

# PLANNING FOR MULTINATIONAL FIRMS USING AN INTELLIGENT NETWORK MODELING SYSTEM

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## ABSTRACT

Multinational planners need to be able to plan and replan rapidly. In addition, they need to be able to model complex events and organization structures. For example, multinational planners need to be able to plan for production in multiple countries and repatriation of funds. This paper presents an intelligent generalized network system (IGNS) that can be used to assist in planning for multinational firms.

## I. INTRODUCTION

Multinational firms need to be able to plan where to produce goods and when to repatriate funds earned in other countries. Multinational firms need to be able to plan rapidly because currency values can fluctuate rapidly. In addition to the need

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to plan rapidly, multinational firms face a complex assortment of changing currency and production situations. As a result, there is a need for a tool that allows firms to rapidly model complex integrated multinational corporate structures and international currency situations.

This paper presents a system that can be used to assist in that planning process in the context of a multinational firm. In particular, this paper presents an Intelligent Generalized Network System (IGNS), that is designed to facilitate such planning and replanning. IGNS helps the user to quickly generate and evaluate a broad range of models for a firm. The system can rapidly evaluate several instances of a model. A model instance is a model with data. IGNS tests for feasibility of the model instance and then solves and interprets it for the user. The system can be used for replanning, since data parameters can be easily changed and nodes and arcs can be easily added or deleted. In order to accomplish these tasks, IGNS employs operations research knowledge about formulation, feasibility, solution and interpretation of generalized network flow problems to help the multinational planner.

This work differs considerably from other work done on using intelligent systems to help in the construction of linear programming models, see Murphy and colleagues and the many papers and books on AMPL and GAMS (for GAMS see Fourer, Gay, and Kernighan 1993). We have specialized our work to network flow related models and have built an interface which allows the user to quickly build, edit, and solve these models. The user need not learn the syntax required to use the algebraic modeling language such as AMPL and GAMS. The user need only to draw the network graph of the problem to be solved on a piece of paper to use as a guide in building the model. Proto-type models can vary quickly be built and tested. Models can be saved in a library in a subdirectory for instant recall and reuse. A novice user can use the system and then reuse the system at a later time without having to remember the special syntax that these other systems use.

Some rather large models can be built using some of the new features recently added to the system. These new features make it much easier to build and solve production models. See Section V for some of the recent extensions.

In addition to the model developed in this paper many other types of models are of interest to multinational firms. Many firms that the authors have dealt with do not permit knowledge of the models they have used to be published to gain or maintain a competitive edge. However, little by little a knowledge of these models slips out into the open literature. Integrated distribution planning systems and the exchange arbitrage problem are two such applications that have helped companies reduce distribution costs and increase profits. IGNS could be used with either of these applications. It always can be used to quickly build proto-type models to help scope out models to be developed using other methods.

Network or embedded network flow models form the heart of integrated distribution planning systems. Many multinational companies have reported great success in building and using such systems as part of Decision Support Systems.

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General Motors, Blumenfeld and colleagues, (1987) and International Paper, Bender and colleagues, (1981) are two such companies that have reported reduced logistics costs by using network flow models. A special logistics module has been developed in IGNS to make it easier to build logistics models, see Section V.

The exchange arbitrage problem can be modeled as a generalized network flow problem. Arbitrage is defined as the act of buying and selling the same asset simultaneously in different markets at different prices with the effect of assuring a "locked in" or good profit. By quickly solving the exchange arbitrage problem multinational firms can take advantage of money-making opportunities momentarily present through divergences in exchange values. See Christy and Roden (1976) for a discussion of this problem.

There have been a number of algorithms to solve generalized network flow problems. A computationally efficient approach was generated by Brown and McBride (1984). In addition, McBride (1985) developed EMNET, a computationally efficient approach for the solution of embedded network problems, network problems with side constraints and/or side variables. These algorithms can solve even extremely large embedded network flow problems rapidly as shown in McBride (1996a). EMNET is currently the solver in IGNS and is being used routinely to efficiently solve logistic embedded flow problems for a multinational company with more than 600,000 nodes (constraints) and 7,000,000 arcs (variables). It is this ability to quickly solve embedded network flow problems coupled with complexity of problems that can be modeled as embedded network flow problems that makes IGNS (and its extensions) so appealing.

#### A. This Paper

This paper proceeds as follows. Section II provides a brief background of the use of generalized network models for planning. Section III illustrates the use of the system. Section IV reviews the nature of the "intelligence" embedded in IGNS. Section V briefly summarizes the paper and discusses some extensions.

## II. PREVIOUS RESEARCH ON NETWORK MODELS OF MULTINATIONAL FIRMS

This section summarizes some of the relevant previous research on network flow models and their use in planning for multinational firms. Then the basic generalized network flow model is summarized.

#### A. Previous Research

The techniques for designing and solving computer-based planning models have undergone an evolution over the last 20 years or so. Perhaps the first network

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flow models for multinational firms were developed by Crum (1974), who in pioneering work modeled for process of planning cash conversion by multinational corporations as a generalized network problem.

### B. Need for IGNS in Multinational Corporations

However, the use of generalized networks to solve multinational planning problems has been limited by the availability of approaches to facilitate the formulation of problems. Generally, in order to use the approaches of Brown and McBride (1984) and McBride (1985) requires that the user is familiar with the basic algorithms and can do substantial formulation work.

In order to use generalized network algorithms the user would be required to write software which could be used to build a model. However, few potential multinational corporate planners are operations research experts. In addition, the typical time requirements associated with the development of mathematical programs would be substantial. Further, if any changes occurred then replanning would be required and the formulation would need to be changed.

One approach to circumvent some of these difficulties is to provide the multinational planner with the assistance of an operations research expert. However, that would not mitigate the time issue. Even an operations research expert could require substantial time to formulate problems for generalized network algorithms. Further, there would need to be substantial feedback from the planner to ensure the model captured reality.

As a result, we can anticipate that if a multinational corporate planner was to employ a generalized network approach then an alternative vehicle would be required to facilitate formulation, feasibility testing and solution generation. IGNS is proposed as a tool that the multinational corporate planner could use to generate generalized network flow models of complex integrated multinational corporate structures and international currency situations. There would be little need for an operations research expert if the user has access to IGNS. Instead, the multinational planner could function relatively independent of the operations research expert and have available an extremely good solver for quick solution times.

IGNS would even be very useful to those operations research experts who work with multinational planners. It would allow him to quickly build proto-type and final production models to be able to respond more quickly to the planner.

### C. Mathematical Formulation

This section presents a mathematical formulation of the generalized network flow problem. Further interpretation of this formulation is provided in the next section. This formulation is basically the same formulation used by Crum and colleagues (1983a).

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Let  $x_{ij}$  be the flow on the arc from node  $i$  to node  $j$ . Let  $L_{ij}$  be the lower bound and  $U_{ij}$  be the upper bound on the flow. Let  $c_{ij}$  be the cost of shipping one unit of flow on arc  $(i,j)$  and  $p_{ij}$  be the multiplier on arc  $(i,j)$ . Let  $b_i$  be demand when negative and supply when positive at node  $i$ .

Each arc in a generalized network represents a variable and each node represents an equation. Let  $A$  be the set of feasible arcs in a network. The general mathematical program can be written as

$$\text{minimize } \sum_{(ij) \in A} c_{ij} x_{ij}$$

$$\text{Subject to } \sum_{(ij) \in A} x_{ij} - \sum_{(ij) \in AP} p_{ij} x_{ji} = b_i \quad i = 1, 2, \dots, m$$

$$0 \leq L_{ij} \leq x_{ij} \leq U_{ij} \quad (i,j) \text{ in } A.$$

Inequalities are handled by the use of singleton arcs. Singleton arcs are especially useful to model indefinite supplies and demands.

Different nodes would be used to represent currency and production resources in both the parent and each of the subsidiaries. Arcs are used to represent direct transfer of cash and product between different nodes, and the conversion of cash to product and vice versa.

### III. USE OF IGNS

IGNS is illustrated using an example problem. Selected screens from the system are presented to indicate how the system would be used to build and solve the example problem.

#### A. Example Problem

In order to illustrate IGNS, the example problem presented in Crum and colleagues (1983a) will be built. This example problem taken from the open literature (a paper on the strategic management of multinational companies) is small but captures the essence of the relationships and concepts being presented. A larger model might be more realistic but harder to grasp and present in a short paper. IGNS (with current enhancing extensions) is perfectly capable of building and solving very large and complex models. The current solver being used routinely solves logistics problems for a multinational company with more than 600,000 nodes and 7,000,000 arcs, see McBride (1996a). In our example problem there are a parent and a subsidiary. There is also a product that is converted into cash. Further, foreign currency can be converted into U.S. currency. The example is summarized in Figure 1, where nodes  $i$ ,  $g$ , and  $k$  illustrate currency and nodes  $j$  and  $h$  illustrate product. Nodes  $i$  and  $j$  are at the subsidiary and nodes  $g$ ,  $h$  and  $k$  are at the parent.



There is a supply of cash (10 units) in the foreign currency at the subsidiary, node  $i$ . There also is a supply of cash (5 units) in U.S. currency, at node  $g$ . There is a supply of product at node  $h$ . Node  $j$  has neither an excess or deficit inventory situation. Node  $k$  has a demand for up to 35 units of U.S. currency. Thus, there are supplies and demands for multiple commodities, and allocation decisions must be made.

The arcs indicate the feasible ways that cash product can be transferred from one node to another node. If there is no arc then that indicates that there is no direct transfer between the nodes. Since there is an arc from node  $i$  to node  $g$ , this means that foreign currency can be translated into U.S. currency. Similarly, an arc from node  $j$  to node  $h$  means that product can be transferred from subsidiary to parent.

There are three paths through which foreign cash can be translated into product in the United States. First, foreign currency can be used to generate product in the foreign country, which is then shipped to the parent, ( $i \rightarrow j \rightarrow h$ ). Second, foreign currency can be used to generate product in the foreign currency, which is sold in the United States and then transferred to product in the United States, ( $i \rightarrow j \rightarrow g \rightarrow h$ ). Third, foreign currency can be transferred to the United States and then transferred into product ( $i \rightarrow g \rightarrow h$ ).

## B. Building and Solving the Problem

Building and solving the example is facilitated using IGNS. This section will summarize the process used to build the example in Figure 1.

First, the user either uses an existing model via the "File" menu or the user must generate the model from scratch. When creating a new model the user begins by creating the node sets (Figure 2) using the "Node Sets" option in the "Create" menu. For illustration purposes, it is assumed that the user will create the model. In this example there are two sets "cash" and "product." The "cash" set has members  $\{i, g, k\}$  while the "product" set has members  $\{j, h\}$ . Here the names  $i, g$ , and  $k$  are given by the user to maintain consistency with Figure 1. However, the system will generate names if the user wishes to use this option.

Second, the arc sets must be generated using the "Arc Sets" option in the "Create" menu. The system generates arcs between the two (sub)sets of nodes which the user specifies to build cross product and 1-1 mappings. In a cross product mapping an arc is created from each node in the first set to every node in the second set. In a 1-1 mapping an arc is created from each node in the first set to the corresponding node in the second set (both (sub)sets must have the same number of members to use the 1-1 mapping). In Figure 3, the arc set "make\_product\_" is being developed. One arc is created in this arc set, from the subset "cash (2-2)", node  $g$ , to the subset "product(2-2)", node  $h$ . Thus, the arc set consists of the arc from node  $g$  to node  $h$ , where the product is made in the United States "cash(s-t)" means the subset of the set "cash" starting from the  $s$ 'th node and ending with the  $t$ 'th node in the

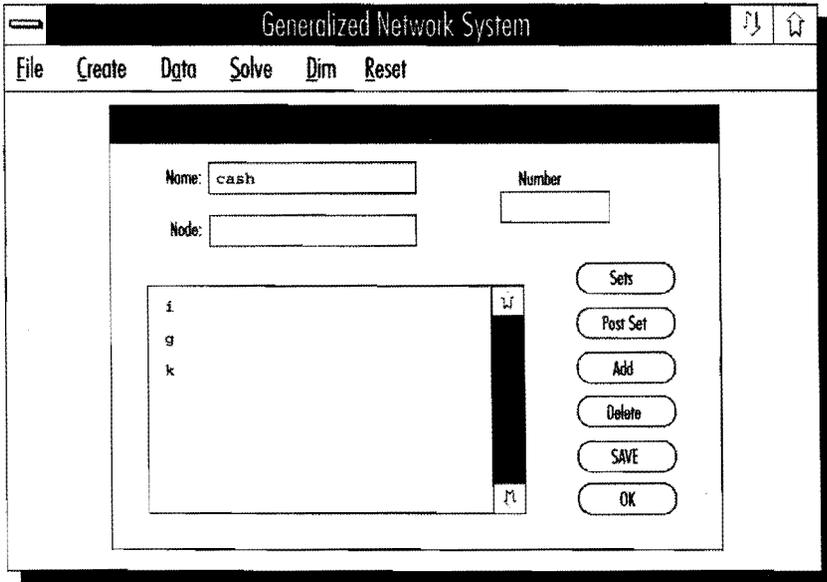


Figure 2.

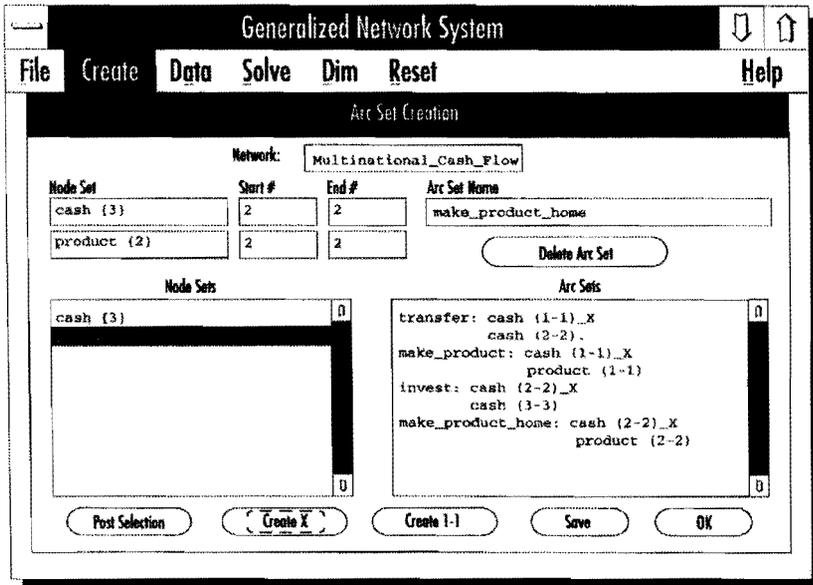


Figure 3.

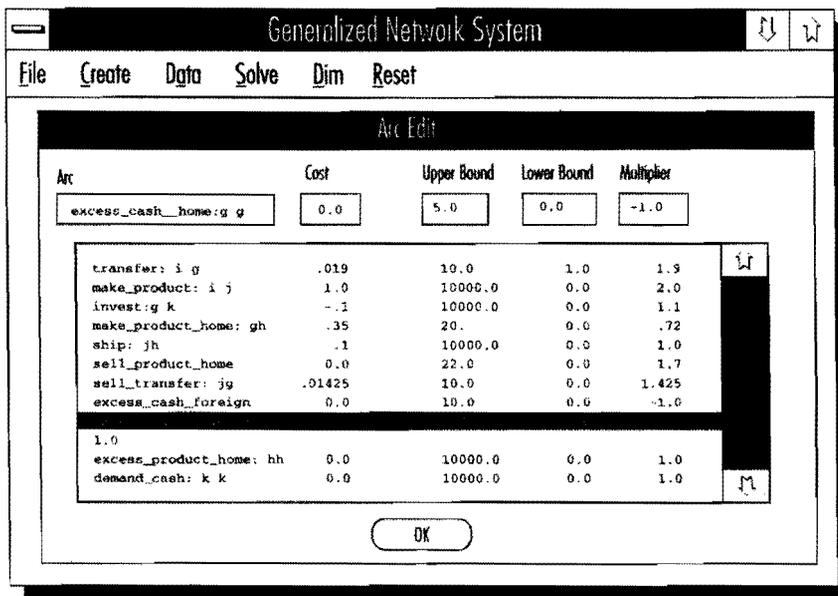


Figure 4.

set. The way subsets are defined has been generalized so that arbitrary subsets can now be defined (see Section V).

Third, data contained in the 4-tuple  $(c_{ij}, U_{ij}, L_{ij}, p_{ij})$  must be entered into IGNS if the data values differ from the default values (see Section IV.C for a discussion of the default parameters). This is illustrated in Figure 4. Once the data is entered then using the "Arc Data" option in the "Data" menu, the data can be edited using the same option. The entering of data has been greatly expanded to include reading from databases (see Section V).

Fourth, the system checks for feasibility and then solves the problem using the "Solve" command. The solution provides the flow and reduced costs on those arcs, as seen in Figure 5. In addition, as seen in Figure 6, additional solution information is provided.

### C. Use of IGNS in Multinational Corporate Settings

IGNS could be used in a variety of corporate settings. In the case of multinational planning, generally a model would be developed with substantial care to capture the parent and each of the subsidiaries. In some cases the subsidiaries also could be U.S. firms. The model could then be used to study the flows of product and cash and other assets that are in the model. Typically, the structural model

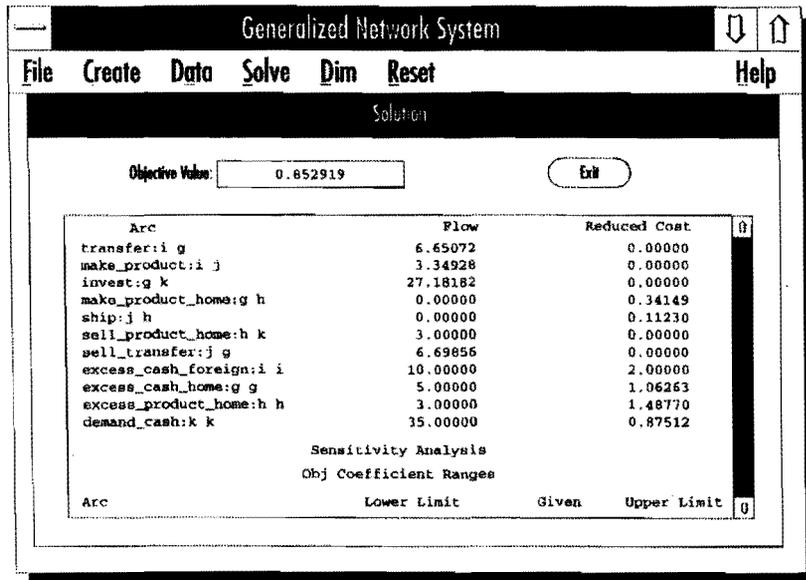


Figure 5.

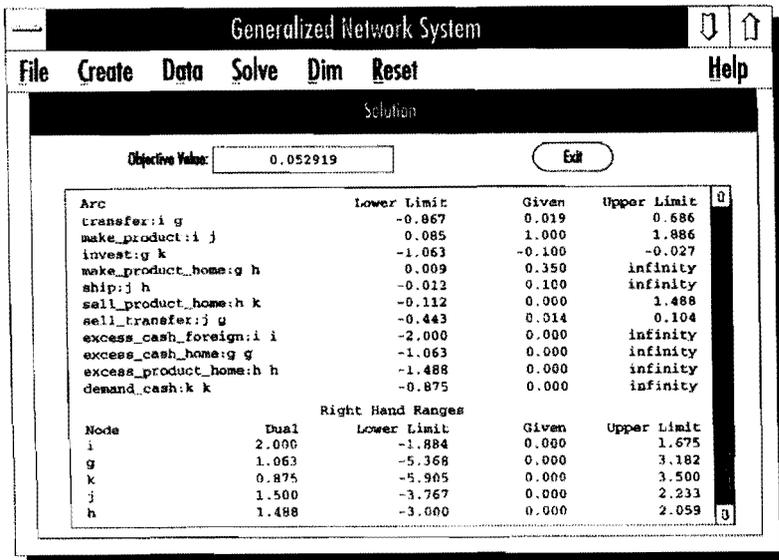


Figure 6.

would be stable, but the data parameters would be subject to fluctuation. As a result, as the data change, such as exchange rates, the model could be quickly updated and resolved in order to facilitate replanning. Here the fast solution times of network related models are a must.

#### D. Hardware and Software

IGNS was developed for a personal computer environment. The system was developed to run using Microsoft's "Windows." IGNS provides a user friendly, mouse-based environment for supporting multinational planners. The system will run on any PC or workstation running any version of Microsoft "Windows."

### IV. IGNS'S KNOWLEDGE OF NETWORK PROBLEMS

IGNS has substantial knowledge about network planning problems. IGNS uses that knowledge to facilitate the planning process by anticipating what the user wants. As a result, IGNS has operations research knowledge to build and debug the model.

IGNS solicits information from the user employing a network model and directly using no mathematical formulations. The IGNS generates a generalized network flow problem, tests feasibility, solves that generalized network flow problem, and provides the user with some interpretation of that network, using sensitivity analysis.

#### A. Different Locations and Operations

IGNS assumes that the firm will group its different type of operations and different locations in different node sets. For example, some nodes could represent cash in different currencies, while other nodes could represent product that is ultimately converted into cash via some conversion process. In addition, cash can be converted from one currency to another.

Once IGNS knows what the particular sets of nodes are, it can rapidly solicit all the nodes necessary requiring only that user provide the subset of nodes in each group. Alternatively, the user has the option of developing and describing each node individually.

#### B. Relationships Between Different Locations and Operations

Arcs establish direct and indirect relationships between different locations and different types of operations, such as cash and production. IGNS allows the user to rapidly define the arcs and direction of arcs, through directional relationships

between node sets or subsets. In addition, the user has the ability to define singleton arcs to model indefinite availability of cash and product supplies and demands.

### C. Default Parameters

Although IGNS attempts to anticipate the user's needs, it is difficult to decide, a priori, default coefficient values. However, IGNS does provide default values. For example, multipliers are set with a value of 1.0, costs are set with a value of 0.0, lower bounds are set to 0.0 and upper bounds are set at infinity (in the current model equals 10,000).

These values are intended to reduce the number of data parameter values the users generally needs to change when building an instance of a model.

### D. Formulation of Problems

IGNS takes the information provided to it regarding the different locations and different types of operations, the direction of flows and data parameter inputs. Using that information, the system formulates a network flow problem that is first analyzed for feasibility and then solved.

### E. Need for Feasibility Knowledge

Users can make errors when constructing a network flow model. For example, users may develop node sets and not develop corresponding arcs, or may develop the arc sets incorrectly. In addition, users may build erroneous parameters into the system, where lower bounds exceed upper bounds. As a result, IGNS automatically does a number of feasibility tests. Those tests include the following:

1. Nodes with supply or demand but no incident arcs;
2. Nodes with leaving arcs capacity less than supply;
3. Nodes with entering arc capacity less than demand;
4. Nodes with arcs only entering, but no demand. (This could result if the user did not create a connecting arc set. This may not cause an infeasibility, so users are only warned and asked if the system should continue to the solver after the remaining checks are performed.);
5. Nodes with arcs only leaving, but no supply. This is similar to the previous check.

If the system finds errors then it provides user friendly messages to the user indicating the problem nodes and arcs and what is wrong.

### F. Solution Knowledge

IGNS takes the resulting, apparently feasible network and solves it. The solution and sensitivity analysis are presented to the user.

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## V. SUMMARY AND EXTENSIONS

This section provides a brief summary of the paper and discusses some extensions.

### A. Summary

Multinational planners face the problem of integrating production and cash generation from multiple subsidiaries on a world-wide basis. Those problems can be couched as generalized network models. This paper has presented an intelligent system that can be used to assist in the planning process by facilitating the use of a generalized network in a user friendly manner. The system guides the users through the process of formulating complex systems in a timely manner. Then the system formulates the inputs as a network flow problem. After examining the resulting network flow problem for feasibility, the system can solve the problem and then present the results to the user.

The user can build a library of models for easy future recall and reuse.

### B. Extensions

There are a number of extensions possible and some have been made. First, the results can be extended to other situations. For example, Crum and colleagues (1983b) develop a network model for analysis of integrated working capital management. That problem considers balancing activities from three relatively separate activities, marketing, production, and finance. Integration of those activities requires simultaneous consideration of intertemporal dynamics, such as, short-run and long-run implications, and cross sectional relationships between the functional areas. Crum and colleagues (1983b) use networks to model temporal and cross sectional relationships. The approach presented in this paper can be extended to that problem.

Second, additional intelligence could be added to the system that is drawn from the particular situation in which the system is being implemented. For example, sets of different organization structures could be developed as templates. This has been done in a new implementation of IGNS called EMSYS, see McBride (1996b). Special templates (screens) have been developed for a typical logistics problem to enter and/or edit its data. The user just clicks on a button to create the flexible logistics model defined within EMSYS. This embedded network flow problem can then be solved within EMSYS or stand alone. EMSYS has the ability to solve network flow problems with general side constraints. The specific side constraints needed for this logistics problem limit plant inventory levels and the use of loading docks.

Third, the current system discussed in this paper uses the basic generalized network model. However, this has been extended to more general forms. As discussed in the previous paragraph, side constraints have been added. The solver has

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been replaced by EMNET, see McBride (1985). EMNET has been shown to be the best code in the world for solving large multicommodity flow problems, see McBride (1996a). The way node subsets are defined has been improved so that arbitrary subsets can be defined. The ability to write to and read from a database has been added. Arc sets can now be replicated to build models that may involve multi-time periods and/or multi-products. Actually, arc sets can be replicated by arbitrary sets that the user can define. Numerous other extensions have been made, see McBride (1996b) for more details.

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