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A VEHICLE-ROAD COMPATIBILITY ANALYSIS AND MODIFICATION SYSTEM (VRCAMS). PART I AND II

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A VEHICLE-ROAD COMPATIBILITY ANALYSIS AND MODIFICATION SYSTEM (VRCAMS)

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PART I: INTRODUCTION

Military operations traditionally have relied upon lines of communications in the field for successful completion. Effective ground movement of men and materiel in support of tactical and logistical operations controls, to a large extent, the outcome of the operations. Consequently, predicting the quantities of men and materiel that can be moved and the ability of tactical forces to advance across, withdraw from, or operate in the various land areas of the world constitutes a military engineering problem of major proportion. The problem incorporates technical and transportation intelligence and can be defined as an analysis of ally or enemy ability to use natural and man-made terrain features to their advantage and to modify terrain for either ally advantage or enemy disadvantage.

Groups from both the civilian and the military communities involved in the study of this problem have recognized the need for analytical systems that treat quantitatively all parameters affecting movement of ground vehicles. This need has generated research in recent years to provide information and methodology required for accurate engineering estimates. These research groups under the principal auspices of the U. S. Army Materiel Command, U. S. Army Corps of Engineers, U. S. Army Transportation Engineering Agency, Highway Research Board, and American Association of State Highway Officials have generated expertise that has been applied to the development of a comprehensive analysis system, the Vehicle-Road Compatability Analysis and Modification System (VRCAMS). This system combines the techniques required to determine a measure of the compatibility of vehicles and roads and the resultant product of movement. The system also treats the effects of constructive or destructive modification of vehicle and/or environment and the resultant impact on vehicle movement. VRCAMS had its first application in a study for the U. S. Army WHEELS Study Group, whose requirement was to assess the off- and on-road performances of a group of standard and modified military and commercial wheeled vehicles.

The first-generation system successfully combines basic relations affecting on-road vehicle movement to account for pertinent vehicle-road-driver interactions and for maintenance required to achieve a specified performance. Planned improvements to the system include road deterioration analysis, vehicle reliability analysis, vehicle-road optimization, and overall related materiel optimization.

PART II: OVERALL STRUCTURE OF VRCAMS

In recognition of the fact that the ultimate usefulness of VRCAMS would depend on its realism, credibility, and flexibility in application, it was designed to: (a) allow validation by parts and as a whole; (b) distinguish clearly between engineering predictions and those that depend significantly upon human judgment; (c) allow updating in response to new vehicle and vehicle-road technology; and (d) use measured or calculated input data. These features, plus the requirement for outputs at several levels of detail, dictated a modular structure that could both provide and accept data at subsystem levels and make predictions for vehicles and roads as a whole.

VRCAMS is a first-generation, comprehensive, digital computer model for predicting the performance of vehicles and roads (fig. 1), whose outputs can be combined for analysis. It is divided into five basic modules (figs. 2-6): (a) mobility-ride dynamics, (b) traffic volume/capacity, (c) structural analysis, (d) vehicle movement, and (e) maintenance analysis. All five modules draw from a common data base consisting of two files, vehicle data and road data. The model has been documented in a technical report (1).

Mobility-ride dynamics module (fig. 2)

The mobility-ride dynamics module predicts the speed of a vehicle operating on a road unit characterized in terms of road type, surface type, surface strength, grade, surface roughness, and curvature. The module is composed of submodels that account for drawbar pull, rolling resistance, power train, curvature, ride, and grade.

The appropriate empirical relations of drawbar pull and rolling resistance for any type of tracked or wheeled vehicle on soft and firm surfaces are used to adjust a theoretical tractive force-speed curve for the medium upon which the vehicle is traveling. The curve is also corrected for slip. The adjusted curve thus represents the vehicle's tractive force-speed capability in each gear ratio for a particular level surface condition. The available speeds and respective gear ratios required to achieve those speeds are determined by subtracting the appropriate resisting forces from the adjusted tractive force-speed curve.

The curvature submodel limits speed as a function of road curvature, superelevation, and road type, and determines the maximum safe speed at which a vehicle can negotiate a given road curve. The factors that control speed are vehicle sliding or tipping as a result of the centrifugal force generated in rounding a curve.

The ride dynamics submodel computes speeds at which a vehicle can traverse discrete road units without exceeding specified limiting shock and vibration criteria. The data output consists of an array of speed values corresponding to the limit of driver tolerance to random vibrations, as a function of root-mean-square (rms) road profile elevation. This limiting condition is defined in terms of the rate at which vibrational energy can reasonably be absorbed by the human body. A single, constant tolerance limit of 6 watts of absorbed power is presently used (2).

Finally, the minimum of the speeds that are determined by the traction, grade, curvature, and ride submodels is selected as the speed for that vehicle-road unit combination. The selected speeds for these individual road units are converted to time and distance and are accumulated to yield the maximum attainable speed of a single vehicle over a road segment that contains a group of contiguous road units. If more than one type of vehicle is involved, the speed for each type is determined and appropriately weighted according to the percentage of each type in the total traffic to yield an effective running speed for the traffic mix.

The road network is represented as a composite of units within each of which the road is considered sufficiently uniform to use a vehicle's maximum permissible speed as the running speed for that particular unit. Each unit is described by seven factors that characterize the surface properties and geometrics in terms of direct engineering relevance to vehicle travel--surface type, strength, roughness, grade, curvature, superelevation, and length. Each unit is described as that in which these factors present the same impediments to vehicle travel throughout its extent. This is implemented by dividing the range of each factor into a number of class intervals based upon considerations of vehicle response sensitivity and practical measurement.

Traffic volume/capacity module (fig. 3)

The traffic volume/capacity module predicts traffic volume of a road segment, based on traffic composition (number and type of vehicles) and the previously determined speeds. The abundance of existing empirical data from which speed-density-volume relations have been developed makes volume determination based on speed highly feasible. Speed determined by the mobility-ride dynamics module is the principal factor in determining the level of service a road unit is capable of supporting. It is used in an empirical relation to first determine the speed at which capacity will occur for the road. This capacity speed is then applied in a speed-density relation to determine density (vehicles/ mile) and flow (vehicles/hr). Flow, which is determined from capacity by computing time intervals between vehicles, represents the theoretical volume at capacity for the road unit in question. The volume of traffic a road can support at its highest level of service is determined from empirical relations that show volume-to-capacity ratios for all levels of service. These relations include such factors as sight distance restrictions, lane width, and shoulder clearances. The traffic volumes at the two levels of service, capacity speeds and maximum speeds, are defined along with speeds applicable to each respective service level.

High-type roads are then defined in terms of the road's maximum level of service, or highest allowable speed, and capacity. Low-type roads are defined in terms of volume at capacity or at the maximum vehicle running speed allowed. Analysis of this type will provide a concise evaluation of the number of vehicles a road can accommodate daily under the following two key circumstances: (a) traffic volume at the highest speeds possible, and (b) capacity and the speed at which capacity occurs.

Information from this module permits catagorizing roads based on the level of service attainable as follows:

a. Class A: A road capable of accommodating vehicles at high speeds (60-70 mph), service level A, with little or no restriction on maneuverability at low densities. Speed and volume are inversely proportional, and capacity occurs at a speed less than operating speed.

b. Class B: A road capable of accommodating vehicles at operating speeds between 50 and 60 mph, service level B, at low volumes wherein drivers have freedom to select their speeds and lanes of operation.

c. Class C (fig. 7a): A road capable of accommodating vehicles at speeds of 45-50 mph, service level C, which can allow higher volumes and less freedom of maneuverability.

d. Class D (fig. 7b): A road capable of accommodating vehicles at speeds of 45-50 mph, service level D, which allow higher volumes. Volume fluctuation and flow restriction can occur. Drivers have little comfort, convenience, or freedom to maneuver at high volumes; operating speed is sufficiently low to permit volumes approaching capacity.

e. Class E (fig. 7c): A road capable of accommodating vehicles at speeds of approximately 30-40 mph, service level E. Traffic volume can vary from zero to capacity at these speeds. At capacity, stoppages can occur.

f. Class F (low type) (fig. 7d): A road capable of accommodating vehicles at speeds less than 30 mph. Traffic volume can vary from zero to capacity at these speeds. At high volumes, stoppages can be frequent and of long duration. Contrary to classes A-E, volumes on a class F road are usually proportional to speeds until congestion occurs. Such roads as these often form the bulk of supply routes from a base of operations to operating military forces.

Structural analysis module (fig. 4)

The structural analysis module determines the design life or design requirements of a road segment subjected to the types and volumes of traffic previously determined. The module is consistent with Corps of Engineers criteria for the design and evaluation of various pavement types, and provides a means for evaluating a road in terms of the number of passes a series of vehicles can make on it before it fails, which is referred to as the number of passes to failure (NPF) (3). The primary input consists of traffic description and road and vehicle characteristics.

The basic approach is to determine the number of passes that a standard axle* can make on a road and, by comparing this number to the number of passes that a specific vehicle can make, determine an equivalency factor. Equivalency factors allow calculations for various mixes of traffic, i.e. many different vehicles. These factors can resolve the traffic into passes of a standard axle load, thereby providing the number of passes a mix can accomplish prior to road failure.

Failure criteria vary among different road surface types, and failure definitions vary among road designers and/or evaluators. Corps of Engineers' failure criteria are defined as conditions of the surface structure and do not necessarily relate to vehicle speed. Further study is expected to provide a definition in terms of vehicle speed that is applicable to all road types. Failure will then be

*Assumed to be a dual-wheel single axle with a load of 18,000 lb.

established as a mission-dependent variable defined as the point when minimum or required speeds are not attainable. This will provide the capability for describing all roads in terms of existing failure status and for determining failure of a road based on specified mobility requirements. In addition, road failure status can be continually monitored by reiteration of the mobility-ride module. Frequent monitoring and adjustment of speed capability of a road segment permit the treatment capacity and volume, which are based on speed, as variables dependent on road deterioration. This ability of the model to vary a road's traffic capacity or volume with traffic at a given level of service is a feature that significantly advances the state-of-the-art in vehicle-road compatibility analysis.

<u>Vehicle movement module (fig. 5)</u>

Military operations frequently require vehicle movements at volume levels well below those that can be accommodated by a road unit at its highest service level. The compatibility requirement then becomes one concerning the number of vehicles, vehicle movement time, and the amount of permissible traffic prior to road failure. The mobility module is used to determine travel time for one or more vehicles, and the structural module is used to determine whether a road can sustain the anticipated traffic. This vehicle movement module is essential when the road or road network is not continually saturated with traffic. Except for this module, VRCAMS presumes that the vehicles in question will be available in sufficient quantity to generate a continuous demand on a road or road network, at least equal to that quantity of vehicles that can be accommodated under given conditions. This module, therefore, is used to compute movement time and delivery rate when traffic demand is less than the capability of the road.

The module permits inputting of optional vehicle intervals dictated by convoy requirements or the commander's judgment, of it can establish the vehicle intervals from the running speed. This allows computation of delivery rates and travel time for controlled movements, such as a convoy of vehicles. Likewise, this module can be used to compare the characteristics of several available vehicles and/or the characteristics of alternative roads to optimize vehicle movement over the range of feasible solutions. The optimum vehicle can be selected for the given requirement, or various road segments can be evaluated in a search for the most suitable route.

<u>Maintenance analysis module (fig. 6)</u>

Road maintenance can have significant effects on road capability. Low-strength or short-life roads often deteriorate at such rapid rates that they require high (often daily) rates of maintenance. The maintenance module takes advantage of road life, determined by the structures module, and an empirical expression developed by the U. S. Army Transportation Engineering Agency (4) of road maintenance time impact on traffic volume to define a traffic-maintenance cycle. The traffic-maintenance cycle defines the hours of maintenance required on a given road unit to permit specific amounts of traffic. The parameters considered are vehicle passes per 24-hr period, number of passes before road maintenance is required (from structures module), fixed time loss due to contingencies, theoretical capacity (vehicles/hr) from the traffic volume/capacity module, and hours per lane per mile to maintain road after each failure. This module provides for adjustments of previously determined daily traffic volumes due to road maintenance.

Miscellaneous considerations

In addition to the major modules discussed, VRCAMS incorporates areas wherein other parameters that affect road capability can be recognized and treated. Among these are such features as temporary bridges, bomb craters, tunnels, and other obstacles affecting traffic flow. Also, factors such as dust, fog, rain, ice, snow, foliage, and smoke, which can affect sight distance, surface characteristics, and driver response, are treated by assigning minimum feasible time penalties for a vehicle, aided or unaided, to negotiate the obstacle.

PART III: IMMEDIATE AND LONG-RANGE APPLICABILITY OF VRCAMS

The immediate application of VRCAMS is to provide rapid assessments of throughput capability of theater-of-operations road networks and predict engineer effort required to maintain or upgrade throughput capability of road networks in support of various types of military operations and for various conditions. This should provide the following benefits: improved road capability estimates; improved road design, evaluation, and maintenance; improved vehicle design and maintenance; optimum road-vehicle usage; more effective operating and planning procedures; and standardization of terminology, procedures, and data collection.

The long-range applicability of VRCAMS is its use as a nucleus of other systems to support various types of strategic and tactical military operations and planning programs. Ideally, such systems could provide information on the following: optimum placement and design of barriers and obstacles; optimum counterbarrier and countermine operations; improved methodology for location of optimum field fortifications and definitive positions; optimum deployment of specialized engineering equipment, such as mobile tactical bridging and special road construction and maintenance equipment; efficient deployment of engineer troops and equipment; optimization of the results of earth movement, land clearing, and road construction; and more effective overall operating and planning procedures.

Network analysis and dynamic programming techniques will be used to optimize a road network with respect to the appropriate constraints. The concept is to use VRCAMS in the initial stage of analysis to determine the compatibility of vehicles and all units of a particular road network. One or more compatibility parameters, e.g. vehicle speed capability on a road, could be the prime consideration in network analysis. The particular parameter, when selected, will be optimized over the entire road network (in the case of vehicle speed, the path through the network providing the highest speeds would be selected). Analysis of this nature, using VRCAMS to provide all pertinent details on given roads in a network, can allow optimization with respect to any or all of the previously stated requirements.

Plans have been made to use VRCAMS in a study to compare the capabilities of certain standard military vehicles and a group of "high-mobility" vehicles. It will also be used in a joint study with the U. S. Forest Service in a comprehensive program to determine its ability to assess the performance factors pertinent to log-hauling operations. At this time an effort will be made to include fuel consumption and transportation cost modules.

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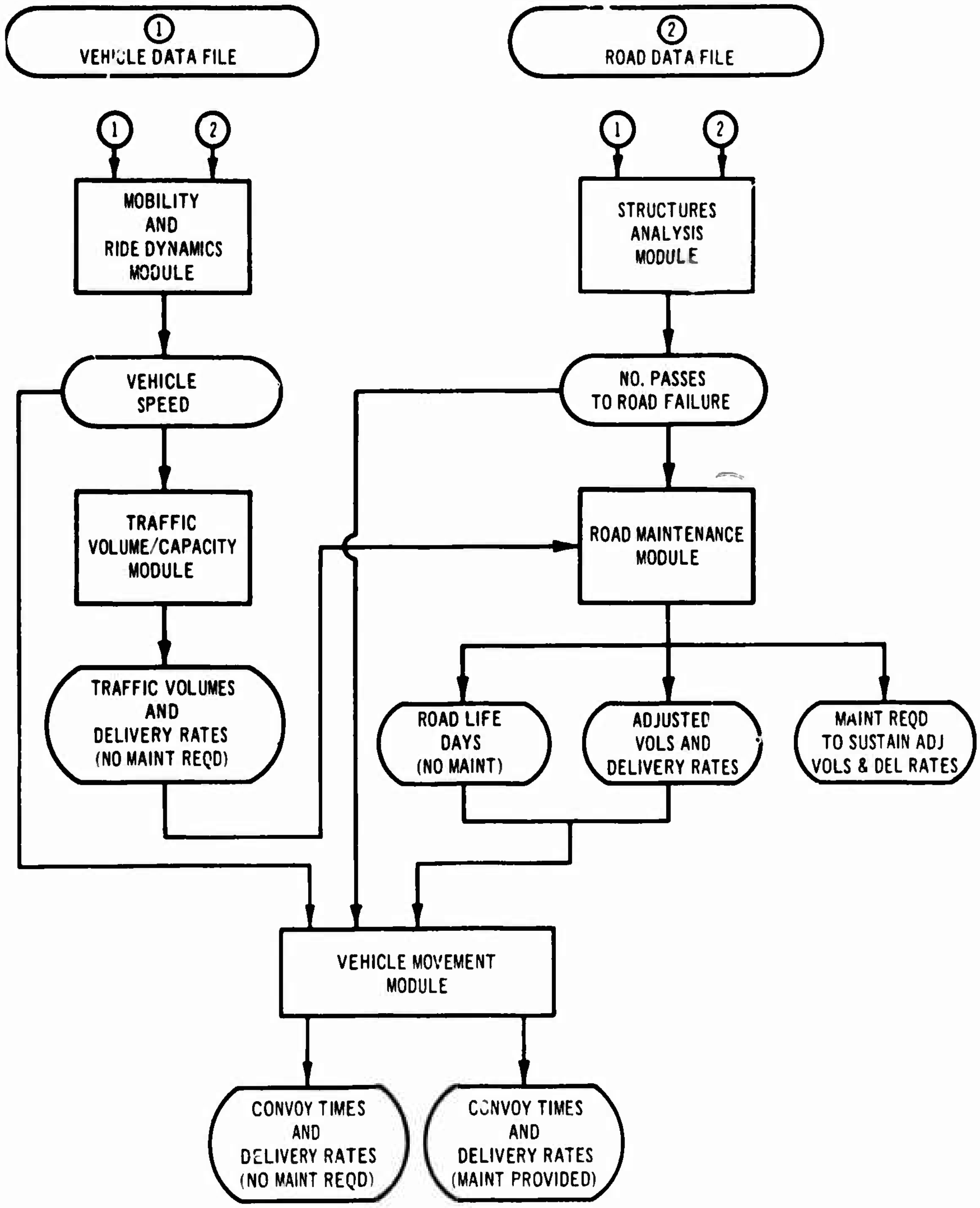

Fig. 1. General structure of VRCAMS model

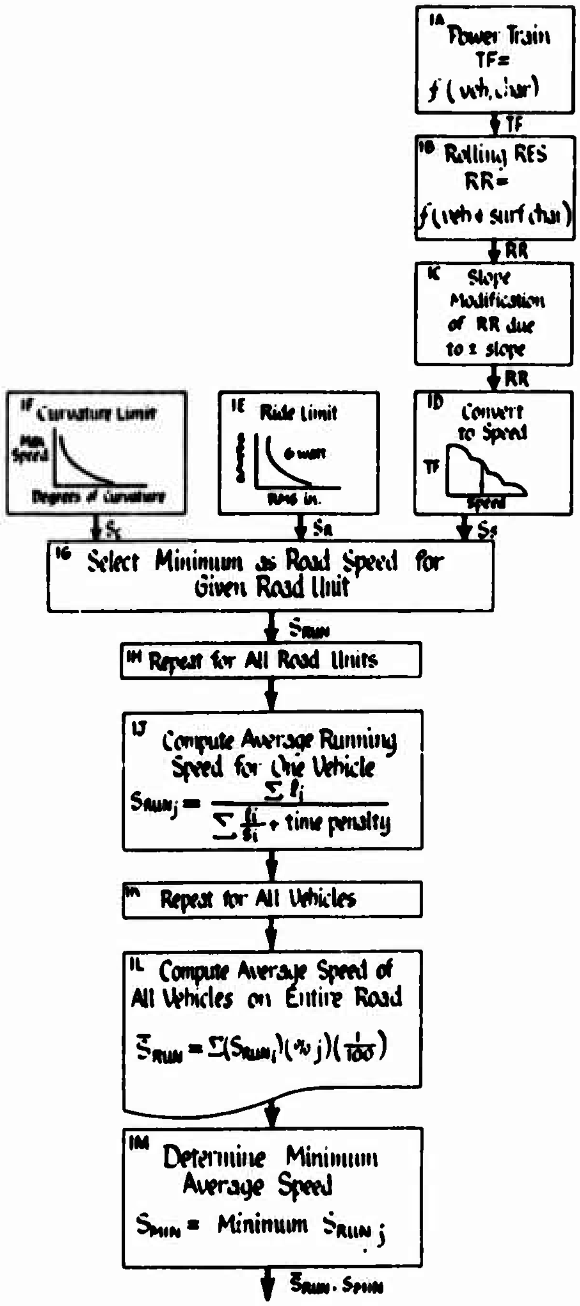

Fig. 2. Mobility-ride dynamics module

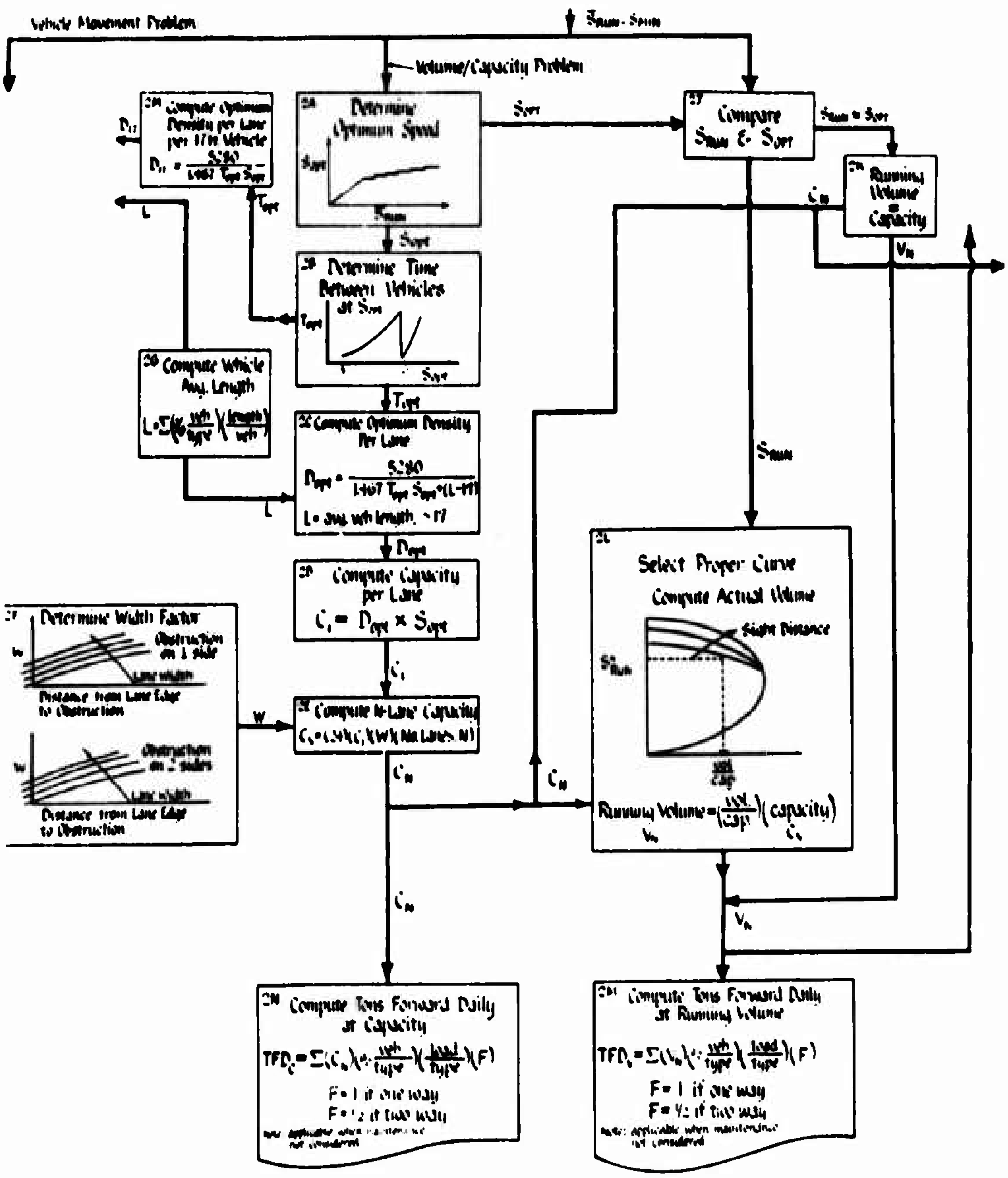

Fig. 3. Traffic volume/capacity module

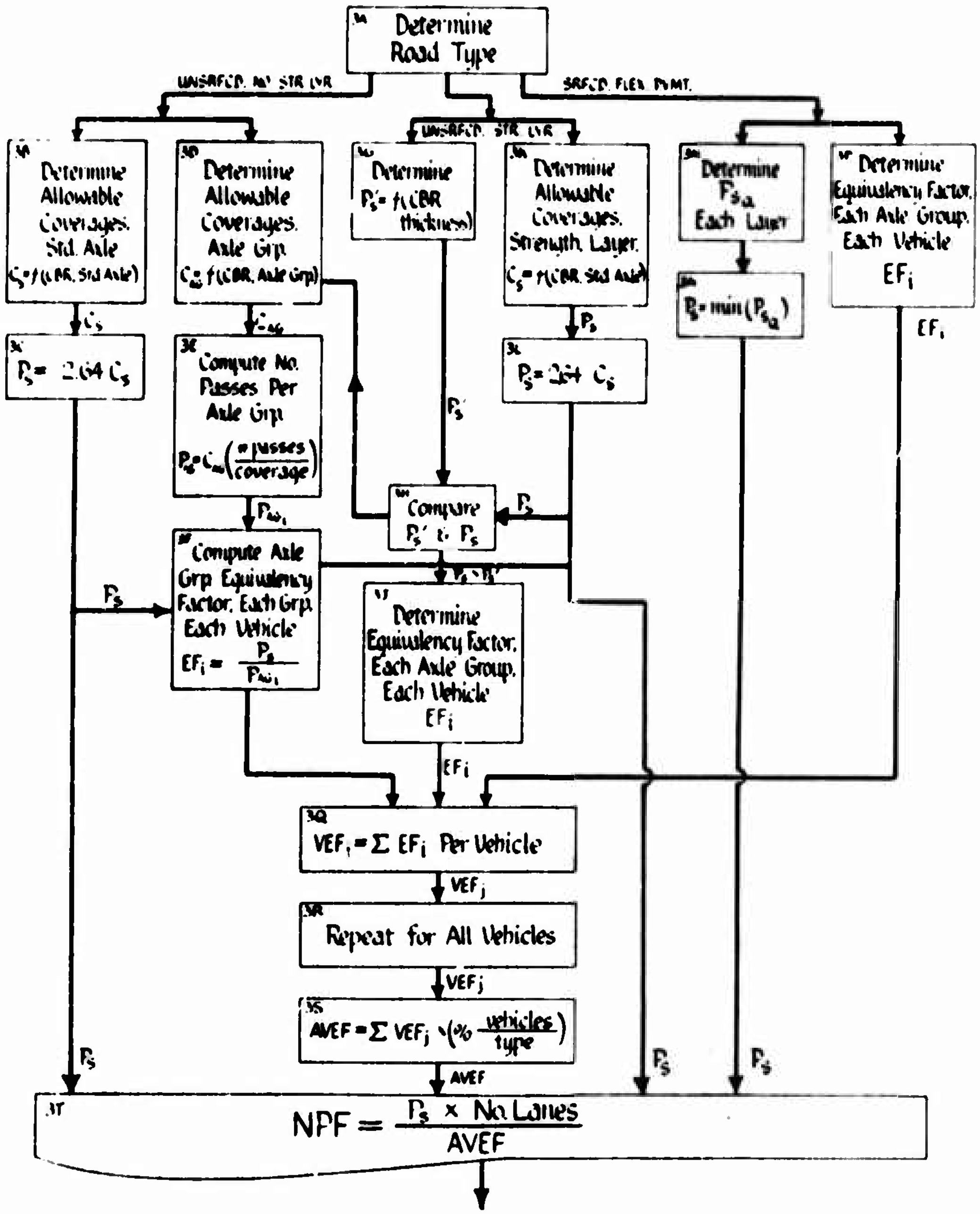

Fig. 4. Structural analysis module

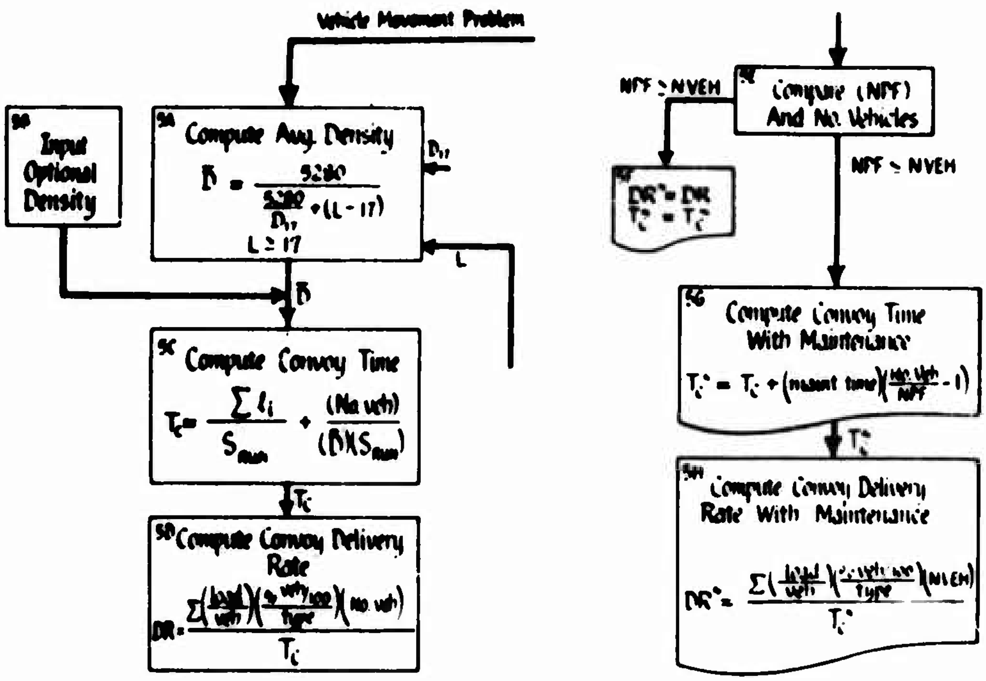

Fig. 5. Vehicle movement module

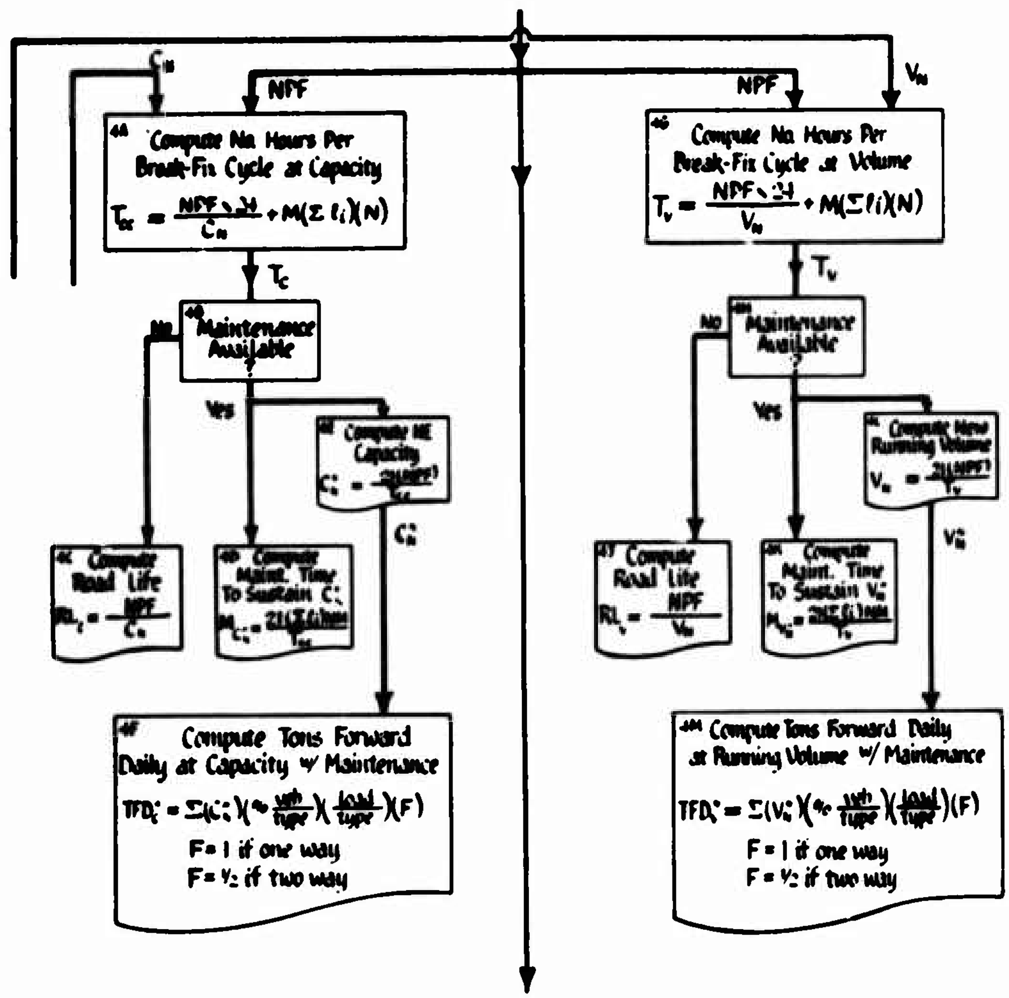

Fig. 6. Maintenance analysis module

Class C road

Class D road

Class E road

Class F road

Fig. 7. Representative types of roads encountered in military operations