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INITIAL TASK SELECTION FOR DETAILED ROBOTIC EVALUATION

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ABSTRACT

This paper provides a methodology for pre-selecting a limited number of activities for detailed investigation using existing robotic feasibility analysis techniques, such as that proposed by Kangari & Halpin [1]. The QCF Delphi method has been employed to survey a significant portion of a company's site management, in order to determine their views on the value of specific robotic or automated systems and to discover the reasons for these views. Using this method reinforcement cage fabrication, site stock control, concrete floor finishing and HVAC installation were found to be the preferred activities for robotic development. It was also shown that service installation and all forms of finishes are presently major sources of construction delay. The method also highlighted the importance of co-ordinating site activities and of controlling the design and management process in order to successfully exploit any automated or robotic system.

1.0 INTRODUCTION

This paper describes work being undertaken at the University of Nottingham, Department of Civil Engineering, in collaboration with a major UK contractor. The initial objective of the work was to ascertain which areas of the company's activities would benefit most from the deployment of robotic or automated systems. Whilst the authors have developed a method for examining the suitability of individual elements of work for automation [2], to apply such a detailed method to each element of a building would be both time consuming and wasteful of effort. We therefore describe a method of identifying a limited number of elements of work to be subjected to detailed investigation and to introduce the results of the study.

2.0 BACKGROUND

Various methods have been proposed for selecting suitable areas for robotic development. Whilst the emphasis of each of these methods varies they all aim to examine :

(1) high payoff areas of projects; (2) high payoff activities within those projects: and (3) construction tasks for which automation is most likely to succeed [1,3].

In order to assess in which areas of activity the greatest benefit could be obtained, the work undertaken by the industry must be examined at an appropriate level of detail. It is at this point that the major divergences in methodology occur; whether to examine the broad range of issues affecting the 'feasibility' of a given task or trade [1,3,4], or to examine the minutiae of the task via a 'hierarchical' classification system [2,5,6,7].

Both of these approaches suffer from the limitation that the entire construction process has to be examined in detail. Using these methods the volume of information to be processed is enormous, as a similar level of information is required for each activity for any given type of construction project. Consequently, the amount of information to be handled makes the application of these techniques impractical without an initial filtering process to reduce the information requirements to a manageable scale.

It is therefore necessary to isolate a limited number of activities for more detailed investigation. The method proposed in this paper uses a survey to:

1. pre-select activities without incorporating implicit assumptions regarding the degree of automation or the configuration of the automated systems [8].
2. select activities which reflect the user requirements within the organization being examined [2].
3. ensure that tasks where robotics may not be pivotal in the development of new systems and methods are considered [9].
4. allow the survey participants to comment upon automation and robotic systems without being restricted to only considering tasks which have previously been assessed as being technologically feasible [8].

3.0 DESIGN AND IMPLEMENTATION OF SURVEY

Managerial staff were asked to select areas for more detailed investigation using a multi-round postal survey which incorporated Delphi techniques [10]. The major objective of the survey was to isolate suitable activities for robotic development, which more accurately reflect the requirements of a specific organization than the methods of initial task identification commonly used by the designers of the hierarchical or feasibility methods. In order to help achieve these objectives the survey tried to:

1. determine which major divisions of work caused most disruption on site,
2. determine which specific activities associated with these tasks were the prime cause of that disruption,
3. examine what problems and benefits contractors believe a robotic system would provide,
4. determine for which activities the participants believed a robotic system would be most desirable.

The different methods used for examining each of these objectives are examined below.

3.1 General Construction Questions

The first two objectives of the survey were examined using conventional survey techniques [11]. The 120 participants were split into two equal groups representing the staff who worked for the building and civil engineering divisions of the company. Each group was then asked to rate items representing the major divisions of work, for their division of the company, using a 6 point rating scale which measured the frequency with which each division of work causes a delay (these divisions were taken from standard method of measurement guides). The participants were then asked to show which 3 causes of delay were the most important for each of the divisions of work using a simple ranking scale. The causes of delay were prepared in consultation with the company's project coordinator and by examination of the justifications offered for cost over-runs on various completed construction projects.

3.2 General Robotic Questions

A number of studies have examined the general problems and benefits associated with robotics in construction [1,8,12 & 13]. Each of these studies has listed similar factors as influencing the feasibility of introducing robotics to construction sites and has tended to present these factors as either 'benefits' or 'restrictions' (although in many cases they can be perceived as either).

In the first round of the survey, the 60 building division participants were invited to grade, on a 7 point rating scale, a list of 7 benefits and restrictions commonly associated with robotic systems which had been selected from those suggested in previous studies. The participants were also given the opportunity to suggest further restrictions or benefits which they believed were associated with robotization. Numerous additional suggestions were made but, as many of these coincided or were sufficiently similar, they were eventually compiled into additional lists composed of 13 further restrictions and 7 further benefits. The additional benefits and restrictions were then presented for grading to the 60 building division participants using the same 7 point rating scale used for the initial items. In addition, the 60 civil's division were also asked to grade all the benefits and restrictions suggested by the builders.

3.3 The Delphi Method - Robotic System Questions

A three round Delphi survey was used to examine which construction activities the 60 building participants believed would most benefit from robotization and what reasons justified this belief. Delphi is a method for structuring the communication process amongst a group of individuals confronted with a complex problem, which enables the participants views and ideas to be presented to the other participants for evaluation and criticism.The main reasons for using the technique are [10] :

1. The problem being studied does not lend itself to precise analytical techniques.
2. The participants do not have a history of adequate communication and may represent a range of backgrounds with respect to experience or expertise.
3. The time available for face to face communication is limited and such communication may be dominated by certain powerful personalities.

4. When allied to suitable stopping criteria the technique would enable areas of consensus and disagreement to be highlighted [14].

Q **Which areas of work do you believe would benefit from some form of automation or robotization ? Please list these below and briefly discuss why you believe such a system would be beneficial to you.**

....

First Round Questionnaire

Q **A number of the participants, in the previous round of the survey, believed that those items listed below would benefit from some form of robotization or automation.**
Please grade each system in accordance with the scale provided having first read and considered the comments (listed in no particular order) made by the participants in the previous rounds.List any additional reasons that influenced the grade you awarded

Asphalting & tanking	Extremely useful	Very useful	Useful	Slightly useful	No use at all

Greater accuracy Greater accuracy would allow reduced falls Specialists do this task - not TMPs problem Huge areas required to be cost effective Reduce present large labour requirement Reduced safety risks Problems with tolerances Variability of material may cause handling problems Problems with upstands, details etc. Quality control Present methods are sufficient Improvement on present primitive methods

Subsequent Round Questionnaire

Figure 1 - Delphi Questionnaire Design

The Delphi process involves a small monitoring team designing a questionnaire posing general questions on a subject, which is then sent to a large respondent group. After the completed questionnaire is returned, the monitoring team summarizes the results and develops a new questionnaire incorporating the justifications and suggestions arising from the previous round (see figure 1). This is then issued to all the respondents in the previous round of the survey. This updated questionnaire enables participants to modify their views in response to those expressed by the other participants. The respondents are not informed of what values were awarded in the previous round to a given statement as this may lead to an artificial consensus developing [15].This variation of Delphi is known as Qualitative Control Feedback (QCF).The process is repeated, with additional comments concerning each system being added,until consensus or, failing consensus, stability in the responses has been achieved. In this survey, the end point was determined by checking the coefficient of variation [16] and Chi-squared respectively [14].

The 60 civil's staff were then presented with the final round questionnaire and asked to grade the preferred systems suggested by the builders using the same scale as shown in figure 1. They were not asked to complete a multi - round questionnaire as the original intent had been to only examine the building division of the company.

4.0 RESULTS & DISCUSSION

The survey results were checked for any variation in response arising from the participants: (1) different educational background; (2) current work in progress on their contract; (3) different work experience; and (4) their rank within the organization. It was generally found that there was little variation in responses due to these factors; with the exception of the general construction and robotic system questions where differing work experiences were of considerable importance [17]. Consequently, only the total results are shown, although comments are provided when a significant difference in response occured.

4.1 General Construction Results

	Commercial	Roads	Civils	Domestic	Industrial	Other
Building Division	41	7	17	6	23	6
Civils Division	1	58	32	0	7	2

Percentage of Time Participants Have Spent on Different Contract Types
Table 1

The survey participants were split into two groups of 60 to examine the different causes of delay in building and civil engineering projects. Each group was given a questionnaire directed towards their different work experience (see table 1). The response rate was satisfactory with 47 (78%) builders and 52 (87%) civil engineers responding to the first round questionnaire.

CIVIL DIVISION RESPONDENTS		DESCRIPTION OF DIVISIONS OF WORK		BUILDING DIVISION RESPONDENTS	
RANK	VALUE*	CIVIL	BUILDING	VALUE*	RANK
2	2.86	Earthworks	Earthworks	2.04	8
5	2.40	Foundations	Foundations	2.46	6
6	2.15	Insitu concrete			
10	1.29	Precast concrete	Structural frame	2.77	3
8	1.81	Structural steel			
11	1.28	Masonry	Masonry	2.22	7
7	1.84	Roads & paving	External works	1.66	12
11	1.28	Landscaping			
3	2.71	Finishes	Cladding	2.52	5
			Roofing	1.96	9
			Internal finishes	2.89	1
1	3.18	Service installation	HVAC	2.86	2
			Electrical installation	2.56	4
9	1.78	Drainage	Drainage	1.93	10
			Lifts & escalators	1.71	11
3	2.71	Tunnelling			

* value represents the sum of scores awarded using the rating scale (0 for 'never a problem' to 5 for 'always a problem') divided by the number of respondents who rated that division of work.

Table 2 - Importance of Divisions of Work in Causing Delay to Building & Civil's Contracts

Table 2 shows the divisions of work believed by the respondents to be the most common causes of delay on building and civil engineering contracts. Despite the different work experiences of the two groups, it is apparent that they both believe Service Installation and Finishes to be the prime causes of delay. In addition, the builders also found the erection of the Structural Frame to be a major problem, whilst the civil's respondents (who are mainly concerned with roads) considered Earthworks and Tunnelling as more significant. However, it should be noted that Tunnelling was only rated by 28 (47%) of the respondents and is consequently a less reliable result [17].

CAUSES OF DELAY	CIVIL DIVISION RESPONDENTS		BUILDING DIVISION RESPONDENTS	
	VALUE*	RANK	VALUE*	RANK
Lack of design coordination	557	5	1151	1
Drawing detail problems	679	2	1081	2
Quality of finished work	569	4	317	7
Time reqd. for carrying out work	460	7	418	4
Repairing post construction damage	264	8	267	8
Lack of site coordination	490	6	527	3
Late delivery of parts	233	9	330	6
Unexpected conditions$^{\delta}$	793	1	388	5
Changing client requirements$^{\psi}$	635	3	201	9

* Value represents the normalized sum of the scores awarded using the ranking scale (3 for 'most important cause of delay' to 1 for '3rd most important cause of delay')

δ Includes weather ψ Includes clients representative

Table 3 - Importance of Causes of Delay to all Divisions of Work

Having determined which divisions of work are most likely to be sources of delay, it was necessary to identify the cause of this delay. Table 3 shows that the different problems encountered by the two groups, and the differing contractural relationships and responsibilities, greatly influences their responses [17]. Significantly, the delays generally involve problems with the managements relationship with the client and designers. For example, the builders, who are more likely to be partly responsible for the design of the work [17], recognize that site co-ordination and control of the design process is of particular importance, whilst the civil engineers are more concerned about the influence of the client and their representative on the progress and execution of the work. Table 4 shows that the most important delays for the divisions of work (identified as most commonly causing delay) reflect the different contractural relationships of the two groups. In addition, the time required to carry out the items of work was a common source of delay.

DIVISION OF WORK		MAJOR CAUSES OF DELAY		
Civils	Service Installation	Design coordination	Drawing details	Client requirements
Civils	Earthworks	Unexpected conds.	Client requirements	Time reqd. for work
Civils	Finishes	Quality of work	Client requirements	Repairing damage
Civils	Tunnelling	Unexpected conds.	Time reqd. for work	Design coordination
Builders	Internal finishes	Quality of work	Design coordination	Drawing details
Builders	HVAC	Design coordination	Drawing details	Delivery of parts
Builders	Structural frame	Drawing details	Design coordination	Time reqd. for work
Builders	Electrical Installation	Design coordination	Site coordination	Time reqd. for work

Table 4 - Main Causes of Delay for Different Divisions of Work

The results in this section show that the perceived causes of delay vary even within organizations, which confirms the need to examine the requirements of an organization in detail before making any investment decision. Furthermore, the problems highlighted in this study indicate that any future robotic development will only be successful if the contractural relationship, management and design problems are first resolved. However, the results do indicate that services and finishes are tasks where this effort could usefully be concentrated, providing that problems of design co-ordination and quality can be overcome.

4.2 General Robotics Questions

The survey participants highlighted 14 general benefits and 20 restrictions of robotic systems. The results show that the greatest benefits were perceived as being: (1) increased operative safety on site; (2) increased productivity; (3) a reduction in materials wastage and construction damage; (4) reduced production costs; and (5) the ability to operate at any time of day or night. The 'benefit' awarded the lowest grade was the ability to assemble standard components, which possibly indicates an abiding distrust of this form of construction.

The greatest restrictions were perceived as: (1) the additional safety hazards arising from operations on site; (2) the training of staff to use the systems; (3) the main contractor undertaking more of the works directly, thus increasing their capital and labour requirements; (4) the need for more technical staff to maintain the systems; and (5) the reliability of the system. These results show that the participants' primary concerns were that by introducing robotic systems their own responsibilities would be greater and that the company's direct exposure to disruption and cost could be increased. Generally, the major concern was the interaction of the system with the operatives on site. The constantly changing site environment was not seen as a significant problem, as the respondents generally believed that most robotic tasks would be remote from the main site.

The perceived benefits and restrictions were checked to see whether there was any correlation between the participant's rank, or the division of the company in which they were employed, and their response. Generally, the views expressed by the participants were found to be uniform, with at most a one point variation in the median answer. However, the following observations may be made:

- Senior managers are more concerned about labour requirements and the cost of production than the remaining participants.
- Concern about site working in adverse weather reduces with greater seniority.
- The junior and middle management are more concerned about the overall quality of the finished product than the senior participants.
- Senior management perceive the greater management discipline required on site when using a robotic system as a major advantage.
- Civil engineers are more concerned about increasing the quality of the work.
- Senior management recognize the resistance of operatives and construction professionals as a significant restriction.

The results of this section indicate that the participants are primarily interested in using robots to undertake hazardous tasks, although they are concerned about the potential hazards that robotic systems would introduce to site. They also believe that robotic systems may aid in reducing the costs of production although the cost of the robot (to purchase, maintain and operate) is of concern. These results indicate that the respondents are generally ambivalent towards the use of robotics, as they cannot see any benefit that cannot be countered by an equally valid restriction.

4.3 Robotic System Results

In the first round of the survey, the building participants suggested 21 different robotic or automated systems which they believed would be useful on site. In subsequent rounds, the participants were invited to grade the suggested systems and comment upon their feasibility. These comments were then issued in the following round (91% & 87% replied to the second and third rounds). Following three rounds of the re-iterative Delphi survey the participants had reached consensus, or stability, in the majority of their responses, including all those listed in table 5 [14,16].

ORDER	PREFERRED ACTIVITIES FOR ROBOTIZATION OR AUTOMATION	
	SECOND ROUND	THIRD ROUND
1st	Concrete floor finishing	Reinforcement cage fabrication
2nd	Sprayed fire protection	Site stock control
3rd	Reinforcement cage fabrication	Concrete floor finishing
4th	Site stock control	HVAC installation
5th	Decorating	Concrete placement

Table 5 - Changes in Preferred Activities Between Second & Third Rounds

Table 5 shows which robotic or automated systems were felt to be most useful by the building participants after three rounds of the Delphi survey.The changes in attitudes towards specific systems arose from the participants being able to alter their response in view of the comments concerning feasibility made by the other participants. The civil engineers were then presented with the final round questionnaire and asked to grade the systems listed. Table 6 shows which activities were preferred by the civil's' division staff.

ORDER	PREFERRED ACTIVITIES FOR ROBOTIZATION OR AUTOMATION
1st	Blacktop & Concrete floor finishing
2nd	Grading
3rd	Site stock control
4th	Drainage
5th	Reinforcement cage fabrication

Table 6 - Preferred Activities for Civil's Respondents

The activities selected by the two groups reflects the respondents differing work experience. Reinforcement cage fabrication and site stock control feature prominently in both lists and consequently should be examined in detail using feasibility or hierarchical techniques. However, as the civil's respondents were not given the opportunity to select their own activities, it should be remembered that, the preferred activities listed in table 6 may exclude activities which they would have suggested had they been involved with the Delphi study.

In addition to grading the different systems suggested, numerous comments were made concerning the feasibility of each of the systems. Whilst these often coincided with comments suggested as general benefits or restrictions of robotic system, they also included additional factors specific to the system being examined. For example, the problem of spring back when bending reinforcement, the labelling of structural steelwork and the monitoring of obstructions when chase cutting were highlighted. These comments could be used to assist in assessing the feasibility of the preferred systems when using the hierarchical or feasibility assessment methods.

5.0 CONCLUSION

The use of the QCF Delphi method in this survey has enabled a large group of skilled construction staff to examine existing general problems of construction. In addition it has led to the identification of the specific benefits and problems of robotic or automated systems, that they believe would arise if such systems were to be deployed on their sites. Reinforcement cage fabrication, site stock control, concrete floor finishing, HVAC installation and blacktop laying were found to be the preferred activities for some form of automation or robotization. However, it was apparent that the success of any robotic system would be dependent upon the quality of project management and the development of designs and working practices that facilitated the use of such systems, both of which are at present major sources of delay to construction.

The preferred systems highlighted by this survey may now be examined in greater detail using existing 'feasibility' or 'hierarchical' techniques in order to assess their technical and economic viability. This more detailed study will need to address both the specific comments concerning each system and the general concerns expressed about robotic systems. It was also evident from the study that service installation, erection of the structural frame and finishes are currently major sources of delay in construction and consequently warrant examination to increase their efficiency. This result provides further support for the development of robotic or automated systems which address aspects of these problems i.e. HVAC installation.

The Delphi technique has generally been successful as it enabled the participants to modify their responses in the light of the additional knowledge they gained through reviewing other participants' views. A further key advantage of using this method was that the list of possible robotic applications was developed solely by the participants and consequently reflected their views rather than those of the survey designer. In addition 120 staff within the organization have been encouraged to consider robotics, possibly for the first time. Whilst this result is intangible it does ensure that they are all more informed about this subject than the vast majority of construction staff.

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