sometimes	Often	Very Often	Constantly
2.1.1	**Helping**								
2.1.1.1	I offer suggestions to other crew members about their work.	Rating (1-7)	1	2	3	4	5	6	7
2.1.1.2	I show other crew members how to accomplish difficult tasks.	Rating (1-7)	1	2	3	4	5	6	7
2.1.1.3	I teach other crew members useful knowledge or skills.	Rating (1-7)	1	2	3	4	5	6	7
2.1.1.4	I provide emotional support for other crew members' personal problems	Rating (1-7)	1	2	3	4	5	6	7
2.1.2	**Cooperating**								
2.1.2.1	I accept other crew members' suggestions and following their leads.	Rating (1-7)	1	2	3	4	5	6	7
2.1.2.2	I put team objectives over own personal interests.	Rating (1-7)	1	2	3	4	5	6	7
2.1.2.3	I inform other crew members of events or requirements that are likely to affect them.	Rating (1-7)	1	2	3	4	5	6	7
2.1.3	**Courtesy**								
2.1.3.1	I show consideration, courtesy, and tact in relations with other crew members.	Rating (1-7)	1	2	3	4	5	6	7
2.1.4	**Motivating**								
2.1.4.1	I applaud other crew members' achievements.	Rating (1-7)	1	2	3	4	5	6	7
2.1.4.2	I cheer on other crew members in times of adversity.	Rating (1-7)	1	2	3	4	5	6	7
2.1.4.3	I show confidence in crew members' ability to succeed.	Rating (1-7)	1	2	3	4	5	6	7
2.1.4.4	I help other crew members to overcome setbacks.	Rating (1-7)	1	2	3	4	5	6	7

Self-Evaluation Form for Contextual Performance and Counterproductive Behaviour

2.2 Contextual Performance - Organizational Support

ID	Performance Measures	Scale of measure	Never	Very Rarely	Rarely	Sometimes	Often	Very Often	Constantly
2.2.1	**Representing**								
2.2.1.1	I defend the organization when others criticize it.	Rating (1-7)	1	2	3	4	5	6	7
2.2.1.2	I promote the organization's achievements and positive attributes.	Rating (1-7)	1	2	3	4	5	6	7
2.2.1.3	I express own satisfaction with the organization.	Rating (1-7)	1	2	3	4	5	6	7
2.2.2	**Loyalty**								
2.2.2.1	I stay with the organization despite temporary hardships.	Rating (1-7)	1	2	3	4	5	6	7
2.2.2.2	I tolerate occasional difficulties and adversity cheerfully and without complaining.	Rating (1-7)	1	2	3	4	5	6	7
2.2.2.3	I publicly endorse and supporting the organization's mission and objectives.	Rating (1-7)	1	2	3	4	5	6	7
2.2.3	**Compliance**								
2.2.3.1	I comply with organizational rules and procedures.	Rating (1-7)	1	2	3	4	5	6	7
2.2.3.2	I encourage others to comply with organizational rules and procedures.	Rating (1-7)	1	2	3	4	5	6	7
2.2.3.3	I suggest procedural, administrative, or organizational improvements.	Rating (1-7)	1	2	3	4	5	6	7

2.3 Contextual Performance - Conscientious Initiative

ID	Performance Measures	Scale of measure	Never	Very Rarely	Rarely	Sometimes	Often	Very Often	Constantly
2.3.1	**Persistence**								
2.3.1.1	I persist with extra effort to complete work tasks successfully despite difficult conditions and setbacks.	Rating (1-7)	1	2	3	4	5	6	7
2.3.1.2	I accomplish goals that are more difficult and challenging than normal.	Rating (1-7)	1	2	3	4	5	6	7
2.3.1.3	I complete work on time despite unusually short deadlines.	Rating (1-7)	1	2	3	4	5	6	7
2.3.1.4	I perform at a level of excellence that is significantly beyond normal expectations.	Rating (1-7)	1	2	3	4	5	6	7
2.3.2	**Initiative**								
2.3.2.1	I take the initiative to do all that is necessary to accomplish crew objectives even if not typically a part of own duties.	Rating (1-7)	1	2	3	4	5	6	7
2.3.2.2	I correct conditions that are not compliant to project standards whenever encountered.	Rating (1-7)	1	2	3	4	5	6	7
2.3.2.3	I find additional work to perform when own duties are completed.	Rating (1-7)	1	2	3	4	5	6	7
2.3.3	**Self-Development**								
2.3.3.1	I develop own knowledge and skills by taking courses on own time.	Rating (1-7)	1	2	3	4	5	6	7
2.3.3.2	I volunteer for training and development opportunities offered within the organization.	Rating (1-7)	1	2	3	4	5	6	7
2.3.3.3	I Try to learn new knowledge and skills on the job from others or through new job assignments.	Rating (1-7)	1	2	3	4	5	6	7

Self-Evaluation Form for Contextual Performance and Counterproductive Behaviour

3. Counterproductive Behaviour

3.1 Counterproductive Behaviour - Interpersonal Deviance

ID	Performance Measures	Scale of measure	Never	Very Rarely	Rarely	Sometimes	Often	Very Often	Constantly
3.1.1	**Inappropriate Verbal Actions**								
3.1.1.1	I make fun of other crew members.	Rating (1-7)	1	2	3	4	5	6	7
3.1.1.2	I say hurtful things to other crew members.	Rating (1-7)	1	2	3	4	5	6	7
3.1.1.3	I argue or fights with other crew members.	Rating (1-7)	1	2	3	4	5	6	7
3.1.1.4	I gossip about other crew members.	Rating (1-7)	1	2	3	4	5	6	7
3.1.1.5	I blame other crew members for mistakes.	Rating (1-7)	1	2	3	4	5	6	7
3.1.2	**Unsafe Behaviour**								
3.1.2.1	I endanger myself by not following safety procedures.	Rating (1-7)	1	2	3	4	5	6	7
3.1.2.2	I endanger other crew members by reckless behaviour.	Rating (1-7)	1	2	3	4	5	6	7
3.1.3	**Inappropriate Physical Actions**								
3.1.3.1	I attack (e.g., pushing, shoving, hitting) other crew members physically.	Rating (1-7)	1	2	3	4	5	6	7
3.1.3.2	I sexually harass other crew members.	Rating (1-7)	1	2	3	4	5	6	7
3.1.4	**Alcohol Consumption or Drug Use**								
3.1.4.1	I come to work under the influence of alcohol or drugs.	Rating (1-7)	1	2	3	4	5	6	7
3.1.4.2	I have crew performance affected due to a hangover from alcohol or drugs.	Rating (1-7)	1	2	3	4	5	6	7
3.1.4.3	I engage in alcohol consumption or drug use on the job.	Rating (1-7)	1	2	3	4	5	6	7

Self-Evaluation Form for Contextual Performance and Counterproductive Behaviour

3.2 Counterproductive Behaviour - Organizational Deviance

ID	Performance Measures	Scale of measure	Never	Very Rarely	Rarely	Sometimes	Often	Very Often	Constantly
3.2.1	**Poor Attendance**								
3.2.1.1	I come to work late or leaving early without permission.	Rating (1-7)	1	2	3	4	5	6	7
3.2.1.2	I are absent from work without a legitimate excuse.	Rating (1-7)	1	2	3	4	5	6	7
3.2.1.3	I leave progressing work for personal matters unexcused.	Rating (1-7)	1	2	3	4	5	6	7
3.2.2	**Misuse of Time**								
3.2.2.1	I take an additional or longer break than is acceptable at the workplace.	Rating (1-7)	1	2	3	4	5	6	7
3.2.2.2	I intentionally work slowly.	Rating (1-7)	1	2	3	4	5	6	7
3.2.2.3	I make personal calls or emailing at work.	Rating (1-7)	1	2	3	4	5	6	7
3.2.2.4	I drag out work in order to get overtime.	Rating (1-7)	1	2	3	4	5	6	7
3.2.3	**Misuse of Resources**								
3.2.3.1	I waste the organization's resources (i.e. materials; energy).	Rating (1-7)	1	2	3	4	5	6	7
3.2.3.2	I use the organization's resources (i.e. equipment) that I am not authorized to use.	Rating (1-7)	1	2	3	4	5	6	7
3.2.4	**Misuse of Information**								
3.2.4.1	I discuss confidential matters with unauthorized personnel within or outside the organization.	Rating (1-7)	1	2	3	4	5	6	7
3.2.4.2	I intentionally fail to give necessary information to supervisor or other crew members.	Rating (1-7)	1	2	3	4	5	6	7
3.2.4.3	I cover up mistakes.	Rating (1-7)	1	2	3	4	5	6	7
3.2.5	**Poor Quality Work**								
3.2.5.1	I perform tasks intentionally below acceptable standards.	Rating (1-7)	1	2	3	4	5	6	7
3.2.5.2	I intentionally do work badly or incorrectly.	Rating (1-7)	1	2	3	4	5	6	7
3.2.5.3	I intentionally do sloppy work.	Rating (1-7)	1	2	3	4	5	6	7
3.2.6	**Destruction of Property**								
3.2.6.1	I deface, damage, or destroy property belonging to the organization.	Rating (1-7)	1	2	3	4	5	6	7
3.2.6.2	I deliberately sabotage equipment in the organization.	Rating (1-7)	1	2	3	4	5	6	7
3.2.7	**Theft and Related Behaviour**								
3.2.7.1	I take tools from work without permission.	Rating (1-7)	1	2	3	4	5	6	7
3.2.7.2	I falsify a receipt to get reimbursed for more money than spent.	Rating (1-7)	1	2	3	4	5	6	7
3.2.7.3	I take consumables from the organization.	Rating (1-7)	1	2	3	4	5	6	7