APPLICATION OF MULTIVARIATE DISCRIMINANT ANALYSIS FOR CLASSIFYING PROFICIENCY OF EQUIPMENT OPERATORS

Ruel R. Cabahug[1], Ruth Guinita-Cabahug[1] and David J. Edwards[2]

[1] Mindanao Polytechnic State College, Cagayan de Oro City, Philippines
[2] Loughborough University, Department of Civil and Building Engineering, Leicestershire, U.K.
Correspond to ruel_cabahug@yahoo.co.uk

ABSTRACT: Using data gathered from expert opinion of plant and equipment professionals; this paper presents the key variables that may constitute a maintenance proficient plant operator. The Multivariate Discriminant Analysis (MDA) was applied to generate data and was tested for sensitivity analysis. Results showed that the MDA model was able to classify plant operators' proficiency at 94.10 percent accuracy and determined nine (9) key variables of a maintenance proficient plant operator. The key variables included: i) number of years of experience as equipment operator (PQ1); ii) eye-hand coordination (PQ9); iii) eye-hand-foot coordination (PQ10); iv) planning skills (TE16); v) pay/wage (MQ1); vi) work satisfaction (MQ4); vii) operator responsibilities as defined by management (MF1); viii) clear management policies (MF4); and ix) management pay scheme (MF5). The classification procedure of nine variables formed the general model with the equation viz:

$$OMP\ (general) = 0.516PQ1 + 0.309PQ9 + 0.557PQ10 + 0.831TE16 + 0.8MQ1 + 0.0216MQ4 + 0.136MF1 + 0.28MF4 + 0.332MF5 - 4.387$$

Key words: equipment operator, MDA classification technique, productivity, maintenance proficiency

1. INTRODUCTION

This research undertaking determines the key variables that may constitute a proficient construction equipment operator using the qualified opinion of supervisors of plant and equipment. Previous studies have reliably provided success with the application of statistical classification method using Multivariate Discriminant Analysis (MDA). Key variables that can classify plant operators' maintenance proficiency were determined and have been disseminated to provide information to construction managers in improving operators' proficiency performance [1a] , [1b].

2. AIMS AND OBJECTIVES

This research aims to develop a quantitative model to classify construction equipment operator attributes, which categorize their level of on-site operation proficiency. Specifically, the research will determine three classifications of operators, these being: good, average or poor. In pursuing this aim, the following objectives will be satisfied and subsequently used as measures by which to determine the success of this research:

i) Operator's attributes that influence equipment productivity and reliability;
ii) Mathematical models and mechanisms to monitor, control and improve the productivity of existing equipment operators;
iii) Qualities of an 'optimum plant operators' and baseline information to aid construction industry in the selection of new recruit plant operatives;
iv) Improvement of wider industry understanding of the impact that operators can have upon plant productivity. Essentially, this includes a more productive construction process with commensurate cost reduction and timely project completion for clients;
v) Provide construction industry of gaining a competitive advantage.

3. METHODOLOGY

The research identified potential attributes (variables) that constitute a proficient equipment operator. These variables were gathered with reviews of related literature and interviews of plant and equipment supervisors and managers. A structured questionnaire was designed and developed to collect data from equipment owners, supervisors and managers. The questionnaire provided systematic and investigative questions. The survey questionnaire also provided the perception of qualified opinions regarding attributes denoting productive equipment operators.

3.1 Concepts of a Weighting Index *(WI)*

The weighting index represents the importance of a given variable or sub-variable for determining the maintenance proficiency of plant operators. Numerical values for the *WI* were computed using formula 5.3:

$$W = 0.5\ IR + 0.5RR \qquad (1)$$

where: W is the weighting index; IR is the importance rating; and RR is the rank rating (cf. Holt, 1995). The philosophy behind the consolidation of these two elements into a final *WI* is that a variable's overall importance to the selection process is a product of its intrinsic relative importance (*IR*) and its potential ranking response *(RR)*. *WI* therefore provides a balanced input of *IR* and *RR*. Derived values of *WI* of each for each of the five generic factors were then translated in terms of percentage importance of Operator Maintenance Proficiency *(OMP)*. Mathematically this is expressed as:

$$Importance\ of\ factor\ WI\ = \frac{Factor\ WI}{\sum Factors\ WI} \times 100\% \qquad (2)$$

Therefore, when all individual *WI* values have been derived, the *OMP*, this equation can be written as:

$$OMP = f\,(aPe + bMo + cTe + dMa + eWs) = 100\% \qquad (3)$$

where: *OMP* is the operator maintenance proficiency rate in percentage terms and is a function of: *a* the percentage weight of Personal factor *(Pe); b* the percentage weight of Motivation factor *(Mo); c* the percentage weight of Training and education factor *(Te); d* the percentage weight of Management factor *(Ma); and e* the percentage weight of Work situational factor *(Ws)*.

Subsequently, each variable within a generic factor will also have its corresponding weighting index *(V)* derived from *IR* and *RR* scales. Individual variable weighting indices were first calculated and then translated into a percentage value that would represent a contribution to its respective generic factor (vibe formula 5.4). For instance, generic factor *Mo* (with five variables identified) consists of five percentage ratios from associated variables. *Mo* can be presented mathematically as formula 5.6.

$$Mo = f\ (aV_1 + bV_2 + cV_3 + dV_4 + dV_5) = 100\% \qquad (4))$$

3.2 Multiple Discriminant Analysis

The history of Multiple Discriminant Analysis (MDA) dates back to the 1930s when Fisher [2] developed a technique to solve classification problem in archaeological findings [3], [4]. MDA has since been utilised in a plethora of research works. Specifically the technique has been used successfully to: study on education testing for examining voting behaviour among citizens or legislators [5]; study sex-role behaviour in children [6] and felony court case dispositions [7] amongst a wide variety of problems studied.

Within the field of civil and construction engineering, the use of discriminant analysis (regression) methods have gained increasing utilization because it provides a pragmatic solution to many industrial problems. Whilst not exhaustive, examples of applied research using MDA include: contractor creditworthiness evaluation and suppliers' debt collection method [8] hydraulic conductivity of soils [9]; highway bridges load capacity reduction with age [10]; estimation of earthmoving productivity [11]; assessment of hoisting times of tower cranes [12] among many other applications.

The mathematical requirements, which underlie MDA are: i) number of groups *(g);* ii) number of discriminating variables *(p);* iii) number of cases in group *i* (n_i) *and ;* iv) total number of cases over all the groups *(n).*

Classification techniques using correlation analysis and multiple regression analysis were studied for application to the research undertaking. However, MDA was selected in favour of other techniques because it provided statistically significant results in the context that was desired. MDA uses a number of predictor variables to classify subjects into two or more distinct groups [3]. The MDA analysis provides a powerful technique for examining differences between two or more groups of objects with respect to several variables simultaneously (ibid). The procedure results in an equation or discriminant function where the scores on the predictors are multiplied by a weighting to permit classification of subjects into groups

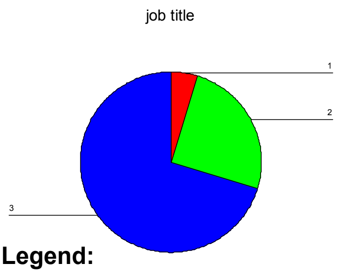
The fundamental concept of MDA is to identify and quantify the linear association between independent variables, thereby classifying them into 'groups' of the dependent variables. MDA can subsequently classify (new) cases into said groups based on the derived MDA functions (models). Linear association is measured via four main statistics namely: i) eigenvalue (λ); ii) Wilk's Lambda (Λ); iii) chi-square; and iv) the canonical correlation.

4. DATA COLLECTION

The literature review identified five factors and 54 potential variables within each factor (Table 1). This further developed into questionnaires for a main survey. The questionnaires were then forwarded to collaborating professional organisations such City Engineers Office and District Offices of selected cities and municipalities within Region 10. A total of 104 respondents, which basically constituted equipment owner-managers, equipment supervisors/ managers and civil engineers represented the target population of the study. Responses were entered into Microsoft Excel database for initial data mining prior to modelling data using complex classification techniques. As part of the data mining process, importance rating scales and rankings for each question were analysed to determine their distribution (parametric or non parametric) and other summary statistical measurements. These 'attitudinal' research data enabled to generate mathematical modelling technique to classify plant operator maintenance proficiency into one of three categories, namely, 'good', average' and 'poor' operators. The classification process itself consisted of four broad stages, namely:

i) determination of importance rating *(IR)* and rank rating *(RR)* of all factors and variables hypothesised as potential classification determinants;
ii) transposition of the *IR* and *RR* ratings into a weighting index *(WI)* so that the relative importance of one variable or factor could be directly compared to others in terms of percentage (Table 2);
iii) quantification of scales of measurement for both independent and dependent variables; and;
iv) utilisation of the culmination of research outcomes emanating from i) to ii) to apply modelling technique using Multivariate Discriminant Analysis (MDA) techniques.

The questionnaires were administered using personal interviews and through the mail. After personal follow-up and phone calls, an overall return rate of 80 percent was achieved by June 2004. A total of 104 respondents, which basically constituted equipment owner-managers, equipment supervisors/ managers and civil engineers represented the target population of the study. Figure 1 shows the distribution of sample respondents categorized by job.



Legend:

1 – Equipment Owner
2 – Supervisor- Manager
3 – Engineer

Fig. 1. Distribution of Respondents by Job Title/ Designation

By combining both rank and rating classification methods, the overall importance of the variable could be deduced using WI = 0.5 IR + 0.5RR, where WI is the weighting index, IR is the importance rating and RR is the rank rating [13]. The philosophy behind the consolidation of theses two elements into final WI is that variable's overall importance to the selection process is a product of its intrinsic relative importance (IR) and its potential ranking response (RR). WI therefore provides a balanced input of IR and RR and is more reliable than using IR in isolation.

5. RESULTS AND DISCUSSIONS

Discursive statistics (mean, median, standard deviation and inter-quartile range) were applied to the survey data to measure central tendency and data distribution characteristics. Tests for normality were then conducted to determine the theoretical distribution of the survey population.

A summary of findings for importance and rank ratings of operator variables are shown in Table 3. Weighting indices *(WI)* of each variable were calculated using the formula WI = 0.5 IR + 0.5 RR. When *WI* value is 0.85 and above, this denotes that the variable is statistically strong. The results revealed eight statistically strong variables. These variables are: : i) number of years of experience as equipment operator (PQ1); ii) eye-hand coordination (PQ9); iii) eye-hand-foot coordination (PQ10); iv) planning skills (TE16); v) pay/wage (MQ1); vi) work satisfaction (MQ4); vii) operator responsibilities as defined by management (MF1); viii) clear management policies (MF4); and ix) management pay scheme (MF5).

The model formulated an equation viz:

$$OMP = 0.516PQ1 + 0.309PQ9 + 0.557PQ10 + 0.831TE16 + 0.80MQ1 + 0.216MQ4 + 0.136MF1 + 0.28MF4 + 0.332MF5 - 4.387$$

6. CONCLUSION

The equipment owners, managers and supervisors opinion survey data was able to derive a profile of a proficient equipment operator. Among a list of fifty-four (54) variables, nine variables were derived. These included: 1) number of years of experience as equipment operator; 2) eye-hand coordination; 3) eye-hand-foot coordination; 4) planning skills; 5) pay/wage; 6) work satisfaction; 7) operator responsibilities as defined by management; 8) clear management policies; and 9) management pay scheme.

Having derived these nine key variables, an in-depth study should be undertaken to focus on the finer details of integrating such variables into the industry's existing training program scheme in order to improve operator performance. This research outcome can be considered a breakthrough in resolving the complex problem of determining which variables, among a long list of variables, may constitute a proficient equipment operator. For this reason, it is recommended that this finding be disseminated to the construction industry in order for managers, owners and supervisors to understand these variables that need serious consideration, which are necessary to bring about real improvements to the human resources who work along equipment. It is believed that integrating these variables in the human resources development plan would ensure increased productivity.

Table 1 Factors and Variables of the Study

Factor	Variable Code	Description
Personal	PQ1	Number of years experience as plant operator
	PQ2	Years experience with equipment item
	PQ3	Age of operator
	PQ4	Marital status of operator
	PQ5	Academic qualification of plant operator
	PQ6	Operator personal disposition
	PQ7	Operator finger dexterity
	PQ8	Eye-hand co-ordination
	PQ9	Eye-hand-foot co-ordination
	PQ10	Reliability of operator
	PQ11	Dependability of operator
	PQ12	IQ of operator
	PQ13	Operator personality
Training and Education	TE1	Type of training attended
	TE2	Operator training by senior operator
	TE3	Training by accredited training provider
	TE4	Operator training by apprenticeship system
	TE5	Duration of training provided
	TE6	Operator knowledge of equipment maintenance duties
	TE7	Knowledge of safety practices
	TE8	Operator knowledge of repair records
	TE9	Operator knowledge of machine manuals
	TE10	Numerical computation skills
	TE11	Oral communication skills
	TE12	Written communication skills
	TE13	Planning skills
	TE14	Mechanical knowledge
Work Situational	WS1	Site condition
	WS2	Extreme weather condition
	WS3	Working alone/unsupervised
	WS4	Working with specific conditions
	WS5	Working nightshifts
	WS6	Operator's 'job specific' learning rate
	WS7	Repetitive cyclical process
	WS8	Personal risk at work site
	WS9	Working under pressure of time
	WS10	Working with managers with little knowledge of plant and equipment
	WS11	Interpersonal relations of operator
	WS12	Working with complex machines
	WS13	New mechanical innovations
	WS14	Continuous muscular control in equipment operation
	WS15	Quality of work
	WS16	Expectation to provide high quality of work
	WS17	Flexibility of operator
Motivation	MQ1	Pay/salary/wage
	MQ2	Fringe benefits
	MQ3	Additional pay for quality output
	MQ4	Work satisfaction
	MQ5	Team-based bonus
Management	MF1	Operator responsibilities defined by management
	MF2	Management – shift assignment
	MF3	Operator career development
	MF4	Clear management policies
	MF5	Management pay scheme

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