THE ECONOMICS OF BUILDING INSPECTION AND TESTING BY A ROBOTIC DEVICE

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ABSTRACT

Inspection, testing, maintenance and repair of civil engineering and building structures has been identified as a prime candidate for robotisation. This paper examines the factors which will determine the economics of a proposed robot for the inspection and testing of buildings. The perspectives of both the prospective developer of the device and its likely user are considered.

From the developer's point of view, the viability of the proposal depends on the net present value of the cashflows associated with its development, marketing and sale over its projected shelf life. A measure of the economic incentive to the user is provided by the net present value of the costs and benefits which would arise from the acquisition and use of the device.

Two particular problems were encountered in this front-end evaluation. Firstly, the more substantial reasons for undertaking these types of projects are qualitative in nature. Secondly, for most of the quantifiable factors the data available are of a very limited quality. Spreadsheets models have been used to carry out sensitivity analysis of the uncertainty surrounding the data used. Other evaluation methodologies have been proposed for the qualitative reasons.

KEY WORDS: robot, economics, evaluation, buildings, inspection, testing.

1 INTRODUCTION

A feasibility study into the areas of application of advance robotics in civil engineering and construction concluded that inspection, testing, maintenance and repair (ITMR) of building and civil engineering structures offered great potential for future development. In response to the report(1) of the study, the UK Department of Trade and Industry has funded a Project Definition Study (PDS) aimed at producing a proposal for the industrial development of a robotic device for the inspection and testing (IT) aspects of ITMR. The Study has been broken down into a number of tasks with each task undertaken by a task group of 3-4 collaborators from industry and academic and research institutions. The remit of the Study is to produce the following in respect of the proposed device:

* performance targets,
* scheme designs,
* further R&D requirements,
* financial and economic analysis,
* a project plan.

A task group, the Economics Task Group, was assigned the responsibility of providing a continuous economic and financial assessment of the robot concept as it was being developed. This role required two key considerations:

* the incentive for an entrepreneur, the robot developer, to pick up the results of the PDS and convert it into a finished product,
* the economic case for an organisation undertaking IT in the course of its business, the operator, acquiring the device.

This paper examines the factors which will determine the economics of the device from these two perspectives.

2 JUSTIFICATION METHODS

A literature review was carried out with the aim of identifying possible strategies for evaluating the evolving robot concept. This review indicated that whilst there is a body of literature on the theory of the evaluation of industrial robots, relatively little has been done in the area of construction robotics (3,4).

By and large, the evaluation methodologies have been applications of the traditional methods of economic analysis of projects involving capital expenditure. Traditionally, capital investment has been justified on the grounds of cost reduction or increased profits on larger turnover resulting from the investment. The status quo is compared with the position which would result from the investment. However, investment in the advanced technologies, such as computers, automation and robotics, are rarely so simple. Terms such as "close to the customer" have become corporate buzz words. Commonly, investments are made in these technologies for reasons of responsiveness to customers, quality, product or service differentiation and general competitive advantage. A more realistic approach should entail a comparison of the position which would arise with no action and that which would arise from the investment. In the present climate of rapid change the result of no action may well be erosion of the firms competitiveness leading to collapse.

It has been very difficult to incorporate the more contemporary reasons for investment within the framework of the traditional methodologies. This is because they are largely of a qualitative nature even though they may be by far more important than the quantifiable factors. Yonemoto, Hasegawa, Shiino and Hatano (11) report a survey of 300 actual users of robots which produced very interesting results. The users were asked to ascribe the benefits actually experienced to a number factors. The qualitative factors accounted for more than two thirds of the total benefits.

More modern evaluation methodologies are beginning to be reported in the literature. For example, Yonemoto etal (11) describe ROBEQ, an evaluation method which takes into account qualitative issues such as improvements in quality and work environment. Other methods which are of a more generic nature include portfolio methods, analytic techniques, and strategic approaches (12).

On this project spreadsheet models have been developed on the basis of the Net Present Value and Discounted Cash Flow techniques. In respect of the developer the models determine the net present value of his cashflows over the investment period. For the IT operator the net present value of the benefits and costs associated with the use of the robot is calculated. On the basis of reported research, some subjective but conservative estimates of the cost/benefit implications of some of the qualitative factors have been incorporated into the models.

The models have been used to carry out sensitivity analysis with the aim of developing a general insight into the effects of the unavoidable uncertainty in some of the data used.

3 THE ECONOMICS OF DEVELOPING THE ROBOT

The attractiveness to the developer of any investment towards the development and manufacture of the device is a function of a number of dynamically interrelated factors. These include the complexity of the robot , development costs, robot prime costs, robot purchase price, the demand for the device, the developer's Minimum Attractive Rate of Return(MARR) and others of a more qualitative nature.

The development costs are those incurred in undertaking all the activities necessary to convert the robot concept into a viable product in the market place. These costs can be classified under three categories: robot system engineering costs, robot component costs, and marketing and distribution costs. The more complex the robot the greater the likely development costs and the longer it will take to produce it.

As a matter of policy it was decided that the amount of innovation in the basic technologies required by the device should be kept to a minimum. Current estimates put the total development cost in the range of £5-8 millions. This estimate is based on data reported in the literature and current costs of robot components. However, some experts are of the view that this is a substantial underestimate as the software development costs alone could account for at least £6 millions.

The robot prime costs represent the manufacturing costs. These are the sum of the following:

* the total costs incurred on the purchase, delivery and storage of robot components and related materials,
* the costs of direct labour,
* the cost of processing,
* cost of supervision and other indirect costs.

The purchase price of the robot depends on a variety of factors, the major ones including:

* development costs,
* robot prime costs,
* the value of the device to an IT operator in terms of its performance capabilities,
* distribution costs,
* market forces.

Figure 1 depicts how demand, robot complexity (a surrogate variable for development costs), and price are related.

A firm's MARR is set by its top management as a matter of policy. It will depend on factors such as availability and sources of investment funds, opportunities for investment, risks, etc. MARR varies from firm to firm for reasons of differences in corporate circumstances and attitudes to risks.

Sources of qualitative benefits include:

* strategic competitive advantage in a technology which has a tremendous growth potential,
* synergy at both the technical and organisational level resulting from integration with related technologies such as computer integrated manufacture,
* spin-offs by way of direct as well as indirect use of the technology in related activities such as routine maintenance of built assets and automated data capture.

4 THE ECONOMICS OF THE ROBOT IN USE

The assessment of the economics of IT by the robot from the point of view of the operator requires a determination of the benefits and costs likely to be associated with its use. The net present value of the benefits and costs represents the value of the robot to the operator. To derive any advantage from the employment of the robot its cost to the operator must be less than the determined robot value.

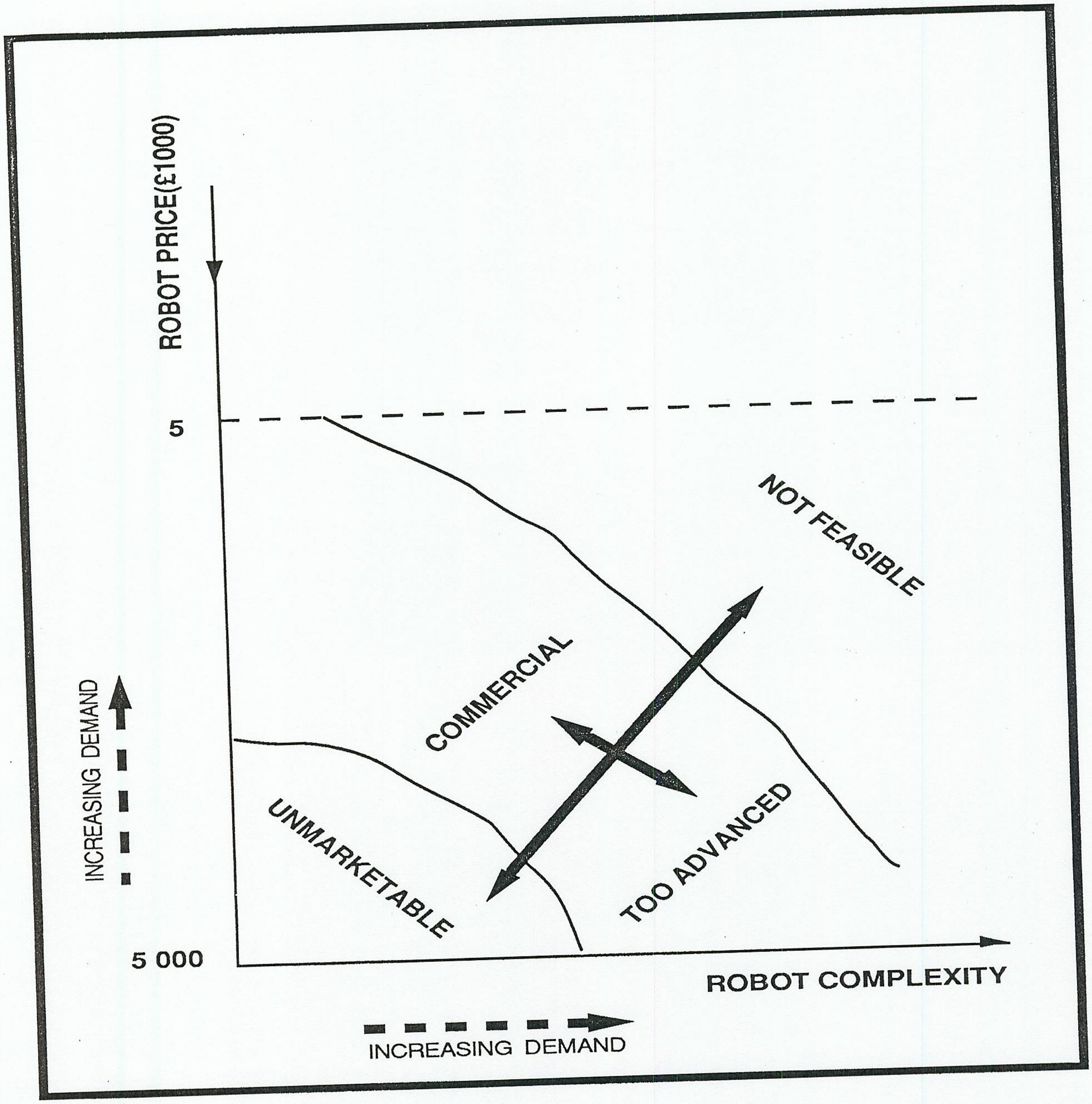

Figure 1: The Relationships between Price, Robot Complexity and Demand.

4.1 THE POTENTIAL BENEFITS OF THE ROBOT

The potential benefits of acquiring the robot to an IT operator relate to:

* the replacement of labour,
* savings on corporation tax,
* savings from the elimination and reduction in hazards to health and safety,
* savings and additional value of improved quality in the activity,
* elimination of the need to use expensive access equipment,
* increased productivity,
* work expansion: doing things not possible with current techniques,
* advancement of construction technology,
* competitive advantage.

A basic requirement of the robot is that it should be capable of eliminating the need for some types of skilled personnel. This capability will be a source of tremendous advantage to the IT operator because of three related reasons:

(1) the high cost of employing skilled personnel, typically being of the order of £1,000/week,
(2) the unavoidable danger of these expensive skills being underutilised,
(3) the shortage of skilled personnel which is expected to become even more severe.

Allowances for equipment depreciation are deductible against corporation tax. The saving is this case would be the amount obtained by applying the rate of corporation tax to the annual depreciation allowance.

The inspection and testing of building structures is characterised by the need to work at very dangerous heights. The inherent potential for accidents is therefore very significant. This view is borne out by published accident statistics on the UK construction industry for the period 1981-985(7). These statistics identify falls from heights, particularly on maintenance activities, as the most serious cause of accidents.

Apart from the human cost, accidents in construction have substantial financial consequences to the contractor. Research in the US suggests that the costs of accidents can be as high as 3% of the total construction project costs(10). The saving from improved safety has been assumed as 1% of annual turnover.

Though there is very little published data on the cost of quality on IT as a separate activity, it has been estimated that the total cost of quality on construction can be up to 15% of total project costs(9). In this case it is assumed that the robot will reduce the total cost of quality to only 8% of the total value of the activity.

Radevsky and Garas(5) write that it is not uncommon for the cost of providing access to form a major component of the total cost of an IT project. This view has been confirmed by interviews with IT operators. They estimated that the cost of access is typically in the region of 30-40% of an IT contract and may even exceed these figures quite substantially in some cases. The lower percentage has been used for the baseline analysis.

One of the requirements of the robot is an ability to work in environmental conditions not conducive to human working. This should result in IT projects being completed more quickly than with conventional techniques. This would represent a market advantage to the operator in situations where there is a need to keep inconvenience of occupants to a minimum.

It is a widely held view that the type and frequency of inspection and testing has been constrained by the techniques available. A common example is that where the cost of conventional access is very high, unusual techniques such as abseiling with all their limitations are often resorted to. Therefore the use of robots may enable types of IT not previously feasible to be introduced.

The combination of a capability to provide a service more quickly and at a higher level of quality should be a source of considerable competitive advantage to the robotised inspection and testing contractor.

4.2 COSTS

On the cost side of the economics equation the following sources of costs have been considered:

* cost of organisational learning,
* the cost of acquiring the robot,
* operating costs,
* maintenance costs,
* finance costs.

There is always a cost attached to the assimilation of change, particularly those of a technological nature. One area of cost is in the of training technicians, scientists, and engineers in the operation of the device and also in interpreting the results obtained by the robot. Senior management may also need training on the more strategic issues that may arise from the use of the robot.

Analysis have been carried for various purchase prices ranging from £350,000 to £500,000. Most of the literature suggests an economic life of 5-10 years for the purpose of depreciation. However Owen(8) writes that the typical product life was generally two to three years in the mid 1980's.

The operating costs are incurred in the following areas:

* labour required to set up and dismantle the robot system,
* programming and software adaptations on site,
* technical expertise to take care of the man/robot interface,
* power,
* insurance against damage to the robot and third party liability.

A rough estimate of £20 000 has been used pending more accurate estimate at the prototype stage.

The maintenance costs cover the costs of repairs, overhauls and other preventive maintenance activities. Experience from robotic applications in manufacturing suggests that this head of cost is of the order of 10% of the capital cost of the robot.(2,6).

The finance costs relates to the purchase price of the robot. If the contractor is borrowing the capital then they are represented by the interest payable. These costs have been taken account of as a percentage of the capital cost. This percentage is a function of the assumed MARR and the anticipated average inflation over the life of the robot.

5 ANALYSIS AND DISCUSSIONS

The ensuing analysis and discussions are based on "what-iffing" exercises carried out on the spreadsheet models already referred to.

A task group responsible for assessing the potential market for the robot has carried out a limited market survey at three assumed price levels: £5,000, £50,000 and £500,000. The sales estimated from the survey were 203, 92, and 23, respectively. Useful as these figures are, they have been treated with due caution. The response of a consumer to a product still on the drawing board is one thing, the same product in an operating situation may well produce a totally different reaction. Putting aside the considerations of the operator, the availability of a suitable device may create legal and client-lead pressures to provide the level of IT of building assets only possible through the use of the device.

Assuming the higher estimated costs of £360 000 for robot components and allowing for additional manufacturing expenditure in processing, labour and indirect costs, the tested purchase price of £500 000 has been used for the baseline analysis.

The shelf life of high technology products is notoriously short. Though they may still be functional more advanced and cheaper products of the same type can always appear on the market. A period of 3 years within which the developer must recover his investment has been considered appropriate. Table 1 shows the minimum numbers of robots which must be purchased within this period to make it economically attractive for the developer. The Table has been compiled on the assumption that all purchases are made in the third year. This approach represents the pessimistic position as the buying pattern is more likely to be spread over the period.

Table 1: Minimum Sales of the Robot

MARR (%)	DEVELOPMENT COSTS(£' 0000 000)				
	5	6	8	10	15
10	67	80	107	134	199
15	78	92	122	153	229
20	87	104	139	173	260
25	98	118	157	196	293

The question of the circumstances in which IT operators will acquire the robot has to be addressed. If labour cost reduction and tax relief from depreciation are the only benefits recognised, a minimum of 5.7 workers have to be displaced to make the device anywhere near economical from the operator's perspective. The implication of this level of worker displacement is that the robot must be advanced enough in terms of task performance or productivity. Displacement of this order is unlikely in view of the very skilled nature of the workers traditionally involved in IT.

There is a dramatic improvement in the economics if the saving arising from the elimination of conventional means of access is taken into account. Even if the labour savings are ignored the value of the robot to the operator is more than £500 000 provided the robot can generate a minimum of £990 000 per annum. Taking into account savings from 1 displaced worker the minimum required robot turnover reduces to £810 000. From a specification point of view the robot must therefore be advanced enough to achieve a minimum of £990 000.

The results of a pilot survey indicate that the annual turnovers of IT firms are between £500,000 and £2 million. It follows therefore that outright purchase may not be possible or commercially advisable for the majority of them. Other modes of acquisition which will be examined in the next phase of the project include hiring, leasing and hire purchase.

As each robot must generate a minimum of turnover of £990,000 it follows that for the whole scheme to be viable, there must be a IT market of between £70 millions and £196 millions. Allowing for a gross underestimate of the development costs a market of £300 million would be required.

Although the analysis of the robot base concept indicates that it will be worthwhile from the two perspectives subject to the conditions outlined, there are two reasons for the consideration of a less ambitious scheme. The first has to do with organisational assimilation of high technology. In general, organisations pass through definite phases of assimilation and it is often the case that any attempt at leapfrogging some phases leads to disaster. Starting with a much simpler device may therefore be advisable. The second reason concerns the level of uncertainty surrounding the development costs. There is a body of opinion which supports the view that the present robot concept is too ambitious for the state of existing technologies and the projected development costs. In view of the fact that the robot manufacturers are hardly making any money at present there must be some doubt as to the likelihood of finding a suitable developer who is prepared to take on the risk.

6 CONCLUSIONS

Assuming a robot selling price of £500,000 and government grants of up to 50% of the development costs the developer needs to sell between 70 and 300 units of the device within 3 years of development to stand a fair chance of justifying his investment. For a sales figure of 70, values of 10% and £5 millions for MARR, and development costs respectively, apply. For a sales figures of 300, the corresponding figures are 25% and £15 millions.

The use of the device would be particularly advantageous on buildings which require expensive conventional means of access. From the operator's viewpoint the device must be capable of generating a minimum annual turnover of £990,000 on this type of building. Whether or not this requirement will be met depends on two issues. On the one hand, there is the question of the availability of sufficiently large market in this type of IT work. On the other, there is the issue of the performance capability of the device which is a question of specification and determines the development costs. The minimum demand required in this type of work is between £70 millions and £300 millions.

The costs of the robot components have been estimated at between £200,000 and £360,000. On these figures the selling price of the robot is likely to be in the region of £500,000. A limited market survey suggests that a price of this order of magnitude is unlikely to be sustainable in the market. However the analysis indicates that if the conditions outlined above are satisfied the acquisition by an operator of the device would be economically worthwhile.

Alternative schemes are still under consideration. The models at their present stage of development will continue to be useful in determining the cost/benefit implications of any changes to the basic scheme.

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