Interactive-Graphic Interfaces for Planning the Transportation and Distribution of Freight

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The development of interactive-graphic systems for the tactical/strategic planning of intercity freight transportation and distribution systems is discussed, with emphasis on the specification of the interactive-graphic interfaces. The requirements, difficulties, and possible ways of graphically representing the various components of the transportation system are analyzed. A number of general solutions to these problems are presented, solutions that are easily adaptable to other related problems. The discussion is illustrated with computer images obtained from an actual rail application.

Freight transportation is one of today's most important activities, not only as measured by its share of a nation's gross national product (which may be quite significant—it accounts for approximately 10 percent of the U.S. GNP), but also by the increasing influence that the transportation and distribution of goods have on the performance of other economic sectors (manufacturing, distribution, foreign trade, etc.). The current economic and regulatory environment "condemns" the transportation sector to economic efficiency, and it also increasingly places the emphasis on the quality of the service offered. Total delivery time and service reliability are increasingly important factors in the choice of a transportation or distribution firm. The forthcoming European and North American free trade zones will have additional impacts on the organization, operation policies, and competitivity conditions in the transportation industry. The constant evolution of this environment requires rapid, but comprehensive, assessments of actual or potentially new situations and of possible ways to adjust to these requirements. A "best" possible answer is normally sought.

Transportation systems, on the other hand, usually have quite complex organizations, involving a great deal of human and material resources and displaying intricate relationships and tradeoffs among the various policies affecting their different components. The planning process of such systems reflects their complexities and generally has an important component of scenario evaluation. Accurate, efficient, and flexible tools are therefore needed to help the planner in his task. A combination of operations research models and computer science techniques may be of considerable help by supplying them.

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The design of such tools, however, has changed recently. For example, systems traditionally required the user to squeeze his problem into predetermined forms, offering a limited range of results and drastically restricting the user's opportunities to intervene in the solution process. Instead of such "black boxes," the present trend is to develop integrated systems where the user is brought right in the middle of the process of defining and solving the problem. Furthermore, he is given the means to easily and efficiently control and direct it. These systems are comprehensive planning tools that integrate sophisticated operations research models and algorithms, large data banks and powerful interactive-graphic interfaces.

Not only has the design of the applications changed, but so has their immediate aim. Thus, these systems do not pretend to find the single, absolute, definitive solution to a given problem. Instead, the system is aimed at offering the planner a large array of means to enter, manipulate, visualize, and analyze vast amounts of data pertinent to a whole class of problems, plus the opportunity to merge the power of operations research methods with his special skills and inside knowledge of the problem. In addition, the planner does not have to worry about tasks that involve programming or data processing. Rather, he can focus on his prime function: investigate, analyze, and decide.

Two major factors have prompted this evolution. On one hand, the major advancements realized in computer science and technology have put tremendous computing power and sophisticated technology in a price range that facilitates their large penetration. We have also realized that, despite undeniable methodological advances, the problems facing us are becoming increasingly complex, requiring the consideration of a variety of policy rules, decision criteria, union conditions, etc., that may not be adequately addressed by traditional operations research or economic modeling techniques, yet are well known to the decision makers. Thus, the integration of operations research methodologies into comprehensive interactive-graphic planning tools offers a most interesting and promising development avenue, one which has already met with considerable success in numerous domains (*1–8*).

For our part, we are interested in the case of the intercity freight carrier, or distribution firm, which may possibly use several transportation modes to move freight of several commodity classes. We focus, in particular, on the issues related to the long and medium-term planning of operations of such a firm.

Models and tools aimed at this problem have been proposed, but the emphasis has been on the methodological, operations research modeling and algorithmic development, aspects of the problem. The objective of this paper is to complement this body of knowledge by looking into the requirements and difficulties involved in graphically representing and displaying the various components of the transportation system of an interurban multimode multiproduct freight carrier, and by presenting the solutions that we propose to these problems.

We start by recalling the main components of a freight transportation system and of the corresponding planning process. We also briefly review the general modeling framework that we have developed for this problem. We then present the main objectives and characteristics of a proposed interactive-graphic planning system. The description of the requirements, alternatives, and selected solutions for the graphical representation and display of the system constitutes the core of the paper. Our method is illustrated throughout the paper by plots drawn from a rail application. We conclude with a discussion on the perspectives and challenges that lie ahead.

FREIGHT TRANSPORTATION PLANNING

General Principles

The underlying structure of any large freight transportation system consists of a rather complex network of large terminals and small stations interconnected by physical (e.g., rail tracks or roads) or conceptual links (e.g., air or navigation lines). Transportation services are usually performed by a large number of vehicles of various types and belonging to several transportation modes that move the freight from one of its nodes (terminal) to another by following the links of this network. Vehicles may move either individually or grouped in convoys such as trains or multitrailer assemblies, and they may sometimes follow predetermined routes and schedules. During the journey, vehicles and convoys may interact with others, thus contributing to and being affected by congestion conditions on the network. These interactions may or may not be controlled by the firm (e.g., rail can be controlled, whereas modes using public routes cannot). In terminals, various operations may be performed on vehicles (classification, convoy formation, etc.) and on freight (classification, consolidation, etc.). The modeling of terminal operations and of their interactions with the rest of the system is a critical component of any comprehensive model of the transportation system. Freight is usually differentiated by commodity group according to physical characteristics, or value, or both.

To control these activities and to make the best possible use of the system's resources, several policies must be defined and implemented. These policies and the associated modeling problems are generally classified into three groups corresponding to the widely used three planning levels: strategic, tactical and operational (*9,10*):

1. *Strategic* (long-term) planning typically involves the highest level of management and usually requires large capital investments for resource acquisition over long-term horizons. Strategic decisions determine the general development policies of the company and broadly shape the operating strategies of the system by deciding upon the design and upgrading of the physical network, the location of facilities, the acquisition of resources, the general definition of service and tariff policies, and so on.

2. *Operational* (short-term) planning is performed by local management, in a highly dynamic environment where the time factor and detailed representations of vehicles, facilities, and activities are essential. Scheduling (timetable generation for service departures, maintenance activities, crews, etc.) and dispatching (vehicles and convoys into, out of, and inside terminals, as well as on the links of the network, when appropriate) are among the most important decisions at this level.

3. *Tactical* planning forms a vital link between the preceding two levels of decision making. It aims at ensuring, over a medium-term horizon, an efficient and rational allocation of existing resources to improve the performance of the whole system. Tactical decisions need to be made concerning the design of the service network (selecting the routes and characteristics of the transportation services that will be offered), the distribution of the traffic of each origin-destination pair in the network with a nonnegative demand, the general rules that specify for each terminal how freight and vehicles are to be sorted and grouped, and the distribution of empty vehicles to satisfy demand and to rectify imbalances in the vehicle availability due to uneven traffic. The output of tactical planning consists of a series of rules and policies that affect the whole system. These rules, which are collected in a transportation (load) plan, are then used to determine the day-to-day policies that guide the operations of the system. The same tactical transportation plan is also a privileged evaluation tool for "what-if" questions raised during strategic planning (*10,11*).

A number of efforts have been made toward the formulation of models aimed at tactical planning problems. The most successful have been the so-called "network models" that take advantage of the structure of the transportation system and integrate policies that affect several terminal and line operations. Important contributions to this field have been made in recent years (*10–19*).

Methodology

We now briefly recall the methodology we use; details may be found elsewhere (*10,20*).

Let $G = (N, L)$ represent the *physical network*, on which transportation activities are carried out. Then, the nodes of the set N mainly represent the terminals, stations and junctions of the network. We identify the set of terminals as Y, $Y \subseteq N$. The set L is the set of links representing the connections between the points in N.

On this network, the transportation demand is defined in terms of tonnage and number of vehicles of a certain commodity c to be moved from an origin terminal o, $o \in Y$, to a destination terminal d, $d \in Y$. To simplify, we refer to the market or traffic class $m = (o, d, c)$ with a positive demand of $g^m = g^m_{od}$ cars to be transported. The set M will identify the set of all markets.

Freight is transported by vehicles, possibly grouped into convoys, that move through the physical network following certain routes and transportation modes defined by the service structure S. A service, $s_i \in S$, has an origin and a destination in Y. Between these two points, it follows a route defined as a set of links that form a path in G and may eventually stop at some of the terminals or stations on this route to drop off or pick up traffic. It is convenient to identify the subpath between each two consecutive stops on the service route as the service leg. When the service has no intermediary stops, as in most trucking applications, the entire service route contains only one service leg. The service is also characterized by its service class, or mode, which defines the transportation mode (e.g., truck size on roads or truck-on-flat car), the speed/priority (e.g., slow- or rapid-moving train), the vehicle type, the vehicle and convoy capacities, etc. Capacities may depend on the physical characteristics of the physical links on its route. Last but not least, each service operates at a certain frequency f_t, specifying how often the service is run during the planning period.

Traffic moves following predefined paths that specify the physical route, the services to use and the terminals where operations have to be performed. For a given traffic-class, one or several such paths may be used, according to the level of congestion in the system and the service and cost criteria of the particular application. One may thus have a physical definition and a service definition of the various product paths. It is more conceptually convenient, however, to define an itinerary for a given traffic-class as a sequence of classification/consolidation terminals, where work is performed on the traffic of the traffic-class, and the respective sequences of services used to travel between two such consecutive terminals. For a given market, $m \in M$, there are several possible itineraries; the set I^m contains them. The volume of traffic that moves on each itinerary $k \in I^m$ is noted v_k^m.

The frequencies and itineraries are the central elements of the model. Fixing the values of the frequencies determines the design of the service network, the level of service and the feasible domain for the traffic distribution problem. On the other hand, the selection of the best itineraries for each traffic-class solves the traffic distribution problem and also determines the workloads and the general classification and makeup strategies for each yard of the system. The model may then be stated as follows:

Minimize $\Psi(v, f)$

$$= \sum_{m \in M} \sum_{k \in I^m} \Phi_k^m(v, f) + \sum_{s_t \in S} \Theta_t(f) + \Pi(v, f) \qquad (1)$$

Subject to

$$\sum_{k \in I^m} v_k^m = g^m \qquad \forall\, m \in M \qquad (2)$$

$$v_k^m \geq 0, \qquad \forall\, k \in I^m, \qquad \forall\, m \in M \qquad (3)$$

$$f_t \geq 0 \text{ and an integer} \qquad \forall\, s_t \in S \qquad (4)$$

where

v_k^m = quantity of flow from the traffic-class m traveling on its itinerary k;
f_t = frequency of service s_t;
v = vector of flows for the whole system;
f = vector of frequencies;
$\Phi_k^m(v, f)$ = total (operating and delay) cost of using the itinerary k for the traffic-class m; the sum represents the "variable" cost of transporting the flow v by a service network operated at level f;
$\Theta_t(f)$ = total (operation and delay) cost of operating the service s_t; the sum represents the "fixed" cost of offering transportation services at level f; and
$\Pi(v, f)$ = special terms modeling specific relations, such as train capacity, performance targets, etc., as "delays."

The objective function principally represents the total system cost: traffic- and itinerary-related costs plus the cost of offering the transportation service. It is a generalized cost, in the sense that both operating costs and service costs (delays, service targets, reliability, etc.) are included. It is at the level of this objective function that the relationships and tradeoffs among the various system and policy components are considered by the combination of the operating costs and the delays encountered by vehicles, convoys, and traffic in terminals and on the lines of the system due to congestion and the operating policies.

The model has the structure of a nonlinear, mixed integer, multimode, multicommodity flow problem, and it is solved by an efficient heuristic algorithm (*20*) based on decomposition, column generation, and "steepest descent" techniques. This approach has been successfully applied to problems from the Canadian (*21*) and French railways (*22*). It has also been adapted with considerable success to the multimode less-than-truckload trucking problem (*16*).

This model is intended as the methodological core of an integrated interactive-graphic planning system called TACTIC (*23,24*). The system combines a data bank together with procedures to access, analyze, and modify it; problem modeling and scenario defining facilities; optimization algorithms and post-optimal procedures; and, most importantly, interactive-graphic capabilities to display and help analyze data and results.

INTERACTIVE-GRAPHIC INTERFACES

Objectives and General Characteristics

TACTIC has a modular structure. Each module is an independent program that performs a specific task. Thus, all data transfers among modules occur exclusively via the data bank. The modular approach has several advantages. It lets the user concentrate on one specific aspect of the problem at a time. It also facilitates the maintenance and the enhancement of the code. The precise characteristics of the system are described elsewhere (*23,24*); here, we concentrate on discussing its graphical aspects. We want, however, to specify some of our major objectives. Specifically, the system aims to offer the decision maker the possibility to:

- Treat the problem globally, networkwide;
- Adjust the model to his problem, not the inverse [he may, for example, specify the cost (delays, reliability, etc.) functions for his particular application];
- Efficiently generate, evaluate, and compare a large number of global operating strategies (he may analyze and evaluate "what if" strategic questions);

• Manipulate a solution until it meets all the unwritten rules and criteria.

From the point of view of the computer implementation, the system offers the following features:

• A stand-alone system, easy to use, that may efficiently run on the current generation of microcomputers and workstations;

• A system where the user may completely define, build, and modify its problem and its network [this contrasts, for example, with the *Princeton Transportation Network Model and Graphic Information System* (*25,26*), which is linked to a representation of the North American transportation network; this implies that, on the modeling side, the user will have the choice among various terminal and line submodels and the corresponding terms in the objective function, while on the network side the system will offer a comprehensive interactive-graphic network editor]; and

• A representation of the data that respects and reflects the "path" structure of most of the elements that make up the transportation system, in particular the transportation services and the traffic distribution (this contrasts with STAN (*7*), for example).

While each of these properties may appear in some systems, to our knowledge they do not characterize any existing system for the strategic or tactical planning of operations for intercity freight carriers.

At present, the graphical procedures are implemented for use on any terminal of the Tektronix 4010 and 4110 series. Any output displayed on the screen may be copied by using the Tektronix 4631 hard copy unit. The output displayed on a Tektronix color terminal may be drawn by using the Tektronix 4696 ink jet color printer. We also make use of a plot file to store the image for further usage (e.g., sending it to a laser printer). In order to increase the portability of the system, drivers for EGA and VGA cards will also be developed.

The code is written in the C programming language. The choice of C is mainly due to the efficiency of the code it produces and to the control of complex data structures (in contrast to FORTRAN) and the manipulation of memory addresses (in contrast to Pascal) that it offers. Another advantage is its portability, since, although C exploits all the capabilities of its host computer, it is independent of any particular machine architecture. For example, we have successfully compiled our graphic procedures on three different computers: the Sun-3 system (operating under Unix), an IBM-AT compatible, and an IBM-XT equipped with a DSI-32 coprocessor board (operating under DOS) without having to make any modifications.

An important aspect of TACTIC is the graphic kernel it uses. According to the choice of the programming language, we wrote a new graphic library in C specifically aimed at network representations (*27*). This library also contributes to the portability of the system, since we control all the codes.

Another important decision in the development of a graphic system is the use of color. Color-enhanced computer images are very attractive, and color may help to distinguish objects. On the other hand, a large number of black and white terminals do exist and are in use. Moreover, the definition of the color set is specific to each terminal. Thus, in defining color tables some degree of portability may be lost if each color receives a particular signification. We therefore adopt a simple solution: when color is available, we use it only to distinguish among elements, without assigning any specific meaning to a particular color; in absence of color, only geometrical symbols and line patterns are used.

The remainder of this paper is dedicated to presenting the difficulties inherent in an efficient graphical representation and display of the various elements that make up the transportation system, and of the approach that we have developed in order to address them.

The Elements to Display

When building or analyzing a transportation plan, several different elements have to be considered simultaneously. These elements are related to (1) the physical network, (2) the service structure, and (3) the freight distribution. Each element has both a set of characteristics (e.g., the length of a link) and a set of results that describe the state of the system (e.g., the link flows). Furthermore, each result may be analyzed according to several different attributes (e.g., the link flow by commodity group or by traffic-class). Note that results may be obtained either from an optimization procedure, a manual solution, or from actual or historical data. The following is an enumeration of the various elements that make up the system, with their main characteristics and attributes that influence the requirements and possibilities of their graphical representation and display:

1. Physical network—

• *description*: nodes and links with their identification (numerical, alphanumerical, or both), type (e.g., single or double line, breakbulk, or end-of-line terminal), physical characteristics, user data, etc.;

• *utilization*: total flows of freight, vehicles, convoys, etc.;

• *result analysis*: see Table 1.

2. Service network—

• *description*: physical route, service segments, intermediary stops, mode or service type, service performance measures (in terms of service targets, delays, reliability, etc.);

• *representation*: physical (the actual routes through the network are displayed) or conceptual (only the service arcs are represented); the display may be by individual service, by origin/destination pair, or the whole network;

• *utilization*: frequency, total and marginal costs;

• *result analysis*: see Table 2.

3. Freight traffic—

• *representation*: demand by origin/destination matrices and aggregations; movements by itineraries, which may be drawn on the physical or service network and may identify working terminals, blocks, services;

• *utilization*: volumes, measured in tons or vehicles, and total and marginal costs (delays, reliability, etc.) for each itinerary or for the traffic-class;

• *selection*: by traffic-class, origin/destination pair, commodity group, etc.

This enumeration, although not exhaustive, covers the main possible applications. Note that not all combinations apply to all applications. We have looked, however, for general solu-

TABLE 1 RESULTS ANALYSIS—PHYSICAL NETWORK

Element	Results	Attributes
Links	Convoys	Mode or service type
	Tons Vehicles Blocks	Commodity group Mode or service type Traffic-class
Nodes	Convoys by mode or service type	Created Terminated Passing through
	Blocks, vehicles, tons by Origin, destination, commodity group, traffic-class, mode or service type.	Originating Terminating Classifying Transferring Passing through

TABLE 2 RESULTS ANALYSIS—SERVICE NETWORK

Element	Results	Attributes
Service arcs	Tons Vehicles Blocks	Traffic-class Origin/destination pair Commodity group

tions that may easily adapt to the particular requirements of each application.

The remainder of this section is dedicated to the analysis of the graphical representation of these elements. We illustrate our discussion with several computer images, originally drawn in color, from a real Canadian railway application (*20*).

Representation of the Physical Network

A drawing of the physical network is shown in Figure 1. The details on the central part of the network, representing the western provinces of Canada, are not distinguishable. By zooming in on this part of the image (this action is called making a "window"), we produced the more detailed representation in Figure 2. On this image, each type of node is represented by using rectangles and circles of different sizes and colors, the choice of which depends on the user. There are two link types in our application: simple and double rail tracks. In order to represent these, we use different colors and line patterns. Note that the terms used in the legend to indicate the node and link types (terminal, single line, etc.) may be customized, depending on the application, by interactively modifying the data bank. Graphical attributes (e.g., colors, line patterns, geometric symbols) used to display the network may be modified at any moment during an interactive session.

In the lower left corner of Figure 2 appears the "skeleton" of the network that is drawn. This feature has to be asked for by the user, and it indicates which part of the network is currently plotted. This feature may also be used to select a new window that is not adjacent to the current one. Physical characteristics of nodes and links can be interactively inspected by pointing (by using the crosshair cursor or a light pen) the desired element. Then, the information appears immediately in a small box. The box position is also determined by the user. This technique for examining data is elegant and very useful, and we use it in other contexts as well (see the following sections). To our knowledge, these two graphical features are unique to TACTIC.

Figure 3 illustrates the display of total freight on links through the use of bars and, possibly, numerical values. The display of similar information on nodes, by using circles, is shown in Figure 4. As usual, hatch width and scale may be interactively modified during the session, as well as the size and contents of the node boxes.

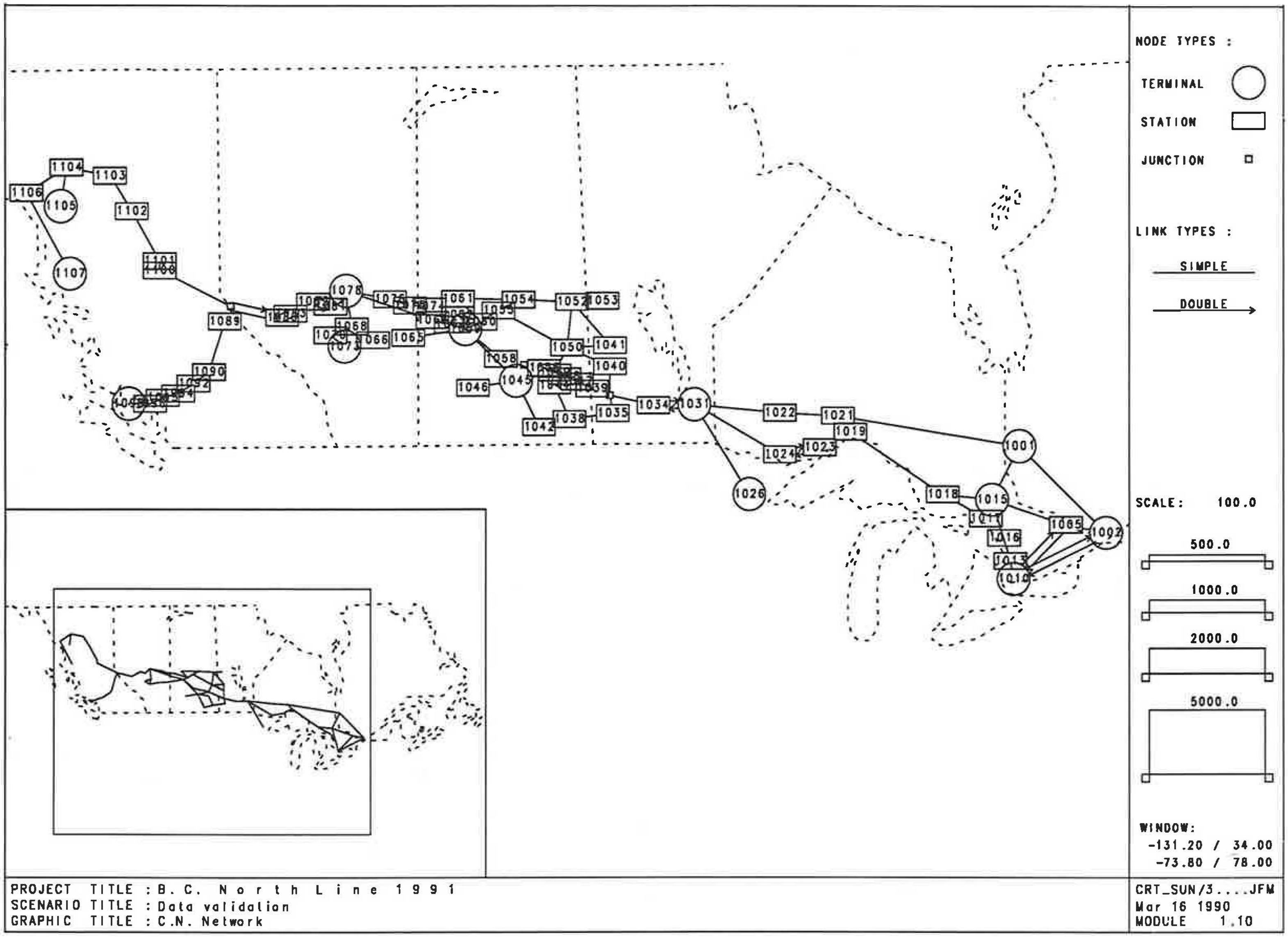

FIGURE 1 Representation of the physical network.

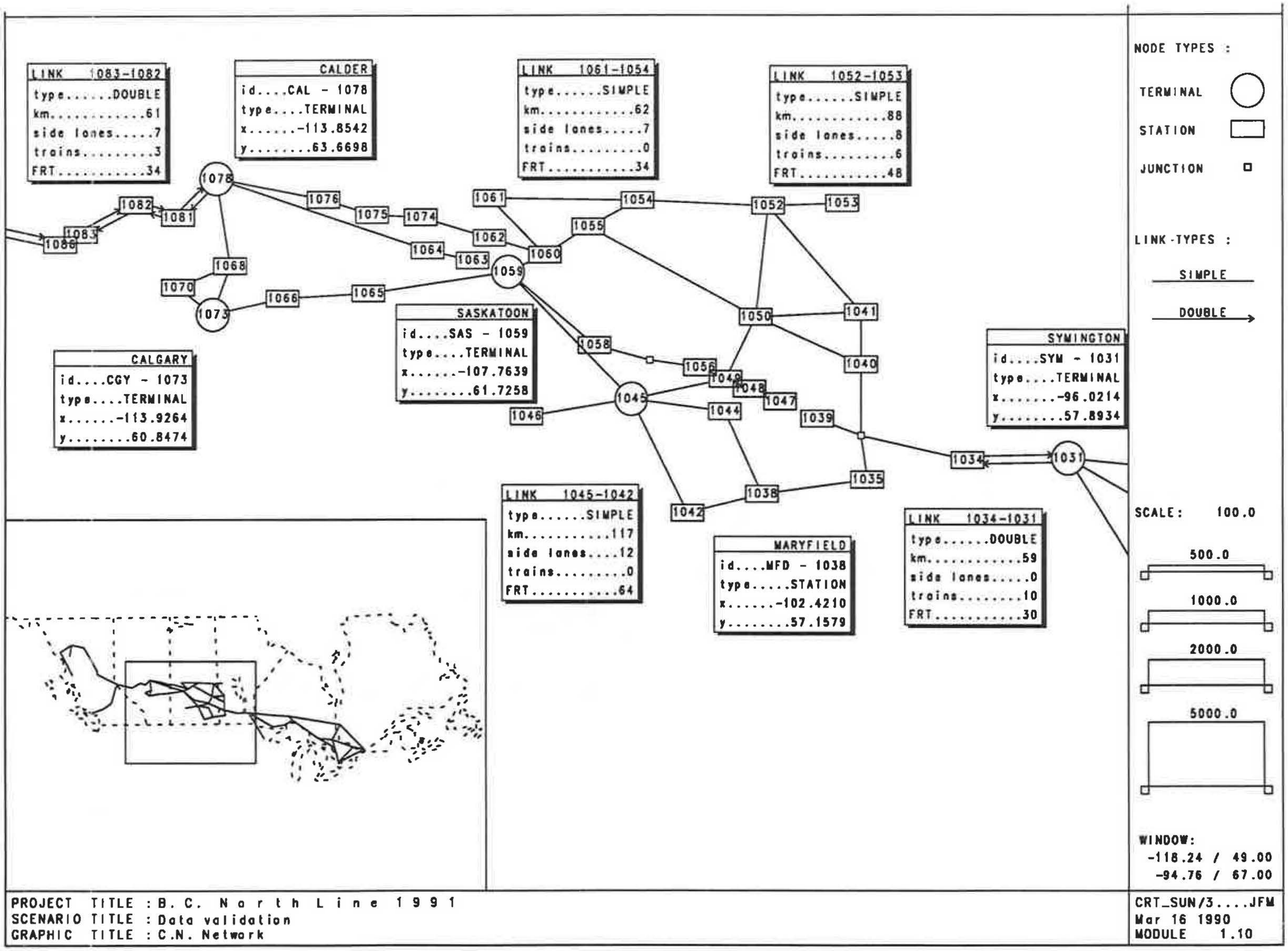

FIGURE 2 Physical network and characteristics.

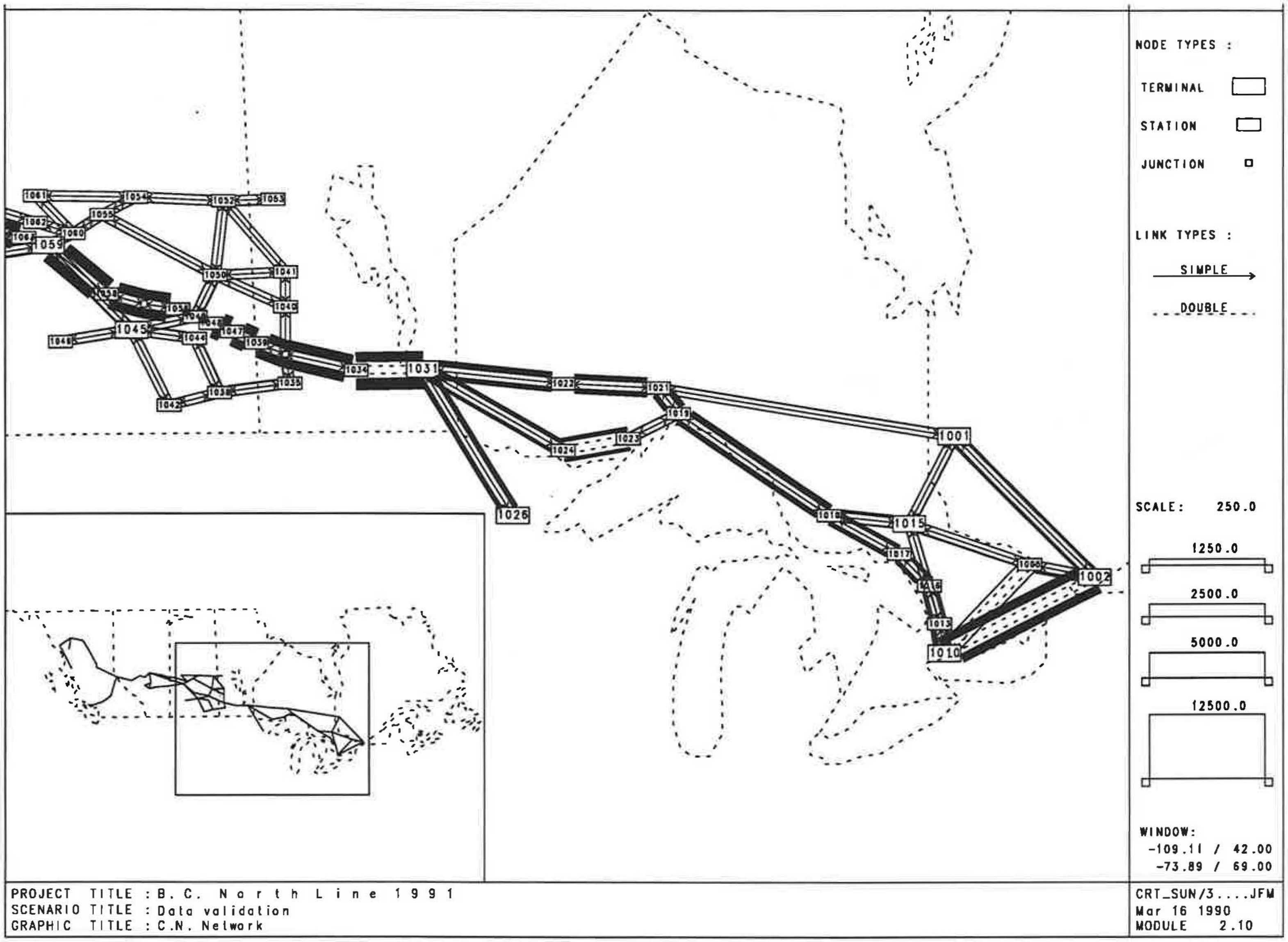

FIGURE 3 Volumes on rail links.

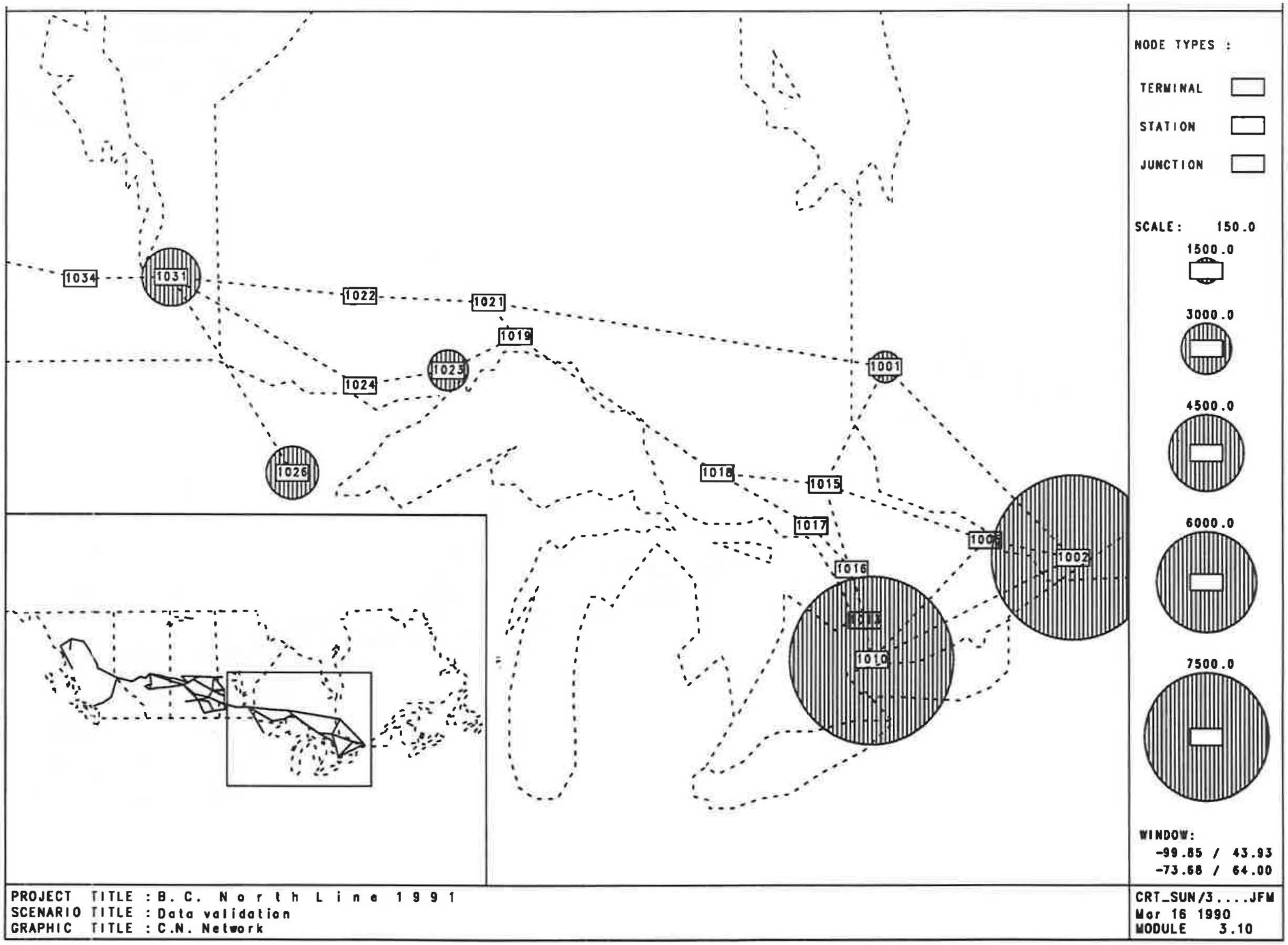

FIGURE 4 Volumes at nodes.

Result Analysis

One of the main problems one is faced with, when contemplating a way to display "results" on networks, is how to obtain a clear representation of the distribution on each element (link, node) of the network, of one or more results, each with several attributes. The problem is not trivial, because there may be a relatively high number of cases for an attribute (in our application, we had to take into account some 30 different commodity/vehicle groups), while networks may be quite dense. To our knowledge, no tactical or strategic planning tool currently allows the graphic display, on a network, of more than one measure at a time.

We first examined the graphical representation of one result-attribute combination on an element, namely a link. An example of such a requirement is the representation of the number of vehicles, per commodity group, using the link. Two solutions caught our attention. The first, illustrated in Figure 5, plots the histogram of the attribute on each link in both directions, if necessary. Unfortunately, the sharpness of the image deteriorates rapidly when the number of possible cases (values) that the attribute may take increases, or when there are several arcs adjacent to the same node, or when links are (almost) parallel.

The second approach, illustrated in Figure 6, uses color. We associate to each link a band, divided into as many sections as the number of cases of the attribute. Then, the color in each section indicates the intensity of the corresponding attribute value. This solution has the advantage of using less plotting space, due to the fact that each bar has the same small width. However, this technique requires a color monitor, since the utilization of filling patterns of variable grey shading, instead of color, is equivalent to the preceding solution, where the quality of the representation deteriorates with the number of possible values for an attribute. Thus, the use of color limits the portability of the system. Besides, it may be difficult to make the color intensity proportional to the attribute intensity, which is easy when using histograms. This may affect the precision of the display.

We also examined a number of ways to simultaneously plot two or more combinations of result-attributes on a network element. An example of such a case is the plotting of the

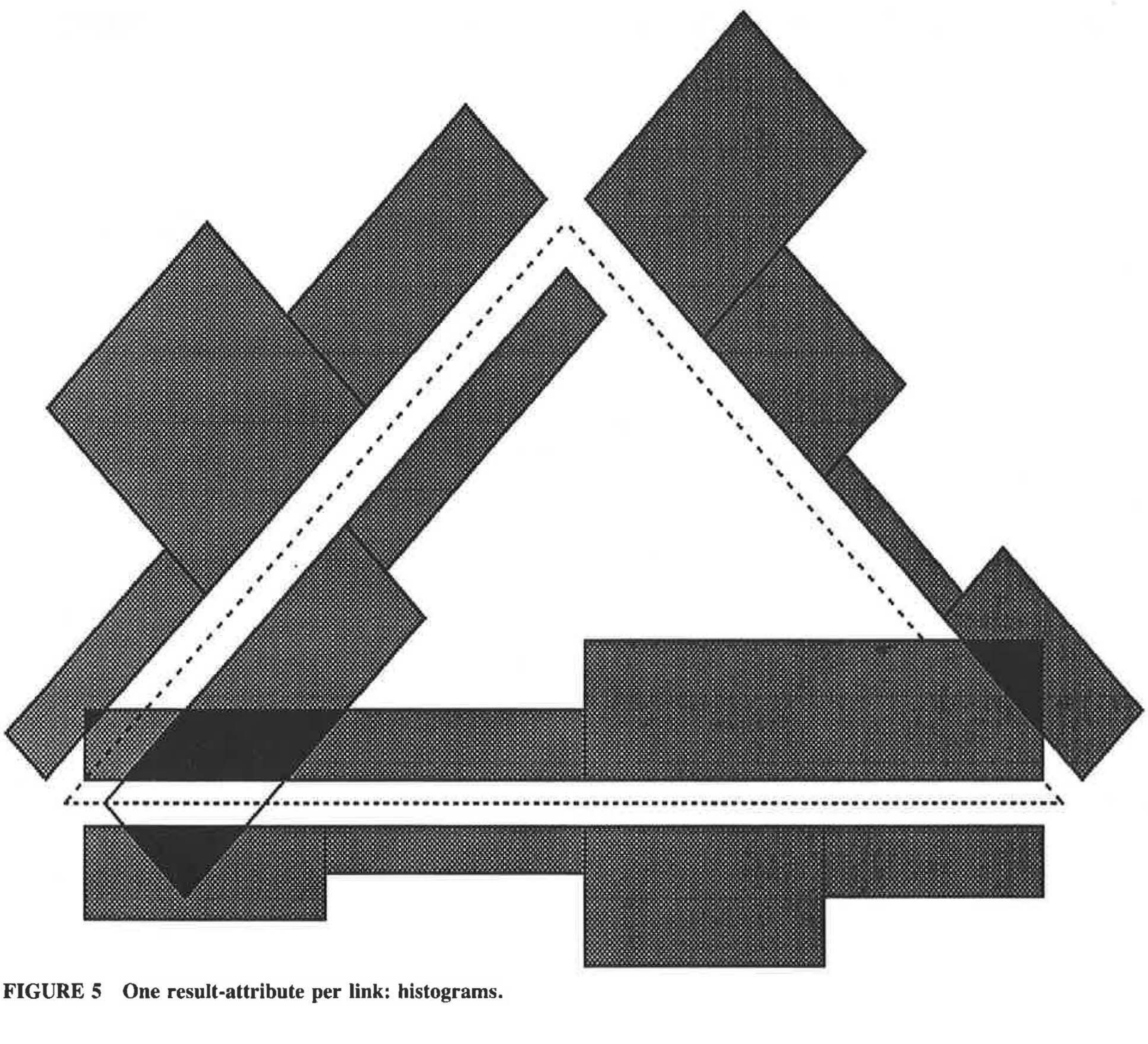

FIGURE 5 One result-attribute per link: histograms.

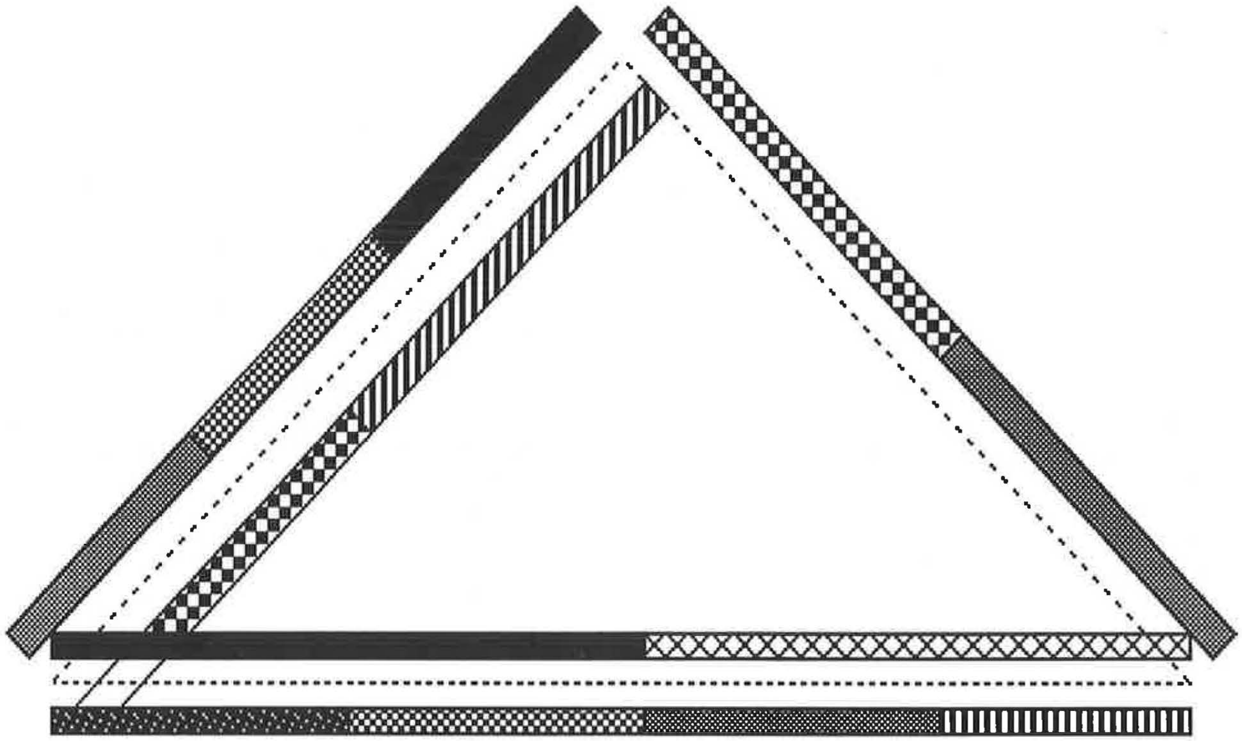

FIGURE 6 One result-attribute per link: color.

number of vehicles and of the number of blocks per service type that use the links of the network. Here are some of these possibilities:

- Three-dimensional histograms (appropriate only for two combinations at a time—see Figure 7);
- One color band for each combination; and
- Simultaneous screen copies of the network, each showing one combination.

Each of these alternatives presents a number of advantages, yet none is really acceptable. Most are not appropriate for the simultaneous plotting of several result-attribute combinations, and some restrict the portability of the system. They all result in unreadable screens when the quantity of data increases.

We therefore had to adopt the following solution, illustrated in Figures 8–10: represent only one combination of result-attribute per element at a time, by using histograms (and color when available), but plot several such combinations per screen or per page. The user chooses the elements and the combinations of results and attributes that he wants displayed, and the number of such combinations to be displayed on each page. Figure 8 illustrates one variant of this approach, where the maximum number of combinations that may be plotted on the same screen is fixed (here, for reasons of clarity, it has been fixed to four). Depending on the particular application and on the equipment used, this number may be easily modified. It is also quite easy to allow the user to determine this maximum number, (*3,7*), or even to completely control the composition of the screen (see Figures 12 and 13).

A second variant of this approach, similar to the method adopted for the display of the physical network, consists in working directly on the network. This approach is illustrated in Figures 9 and 10. Here, the user graphically selects an element, then chooses the result and attribute he wants plotted and, finally, points the position on the screen where the information has to be displayed. This second approach is very simple to implement and it is general, in the sense that it may successfully be used for the display and analysis of all the elements of the problem: physical network and results on network elements, services and itineraries.

Path Representation

In the physical network, a service is characterized by an origin, a destination, a link path connecting these two terminals, and possibly some intermediate stops on the route. The representation of services is similar to the display of bus lines (*3*).

Services often use the same physical links. Thus, it is necessary to use a rather complex mechanism to shift the representation of "parallel" services in order to clearly identify each one. Additionally, we have to identify intermediate stops and service legs and, to do so, we use special symbols to represent nodes. Figures 11–13 illustrate these features: stars represent intermediate stops, while small squares represent nodes that are bypassed on the route.

An image becomes rapidly incomprehensible when the number of services plotted on the same screen is too large. When this is the case, we let the user divide the screen into zones and plot one service per zone. The user is completely in charge of the image composition and is responsible for its quality. He may thus maximize the utilization of the visualization area. Figures 12 and 13 illustrate this feature. This approach is more efficient when the graphic terminal allows the selective erasing of the screen.

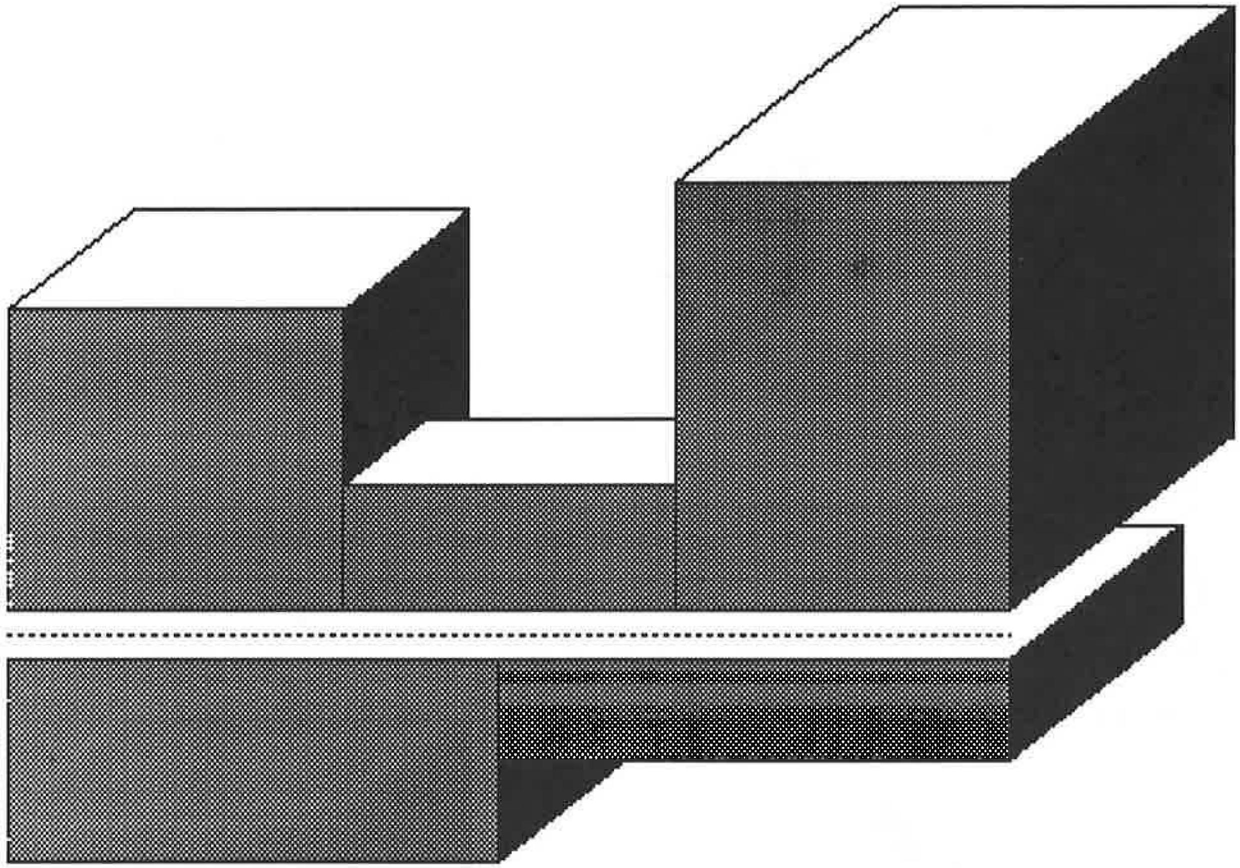

FIGURE 7 One result and two attributes per link: histograms.

Figure 14 illustrates the detailed representation of a service and of its utilization. Color and geometric symbols are used to identify elements of particular interest: circles for the origin and destination, dark-blue boxes for the intermediary stops, light-blue boxes for the other nodes on the service route, etc. All these characteristics are specified as module parameters that may be modified by the user. The descriptions of the service and its components are indicated in small boxes, interactively requested by the user and positioned on the screen by following his indications. Total flows on the service arcs complete the display. Detailed result-attribute analyses may also be added by using the same approach described above for the physical network. Finally, the origin and destination terminal of the segment are indicated on the skeleton network.

Itineraries used to move the freight of traffic-classes display structures very similar to those of services: an origin and a destination, both terminals in the network; a series of intermediate terminals where work is done on traffic, on vehicles, or on both; and service leg paths (doubled by link paths) connecting these terminals. The requirements for representation and display of itineraries are therefore similar, and the solutions we adopted use the same principles. Figures 15 and 16 illustrate the application of these ideas to the display of itineraries. Here, only the arcs of the service structure (i.e., the service legs) are identified, but their illustration follows the pattern of the physical network. Nodes that play a special role are identified by color and geometric symbols. In this application, special nodes are the origin, the destination, and the yards where classification or transfer operations occur. Arrows indicate the direction of movement, while the service number is identified on the service legs. Pop-up boxes and histograms, similar to those used for the physical and service networks, are used to describe the characteristics of the traffic-class, the itineraries, their composing elements (terminals, services, etc.), and the distribution of flows.

CONCLUSIONS

Interactive-graphic capabilities, interfaces, and procedures play an increasingly important role in the design and development of comprehensive planning systems for the transportation and distribution of freight. We have identified the requirements and explored the difficulties related to the development of such interfaces and have proposed general and elegant solutions to the problems of graphically representing and displaying the various elements, characteristics and results that make up the transportation system of an interurban freight carrier. These solutions may be used to display results obtained from optimization or simulation models, from actual operations or from historical sources. They are equally valid for representing freight carrier networks or logistic structures for freight distribution firms, at the tactical or strategic planning level.

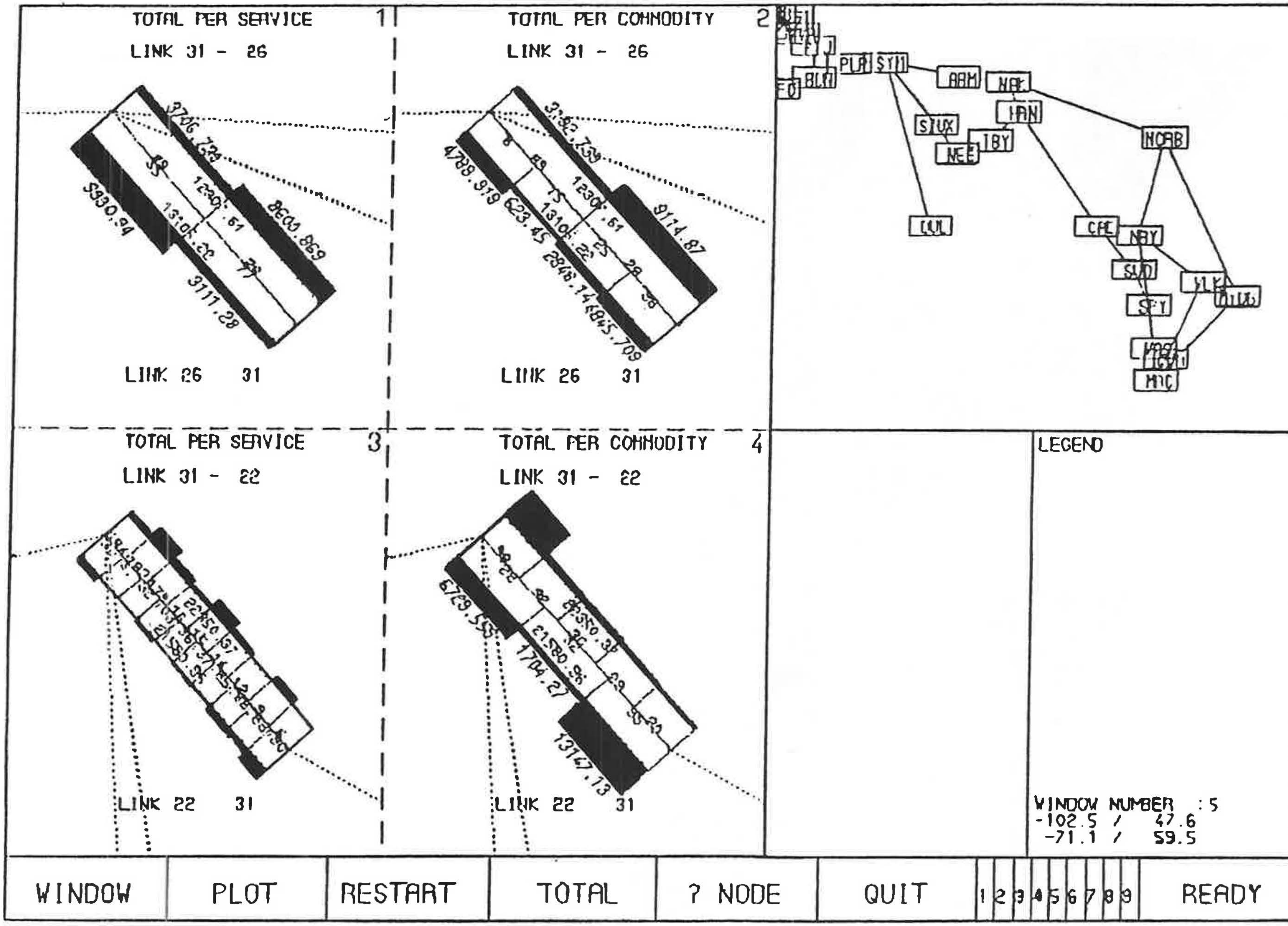

FIGURE 8 Link result analysis—fixed split screen.

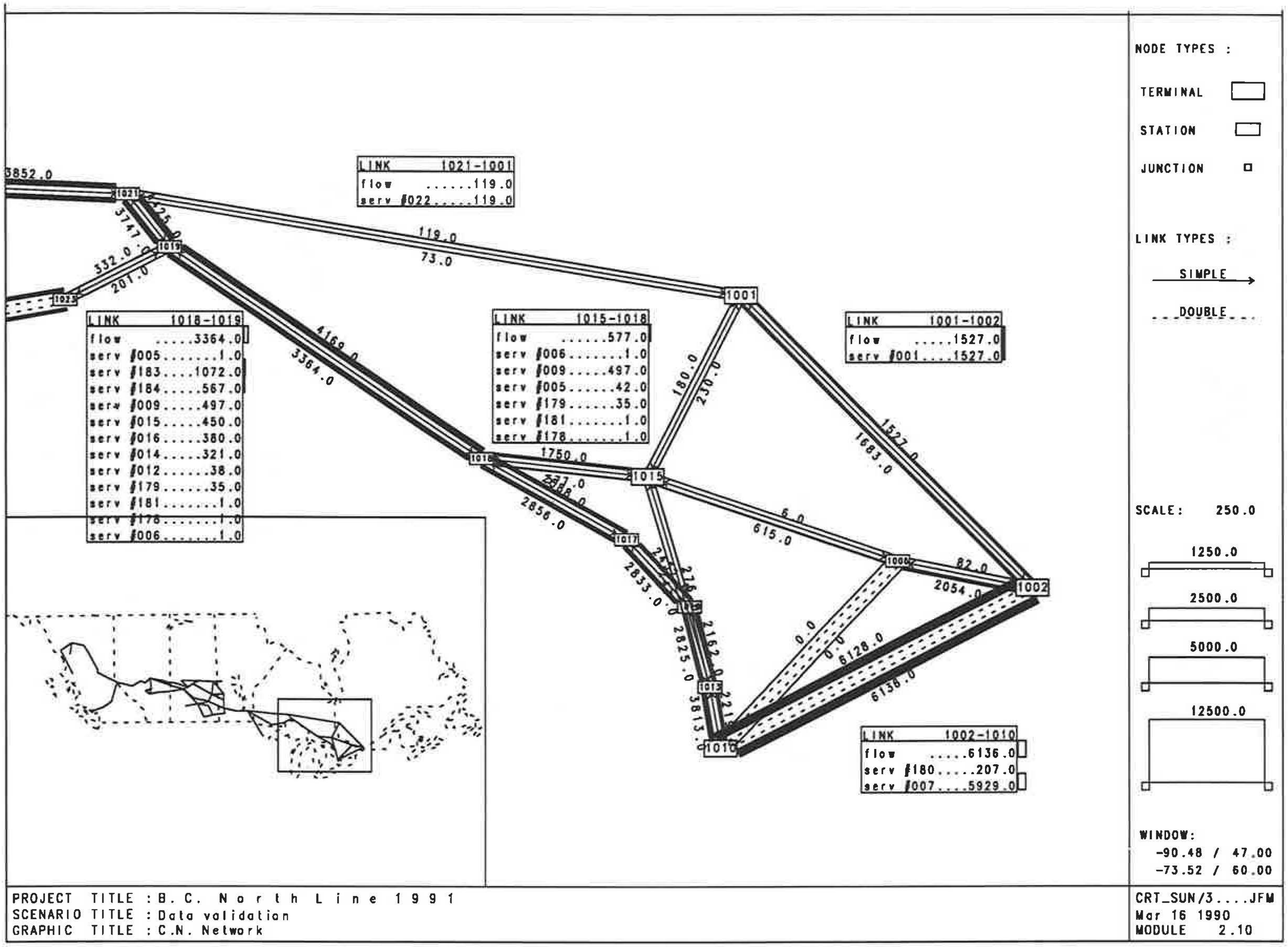

FIGURE 9 Link result analysis—moveable boxes and histograms.

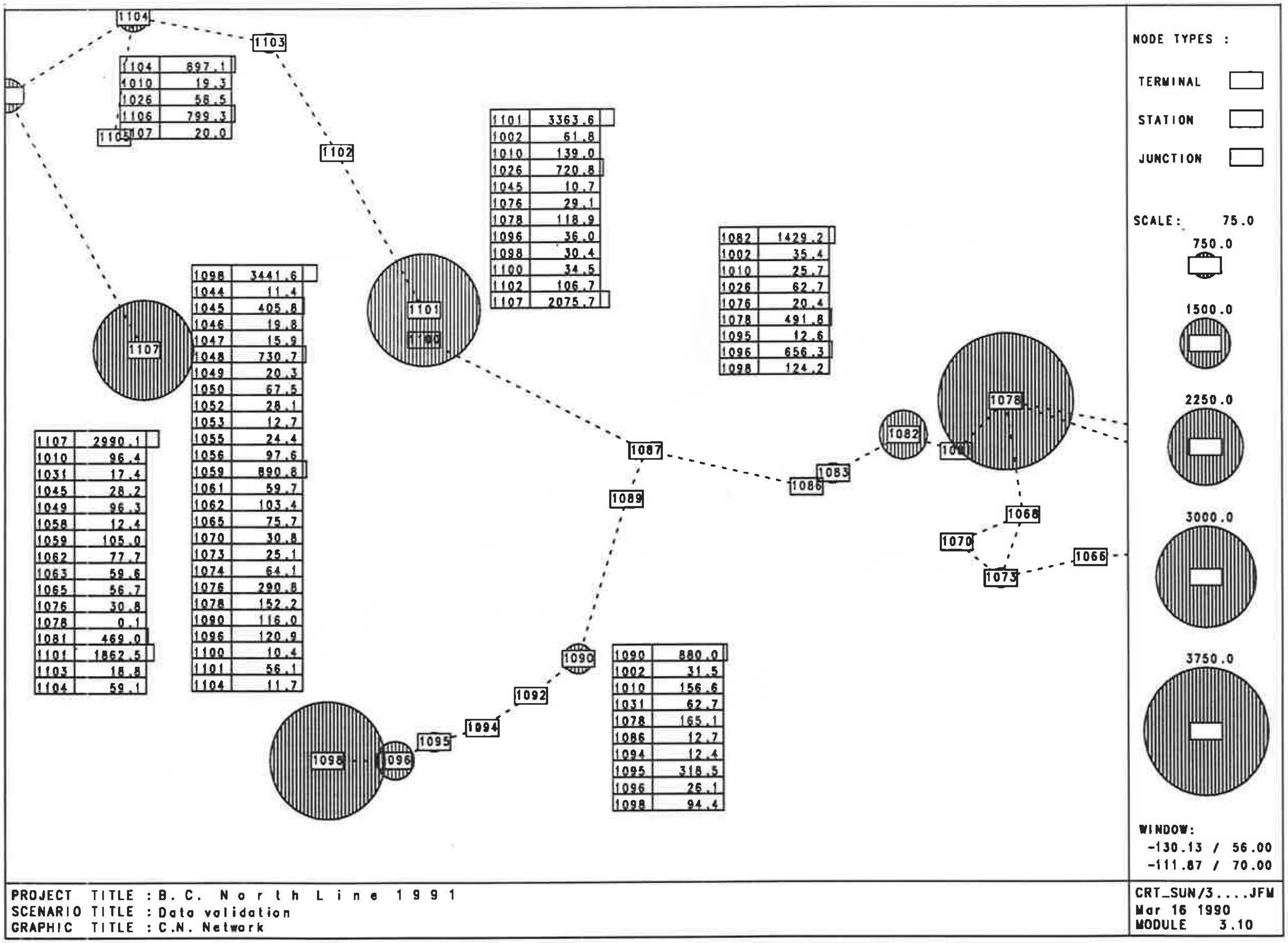

FIGURE 10 Node result analysis—moveable boxes and histograms.

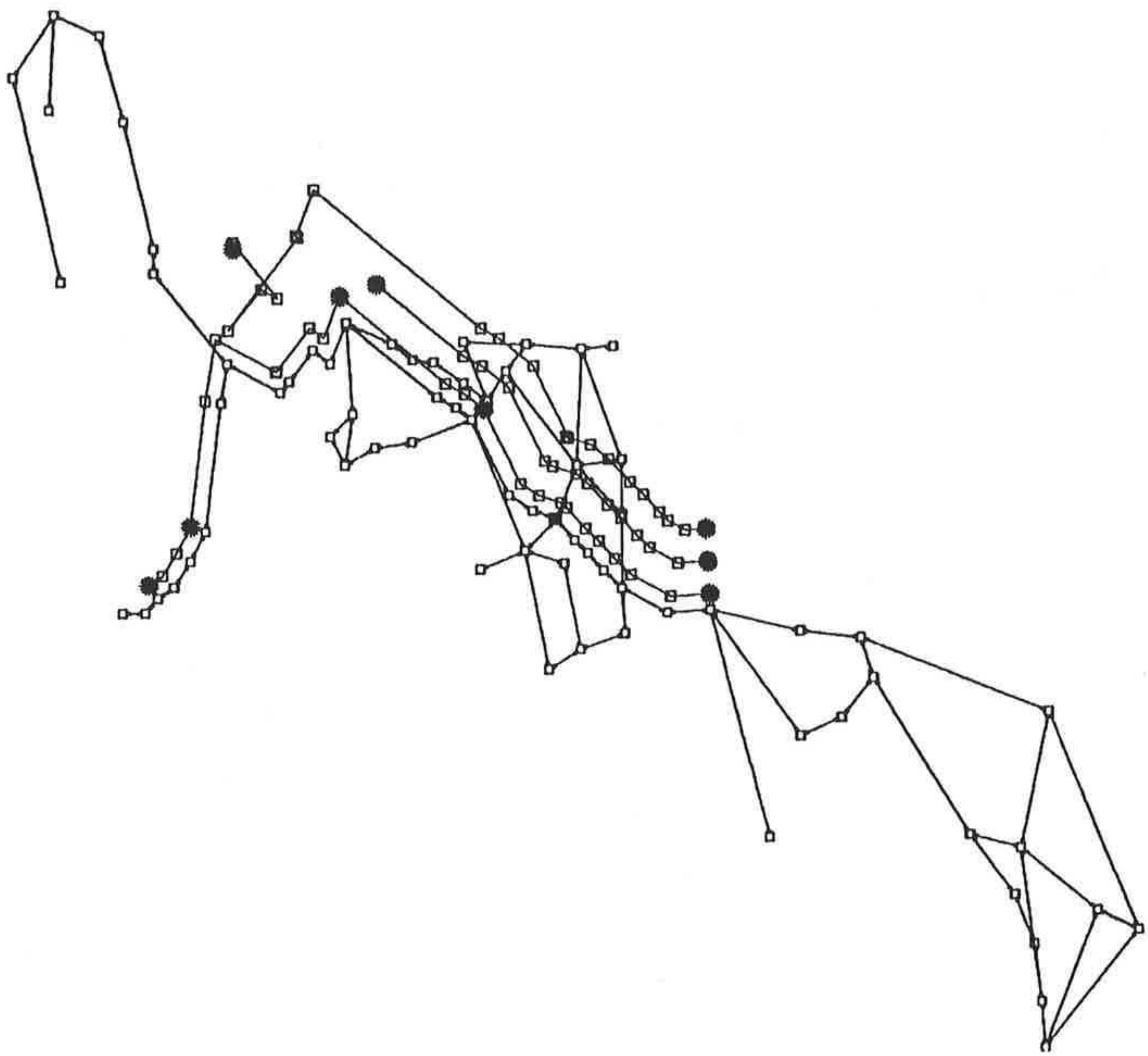

FIGURE 11 Plot of several services on the physical network.

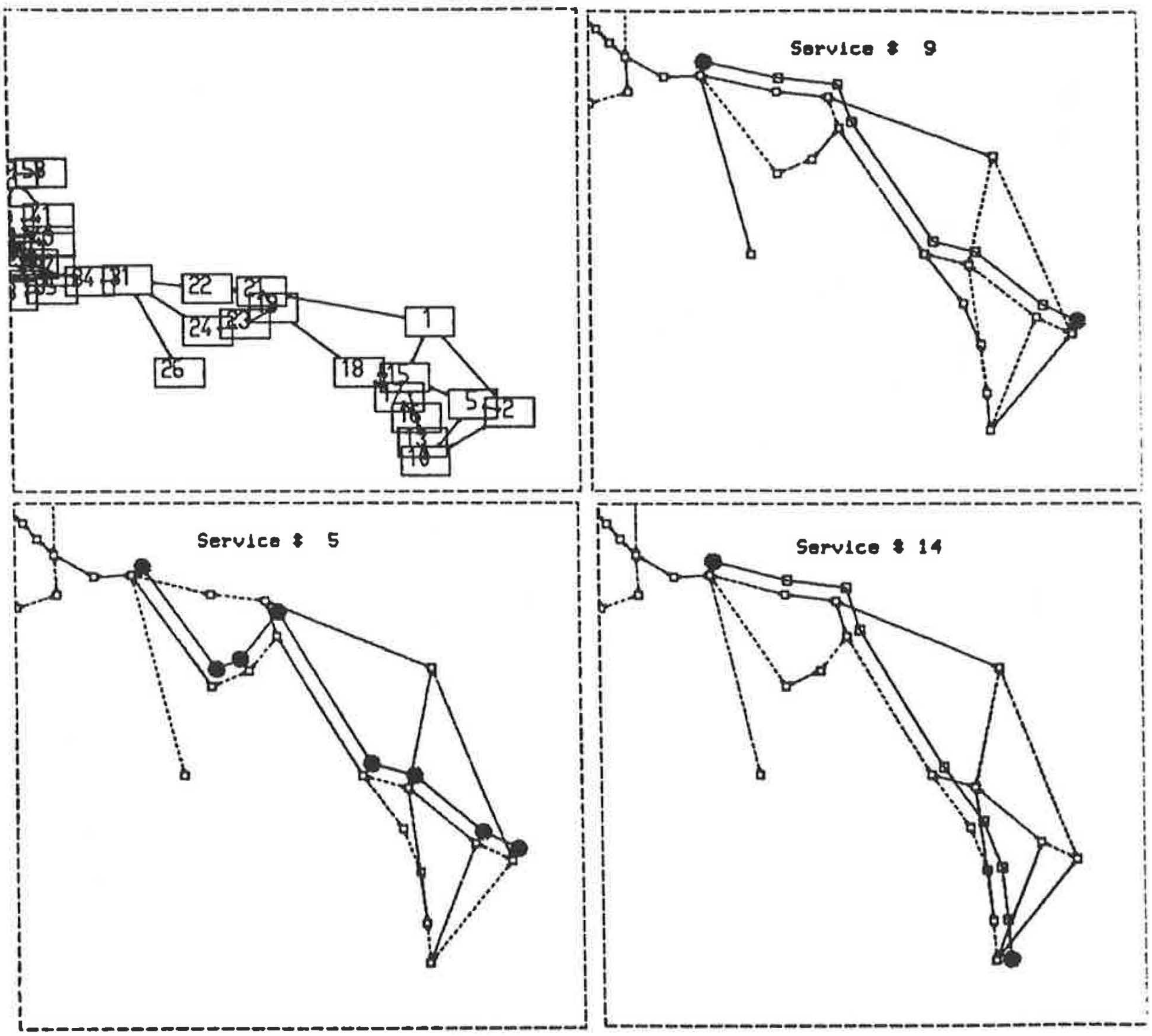

FIGURE 12 User-controlled screen composition—service representation.

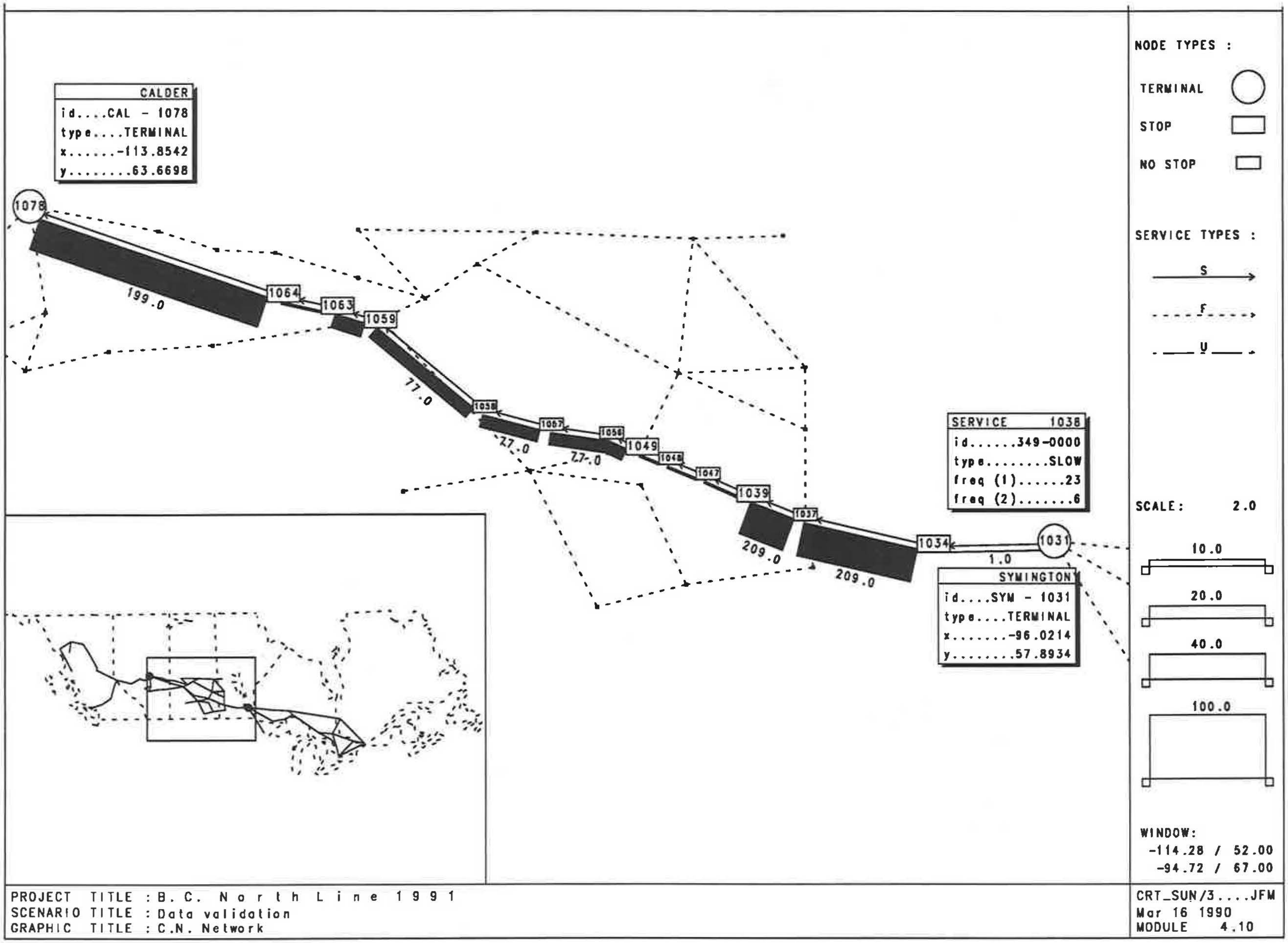

FIGURE 14 Detailed service analysis.

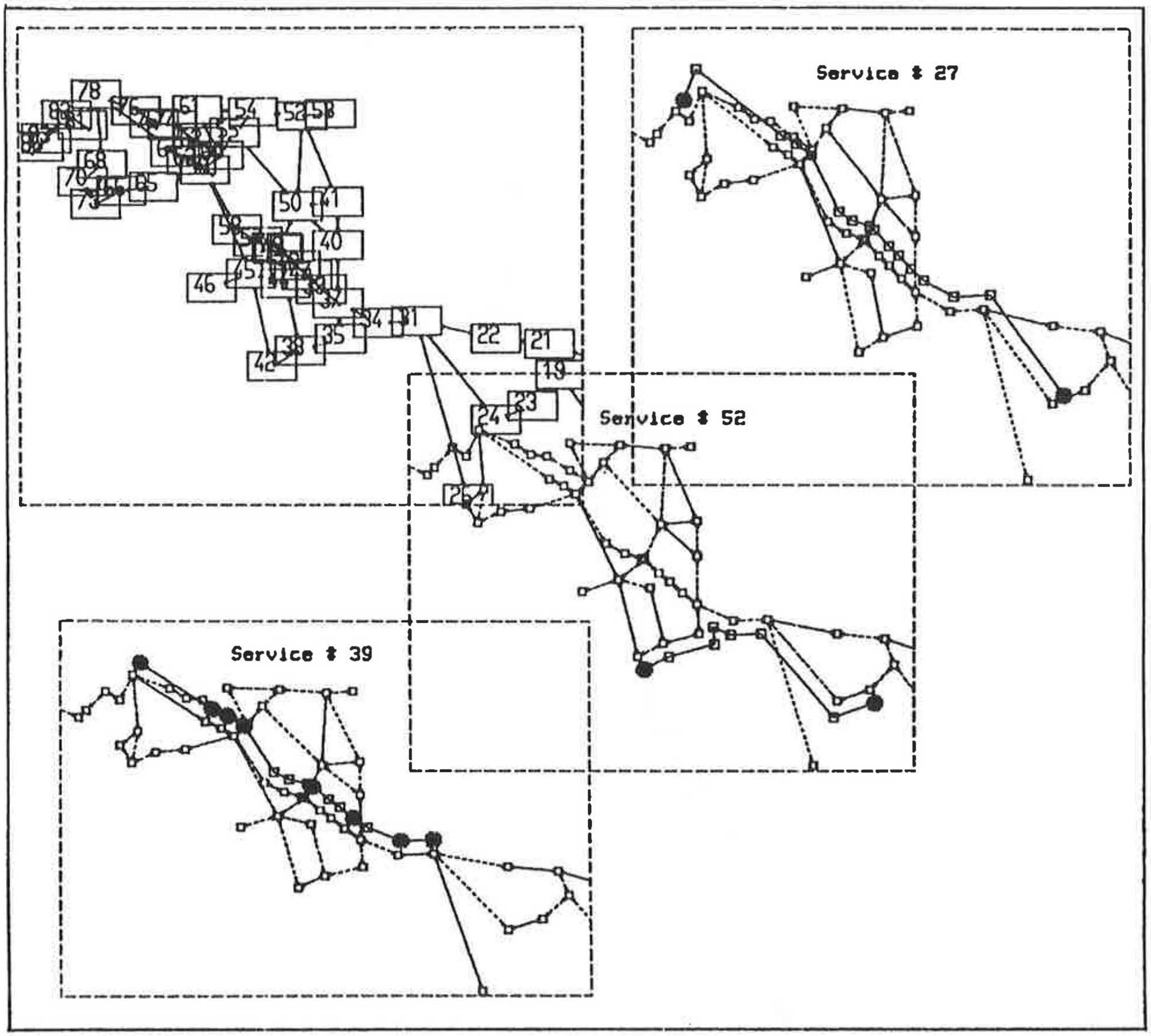

FIGURE 13 "Bad" image composition on screen without selective erasing.

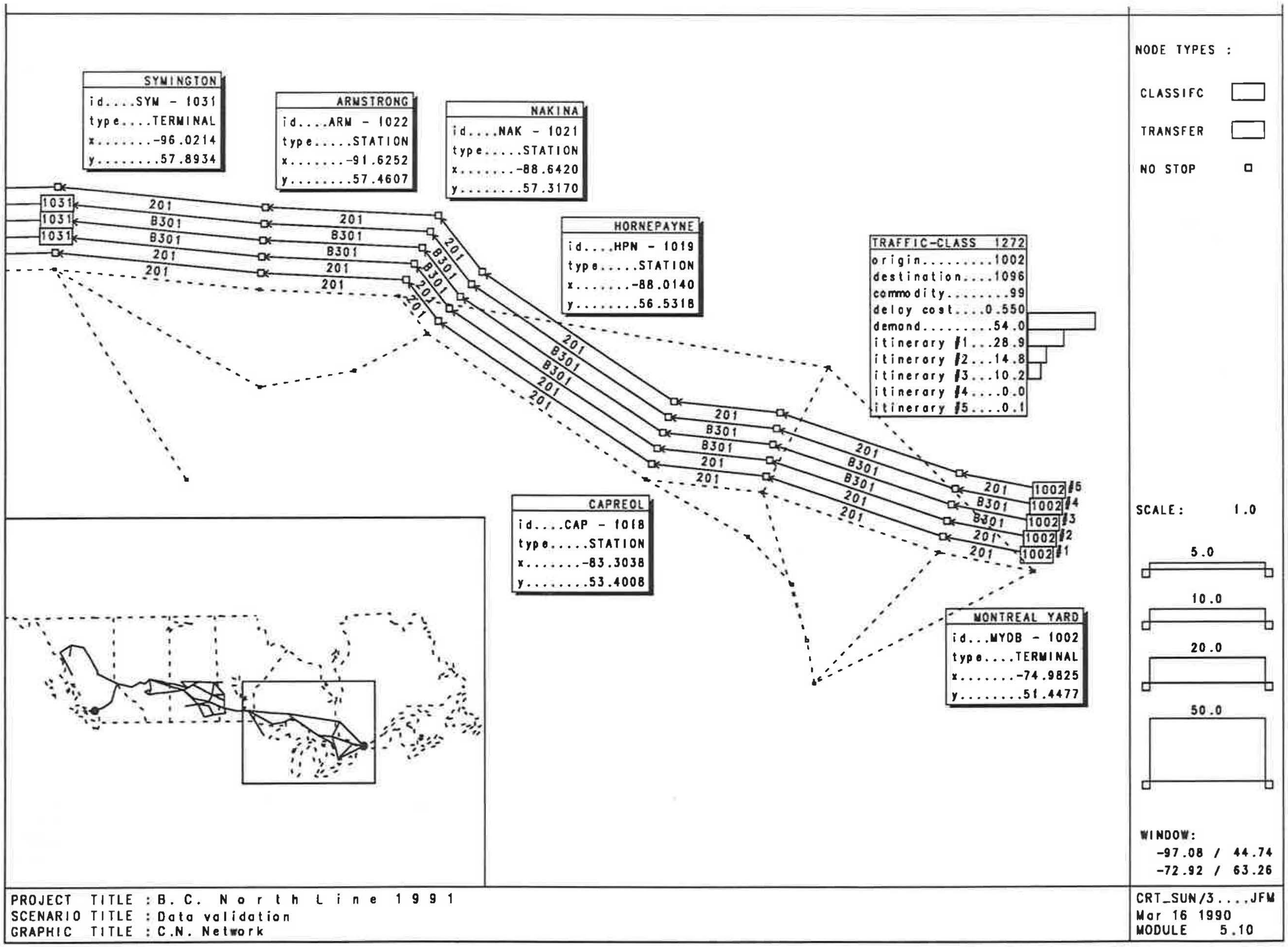

FIGURE 15 Plot of parallel itineraries for a traffic-class.

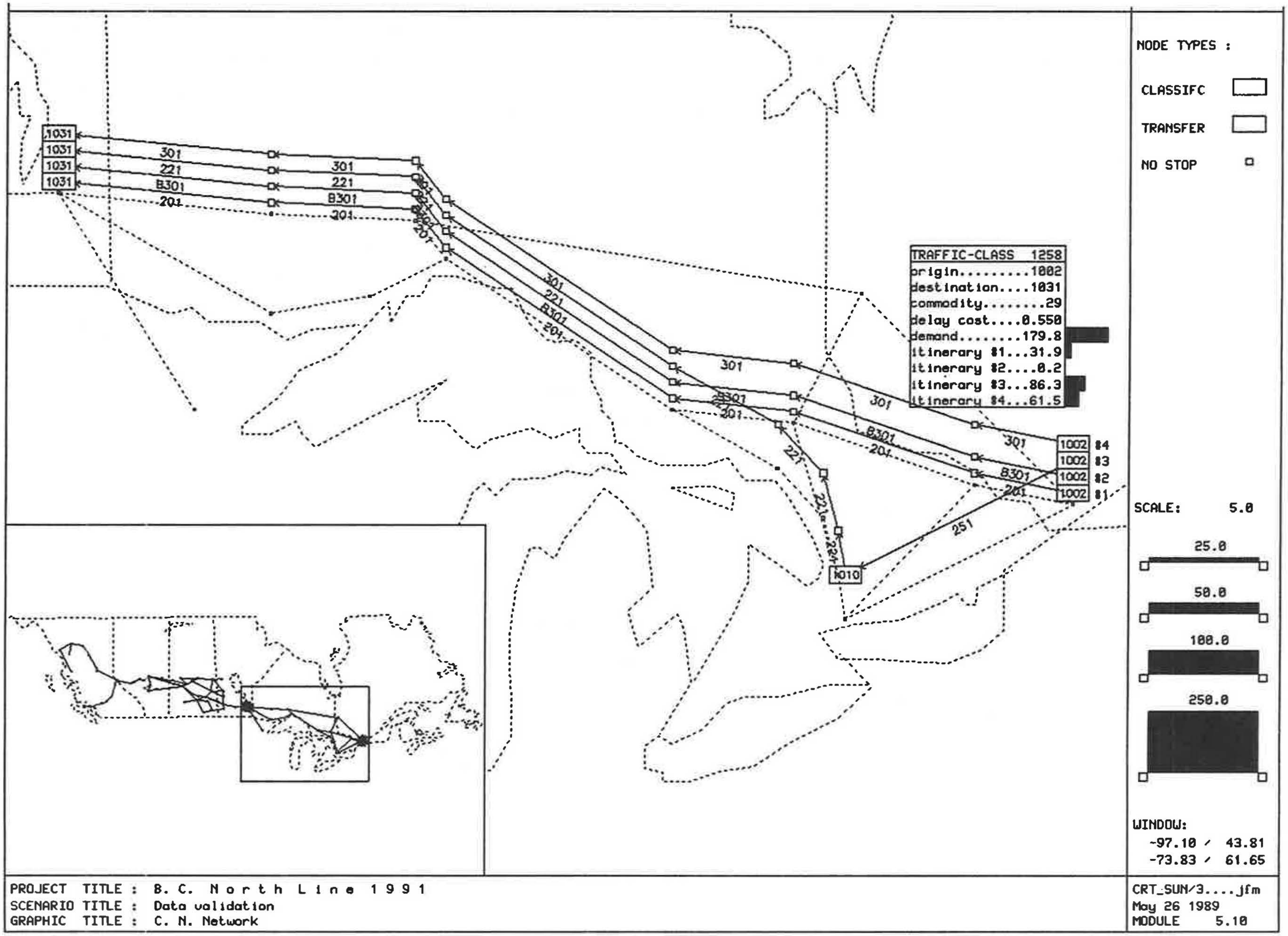

FIGURE 16 Plot of four itineraries for a traffic-class.

The graphic system we propose is particularly efficient for the representation of network features and operations. Moreover, it has been built to allow simple modifications and enhancements required by future developments in computer hardware or software. We made certain not to be linked to one particular graphic architecture, so that our procedures would not be restricted to a few machines.

For our part, we will continue to develop interactive-graphic planning systems that integrate powerful operations research models and algorithms. In this context, we are continually enriching the modeling framework and improving the performances of the solution algorithm. We are also working on the development of the graphical command language, the data bank structure, and all other operations research and computer procedures and modules required to complete a useful system.

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