Revised Paper for

Construction Innovations – Information, Process, Management

Negotiation of On-site Buffer Stocks: A Fuzzy Non-Structural Fuzzy Decision Support System Approach

(Manuscript No.: 430)

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Version 2c (21st June 2007)

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NEGOTIATION OF ON-SITE BUFFER STOCKS: A NON-STRUCTURAL FUZZY DECISION SUPPORT SYSTEM APPROACH

Abstract:

Purpose – This paper examines the potential for applying non-structural fuzzy decision support theory to modelling the negotiation between various participants with conflicting objectives so as to establish the optimum buffer stocks for a construction project.

Design/methodology/approach – In view of the divergence in objectives between various decision-makers when determining the amount of materials to be delivered to site, the concept of integrating the Non-Structural Fuzzy Decision Support System (NSFDSS) to multi-attribute decision making is reviewed. With the help of a case example, the process involved in the NSFDSS and the methodology of evaluation is illustrated. Finally, the paper proposes the use of the Nash criterion to measure the utility of various decision-makers so as to identify an equilibrium solution for the quantity of materials to be supplied.

Findings – The results indicate that the requisite number of on-site stocks can be determined by referring to the utility of the parties involved in decision making.

Research limitations/implications – The NFDSS systematically evaluates each scenario under different affected factors such as cost, schedule, quality, safety, etc. Finally, a scenario utility is computed to establish the preferences of each party.

Practical implications – NFDSS can systematically analyse human judgments to generate relative weightings for the decision factors and elements. The NFDSS model can be applied to real-world cases to determine the frequency of delivery and the amount of buffer stocks that would meet the requirements of the various project participants.

Keywords: Buffer stocks, fuzzy theory, two-party negotiation, utility.

INTRODUCTION

It is well known that construction industry productivity levels consistently lag behind other sectors of the economy and there has been ample debate on how these may be raised. Increased buildability has been suggested as one way forward (Poh and Chen, 1998). The use of off-site prefabrication has some potential (CIRC, 2001), although other factors, such as management methods and quality of subcontractor work, also have a significant effect on output. It is also considered possible to raise productivity levels by enhancing logistics management on site (Bertelsen, 1995). According to the Danish Building Research Institute, a saving of 5% of construction costs can be achieved through better planning in the purchase, delivery, storage and movement of construction materials (Caron *et al*, 1998). Streamlining production with minimum holding inventories is a commonly used method in the manufacturing industry to reduce the time and cost of production (Low and Choong, 2001).

Ideally, construction materials can be scheduled to arrive Just-In-Time (JIT) for assembly (Low and Mok, 1999), thereby eliminating the amount of equipment, materials and time required for production (Low and Tan, 1997a,b). In the JIT philosophy, raw materials are not stocked (Hay, 1988). Instead, they are delivered in the right amounts, in the right condition, to the right place, and at the right time for production (Harber, 1990). JIT has been shown to work well in the manufacturing sector (Lim and Low, 1992; Low and Chan, 1997) and would seem to have some potential in the construction industry, especially for projects on confined sites where massive prefabricated components are specified (Oral *et al*, 2003; Fang *et al*, 2004; Ng *et al*, 2004). However, avoiding stockpiling on site is very difficult, if not impossible, to implement in construction practice, as miscalculations due to the uncertainties involved result in the excessive idling of plant and human resources (Ofori, 1994; Low and

Mok, 1999). What is needed is the maintenance of just a sufficient stock of essential materials on site. It is necessary, therefore, to have a means of identifying the optimal number of buffers required (*cf:* Jostes and Helms, 1995).

As the construction programme and supply conditions are dynamic and vague in nature, continual negotiations have to take place between the various participants involved to establish the buffer stocks needed at different stages of the project. In this paper we show how fuzzy theory can help in optimising this process. Firstly, the background to non-structural fuzzy decision support systems is introduced. A case study is then provided to illustrate how the number of stocks relates to the level of utilisation. Finally, the bargaining process involved in identifying the requisite number of on-site stocks is outlined and discussed.

NON-STRUCTURAL FUZZY DECISION SUPPORT SYSTEMS

Decision problems can be broadly classified into Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM) types (Hwang and Masud, 1979). MADM problems require various alternatives to be identified and a course of action selected from multiple and often conflicting attributes. MODM problems, on the other hand, require decision-makers to determine the most promising alternative with respect to the limited resources available. Having systematically categorised the methods pertinent to MADM and MODM, Hwang and Masud (1979) and Hwang and Yoon (1981) suggest how they can be applied for solving problems concerning a single decision-maker. When more than one person is involved in the decision making process, the analysis must be extended to cover possible conflicts in the decision-makers' goals. To do this, it has been suggested that incorporating the theory of fuzzy sets into MADM problems may yield more satisfactory results (Zimmermann *et al*, 1984) and Kickert (1978) has summarised some applications.

Being first introduced by Zadeh (1965), the fuzzy set is defined as a class with a continuum of grades of membership (Goguen, 1967, 1969). Instead of imposing precisely defined criteria to classes of objects, the boundary is not as clear as in the conventional 'crisp set' theory. Fuzzy set theory is therefore suitable for solving problems in which the description of activities and observations is imprecise, vague, and uncertain (Chen, 1998). According to Dubois and Prade (1980), a fuzzy MADM problem consists of (i) a fuzzy rating phase in which the fuzzy utility of each alternative is obtained; and (ii) a fuzzy ranking phase in which the fuzzy utilities are compared. A Non-Structural Fuzzy Decision Support System (NSFDSS) was developed to rank all elements on the basis of agreed-upon criteria so as to facilitate the analysis of complicated MADM problems (Chen, 1998). By incorporating the relative fuzzy set theory, NSFDSS allows the use of linguistic variables, such as "the same", "marginally different", "significantly different", etc. rather than relying on quantitative variables to represent the imprecise concepts involved.

The three steps of NSFDSS include (i) decomposition of the MADM problems; (ii) pairwise comparative judgment of alternatives under different attributes and attributes' pairwise comparative judgements; and (iii) rank ordering of the alternatives according to the aggregated scores (Tam *et al*, 2002).

(1) Although MADM problems are widely diverse, they all comprise alternatives and multiple attributes. The alternatives concern the range of end results that may be

achieved. A finite number of alternatives from several to thousands are screened, prioritised, selected and ranked. The attributes refer to the goals or criteria. A decision-maker needs to generate several attributes for each problem setting. The decomposition stage structures the problem into attributes of different levels, each independent of those in successive levels, working downward from the goal at the top level through criteria bearing on the goal at the second level, to sub-criteria at the third level, and so on, working from the general (and sometimes uncertain) to the more specific at the lower levels (Yoon and Hwang, 1985).

(2) The alternatives are compared pairwise for relative importance with respect to the shared attributes at the level above, giving rise to a corresponding matrix. The comparisons are made by the decision-maker from his own point of view. Scores are given to the alternatives based on: if *A* is better than *B*, the score to *A* will be 1 and 0 for *B*; if *A* has equal effect with *B*, they will both receive a score of 0.5.

(3) Utilities are calculated from the second level down by multiplying local priorities with the priority of their corresponding attributes at the level above and the weighting of each element at that level according to the attributes it affects (the second-level elements are multiplied by unity, which is the weight of the single top-level goal).

Another commonly used decision approach for MADM problems is the Analytical Hierarchy Process (AHP) (Paulson and Zahir, 1995; Lipovetsky and Tishler, 1999; Zeshui and Cuiping, 1999). Using the AHP, a consistency ratio is generated after the evaluation process and its global acceptance criteria are limited (Tam *et al*, 2006). Despite that, there is no guarantee that a consistent pairwise comparison between voluminous decisions exists (Belton and Gear, 1983; Zahir, 1991; Murphy, 1993). Instead, the NSFDSS is able to overcome these disadvantages by changing the consistency checking scale and adding a fuzzy scale to the priority scores.

THE STORAGE AND DISTRIBUTION PROBLEM

The supply of building materials and components to site is fraught with difficulties, which can have a significant effect on productivity levels. For most of the materials purchased, the planning of deliveries is undertaken on an *ad hoc* basis (Clausen, 1995). This can lead to two types of problems. First, some materials may be purchased just before they are required, resulting in delays, and interruptions to the working schedule. Second, other materials may be procured in large quantities irrespective of the production needs on site. This can result in a waste of resources when stocking, handling and transporting. Building materials often require a large storage capacity, while most sites are of a limited size. At the same time, storage facilities are usually temporary structures or compounds, and the conditions in which the materials are kept can lead to damage from bad weather or the movement by people, plant and equipment.

Unless stringent quality control systems are adopted, sub-standard materials may arrive on site and have to be returned to the fabrication shop or manufacturing facility, thus halting production and, in the worst cases, leading to project delays (Agapiou *et al*, 1998). Given the very different conditions pertaining to construction in contrast with manufacturing work, it is inevitable that contractors seek to maintain the availability of materials by keeping a reasonable amount of stock on site. To do this effectively, it is necessary to determine the number of delivery loads of materials to be made and the associated on-site buffer stocks.

The key organisational entities involved in the material acquisition process are the planning and purchasing departments. These two departments would have very different objectives under the criteria of time, cost, quality and safety. These criteria, termed the *affected factors*, would therefore be weighted differently by these two departments. The problem is aggravated when numerous combinations of storage and distribution solutions exist, as this could result in a dissimilar evaluation result between the two entities. For instance, when considering the costs involved in purchasing, the unit material price is expected to decrease as the quantity of purchase increases due to bulk discounting. Therefore, the purchasing department tends to order the materials in large quantities in return for a less frequent delivery schedule. The concerns of the planning department are less related to delivery charges than issues associated with storage (such as multi-handling, damages, safety hazard, circulation space, etc). This lends itself to a MADM problem with two parties involved in the negotiation process as shown in Figure 1.

< *Figure 1* >

METHODOLOGY OF EVALUATION

Based upon a project schedule with eight construction activities as shown in Table 1, the project will take 40 days to complete while requiring 400 units (i.e. $\sum_{d=1}^{40} R = 400$) of material for construction. As shown in Table 2, five possible scenarios may occur in this project.

These comprise delivering the resources in a quantity of: (i) 10 units per day; (ii) 20 units every 2 days; (iii) 40 units every 4 days; (iv) 80 units every 8 days; and (v) 200 units every 20 days. It is a requirement that when the on-site storage prior to the delivery falls below 10 units, the next supply will be twice as much as that originally planned so as to eliminate the chance of shortage which would otherwise give rise to additional costs due to idling of labour and plant. Therefore, the actual frequency of delivery may be less than that derived by simply dividing the total units of material by the number of units delivered each time.

< Table 1 >

If 10 units of material can be loaded by a truck each time, and the transportation cost is £50 per load with an additional fee of £20 being added to cover the costs of planning, scheduling, safety checking, cleaning, etc., then the total delivery cost can be calculated as follows:

$$\text{Total delivery cost} = \pounds 50 \times \frac{\text{400 units (total materials needed)}}{\text{10 units (units delivered each time)}} + \pounds 20 \times \text{times of delivery}$$

At a daily site storage cost of £20 per unit, the storage fee for each scenario as shown in Table 2 is:

$$\text{Total storage cost} = \pounds 20 \times \sum_{i=1}^{40} \text{daily storage} + 10 \times \sum_{i=1}^{40} \text{daily shortage}$$

From Table 2, it is clear that storing too many resources will lead to a higher total storage cost despite the decrease in delivery cost.

< Table 2 >

Pairwise Comparisons

The problem firstly is considered from the planning department's point of view. The main responsibility of this department is to plan the project according to cost, schedule and other factors. In the process of prioritisation, pairwise comparisons are conducted between any two scenarios. This can be represented in a matrix form as shown in Table 3. Taking the first column of Table 3 as an example, when comparing with other scenarios, the cost of the other scenarios has to be divided by the cost of Scenario 1. To enable other comparisons to be made, one half of this result is taken as the outcome. Therefore, 0.5 signifies that two scenarios have the same score for each department, while the scenario with the lowest cost will have the highest score.

< Table 3 >

For the pairwise comparisons in the schedule, focus is placed on the probability of delay in each scenario. There are three scales – less, same and more – as follows (note that the 0, 0.5, and 1 refer to the comparison of x and y). If Scenario X has a greater probability of leading to delay than Scenario Y, X is given 0 and Y is given 1. If two scenarios have the same probability of leading to delay, both are given 0.5. Scenarios 1 and 5 are assumed to have the same probability of leading to delay. This is because the schedule will be affected by the unexpected factors if delivery is made frequently. On the other hand, storing too much on site will make delivery very difficult – possibly leading to rework due to substandard quality caused by store damage. For other scenarios, storing more materials will be given higher scores because they have little probability of a shortage occurring.

As with the comparisons in the schedule, the comparisons concerning quality and safety also involve the probability of damage and danger. Three scores may be given to *X*: 0 if Scenario *X* has a greater probability of leading to damage/danger than Scenario *Y*; 0.5 if both have the same probability of leading to damage/danger; and 1 if Scenario *X* has less probability of leading to damage/danger than Scenario *Y*. Delivering more resources is assumed to result in lower quality levels as less attention can be paid to each delivery. The planning department will consider storing less resources to maintain better on-site safety. But S_1 and S_5 are assumed to have the same probability because too many deliveries involve storing too many materials and cause danger to the workers.

The important scales of comparison between affected factors are: important, the same, and less important. 0 indicates that Scenario *X* is less important than Scenario *Y*; 0.5 that two scenarios are the same; and 1 that Scenario *X* is more important than Scenario *Y* (Table 4).

< *Table 4* >

Priority Ordering and Assignment of Utilities to Scenarios

Having presented the priority matrices of the pairwise comparisons among the scenarios with respect to affected factors and by summing the values of the indicators on each row, the scenarios can then rearranged in descending order. This enables decision-makers to ascertain the importance of the scenarios for each factor. In order to provide each department with the utilities associated with the scenarios, experts can assign a linguistic description to each scenario by comparing it with the one with the highest summed value. For example, in Table 5 the scenarios are arranged in the order of $\{S_1\ S_2\ S_3\ S_4\ S_5\}$. S_5 has the lowest sum of 1.341 and is first compared with S_1 (5.790). The expert then gives a linguistic description of "between the same and marginally different" to describe their relative importance. Following Chen (1998), each semantic description (e.g. "marginally different", "quite different", etc.) is assigned a score (see Table 6). These scores, a_j, within the range of [0.5,1] (0.5=same; 1=different) are converted to priority scores, r_j, in the range of [0,1], by applying fuzzy set theory using the following equation:

$$\mathrm{r_j} = \frac{1-a_j}{a_j}\ ;\ 0.5<a_j<1 \qquad [1]$$

where a_j=semantic score and r_j=priority score.

< ***Table 5*** >

< ***Table 6*** >

For the scenario under cost in Table 5, 5.790/1.341≈4, so scores of the first four steps are selected. Then, using the insert point method, S_1=1, S_2=0.921, S_3=0.828, S_4=0.767, S_5=0.739 can be obtained. Table 5 also shows the priority scores for each affected factor.

Normalising Priority Scores of Affected Factors into Weightings

To enable comparison as a whole, the use of the affected factors as a means of weighting the utilities is needed. The priority scores of *AF* are normalised. The result is shown in Table 7.

< Table 7 >

Calculation of Scenarios Utilities

Eqn. (2) is used to calculate the Hamming distance for p=1 and the Euclidean distance for p=2 (Chen, 1998):

$$u_j = \frac{1}{1+\left\{\frac{\sum_{i=1}^{m}\left[w_i\left(r_{ij}-1\right)\right]^p}{\sum_{i=1}^{m}\left(w_i r_{ij}\right)^p}\right\}^{2/p}} \qquad [2]$$

where p=1,2 and $u=(u_1,\ldots,u_j,\ldots,u_n)$, with u=utility; u_j=average distance for p=1 and 2; w_i=weight of AF_n; $r_{ij}=ir_j$=priority score; and p=distance parameter.

The utilities can then be obtained by taking the average of the two values (Table 8). The scenarios can be rearranged by their utilities in Table 8.

< Table 8 >

< Table 9 >

From Table 8, it is apparent that the planning department would most prefer Scenario 2, i.e. each time delivery 20 units in 17 times.

As the purchasing department mainly considers the purchasing and delivery process, the scenario comparisons under cost, schedule and safety for the purchasing department are different to the planning department. The purchasing department will only consider the delivery cost (the discount for bulk purchasing is not considered in this paper). The comparison under cost is made by examining the delivery cost of the five scenarios. When considering the schedule, the purchasing department will give a higher score to the scenario where the materials are delivered more frequently in small quantities as excessive stockpiling may lead to delay. Scenarios 1 and 5 both have the lowest scores because supplying daily has a greater chance of creating delays. As for the safety, delivering in small quantities allows supervisory staff to pay more attention to the safety and hence Scenario 1 has the higher score. The comparison of affected factors is also different. Cost and quality are considered firstly by the purchasing department. The comparison is shown in Tables 10-11. The priority score and weighting of *AF* is shown in Table 12, with the utilities of every scenario for the purchasing department shown in Table 13. From the results although cost is considered first but the delivery costs are not very different for the five scenarios. Delivery in small quantities has benefited the schedule, quality and safety from the purchasing department's point of view.

< ***Table 10*** >

< ***Table 11*** >

< ***Table 12*** >

< ***Table 13*** >

TWO-PARTY NEGOTIATION PROCESS

Negotiations involve either distributive or integrative bargaining (Wasfy, 1996). Distributive bargaining occurs when one's goals are in fundamental conflict with those of the other party. In distributive bargaining, one party's gain is a loss to the other. Integrative bargaining may occur when one's goals are not in fundamental conflict with those of the other party and which therefore can be integrated to some degree. Integrative potential exists when the type of issue allows solutions that are beneficial to both parties, or at least when one's gains do not represent equal sacrifices by the other. Cooperative communicative moves, such as information sharing, may be used in the case of multiple-issues to promote trading concessions in integrative negotiation.

Clearly, one would prefer that the negotiations between the planning and purchasing departments involve integrative bargaining so that the negotiation process can provide a satisfactory result for both parties. From the calculations above, the negotiation process of scenarios for the two departments is represented in Figure 2. Using Nash's (1953) criterion, by which the bargaining solution is deemed to have occurred when the two negotiators are set to receive the same total payoff, the termination of negotiation will be when the two parties find a scenario that provides each with the same total utilities. In this example, according to the comparison of results in Table 14, this occurs where deliveries are in about 45 or 110 units each time (Figure 2). But delivering 45 units have a higher utility for both departments. This delivery pattern should be selected as it satisfies both the planning and purchasing departments. According to the calculation, the delivery is made every 5 days in 7 times and at 15th and 25th day the delivery units is twice (90 units) because at 14th, 23rd and 24th day the on site storage is less than 10 (short of 7, 3 and 20 units). The delivery comes to an end at the 30th day. The storage and delivery costs are \$23,700 and \$2,240 respectively. From an economic standpoint, this scenario does not lead to the cheapest total cost, as it costs slightly more than Scenario 2 (the cheapest option among the five scenarios). But this is indeed the most optimal solution when considering the problem collectively.

< *Table 14* >

< *Figure 2* >

CONCLUSIONS

In view of the large storage capacities required for building materials and the limited storage space on most construction sites, this paper suggests an effective way to determine the number of delivery loads of materials to be made and associated on-site buffer stocks. Driven by the need to negotiate between the various parties within a dynamic and vague environment, the Non-Structural Fuzzy Decision Support Systems (NFDSS) approach is used as an analytical tool to model the two-party negotiations of Multi Attribute Decision Making problem concerning the amount of on-site buffer stocks required for a project. The NFDSS systematically evaluates each scenario under different affected factors such as cost, schedule, quality, safety, etc. Finally, a scenario utility is computed to establish the preference of each party.

The concept of the NFDSS in determining optimal buffer stocks on site is presented through a case example. This case is very close to the real construction process. The lowest supply point is used as a resource supply policy. The results suggest that NFDSS has the potential to systematically analyse human judgments to generate relative weightings for the decision factors and elements. It uses a simple comparative rating scale to evaluate the relative importance of different factors, providing a built-in consistency checking mechanism to maintain and correct discrepancies in the evaluation process. The example demonstrates the use of the method to show how a Nash equilibrium decision can be obtained. It is envisaged that the NFDSS model can be applied to real-world cases to determine the frequency of delivery and the amount of buffer stocks that would meet the needs of the various project participants. Future research should incorporate more factors and involvement of the resource suppliers in the negotiation process. Applying the model to a real construction project would also help valid the effect of the method.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support of The University of Hong Kong under the Small Project Funding Programme (Grant No.: 10205125).

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LIST OF CAPTIONS

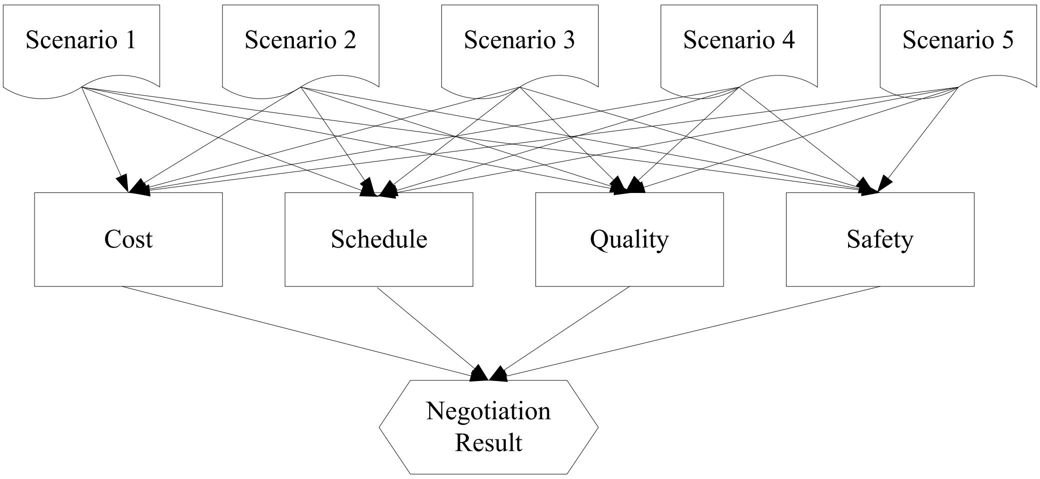

Figure 1: Decomposition of storage-distribution (MADM) problem

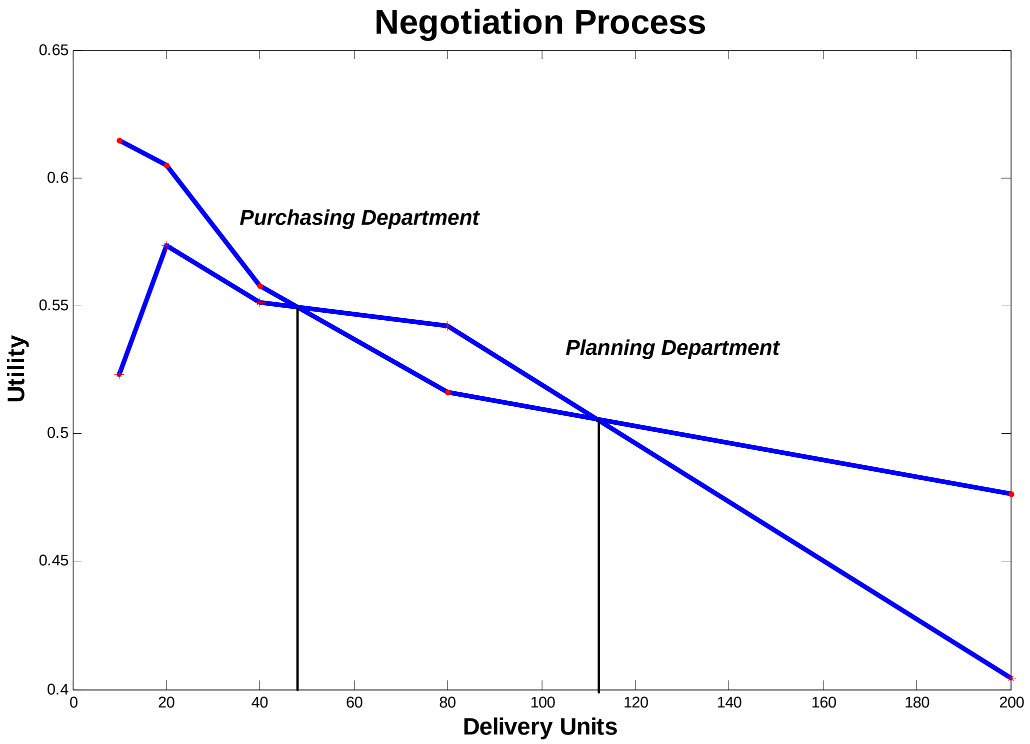

Figure 2: Negotiation process between the planning and purchasing departments

Table 1: Working schedule

Work	***Duration***	***Work Start Time (TiS)***	***Resource Consumption Per Day (R/d)***	***Total Resource Consumption***
A	8	0	5	40
B	10	0	3	30
C	10	8	4	40
D	11	8	4	44
E	17	8	4	68
F	16	18	7	112
G	6	19	6	36
H	6	34	5	30
Sum				400

Table 2: Delivery and storage scenarios

Scenario	***Delivery***			***Storage***	***Total Cost***
	Delivery Units (no.)	*Time of Delivery (no.)*	*Delivery Cost (£)*	*Storage Cost (£)*	*(£)*
S_1	10	33	2660	13400	16,060
S_2	20	17	2340	18000	20,340
S_3	40	8	2160	28800	30,960
S_4	80	4	2080	47200	49,280
S_5	200	2	2040	67300	69,340

Table 3: Comparison of cost, schedule, quality and safety effects

	Cost					**Schedule**					**Quality**					**Safety**				
	S_1	S_2	S_3	S_4	S_5	S_1	S_2	S_3	S_4	S_5	S_1	S_2	S_3	S_4	S_5	S_1	S_2	S_3	S_4	S_5
S1	0.5	0.395	0.259	0.163	0.116	0.5	1	1	1	0.5	0.5	0	0	0	0	0.5	1	1	1	0.5
S2	0.633	0.5	0.328	0.206	0.147	0	0.5	1	1	0	1	0.5	0	0	0	0	0.5	1	0	0
S3	0.964	0.761	0.5	0.314	0.223	0	0	0.5	1	0	1	1	0.5	0	0	0	1	0.5	0	0
S4	1.534	1.211	0.796	0.5	0.355	0	0	0	0.5	0	1	1	1	0.5	0	0	1	0	0.5	0
S5	2.159	1.705	1.120	0.704	0.5	0.5	1	1	1	0.5	1	1	1	1	0.5	0.5	1	1	1	0.5
Sum	5.790	4.572	3.004	1.887	1.341	1	2.5	3.5	4.5	1	4.5	3.5	2.5	1.5	0.5	1	4.5	3.5	2.5	1

Note: 0 = one has more probability than the other
0.5 = both have the same probability
1 = one has less probability than the other

Table 4: Affected factor comparison for the planning department

AF	***Cost***	***Schedule***	***Quality***	***Safety***
Cost	0.5	1	0	0.5
Schedule	0	0.5	0	0
Quality	1	1	0.5	1
Safety	0.5	1	0	0.5
Sum	2	3.5	0.5	2

Note: 0 = one is less important than the other
0.5 = both are equally important
1 = one is more important than the other

Table 5: Priorities and scores

Cost			**Schedule**			**Quality**			**Safety**			**AF**		
S	*Sum*	*Score*	*S*	*Sum*	*Score*	*S*	*Sum*	*Score*	*S*	*Sum*	*Score*	*AF*	*Sum*	*Score*
S1	5.790	1.000	S_4	4.5	1.000	S_1	4.5	1.000	S_2	4.5	1.000	*Schedule*	3.5	1.000
S2	4.572	0.921	S_3	3.5	0.905	S_2	3.5	0.818	S_3	3.5	0.905	*Cost*	2	0.739
S3	3.004	0.828	S_2	2.5	0.818	S_3	2.5	0.667	S_4	2.5	0.818	*Safety*	2	0.739
S4	1.887	0.767	S_1	1.0	0.703	S_4	1.5	0.538	S_1	1.0	0.703	*Quality*	0.5	0.538
S5	1.341	0.739	S_5	1.0	0.703	S_5	0.5	0.429	S_5	1.0	0.703			

Table 6: Semantic operators, scores, and transformed priority scores

Semantic Operators	***Step***	***a_j***	***r_j***
Same	1	0.500	1.000
In-between	2	0.525	0.905
Marginally different	3	0.550	0.818
In-between	4	0.575	0.739
Slightly different	5	0.600	0.667
In-between	6	0.625	0.600
Quite different	7	0.650	0.538
In-between	8	0.675	0.481
Markedly different	9	0.700	0.429
In-between	10	0.725	0.379
Obviously different	11	0.750	0.333
In-between	12	0.775	0.290
Very different	13	0.800	0.250
In-between	14	0.825	0.212
Significantly different	15	0.850	0.176
In-between	16	0.875	0.143
Very significantly different	17	0.900	0.111
In-between	18	0.925	0.081
Extremely different	19	0.950	0.053
In-between	20	0.975	0.026
Absolutely incomparable	21	1.000	0.000

Table 7: Normalization priority score of affected factors into weighting

AF_n	***Priority Score***	***Normalization***	***Weighting***
Schedule	1.000	1.000 / 3.016	0.332
Cost	0.739	0.739 / 3.016	0.245
Safety	0.739	0.739 / 3.016	0.245
Quality	0.538	0.538 / 3.016	0.178
Sum	3.016	--	--

Table 8: Scenario utilities to the planning department

S_n	**For p=1, u_j**	**For p=2, u_j**	**Average u_j**
S_1	0.525	0.521	0.523
S_2	0.572	0.576	0.574
S_3	0.542	0.560	0.551
S_4	0.524	0.560	0.542
S_5	0.394	0.415	0.404

Table 9: Rearranged scenario utilities and descriptions

S_n	u_j	***Delivery Unit***	***Delivery times***
S_2	0.574	20	17
S_3	0.551	40	8
S_4	0.542	80	4
S_1	0.523	10	33
S_5	0.404	200	2

Table 10: Comparison of cost, schedule, quality and safety effects for the bpurchasing department

	Cost					**Schedule**					**Quality**					**Safety**				
	S_1	S_2	S_3	S_4	S_5	S_1	S_2	S_3	S_4	S_5	S_1	S_2	S_3	S_4	S_5	S_1	S_2	S_3	S_4	S_5
S1	0.5	0.568	0.616	0.639	0.652	0.5	1	1	1	0.5	0.5	0	0	0	0	0.5	0	0	0	0
S2	0.440	0.5	0.542	0.563	0.574	0	0.5	0	0	0	1	0.5	0	0	0	1	0.5	0	0	0
S3	0.406	0.462	0.5	0.519	0.529	0	1	0.5	0	0	1	1	0.5	0	0	1	1	0.5	0	0
S4	0.391	0.444	0.481	0.5	0.510	0	1	1	0.5	0	1	1	1	0.5	0	1	1	1	0.5	0
S5	0.383	0.436	0.472	0.490	0.5	0.5	1	1	1	0.5	1	1	1	1	0.5	1	1	1	1	0.5
Sum	2.120	2.410	2.611	2.712	2.765	1	4.5	3.5	2.5	1	4.5	3.5	2.5	1.5	0.5	4.5	3.5	2.5	1.5	0.5

Note: 0 = one has more probability than the other
0.5 = both have the same probability
1 = one has less probability than the other

Table 11: Affected factor comparison for the purchasing department

AF	***Cost***	***Schedule***	***Quality***	***Safety***	***Sum***
Cost	0.5	1	1	1	3.5
Schedule	0	0.5	0	1	1.5
Quality	0	1	0.5	1	2.5
Safety	0	0	0	0.5	0.5

Note: 0 = one is less important than the other
0.5 = both are equally important
1 = one is more important than the other

Table 12: Priority, score and weighting

AF	***Sum***	***Score***	***Normalization***	***Weighting***
Cost	3.5	1.000	1.000 / 3.023	0.331
Quality	2.5	0.818	0.818 / 3.023	0.271
Schedule	1.5	0.667	0.667 / 3.023	0.221
Safety	0.5	0.538	0.538 / 3.023	0.178
Sum	--	3.023	--	--

Table 13: Scenario utilities and descriptions for the purchasing department

S_n	u_j	***Delivery Units***	***Delivery times***
S_1	0.615	10	33
S_2	0.605	20	17
S_3	0.558	40	8
S_4	0.516	80	4
S_5	0.476	200	2

Table 14: Comparison of results

S_n	Planning Department (u_j)	Purchasing Department (u_j)	Delivery Units	Delivery times
S_1	0.551	0.615	10	33
S_2	0.574	0.605	20	17
S_3	0.542	0.558	40	8
S_4	0.523	0.516	80	4
S_5	0.404	0.476	200	2