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Using an analytic network process model to incorporate qualitative factors into multi-criteria global modal choice decisions

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USING AN ANALYTIC NETWORK PROCESS MODEL TO INCORPORATE QUALITATIVE FACTORS INTO MULTI-CRITERIA GLOBAL MODAL CHOICE DECISIONS

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ABSTRACT

This research develops and evaluates an Analytic Network Process (ANP) model to choose the correct mode of global transportation in the presence of complicating qualitative influences. The ANP model effectively combines important qualitative and quantitative factors into a global modal choice model. Although there is a great deal of research in the area of modal choice, the research often focuses singularly on cost or time factors. This research incorporates security, public opinion, and customer opinion into modal choice. One of the most difficult choices a transportation planner faces is deciding when qualitative factors outweigh the quantitative ones. A reliable tool to validate choice by including the important qualitative factors with the quantitative is quite valuable in military operations, humanitarian support, and disaster relief.

INTRODUCTION

Modal choice for global transportation requirements is a complex decision. Generally, sealift is slower, but more cost-effective, while airlift is faster and more expensive. The decision to move something by air or sea is influenced not only by cost and technical limitations, but also by qualitative factors. This seemingly simple decision is complicated by a myriad of influential factors.

Most transportation research has focused on measurable metrics that address such factors as how much it costs to move something, whether the cargo arrives on time, the volume of cargo moved, or the number of items moved. This research is useful, but sometimes falls far short of what's needed, as it neglects to consider the elements of the decision that aren't dependent on numbers. Examples of 'qualitative' factors include pressure from public opinion, urgent need of materials for human survival and the political message conveyed. One only needs to look at the news, both historical and modern day, to see how political, social, environmental, and public administration considerations affect the execution of many important endeavors.

Construction of the Trans-Alaskan pipeline is a vivid historical example of how a failure to consider the people and the environment, despite a national need for the oil, would cost billions of dollars and years of progress (Coates, 1991). A more recent example of choosing between 2 important alternatives in the face of many complicating factors is phase 4 construction of the Keystone Pipeline, also known as the Keystone XL Pipeline. The Keystone XL proposal faced criticism from environmentalists and a minority of the members of the United States Congress. In January 2012, President Barack Obama rejected the application amid protests about the pipeline's impact on Nebraska's environmentally sensitive Sand Hills region (Bloomberg BusinessWeek, 2012). The debate on building the pipeline rages on. These are just 2 examples of the difficulty that looms when many qualitative factors are involved. These factors are common in military transportation, humanitarian assistance and disaster relief efforts, but decisions must be made much faster, as lives are at state. There has not been a systematic examination of qualitative factors in the area of global modal choice, yet these factors can greatly influence mode choice.

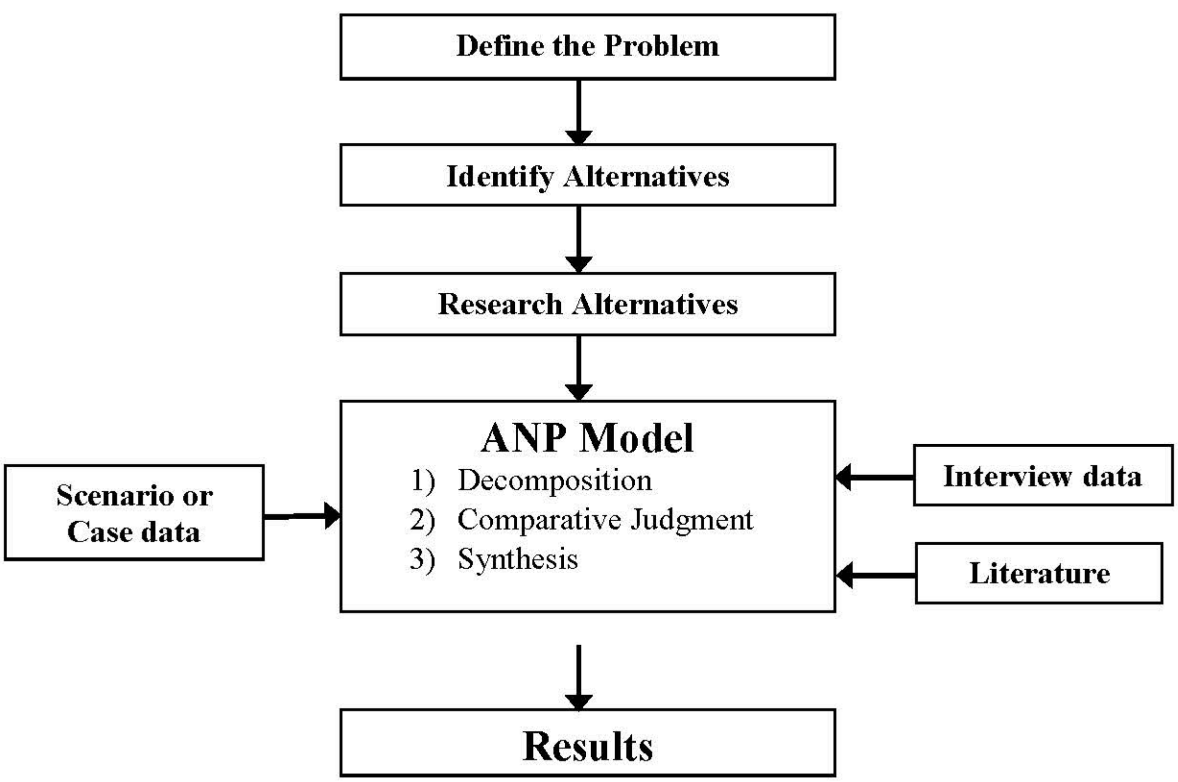
In order to address the problem of choosing the correct mode of global transportation in the presence of complicated qualitative influences, this research formulates an Analytic Network Process (ANP) model that effectively and efficiently combines the qualitative and quantitative factors into a single global modal choice model. The goal of the model is to get the required equipment to its destination at the required time, but to do it at the minimum total cost, while addressing the qualitative variables as best as can be done. The importance of incorporating qualitative factors into a transportation decision model is further demonstrated through the details of the High Mobility Multipurpose Wheeled Vehicle (HMMWV) case used to validate the developed model.

We will first use a Literature Review to show this research's position within the existing body of work, as well as to justify this research and the methodology. The development and use of the ANP model follows the literature review in the order presented in Figure 1. This figure shows both the flow and order of the discussion as well as the methodology used to create and utilize the ANP model. All of the inputs to the ANP Model are described in the Research Design (Building the ANP Model) section. ANP Model Implementation is described in the following section, and Model Building Results are shown in the next section. The paper concludes with the HMMWV Case and Recommendations for Future Research.

LITERATURE REVIEW

Perhaps the two most thorough reviews of modal choice research were conducted by McGinnis (1989) and Meixell & Norbis (2008). However, none of the examined models consider qualitative aspects, nor do they integrate experts' opinion into the decision.

FIGURE 1
DEVELOPMENT AND USE OF THE ANP MODEL



Some research efforts have attempted to identify the qualitative criteria that influence the freight mode choice like Brooks (1990), Lu (2003) and Jeffs and Hills (1990). Jeffs and Hills (1990) formulated a factor analysis of the determinants applicable to freight movement in the United Kingdom. They highlight six categories of variables that influence the decision, but they were unable to formulate an overall decision model that incorporated the complex interactions among the variables, as is needed for an accurate decision to be made in research such as this. Without modeling those interactions, accuracy of the results is not assured. Jeffs and Hills (1990) recommended future research focus on the specific situation, characteristics and needs of the organization. Their view of evaluating determinants of the mode choice with an organizational-specific model is shared by Young, Richardson, Ogden, and Rattay (1982).

In their examination of behavioral influence on freight mode choice criteria, Bolis and Maggi (2003) conclude that the mode choice must be in alignment with the organization's overall logistics strategy. The authors interviewed 4 logistics managers within an Adaptive Stated Preference experiment. While this is a small sample size, Bolis and Maggi (2003) argue that because of the expertise of these managers in the transportation system, their inputs can yield valid results. This paper utilizes a similar argument, but uses a greater number of interviews that better encompass the entire transportation system. Bolis and Maggi (2003) present the notion that an organization's overall logistics strategy will impact how important different criteria are to the decision maker in any given situation, which is also key to this research.

While existing research focuses on rail vs. truck modalities, Bergantino and Bolis (2004) considered the behavioral elements associated with a maritime mode choice. The study again shows that the particular situation and strategy of the customer plays an important role in determining applicable criteria for the mode choice. Their research relies on comparisons between the criteria, but also does not account for interactions among the criteria in a systematic way. Therefore, it is not particularly useful for a high visibility global mode choice.

The ability to consider both quantitative and qualitative data in a systematic way is a particular strength of an Analytic Hierarchy Process (AHP). Liberatore and Miller (1995) considered the mode choice between sealift and airlift using the AHP methodology with a focus on the entire logistics strategy of the focal firm. The authors note that their research represents the first time that AHP had been specifically applied to mode choice (Liberatore and Miller, 1995). They conclude that AHP offers a comprehensive, yet flexible methodology for addressing transport carrier and mode selection problems (Liberatore and Miller, 1995). Hundreds of researchers have used this methodology to model and make real-world decisions, such as choosing a subway layout in Istanbul or determining an appropriate mix of advertising media (Saaty, 2000).

The AHP decision model approach has also been subject to some criticism. Some authors have voiced objections to the model's mathematical and theoretical base, arguing that relative comparisons can be arbitrary, and that the higher and lower criterion of the decision can have interdependencies (Dyer, 1990; Harker and Vargas, 1987). The basis of this criticism is that the AHP only allows unidirectional influence along the hierarchical relationships (Cheng, Li, and Yu, 2005). Another limitation of the AHP is that the criteria at any given level of the hierarchy are considered to be mutually independent (Büyükyazici and Sucu, 2003). While this may be true in some cases and may be assumed in some cases to simplify the decision model, real-world problems are seldom so simple. Saaty (1999) points out that assuming independence unnecessarily limits interactions among elements within the same level and at different levels of the hierarchy. Another criticism of the model is that the decision maker can introduce inconsistencies into the model. For example, suppose in a car purchase example the buyer said that speed was more important than style, that style was more important than cost, but that cost was more important than speed. This is the circular inconsistent logic of A>B, B>C, but C>A.

To properly deal with these criticisms, the decision model developed here has been generalized to include interdependencies between internal elements and feedback between hierarchical criteria levels of the decision. This generalization of the AHP is termed an Analytic Network Process (ANP) model (Saaty, 2001). Feedback and inner dependence are included by way of another matrix transformation on relative priorities. Inner dependence is observed when an element within a cluster influences another element within the same cluster. A cluster is a group of closely related model elements, like the sub-criteria of an overall criterion or the alternatives to be considered. This model is also seeing wide usage in academic and professional arenas to assist in decision making (Coulter and Sarkis, 2005; Cheng and Li, 2005; Shang, Youxu, and Yizhong, 2004; Lee and Soung, 2000).

The ability of ANP to model inner dependence and feedback within a decision hierarchy makes it an appropriate model for mode choice. Ali Görener provides significant proof and further validation that ANP is the proper and most suitable method to use. His comparison of ANP and AHP in a manufacturing setting shows that there are significant differences between AHP and ANP outcomes derived from interdependencies, outerdependencies and feedbacks (Görener, 2012). In Rozann Saaty's paper "A Validation of the Effectiveness of Inner Dependence in an ANP Model," she shows at each step the results are nearer what we know occurs in the real world. Using a direct comparison of the AHP and ANP models, this validation shows that using feedback and dependence in an ANP model can get us closer to reality (Saaty 2013).

However, a review of the literature revealed no previous research of modal choice using the ANP methodology.

RESEARCH DESIGN (BUILDING THE ANP MODEL)

To build an ANP model, we begin with the three distinct steps of problem identification (Forman and Selly, 2001). These steps are - 1) defining the problem, 2) identifying alternatives and 3) researching the alternatives. The first two steps are straightforward, as our problem is in choosing the correct mode of global transportation, and the choices are airlift or sealift. Researching the alternatives for step 3 is quite challenging and reflects most of the effort and reason behind this research. ANP was chosen as the modeling methodology for the third step, due to its capacity to incorporate complex interactions among criteria and to capture qualitative and quantitative variables. After the three problem identification steps are properly addressed, the ANP model is constructed for determining global modal choice.

To build the model, data is incorporated from the literature and personal interviews with transportation experts in different regions. Existing literature and interviews are used to determine appropriate criterion to include in the decision model, as well as their relative importance. Subjects for the interviews were selected by contacting the U.S. Transportation Command for experts in the matching of sealift or airlift assets to a movement request. Ten subject matter experts, of those requested, agreed to be interviewed. The interviewees consist of both service providers and customers in different regions of the world and all four service branches of the U.S. military (Army, Air Force, Navy and Marines). Experience ranges from a senior leader with 34 years of logistics experience to an interviewee with seven months experience in coordinating movement requests. All interviewed subjects have detailed knowledge of transportation functions and limitations and are experienced in both movement requests and mode selections. The subjects collectively have experience in all major regions of the world.

Interviews were conducted with subject matter experts during which each was asked seven primary and very open ended questions as follows:

1. Where do you work? How long have you worked in the transportation system? What do you do in the strategic Airlift/sealift system?
2. How does a movement request happen?
3. What do you perceive as the major criteria to consider when requesting sealift or airlift as a mode of transportation?

4. How often does the lift occur exactly as requested? Can you recall any cases where one mode was requested, but a different mode was used?
5. From your perspective, what are a few **major** Criteria that complicate the modal choice?
6. What could be done to improve the decision making process?
7. Is there someone else you could recommend I talk to about these kinds of issues?

An affinity diagram procedure was used to organize the ideas using the following steps (Brassard, 1989):

Step 1 - Generate Ideas. The survey questions were used to generate a list of ideas. Interviews were recorded and subsequently transcribed to text. All subjects were advised that the interview would be recorded and that their identities would remain confidential.

Step 2 - Display the Ideas. The ideas were posted randomly on a table. Each interview was decomposed into discrete statements of the criteria that influence the mode decision, resulting in 240+ individual statements. Each statement represented a specific criterion and element applicable to the mode choice, and could also indicate interaction with other elements.

Step 3 - Sort the Ideas into Related Groups. The researchers physically sorted the individual statements and they were then reorganized into related concepts and groupings, using the following process:

- Start by looking for two ideas that seem related in some way. Place them together in a column off to one side.
- Look for ideas that are related to those you've already set aside and add them to that group.
- Look for other ideas that are related to each other and establish new groups.

Step 4 - Create Header Cards for the Groups. A header is an idea that captures the essential link among the ideas contained in a group of cards. This idea is written on a single card or post-it and must consist of a phrase or sentence that clearly conveys the meaning. The researchers developed headers for the groups by:

- Finding already existing cards within the groups that will serve well as headers and placing them at the top of the group of related cards.
- Alternatively, discussing and agreeing on the wording of cards created specifically to be headers.
- Discovering a relationship among two or more groups and arranging them in columns under a superheader. The same rules apply for superheaders as for regular header cards.

Step 5 - Draw the Finished Affinity Diagram.

- Write a problem statement at the top of the diagram.
- Place header and superheader cards above the groups of ideas.
- Review and clarify the ideas and groupings.
- Document the finished Affinity Diagram.

Once the cards have been sorted into groups, large clusters are sorted into subgroups for easier management and analysis. The result of the affinity diagramming procedure is a cause and effect diagram. Once the statements are transformed into the needed criterion, elements, and interactions that represent policy, practice, and priorities, they are all inputted to the *SuperDecisions 1.6.0* software selected for this task and utilized for the mathematical formulation of the mode choice. Data for needed mode decisions are inputted to the model for recommendation as discussed later in the HMMWV case study.

ANP MODEL IMPLEMENTATION

Now that we have developed our ANP model, we discuss the steps the model goes through in modeling a decision and presenting a recommendation. *SuperDecisions 1.6.0* software is utilized for the mathematical formulation of the model in this research, where the pairwise judgments and synthesis are performed via graphical user interface (Super Decisions, 2006). There are three basic steps to modeling a decision using AHP that are also applicable to ANP: 1) decomposition, 2) comparative judgment, and 3) synthesis (Saaty, 1990; Büyükyazici and Sucu, 2003).

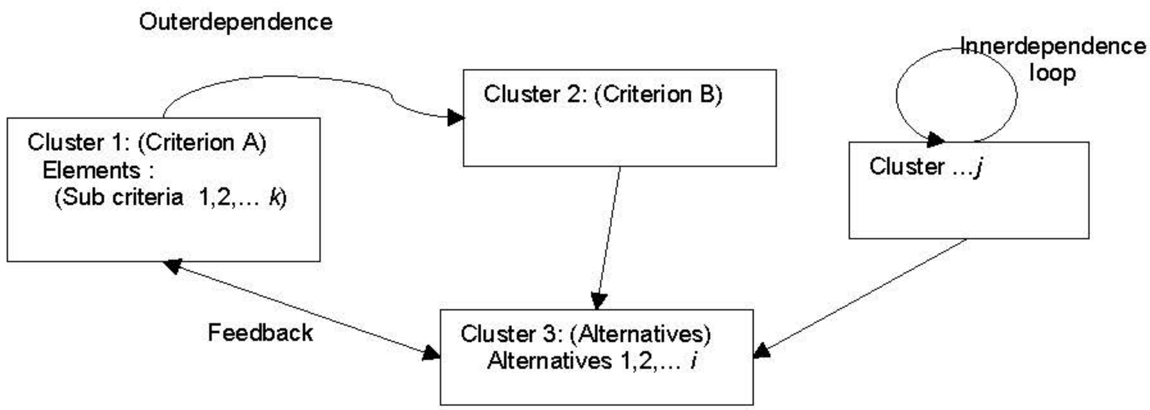
Decomposition

Decomposition of the decision problem is very similar between ANP and AHP and is the first phase of AHP model development. Since ANP breaks down the traditional one-way influence of the hierarchy, it is graphically represented differently as seen in the following figure as adapted from Büyükyazici and Sucu (2003).

There are several important differences in this ANP network model. The first is terminology. The numerous criteria and alternatives depicted in the model are represented by the multiple *clusters* and the sub-criterion are called *elements*. When an element within a cluster influences another element within the same cluster, this relationship is called *inner dependence* and is represented by the arrow looping back to the same cluster as shown above. Similarly, when an element from one cluster influences an element from another cluster, this relationship is called *outer dependence* and is represented by the arrows between clusters. When the characteristics of one of the alternatives influences a criterion or sub-criterion, this relationship is called *feedback* and is represented by an arrow moving from the alternatives cluster to a criterion cluster. In this way, the importance of the criteria and their sub-criteria not only influence the priority of the alternatives, but also influence the priority of the various criteria and other elements within the model. Saaty (1990/1997) helps us understand these relationships with a couple of examples.

> "In inner influence one compares the influence of elements in a group on each one. For example if one takes a family of father mother and child, and then take them one at a time say the child first, one asks who contributes more to the child's survival, its father or its mother, itself or its father, itself or its mother. In this case the child is not so important in contributing to its survival as its parents are. But if we take the mother and ask the same question on who contributes to her survival more, herself or her husband, herself would be higher, or herself and the child, again herself. Another example of inner dependence is making electricity. To make electricity you need steel to make turbines, and you need fuel. So we have the electric industry, the steel industry and the fuel industry. What does the

FIGURE 2
ANP MODEL REPRESENTATION



electric industry depend on more to make electricity, itself or the steel industry, steel is more important, itself or fuel, fuel industry is much more important, steel or fuel, fuel is more important. The electric industry does not need its own electricity to make electricity. It needs fuel. Its electricity is only used to light the rooms, which it may not even need. If we think about it carefully everything can be seen to influence everything including itself according to many criteria. The world is far more interdependent than we know how to deal with using our existing ways of thinking and acting. The ANP is our logical way to deal with dependence."

This powerful network model can also represent extremely complex decision making by including as many clusters and elements as required for the objective, and each cluster can also entirely contain sub networks of criteria. The depth and complexity of the network model is limited only by the needs of the decision maker. The network model can also be expanded to incorporate different dimensions of the decision, each of which corresponds to a given preference for an alternative based on an overall environment. For example, in estimating market share one might evaluate different alternatives based on the risk, opportunity, costs, or benefits each alternative presents (Saaty, 2003). These higher level dimensions are called *control hierarchies*, and represent a separate network of the same criteria for each dimension being considered (Saaty, 1999). The control hierarchies can be viewed as important higher level aspects in choosing between the model alternatives identified by the decision maker and integrated via the questions asked to gather the needed data. Saaty shows some example questions on bringing in data for a control hierarchy:

> "For benefits and opportunities, ask what gives the most benefits or presents the greatest opportunity to influence fulfillment of that control criterion. For costs and risks, ask what incurs the most cost or faces the greatest risk. Sometimes (very rarely), the comparisons are made simply in terms of benefits, opportunities, costs, and risks in the aggregate without using control criteria and subcriteria."

In this transportation model the control hierarchy encompasses the entire model represented by the overall objective of "Sealift or Airlift for Global Modal Choice?"

In this research, data is drawn from interviews with subject experts in the military distribution system, and it is compiled to determine appropriate criteria to include in the model. Decomposition of the decision through interviews has been used by many researchers such as Bolis and Maggi (2003). After decomposition is complete, we begin the second phase of AHP building, which is comparative judgment.

Comparative Judgement

The comparative judgment phase of ANP is essentially the same as AHP. Each cluster is compared in a pairwise fashion relative to its importance to the objective. Similarly, pairwise comparisons of each element within a cluster are also constructed using the same qualitative and quantitative methods as described with AHP models. The comparisons are done to establish their relative importance to weight the corresponding blocks of the supermatrix and make it column stochastic. A cluster impacts another cluster when it is linked from it, that is, when at least one node in the source cluster is linked to nodes in the target cluster. The clusters linked from the source cluster are pairwise compared for the importance of their impact on it with respect to mode choice, resulting in the column of priorities for that cluster in the cluster matrix. The process is repeated for each cluster in the network.

Relative comparisons for all of the information in the decision can be interpreted as pairwise judgments and included in the overall decision model. In Saaty's *SuperDecisions 1.6.0* software, this pairwise comparison can be made by pie chart, bar chart, questionnaire, or input directly into a pairwise comparison matrix (Super Decisions, 2006).

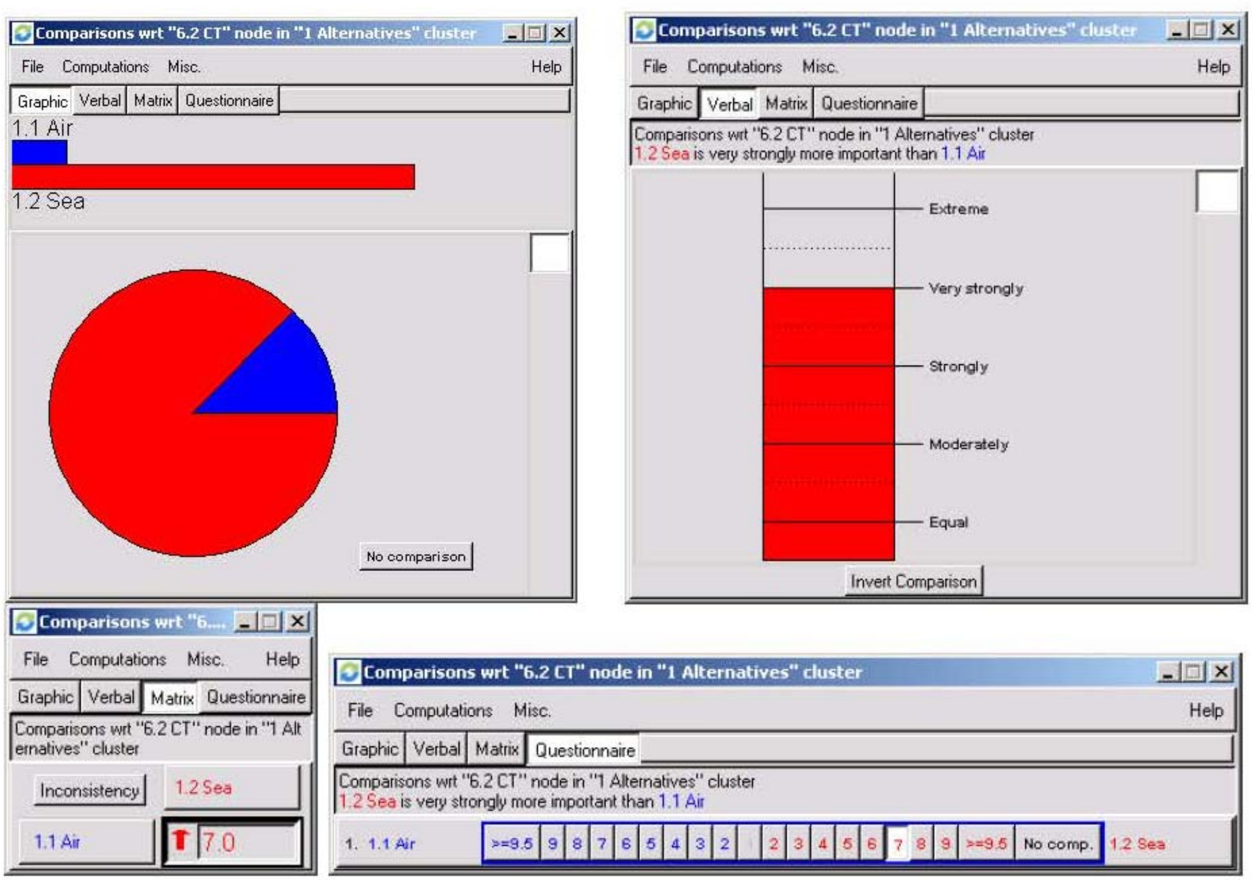
A node is a sub-division of a cluster and typically represents the lowest level of input data that is examined. If customers is a cluster, then age, gender, and salary could be used as nodes. After all the nodes are created, nodes are chosen and linking to the other nodes in the model that influence it. The "children" nodes will then be pairwise compared with respect to that node as a "parent" node. An arrow will automatically appear going from the cluster the parent node cluster to the cluster with its children nodes. When a node is linked to nodes in its own cluster, the arrow becomes a loop on that cluster and we say there is inner dependence (Saaty, 1990/1997).

As an example, Figure 3 shows a notional model node that indicates that the type of cargo being transported "very strongly" favors the use of sealift. The reason for the strength of the pairwise comparison might be that the commodity is extremely dense or heavy and might not be able to be transported by air. Within the software, a similar comparison is accomplished for each sub-criterion with respect to the alternatives.

Synthesis

After the second phase of AHP development is complete, we can begin the third and final stage of model development, known as Synthesis. The synthesis phase of ANP is much different than in AHP. In ANP, a supermatrix of the pairwise comparisons is constructed. This supermatrix consists of several partitions or sub-matrices which take into account the impact of elements on each other (Büyükyazici and Sucu, 2003). The supermatrix is organized with each element of the model occupying a column and a row. These columns and rows are grouped by their parent

FIGURE 3
PAIRWISE PREFERENCES IN SUPERDECISIONS 1.6.0 SOFTWARE



cluster. In this way, there is a representation for how much each element of the model influences every other element of the model. Of course, elements can also exert no influence on each other, and a '0' is entered in the matrix where these two elements intersect. The intersection of two clusters of elements represents a single pairwise comparison matrix, and the supermatrix represents the compilation of all the priorities derived from pairwise matrices (Büyükyazici and Sucu, 2003). An important point is that the supermatrix must be column stochastic (Saaty, 1999). This means that the sum of each column within the supermatrix must sum to one so that the supermatrix converges when raised to an acceptably large power (Büyükyazici and Sucu, 2003). This can be done by multiplying the values within the sub-matrix by the relative weight of their interaction. Saaty (1999) represents the supermatrix using the notation: W is the supermatrix, N represents the number of clusters, C_N represents each cluster, e_{Nn} represents each element of the model, and W_{Nn} represents the appropriate sub-matrix weight.

The desirability of an alternative can then be computed in a similar fashion to AHP while incorporating the effects of dependence between the elements of the model. While Saaty uses matrix representation for deriving the priority of alternatives, this process can also be represented mathematically. The following summation was adapted from the work of Meade and Sarkis (1999) to represent the needed ANP related decision variables and represents the desirability of an alternative for a given control hierarchy.

$$D_i = \sum_{j=1}^{J} \sum_{k=1}^{K_j} P_j W_{kj}^D W_{kj}^I S_{ikj} \quad (1)$$

Where:

D_i is the desirability of alternative *i*.

P_j is the relative importance weight of the criterion *j* for the control hierarchy,

W_{kj}^D is the relative importance weight for element *k* of criterion *j* for dependency between component levels of the model.

W_{kj}^I is the stabilized relative importance weight as determined by the supermatrix for element *k* of criterion *j* for interdependency relationships between elements of the model.

S_{ikj} is the relative preference of alternative *i* with respect to element *k* under criterion *j*.

K_j is the index set of elements for criterion *j*, and *J* is the index set for all criterion.

The synthesis step is accomplished after entering all the pairwise comparisons. The relative priority of the alternatives will be displayed graphically and in terms of the raw derived priorities.

MODEL BUILDING RESULTS

The following table summarizes the model elements of the developed modal choice model.

Criteria 1.0 represents the alternatives available to the decision maker, and criteria 2.0 to 7.0 represent elements of the decision. This procedure resulted in the identification of six main criteria elements and 28 sub-criteria elements for consideration in modal choice decisions (not including the airlift and sealift alternatives in this total). Throughout the interview process, it became apparent that criteria were indeed highly influential to each other. For example, the availability of aircraft was influenced to a high degree by worldwide global demand for airlift. These various relationships are captured by including inner dependence and outer dependence loops within the decision network. The interdependencies (both inner and outer dependence) can be seen in the following table by the many sub-criterion that influence other sub-criterion.

Table 2 shows that the subjects indicated a high degree of interaction among the elements of the model. The left most column indicates the element that has influence over the criteria to the right. Some elements such as Leader's Preferences and Platform Availability have a widespread influence over many other elements in the model. These criteria, sub-criteria and their dependencies were all entered into *Super Decisions* 1.6.0 (Super

TABLE 1
TABLE OF MODALITY DECISION CRITERIA

Main Criteria	Sub-Criteria (Elements)	Abbr.
1.0 Alternatives	1.1 Airlift	Air
	1.2 Sealift	Sea
2.0 Costs	2.1 Monetary Considerations	MC
	2.2 Security Considerations	SC
3.0 Geography	3.1 Distance to be moved	DM
	3.2 Location of the Port	LP
	3.3 Weather Considerations	WC
4.0 Operational Requirements	4.1 Higher Headquarters taskings	HT
	4.2 Mission Type	MT
	4.3 Standard Operating Procedure	SO
	4.4 Time Phased Deployment layout	TL
5.0 Political Influences	5.1 Leader's Preferences	CP
	5.2 Host Nation Sensitivities	HN
	5.3 Inflated Requirements	IR
	5.4 Organizational Bias	OB
	5.5 System Knowledge	SK
	5.6 Trust	TR
	5.7 Visibility in the System	VS
6.0 System Limitations	6.1 Cargo Handling Limitations at the Port	CH
	6.2 Cargo Type	CT
	6.3 Load Efficiency	LE
	6.4 Platform Availability	PA
	6.5 Speed of Delivery	SD
	6.6 Volume of Cargo	VC
7.0 Time Available	7.1 Advanced Notice	AN
	7.2 Criticality	CC
	7.3 Emerging Requirements	ER
	7.4 Force Flow Model	FF
	7.5 Force Provider Availability	FA
	7.6 Late Requests	LR

Decisions, 2006) software to arrive at an overall network model.

Now that the decision model has been developed, it is necessary to evaluate the model. We will examine a specific case to validate the developed model. Complete data for a situation such as is modeled here is not easy for everyone to obtain, as many factors we consider are often either not collected or the data is not freely distributable. We were able to obtain needed data for validation and used the very relevant Department of Defense case of transporting up-armor kits and armored High Mobility Multipurpose Wheeled Vehicles (HMMWVs).

HMMWV CASE (MODEL VALIDATION)

On December 25, 2003 The New York Times published the story "Army Stepping Up Its Humvee Orders For Troops in Iraq" where they expound on how the U.S. Army sent out an urgent call for armored HMMWVs, realizing that it had not ordered enough to protect its troops. In April 2005, the Government Accountability

TABLE 2
SUB-CRITERIA INFLUENCE OTHER ELEMENTS

Sub-Criterion	Is Influenced by:
2.1 Monetary Considerations	3.1 Distance to be moved 6.6 Volume of Cargo 7.1 Advanced Notice 7.5 Force Provider Availability
2.2 Security Considerations	6.5 Speed of Delivery
3.2 Location of the Port	6.2 Cargo Type
4.2 Mission Type	2.1 Monetary Considerations
4.3 Standard Operating Procedure	2.2 Security Considerations 3.2 Location of the Port 5.4 Organizational Bias 6.2 Cargo Type 7.2 Criticality
4.4 TPFDD layout	5.1 Leader's Preferences 6.5 Speed of Delivery 7.4 Force Flow Model 7.5 Force Provider Availability
5.1 Commander's Preferences	2.1 Monetary Considerations 4.2 Mission Type 4.3 Standard Operating Procedure 5.3 Inflated Requirements 5.4 Organizational Bias 5.5 System Knowledge 5.7 Visibility in the System 6.2 Cargo Type 6.5 Speed of Delivery 7.3 Emerging Requirements 7.5 Force Provider Availability
5.2 Host Nation Sensitivities	6.2 Cargo Type
5.3 Inflated Requirements	2.1 Monetary Considerations 5.1 Commander's Preferences 5.4 Organizational Bias 5.5 System Knowledge 5.6 Trust
5.4 Organizational Bias	3.2 Location of the Port 4.2 Mission Type 5.5 System Knowledge 6.2 Cargo Type 6.4 Platform Availability
5.5 System Knowledge	3.2 Location of the Port 4.3 Standard Operating Procedure
5.6 Trust	2.1 Monetary Considerations 5.1 Commander's Preferences 5.4 Organizational Bias 5.5 System Knowledge 6.5 Speed of Delivery 6.6 Volume of Cargo
5.7 Visibility in the System	3.2 Location of the Port
6.1 Cargo Handling Limitations at the Port	3.2 Location of the Port 5.3 Inflated Requirements 5.5 System Knowledge
6.3 Load Efficiency	5.5 System Knowledge 6.4 Platform Availability
6.4 Platform Availability	2.2 Security Considerations 3.2 Location of the Port 3.3 Weather Considerations 5.2 Host Nation Sensitivities 5.3 Inflated Requirements 6.2 Cargo Type 6.3 Load Efficiency 6.6 Volume of Cargo 7.2 Criticality 7.3 Emerging Requirements 7.5 Force Provider Availability 7.6 Late Requests
6.5 Speed of Delivery	3.1 Distance to be moved 3.2 Location of the Port 4.3 Standard Operating Procedure 6.1 Cargo Handling Limitations at the Port 6.6 Volume of Cargo
6.6 Volume of Cargo	3.2 Location of the Port 5.3 Inflated Requirements 6.1 Cargo Handling Limitations at the Port 7.2 Criticality 7.3 Emerging Requirements
7.1 Advanced Notice	4.3 Standard Operating Procedure 5.6 Trust 6.4 Platform Availability 7.5 Force Provider Availability
7.2 Criticality	4.3 Standard Operating Procedure 5.1 Commander's Preferences 6.2 Cargo Type 7.3 Emerging Requirements 7.5 Force Provider Availability
7.3 Emerging Requirements	7.1 Advanced Notice 7.2 Criticality
7.4 Force Flow Model	5.3 Inflated Requirements 6.2 Cargo Type 6.5 Speed of Delivery
7.5 Force Provider Availability	6.2 Cargo Type
7.6 Late Requests	7.5 Force Provider Availability

Office published a report to Congressional Committees identifying nine commodities that were subject to systemic deficiencies and five reasons the shortfalls were realized. Ineffective distribution of armored HMMWVs and up-armored kits was cited as one of the prevalent systemic deficiencies (GAO-05-275, 2005).

Sealift is generally about 1/10th the cost of airlift, and it is the obvious choice for bulk and heavy assets to be moved, especially over long distances. However, monetary considerations were considered less important because armor kits and vehicles were considered critical to troop survival. News stories of American casualties due to roadside bombings of HMMWVs without armor led to heavy political influence on mode choice. Security and time considerations favor the use of airlift. Geographical influence on mode choice is mixed. While the items are heavy and the distance to move them is great, which would favor sealift, the required location for these items is inland, which would favor airlift. Another important factor in this decision is that during the initial stages of the transportation problem there were very few armor kits to aggregate to an entire shipload for transportation.

The following table summarizes the data for sub-criteria preference with respect to the alternatives:

The table represents preference for sealift or airlift based on the HMWVV data and can be interpreted as the relative importance of one criteria over another with respect to a given criteria. For example, in the 2.0 Costs table in Table 3 the bolded entry indicates that operational requirements are 2 times as important as system limitations with respect to the costs criteria. When a criterion does not have an impact on another criterion, it is not included in the pairwise comparison.

Once the steps of ANP are completed, as previously discussed, the resulting vector is obtained from the HMMWV data and presented in Table 4.

The bolded priorities within the table for airlift and sealift match the priorities derived using the *Super Decisions 1.6.0* software, and represent a preference for using airlift for mode choice using the HMMWV case data (Super Decisions, 2006). The derived priorities for the individual sub-criteria presented in the table indicate the amount of influence each of these elements had in identifying airlift as the mode of choice. Each of the elements grouped in their main criteria display the amount of influence each main criteria had in the overall mode choice.

TABLE 3
MAIN CRITERIA PAIRWISE PREFERENCES

2.0 Costs

	4 Op. R	5 Pol.	6 Sys.
1 Alter	0.22	0.50	0.50
4 Op. R		2.30	**2.00**
5 Pol.			0.83

3.0 Geography

	2 Costs	4 Op. R	5 Pol.	6 Sys.
1 Alter	1.20	3.00	6.00	2.22
2 Costs		2.50	2.50	1.00
4 Op. R			2.00	1.00
5 Pol.				0.50

4.0 Operational Requirements

	2 Costs	4 Op. R	5 Pol.	6 Sys.	7 Time
1 Alter	2.00	1.00	1.00	1.00	1.00
2 Costs		1.00	0.33	0.33	0.25
4 Op. R			2.00	0.50	0.33
5 Pol.				1.00	0.50
6 Sys.					0.50

5.0 Political Influences

	4 Op. R	5 Pol.	6 Sys.	7 Time
1 Alter	1.20	0.60	2.00	4.00
4 Op. R		0.33	2.00	1.20
5 Pol.			2.00	3.00
6 Sys.				0.50

6.0 System Limitations

	2 Costs	3 Geo	4 Op. R	5 Pol.	6 Sys.	7 Time
1 Alter	3.00	1.20	0.80	2.00	0.90	0.80
2 Costs		0.25	0.25	0.50	0.25	0.25
3 Geo			0.50	2.00	1.00	2.00
4 Op. R				2.00	0.50	2.00
5 Pol.					0.20	0.33
6 Sys.						3.00

7.0 Time Available

	2 Costs	4 Op. R	5 Pol.	6 Sys.	7 Time
1 Alter	5.00	1.00	3.00	1.00	1.20
2 Costs		0.17	0.17	0.17	0.17
4 Op. R			1.00	1.20	0.50
5 Pol.				0.50	0.33
6 Sys.					0.50

HMMWV CASE CONCLUSIONS

Overall, the developed ANP decision model shows a relative preference for airlift to deliver the HMMWV armor requirements. In practice, this is the actual outcome chosen by decision makers. In a hearing of the House Armed Services Committee, Congressman Hunter relayed that even much later in the conflict airlift delivered the majority of level 2 armor due to the “extreme importance to our warfighters” (Hunter, 2006).

Although the choice of airlift or sealift is a seemingly simple binary choice, it is anything but simple. One of the most difficult choices a transportation planner faces is deciding when qualitative factors outweigh the quantitative ones. Having a reliable tool to validate that choice by including the important qualitative factors with the quantitative is quite valuable.

TABLE 4
OVERALL PRIORITIES

			Priorities (N. EV)	
		EV	Sub. Criteria	Main Criteria
1 Alt.	1.1 Air	0.197	**0.561**	1.000
	1.2 Sea	0.155	**0.439**	
2 Costs	2.1 MC	0.007	0.011	0.015
	2.2 SC	0.002	0.004	
3 Geo	3.1 DM	0.000	0.000	0.000
	3.2 LP	0.000	0.000	
	3.3 WC	0.000	0.000	
4 Op. Req.	4.1 HT	0.000	0.000	0.111
	4.2 MT	0.007	0.011	
	4.3 SO	0.027	0.041	
	4.4 TL	0.039	0.059	
5 Pol. Inf.	5.1 CP	0.059	0.091	0.258
	5.2 HN	0.000	0.000	
	5.3 IR	0.047	0.073	
	5.4 OB	0.020	0.031	
	5.5 SK	0.004	0.006	
	5.6 TR	0.037	0.057	
	5.7 VS	0.000	0.000	
6 Sys. Lim.	6.1 CH	0.003	0.005	0.326
	6.2 CT	0.000	0.000	
	6.3 LE	0.065	0.100	
	6.4 PA	0.098	0.152	
	6.5 SD	0.020	0.031	
	6.6 VC	0.025	0.038	
7 Time Av.	7.1 AN	0.046	0.071	0.290
	7.2 CC	0.059	0.091	
	7.3 ER	0.066	0.101	
	7.4 FF	0.018	0.027	
	7.5 FA	0.000	0.000	
	7.6 LR	0.000	0.000	
		0.648	1.000	

FUTURE RESEARCH

The presented decision model was built using the inputs of 10 experts in the mobility system. One area of future research that could add validity to the model is to evaluate the accuracy and completeness of the model through additional case studies or by using a Delphi Methodology. Additional case studies would further validate the model, as would a follow-up survey of all subjects or examining the inputs of new experts. A survey could easily be built using *WebSurveyor Desktop 4.1*, and contain Likert scale ratings of each criteria and sub-criteria with respect to how frequently it impacts the modal choice, and how important it is to the modal choice.

CONCLUSSIONS

This research presents a unique decision model as well as a unique method of developing mode choice using ANP. Tools such as this decision model and other initiatives serve to aid decision makers by allowing them to make more thoroughly informed decisions in a systematic way that includes both quantitative and qualitative inputs not included in previous modal choice models. This multi-criteria integrated methodology and modeling technique could be applied to other transportation problems that require an important degree of qualitative factor decision making integration. This could include other military operations, humanitarian assistance/ logistics, or disaster relief where many qualitative factors need to be considered and priorities are not solely cost based.

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