

Predicting Subcontractor Performance Using Artificial Intelligence

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Abstract

Subcontractors contribute to almost 90% of the overall construction work hence, assessing the performance of their work from commencement till the completion stage is essential. This paper focuses on identifying different factors affecting the subcontracted work performance and developing a predictive model using classification - based algorithm to find the proficient subcontractors.

Data collected from the building construction projects was analyzed and utilized. Expert validation method was carried out to validate the factors that were obtained from literature review and a survey was conducted to assess the subcontractor's performance level. Different classification algorithms such as Naïve Bayes, Logistic, Multilayer Perceptron, Sequential Minimal Optimization (SMO), KStar, J48 and Random Forest were applied to the collected data. Waikato Environment for Knowledge Analysis (WEKA), an opensource machine learning tool was used to compare the performance of several algorithms. Statics were generated and compared using k-folds cross validation (k=10) method.

Among the seven algorithms/classifiers, Random Forest had the highest accuracy in schedule performance model and Multilayer Perceptron in quality performance model.

Keywords: Subcontractors, Schedule Performance, Quality Performance, Building construction contractors, Prediction model, Waikato Environment for Knowledge Analysis, algorithms/classifiers

1. Introduction

Evaluation and prediction of subcontractor's performance is crucial as it will help the contractor to select the right subcontractor to improve the productivity of work for better project delivery (Kozlovská & Struková, 2013). The major purpose of hiring a subcontractor is to achieve better quality of work at a faster rate and lower cost as they develop expertise in a specific area. Furthermore, subcontractor's performance is extremely important for construction projects, firms, and the industry poor performance of the subcontractors directly impacts the quality of work. Assessment of subcontractor's performance in terms of time, cost, quality, safety, service, professional behavior, leadership, technical skills, and critical reasoning is very essential. Since, there are various factors that affect the works of each subcontractor individually and eventually in overall construction period, it is very important to assess the performances of all the subcontractors at different project stages under numerous factors. For a contractor, it is crucial that they hire good subcontractors as well as monitor and control their performance to channelize them according to the requirement. Construction industry in Nepal has been criticized for low quality and delay in completion which has been reflected by various past and ongoing projects (Kusi et al., 2018). Unnecessary delay, cost overruns, and slow progress have been the characteristic features of Nepal's development projects for many years, but it can be solved to a large extent if the hired subcontractor performs as anticipated.

Lately several artificial intelligence techniques such as developing EFNNs (Evolutionary Fuzzy Neural Network) outperforms NNs (Neural Networks) and FL (Fuzzy Logic) have been applied in predicting subcontractor's

performance. Subcontractor Performance Evaluation Model (SPEM) using a synergism of generic algorithm, fuzzy logic and neural networks has been used to select the subcontractor (Ko et al., 2007). Neural networks (NNs), fuzzy logic (FL), and genetic algorithm (GA) were hybridized to develop EFNNs (Ko, 2013) for decision making. Multiple regression technique was applied to predict the subcontractors' performance using 70 projects (Le-hoai et al., 2013). Regression model was developed to conduct weekly assessment of the subcontractors' performance by rating quality, safety, schedule, and cleanliness (Maturana et al., 2007) but there is a lack of research that aims to develop a model in predicting the subcontractor's performance on the basis of time, cost and quality by using machine learning approach as timely assessment and prediction is requisite during the overall execution of the project to help the subcontractor's improve their productivity and quality of work.

The objective of this research is to study and evaluate several factors that influence time and quality performances of the subcontractors at different work stages and to develop performance prediction models by classification technique using Waikato Environment for Knowledge Analysis (WEKA). The factors from literature review were validated by expert's opinion method and used for survey questionnaire development for data collection and further for the model development.

2. Literature Review

2.1 Subcontractor Performance

Subcontractors are the construction firms that tend to develop expertise in a specific area and try to develop network with contractors to get jobs related to their specialization. Subcontractors have contractual agreement with the main contractor therefore, it is the responsibility of the contractor to hire good subcontractors, monitor and control their work for the successful delivery of products or services. Subcontractor's performance is extremely important for construction projects, firms, and the industry because the poor performance of subcontractors directly impact the quality of projects and outcomes of the assets. The evaluation criteria generally should align with the old business concept that every product-producing business offers the following elements to the customers: price, quality and service (Whitten, 1991). Moreover, assessment of subcontractor performance in terms of time, cost, quality, safety, service, professional behavior, leadership, technical skills, and critical reasoning are important for project success. However, quality and schedule performances are considered for the evaluation of their performance. Construction industry in Nepal has been criticized for low quality and delay in completion which has been reflected by various past and ongoing projects (Kusi et al., 2018). Therefore, it is important that Nepalese contractors assess the factors to evaluate and adopt necessary steps to enhance the quality and schedule performances of the subcontractors.

2.2 Factors for evaluating subcontractor's performance

One of the most important purposes of hiring subcontractors is that they have specialized technical skills that are superior to general contractors (Whitten, 1991). Technical skills of the subcontractors depend on factors such as experience in the relevant field, trainings, understanding of the specification, updated newest methods and technology, and accurate estimation. According to Enshassi et al., (2012) subcontractor should have a good understanding and awareness about the scope of construction work, methods, materials, equipment and schedule. In addition, the subcontractors shall be aware of shortage of materials, construction methodology, labor supply, payment related issues, site establishment, discrepancies in contract documents, worker's skills, efficiency of workers, weather conditions to avoid project failure (Mishra et al., 2018). Nowadays, considering only the bid price for subcontractor's selection is a major cause of project delivery problems therefore, it is required to find out their previous works regarding the claims for extension of time, additional fees, quality of materials according to the specification, contractual compliance, material wastage (Kozlovská & Struková, 2013). For predicting the "time" performance, contractors need to evaluate the subcontractors' previous trend of achieving milestones and duration control abilities (Ko et al., 2007).

According to Kozlovská & Struková, (2013), while selecting subcontractors owner and general contractors should consider factors such as experience of relevant previous projects, quality of materials, equipment and workmanship, employment of qualified members, compliance with safety and environment requirements, contractual performance and collaboration with other contractors and subcontractors, reputation of the company, accessibility of the company etc. Safety performances of the subcontractors are reflected by the adequacy of supervision, and workers' preparation for safe working environment (Novotny, 2018). Good subcontractors provide service like instructions, manual, maintenance etc. even after the work is finished (Ko et al., 2007). Organization skills of subcontractors regarding tools, materials and work balance in different concurrent projects also demonstrate their professionalism. Subcontractors must also possess leadership skills such as team development with qualified members, risk identification, and problem solving (Novotny, 2018). According to (Enshassi et al., 2012), it is recommended for contractors to consider previous experiences, reputation and capabilities in terms of qualified technical staffs, labor, equipment, materials, machineries and their quality

standards, implementation of engineer's instructions, adherence to contract requirements for evaluation and selection of subcontractors.

2.3 Predicting subcontractor performance

Subcontractor's performance history is considered an important indicator for general contractors to select subcontractors. Prediction of the performance of the subcontractors can be done by assessment of various attributes of the subcontractor's performance prior to, during, and after the construction completion. The results of subcontractor's performance prediction helps the contractors to select the most suitable subcontractors for their new projects, whereas during the project execution, it provides feedbacks to contractors and subcontractors that would help them to improve their productivity (Kozlovská & Struková, 2013). Therefore, record keeping and documentation of all the activities performed by the subcontractors should be done for accurate prediction. It is important to predict the subcontractors' performance based on the combined assessment of various criteria. The factors may be known or unknown, so the guidance of experts is necessary.

2.4 AI application in subcontractor performance

In the recent years, artificial intelligence methods have been used in the construction sector for assessing subcontractor's performance to enhance project delivery with less error, safety and better workflow. Application results have shown that the proposed EFNNs (Evolutionary Fuzzy Neural Network) outperform NNs (Neural Networks) and FL (Fuzzy Logic) in predicting subcontractor performance. Subcontractor Performance Evaluation Model (SPEM) using a synergism of generic algorithm, fuzzy logic and neural networks has been applied to study the historical contractual performance for appropriate subcontractor selection (Ko et al., 2007). To facilitate the decision-making, neural networks (NNs), fuzzy logic (FL), and genetic algorithm (GA) were hybridized to develop EFNNs (Ko, 2013). The Evolutionary Support Vector Machine Inference Model (EISM) was studied and analyzed to develop Subcontractor Rating Evaluation Model (SREM) to fit subcontractor performance cases in the historical record for evaluation (Cheng & Wu, 2012). Mbachu & Mbachu (2008) investigated the key criteria for subcontractor performance assessment and the results showed that subcontractors' previous performance record is the influential criterion for selecting high performing subcontractors during prequalification stage, and for assessing their performance at construction stage. Le-hoai et al. (2013) applied the multiple regression technique to predict the subcontractors' performance using 70 projects. Likewise, Maturana et al., (2007) conducted weekly assessment of the subcontractors' performance by rating quality, safety, schedule, and cleanliness.

2.5 WEKA and classifiers

Waikato Environment for Knowledge Analysis (WEKA) is a collection of machine learning algorithms to perform data mining tasks such as linear regression and attribute selection. WEKA contains the tools for data pre-processing, classification, regression, clustering, association and visualization. The WEKA GUI tool allows loading the data sets in ARFF format, analyzing the data by running different algorithms and public the results statistically. There are different classifiers or algorithms which are divided into main groups such as bayes, function, lazy, meta, misc, rules and trees. WEKA provides the opportunity to implement these algorithms easily on the data without having to write the code.

3. Research Methodology

The purpose of this research is to identify different factors that affect the schedule and quality performances of the subcontractors. For this, expert opinion method was adopted to validate and finalize the factors that were obtained from literature review. It was then, followed by pilot testing and questionnaire survey of respondents which in this research, are the contractors of building construction in Nepal. Data analysis was done, and prediction models were developed for schedule and quality performances using a machine learning software, WEKA.

3.1 Questionnaire development and Data Collection

In the first round, contractors or their representative having experience in building construction sector in Nepal for at least 5 years were considered as experts. There were 18 factors to be considered that were validated by them that affected the schedule and quality performances of the subcontractors. The 18 factors approved by the expert opinion method were: understanding of scope of work by subcontractors, no. of workers of subcontractor, availability of tools and equipment, availability of materials, quality of materials, financial resources, preparedness for weather conditions, site establishment facilities for workers, experience of subcontractor in the related field, understanding of drawings and specifications by subcontractor, protection of completed works, understanding of method statement by subcontractor, Quality Assurance Plan, workers' skill level, quality of

supervision, clear contract conditions, previous experience with the contractor and workplace difficulty. The expert-validated factors were used to conduct questionnaire survey among the contractors or their representative to evaluate their subcontractors' work. Based on their subcontractors' activities, they rated them in each of the attributes (factors) as very poor, poor, medium, good, or very good. They were asked to evaluate the actual performances where schedule performance was assessed as "delay", "on time" or "ahead" and quality performance as "poor", "normal" or "good".

4. Results and Analysis

4.1 Analysis of expert opinion

As per the majority of experts 15 factors were approved of as those affecting the schedule performance whereas 14 factors were approved for quality performance. No factors were fully disregarded.

4.2 Analysis of survey data

A total of 201 datasets were collected from 67 construction projects in Nepal. Out of the 201 subcontractors, 31 of them were behind schedule, 160 were on time and 10 were ahead of schedule. On the other hand, the quality performance of 5 of the subcontractors was poor, 71 was normal and 125 was good.

4.3 Model building

4.3.1 Data preparation

In order to feed the data to WEKA, the Excel files comprising of the data were first converted to Comma Separated Value (CSV) file which was then imported to notepad to convert into Attributed Relation File Format (ARFF). The ARFF file consisted of three sections, and they were @relation [name of the file], @attribute [different factors along with the data type for each factor] and @data [the actual data]. The analysis of all the 4 categories were carried out using different seven different classifiers using k folds cross validation.

4.3.2 Analysis using K fold cross validation

In k-fold cross validation method, the data is divided into k different sets where k-1 datasets are training set and the remaining 1 is the test set. The data analysis process continues for k times in such a way that each of the set is used as test set at least once. Since the data was limited (201 dataset), cross validation was adopted over percentage split method so that all the data are utilized, and the results are more accurate. For this analysis, k=10 referring to the fact that k=10 was found to provide good trade-off of low computational cost and low bias in model performance in many studies (Brownlee, 2020).

4.3.3 Selection of best performing prediction model

The Random Forest classifier has the highest accuracy of 85.6% and Receiver Operating Characteristics (ROC) area as 0.85 which are the highest among all the classifiers for schedule performance (as shown in Figure 1) and highest weighted average ROC of 0.85 (as shown in Figure 2). Therefore, Random Forest is the best performing classifier for this prediction model.

According to the confusion matrix in Table 1, 14 instances of the class "Delay" are correctly classified and the remaining 17 of this class is incorrect. 158 of the class "On time" are correctly classified and the remaining 2 are incorrect. Finally, 10 instances of class "Ahead" are incorrectly classified.

Table 1. Confusion Matrix

a	b	c	←classified as
14	17	0	a=Delay
2	158	0	b=On time
0	10	0	c=Ahead

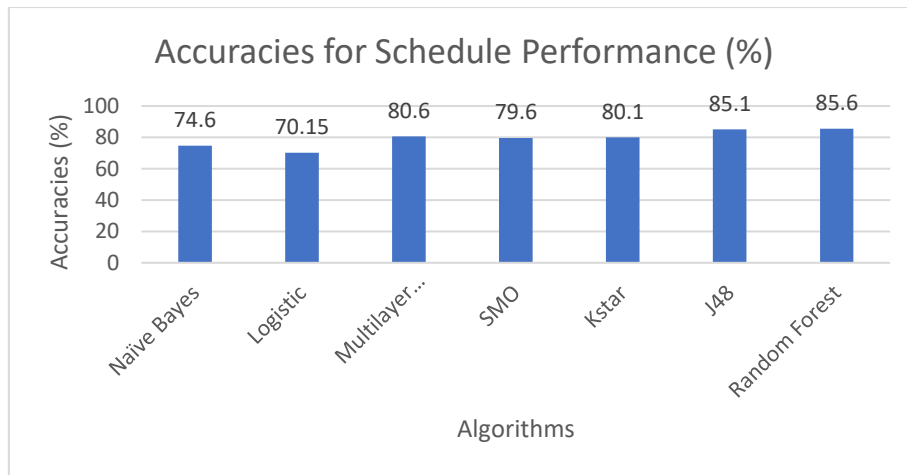


Figure 1. Comparison of different Classifiers on the basis of Correctly Classified Instances using K-fold Cross Validation for Schedule performance

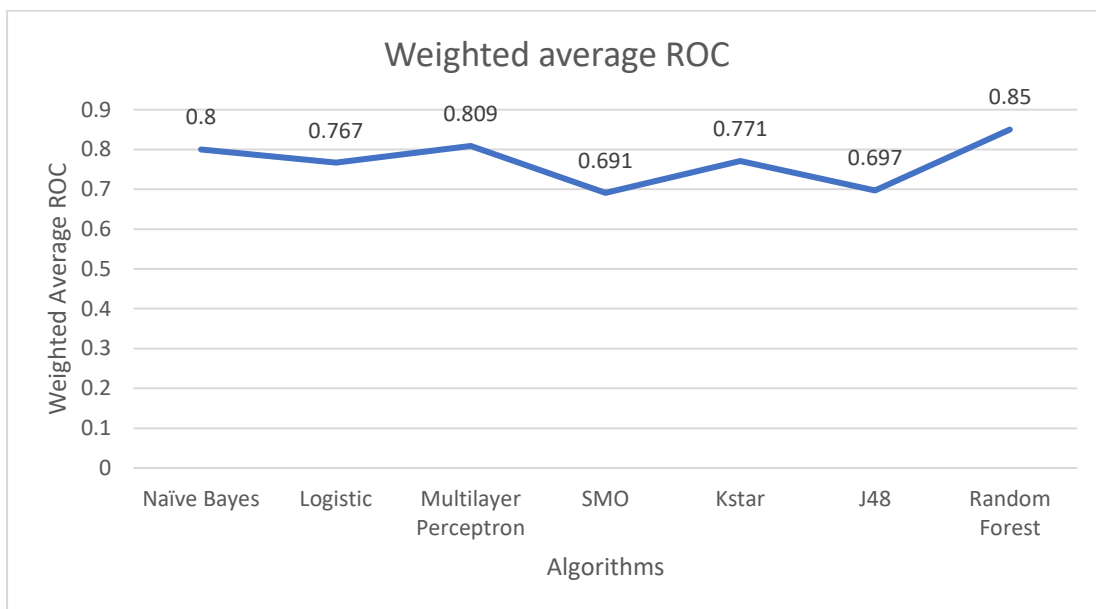


Figure 2. Comparison of different Classifiers on the basis of Weighted Average ROC using K-fold Cross Validation for Schedule performance

The Multilayer Perceptron classifier is the best performing classifier for quality performance with the highest accuracy of 89.05%, kappa statistic value of 0.7754 and ROC Area of 0.950 (as shown in Figure 3) and weighted average ROC of 0.950 (as shown in Figure 4). Therefore, Multilayer Perception is the best performing classifier for this prediction model.

According to the confusion matrix in Table 2, 3 instances of the class “Poor” are correctly classified and the remaining 2 of this class are incorrect. 62 of the class “Normal” are correctly classified and the remaining 9 are incorrect. Finally, 114 instances of class “Good” are correctly classified and 11 of them are incorrectly classified.

Table 2. Confusion Matrix

a	b	c	←classified as
3	2	0	a=Poor
0	62	9	b=Normal
0	11	114	c=Good

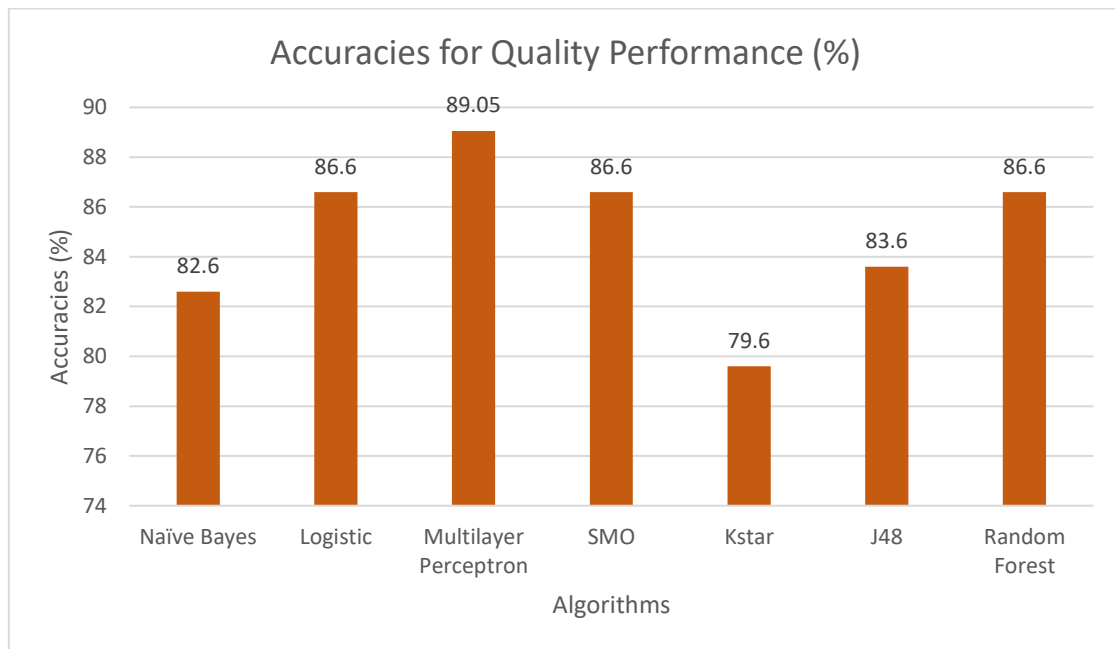


Figure 3. Comparison of different Classifiers on the basis of Correctly Classified Instances using K-fold Cross Validation for Quality performance

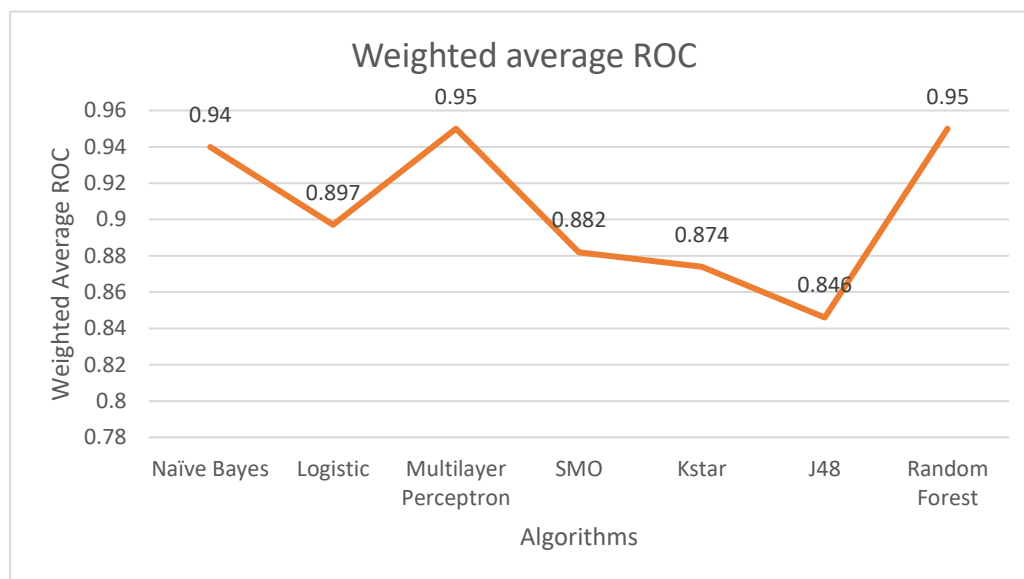


Figure 4. Comparison of different Classifiers on the basis of Weighted Average ROC using K-fold Cross Validation for Quality performance

4.4 Analysis of the Importance of Different attributes

The importance of each attribute in the contribution to the schedule and quality performances of the subcontractors at each stage was conducted by removing each attribute and analyzing the model each time. The accuracies of the model after removal of each attribute for schedule and quality performances can be observed in Figures 5 and 6 respectively. Using Random Forest classifier (best model for schedule performance), the accuracy of the model for schedule performance dropped from 85.6% to 82.1% when the attribute “adequate number of workers” was removed, thus, it is the most important factor as per the Random Forest classifier. The top 5 attributes based on drop in accuracies of schedule performance are adequate number of workers, preparedness for extreme weather conditions, understanding of scope of work, planning for workplace difficulty, and availability of tools and equipment. Likewise, the accuracy of the model for quality performance decreased from 89.05% to 83.08% when

the attribute “Experience of the subcontractor in the related field” was removed which is the maximum drop. So, as per the Multilayer Perceptron, it is the most important factor affecting quality performance and the top 5 factors for quality performance of subcontractors are experience of subcontractors in the related field, quality of materials, Quality Assurance Plan, protection of completed works and worker’s skill.

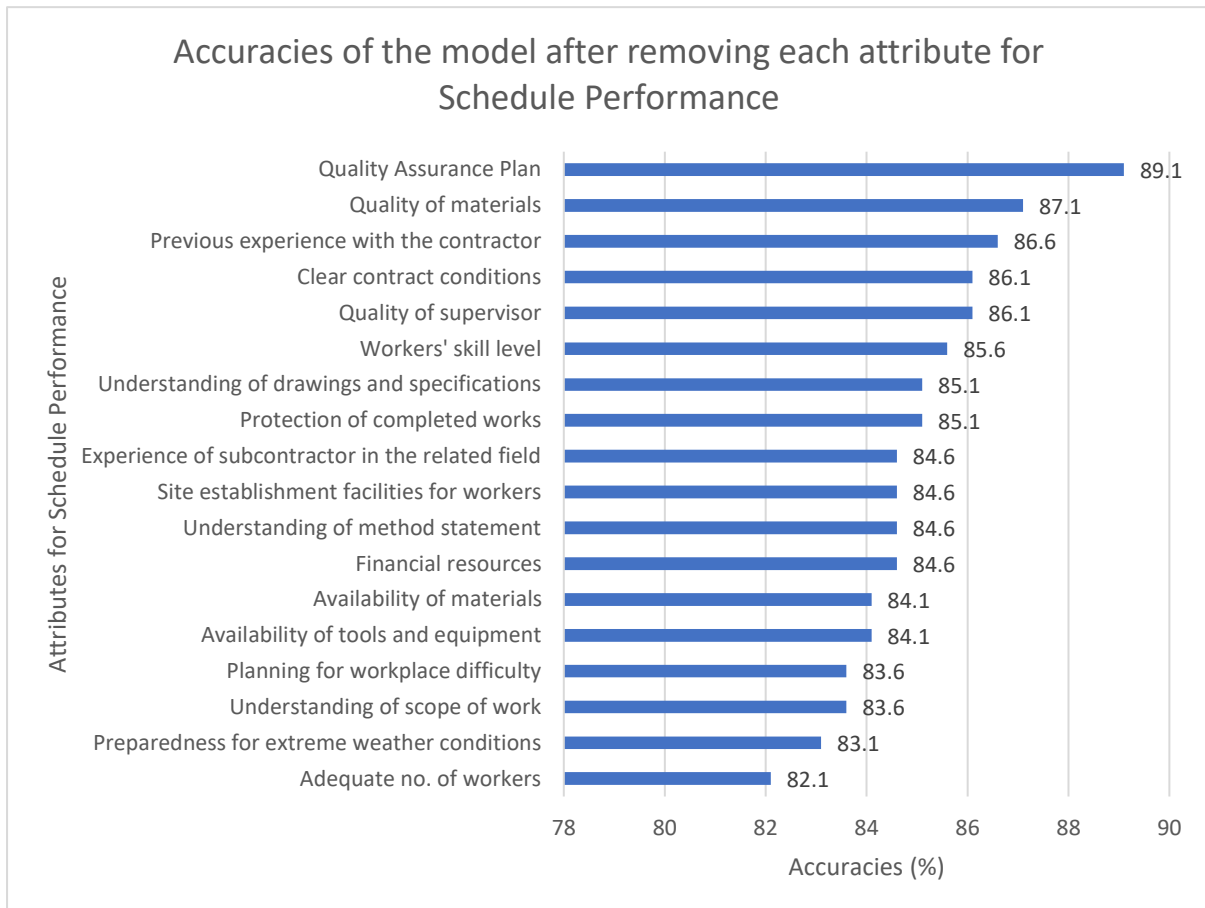


Figure 5. Accuracies of the model after removing each attribute for Schedule Performance

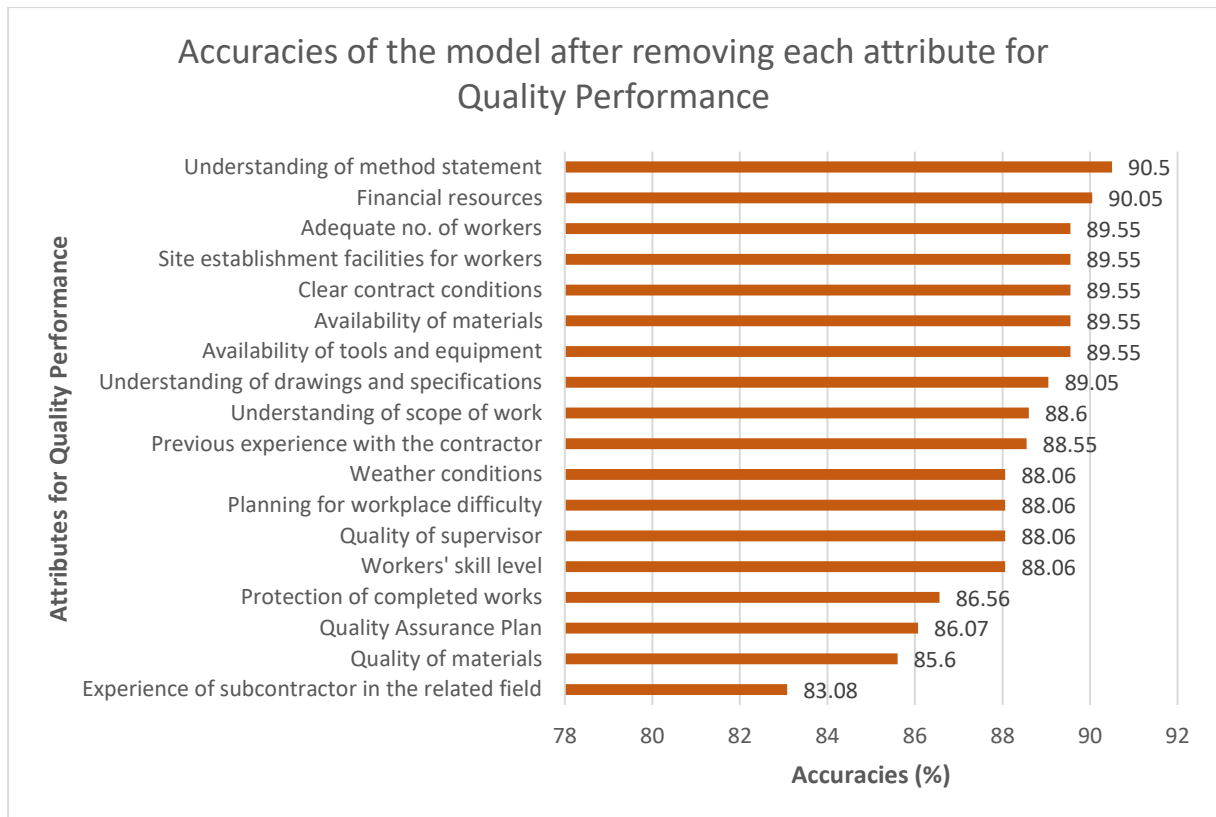


Figure 6. Accuracies of the model after removing each attribute for Quality Performance

4.5 Trend Analysis

Since the size of the dataset is small (201), datasets were created by randomly selecting 50 and 100 data. The models were run using the same algorithms. The trend for each of the schedule and quality performances can be observed in figures 7 and 8 respectively. Using the best algorithm for each of the models, the top 5 factors were obtained that affected the schedule and quality performances which are listed out in figures 9 and 10 respectively.

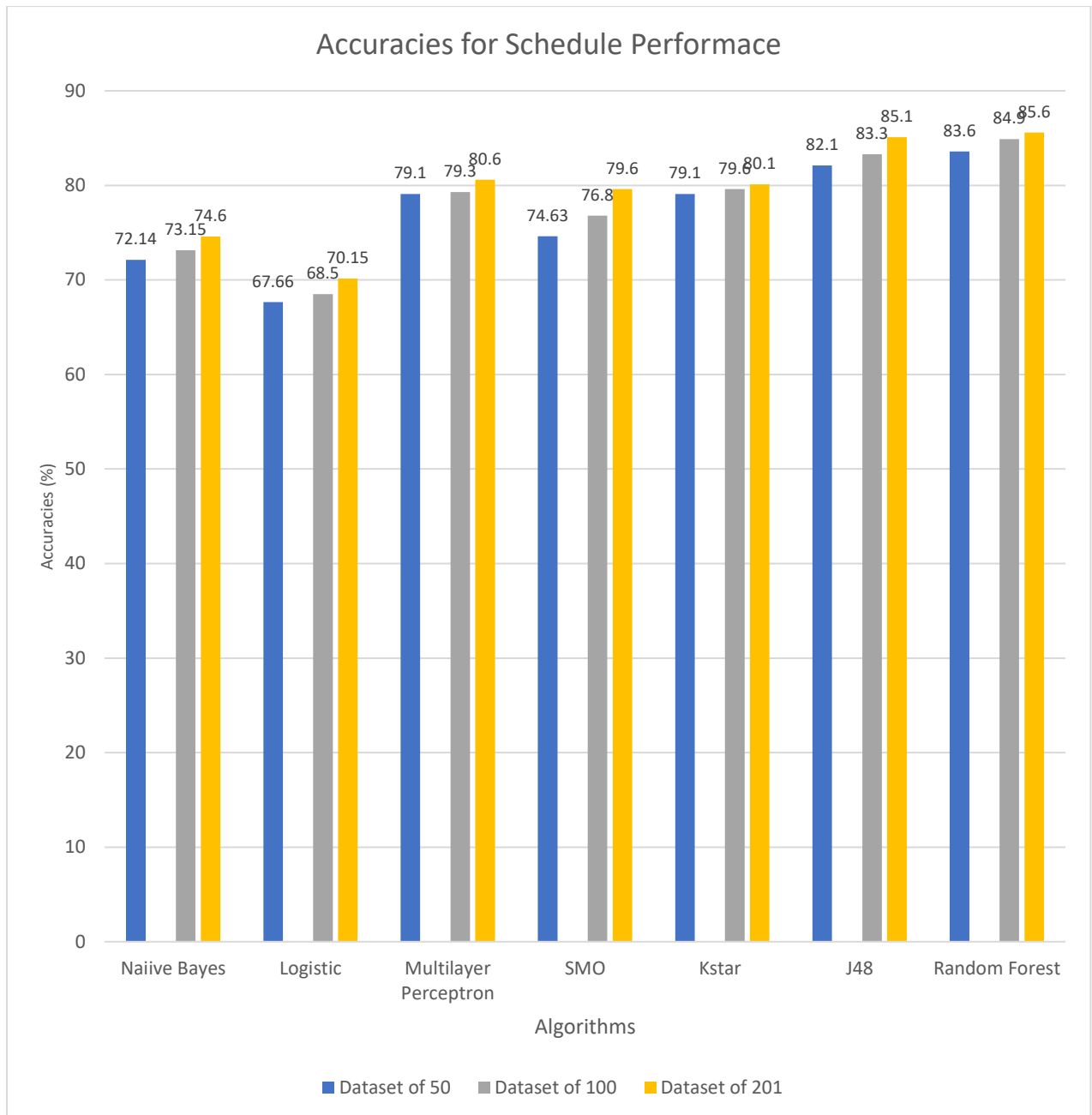


Figure 7. Trend analysis for accuracies of the model for Schedule Performance



Figure 8. Trend analysis for accuracies of the model for Quality Performance

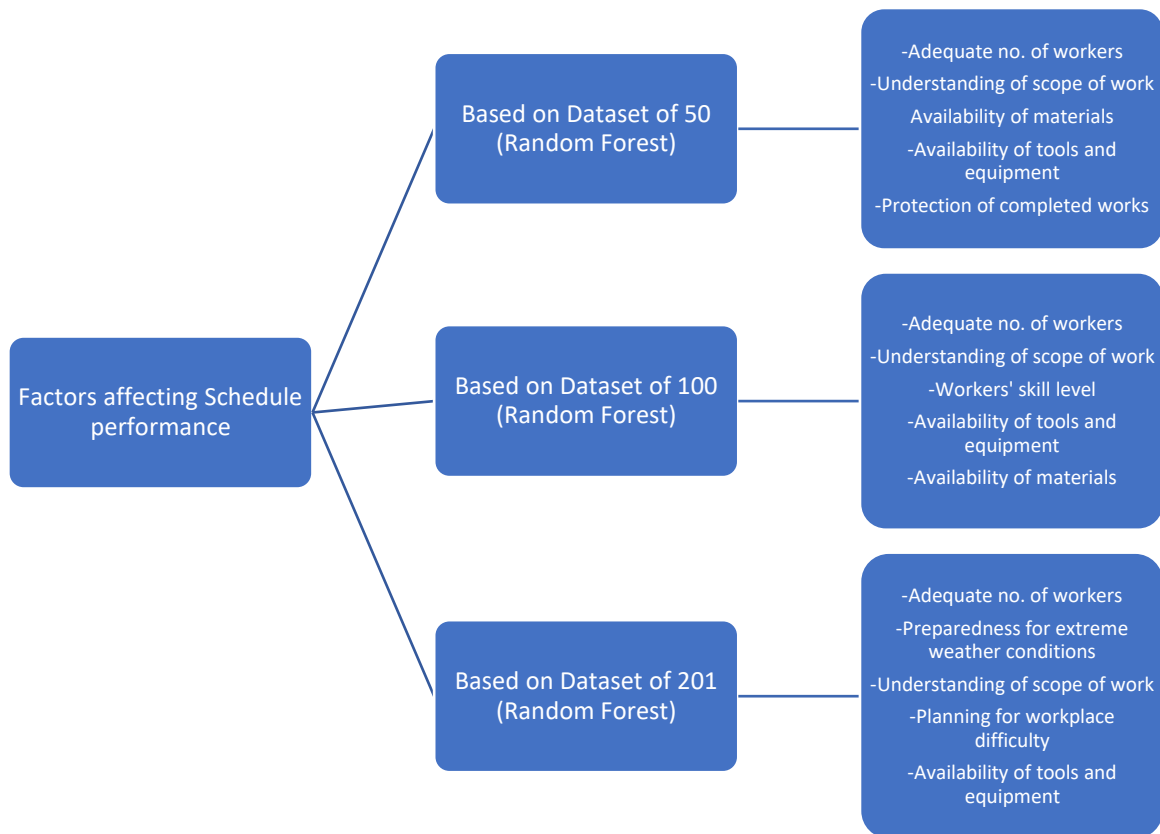


Figure 9. Factors affecting Schedule Performance

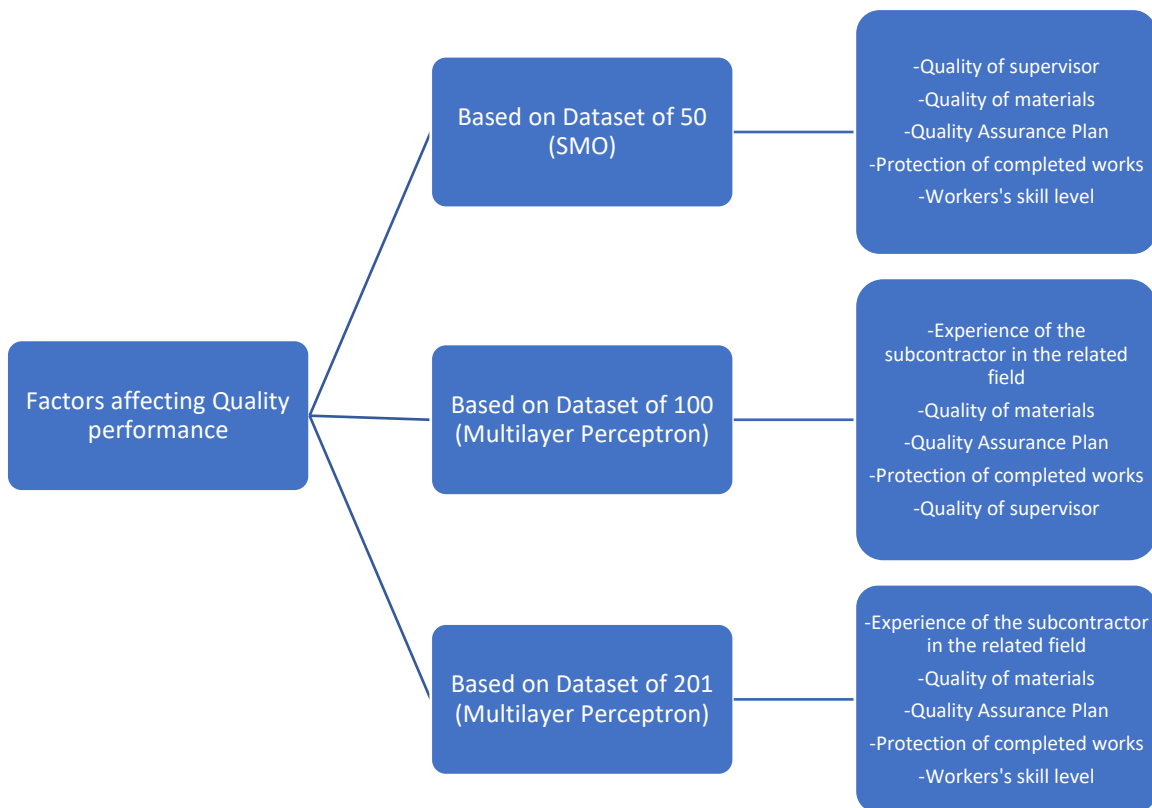


Figure 10. Factors affecting Quality Performance

5. Conclusion

K-folds cross-validation (k=10) method was adopted for model development. The model obtained by Random Forest classifier was chosen for schedule performance and the model obtained by Multilayer Perceptron was chosen for quality performance.

Analyses were done based on the dataset of 50, 100 and 201 in order to build better performing models. From the analysis of all 201 data, the top 5 attributes based on importance for schedule performance of schedule performance are adequate number of workers, preparedness for extreme weather conditions, understanding of scope of work, planning for workplace difficulty, and availability of tools and equipment. Likewise, the top 5 factors for quality performance of subcontractors are experience of subcontractors in the related field, quality of materials, Quality Assurance Plan, protection of completed works and worker's skill.

For further study, the scores for qualitative factors can be assigned values using "Utility Theory" and that for normalizing quantitative factors, "Min-max normalization" can be used. This will assist in bringing uniformity in the score values for both qualitative and quantitative factors as they will lie in a common range (0-1) as well as reduce the biasness when the model is used in a different area apart from Nepal especially in qualitative factors. Also, further study using reinforcement learning could be conducted. Additionally, other sectors of construction than the building sector could be considered for study.

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