An exploration of warehouse automation implementations: cost, service and flexibility issues

Peter Baker
Centre for Logistics and Supply Chain Management, Cranfield School of Management, Cranfield University, Cranfield, UK, and
Zaheed Halim
Department of Industrial & Production Engineering, Shah Jalal University of Science and Technology, Sylhet, Bangladesh

Abstract
Purpose – Automated warehouse equipment is often regarded as being inflexible, and yet its use continues to rise even though markets are becoming increasingly volatile. The purpose of this paper is to explore the reasons for, and nature of, warehouse automation implementations in order to further this understanding.
Design/methodology/approach – The research is based on semi-structured interviews with some of the key stakeholders in automation projects. This is followed by a survey questionnaire to widen the findings.
Findings – The research indicates that the main reason for automation is to accommodate growth, with cost reduction and service improvement also being important. The implementation process tends to be complex and lengthy, although most projects are controlled within the planned budget and timescale. There is, however, a real risk of disruption and service level failings during the operational start-up of these projects, as well as some concerns about ongoing flexibility.
Research limitations/implications – The findings provide a useful insight into these areas but further research is required to explore the key characteristics of successful implementations and to understand how warehouse automation can be designed to provide responsiveness to rapidly changing market conditions.
Practical implications – The findings have important implications as regards the need to incorporate scenario planning into the design process and to plan for the management of the ongoing operation.
Originality/value – There has been relatively little previous research into this important area, which involves a substantial proportion of the capital budget of many supply chains. The above findings are of value to academics and practitioners.

Keywords Warehousing, Automation, Risk management, Agile production

Paper type Research paper

Introduction

Warehouses are important components of most supply chains. In terms of cost, they represent approximately 20 per cent of total logistics costs (European Logistics Association and A.T. Kearney Management Consultants, 2004; Establish Inc. and Herbert W. Davis & Co., 2005), whilst in terms of service they are critical to the achievement of customer service levels (Frazelle, 2001), particularly as distribution centres are often the final point in the supply chain for order assembly, value added services and despatch to the customer. Automation is reasonably commonplace in large warehouses, particularly with regard to conveyor/sortation, and automated storage and retrieval systems, with each of these types of equipment being present in more than a third of large warehouses (Baker, 2004a). However, in spite of this significance in supply chains, warehouse automation has received relatively little research attention and this paper sets out to review the literature in this area and to explore the reasons for automation, how companies undertake automation projects, and the factors that may be relevant in their successful implementation.

Warehouse automation has been defined as "[T]he direct control of handling equipment producing movement and storage of loads without the need for operators or drivers" (Rowley, 2000, p. 38) and this is the definition used in this paper. The term warehouse automation therefore includes equipment such as automated storage and retrieval systems (AS/RS), automated guided vehicles (AGVs), and conveyorised sortation systems, but excludes technology where warehouse operators are still necessary (such as warehouse management systems *per se* and radio data terminals).

The current issue and full text archive of this journal is available at
www.emeraldinsight.com/1359-8546.htm

Supply Chain Management: An International Journal
12/2 (2007) 129–138

[ISSN 1359-8546]
[DOI 10.1108/13598540710737316]

Warehouse automation

Warehouses perform a number of different roles in supply chains, as identified by Higginson and Bookbinder (2005):

- make-bulk/break-bulk consolidation centres;
- cross-docks;
- transshipment facilities;
- assembly facilities;
- product-fulfilment centres;
- returned good depots; and
- centres for miscellaneous activities, such as repairs and factory-outlet.

A report by Maltz and DeHoratius (2004) indicates that the trend is towards more added value services and cross-docking activities. Whilst this trend may be discernible generally, survey results in the UK suggest that value added services, whilst widespread, are fairly minor in nature and that cross-docking only applies to a minority of the throughput of large distribution centres (Baker, 2004b).

Some insight into these trends can be discerned from the sales of automated materials handling equipment, which have been growing steadily in recent years. The reasons for this general sales growth include potential improvements in productivity, order accuracy, reduced space requirements, increased volume capacity, control of inventory and increased customer service (Adams *et al.*, 1996). In 2000, European sales amounted to approximately US$2 billion and are expected to grow at a rate of 3.2 per cent per annum (Frost & Sullivan, 2001). Within this overall sales increase, it is interesting to note that storage equipment such as automated storage and retrieval systems (AS/RS) are expected to continue to experience the most rapid growth. Carousels and robotic devices are also expected to grow at above average rates, with conveyor systems maintaining their share of the market. Overhead conveyor systems and automated guided vehicles (AGVs) are expected to lose market share, with growth expected at or just above the general level of inflation. This overall growth trend is supported by global figures that have been published showing that the average sales increase for the top 20 materials handling system suppliers increased by 4 per cent in 2003 and by 15 per cent in 2004 (*Modern Materials Handling*, 2004, 2005).

Whilst this growth in automation is occurring, there is also a need for supply chains to become more agile so as to serve rapidly changing markets. Many marketplaces are now highly volatile and demand is difficult to predict (Christopher and Towill, 2002). Under these conditions, the focus of supply chain management is shifting towards service, and in particular responsiveness, as the market winner (Mason-Jones *et al.*, 2000). In terms of warehouse design, this may mean that such "lean" principles as maximising space and equipment utilisation may be less important than providing high service levels to the customer. The latter aim may well involve pieces of equipment normally working at much lower levels than their capacity throughput limit so that they can cope immediately with demand peaks.

There is potential scope for automation in various aspects of warehouses serving volatile markets. For example, A-frame dispensers, pick-to-light systems, conveyors and sortation systems are all listed as examples of appropriate equipment for e-fulfilment centres (Tarn *et al.*, 2003). Whilst these may be suitable in certain circumstances, there have been concerns expressed in the trade literature as to whether automation can be sufficiently flexible to meet changing market requirements (e.g. Matthews, 2001; Allen, 2003). These concerns have centred on possible changes in throughputs and product profiles during the life of the equipment. The inability to respond to demand variations has been supported by Kamarainen and Punakivi (2002), who highlighted the inflexible capacity issues associated with such systems in the e-grocery market. In that study, over-investment in picking automation was identified as a main weakness of the business models employed. On the other hand, research by Fernie *et al.* (2000) has indicated that automated sortation systems are being developed by retailers to accommodate the picking of case quantities. This use of automation appears to be more viable for established retailers where demand can be predicted with more confidence. This is supported by Rushton *et al.* (2000), who state that "high-tech" installations should be based on some assurance of long-term demand for the products handled. The provision of overcapacity to handle peak demands thus needs to be part of a costed marketing and supply chain plan.

Within the concept of agility, automation is viewed as having an important role in a number of activities. For example, automated sortation equipment may offer the possibility of stockless distribution centres operated on a true cross-docking principle (Harrison and Van Hoek, 2002). This concept can be extended to incorporate production postponement and value-added services, whereby conveyor and sortation equipment may be used in a cross-docking facility to direct goods to warehouse areas where such activities as labelling, kitting and hanging may take place, without the goods ever being placed into storage (Marvick and White, 1998). Automation may also be viewed as offering the flexibility to handle peak throughputs at short notice, particularly in areas where staff availability is a problem or in operations where the use of additional staffing may result in congestion and productivity issues (Naish and Baker, 2004).

Whilst responsiveness may be viewed as the market winner in unpredictable markets, cost is still important as a market qualifier (Christopher and Towill, 2000). In more stable markets, cost may in fact be the market winner (Mason-Jones *et al.*, 2000). With regards to cost, warehouse automation is often viewed as being cost effective in large volume situations (Rowley, 2000). However, this has been questioned by some research (Hackman *et al.*, 2001), which found that warehouses using higher levels of automation tend to be less efficient. This association was partially mitigated by size in that this relationship was not so pronounced in large warehouses. Possible reasons given were inappropriate selection of system types, lack of adequate system maintenance and the difficulty of reconfiguring to changing business requirements. The first two reasons are associated with implementation procedures and ongoing management, whilst the last reason is associated with agility. Research into picking automation reached similar conclusions finding that the productivity gained by mechanisation is sufficient only to offset the higher operating costs that result from the increased complexity of larger warehouses (Pfohl *et al.*, 1992). The main benefit of automation may thus be achieved in the wider supply chain (e.g. by the centralisation of inventory), with automation playing a key role in facilitating this by containing costs in the resultant large distribution centres.

Previous research into the reasons for automation has indicated that service and cost benefits are both sought by end users (Dadzie and Johnston, 1991). The major motivations identified were to reduce material handling in the warehouse, increase accuracy levels, improve service consistency and increase speed of service, whilst the main decision criteria were found to be reduction in labour cost, increase in output rate and improvement in service availability.

However, it appears that warehouse automation projects may adversely affect service levels in the short term, with "burn-in" difficulties being experienced (Hackman *et al.*, 2001) leading to a "service level dip" (Naish and Baker, 2004). This is often due to the need for substantial testing, commissioning and "snagging" (i.e. the rectification of faults) of automated equipment. Responsiveness can be severely affected during this early period. There have been a number of high profile instances of difficulties with the implementation of automated warehouse projects and some of these have led to profit warnings in blue-chip companies (Emmett, 2005).

The reasons for the difficulties encountered in some warehouse automation projects are not clear. Drury and Falconer (2003) highlight that such projects are normally very complex, involving a number of different systems that need to be designed and developed in parallel, including the equipment itself, the software and the building in which it will be housed. Naish and Baker (2004) also stress the importance of these interfaces, whilst emphasizing the need for realistic timescales for the overall project.

The decision to automate is viewed as an early decision within the warehouse design process by Rouwenhorst *et al.* (2000), i.e. it is a "strategic" decision that will have a long-term impact on the facility. Step-by-step warehouse design processes, based on business requirements and data analysis leading to the decision as to whether to automate, are described in Rushton *et al.* (2000) and Rowley (2000). Interestingly, only the latter includes a specific step on examining flexibility issues (i.e. "simulation of the proposed warehouse with different volumes", p. 4) and this is the final step in the process.

Overall, there are some conflicting findings on the effectiveness of warehouse automation in terms of both responsiveness and cost. In order to understand how warehouse automation may, or may not, aid the provision of agility in a cost effective manner, there is a need for further research in this area. The purpose of this paper is to explore the reasons for, and nature of, warehouse automation implementations in order to assist this understanding. In particular, the research described below sets out to explore:

- *why companies automate and the concerns that they may have in doing so*: to compare with the reasons given in the literature (e.g. Adams *et al.*, 1996) and to update the research undertaken 15 years ago in the USA by Dadzie and Johnston (1991);
- *how companies automate and how long such implementation projects take*: to explore this area, for example in relation to the normal steps described for warehouse design (as per Rouwenhorst *et al.*, 2000; Rowley, 2000; Rushton *et al.*, 2000); and
- *why certain projects were successful, and others not, in terms of successfully maintaining the ongoing operations and keeping to time and cost budgets*: to develop understanding in this area.

By exploring these questions, it is intended to provide a better understanding of the role of warehouse automation within supply chains, particularly in the light of concerns expressed about the potential impact on customer service levels and longer term flexibility.

Research method

The research was undertaken in two parts. The first part comprised semi-structured interviews with eight companies in order to understand the main steps and issues involved in warehouse automation projects. These companies were selected to provide the viewpoints of a number of stakeholders in such projects, namely four consultancy firms, two materials handling systems suppliers, and two end user companies.

These interviews, together with the relevant literature, were then used to compile a survey questionnaire. This questionnaire was sent out to members of the Warehouse and Materials Handling Forum of The Chartered Institute of Logistics and Transport (UK), who facilitated this survey. The members were selected on the basis of those who had previously indicated that they would support a study of this nature. A total of 32 questionnaires were sent out by post and 19 useable responses were received. This represented a response rate of about 60 per cent. The survey questionnaires were followed up by telephone where information was missing or where any clarification was needed of the responses. A number of the responses covered more than one project and, in total, information was obtained on 27 warehouse automation projects.

Although this is a small sample in terms of the quantitative analysis that can be undertaken, it is not an insignificant number in terms of warehouse automation projects. Precise information in this regard is difficult to assess, but, as an indication, the UK warehouse automation market has been estimated to be worth approximately £254 million in 2000 (Frost & Sullivan, 2001). On contacting one automation company, an average value per project was given as £3.9 million. This would mean that the sample represents approximately five months of the UK spend on warehouse automation. Viewed another way, as most of the projects were completed within about four to five years of the survey, the sample would therefore be in the region of 10 per cent. This is a very approximate estimate but it provides an indication of the relevance of the sample. Owing to the relatively small absolute numbers in the sample, descriptions and comments were also requested from the respondents to provide a qualitative insight into their decisions and views.

The respondents were from a range of sectors and held various positions, as set out in Table I. All of the respondents were involved in different projects.

Some of the consultancy firms supplied more than one questionnaire response, giving the total of 27 separate warehouse automation projects for which information was obtained. These projects covered a range of industries, as set out in Table II.

Many of the projects were in new buildings (13 projects), some were new automation projects within existing buildings or extensions (12 projects), and the remainder were modification projects to existing automated equipment (two projects).

The types of automation comprised storage (included in 17 projects), material movement (11), sortation (10), order

Supply Chain Management: An International Journal
Volume 12 · Number 2 · 2007 · 129–138

Table I Respondent profiles

Sector	Number of respondents	Positions
Manufacturing	3	Director, Manufacturing & Supply Distribution Director Logistics & Planning Manager
Wholesaling	2	Distribution Centre Controller Operations Manager
Retailing	2	Director of Distribution IT Strategy Manager (Supply Chain)
Third-party logistics	6	Director General Manager Development Manager Project Manager (× 2) Transport Manager
Consultancies	6	Director (× 3) Engineering Manager Project Manager Materials Handling Consultant

Table II Industry profiles of the automation projects

Industry	Number of automation projects
Retail	5
Food/drink	5
Automotive	2
Electrical/electronics	2
Music	2
Clothing/footwear	2
Logistics	2
Manufacturing (other)	3
Miscellaneous	4

picking (nine) and unloading/loading systems (five). Many projects included a number of these different aspects.

The initial interviews with consultants, materials handling suppliers and end users provided the generic steps of warehouse automation projects. These steps may be grouped into pre-project, implementation and post-project phases, as set out in Figure 1.

The pre-project phase includes the design steps up to the point of obtaining board approval for the capital sums involved and formal agreement to proceed with the project. The steps undertaken by the interviewees were broadly in line with the design methods described by Rouwenhorst *et al.* (2000), Rowley (2000), and Rushton *et al.* (2000).

The implementation phase then starts with forming the project team and setting in place all of the budgetary and control procedures. This phase includes the purchasing and manufacturing of the equipment, any building works, software development and full installation, testing and commissioning, up to the point of "going live" (i.e. when the equipment is first used operationally). Normally, the supplier was selected by tender during this phase, although sometimes the supplier (or systems integrator) was selected at the pre-project stage and the whole project developed with them.

The post-project phase includes the build-up of throughput to full capacity and the elimination of all faults, leading to final acceptance by the client (often payment is staged, so that this final acceptance would trigger the final payment for the equipment). Subsequently, a follow-up evaluation may be conducted to ensure that the equipment is still working to specification and to identify any modifications that may be required as a result of changes to such factors as throughputs, product sizes and order characteristics.

The three phases formed the basis of the questionnaire structure, with the research questions being drawn from key issues highlighted during these steps. The questionnaire was ten pages long, and was set out as follows:

- general information about the company and project (six questions);
- decision factors (six questions);
- pre-project stage (five questions);
- implementation stage (18 questions); and
- post-project stage (12 questions).

Most of the questions were set out in tick box format, but, where appropriate, spaces were left for respondents to write their answers (for example, their views on the main lessons learned from the project).

Results

Reasons for automation

In the pre-project phase, the questionnaire explored why companies automate and what concerns they may have with automation.

The prime factor that brought about the need for automation was the requirement to accommodate growth, as shown in Table III. There was thus a business need in terms of capacity and it was decided by the respondents that automation was the best way to meet this need. For example, one respondent stated that the reason for automation was "to prolong the operational life of a distribution centre, thereby delaying the need to close". The next two factors, those of cost and service, indicate that companies believe that automation can, in the correct circumstances, meet both of these potential "market winning" criteria. The fourth factor, that of reducing staffing levels, may be driven by a number of factors, such as productivity, head-count, industrial relations or staff availability. The latter was mentioned during a number of the initial interviews as an issue at key distribution centre sites in the UK.

These results shed new light on the findings of the Dadzie and Johnston (1991) survey, in which the accommodation of growth did not feature as a motivation for automation. Reduction in materials handling, increased accuracy, improved speed, and improved consistency of service were the four motivations given in that survey. However, the statement "Ability to increase output rate" was agreed with, or strongly agreed with, by 95.2 per cent of the respondents in that study as one of the "criteria used in the decision to automate", and therefore the motivation may have been relevant at that time, even though the survey questions did not bring it out as a key factor. Both studies do appear to support both cost and service reasons for automation.

Supply Chain Management: An International Journal
Volume 12 · Number 2 · 2007 · 129–138

Figure 1 Typical warehouse automation project steps

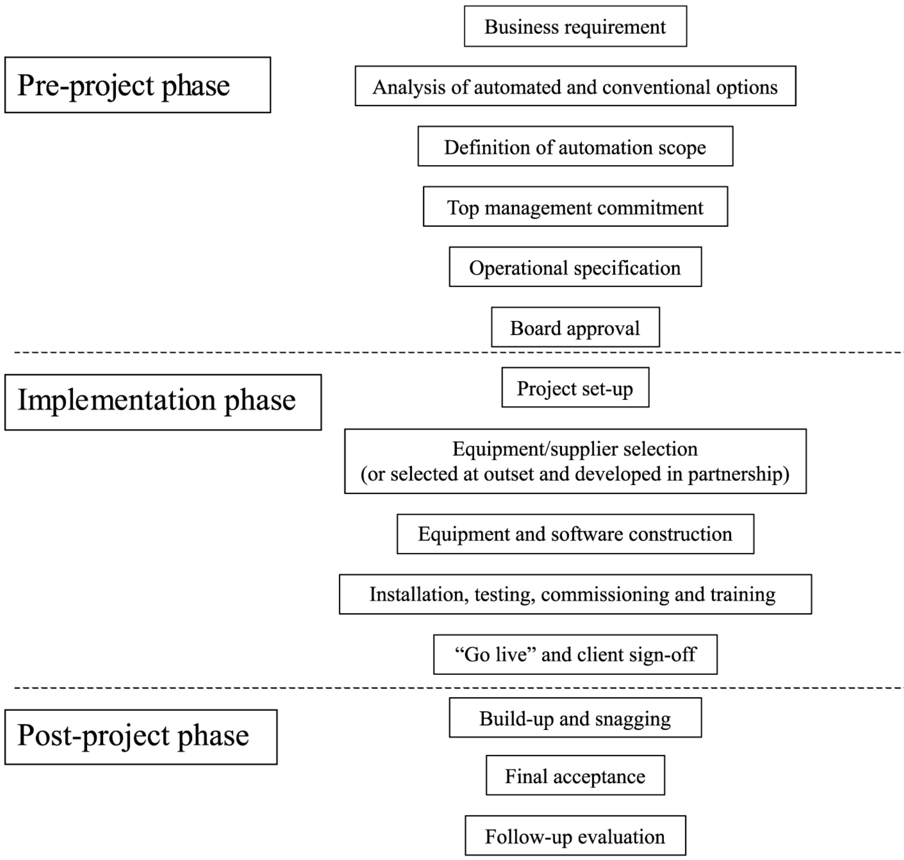


Table III Prime factors that brought about the need for automation

Factors	Number of projects
To accommodate growth	14
To reduce operating cost	11
To improve customer service	11
To reduce staffing level	6
To consolidate inventories	4
To improve accuracy	3
To increase stock rotation	1
To improve image	1

Concerns

Staffing issues were considered to be very important as regards the change in culture that may be associated with automation (see Table IV). For example, one company recognised that there was a need to "fully involve the whole workforce in testing and preparing procedures" so that there would be "ownership" of the automation project. Interestingly, a further concern was the fear of the technology not working, in spite of the maturity of most automated systems. On the cost side, there was a concern about the high capital investment involved, whilst on the service side there was some anxiety about the lack of flexibility. The fear of a service level dip was recorded for just three projects, and this aspect is examined further later in this paper.

Table IV Major concerns about warehouse automation

Factors	Number of projects
Issues concerning the change in culture	9
Fear of technology not working	8
Flexibility	8
High capital cost	7
Fear of service level dip	3
Internal politics	1

How companies automate

Projects normally have a Project Manager (who is responsible for the operation of the project on a day-to-day basis) and a Project Sponsor (who is responsible to the company's senior executives for the successful outcome of the project). Most of the warehouse automation projects in the survey were sponsored at director level, indicating that they were regarded as major projects by the companies. This is in line with the success criteria identified for other major supply chain projects, such as major information technology implementations (Favilla and Fearne, 2005). Most of the projects were sponsored by the Logistics or Distribution Director, whilst four were sponsored by the Managing Director, as shown in Table V. This level of sponsorship matches the investment and service level importance, as well as the cross-functional nature of the projects, mentioned in the literature.

Table V Project sponsor

Project sponsor	Number of projects
Logistics/Distribution Director	11
Managing Director	4
Operations Director	3
Other Director or Board	4
Manager level	2

The high-level design of the project is set out in the operational specification. This document normally includes outlines of the automated equipment, buildings, layout, software requirements, operational processes, manual interfaces, maintenance regimes and capital/operating costs. The operational specification of the projects surveyed was normally completed by a combination of in-house staff together with an equipment supplier, consultancy firm and/or a systems integrator (i.e. a company that takes prime responsibility on the contract for providing a working system that may involve a number of different equipment suppliers). Sometimes, all of these types of company were included in the team. The in-house staff were normally drawn from a range of functions, including logistics planning, operations and information technology (IT) departments. Occasionally, a third party logistics provider (3PL) was also part of the team, as set out in Figure 2.

A formal tender procedure was used in 22 out of the 25 projects (for which answers were received for this question), with the tender being sent out to an average of three to four suppliers (two suppliers being the minimum number recorded and eight suppliers the maximum). These respondents were asked to list their key selection criteria (see Table VI). A wide range of criteria was used, with cost and experience being the two most common.

Particularly for complex projects, the equipment suppliers and systems integrators who were interviewed expressed the view that they could bring much more added value to the project by working with clients from the outset in developing a solution with them, but this approach only seemed to be used in two of the projects. They also mentioned their preferred approach of responding to performance requirements, rather than to tenders that specified particular equipment in detail, as this reduced their scope for innovation. This was not explored within this survey, but could be part of a further exploration of what constitutes a successful project.

Figure 2 Operational specification team members

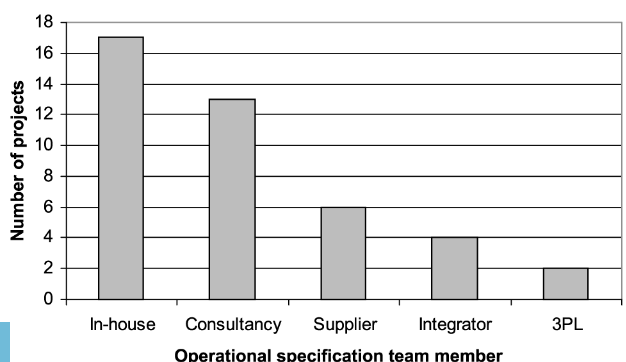


Table VI Supplier selection criteria

Selection criteria	Number of projects
Cost	18
Experience/track record	13
Technology offered	8
Relationship with supplier	8
Understanding of requirements	4
Quality and reliability	3
Design flexibility	3
Implementation capability	2
Various (culture, interest shown, system design capability, software skills, WMS capability, standardisation opportunities, trial systems, late penalty clauses, and follow-up engineering provision)	1 each

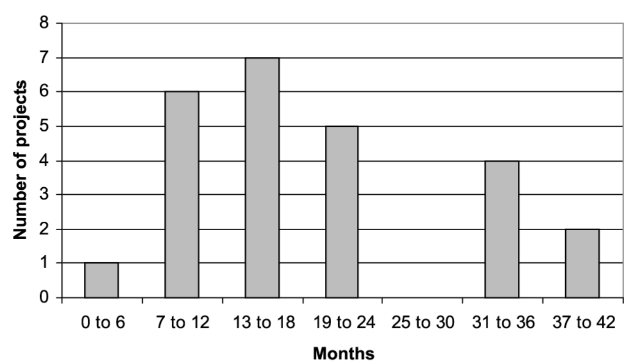
Warehouse automation projects tend to be complex by nature and, therefore, appropriate for computer simulation. Such simulation can be used to test the operation and identify potential bottlenecks (Vega, 2004), as well as simulating how the operation would continue to operate in the case of breakdowns (e.g. to assess the impact of one stacker crane failing in an AS/RS installation). In the projects surveyed, computer simulation was used in seven of the projects at the pre-project stage and 11 during the implementation phase. In total, simulation was used in 13 of the 23 projects for which answers were received. The simulation tended to be used to examine particular aspects of the operation. For example, one respondent stated that simulation was used "as part of the debugging exercise after implementation".

To summarise the way that companies automate, they are typically sponsored at director level, involve multi-disciplinary and multi-company teams, utilise formal tender procedures, select suppliers based on a range of selection criteria, and often support the design with the use of computer simulation tools. Warehouse automation projects are thus generally set up and run as major projects within the companies.

Project timescales

The project length was defined in the survey as from the start of planning for the project to the project going live. This averaged 20 months, with a range from five months for the shortest to 39 months for the longest project. The overall profile is shown in Figure 3. These timescales were generally

Figure 3 Project timescales



Supply Chain Management: An International Journal
Volume 12 · Number 2 · 2007 · 129–138

within the anticipated lengths of the projects, with 22 of the projects being reported as on time, and two being late. The projects were thus generally well planned and controlled, and this appears to be supported by the corresponding cost responses, with 21 of projects being reported as within budget, and two as over budget.

After the "go live" date, there is normally a build-up period to the full operation of the warehouse. For example, different product groups or geographical areas may be allocated to the warehouse gradually so as to minimise any disruption to service. The average build-up periods of the respondents was three months, with the range being from an immediate "big bang" approach to a build-up of over one year. The approach taken was normally a balance between realising the benefits quickly (for example, by improving pay-back periods by releasing other assets quickly) and mitigating the possible risks involved with becoming fully operational too quickly.

These figures give an average overall time-span from inception of the project to full operation of nearly two years. This is a fairly lengthy time period for many companies to plan ahead, particularly when the pay-back after this may be in the order of three to ten years (Emmett, 2005).

The impact of the projects on the ongoing operations

There is some concern in the literature concerning the impact of automation projects on the ongoing operation and, in fact, only five out of 24 projects involved no disruption to operations (this question was not relevant for projects relating to new operations). Whilst 11 of the implementations involved "minimal" disruption, eight suffered from "moderate or extensive" disruption (as shown in Figure 4). These findings appear to justify the concern about the technology not working, at least in the short-term. Whilst most automated equipment types have been in existence for many years now and are therefore fairly mature, the complexity of the projects normally involves numerous testing and commissioning problems. Although these are normally resolved, there can be a period when service levels suffer before the designed benefits are achieved.

The way in which the disruption is manifested can be wide ranging. For example, one respondent described the situation as follows: "a failure to process orders, excessive labour hours, and first time order fill reduced to unacceptable levels".

The main reasons for disruption are shown in Table VII, with the IT system being the most common reason cited, followed by installation of the automated equipment. Building construction, people factors and the difficulties associated

Figure 4 Extent of disruption to the ongoing operation

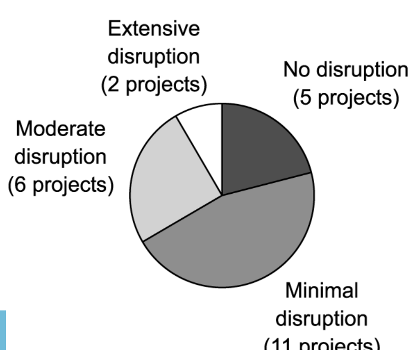


Table VII Reasons for disruption to the ongoing operation

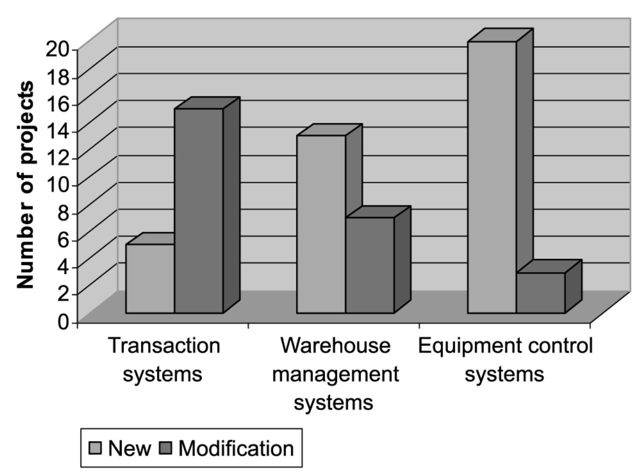
Factors	Number of respondents
IT system	6
Equipment installation	5
Consolidation of sites	2
Building construction	1
Impact of new technology on people	1
Failure of system to work on time	1
Equipment not performing to specification	1
Extended hand-over time	1

with consolidating a number of sites are amongst the other reasons quoted. These reasons demonstrate the different facets of automation projects and, hence, the complexity of the projects. The successful outcome of the projects may be affected by delays or problems in any one of these areas, as well as in the interface areas between them. For example, the installation of sprinkler pipes requires co-ordination between the building and storage equipment aspects, whilst the reading of bar codes needs co-ordination between sortation equipment and the control software. One respondent commented that "co-ordinating the different streams can be difficult and result in phasing issues".

One reason for the IT system being such a critical part of the project is the extent of the IT changes that are normally involved with warehouse automation projects, as shown in Figure 5. In addition to most projects involving new equipment control systems, almost half the projects involved new warehouse management systems (WMS) and most involved at least modifications to the company's transaction systems (e.g. enterprise resource planning or legacy systems). Interfacing across these various systems can be a major issue in terms of complexity, time and cost (Higginson and Bookbinder, 2005). The software development time was often cited in the interviews as the critical path in automation projects.

The extent of the effort that may be required in the information technology area is demonstrated by one response that related to an implementation that suffered only minimal disruption to the ongoing operation. This respondent stated

Figure 5 Extent of information technology changes



that there was "non-stop testing over 7 months, undertaken by a dedicated IT test and implementation team, with first phase testing done alongside programmers".

Looking further ahead, many of the perceived challenges to be faced in the future related to flexibility. Six respondents cited flexibility directly, nine noted increasing SKU ranges, and six noted the likely challenge of further reducing lead-times within their automated environments. Another important challenge was the likely requirement to reduce operating costs still further, cited by seven respondents.

Reasons for project difficulties

Interestingly, the two projects that were associated with extensive disruption to the ongoing operations were the same two projects that overran budgeted costs. One of these projects also overran on time. The only other project that overran in terms of time suffered from moderate disruption to the ongoing operations. There thus appears to be an association between these implementation "success" factors (e.g. time overruns causing disruption, or badly managed projects resulting in poor performance in each of these areas).

An inspection of the results does not show any apparent relationship of these "success" factors to many of the project attributes mentioned, such as the respondent category (e.g. consultant), nature of the project (e.g. greenfield site), equipment type (e.g. sortation), sponsor, operational specification team, or the use of simulation.

However, there are two attributes that may be related. Firstly, the reasons for automation were given as "to reduce operating cost" and "to reduce staffing levels" for both of the sites that had major disruption. Cost reduction was also associated with four sites that experienced "moderate" disruption, but only two sites that had "minimal" disruption, and zero sites that had "no" disruption. The sample size does not allow a statistical correlation to be established, but this may warrant further research. Inspection of the responses from the two problem sites appears to indicate other aspects associated with a concentration on cost reduction, such as one using "the acceptance of penalty clauses" as a criterion for supplier selection. Statements from respondents at the two sites also referred to "completely unrealistic expectations, with no validation" and "expectations were too high". Unrealistic cost benefit analyses thus also appear to have been associated with these two sites.

The second attribute that may be related to disruption is that of the project and implementation timescales. The two sites that suffered extensive disruption had an average project time-span of seven months and "ramp up" of less than a month, compared to the overall averages of 20 months and three months, respectively. This contrasts to the sites that had no disruption, which had an average project time-span of 20 months and a "ramp up" of one month (i.e. much closer to the overall averages). Owing to the wide range of project types (and hence complexity), it is difficult to provide firm conclusions from this sample size, but this appears to support the importance of setting realistic timescales mentioned in the literature (Naish and Baker, 2004).

Interestingly, the two companies that listed implementation capability as a key selection criterion suffered only minor or no disruption.

The survey also asked about lessons learned from the projects. The pitfalls to avoid that were mentioned for the two projects that appeared to have gone wrong were around the need for good initial planning. The advice included:

- "Plan, plan some more".
- "Plan it, scrutinise it, criticise it, refine it – on paper before you put it in. One month additional planning will save six months post-implementation headaches. Difficult to debug system that has been badly engineered".

The benefits of longer timescales than planned were also mentioned by four other respondents, and thus these qualitative comments appear to reinforce the importance of setting out realistic timescales for warehouse automation projects.

Other lessons learned that were mentioned more than once were:

- equipment commissioning: the importance of test scripts, leverage on supplier, phased approach (five projects);
- involvement and training of operational staff (five projects);
- attention to system interfaces and testing (three projects);
- clear responsibilities (three projects); and
- key performance indicator monitoring (three projects).

Many of these lessons stemmed from the desire to minimise any "service level dip" that may occur in any such future projects.

One respondent, who suffered no disruption to the ongoing operation, stated that this was achieved by developing a "very detailed plan of how the operation would continue as each new piece of equipment was installed, and each old part dismantled".

Conclusion

Whilst both improved service and lower costs are significant reasons for companies to implement warehouse automation, it is the imperative of the need to accommodate growth that is found to be the main reason. There are various factors that may lead to an increased scale of operation, such as business acquisitions, inventory consolidation, product range proliferation and the increased safety stock associated with lengthy global supply chains. In such circumstances, the literature indicates that automation is a means of achieving the necessary throughput at high levels of speed and accuracy, whilst maintaining costs at an acceptable level. The accommodation of growth as an additional major reason for automation extends the understanding of this area from that set out by Dadzie and Johnston (1991).

The large number of steps involved in automation projects reflects the inherent complexity of such projects, but the process that has evolved appears to be fairly successful in keeping projects on time and within budget. There is however a real risk of a "service level dip" and this needs to be addressed in the planning process. Although there are formal planning processes in place for most automation projects, these appear to be focussed chiefly on the installation of the new equipment rather than on the management of the ongoing operation. In fact, only one survey response mentioned a detailed plan for the ongoing operations (and that project was one that had no "service level dip"). This may be an area that needs to be addressed by practitioners.

Supply Chain Management: An International Journal
Volume 12 · Number 2 · 2007 · 129–138

The implementation of warehouse automation frequently involves fairly lengthy projects (averaging 20 months) and often requires substantial build-up periods (averaging 3 months). Automation therefore needs to form part of a long-term plan, rather than be part of a short-term response to the market. This implies that companies need to know with some certainty their overall volumes for the facility, as well as the likely product and order profiles. Flexibility then needs to be built into the design so that the automated equipment can respond positively to changes that may occur to these market requirements. This implies the need to incorporate scenario planning in the design process (as described by Sodhi, 2003), rather than basing the project on "the business plan". Although it is common to undertake some sensitivity analyses at the operational specification stage, the use of scenario planning was not explicit in the steps mentioned. Scenario planning may thus represent a valuable addition to the formal design process that is used and that is described in the literature (e.g. Rouwenhorst *et al.*, 2000, Rowley, 2000, and Rushton *et al.*, 2000).

The results of this study indicate that there is a need to understand the strategic role of warehouse automation:

- Automation is often motivated by the need to achieve business growth and, from the literature, this appears to be, in particular, to gain the supply chain benefits of inventory centralisation whilst maintaining costs in the resultant large distribution centres at acceptable levels.
- Automation may involve flexibility risks and thus scenario planning needs to be undertaken at the business requirements stage, involving such principles as demand chain management (i.e. integrated decisions taking into account marketing and supply chain factors concurrently).
- Automation may also involve service levels risks and these need to be fully addressed in the planning for the management of the ongoing operation, as well as in the time allowed for "snagging" the automated equipment. Realistic timescales appear to be an important pre-condition to avoiding any "service level dip".

In summary, it appears from industry figures that the adoption of warehouse automation is continuing to grow and, from this research, the main reasons are associated with growth, cost and service. There are however real concerns about disruption to the ongoing operation in the short term and the degree of future flexibility in the longer term. Further research is required in these areas to explore the key characteristics of successful implementations and to understand how (and to what extent) warehouse automation can be designed to provide responsiveness to rapidly changing market conditions.

References

Adams, N.D., Brown, T.W., Firth, R.V.D. and Misenheimer, L.P. (1996), *Warehouse and Distribution Automation Handbook*, McGraw-Hill, New York, NY.

Allen, N. (2003), "Upping the stakes", *Logistics Europe*, March, pp. 23-6.

Baker, P. (2004a), "The adoption of innovative warehouse equipment", *Logistics Research Network 2004 Conference Proceedings*, pp. 25-35.

Baker, P. (2004b), "Aligning distribution center operations to supply chain strategy", *International Journal of Logistics Management*, Vol. 15 No. 1, pp. 111-23.

Christopher, M. and Towill, D.R. (2000), "Supply chain migration from lean and functional to agile and customised", *Supply Chain Management: An International Journal*, Vol. 5 No. 4, pp. 206-13.

Christopher, M. and Towill, D.R. (2002), "Developing market specific supply chain strategies", *International Journal of Logistics Management*, Vol. 13 No. 1, pp. 1-14.

Dadzie, K.Q. and Johnston, W.J. (1991), "Innovative automation technology in corporate warehousing logistics", *Journal of Business Logistics*, Vol. 12 No. 1, pp. 63-82.

Drury, J. and Falconer, P. (2003), *Building and Planning for Industrial Storage and Distribution*, 2nd ed., Architectural Press, Oxford.

Emmett, S. (2005), *Excellence in Warehouse Management*, Wiley, Chichester.

Establish Inc. and Herbert W. Davis & Co. (2005), "Logistic cost and service 2005", paper presented at the Council of Supply Chain Managers Conference 2005.

European Logistics Association and A.T. Kearney Management Consultants (2004), *Differentiation for Performance Excellence in Logistics 2004*, Deutscher Verkehrs-Verlag GmbH, Hamburg.

Favilla, J. and Fearne, A. (2005), "Supply chain software implementations: getting it right", *Supply Chain Management: An International Journal*, Vol. 10 No. 4, pp. 241-3.

Fernie, J., Pfab, F. and Marchant, C. (2000), "Retail grocery logistics in the UK", *International Journal of Logistics Management*, Vol. 11 No. 2, pp. 83-90.

Frazelle, E. (2001), *Supply Chain Strategy: The Logistics of Supply Chain Management*, McGraw-Hill, New York, NY.

Frost & Sullivan (2001), *European Automated Materials Handling Equipment Markets 3947-10*, Frost & Sullivan Ltd, London.

Hackman, S.T., Frazelle, E.H., Griffin, P.M., Griffin, S. and Vlasta, D.A. (2001), "Benchmarking warehousing and distribution operations: an input-output approach", *Journal of Productivity Analysis*, Vol. 16 No. 1, pp. 79-100.

Harrison, A. and Van Hoek, R. (2002), *Logistics Management and Strategy*, Pearson Education, Harlow.

Higginson, J.K. and Bookbinder, J.H. (2005), "Distribution centres in supply chain operations", in Langevin, A.L. and Riopel, D. (Eds), *Logistics Systems: Design and Optimization*, Springer, New York, NY.

Kamarainen, V. and Punakivi, M. (2002), "Developing cost-effective operations for the e-grocery supply chain", *International Journal of Logistics: Research and Applications*, Vol. 5 No. 3, pp. 285-98.

Maltz, A. and DeHoratius, N. (2004), *Warehousing: The Evolution Continues*, Warehousing Education and Research Council, Oak Brook, IL.

Marvick, D. and White, J. (1998), "Distribution operations: managing distribution facilities for strategic advantage", in Gattorna, J. (Ed.), *Strategic Supply Chain Alignment*, Gower, Aldershot.

Mason-Jones, R., Naylor, B. and Towill, D.R. (2000), "Engineering the leagile supply chain", *International Journal of Agile Management*, Vol. 2 No. 1, pp. 54-61.

Matthews, R. (2001), "Automated flexibility", *Industrial Handling & Storage*, June/July, pp. 12-19.
Modern Materials Handling (2004), "Top 20 system suppliers", *Modern Materials Handling*, April, pp. 39-42.
Modern Materials Handling (2005), "Top 20 system suppliers", *Modern Materials Handling*, April, pp. 29-32.
Naish, S. and Baker, P. (2004), "Materials handling: fulfilling the promises", *Logistics and Transport Focus*, Vol. 6 No. 1, pp. 18-26.
Pfohl, H.-C., Zollner, W.A. and Weber, N. (1992), "Economies of scale in customer warehouses: theoretical and empirical analysis", *Journal of Business Logistics*, Vol. 13 No. 1, pp. 95-124.
Rouwenhorst, B., Reuter, B., Stockrahm, V., van Houtum, G., Mantel, R. and Zijm, W. (2000), "Warehouse design and control: framework and literature review", *European Journal of Operational Research*, Vol. 122 No. 3, pp. 515-33.
Rowley, J. (2000), *The Principles of Warehouse Design*, 2nd ed., Guideline No. 4, The Institute of Logistics and Transport, Corby.
Rushton, A., Oxley, J. and Croucher, P. (2000), *The Handbook of Logistics and Distribution Management*, 2nd ed., Kogan Page, London.
Sodhi, M.S. (2003), "How to do strategic supply-chain planning", *MIT Sloan Management Review*, Fall, pp. 69-75.
Tarn, J.M., Razi, M.A., Wen, H.J. and Perez, A.A. Jr (2003), "E-fulfilment: the strategy and operational requirements", *Logistics Information Management*, Vol. 16 No. 5, pp. 350-62.
Vega, R. (2004), "Warehousing: time to think outside the box", *Focus*, Vol. 6 No. 2, pp. 16-21.

About the authors

Peter Baker is a Lecturer at the Centre for Logistics and Supply Chain Management at Cranfield University. He gained his MSc in Distribution Technology and Management from the same university. His early career was in international freight forwarding and he then entered management consultancy, where he completed over 75 supply chain projects, across a wide range of industries, in many parts of the world, including Western and Central Europe, the USA, West Africa, the Middle East, Central Asia, and the Far East. He currently lectures on warehousing and international transport. His research interest is in the link between warehousing and supply chain strategy. Peter Baker is the corresponding author and can be contacted at: peter.baker@cranfield.ac.uk

Zaheed Halim joined the Department of Industrial and Production Engineering at Shah Jalal University of Science and Technology as a Lecturer on completing his BTech in Industrial Engineering at IIT – Kharagpur, India. He has taught undergraduate courses on diverse fields such as engineering economy, product design and material handling. He has gained his MSc in Logistics and Supply Chain Management from Cranfield University. He currently lectures on industrial simulation and manufacturing management. His research interests include logistics system dynamics modelling and application of theory of constraints in supply chain strategy.