Towards a Comprehensive Feasibility Analysis for the Use of Robots in the Construction Industry

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ABSTRACT: Feasibility studies must cover different disciplines such as need-based feasibility, technological feasibility and economical feasibility. In the present work a comprehensive feasibility analysis model for the use of robots in performing construction tasks is presented. This model is mainly focussed on the need analysis in order to present criteria for decision making. The decision making is performed using the (give in full?)AHP process as a judgement tool for multiple criteria decision-making problems. Four criteria are developed for the decision-making process based on the parties involved in the construction process such as labour criteria, process criteria, site criteria, and management criteria. Safety risk assessment tools are used to emphasize the motivation for task automation from the safety point of view. Simulation tools and existing robot prototypes are used to demonstrate solutions for resolving the safety and technical problems involved in the elected tasks, and to identify the required level of automation. A case study is presented based on the use of the Starlifter robot in heavy tool deployment such as diamond core drilling and plunge sawing in hazardous environments.

KEYWORDS: Robots, Automation, Feasibility analysis, The AHP Process, Safety, Risk Assessment, and Simulation

1. INTRODUCTION

The automation of construction processes can be considered at different levels namely:

- *area level* such as general concrete work,
- *activities level* such as rebar fabrication
- or *task level* such as bending, positioning and tying tasks.

Breaking down the construction process this way makes the automation process easier [Gue]. The automation at task level is more feasible than higher levels, because the higher levels include multiple tasks, which makes the automation process more complex and difficult to control.

The potential for construction task automation needs to be justified from different perspectives. The first perspective is the *need* for automation, the second is what *level* of automation is desirable and the third is *economic feasibility*.

Kangari and Halpin identified a range of factors affecting the use of robots in construction. These factors are divided into three groups, *need-based feasibility*, *technological feasibility* and *economic feasibility*, which are similar to the above-mentioned perspectives. [Kangari] These groups are used in the overall feasibility analysis. Which adopted a fuzzy logic model for the evaluation of the decision to use robots. Kangari suggested that economic benefits, improved production and quality must pay-off the cost of development and marketing of the automated process and that it should not depend only on safety arguments.

Gue and Tucker presented a systematic framework for evaluating the potential of automation of generic tasks using an automation concern index, ACI, which is based on the AHP process. [Gue] Hastak, developed a conceptual decision support system for the use of robotic systems in construction activities. [Hastak94] This system is based on AHP and the criteria of judgements are need-based criteria, technical criteria, economic criteria and safety and risk criteria. Hastak applied the same methodology to a pipe laying process. [Hsatak98] The data used for this study was based on interviews with experts in the field of pipe laying. The results of this study showed a preference for the use of automated pipe laying equipment over conventional open cut trench methods.

In the above-mentioned studies, the decision to use automated processes assumes the availability of the required technology on which a complete feasibility study can be performed. In the broader case of choosing which new tasks can be automated and what levels of automation can be achieved we need to modify the steps of the decision-making process to count for these unknowns i.e. needs and technology.

Many barriers come in front of the final implementation of a robotic system in the construction industry. The identification of these barriers is of great importance because it greatly influences the final decision to use a robotic system. It needs emphasizing that the identified barriers, technological or economical, must not affect the need feasibility. I.e. The need feasibility must be done on the basis that the elected task for automation is identified based on safety risk and productivity related factors. This allows a structured feasibility analysis.

In the present work a comprehensive feasibility analysis model is presented in a structured way to enable a comprehensive need analysis which is followed by a decision making process based on the factors identified in the need analysis part. The identified barriers can then be analysed and resolved according to their category, i.e. technological or economical, to move forward to the final implementation.

2. FEASIBILITY ANALYSIS MODEL

For any construction task it is not easy to judge the immediate benefits of using new technology unless a complete analysis and evaluation are performed to define the needs and benefits. The present model provides tools for the analysis and defining the benefits of using automated processes through a systematic way. One of the main objectives of this feasibility analysis is to examine the possibility of using one robotic system for multiple tasks with different characteristics. In other words to develop a flexible robotic system that can be configured to perform different jobs i.e. a general purpose robotic system. This analysis could lead eventually to the economically feasible use of such robots. This approach can be applied to a wide range of tasks and jobs that share similar characteristics.

In the present project several case studies are considered in order to examine the feasibility of using the Starlifter robot, [Zied]. These applications cover situations that encompass both safety and technical capability problems.

2.1 Model description

In the present work, an integrated systematic model is developed to help the decision maker to analyse, evaluate and decide the implementation of new robotic technology. The feasibility analysis model basically consists of four stages namely; need analysis, decision-making, technology approval and economic analysis.

In the need analysis stage, comprehensive analyses are made to identify the task characteristics and the level or levels of automation the automated task is going to use. The outputs of this stage are: firstly alternatives for performing the task (this could include the recommendation to use a refined version of conventional methods of carrying out the task, or even to use the conventional methods as they are). Secondly, selection criteria for the decision making stage for each alternative. These criteria are based on risk analysis and identification of operational characteristics.

The alternatives and their selection criteria are together passed to the decision making process which uses methods such as AHP Interview-based questionnaires are made with experts or other related people in the field. . This approach is usually employed when using the AHP process [Saaty]. The alternatives and criteria should be strictly defined for particular cases and not be generic. The experts in the field should be knowledgeable concerning conventional methods, however, in addition, they should be aware of new technology. Some form of demonstration of the new technology is required to get reliable information. This could be done using existing production versions of the technology, working prototypes or at minimum, reliable simulations of the technology if it is still under development.

The outcome from the decision making process supports the use of one of the alternatives, which could be the traditional methods, however if the decision-making process suggests the use of automation, further analysis needs to be done. For the elected level of automation a technology approval procedure will be employed to identify the details in terms of the robotics system requirements in order to satisfy the working conditions specified in the need analysis process. The robotic system requirements for a certain level include five modules identified by Esposito et al:

- locomotion,
- robotic platform,
- sensors,
- controller
- and endeffector. [Esposito]

These five modules vary for each level of automation. For example for the basic level of automation; the modules could be reduced to a manipulator, a teleoperation controller and a simple grasping endeffector. For a higher level of automation a mobile platform could be integrated to do the locomotion function with a sensor guided controller and automatic tool changer endeffector.

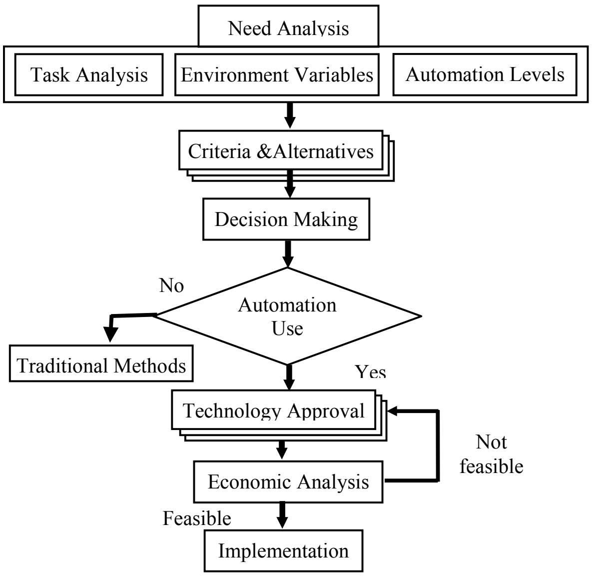

Figure (1) the feasibility analysis model

It is necessary to look at the available technology and how far it can be practically implemented. In this stage a detailed architecture of the system must be identified to enable an economic evaluation of the level or levels of automation under study. The economic analysis includes the comparison of the cost associated in performing a task using = traditional methods and the suggested level of automation. The output from the economic analysis stage will approve the implementation of the suggested level of automation from an economic point of view or indicate that alternative technologies should be considered.

2.2 Methodology

The task analysis part describes the characteristics of the task using traditional methods. The task characteristics can be obtained using the standard rules of task execution, the code of practice or from field experts etc. A knowledge acquisition technique can be employed to collect all the required information about the task under automation. The task characteristics can be identified in terms of:

- Working Environment
- Links to other processes
- Process duration and frequency
- Current operational techniques
- Worker numbers and level of skill
- Tools and supporting equipment

3. ENVIRONMENT VARIABLES AND ROBOTIC AUTOMATION

The task analysis process defines the characteristics of the task and its surroundings. In other words the characteristics of the environment (the system) under study. As described by Hathaway, a system is composed of many interacting sub systems -See Figure (2). {Hathaway] These subsystems are procedures, support equipment, people, software, hardware systems, facilities, operating environment and other interfaces. The subsystems are linked and interacted together in the overall natural environment.

In a survey reported by the North West Development Agency about the potential benefits of automation in construction, based on interviews with experts in the construction industry in the area, reveals the following benefits: [Thomas]

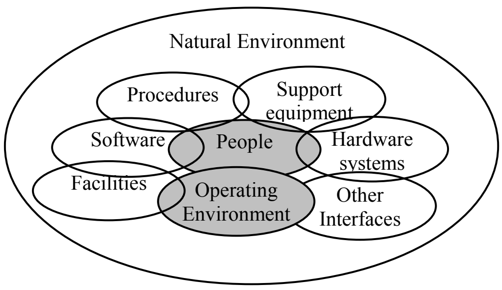

Figure (2) the environment variables when using traditional methods [Hathaway]

- Improved working conditions
- Improved health and safety
- Simplified operations
- Improved productivity
- Competence in the face of a shortage of workforce and skills

The above benefits can be simplified to two primary Firstly safety and secondly improvement in operational characteristics.

From the safety point of view it is desirable to reduce the amount of the interaction and the link between people and the operating environment. Figure (2) shows the direct interaction of humans with the operating environment and other subsystems such as hardware systems; while in Figure (3) human interaction is limited to the interaction with software and procedures such as operation instructions and safety precautions. The degree of interaction with the hardware subsystem depends mainly on the level of automation the process under consideration The level of automation needs to be linked to the level of hazards involved in the system, consequently it is essential to perform a hazards analysis to determine the safety risk level

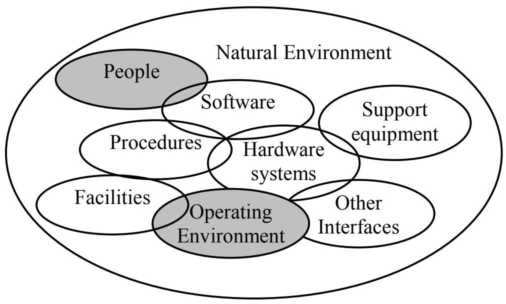

Figure (3) the environment variables modified for using robotic automation (adapted from Hathaway)

From the improvement of operational characteristics point of view, the objective is to modify or eliminate one or more of the subsystems to improve the system efficiency. This can be explained as follows:

A. People (labour)

Labour are an essential part of the system when performing tasks using traditional methods. The nature of task characteristics could lead to the following problems, which could be solved by using robotic automation:

A.1 The task requires highly skilled labour, which results in high cost and longer operating times. The reasoning behind this is high wages and declining skilled workforce.

A.2 The task is tedious and boring, for example the worker has to hold a heavy tool in an inconvenient position repeatedly.

A.3 The task requires multiple tools. The task requires high precision and accurate positioning of tools.

B. Procedures

Procedures are the steps the worker should follow during task performance. This can be explained in the following points for a core-drilling process as an example:

B.1 working area marked

B.2 tools adjustment; positioning and rate of feed.

B.3 testing the working area for reinforcement if it is required to avoid drilling through it.

B.4 planning the working area in the case where more than one worker is doing the same task at the same time.

B.5 procedures that should be followed in case of an emergency such as a tool jam, injuries or accidents.

It is essential to identify these procedures and analyse the situation when a robotic system is employed to determine how far the use of a robotic system can modify these procedures.

C. Hardware systems

Hardware systems include any tools or rigs that are used in the task performance. Some organizations have a technology strategy to consciously develop and implement new tools and logistics to improve the performance of traditional methods. Examples of this are changing from manual feed to automatic feed of the core drilling process, which results in accurate cutting and safe operation, and the use of less noisy and vibration free equipment.

D. Support equipment

Supporting equipment such as power generators, water sources and air compressors are needed for both traditional methods and automated processes. Modifications can integrate this equipment into one platform to support the robotic system and make the control process more efficient and easy.

E. Facilities

In construction sites facilities like site access, scaffolding and material handling are required before starting any construction tasks. In some situations it is necessary to scaffold the entire working area to enable workers to perform the task easily and safely. This adds extra cost, which can be eliminated or reduced by using a robotic platform capable of performing the in areas with difficult access .

F. Software

Operators are increasingly comfortable interacting with software rather than hardware systems. Robotic automation is mainly characterised by software. Designing the software with user-friendly interfaces is vital to enable the operator to control the system efficiently and providing feedback from sensors, etc is essential for safe operation.

4. THE DECISION MAKING PROCESS

The basic idea of AHP is to decompose a complex system into a structured hierarchy in order to identify the elements or criteria that control the problem. Simple pairwise comparisons are then made between criteria, sub-criteria and alternatives to provide priorities at each level, which finally contributes to the final decision.

4.1 Preliminary Control of the Decision Problem

A hazard analysis process defines the system characteristics and the hazard risk categories. It is necessary to control the decision making process by eliminating non-relevant criteria. A primary list of criteria and sub-criteria can be prepared according to the factors discussed by Kangary and Halpin. [Kangari]. This list can be modified to suit the system under study. A questionnaire can be prepared for the task under study describing the system characteristics when using traditional methods.

4.2 Criteria for the Need Analysis

Decision-making models were employed to validate the use of automation in construction. Most of these models utilised the opinions of experts in the field. From the literature, need-based feasibility; technological feasibility and economic feasibility are used as the main criteria for decision-making. The decision-making process is based on the fact that the automated process is already existing and developed to a stage that the economic and technological feasibilities can be investigated.. For the purpose of decision-making in connection with the development of robotic systems for multifaceted construction process, it is necessary to construct a hierarchy for the problem. In the present work four criteria are used which represent the elements of the construction process, namely, labour, process, working environment, and management. Some of the sub-criteria are previously identified by Kangary and Haplin. Figure (4) shows the complete hierarchy of the decision problem of the automation of concrete sawing and core drilling processes as examples of multifaceted processes. The following is a list of the main criteria and sub-criteria:

- Labour-wise criteria
- Process-wise criteria
- Working Environment-wise criteria
- Management-wise criteria

5. CASE STUDIES

Case I: Innovation of a lead contaminated building [CSDA]

Renovation is required of a building formerly used for storage by a battery manufacturing company. It is required to remodel an antiquated plumbing system, enhance the look of the building and open it up to provide more natural light into the work area and provide easier access for people and products. The work includes cutting and removing the concrete floors with openings varying from 450 mm to 1.5 metres, the floor thickness varying from 150 to 200 mm.

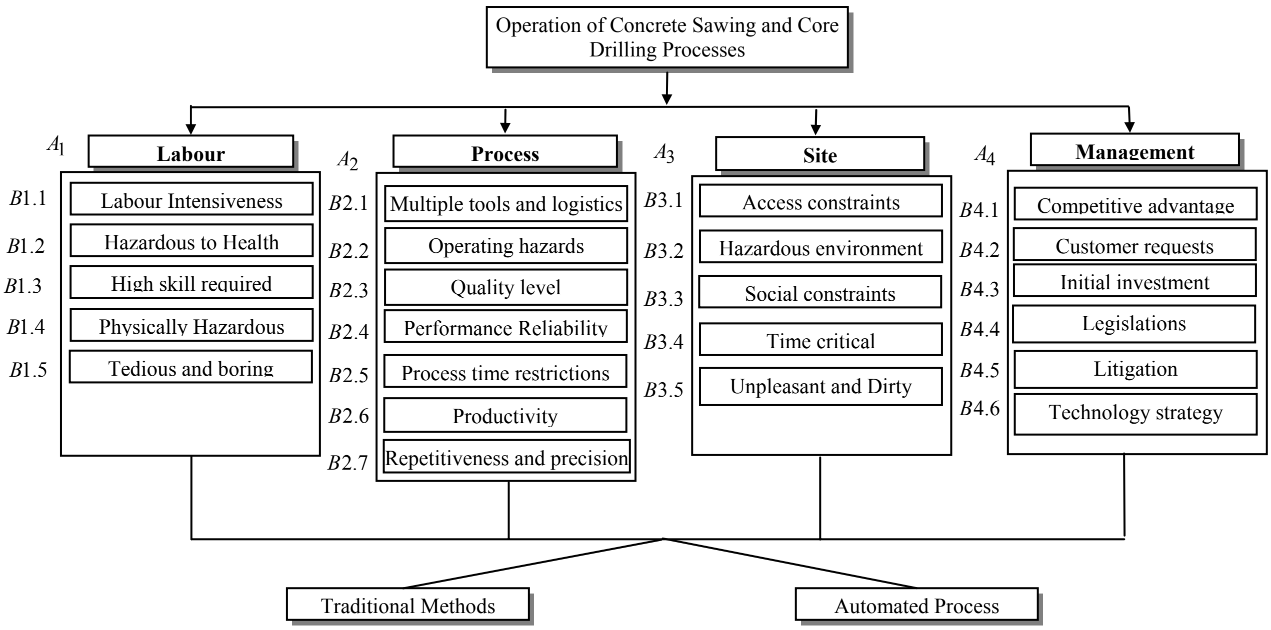

Figure (4) the decision making problem hierarchy

A total of 2000 lineal metres of floor contain 407 tones of concrete. Wall sawing is required to open 37 new windows and doors ranging from normal size to openings of 3 m × 8 m I.e. a total of 200 metres of wall sawing to remove 250 tones of concrete The building can be considered as a hazardous environment as it is contaminated with lead. It is necessary for all workers to pass a battery of blood tests and to wear disposable hazard suits. The equipment used in the traditional process are cushion cut hydraulic wall saws, Target 35 HP saws equipped with clean air catalytic converters, skid steer vehicles and fork-lift trucks.

Case II: Drilling holes for power cable brackets inside a rail tunnel. [Reihl]

It is required to drill holes through a rail tunnel wall for fixing power cable brackets. The work volume: core drilling is performed to provide four holes per one cable holder for a total of 1000 holders for a tunnel length of 3 km. Work to continue without closing of the tunnel, i.e. the drilling tasks are performed while trains are moving on the other track. The equipment used: diamond core drills on SRS rail track trucks as a platform for the supporting equipment.

Case III Anti rust cathode inserts, [Zied]

The case study is based around a real contract that was completed, using traditional methods, in Southern England in 1998. The main task consists of the drilling of 1000 holes 300-400 mm in depth in the underside of a major motorway bridge for the purpose of inserting cathodic protection rods, in order to reduce corrosion of the reinforcement bars. The task must avoid drilling through existing reinforcement bars.

For these three case studies, hazard and job characteristics are identified according to the subsystems involved for each case. Simulations of the proposed robotic systems to perform the involved tasks are prepared for illustration purposes in the first place to appraise the robotic solution. The same problem hierarchy illustrated in Figure (4) is used for all the case studies however in some cases it is useful to eliminate the non-relevant sub-criteria to reduce the calculation volume of the priority vectors.

6. RESULTS AND DISCUSSION

The decision making process was performed using the EC2000 software {EC2000]. The EC2000 software is basically based on the principles of the AHP process developed by Saaty. For each case the priority vectors are estimated for the two alternatives, robotic automation and traditional methods. The input data are based on the personal judgement; however sensitivity analysis is applied to show the variation of the final decision with different judgements. For the three cases, the decision favours the use of robotic automation s because all of these cases involve safety and technical difficulties when using the traditional methods. For case I, the decision is in favour of robotic automation with 67.1%. Figure (5) shows the percentage contribution of each criteria and sub-criteria. The labour and process criteria show significant effects in influencing the preference for a robotic solution. Robotic systems are assumed to reduce or eliminate hazards by reducing direct contact of labour with the working area. Also removing humans from the loop can increase productivity and reduce delay in task performance due to the elimination of tedious and boring tasks. This conclusion can be withdrawn when we look at the nature of the environment in which hazardous environment contributes by 4.7% of the total preference or robotic automation. For case II the preference of robotic automation is 61.84% which should be set against the technical problems involved in this case study when using robotic automation. For case III, preference is 60.8% in favour of the robotic automation which is compromised by economic factors that result from a less hazardous environment with fewer technical difficulties.

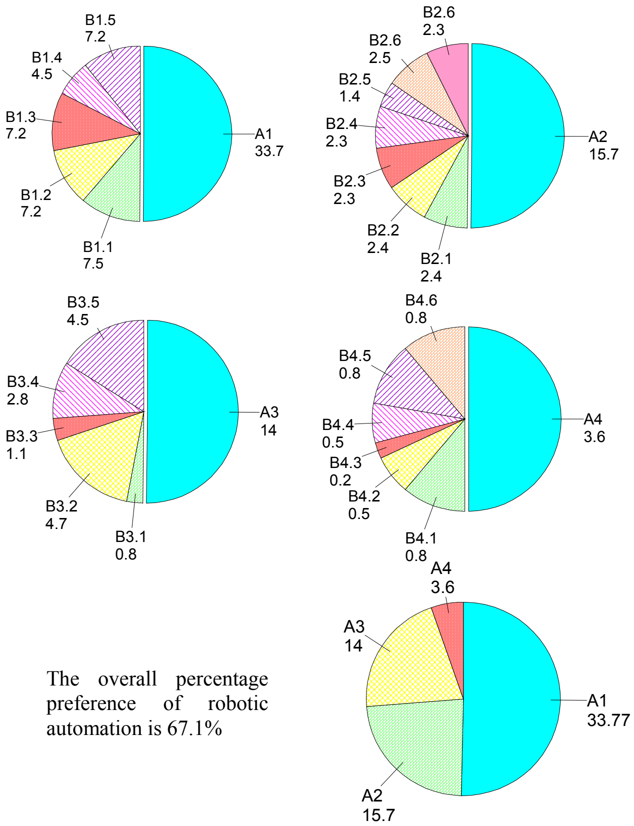

Figure (5) Percentage contribution of the main criteria and sub-criteria in the preference of robotic automation for Case I

7. CONCLUSIONS

The present model provides a comprehensive (Only part of the analysis?) analysis for the use of robots in construction industry. The need analysis part provides important information for the system developer as well as the decision makers in which detailed analysis of the task under automation from different points of view can be performed. The use of AHP in the decision making provides immediate decisions according to the entered judgements. The hierarchy of the problem is flexible, whereby different criteria and sub-criteria can be introduced to consider different aspects of the task under automation. The technology approval part of the feasibility model is needed to solve the technical problems raised during the need analysis. The economic feasibility is the driving force for the final implementation of a robotic system once the need and technology approval analyses are fulfilled.

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