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Application of Analytic Hierarchy Process to the Evaluation of Logistics Factors and their Contribution to Improvements in Construction Materials Supply

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Abstract

As the most important element among logistics elements is customer service, all logistics activities should ensure the highest level of customer service at any given total cost of materials supply. Achieving efficiency and cost-effectiveness in materials supplies at any preferred level of customer service involves trade-off decision-making among various logistics elements. Thus, managing construction materials efficiently requires an understanding of elements that contribute most to customer service.

An evaluation of the importance UK contractors attach to the contribution of various logistics factors to improved customer service in the supply of construction materials has been presented. The analytic hierarchy process was used to quantify the subjective assessment made by contractors on the contribution of various logistics factors to overall improved customer service. The general view of surveyed buyers was that improving contractor-supplier relationships would contribute more to improved customer service in the supply of construction materials by ensuring better reliability, cost-effective sources of supply, increased flexibility, improved lead times and greater value-added service. Traditional elements (such as capability of suppliers (viewed in terms of financial strength, technical ability, and experience), administrative and management ability, quality management systems, quoted prices and locations in relation to projects) were also considered important. The interviewed buyers considered information and communication technologies to have less influence in improving customer service as were health and safety, and environmental records of suppliers.

Keywords: Construction Materials, Logistics, Customer Service, Analytic Hierarchy Process

Introduction

The paper reports on findings of research that was designed to establish the importance attached to contemporary materials supply logistics practices by UK contractors. The aim of the study was to shed light on elements that are perceived by interviewed buyers to contribute most to customer service and thus provide some understanding on how construction materials may be managed efficiently and where opportunities are being missed. This was achieved by asking industry buyers to prioritise, using the analytic hierarchy processes, both factors normally considered in the evaluation and selection of materials suppliers and factors proposed in literature as important in improving efficiency and cost-effectiveness in the supply of construction materials.

The paper is in three main parts. The first part provides background information on construction materials management and argues for adopting the logistics viewpoint in order to embrace elements ordinarily overlooked when the process is examined from the materials management standpoint. The second part of the paper presents the analytic hierarchy process (AHP) theory and how it has been applied to assess relative contributions of logistics elements to customer service in the supply of construction materials. The last part of the paper presents and discusses the results of evaluations by nine UK contractors of the Analytic Hierarchy Process Model (AHP) model to assess relative contributions of logistics elements to customer service in the supply of construction materials.

Background

The supply of construction materials has been estimated to: control 80 per cent of the project schedule from initial materials acquisition to the delivery of the last item (Kerridge, 1987); and to account for 30 to 80 per cent of the total project installed cost depending on the type of project (Kerridge, 1987; Muehlhausen, 1991; Stukhart, 1995). This has led to the recognition that the way to

control project costs and schedules in construction is via an integrated materials management approach embracing the total construction materials procurement cycle (Marquadt, 1994; Berka and Conn, 1994).

Despite the high proportion of material costs and their influence on construction schedules, the materials delivery process is fraught with problems (Stukhart, 1995; Thomas et al, 1989; Majid and McCaffer, 1996). For example, from a synthesis of literature, Majid and McCaffer (1996) demonstrated that the late delivery of materials was one of the critical factors that caused construction schedule delays.

Arguing from a manufacturing perspective, Towill (1996) viewed the supply of materials as the main arena for reducing bottom line costs through the reduction of lead times. Enhancing efficiency in the supply of construction materials can result in major cost savings not only in materials management, but also in the utilisation of other construction resources. In the early eighties, improvements in materials supply were identified as a possible source of a six per cent increase in labour productivity (The Business Roundtable, 1983).

Simulation of the electronically integrated construction materials procurement cycle using electronic data interchange (EDI), bar codes and integrated database management systems (IDMS) between contractors and suppliers pointed to potential savings in cycle time of the order of 48 - 76 per cent and cost savings in labour of 24 - 50 per cent (Back and Bell, 1994; Carter, et al, 1996). Furthermore, a bar coding feasibility study by Alkaabi (1994), at a UK company specialising in the manufacture of pre-cast concrete flooring systems, established the following savings:

- an 85 per cent time saving in clerical time for entering data on to the company's computer;
- a 70 per cent time saving in checking beams prior to delivery; and
- a 30 per cent time saving in locating a beam within the stockyard.

Work already conducted on the procurement process of construction materials indicates that enormous scope exists for reducing lead times and lowering costs in this area. Further benefits in materials procurement processes can be obtained by implementing contemporary changes in management practices, such as logistics, taking place across industries.

Christopher (1992) noted a number of paradigm shifts in the logistics focus of enterprises: from functions to processes; from profit to profitability; from transactions to relationships; and from inventory management to information management. These changes should result in: new business practices; integral management of materials and goods flow; more focus on resource management and utilisation; more focus on markets and customers; co-manufacture and co-shipping partnership; resource based replenishment; and quick response systems. The paradigm shifts and changes in business practices have been induced by aggressive competition across markets and industries and ultimately are a search for long-term survival of companies.

Materials Management from the Logistics Perspective

Logistics is the umbrella term covering materials management and physical distribution (Rushton and Oxley, 1989). Logistics activities include: demand forecasting, requirements planning, production planning, purchasing, inventory management, warehousing, materials handling, industrial packaging, distribution planning, order processing, transportation and customer service (Coyle et al, 1996). Viewing the flow of materials input into construction operations from the logistics perspective is useful in order to capture elements that may otherwise be overlooked when the process is considered from a materials management viewpoint.

From the logistics standpoint, the most important aspect when examining materials management is customer service. All logistics activities should ensure the highest level of customer service at any given total cost of materials supply (Coyle et al, 1996). Achieving efficiency and cost-effectiveness in materials supplies at any preferred level of customer service involves trade-off decision-making among various logistics elements. The analytic hierarchy process was used to segregate logistics elements and evaluate their relative importance in contributing to efficiency and cost-effectiveness in the supply of construction materials.

The Analytic hierarchy Process

The Analytic Hierarchy Process (AHP) is a problem-solving framework with a structure that systematically represents the elements of a problem into a hierarchy. The AHP organises a problem into smaller parts, which when pairwise compared lead to development of priorities in the hierarchy.

Hierarchies are well recognised in the physical, behavioural and systems science as powerful mental constructs for studying complex systems. Even if used only to understand the structure of a system or the interaction of its parts, a hierarchical model of any system is a powerful means for representing the constituent parts of the problem being studied. There are many types of hierarchies (Saaty, 1983). The AHP falls in the category of dominance hierarchies. It is based on the theory of influence of elements of lower levels on the main focus or objective of the hierarchy. The AHP is based on three main problems solving approaches: decomposition, comparative judgements and synthesis of priorities (Saaty, 1983).

Decomposition

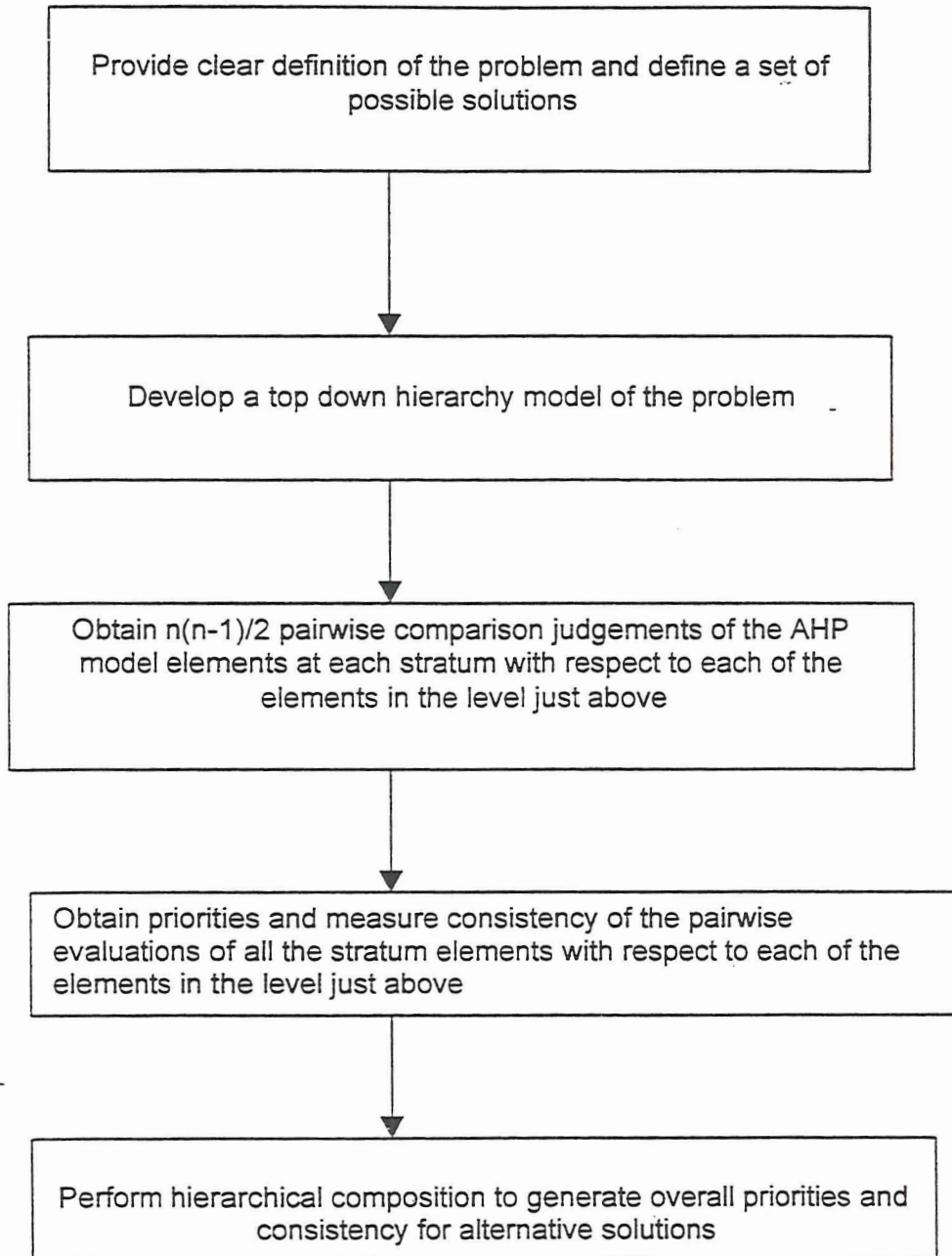
Decomposition involves structuring a problem into its basic elements, working from the focal objective down through various levels; from the more general to the particular and definite elements. Then starting at the bottom, alternatives for that level and criteria under which they should be compared in the next higher level are identified. An intermediate set of higher criteria that decomposes into these criteria are found which are themselves decompositions of higher level criteria or subcriteria identified in the downward process. Using this approach, the focal objective of the hierarchy can be linked to its bottom level in sequential intermediate levels. This constitutes the basic law of hierarchic decomposition, in which priorities of elements in the last level reflect as best as possible their relative impact on the focal objective of the hierarchy. Generally, the bottom level of the hierarchy contains resources to be allocated or alternatives among which choice is to be made (Saaty, 1983). The method for developing the analytic hierarchy model and analysing the solution to a problem has been presented in Figure 1.

There is no single universal AHP hierarchy (Wind and Saaty, 1980). This turns out to be an advantage because it offers flexibility to fit unique or specific needs of problem situations. The AHP can suitably be applied to modelling any decision-making or choice situation that can be hierarchically represented on more than one level.

Using the AHP methodology presented in Figure 1, a decision model for evaluating contributions of logistics performance indicators and enablers to improve customer service in the supply of construction materials was constructed as shown in Figure 2. The defined overall objective in this case was improving customer service, otherwise construed as ensuring efficient, cost-effective construction materials supplies. The logistics performance indicators and enablers were identified from literature and confirmed by industry buyers through two almost identical self-administered postal questionnaires, one to contractors and the other to construction materials suppliers.

A logistics performance 'indicator' is defined as a metric by which a supplier can be evaluated in satisfying customer requirements and an 'enabler' is a characteristic which makes it possible for a supplier to meet customer requirements.

Figure 1: Steps for formulating an Analytic Hierarchy Process Model



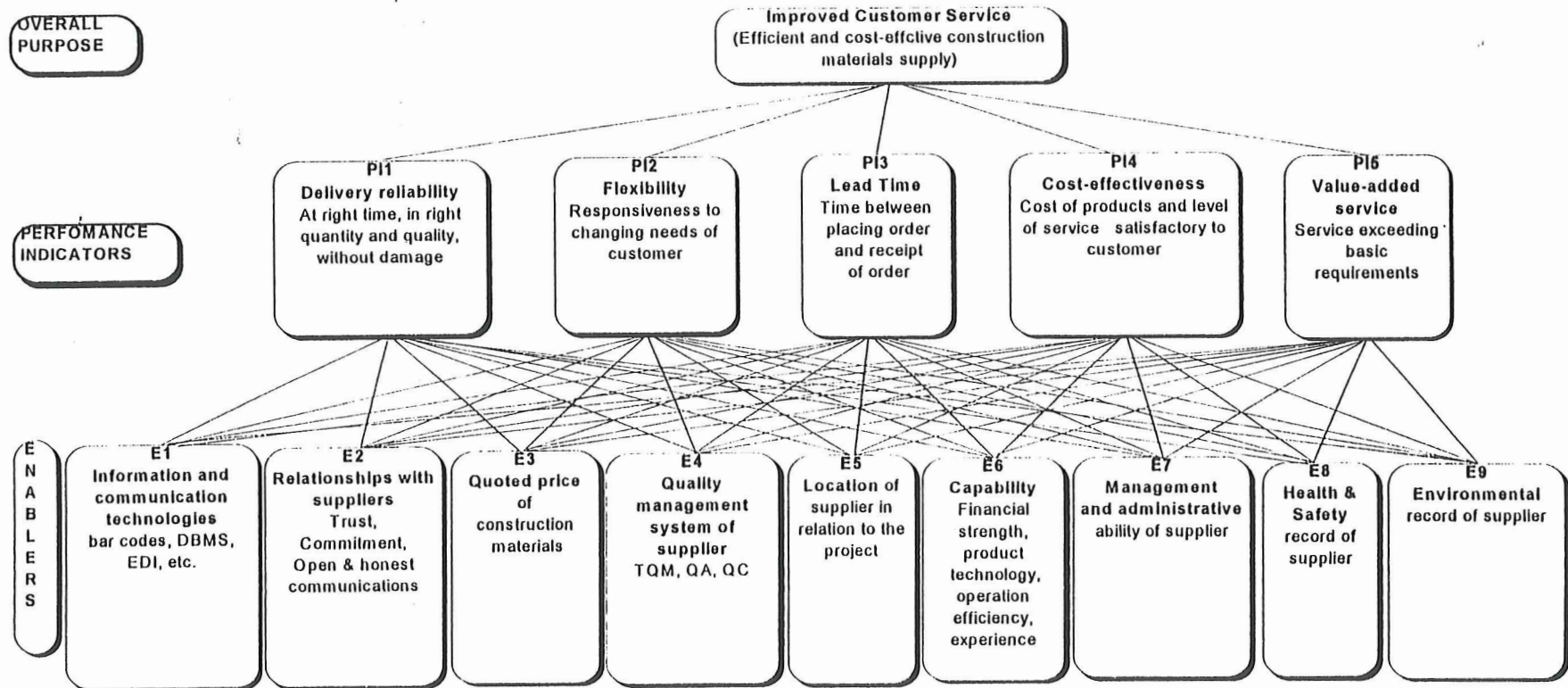


Figure 2: Analytic Hierarchy Model for construction materials supply logistics

Performance indicators

The NEVEM-workgroup (1989) identified lead time, delivery reliability and flexibility as factors that directly relate to a supplier's performance in meeting customer requirements. Cost-effectiveness and value-added service are additional performance indicators (Tuominen and Korpela, 1996). All these factors are considered by companies in their evaluation of suppliers (Dobler et al, 1990; Stukhart, 1995; Korpela and Tuominen, 1996).

Delivery reliability: is viewed in terms of the ability of the supplier to provide materials according to schedule requirements: on time, of the right quality, in right quantities, and without damage. High delivery reliability helps reduce inventory holding by the customer company.

Flexibility: is the ability to adapt to changing circumstances. Logistically, it is viewed in terms of the supplier's ability and willingness to adjust to - changing delivery requirements such as facilitating urgent deliveries, of right products, in right quantities on the customer's requests.

Lead time: is the elapsed time between placing an order with a supplier and the receipt of that order by the customer.

Cost-effectiveness: is the supplier's ability to provide products and level of service at a cost satisfactory to the customer.

Value-added service: is that level of service provided by a supplier over and above ordinary or basic requirements.

Enablers

Enablers are the characteristics which help a supplier achieve superior performance as measured on the basis of logistics performance indicators. In their theoretical approach to benchmarking distribution effectiveness based on experience from the forest industry, Korpela and Tuominen (1996) included management systems, process integration, information systems, organisation, technology and relationships as enablers in their AHP analysis. The various logistics characteristics which enable a supplier achieve customer satisfaction and which organisations, including construction companies, normally considered when evaluating suppliers include (Compton, 1985; Stukhart, 1995; Dobler et al, 1990; Construction Industry Institute, 1987):

- location of suppliers;
- quality management systems of suppliers;
- capability assessed in terms of financial strength, product technology and operation efficiency, and experience of the supplier;
- management and administrative ability of a supplier;
- quoted price; and
- relationships.

Information and communication technologies are important for the integration of logistics activities within and between companies and were included among factors upon which suppliers should be evaluated. These technologies are essential in activities such as order processing and can help reduce non-value-adding activities.

After preliminary interviews with one client, two contractors, and one supplier, it was also considered appropriate to include environmental, and health and safety records of suppliers as enablers because evidence suggested that these were increasingly being considered important in the evaluation and selection of suppliers.

The rationale of the model in Figure 2 is that customer satisfaction in delivery of construction materials is a function of the impact of each of the performance indicators on customer service. However, optimisation of performance indicators is dependent upon an array of factors which have been termed enablers. Thus, through their contributions to performance indicators, enablers can be viewed as the critical success factors which influence improved customer service, and consequently its derivative, customer satisfaction, in the delivery of construction materials.

The next step that follows after decomposing a problem into its constituent elements is to make comparative judgements.

Comparative Judgements

A measurement methodology is used to set priorities among elements of every stratum. This is accomplished by asking the decision maker(s) to evaluate stratum elements pairwise with respect to elements in the next higher stratum. This measurement methodology is the central feature of AHP and constitutes the framework for data collection and analysis.

The 9-point scale in Table 1 is widely used for making numerical judgements in the AHP pairwise comparisons (Dyer and Forman, 1992; Korpela and Tuominen; 1996; and Saaty, 1983). The progenitor of the AHP, Thomas L. Saaty strongly recommends the scale and argued that it has been thoroughly validated for effectiveness (Saaty, 1983).

Using the scale, the decision maker or the group of people involved in making a decision exercise judgement about the dominance of each element at a given stratum over the other elements at the same level with respect to each element at the next higher level. This leads to the construction of matrices from which relative weights of the elements with respect to each element of the stratum above can be determined. Relative contributions of enablers to performance indicators, and consequently to the overall objective (i.e. improved customer service) can be evaluated. Such an evaluation can indicate the relative importance of enablers in contributing to efficient and cost effective materials supply logistics.

Table 1: The AHP response scale

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one activity over another	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance is demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest order of affirmation
2, 4, 6, 8	Intermediate values between the two judgements	When compromise is needed
Reciprocals of judgments	If activity i has one of the above numbers assigned to it when compared to with activity j, then j has the reciprocal value when compared with i.	

Synthesis of Priorities

Priorities are calculated next. The constructed matrices are used for computing weighted priorities for elements of a given stratum over the other elements of the same stratum with respect to each element of the level just above. In this way, the priorities of the enablers can be determined.

The mathematical procedure for arriving at the priorities has been outlined by (Saaty, 1983). Repeating the comparisons for all elements at each level with respect to criteria at the next higher level, relative weights for all elements in relation to higher objectives are calculated. The computation to arrive at the prioritisation of elements has been made simpler by the use of a software package called Expert Choice.

Consistency Test

Any measurement, even when an instrument has been used, is subject to errors from two sources: the experiment itself and the measuring instrument (Oppenheim, 1992). Errors in measurement can lead to inconsistent conclusions. In practice, however, perfect consistence in measurements is unattainable. Different measurement methods have their own approaches for assessing the amount of error in a measurement. Every response system requires to satisfy some criteria imposed by the algebraic measurement model employed as a test of validity. With the AHP, the consistency ratio is used as a test of validity (Saaty, 1983).

After synthesis of priorities, a consistency test is performed to assess the quality of the judgements made during the pairwise comparisons (Saaty, 1983). From the consistency index, the consistency ratio is calculated. Values of the consistency ratio below 10 per cent are preferred and those greater than 10 per cent indicate that decisions made during the pairwise comparisons were inconsistent and should be revised. Inconsistency can arise due to any or a combination of: a clerical error; lack of information or experience about the factors being compared; imperfection in the real world; or inadequate model structure (Dyer and Forman, 1992).

The first approach in the revision is to change the manner in which questions are asked in the pairwise comparisons. This failing, the problem should be more accurately structured by arranging elements under more meaningful criteria. A return to the second step in the restructuring of the process becomes necessary.

Analytic Hierarchy Process Model Evaluation Interviews

Evaluations of the AHP model in Figure 2 were performed using Expert Choice installed on a lap-top computer. Before soliciting for comparative judgements of construction industry experts, the model evaluation process was pre-tested by two 'stand-in experts'. Appropriate corrections to the model and changes in the evaluation procedure were made following their suggestions. From a previous postal questionnaire survey, eleven contractors agreed to take part in the subsequent phase of the research programme. These were later contacted by telephone to inform them that an outline format of the model evaluation interview was being sent to them. One week after the interview outline formats had been dispatched via the post, the interviewees were again contacted to arrange dates for the interviews. At the outset, each interviewee was briefly introduced to Expert Choice before they evaluated the AHP model following the steps outlined in Figure 3.

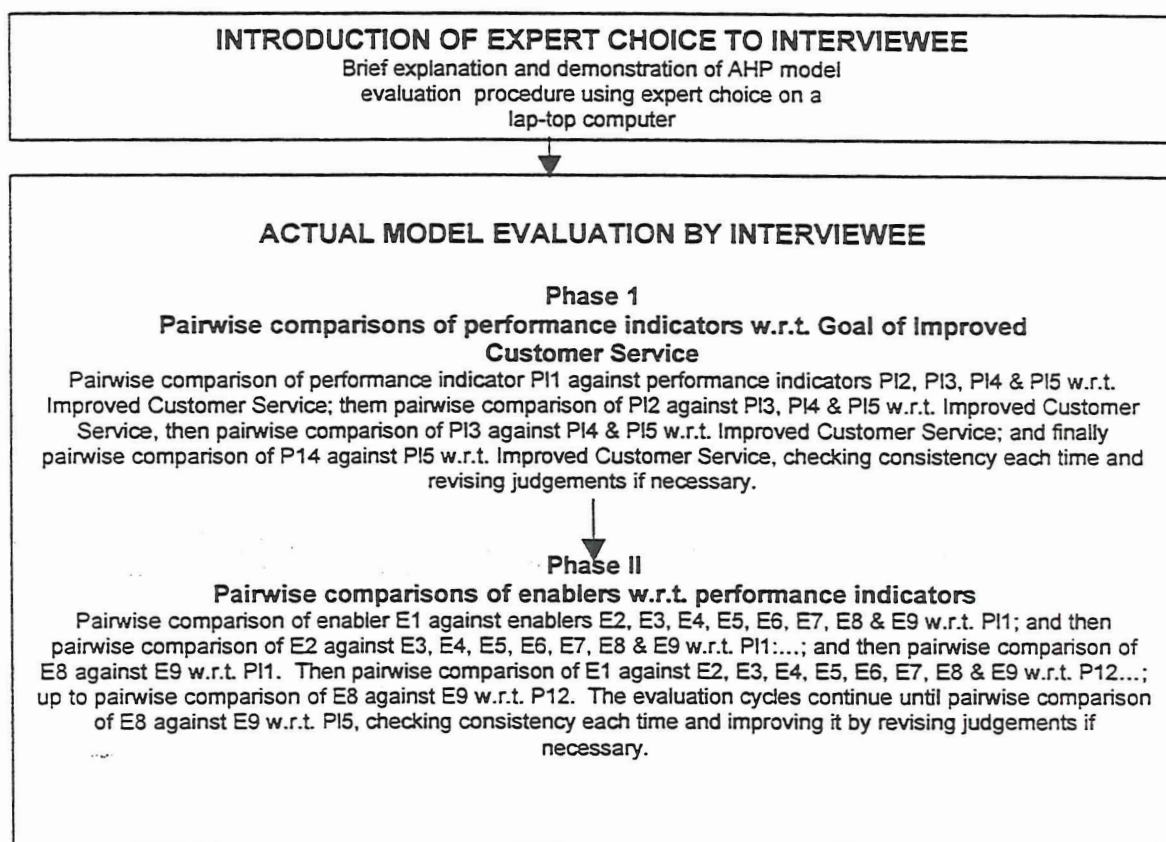


Figure 3: Steps followed during AHP model evaluation interviews

Interviewed Contractors

Table 2 gives names and types of interviewed construction companies. The companies had 1996/97 annual turnover ranging from £80 million to £400 million and workforce ranging from 120 to 3 500 people. All these companies were large contractors listed among the top 100 UK contractors in 1996 (Construction News, 1996).

Interviewed Experts

Table 2 also shows titles and experience of interviewed experts who represented the construction companies. All except one buyer held senior positions in their companies. Their experience in the construction industry ranged from 8 to 36 years and all were either directly involved in procurement/materials management or had detailed knowledge of the function.

To illustrate the evaluations performed by the experts via an example, pairwise comparisons of performance indicators with respect to the goal of improved customer service by Contractor 1 resulted in the direct output from Expert Choice of judgements displayed in Figure 4.

Table 2: Itinerary for evaluation of AHP model by construction industry experts

Interview date	Business area of company interviewed	Interviewee	
		Position in company	Experience in construction industry
Contractor 1 18-Nov-97	Building, Civil & Process industries	Purchasing Manager	25 years
Contractor 2 19-Nov-97	Building, Civil & Process industries	Purchasing Manager	18 years
Contractor 3 21-Nov-97	Building	Procurement Manager	15 years
Contractor 4 25-Nov-97	Building & Civil	Marketing Manager	11 years
Contractor 5 28-Nov-97	Civil Engineering	Head of Procurement	30 years
Contractor 6 04-Dec-97	Building	Buyer	8 years
Contractor 7 05-Dec-97	Building & Civil	Procurement Director	36 years
Contractor 8 10-Dec-97	Civil Engineering	Head of Procurement	27 years
Contractor 9 16-Dec-97	Building	Procurement Coordinator	24 years

Synthesised pairwise comparison judgements by Contractor 1 of both performance indicators and enablers with respect to the goal of ensuring efficiency and cost-effectiveness in the supply of construction materials produced results from Expert Choice shown in Figure 5.

Goal: Achieving efficiency and cost-effectiveness in construction materials supply logistics

Compare the relative IMPORTANCE with respect to: GOAL

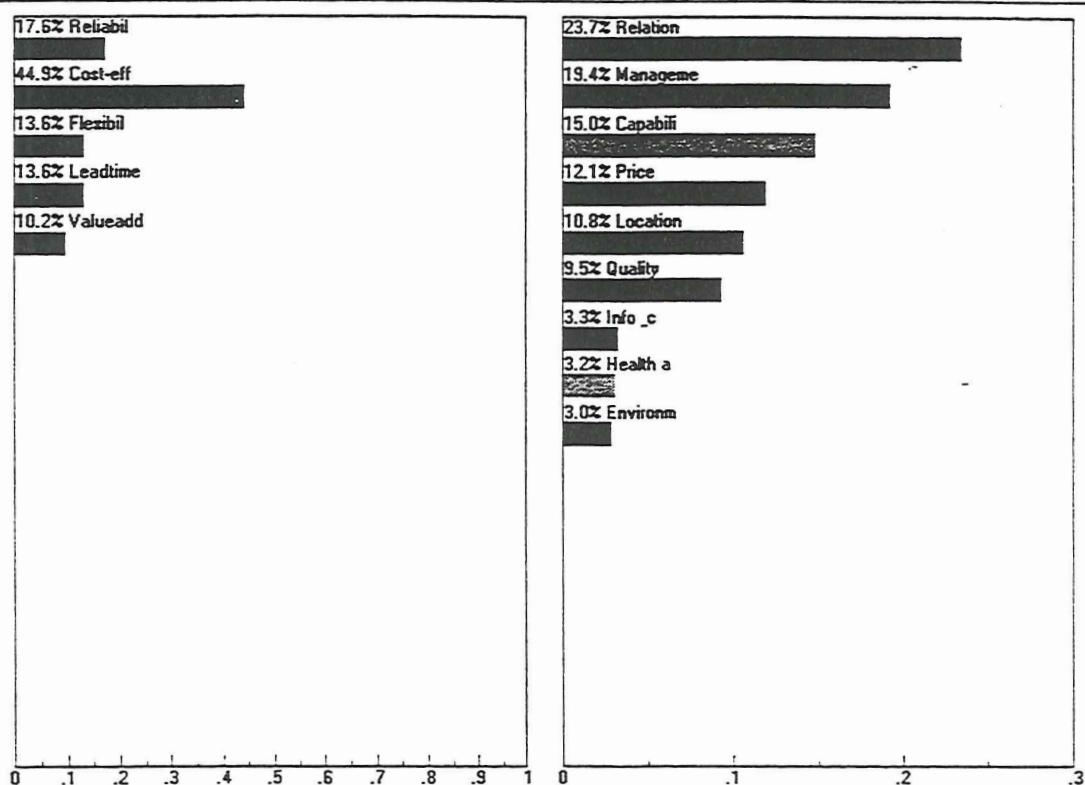
	Cost-effectiveness	Flexibility	Leadtime	Valueadded
Reliability	(3.0)	1.0	1.0	3.0
Cost-effectiveness		3.0	3.0	5.0
Flexibility			1.0	1.0
Leadtime				1.0

Row element is __ times more IMPORTANT than column element unless enclosed in () in which case the reciprocal of the number in brackets is taken

Abbreviation	Definition
Goal	Improved Customer Service: Efficient, cost-effective logistics
Reliability	Delivery of products at right time, in right quantity & quality, without damage
Cost-effectiveness	Level of service or cost of goods satisfactory to customer
Flexibility	Responsiveness to changing needs of customer
Leadtime	Time between placing order and receipt of order
Value-added	Service level exceeding basic requirements

Figure 4: Pairwise comparison judgements by contractor C1 of performance indicators with respect to the GOAL of achieving efficiency and cost-effectiveness in the supply of construction materials

Goal: Improved customer service (efficient & cost-effective logistics)



Abbreviation	Definition
Reliabil	Delivery of products at right time, in right quantity & quality without damage
Cost-eff	Level of service or cost of goods satisfying to customer
Flexibil	Responsiveness to changing needs of customer
Leadtime	Time between placing order and receipt of order
Valueadd	Service level exceeding basic requirements
Relation	Trust, commitment to agreed goals, open & honest communications
Manageme	Organisational and administrative ability of supplier, i.e. people management
Capabili	Financial strength, technology, operation efficiency, experience.
Price	Quoted price of materials or service
Location	Location of supplier in relation to project
Quality	Quality management system (TQM, QA, QC), quality of products
Info & comm	Electronic data management, information & communication technologies: (DBMS, EDI, etc)
Health & Safety	Health and safety of record of supplier
Environmental	Environmental record of supplier

Figure 5: Synthesised pairwise comparison judgements by Company C1 of both performance indicators and enablers with respect to the GOAL of ensuring efficiency and cost-effectiveness in the supply of construction materials

Combined Evaluation of the AHP Model by all the Nine Contractors

Overall priorities of the elements resulting from combined evaluations by all the nine contractors were arrived at by entering into the model, geometric means of pairwise comparison judgements of all the nine companies. Geometric means of the judgements for the group of interviewed construction companies, for example, were calculated using the formula (Saaty, 1996);

$$GM = (C_1 \times C_2 \times C_3 \times C_4 \times \dots \times C_n)^{1/n}$$

Where: GM = geometric mean;
n = number of companies; and
C_n = pairwise comparison judgement by Contractor n.

For example, the combined judgement of all the nine contractors for the comparison of reliability versus value-added service in contributing to improved customer service was arrived at by taking the geometric mean of the judgements by all the nine contractors in the calculation shown below:

$$GM = (3 \times 6 \times 3 \times 3 \times 5 \times 5 \times 9 \times 7 \times 7)^{1/9} = 4.95 = 5 \text{ (in the pairwise comparison scale),}$$

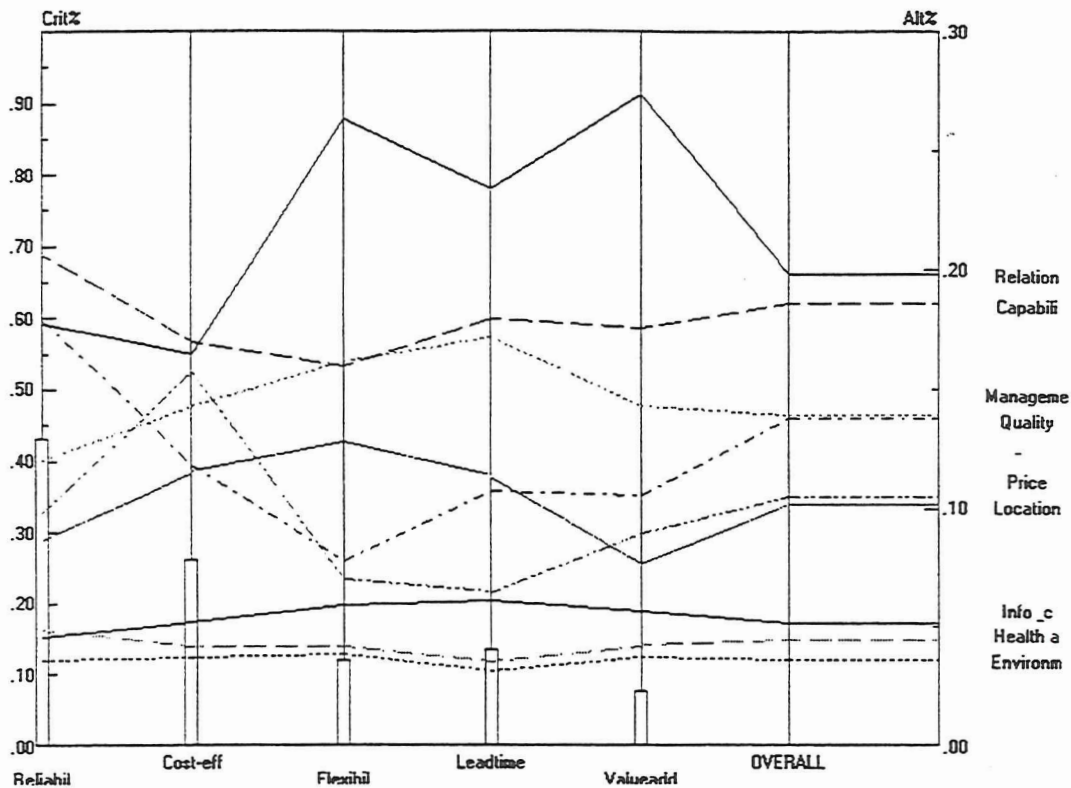
Where; Contractor 1 considered reliability to be three times more important than value-added service (see Figure 4), Contractors 2 considered reliability to be six times more important than value added service, and so on.

The resulting geometric means were rounded off to the nearest whole number. Then overall priorities and corresponding inconsistency ratios were derived by entering the geometric means of all the elements as combined group pairwise comparison judgements in the original model.

Discussion of Results

Evaluations of the AHP model by each of the nine contractors and that resulting from using the geometric means of all the contractors yielded inconsistency ratios less than or equal to 10 per cent for both logistics performance indicators (Table 3) and enablers (Table 4). A graphical summary of the overall prioritisation of both performance indicators and enablers in contributing to efficient and cost-effective logistics by all the nine companies has been presented in Figure 6.

Goal: Improved customer service (efficiency & cost-effective logistics)



Abbreviation	Definition
Reliabil	Delivery of products at right time, in right quantity & quality without damage
Cost-eff	Level of service or cost of goods satisfying to customer
Flexibil	Responsiveness to changing needs of customer
Leadtime	Time between placing order and receipt of order
Valueadd	Service level exceeding basic requirements
Relation	Trust, commitment to agreed goals, open & honest communications
Capabili	Financial strength, technology, operation efficiency, experience.
Manageme	Organisational and administrative ability of supplier i.e. people management
Quality	Quality management system (TQM, QA, QC), quality of products
Price	Quoted price of materials or service
Location	Location of supplier in relation to project
Info & c	Information & communication technologies: bar codes, DBMS, EDI, etc
Health a	Health and safety of record of supplier
Environm	Environmental record of supplier

Figure 6: Graphical summary of overall prioritisation of performance indicators and enablers in contributing to efficiency and cost-effectiveness in the supply of construction materials by surveyed contractors

Perceived Contribution of Logistics Performance Indicators

Among the performance indicators, reliability of a supplier was ranked highest followed in second place by the cost-effectiveness of the service provided by a supplier. Overall, reliability of a supplier

was considered to contribute 42.6 per cent to improved customer service, compared to 25.6 per cent contribution by the cost-effectiveness of the service provided by a supplier.

Table 3: Contractors' perceived percentage contribution of logistics performance indicators to efficient and cost-effective construction materials supplies

Performance Indicators	Company									Overall Evaluation
	C1	C2	C3	C4	C5	C6	C7	C8	C9	
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	
Reliability	17.6	32.9	43.8	35.2	26.7	36.1	44.8	49.3	61.3	42.6
Cost-effectiveness	44.9	17.3	24.8	35.2	41.8	29.4	31.6	20.2	13.8	25.6
Lead time	13.6	34.9	13.3	9.6	9.7	8.0	7.4	11.7	7.9	13.1
Flexibility	13.6	11.1	9.9	10.5	17.1	13.4	13.2	14.6	9.8	11.5
Value-added service	10.2	3.8	8.2	9.6	4.6	13.1	3.0	4.3	7.1	7.2
Inconsistency Ratio	3.0	8.0	7.0	1.0	9.0	9.0	10.0	10.0	9.0	1.0

Improved lead time was ranked the third most important performance indicator, estimated to contribute 13.1 per cent to improved customer service followed by flexibility of a supplier which was assessed to contribute 11.5 per cent. Value-added service was assessed to have the least impact on improved customer service at 7.2 per cent contribution.

Perceived Contributions of Enablers

Among characteristics which make it possible for a supplier to achieve improved performance in the delivery of materials, improved relationships were ranked highest. Overall, it was assessed that improved contractor-supplier relationships contribute 19.9 per cent to efficiency and cost-effectiveness in the supply of construction materials. The capability of a supplier viewed in terms of financial strength, operation efficiency, product technology and experience was ranked second in importance and was estimated to contribute 18.6 per cent to improved customer service. Administrative and management capability (people management) of a supplier, and the quality management system employed by a supplier were both considered to have almost the same impact on efficiency and cost-effectiveness. Administrative and management ability of a supplier was ranked third in importance at 13.9 per cent contribution,

Table 4: Contractors' perceived percentage contribution of enablers to efficient and cost-effective construction materials supplies

Enablers	Company									Overall Evaluation
	C1	C2	C3	C4	C5	C6	C7	C8	C9	
	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	
Relationships	23.7	25.1	24.3	19.8	16.6	18.8	7.1	21.4	17.1	19.9
Capability	15.0	13.7	26.4	9.6	14.6	18.9	15.2	23.9	24.0	18.6
Management	19.3	11.0	9.9	13.6	8.8	14.8	24.9	13.6	12.3	13.9
Quality management	9.5	14.4	10.8	18.8	9.7	14.3	4.4	16.0	16.4	13.8
Price	12.1	16.1	16.4	6.2	19.9	4.5	15.4	4.2	7.2	10.5
Location	10.8	5.0	4.5	5.8	17.4	12.0	21.6	11.0	13.3	10.2
Inform. & comm. tech.	3.3	4.6	2.7	6.0	5.4	10.1	3.7	5.5	4.2	5.2
Health & safety records	3.2	6.0	3.2	11.2	4.1	3.5	3.8	2.3	3.4	4.4
Environmental records	3.0	4.1	1.8	8.9	3.4	3.1	3.8	2.1	2.1	3.6
Inconsistency Ratio	4.0	7.0	9.0	5.0	9.0	8.0	10.0	10.0	10.0	2.0

slightly above quality management systems of suppliers in the fourth position at 13.8 per cent contribution. The closeness of the assessed percentage contributions of administrative and management ability on one hand and quality management systems used on the other was not surprising because during model evaluation, some interviewees commented that these were almost synonymous. Deployment of such quality management systems as TQM was closely linked to organisations' overall management and administrative effectiveness.

Surprisingly, both quoted prices of materials and location of suppliers in relation to projects were not ranked very highly in improving efficiency and cost-effectiveness. Price was ranked fifth and assessed to contribute 10.5 per cent while the location of a supplier was ranked sixth at 10.2 per cent contribution to improved efficiency and cost-effectiveness.

Contradicting research findings (Alkaabi, 1994; Back and Bell, 1994; and Carter et al, 1996) probably due to low or non usage of information and communication technologies, interviewed experts did not regard information, communication and data management technologies to have high influence in improving performance in the supply of construction materials. The contribution attributed to this factor was 5.2 per cent nearly as low as that by health and safety records of suppliers at 4.4 per cent and suppliers' environmental records at 3.6 per cent.

Conclusions

This paper has presented the AHP as a systematic approach that involves performing simple pairwise comparison judgements of elements in order to prioritise solutions. As a theory of measurement that can use subjective judgements when dealing with both tangible and intangible criteria, the AHP offers a novel avenue to addressing problems for which there might otherwise have been no satisfactory solution. Its capability in quantifying comparison judgements in order to set priorities has been demonstrated in this paper through evaluation of relative importance of logistics factors in contributing to customer service.

Through the evaluations, this study has established that reliability is the most important measure of performance of a material supplier, followed by the cost-effectiveness of the service being provided. A supplier's lead time and flexibility were also assessed to be moderately important measures of performance. Value-added service in the delivery of construction materials was assessed to be the least important measure of performance.

Even though the one-off project nature of construction may constrain formation of long-term contractor-supplier relationships, experiences of the interviewed industry experts suggest that greatest benefits to contractors accrue from improved relationships with suppliers. It is mainly from such arrangements that trust, commitment to agreed goals, and open and honest communications between interacting organisations meaningfully evolve. Thus there is need for development of closer contractor-supplier relationships, even on such short-term basis as project specific partnering if long-term relationships are not optional, in order to improve customer service in the delivery of construction materials.

Traditional factors such as capability, management and administrative ability, quality management systems, quoted prices and locations of suppliers in relation to projects continue being considered important by industry experts and have to be taken into account in the evaluation and selection of suppliers. On the other hand, though considered in the evaluation and selection of suppliers, environmental and, health and safety records of suppliers could have other wider impacts on individual project participants and affected public interests but were assessed to have little direct contribution to providing place and time utility in the supply of construction materials.

Several reports highlight the many benefits that can be obtained from use of information and communication technologies. In contrast, the low level that the interviewed contractors attached to contribution of the technologies to improvements in efficiency and cost-effectiveness in the supply of construction materials suggest very low or non usage of the technologies by the interviewed companies and probably their suppliers. This suggests the need to raise awareness which should lead to implementation of information and communication technologies within and between contractors and their suppliers and also so that the technologies are taken into consideration in the evaluation and selection of suppliers in order to improve efficiency and cost-effectiveness in construction materials supply chains.

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