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EFFECTS OF NUCLEAR ATTACK ON FREIGHT TRANSPORTATION SYSTEMS:

Interactions and Comparisons Among Modes

Prepared for:

OFFICE OF CIVIL DEFENSE
DEPARTMENT OF THE ARMY
WASHINGTON, D.C. 20310

CONTRACT NO. OCD-PS-64-201

STANFORD RESEARCH INSTITUTE

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ABSTRACT

The operations and equipment used in transferring vehicle loads between two vehicles or between a vehicle and a terminal are examined for seven different classes of cargo. For each of these classes, the usual method of load transfer is discussed, and expedient methods that could be used in a postattack situation are suggested.

St. Louis, Missouri is used to illustrate the problem of moving cargo through a damaged area after a nuclear attack. Several alternative methods of moving cargo via multiple transportation modes are analyzed, and a simple procedure for determining the minimum-time route among the alternatives is proposed.

The transportation resources required to deliver the minimum supplies for survivor support in the St. Louis area are analyzed for different mixes of trains and trucks and for movements of the supplies over a range of distances.

A general summary of the vulnerability of each transportation mode to nuclear attack is provided, and the remedial actions that might be taken in the preattack period to enhance postattack capability are discussed.

PREFACE

This study was conducted under Contract OCD-PS-64-201 for the Office of Civil Defense. The research was carried out at Stanford Research Institute in the Logistic Systems Research group, Management and Social Systems area.

From May 1959 to date, Stanford Research Institute has been conducting an almost continuous comprehensive research program to study the effects of nuclear attack on all domestic transportation systems. This report, prepared by Harvey L. Dixon, project leader, and Thomas H. Tebben, presents the last of the studies in the research program. Previously reported studies are listed as References 1-10 at the end of this report.

ILLUSTRATIONS

TABLES

I INTRODUCTION

When the studies in this series were initiated in 1959, the study plan was to analyze the effects of nuclear attack on each of the domestic transportation modes--rail, truck, water, pipeline,* and air. For a variety of reasons, the modes were to be analyzed one at a time for freight, and all modes were to be analyzed together for passenger transportation. Finally, the last study of the series was to result in a report which would integrate the findings of the separate mode studies and to consider some of the problems of providing transportation services in a postattack environment using all modes.

With the publication of this report, all of these tasks have been accomplished. Reports for previous tasks are listed as References 1-10. Although this study and the one on passenger transportation were conducted with approximately half the funds needed to provide studies of comparable depth to the other major reports in the series 4, 7, 8, and 9, an attempt has been made to cover the most significant aspects of the studies as initially planned.

The most significant new information presented in this report concerns the problems of transferring loads between modes (or vehicles). The analysis of problems of loading and unloading was deliberately deferred to this mode integration study. The character of the problem is described for a number of different commodity types. Since no damage assessments and detailed analyses could be conducted in this study, no quantitative information could be provided to indicate the magnitude of the loading and unloading problem throughout the country following a nuclear attack. Accordingly, the problem is discussed qualitatively for the different types of load.

A section has been written to illustrate some of the problems of integrating the operations of two or more transportation modes for St. Louis, Missouri. The data on load transfer time are combined with assumptions of vehicle speed to illustrate the problems of planning for the most efficient use of transportation resources in a postattack environment. As has been amply illustrated in previous reports in this series, not enough is known about the demand for transportation services following a nuclear attack to warrant an extensive analysis of demand, and of capability of postattack transportation systems to satisfy that

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* Pipeline transportation was analyzed as a part of the petroleum industry. The report for that study is listed as Reference 14.

demand. Therefore, the mode integration example presented in this study has necessarily used assumed data regarding demand for food and other survivor support, but will serve to illustrate the problem.

Aside from this new material, the report is largely devoted to integrating the findings of the earlier reports. For the convenience of the reader, selected data from the individual mode studies have been summarized here, with appropriate specific references to the individual mode studies.

II LOAD TRANSFER

Before an integrated analysis of cargo movements can be performed, some knowledge of the nature of the loads to be moved is required. This section classifies cargo loads so that all of the cargo in a given class is handled with the same general type of equipment and transported in the same type of transport vehicle (e.g., tank car, dump truck, flatcar). The classes developed here will be referred to in later sections where commodity movements over specific routes are discussed.

Several observations can be made regarding cargo loading and unloading after a nuclear attack. First, the vulnerability of loading and unloading equipment will probably be comparable to the vulnerability of the plant where the equipment is located. Second, the postattack operations required of the loading and unloading equipment will be consonant with the normal preattack function of the equipment. Thus if the facilities are not damaged or destroyed, neither will the loading and unloading equipment be damaged, and the postattack operations should be able to proceed as in the normal preattack situation, provided that nothing is asked of the equipment that it cannot reasonably do. For example, if a chemical plant using sulfuric acid as a feed material survives an attack, the terminal facilities that transport the acid would also survive. Therefore, where vehicles can be loaded and unloaded at their usual terminals with their usual load types, the load handling methods will be the same as in the preattack situation.

However, if vehicles must be loaded or unloaded at makeshift terminals, or if a particular terminal is used for transferring load types for which it was not designed, these requirements are asking the equipment to operate outside its normal preattack functions, so that it may not be possible to achieve efficient load transfer.

In a postattack environment with destroyed road sections, the problem of load transfer between transportation modes would be a very important one. References 4, 5, 7, 8, and 9 have examined the rail, road, water, and air transportation modes individually. Equipment, techniques, and handling rates associated with existing loading and unloading operations are described in this section. The load transfer information developed here is used in a mode interaction case example in a subsequent chapter.

Load Classes

To facilitate the discussion of loading and unloading operations including load transfer from one means of transportation to another, the following load classes were established:

1. Bulk liquids: Bulk liquids are defined as liquids that are transported in tanks integral to a transportation vehicle. They are loaded and unloaded by pumping. Three major subclasses are recognized.

   a. Noncorrosive: This category includes those nonfood liquids that are not corrosive and can, therefore, be shipped in ordinary steel tanks.

   b. Corrosive: This category includes acids, caustics, and other liquids that attack ordinary steel tanks.

   c. Food: These liquids are destined for human consumption; therefore, special sanitation precautions must be observed. Examples include milk and salad oil.

2. Bulk friables: This category consists of nonliquid cargo, unidentified by piece and unpackaged. Two subclasses are recognized.

   a. Food: Bulk commodities such as grain that are to be consumed by humans.

   b. Nonfood: Those bulk friables not included in category 2a--e.g., coal, ore, sand.

3. Heavy unit loads: This category consists of large, heavy items that are handled as units rather than being subdivided. An example is skid-mounted machinery.

4. Palletized cargo: This category consists of those identifiable pieces that have been aggregated to form a unit load by assembling them on a pallet.

5. Containerized cargo: This category includes identifiable pieces that have been packed into containers to form unit loads. Standard shipping containers, van containers, and van semitrailers are included in this category.

6. Loose cargo: This category consists of identifiable pieces that have not been aggregated to form unitized loads on pallets or in containers.

7. Refrigerated cargo: All of the cargo in this category must be refrigerated if it is to remain usable. Examples include meats, vegetables, and pharmaceuticals.

These load classes were defined so that the items within each class could be handled with similar types of materials handling equipment and transported on the same general types of transport vehicles.

Bulk Liquids

The transfer of bulk liquids characteristically occurs in highly specialized terminals owned by the shipper. Rail, truck, or barge terminals for bulk liquids typically include flexible hose, piping, storage tanks, pumps, and any special equipment (such as heating coils to speed the flow of highly viscous liquids) used to facilitate transfer. Since these terminals are owned by the shipper and have been designed to transfer a particular liquid, they are not readily adapted to the handling of other liquids. For example, many corrosive liquids are transported in glass-lined tank cars and stored in glass-lined tanks. These liquids cannot be transferred or stored in ordinary steel equipment without seriously damaging it.

Under normal circumstances, bulk liquids are transferred primarily at the source and destination points of the transportation network. When an intermediate transfer is made, e.g., from a railroad tank car into a tank truck, the trucker's equipment is usually used. The transfer rate depends on the liquid, but for liquids having low viscosity, rates of 300-1,000 gallons per minute are typical.

In a postattack situation in which transfer terminals are unusable, transfer might be accomplished with portable reciprocating or turbine-powered pumps used with lightweight connecting hose or by gravity flow from a transfer vessel into a storage tank (or vice versa, depending on the terrain).

It is also conceivable that bulk liquids could be transferred into containers such as 55-gallon drums, and the drums placed on pallets or skids, which could be handled with forklift trucks. However, at least 2-1/2 hours would be required to empty an 8,000-gallon tank car into 55-gallon drums. Losses due to spillage might also be substantial.

A makeshift terminal for a non-corrosive liquid could be assembled quite readily. All that would be required would be a motor or engine drive pump, flexible hose, and a pillow-type tank. These items are the major elements of portable Army fuel system supply points. That equipment possibly could be made available in limited quantities in an emergency.

Bulk Friables

Terminals for loading and unloading bulk friables are characterized by (1) their specialized cargo handling equipment designed to handle one commodity and (2) the fact that terminals are owned by the processors of the commodities. A typical terminal consists of cargo handling facilities and storage space.

As in the case of bulk liquids, in normal peacetime operations bulk friables are not usually transferred between transportation modes except at the source and destination nodes of the transportation network. In those instances where an intermodal transfer is made, e.g., from a railroad car to a truck, the trucker's transfer equipment is usually used.

Many different types of equipment are used for loading and unloading bulk friables. These include: (1) automatic railroad car dumpers that can unload twenty to sixty 60-ton hopper cars per hour, (2) continuous bucket unloaders that can unload a 900-ton barge in 1/2 hour, (3) portable mechanical conveyors capable of transferring 100 to 500 tons per hour, (4) gravity or gravity-pneumatic car unloaders that can unload a 50- or 60-ton hopper car in an hour or less, (5) clamshell buckets that transfer 5 to 35 tons per bite, and (6) earth-moving machinery such as bulldozers and scoop loaders. These high capacity transfer devices are installed only at those locations where large volumes of bulk friables are handled, i.e., primarily at shipping sources or destinations such as mines, mills, or seaports.

At terminals, bulk friables may be stored in containers such as covered or uncovered hoppers or grain elevators or on the ground in stockpiles.

In a postattack situation, several methods might be used to effect an emergency intermodal transfer of bulk friables. The most efficient method would be to use portable bulk materials handling equipment such as wheel-mounted screw or bucket conveyors to transfer material from one mode to another. With these types of equipment, transfer rates of 25 to 50 tons per hour can be achieved. Another possibility is to use scoop loaders or cranes with clamshell buckets for the transfer. With these types of equipment, transfer rates of 15-30 tons per hour per loader can be achieved with portable equipment. As a last resort, three men with shovels could unload a 60-ton hopper car in one 8-hour day.

In a postattack situation where there is no electrical power available for materials handling equipment, one method facilitating the handling of bulk friables is to load the bulk substances into containers or cartons and then to use forklift trucks for the intermodal transfer of the containers. Specially designed bulk containers are in limited use; they are especially useful when it is important to keep the bulk cargo free from contamination.

Heavy Unit Loads

Unlike bulk friables or bulk liquids, terminals for heavy unit loads are not highly specialized. The equipment used to transfer heavy unit loads--high capacity forklift trucks or cranes--is standard in large freight terminals. However, the transfer of some very heavy loads will be restricted to a few terminals possessing special handling equipment.

Heavy unit loads are typically transported on railway flatcars, flatbed trucks or semitrailers, or barges. Transfer of these loads will generally be made at intermodal general freight terminals and at the source and destination for a shipment.

At terminals, heavy unit loads are usually stored in covered warehouses, but they may also be kept in open yards. If they are stored in the open and have not been weatherproofed, they must be covered with a waterproof cover.

In a postattack situation, it would be difficult to devise makeshift terminal facilities to handle heavy unit loads. Unlike other cargo classes, heavy unit loads cannot easily be subdivided and manually handled. The availability of the forklift trucks or cranes normally used to handle such loads will greatly facilitate the transfer process. However, if such equipment is not available, a ramp and two winches, one to pull the load and the other to snub it, can be used for loading or unloading a flatcar or a truck. As an alternative to rail-truck transfer, loads of up to 20,000 pounds could be transported across rivers or ravines where bridges have been destroyed, by slinging them under a helicopter such as the Army's YCH-54H ("Flying Crane") provided the helicopters could be made available for the service. These loads could be moved up to 100 or 200 miles in this way.

Palletized Cargo

Pallets come in a number of standard sizes. Some of the more common are 40 by 32 inches, 48 by 40 inches, 72 by 48 inches, and 88 by 108 inches. These pallets have varying weight capacities ranging up to 10,000 pounds for the 88 by 108 inch pallet of the Air Force 463L system.

Pallets are usually handled and transported by forklift trucks. In some warehouses or shipping areas where movement patterns are well established, overhead or conventional conveyors are used.

In general, pallets are stored in covered areas, but sometimes they are covered with a waterproof tarpaulin and left in open areas.

Forklift trucks are used very widely for handling pallets and skids. Consequently, they are more likely to be available in adequate numbers in a postattack situation than other more specialized materials handling equipment. Equipment such as dolly trucks and unpowered lift trucks can also be used to handle pallets in lieu of forklift trucks. If no materials handling equipment is available, a palletized load can be disassembled and the contents carried individually by men. If the cargo must be manually handled, the transfer rate will be drastically reduced in comparison with mechanical handling methods. For example, a 50-ton boxcar of palletized cargo can be unloaded by one man with a forklift truck in about one hour. However, if the palletized loads must be broken down and the cargo unloaded in pieces, about three to four man-days are required.

Containerized Cargo

In addition to the specialized bulk shipping containers discussed above, containers can be divided into three major types: cargo containers, vantainers, and trailers. Cargo containers come in many shapes and sizes, depending on the cargo they were designed to carry. Vantainers are demountable truck bodies that can be carried on railway flatcars, flatbed trucks, or trailer chassis. These containers commonly have outside cross sections of about 8 feet by 8 feet and lengths of 8, 11, 17, 23, or 34 feet. Trailers are finding increasing use as containers for combination sea-truck, rail-truck, and rail-sea-truck movements of cargo.

In normal terminal operations, regular cargo containers are loaded and unloaded from trucks and railroad cars by overhead cranes or forklift trucks. Because of their length, vantainers are not readily handled by regular forklift trucks. Therefore, they are usually handled by side loading forklift trucks or by overhead cranes.

Trailers are transferred to and from railroad cars in several different ways. One common way is to use a ramp at the end of a string of rail cars and run the trailers lengthwise across cars and ramps between cars. Another method is to use a rotating, tilting ramp at the side of a rail car. In some cases, high capacity (70,000-lb) forklift trucks are used for side transfer. It appears that the trend in developing TOFC (trailer on flatcar) terminal equipment is toward overhead cranes that can quickly transfer trailers to and from rail cars.

Cargo containers, vantainers, and trailers require no special storage facilities.

The principal reason for aggregating cargo into containers is to take advantage of modern powered equipment that makes it possible to handle large unit loads more efficiently than a load of small, separate pieces. In a postattack situation, much of the equipment normally used to handle containers might not be avilable. Consequently, the following techniques might be employed. Cargo containers or vantainers might be winched from a flatcar over a ramp onto a truck bed. They might also be unpacked and their contents hand carried from one vehicle to another. The unpacking of containers defeats the basic purpose for containerizing cargo--to facilitate handling and reduce damage.

The absence of gantry cranes for TOFC loading and unloading should not greatly slow these operations. A ramp can be easily constructed so that trailers can be towed on and off the flatcars. This method would not be as efficient a method of loading or unloading as lifting the trailers with a crane or side loading forklifts, but the increase in handling time for TOFCs in an emergency situation would be less than for any other cargo class.

In a postattack situation, where loads must be transferred between modes, TOFC movement becomes even more desirable than it is in normal operations. The inherent capability of TOFC to handle large volumes of cargo without specialized materials handling equipment is very important in a postattack situation. Therefore, it will be desirable to maximize the amount of rail cargo shipped via TOFC. According to representatives of a large railroad, the railroads would probably be able to supply flatcars for emergency service proportionately more easily than they could supply boxcars or hopper cars. (There are more than ten times as many boxcars available as flatcars, but boxcars are more fully utilized than flatcars. Therefore, a higher proportion of flatcars than boxcars would be available on short notice for emergency service.)

Loose Cargo

Loose cargo is transferred by less sophisticated means than are used for any of the other cargo classes. Because of the inherent inefficiency in handling cargo piecemeal, individual items are aggregated into unit loads on pallets or in containers whenever possible. This aggregation is especially desirable for cargo that must be shipped via multiple transportation modes and therefore must be handled several times.

Two basic types of materials handling equipment are used for loose cargo in terminals: fixed path equipment, and variable path equipment. Fixed path equipment is used where material travels continuously between two points. Examples include conveyors, cranes traveling on overhead tracks, and elevators. Variable path equipment handles cargo in separate batches and is not restricted to a fixed path. Forklift trucks, dollies, and tractor-trailer combinations are examples of variable path equipment.

In general, loose cargo must be manually handled at some stage of every movement cycle. For example, with either fixed path or variable path equipment, the cargo must be loaded onto the transfer equipment at one end and unloaded at the other end. These loading and unloading steps are usually performed manually.

Rates for manual loading or unloading of trucks or boxcars vary widely depending on the nature of the cargo handled and the equipment used. For example, approximately 3,000 pounds of 50-pound packages can be unloaded and carried 50 feet by an unaided man in an hour. With a hand truck, the rate is increased to approximately 12,000 pounds per man-hour.

For loose cargo, the handling techniques in a postattack situation will probably be more like normal preattack handling methods than the techniques for any other cargo class. For those terminals that are both accessible and usable in the postattack situation, no shortage of variable path materials handling equipment is anticipated. Since most of the powered equipment uses gasoline, the absence of electric power will of course be irrelevant, whereas a severe petroleum shortage will restrict usage of this equipment over the long term.

In a postattack situation, fixed path materials handling equipment in terminals could be unusable because of blast damage or absence of electric power. Powered or unpowered variable path equipment might be used in place of the fixed path equipment. If this substitution must be made, handling rates will be degraded. If sufficient variable path equipment is not avialable, the loose cargo must be manually handled, thus resulting in a further degradation in handling rates.

Refrigerated Cargo

All of the cargo items included in the refrigerated cargo class also belong to one of the other classes. Refrigerated cargo will most commonly be a bulk liquid, loose cargo, or palletized cargo. In addition, the number of refrigerated vans are increasing. Refrigerated cargo belonging to any of these classes will be transferred with the same equipment and techniques as the other items in the class. Yet storage of refrigerated cargo at terminals introduces special problems if the cargo must be stored for long periods. Mechanical refrigeration units must be refueled, and ice-refrigerated units must be recharged so that the cargo is maintained at a temperature sufficiently low to prevent spoilage.

Within the refrigerated cargo class are several sub-classes, based on the temperature that must be maintained to prevent spoilage. Commodities such as milk, fresh fruits, and fresh vegetables must be maintained below 50° F. At the other end of the spectrum, frozen foods are kept below 0° F. In the absence of refrigeration, the lengths of time that these foods may be kept without spoiling vary widely. Items in the 50° F. class can be maintained at that temperature for only a few hours without refrigeration, even if the storage area remains unopened. On the other hand, frozen foods may be kept up to a week without thawing, provided the storage vault is not opened. Clearly, these holding times depend upon the ambient outdoor temperature.

According to railroad officials, about 25 percent of all refrigerated railroad cars now contain mechnical refrigeration units. The remainder are some version of "icers," which require that ice or chilled brine be placed in them. "Icers" are being converted to mechanical refrigeration at a rapid rate, and nearly all cars should be converted within ten years.

The typical mechnically refrigerated car starts its journey with a full 400-gallon tank of diesel fuel. Since the diesel consumption rate for refrigeration is about one gallon per hour, the car can maintain the proper temperature for at least 16 days. Refrigerated trucks usually have 150-gallon tanks and can continue to refrigerate cargo for at least 150 hours after the tank is filled.

III MODE INTERACTION EXAMPLE

St. Louis Case Example

In other major reports in this series[5,7], several large metropolitan areas of the United states were selected as illustrative case examples. Postattack transportation in those areas was analyzed in some detail, based on a range of four standardized nuclear attacks.* The case method is also used in this report so that the postattack intermodal transportation problems of one area can be examined.

St. Louis, Missouri was selected for the case study. St. Louis, like many of the nation's larger cities, is situated on a major river. Its location on the Mississippi River just south of the mouth of the Missouri River is such that both the major north-south and east-west traffic through St. Louis must cross one of a few major bridges. As of the early 1960s, the highway bridges in the St. Louis area carried almost 50 percent of the total highway traffic that crossed the Mississippi River between East Dubuque and Cairo, Illinois--a distance of 450 miles.

There are four major highway bridges and one railroad bridge across the Mississippi River near the downtown St. Louis area. In addition, highway bridges are located near the northern and southern city limits, and a railroad and a highway bridge are located at Alton, Illinois, 20 miles to the north.

Other Mississippi River highway bridge crossings within 150 miles to the north are at Louisiana, Missouri (90 miles); Hannibal, Missouri (110 miles); and Quincy, Illinois (135 miles). River highway crossings to the south within 150 miles of St. Louis are at Chester, Illinois (60 miles); Cape Girardeau, Missouri (110 miles); and Cairo, Illinois (150 miles). Railroad crossings of the Missouri River are available at St. Charles, Missouri (15 miles northwest) and Boonville, Missouri (150 miles west), and Mississippi crossings at Illmo, Missouri (120 miles south), Louisiana, Missouri (85 miles north), Hannibal, Missouri (110 miles north), and Quincy, Illinois (135 miles north).

In terms of the number of railroads serving cities of the United States, St. Louis is the second largest rail center in the nation. There is an extensive set of classification yards on both sides of the Mississippi River, with an aggregate capacity of 60,000 cars. In addition, there are small yards at various locations near St. Louis.

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* See Reference 7 for the attack descriptions.

St. Louis is also an important highway and trucking center. Highways 40, 50, 66, 67, 460, and their alternates pass through St. Louis. The total inventory of trucks in the area was about 94,000 in the early 1960s.

St. Louis is an important air terminal. Reference 9 estimates that the St. Louis airport, Lambert Field, ranks sixteenth in the nation with respect to the average inventory of aircraft on the ground. In addition, Ozark Airlines has a maintenance facility there.

Methodology for Parametric Analysis

Even in a postattack environment, alternative transportation modes will frequently be available for cargo movements. It is the purpose of this section to present a method for evaluating the relative efficiency of a transportation mode or combination of modes for moving cargo.

In the preattack situation, the selection of a transportation mode or modes for cargo shipment is made primarily on the basis of cost and urgency. In a postattack environment, dollar cost is not an important consideration, but time and consumption of scarce resources are of paramount importance, within the constraints of feasibility. Many complicated situations could exist in a postattack transportation operation in which time, fuel, manpower, or some other resource could be the most critical item. Although it is clearly impractical to analyze all contingencies, many postattack situations can be visualized in which time is the most critical factor or even the most typical factor, especially in the early postattack phase that is often termed the emergency period. In such situations, time is the overriding factor--e.g., food or medical supplies must be moved quickly to an area of urgent need, or must be moved swiftly through fallout areas to minimize radiation exposure. For these reasons, a simple mathematical model has been derived to assist in selecting the combination of routes and modes that requires the least time for a cargo movement.

The model was developed to compare situations in which a shipment could be made between two points using the following alternatives: (1) rail entirely, (2) a combination of rail and truck, or (3) a combination of rail, truck, and barge. These alternatives were selected because they represent likely postattack situations. For example, railroad networks are not as various or redundant as highway networks, and therefore alternative re-routings cannot be chosen as easily as for highway networks.

The model is designed to discriminate among rail, rail-truck, and rail-truck-barge movements. Basically, the following expression is evaluated:

$$T_{min} = \mathrm{Min}\left[\frac{d_1}{V_r}, \left(\frac{d_2}{V_r}\ \frac{d_3}{V_t} + t_1\right), \left(\frac{d_4}{V_r} + \frac{d_5}{V_t} + \frac{d_6}{V_b} + t_2\right)\right]$$

where

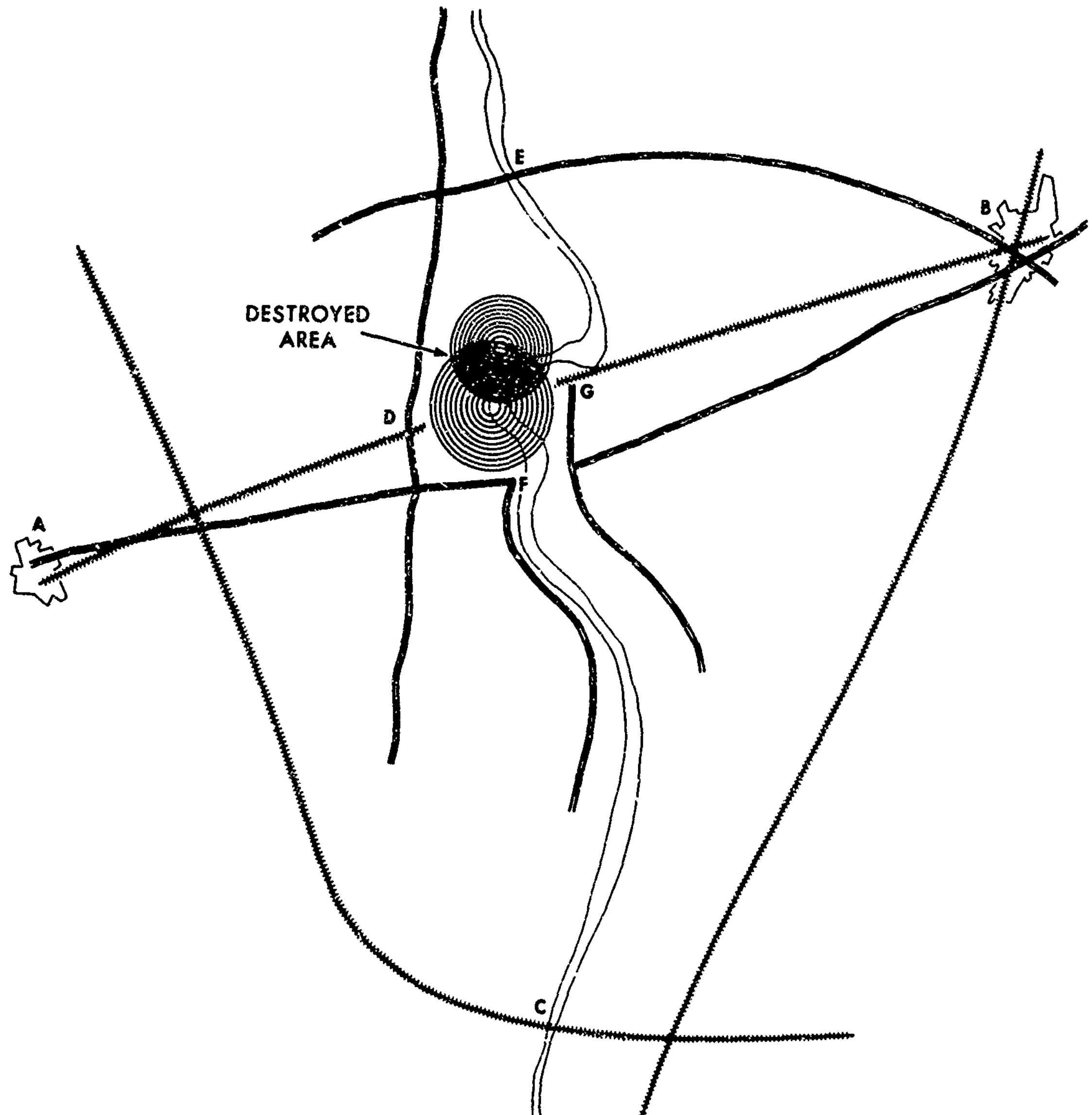
T_{min}	is the minimum total time between the source and destination
d_1	is the distance to be covered by rail between the source and the destination
d_2	is the distance to be covered by rail if a rail-truck intermodal system is used between the source and destination
d_3	is the distance to be covered by truck if a rail-truck intermodal system is used
d_4	is the distance by rail if a rail-truck-barge intermodal system is used
d_5	is the distance by truck if a rail-truck-barge intermodal system is used
d_6	is the distance by barge if a rail-truck-barge intermodal system is used
t_1	is the time (including expected delays) required to perform rail-truck intermodal transfers
t_2	is the time (including expected delays) required to perform rail-truck-barge intermodal transfers
V_r	is the average speed of rail travel
V_t	is the average speed of truck travel
V_b	is the average speed of barge travel

The alternative types of movement for which the model is designed are illustrated in Figure 1. The situation shown schematically in Figure 1 is typical of a situation that could occur at many cities in the United States following a nuclear attack.

Suppose a trainload of food is passing through A on its way to B. Several options are available for transporting the trainload of food to B. The train could continue and take a detour to the river crossing at C and then proceed to B. Alternatively, the train might proceed to D and transfer its load to trucks. At this point, the trucks have some options: (1) cross the bridge at E and proceed to B, (2) cross the river on a barge (or other ferry) at F and proceed to B or proceed to G and transfer the load to rail cars for movement to B. The best option in a particular situation will depend upon a number of considerations including traffic congestion on the bridges; availability of rail, truck, and ferry equipment; fallout patterns; and time required to go from A to B. The model presented above is designed to evaluate the time required for each option.

FIGURE 1

SCHEMATIC OF ALTERNATIVE TRANSPORTATION ROUTES BETWEEN TWO POINTS



If values for t_1, V_r, and V_t are known, a graph can be drawn that will permit rapid determination of the minimum time option. Such a graph is shown in Figure 2 for t_1 = 2.7 hrs, V_r = 20 mph, and V_t = 35 mph.

A specific comparison of rail and rail-truck systems can be made by using Figure 2 instead of the model above. To use Figure 2, one determines the mileage that must be traveled between the source and destination for the rail system and the equivalent rail and truck mileages for the rail-truck system. The sum of the rail-truck distances is then subtracted from the rail distance between the points. The net distance detoured by rail is converted to the time required for a train to travel this distance, and this travel time is compared to the time required to transfer the cargo from a train to a truck. These operations can be accomplished easily with Figure 2 by locating the rail detour distance on the ordinate at the right side of the figure. Next, the distance ordinate is followed directly across to the time ordinate on the left side of the figure, and the time required for the train to travel the detour distance is obtained. The time enables the user to locate one of a family of rail lines extending from the positive y-axis. A straight edge is used to define the rail line parallel to the other lines and passing through the detour time already located. Next, we locate the point where the rail line intersects the line drawn perpendicular to the x-axis at the point corresponding to the distance traveled by the truck in the rail-truck system. Then the ordinate of the intersection point just drawn is subtracted from the ordinate of the point where the truck line for the proper number of intermodal transfers intersects the truck distance line. If this difference is positive, it represents the time saved if rail is used. If the difference is negative, it represents the time saved if a rail-truck system is used.

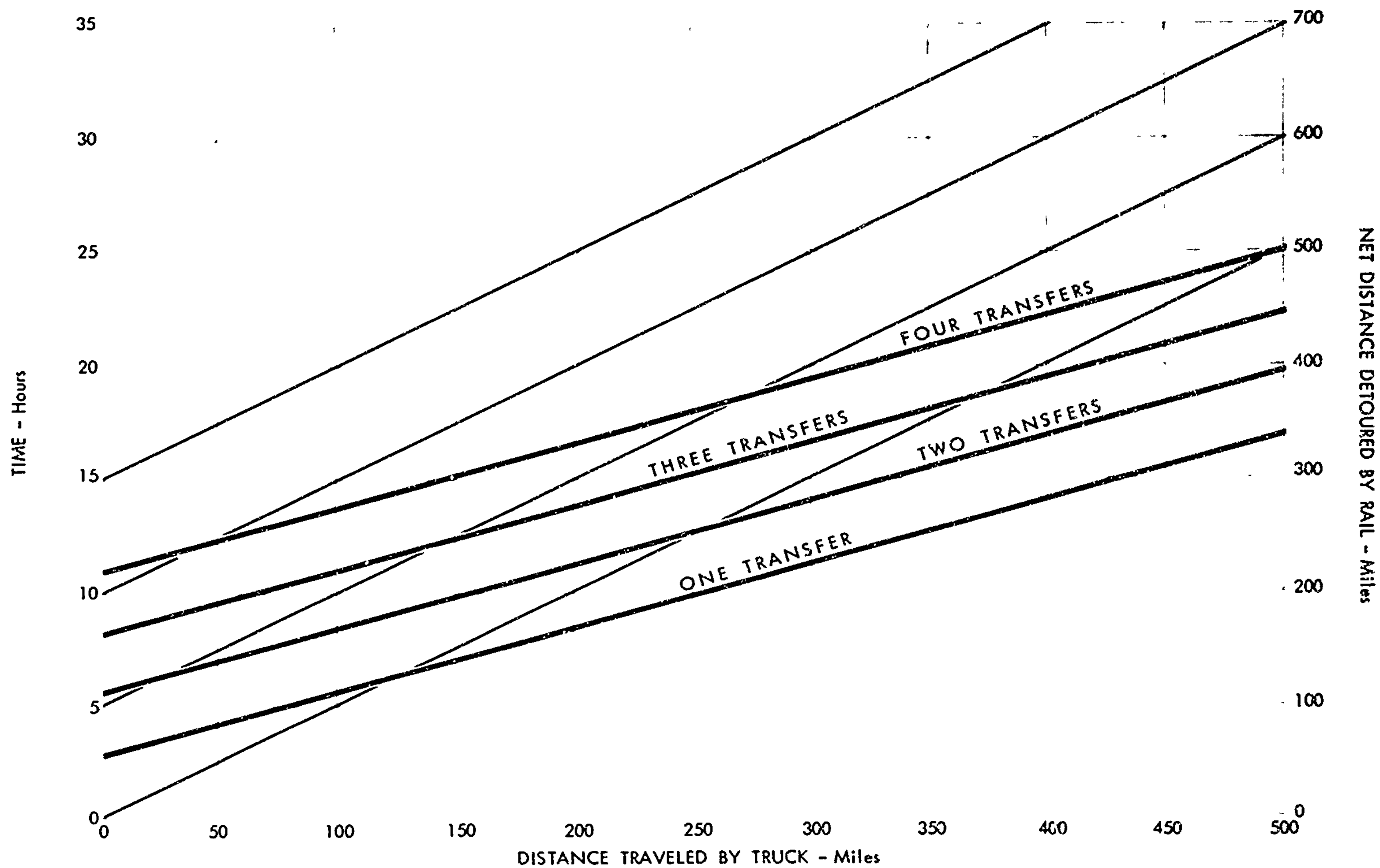
Figure 2 can be used in two different ways. First, all-rail versus rail-truck systems can be compared. When the truck line corresponding to one transfer is examined, it is clear that for a rail detour of 54 miles, the amount of time required to transport the cargo solely by rail is equal to or less than the time required to transfer the cargo into a truck. Therefore, for rail detours greater than 54 miles, less time would be required to transfer the cargo from rail to a truck than to detour the cargo by rail.

Second, Figure 2 can be used to determine whether rail-truck, rail-truck-rail, or rail-truck-rail-truck types of intermodal transfers are faster than rail detours. For example, assume that a section of railroad track has been destroyed and that this area may be bypassed either by a rail detour of R+T miles or by transferring the cargo to a truck, moving it by road for T miles, and transferring it back onto a train. From Figure 2, it is clear that for R+T = 120 miles and T less than 20 miles, two intermodal transfers are faster than a detour.

The preceding analysis is obviously not comprehensive. Several possible combinations have not been considered, e.g., a "pure" truck system. For the speeds assumed in the above example, this system will be faster than a rail system if truck and rail route distances are equal.

FIGURE 2

COMPARISON OF RAIL SYSTEM AND RAIL-TRUCK SYSTEM TRAVEL TIMES
FOR PALLETIZED CARGO



Postattack Transportation Facilities

A range of four standardized nuclear attacks was considered in this series of studies. Only one of them--the Early 1960s Military and Population Attack*--is used here to provide a framework for a discussion illustrating the transportation problems that could occur in and around cities subjected to nuclear attack. Although the details will differ from city to city, analyses of transportation facilities in and around a number of cities subjected to a variety of attacks suggest that the results presented in this section for St. Louis are typical.

In the Early 1960s Military and Population Attack, four 4-MT weapons were assumed detonated in the St. Louis area. Since there are uncertainties connected with predicting enemy aim points and intentions, the analysis based on the attacks should not be used for detailed planning for the St. Louis area.

References 4, 5, 7, and 9 describe the surviving transportation facilities in St. Louis in considerable detail, and that detailed information will not be reproduced here. However, certain data pertaining to intermodal transfer and relating directly to this study will be reproduced.

As has been stated earlier, intermodal transfers are usually carried out at the plants of shippers or in rail, truck, barge, or air terminals. Although no separate damage assessment of terminals in the St. Louis area has been performed, extrapolation of the studies mentioned above results in a pessimistic outlook.

Rail operation in postattack St. Louis would be extremely difficult. The extensive system of yards with an aggregate capacity of 60,000 cars, along both sides of the Mississippi River, would be lost. Within the rail activity center, only two small yards at Mitchell with a 1,330-car capacity would survive. The 5,100-car yard at Dupo would have a 79 percent probability of surviving destruction, but only a 31 percent probability of avoiding damage. In view of its low H+1 fallout intensity of 900 r/hr, this yard might be repaired and placed in operation shortly after the attack.

The classification load would fall on yards outside the St. Louis rail activity center. The most likely center for this activity would be southern Illinois, where yards at Centralia have a capacity of 4,400 cars, Bluford, 2,000 cars; and other yards, an additional 6,000 cars. Yet most of these yards now serve the coal mining area, and are not likely to be well-adapted to general classification. In addition to these yards, several small yards are scattered about the area.

There is a high probability that the railroad bridge across the Mississippi River in downtown St. Louis would be destroyed or severely damaged. Most of the private road and rail terminal facilities are located

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* See Reference 7 for attack description and figure showing placement of weapons in St. Louis area.

in the manufacturing district near the heart of the target area, and probably a large fraction of these facilities would be lost.

The closest rail line around St. Louis can hardly be called a belt line since it extends west to Boonville and south to Illmo. It is likely that north-south traffic would pass through Illinois and east-west traffic would cross the Mississippi at Alton, having been classified at Centralia, or farther north at Mattoon, Illinois. To avoid a detour through Springfield, Missouri, the belt line must pass close to aim points at Kirkwood, Missouri. However, Reference 5 states that the probability of the track surviving is greater than 90 percent.

Of the 94,000 trucks in the St. Louis area, approximately 49,500 are expected to be in areas where the blast overpressure is less than 3.0 psi. In accordance with the discussion in Reference 7, all vehicles in areas where the overpressure is less than 3.0 psi are assumed to be available in the postattack situation.

The four bridges near the central part of St. Louis (McKinley, Veterans Memorial, Eads, and MacArthur) would have a high probability of heavy damage or destruction in the Early 1960s Military and Population Attack. Two additional bridges, Chain of Rocks and Jefferson Barracks, are near the fringe of the damaged area shown in Figure 3. Roads leading to each end of the Chain of Rocks Bridge and to the west end of the Jefferson Barracks Bridge are in the outer fringes of the medium rubble area. The probability that the Chain of Rocks Bridge would sustain moderate damage is slightly more than 0.5. The probability that the Jefferson Barracks Bridge would sustain moderate damage is somewhat less than 0.5. If both of these bridges were lost, the only connection in the St. Louis area across the Mississippi would be Clark Bridge at Alton, Illinois.

Both the Jefferson Barracks Bridge and the Chain of Rocks Bridge are part of the ring road around St. Louis and a portion of East St. Louis. This ring road, which is important to through traffic, is composed of U.S. 61 and U.S. bypass routes 40, 50, 66, and 67. Even if the two bridges survive, there is some doubt that they could be used until rubble could be cleared in the vicinity of the bridges. About 13 miles of the ring road in the southwest portion are less than one mile inside the medium rubble area. Approximately one mile of road on each end of the Chain of Rocks Bridge is in the fringe of the medium rubble area.

The movement of heavy line-haul vehicles through or around St. Louis is subject to the same probable restrictions noted above for intra-area travel. If the Jefferson Barracks Bridge were to sustain no more than light damage, the short length of U.S. bypass 50 from Mehlville to the bridge could probably be reactivated in a few days by removal of the light debris and medium rubble from that section. If the Jefferson Barracks Bridge was not used, truck traffic to and from south and southwest of St. Louis could cross the river at Alton by following one of several Class III roads north to U.S. 60/61. From that point, traffic could follow the Class Ic roads to Clark Bridge at Alton. Other areas west of the Mississippi would have access to the bridge at Alton along the roads shown in Figure 3.

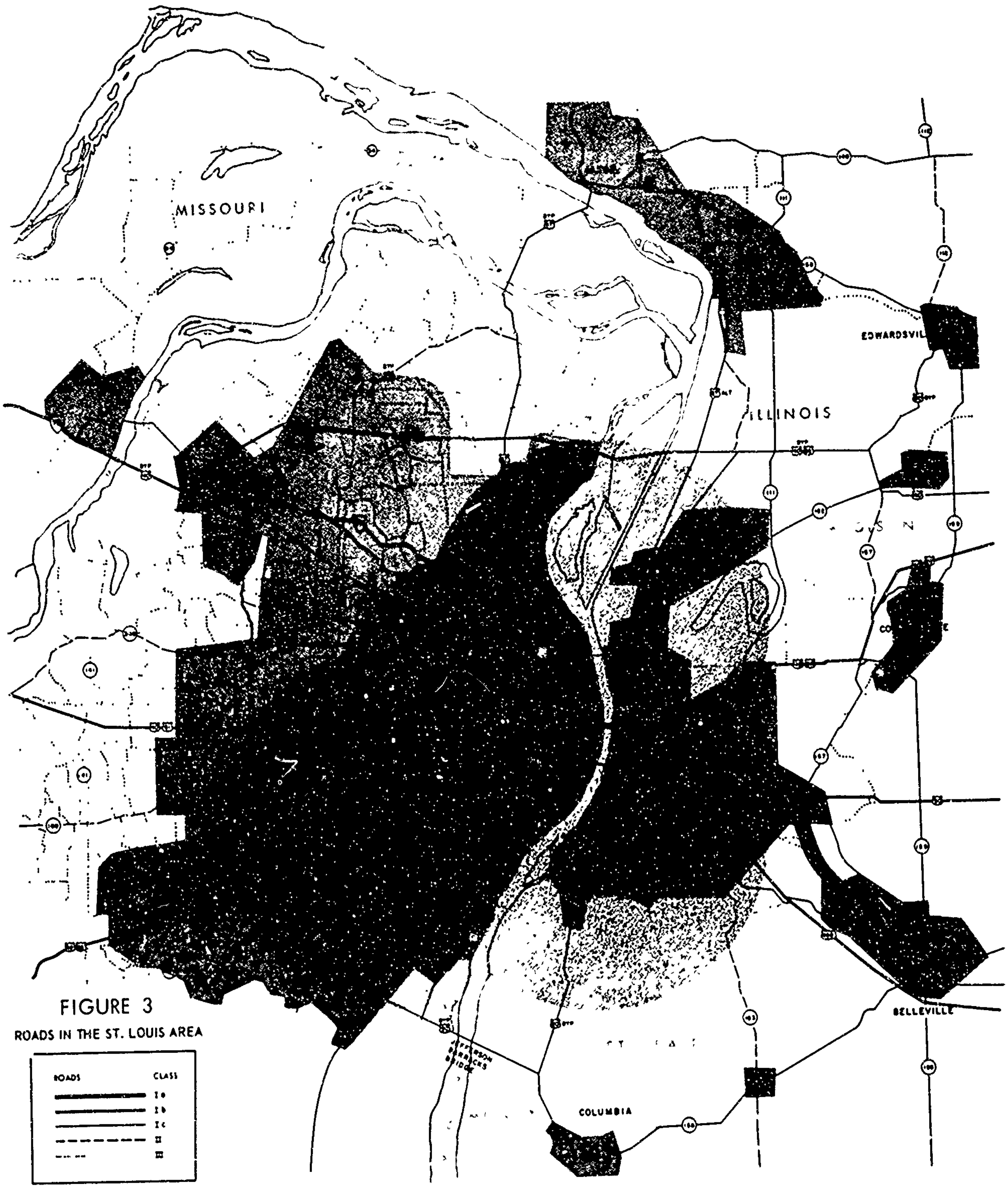


FIGURE 3

ROADS IN THE ST. LOUIS AREA

East of the Mississippi, heavy trucks could move more freely than would be possible west of the river. Access to the bridge at Alton would be the same as in the preattack period. Access to the Chain of Rocks Bridge would be subject to blockage by rubble, as discussed above, for about a mile near the east end. Otherwise, access to the north and east near St. Louis would be the same as it was before attack, and so would access to the Jefferson Barracks Bridge from the east, except for state route 3 to the north into the damaged East St. Louis area.

Reference 9 estimates that there would not be significant blast damage to the structures at Lambert Field. Fallout at H+1 would be in the 100-3,000 r/hr range, so that the facilities would be usable in a matter of days.

As in the case of air transportation, water transportation does not require a manmade right-of-way such as railroads or roads. Consequently, water transportation is somewhat less vulnerable to nuclear attack than rail or road. Reference 8 estimates that transportation along the Mississippi River channel would not be seriously disrupted by nuclear attack except for possible channel blockages by fallen bridges. About 10 percent of tugs and 15-20 percent of the barges in the Mississippi River system would be destroyed or seriously damaged. Therefore, an adequate number of barges and tugs would be available to act as makeshift ferries across the river in case of need.

Rail-Truck-Barge Methodology

In a postattack situation, with bridges down, the Mississippi and Missouri Rivers would pose formidable barriers to the movement of cargo through St. Louis. Previous reports 4, 5, and 7 have discussed unimodal movements through St. Louis by rail or truck. This section will consider cargo movement into and through St. Louis via mixed systems such as rail-truck or rail-truck-barge.

Reference 5 discusses the difficulty of moving cargo into St. Louis by rail in a postattack situation. Table 1 provides an analysis of the operations, times, and resources required to transfer the various classes of cargo from railroad cars into trucks, drive the trucks onto a barge which crosses the Mississippi River, and unload the trucks from the barge. The times required for this transfer assume three hours of delay due to unavailability of equipment. A one-hour allowance is assumed for the truck, and the estimated wait for a barge is two hours.

The times developed in Table 1 were used to construct Figure 4, which is quite similar to Figure 2 in the previous section. However, Figure 2 can be applied to all rail and rail-truck comparisons, while Figure 4 is designed for a specific crossing of the Mississippi River near St. Louis. The purpose of Figure 4 is to provide an easy means of evaluating whether rail or rail-truck-barge movements into St. Louis require less time. In order to use the figure, the procedure for Figure 2, previously given, is followed.

Table 1

OPERATIONS AND TIMES REQUIRED FOR RAIL-TRUCK-BARGE MOVEMENT

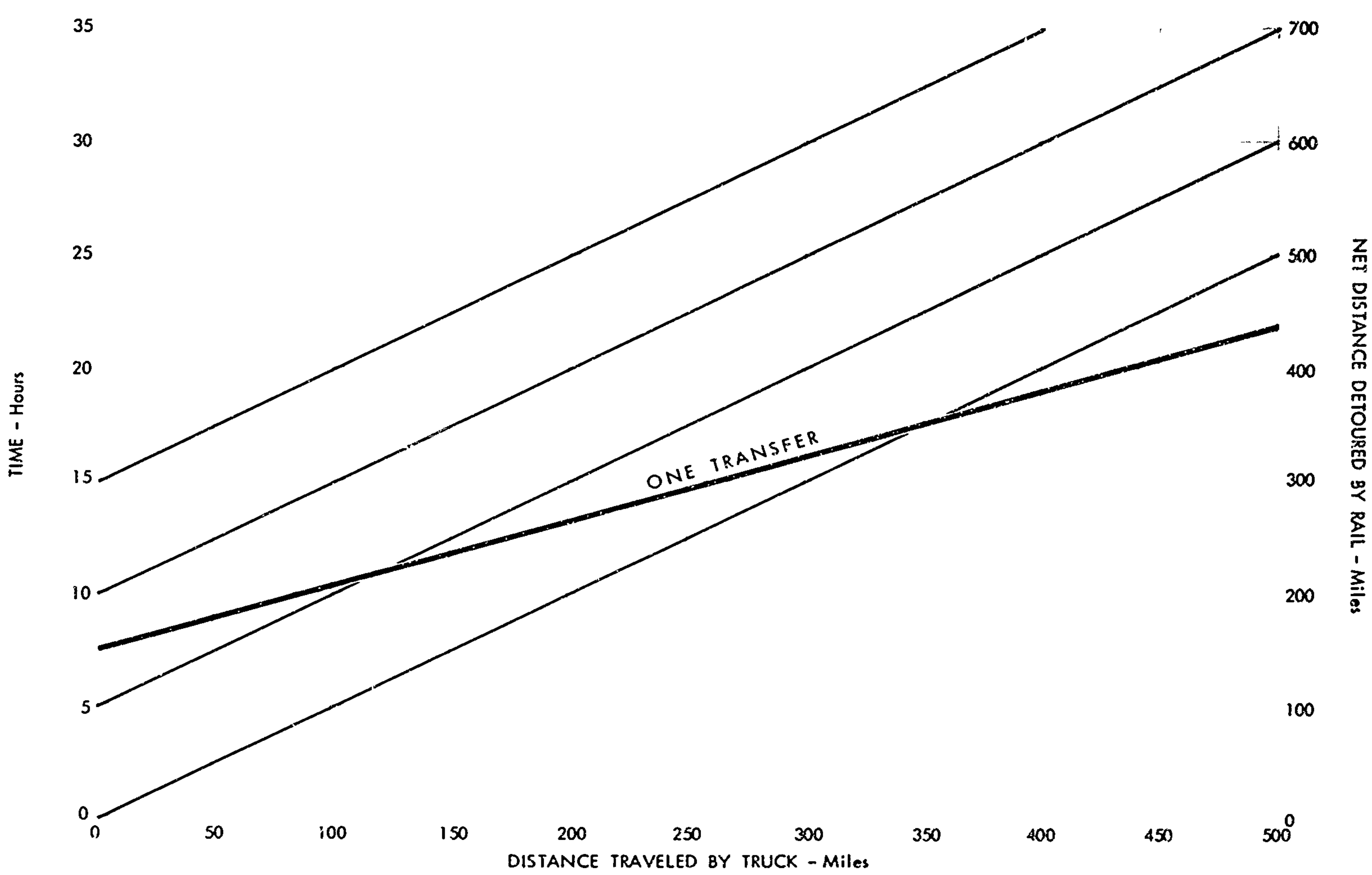
Operations	Time Required for Each Cargo Class - hours					
	Bulk Liquids*	Bulk Friables†	Unit Loads‡	Pallets§	TOFC**	Loose Cargo††
Set-up	0.5	1.0	--	--	0.5	--
Transfer 60 tons of cargo	2.2 (13,200 gal @ 100 gpm)	1.0 (50 tons @ 50 tons/hr)	0.4 (5 10,000-lb loads @ 5 min./load)	1.7 (50 1-ton loads @ 2 min./load)	0.6 (4 34,000-lb trailers @ 10 min. each)	4.2 (2 men @ 6 tons per man-hr)
Delay-wait for truck	1.0	1.0	1.0	1.0	1.0	1.0
Travel to Kimmswick	0.5	0.5	0.5	0.5	0.5	0.5
Delay-wait for barge	2.0	2.0	2.0	2.0	2.0	2.0
Barge loading	0.5	0.5	0.5	0.5	0.5	0.5
Barge travel to Harrisonville: 7 miles @ 5 mph	1.4	1.4	1.4	1.4	1.4	1.4
Barge unloading	0.5	0.5	0.5	0.5	0.5	0.5
Total time	8.6	7.9	6.3	7.6	7.0	10.1

Resource requirements:

*	One 100-gpm pump, hose, and couplings	One man
†	One 50-ton/hr conveyor-unloader	Two men
‡	One 10-ton forklift truck	One man
§	One 1.5-ton forklift truck	One man
**	One truck tractor, one ramp	One man
††	Two hand trucks	Two men

FIGURE 4

COMPARISON OF RAIL SYSTEM AND RAIL-TRUCK-BARGE SYSTEM TRAVEL TIMES
FOR PALLETIZED CARGO



Movements into St. Louis

According to the rail model in Reference 4, the primary cities from which cargo is moved directly into St. Louis are Kansas City, Indianapolis, Peoria, Toledo, and Houston. Shipments from Kansas City and Houston do not have to cross the Mississippi River, but can move into the St. Louis area by rail from the west or south and be transferred into pickup and delivery trucks at the fringes of the area.

Material from Peoria, Indianapolis, and Toledo must cross the Mississippi River in order to enter St. Louis. The following feasible methods for bringing rail cargo from these origins into St. Louis will be examined. First, the trains might be routed across the railroad bridges over the Mississippi and Missouri Rivers near Alton and enter St. Louis directly. Reference 5 estimates that 66 percent of the traffic capacity of the single-track bridge over the Mississippi would be required for the movement of trains carrying food for survivors in St. Louis and elsewhere. Since other cargo will also be required, it appears that this bridge will not have an adequate capacity to meet all needs.

Second, according to Reference 7, the Lewis and Clark highway bridges across the Mississippi and Missouri Rivers will be intact at Alton; highway access to the bridges will be the same as in the preattack situation. In addition, the probability, from Reference 7, is about 0.5 that the Chain of Rocks Bridge at the northern edge of St. Louis will sustain moderate damage. The equivalent damage probability for the Jefferson Barracks bridge at the south edge of the city is nearly 0.5. These bridges might be used for the movement of cargo into St. Louis by truck after the cargo was transferred from railroad cars into trucks on the east side of the Mississippi.

A third possibility is to use the highway bridges across the Mississippi at Louisiana, Missouri (90 miles north), Chester, Illinois (60 miles south), or Cape Girardeau, Missouri (110 miles south), for shipping cargo by truck after it has been transferred from railroad cars in Illinois. This concept might prove desirable for some cargo movements destined for locations near St. Louis.

A fourth possibility for trains coming from the east or southeast is for the trains to come as far as Waterloo, Illinois, 20 miles south of East St. Louis. At that point, the loads would be transferred into trucks, which would drive to Harrisonville. At Harrisonville, the trucks would drive onto barges and be ferried across the Mississippi to Kimmswick, from where they would drive into St. Louis. This route is the one outlined in Table 1.

Figure 2 provides a means for determining whether unimodal rail or rail-truck transportation should be used for bringing cargo into St. Louis. It is obvious that the railroad bridge at Alton should be used to full capacity by trains coming from the north or east because only a slight detour is required, and an intermodal transfer into a truck is eliminated.

However, it will be of interest to rank the other alternatives (including detour by rail to the bridges at Louisiana, Illmo, or Hannibal, Missouri).

Traffic from the Peoria area can choose one of several direct rail routes to St. Louis, crossing the Mississippi at Quincy, Illinois, or Hannibal or Louisiana, Missouri. An alternative is to move the cargo by rail to the Alton area, then by truck across the Chain of Rocks or Lewis and Clark Bridges. It is approximately 130 miles farther by rail to go all of the way into St. Louis. If trucks are used from Alton, the total distance they travel is approximately 16 miles. When the point corresponding to a 114-mile net rail detour and a 16-mile truck trip is located on Figure 2, it is clear that the intermodal transfer from train to truck should be made for palletized cargo. A similar analysis of traffic from Danville, Illinois to St. Louis shows that the rail route is about 115 miles longer than the rail portion of the rail-truck route. When the 16-mile truck movement portion of the rail-truck route is considered (net rail detour of 99 miles), and Figure 2 is consulted, we see that for palletized cargo, the rail-truck mode is the more efficient.

If the rail and highway bridges at Alton and the Chain of Rocks and Jefferson Barracks Bridges are either saturated with traffic or too badly damaged to be used, additional alternatives need to be analyzed. These alternatives entail a rail-truck-barge movement in which the cargo is moved as close as possible to a suitable expedient barge landing by rail, then transferred to a truck which is ferried across the river by a barge. The cargo remains on the truck for final movement into St. Louis. This alternative is of interest when the movement of cargo from Terre Haute, Indiana to St. Louis is considered.

Cargo may be moved from Terre Haute to St. Louis by three different means: (1) a rail movement of approximately 310 miles; (2) a 190-mile rail movement and 60 miles by truck; or (3) rail, truck, and barge movements of 190, 20, and 7 miles, respectively. When the above information with appropriate delays for bulk friables is inserted into the model given in the Parametric Analysis section, it is apparent that the rail-truck alternative results in the minimum shipping time, 14.2 hours, from Terre Haute to St. Louis. The rail and rail-truck-barge alternatives have associated shipping times of 15.5 and 18.0 hours, respectively.

Assuming the Early 1960s Military and Population Attack, the foregoing analysis leads to the following conclusions. First, References 5 and 7 state that the railway and highway bridges at Alton will probably be usable in the postattack situation. These bridges should be used to the extent of their capacity for the movement of rail and truck cargo. Second, according to Reference 7, it is likely that either the Chain of Rocks Bridge or the Jefferson Barracks Bridge will be usable after the attack. The clearing of the approaches to these bridges and the repair of the bridges should be given a high priority. After the clearing and repair have been completed, these bridges should be used as the primary highway approaches to St. Louis. For cargo coming from the East, it appears to be faster to transfer the loads from rail to trucks near the bridges than to detour trains through Louisiana, Hannibal, or Illmo, Missouri, or through Quincy, Illinois.

Third, if the Chain of Rocks and Jefferson Barracks Bridges are saturated with traffic or unusable due to damage, travel by rail to the highway bridge near Chester, Missouri, transfer of the cargo to a truck, and trucking it into St. Louis appears to be faster than a rail detour through Louisiana, Missouri.

Fourth, the rail-truck-barge movement of cargo into St. Louis appears to be desirable only if the railway bridges at Alton, Louisiana, and Hannibal and the highway bridges at Alton, Chain of Rocks, Jefferson Barracks, and Chester are unavailable or saturated with traffic. The expected delays in this three mode system are sufficiently great that it should only be used as a last resort or to supplement the more efficient rail and truck facilities if they are saturated.

Movements Through St. Louis

Cargo movements through St. Louis follow the same general patterns as movements into the city under preattack circumstances. The basic problems involved in moving cargo through St. Louis in a postattack situation are to find ways to detour around the city and to establish terminals where any necessary intermodal transfers normally performed at St. Louis can be made.

The rail transportation model described in Reference 4 shows that Kansas City, Indianapolis, Peoria, Toledo, and Houston are the cities sending and receiving the most traffic to and from St. Louis. The routes between each of those cities and St. Louis were examined. Alternate routes around St. Louis are discussed below to illustrate the most efficient means of moving cargo through St. Louis following the Early 1960s Military and Population Attack.

There are several alternate routes between Kansas City and St. Louis, but there are only three main approaches to St. Louis: (1) along the north bank of the Missouri River, crossing the river at St. Charles, and entering the city at Berkeley on the north side; (2) along the south bank of the Missouri River from Jefferson City and entering the city from the northwest at Clayton; and (3) along a southern route through Owensville and Union and entering the city on the west at Kirkwood.

In a postattack situation, cargo from Kansas City bypassing St. Louis and headed north or east could travel the first route (above), but instead of crossing the Missouri River at St. Charles, it could continue on the north side of the river through Machens and cross the Mississippi River near Alton. In order to avoid the damaged Granite City area, it would then be necessary to head north to Carlinville and then south to Smithboro to join the main line to Terre Haute if the destination were

Indianapolis. A detour of 35-50 miles is encountered if the alternate route through Alton is used. Figure 2 shows that it is always faster to make this detour than to transfer the cargo to a truck. No detour is necessary if the destination is Peoria or Indianapolis.

A substantially longer detour is necessary if the destination is the Belleville area. In fact, this is one of the worst cases for movements originating in Kansas City. There are four alternatives: (1) to head south to Pacific, then through the southwest corner of the metropolitan area, including Kirkwood and Shrewsbury, and transfer the cargo to a truck for a barge ferry crossing of the Mississippi; (2) to cross the rail bridge at Alton, head north to Carlinville, and then to come down through Centralia to Belleville; (3) to proceed by rail to Claryville, Missouri, transfer the cargo to trucks, cross the highway bridge to Chester, Illinois, and continue up Illinois Route 3 to Belleville; or (4) if the railroad bridge at Alton is unavailable, to proceed from Kansas City through Moberly and across the railroad bridge at Hannibal, Missouri; then the route runs through Jacksonville, Girard, and Centralia into Belleville.

The distances associated with these routes are: (1) 310 miles by rail, 7 miles by barge, and 35 miles by road; (2) 410 miles by rail; (3) 345 miles by rail, and 45 miles by road; (4) 430 miles by rail. From the model presented previously, the 20.5 hours required to traverse the 410 mile rail route for palletized cargo is less than the travel times for either the rail-truck or the rail-truck-barge system. The rail-truck system and the 430 mile rail route both require 21.5 hours to move the cargo, while the rail-truck-barge system requires 24.1 hours.

In a postattack situation, cargo moving from Peoria, Indianapolis, or Toledo west towards Kansas City would follow the path through Alton described above but would travel in the opposite direction. Alternatively, a northern route through Hannibal, Missouri or Quincy, Illinois might be used. Traffic destined for southern Missouri from Peoria, Indianapolis, and Toledo could follow several alternate courses, but the best of these appears to be to ship the cargo south through Illinois and to cross the Mississippi River at Thebes, Illinois to Illmo, Missouri. The cargo can then proceed south or southwest without an intermodal transfer.

Cargo from Houston can be divided at Hoxie, Arkansas, with the material destined for northern Missouri and Iowa being shipped through Springfield, Missouri through Clinton to the Missouri River crossing at Boonville. The Cargo en route to Illinois and the east can be shipped through Pine Bluff and McGehee, Arkansas, and can cross the Mississippi River at Helena, Arkansas. It can then proceed north around Memphis, Tennessee, and through Paducah, Kentucky. An alternative is to move the cargo north through Little Rock, Arkansas and Poplar Bluff, Missouri, then across the Mississippi at Illmo. For shipments from Houston and the southwest through St. Louis, there does not appear to be a need for intermodal transfer in order to bypass St. Louis, on the basis of this study. However, the destruction of railroad bridges at locations such as Memphis and St. Louis may saturate the remaining bridges at Alton, Illmo, Helena, etc., thus making it necessary to establish an emergency barge ferrying service across the Mississippi.

IV RESOURCE REQUIREMENTS

Survivor Support in St. Louis

According to Reference 7, population blast survivors in the St. Louis area would number about 587,000 west of the Mississippi and about 387,000 east of the Mississippi, or a total of 974,000 of the original 2,060,000 preattack population. Based on allowances of six pounds per day for food and three pounds per day for additional necessities such as water, medical supplies, and clothing, each survivor will require nine pounds of supplies per day. Therefore, the toal requirements for survivor support in the St. Louis area amount to about 4,400 tons per day.

Survivor support material will move into St. Louis primarily on trucks and trains. Since the mix of trucks and trains is not known, a brief parametric analysis showing the resources required for transporting the necessary supplies is shown in Table 2. In order to provide some perspective for postattack railroad and truck capability, the following information is presented.

Reference 5 states that delivery of 78 carloads of food per day to survivors would require careful coordination. Direct delivery to centers near consumers was estimated to require 15 additional locomotive units plus a comparable number to work in small yards where none are now located. The locomotives working in the yards would be capable of handling all traffic moving through St. Louis. If the additional burden of non-food materials for survivor support is considered, the requirement for locomotive units would be increased to 21 for the local delivery of supplies to survivors, assuming that all supplies are delivered by rail. However, the 15 locomotive units mentioned above would still be adequate for yard work.

Although postattack circumstances could dictate the delivery of food by rail to locations very near consumers, such circumstances are not likely to prevail. Terminals would be established in the best available areas (probably along rail spur tracks or sidings around the periphery of St. Louis), and supplies would be transferred from trains to pickup and delivery (PUD) trucks for delivery to the survivors. Therefore, a maximum of 15 locomotive units would be required for yard work in the St. Louis area, and a flow of 110 cars per day into St. Louis would be needed to bring in all survivor supplies by rail. Since not all survivor supplies would be transported by rail, the actual requirements could be substantially less. Movement of 50 percent of the cargo by train and 50 percent by truck seems more realistic. This would correspond to a requirement for 55 railroad cars per day for incoming survivor supplies.

Table 2

RESOURCE REQUIREMENTS FOR TRANSPORTING SURVIVOR SUPPORT MATERIALS

Transportation Mode	Percent of Survivor Support Requirements Shipped via Transportation Mode	Number of Vehicle Loads Required to Move One Day's Survivor Support Requirements
Rail*	100%	110
	75	73
	50	55
	25	28
Truck-Line-Haul†	100	259
	75	194
	50	130
	25	65
Truck-Pickup and Delivery‡	100	550
	75	413
	50	275
	25	138

* Assuming 40 tons per car.
† Assuming a 17-ton payload.
‡ Assuming an 8-ton payload.

Source: Stanford Research Institute.

Movement of all survivor support supplies by line-haul (L-H) trucks with 17-ton payloads would require nearly 260 loads each day. Assuming that the trucks are in service 16 hours per day, 290 L-H units would be needed if the average distance of movement were 250 miles. If the distance were as high as 500 miles, some 530 units would need to maintain the stated delivery rate. For a 250-mile length of haul, the number of trucks needed represents 20 percent of the 4-or-more axle, heavier than 50,000-pound gross cargo weight combinations estimated to be in areas with overpressures less than 3.0 psi. For the case where half of the survivor support cargo is shipped by rail and half by L-H truck, about 145 vehicles would be required, assuming a 250-mile hauling distance. This number is about 10 percent of the available vehicles of that type.

Assuming that L-H vehicles or railroads would deliver survivor support items to transfer points located an average of 5 miles away from the survivors, nearly 190 2-axle, 20,000-26,000 gross vehicle weight, single unit trucks would be required for final delivery. It is assumed that these trucks have an 8-ton payload, travel at an average speed of 10 mph, are used 8 hours per day and can be loaded or unloaded by two men with hand trucks at the rate of 18,000 pounds per hour.

Fuel Requirements in St. Louis

References 2, 4, 7, and 9 do not anticipate critical postattack fuel shortages for any set of attacks other than a direct attack on refineries. However, Reference 9 points out that if there is a direct attack on the refineries, the surviving fuel stocks would have to be rationed and apportioned between civilian and military needs. Therefore, some general ground rules will be given that might be applied to optimize the use of fuel if fuel shortages became a constraint on transportation operations.

References 4 and 8 give the fuel consumption in terms of gallons per net ton-mile--0.0036 for trains and 0.0032 for barges. Reference 7 shows consumption ranges of 0.011 to 0.018 gallons per net ton-mile for combinations in L-H operations, and of 0.05 to 0.4 for combinations and single units likely to be used for PUD activities. These fuel consumption rates show that truck transportation uses from 3 to 5 times more fuel per net ton-mile than do barges and railroads.

Figure 5 provides a means of determining whether rail or trucks of sizes varying from a 5-axle, diesel-powered, 62,000-lb gross combination weight (gCW) L-H vehicle to a 3-axle, gasoline-powered, 38,000-lb gross vehicle weight (GVW) vehicle should be used for transporting cargo, based on the minimum amount of fuel consumed per ton-mile. In order to determine whether rail or truck should be used, one locates the rail distance between the source and destination on the x-axis and the road distance along the y-axis. The point defined by these coordinates will fall into either the "Use Rail" or the "Use Truck" zone, for the particular truck of interest.

FIGURE 5

GRAPH TO DETERMINE WHETHER RAIL OR TRUCK SHOULD BE USED FOR CARGO DELIVERY (MINIMUM FUEL CONSUMPTION BASIS)

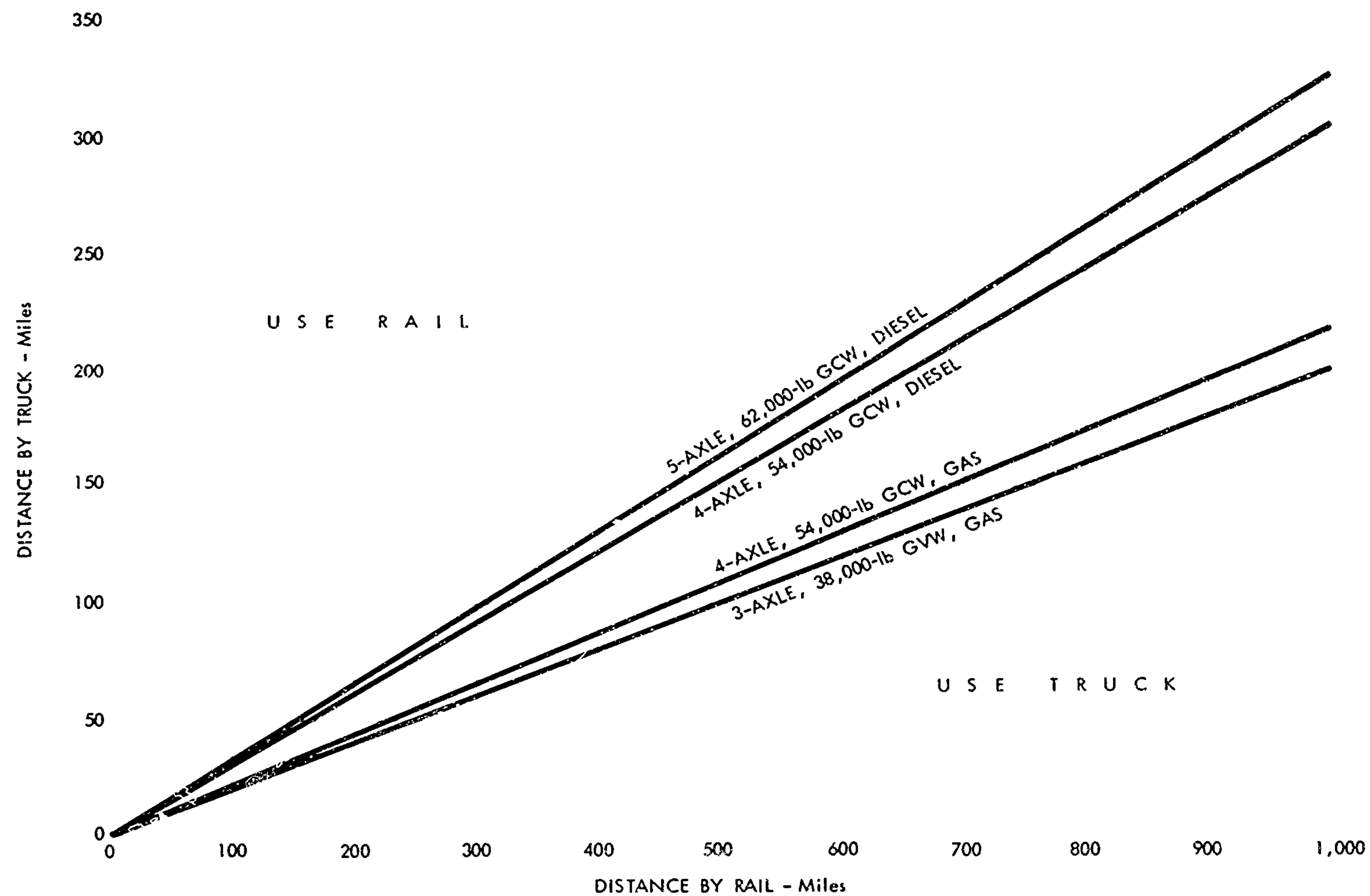


Figure 5 shows that if minimum fuel consumption per ton-mile is the measure of effectiveness, circuitous rail routes often are more economical than direct truck routes.

Manpower Requirements

The manpower required for load transfer depends upon the nature of the load and the available transfer equipment. For example, two men operating an atuomatic car dumper can transfer 2,000 tons per hour of bulk friables from railroad cars into hoppers, a rate of 1,000 tons per man-hour. When a man is equipped only with a shovel, his rate drops to about 2-1/2 tons per man-hour. This example is especially dramatic, but differences of a factor of ten in transfer rates (on a man-hour basis) for men with different types of equipment are not uncommon. Table 3 examines the load classes defined earlier and postulates transfer rates based upon likely available equipment. The rates in Table 3 should be regarded as reasonable average rates; however, the variance about these averages is sometimes quite large, as in the example above.

The relative productivity of a train crew measured in net ton-miles per day per man is normally substantially greater than the productivity of a truck driver. The train crew productivity per man could be as low as 3 times that of a truck driver or as high as 40 times that of a truck driver, depending primarily on the net tons being hauled by the train.

Table 3

LOAD TRANSFER RATES

Load Class	Transfer Equipment	Transfer Rate (tons per man-hour)
Bulk liquids	Engine driven pump (100 gpm), hose, couplings (1 man part-time)	24*
Bulk friables	Portable screw or bucket conveyor (2 men)	25
Heavy unit loads	Forklift trucks (10 tons), 1 man	120†
Palletized cargo	Forklift truck ($1\frac{1}{2}$ tons), 1 man	30‡
Containerized cargo		
TOFC	Truck tractor, 1 man	72§
Container	Forklift truck, 1 man	120**
Loose cargo	Hand truck	6††
Refrigerated cargo	See the appropriate class above for handling	

* Based on 8 lb/gal density.
† Based on 10-ton loads, 5-min. cycles.
‡ Based on 1-ton loads, 2-min. cycles.
§ Based on 24,000-lb net load, 10-min. cycle.
** Based on 10-ton container, 5-min. cycle.
†† Based on 50-lb packages.

V VULNERABILITY AND REMEDIAL ACTIONS

General Considerations

The purpose of this section is to summarize from the prior reports the data regarding vulnerability of domestic transporation systems. Two kinds of vulnerability are discussed in this section: (1) the vulnerability of specific transporation components to nuclear weapons effects--for example, the vulnerability of a truck, a bridge, an aircraft, or a particular type of building; and (2) the vulnerability of entire transporation systems to the sum of all weapons effects--i.e., total attack effects.

In determining vulnerability of components or of the total transportation system, our research has considered the various nuclear weapon effects (thermal radiation, dynamic pressure, overpressure, initial nuclear radiation, and residual nuclear radiation), and has eliminated all effects but two: overpressure and residual nuclear radiation (gamma radiation from fallout). The reasons are as follows. For thermal radiation effects, the damage radii were generally smaller than the damage radii based on overpressures. It was recognized that large areas could be devastated by fire, but the likelihood of such occurrences depends on too many uncertainties to be analyzed as a part of the transporation studies. As for blast effects, overpressure was selected because its effects have been quantified by previous research, whereas dynamic pressure is less understood. Finally, initial radiation is an immediate effect that cannot be separated from blast or fire except by arbitrary assumptions; delayed radiation, especially gamma from fallout, is readily isolated because it occurs alone and can be a serious hazard.

Blast Effects

Past work on blast effects is summarized below, by reference number and page number.

Reference 4

Rail network	page 38
Classification yards	page 41
Rolling stock	page 41
Labor force	page 43

Blast damage to an individual piece of equipment or a facility generally depends on a large number of variables. For example, the overpressure or dynamic pressure required to create a specific level of damage to a boxcar will depend partly on the orientation of the car to the direction of blast, partly on whether the car is loaded or empty, and partly on whether it is protected by surrounding cars. Of all of the transporation equipment and facilities examined in the series of studies, aircraft were found to be the most vulnerable to blast effects. Aircraft would be subject to light damage from overpressures in the 0.5 to 1.5 psi range and moderate to severe damage if overpressures were 1.5 to 3.0 psi.

The hardest target was considered to be waterway channels. These would be destroyed only by cratering.

In each of the studies, the criterion used for postattack availability of equipment or facilities was whether the equipment or facilities could be used following an attack with little or no repair or with little or no debris clearance. Use of this criterion resulted in roads and railroads being considered unusable in areas receiving overpressures of 3.0 psi or greater. At such overpressures, the probability would be greater than 0.5 that debris from trees, structures, telephone poles, and other roadway surroundings would block roadways. In addition, if a location was subjected to overpressures of 3 or more psi, the level of fallout would likely be high when weapons were detonated at or near the surface. Therefore, if any repairs were required or heavy debris needed to be cleared, it would be necessary to allow the fallout to decay to permit workmen to make the repairs or clear the debris.

When these criteria were used, railroads and highways were found to be about equally vulnerable to closure by blast effects. Airport runways would be considerably less vulnerable to closure than would highways and railroads, but terminal facilities and fueling facilities might not be available at the airports. Finally, waterways would be least vulnerable unless they were blocked by fallen bridge spans.

Fallout Hazards

The general method adopted in the initial study of this series (Reference 4) has been used throughout all of the studies. However, the method of assessing damage has changed during the period of the studies, and the results of the fallout analysis vary in form, depending on when the results were presented in this series. A general description of the method used is provided below.

Concerning the hazards created by fallout to workers in transportation, two major questions were asked:

1. How many or what fraction of the workers would be likely to survive and receive a sufficiently small radiation dose so that they could work effectively in the postattack period?

2. How soon could transportation operations be safely resumed in areas of various radiation intensities?

Answers to these questions were sought for all the workers in a particular transportation mode. The analysis required to produce these answers is a complex one. The possible combinations of exposure conditions for workers throughout the country are almost limitless, because there are a large number of variables affecting the postattack availability of workers. These variables include initial shelter conditions, exit times from shelter, exposure times, fallout intensities, decontamination procedures, protection factors applicable to worker environments, and authorized tolerance dose. To reduce the variables to a manageable set for workers in the transportation industry, a few representative combinations were used as illustrations of the fallout hazard. Other documents contain graphs and tables with a much wider variety of combinations of conditions. For example, see References 11 and 12.

The only type of radiation hazard considered in these transportation studies was external whole-body gamma radiation. Alpha and beta radiation and radiations from ingested particles were not considered, because such radiations would be much less significant in the immediate post-attack phase than external gamma, and could also be easily protected against. It was assumed that transportation personnel could work effectively if they receive an ERD (effective residual dose) of 200 roentgens (200 r) or less. This dose level has been generally adopted as a dose that would not prevent the average adult from performing normal activities and probably not cause sickness that would require medical care.[13] In converting total received dose to ERD, it has been assumed that 10% of the damage to cells in the body would be irreparable and that recovery from the remainder would occur at a rate of 2.5 percent per day. Fallout intensity was assumed to decay according to the familiar $t^{-1.2}$ law. Chapter 3 of Reference 11 provides a good discussion of these assumptions regarding decay rate, irreparable fraction, and recovery rate.

Number of Available Workers

The question of how many workers would be available following a nuclear attack could be answered if the attack characteristics and the number and location of the workers were known. Satisfactory data are not available on the number and location of workers in the transportation industry. However, in each of the studies a procedure was used to obtain a "best estimate" of the number of workers that would be available under the assumed attack conditions. Because of the differences in the data bases for the analyses of the different modes and the differences in damage assessment techniques over the period of the series of studies, the data presented in the reports are not directly comparable. Therefore, a convenient summary listing cannot be provided in this short report. Estimates of the number of workers that would be available in each of the modes following an attack can be found in the reference documents as follows:

Rail: Reference 4, page 60 ff

Truck: Reference 7, page 55 ff

Water: Reference 8, page 86 ff

Air: Reference 9, page 52

In each of the studies, it was noted that the quality of shelter available to transportation workers would significantly affect the number of available workers. For example, in the rail transportation industry, it appeared that following the assumed Early 1960s Military and Population Attack, if shelter with a protection factor of 200 were available to workers, about twice as many workers would be available compared to those occupying shelters with a protection factor of only 2.

Time That Transportation Operations Could Resume

The procedure for estimating the time when transportation operations could resume after attack was the same for the entire series of transportation studies. The basic equation in the evaluation is given as follows:

$$ERD = \frac{(I_1)(ERD/I_1)_{max}(F)}{P_e}$$

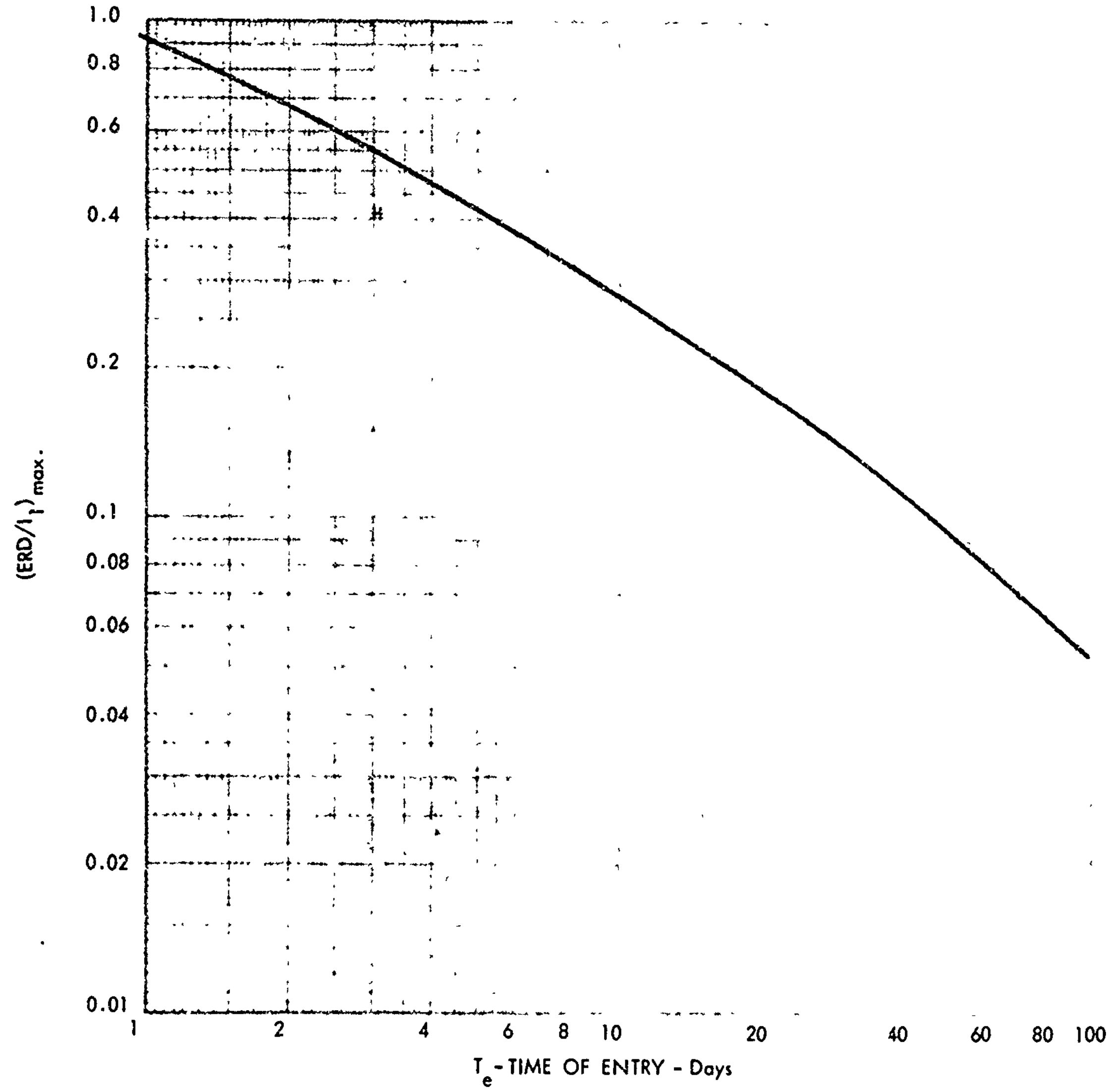
where ERD is the effective residual dose (in roentgens) that an individual would receive if he were in an environment in which the free field dose rate was I_1 r/hr, if he spent a fraction F of each day in the environment, if the environment equivalent protection factor were P_e, and if $(ERD/I_1)_{max}$ represented the maximum of the ERD curve for the appropriate time of entry into the environment. This simple equation can be used to compute the value for any one of the parameters when all the others are given or assumed. It can be applied in situations where the operational routine is a very simple one. For complex operational routines where a worker may be subjected to differing radiation intensities throughout the day, the computation of the equivalent residual dose in an "exact" fashion is a laborious task. However, for computing the time when transportation operations in general could be resumed following a nuclear attack, the above equation is entirely adequate.

Figure 6 shows a plot of $(ERD/I_1)_{max}$ versus time of entry (Te). By use of the values shown in Figure 6, it is a straightforward matter to draw curves showing the relationship between radiation intensity and time when operations could be resumed, for various protection factors and various operational routines expressed in terms of hours per day for each workshift. A few such curves are plotted in Figure 7.

In Figure 7, four sets of conditions are shown for each of two equivalent protection factors. One set of curves is applicable where the allowable dose is 200 r and the individual occupies the fallout area 24 hours per day. A second set of curves represents an allowable dose of 150 roentgens and a work shift of 8 hours per day, 7 days per week. A third set of curves represents an allowable dose of 100 roentgens and a workshift of 8 hours per day, 7 days per week. The final set of conditions represents an allowable dose of 25 roentgens and a workshift

FIGURE 6

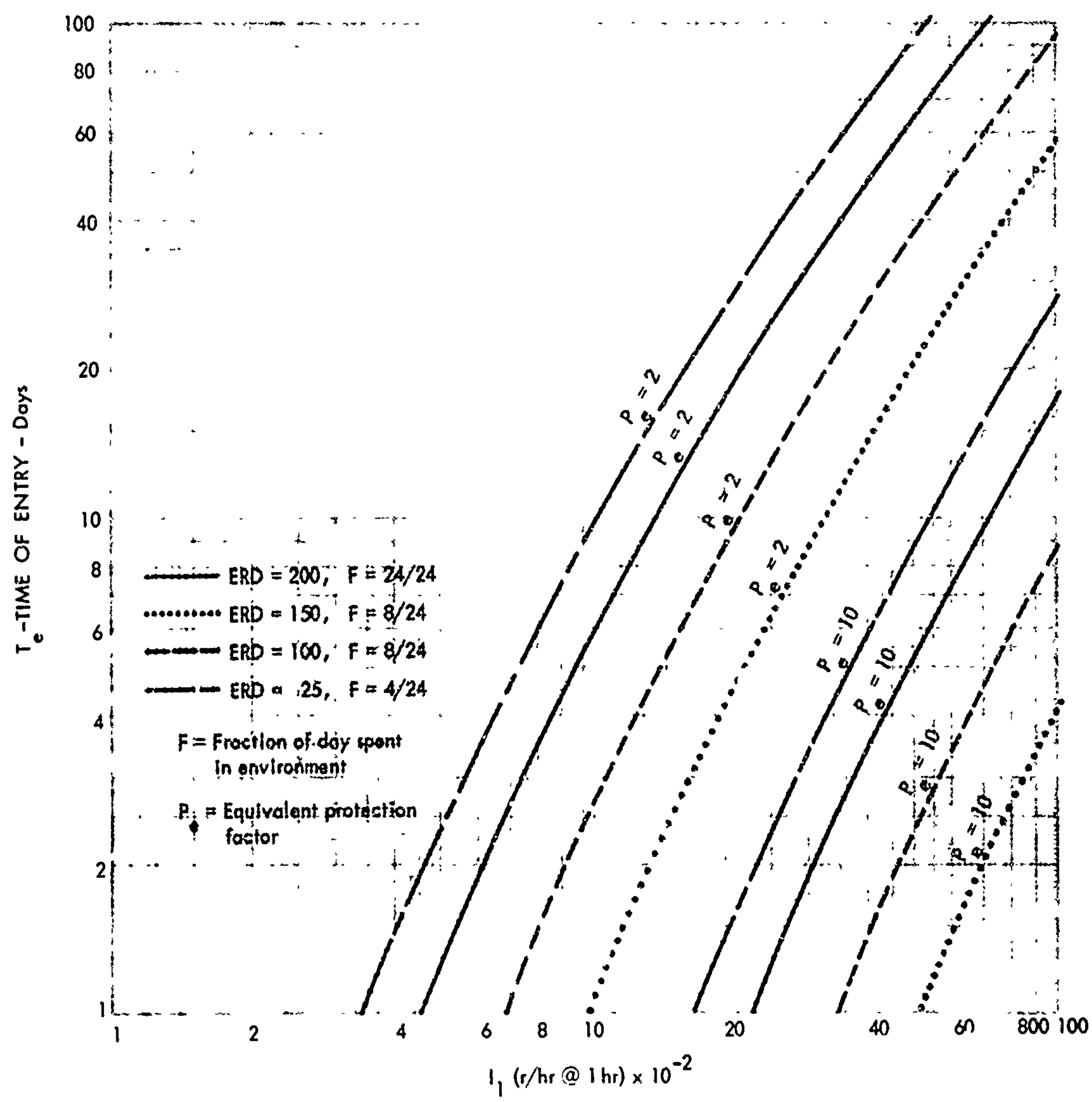
$(ERD/I_1)_{max.}$* VS TIME OF ENTRY



* $ERD/I_1 = f \int_{T_e}^{T} t^k dt + (1-f)e^{-\beta T} \int_{T_e}^{T} e^{\beta t} t^k dt$ where $f = 0.1$ $\beta = 0.025$ per day, $k = -1.2$

FIGURE 7

TIME OF ENTRY (T_e) VS REFERENCE INTENSITY (I_1)



of 4 hours per day, 7 days per week. It is a simple matter to draw similar curves to those in Figure 7 using the above equation and the curve in Figure 6.

In each of the studies in this series, the viewpoint was taken that the total dose received by workers could be divided into parts: the portion they received while occupying shelter immediately following an attack, and the portion they would receive after returning to work. The procedure followed in the studies was a conservative one; that is, the re-entry times computed following the procedure for any given intensity were later than the re-entry times that would be computed if the dose for the individual were continuously integrated along with the recovery rate in an "exact" fashion.

To arrive at an estimate of the allowable dose for workers after they returned to work, the weighted average of doses received by all workers in both the rail industry and the trucking industry was estimated (see References 4 and 7). It was estimated that the weighted average ERD_{max} for the available experience railroad labor force* would probably be less than 50 roentgens for all the attacks and conditions considered in the study. An improved means for damage assessment used in the truck study suggested that the equivalent figure for all truck drivers in the United States would be about 35 roentgens, and for the truck drivers in the metropolitan areas, about 60 roentgens. Thus, if the total allowable dose for workers were taken as 200 r ERD, it would be reasonable to assume that approximately 150 r ERD could be accumulated during work activities. These figures are considered as maximums for purposes of analysis. Obviously, any dose is undesirable, and the dose would be held to the minimum consistent with the importance of the task to be performed.

From Figure 7, some examples are tabulated below for given conditions under which workers can return to work in the postattack period:

Conditions	Time When Operations Can Be Resumed
1. Allowable dose 150 r ERD Work shift 8 hours per day, 7 days/week Protection factor of 2 Reference intensity 1,000 r/hr	Within 1 day
2. Same as 1 except that reference intensity is 3,300 r/hr	Within 10 days
3. Same as 1 except that the protection factor is 10 and the reference intensity is 5,000 r/hr	Within 1 day

* Available means all workers that would survive blast and would receive less than 200 roentgens ERD if they remained in their usual environment for the rest of their lives.

Conditions	Time When Operations Can Be Resumed
4. Same as 3 except that the reference intensity is 10,000 r/hr	Within about 4 days

Curves for lower doses of 100 r ERD and 25 r ERD are shown in Figure 7.

The curves in Figure 7 can be used to characterize in general the times when transportation operations could resume. For operations conducted in a building (e.g., loading and unloading at terminals), it should not be difficult to achieve an equivalent protection factor of 10 through a combination of decontamination and protection provided by the building. If operations in those areas were of sufficient importance to warrant personnel receiving 150 r ERD on the job, they could be started in a matter of one to a few days at very high reference intensities. For vehicle operations over the road, decontamination of a long roadway is not very practicable; therefore, equivalent protection factors would be those provided by the vehicle only. These factors might range from as low as 2 or 3 for a truck to almost 10 for a railroad locomotive. Trucks and trains travelling over the road would of course be subjected to varying intensity levels. Analyses of trucks crossing a very heavy fallout pattern (downwind from seven 4-MT weapons) indicated that even for a protection factor of 2, trucking operations could be started back and forth across such a high-intensity area within about 2 days if the allowable dose were 150 r ERD. Examination of fallout contours on a countrywide basis from a variety of attacks suggests that average fallout intensities would not be as great as those used in this particular analysis. Thus it seems safe to assume that if transportation operations were of sufficient importance to warrant vehicle crews receiving up to 150 r ERD on the job, rail and truck operations could be resumed in most areas of the country within a matter of a few days following a nuclear attack. Nevertheless, in the most urgent cases, a few days would be too long to wait. In these cases, shielding, decontamination, or other countermeasures could be applied to shorten the waiting time.

One characteristic of water transportation is worth noting in this general summary. Since most navigable waterways in the United States are hundreds of feet wide and several feet deep, water transportation operations could be resumed immediately after fallout had been deposited with little hazard to the crew while the vessel is operating in the waterway. Also, for air transportation, if the terminal area was decontaminated, operations could be resumed within a matter of days (or even hours) following a nuclear attack.

System Vulnerability and Remedial Actions

A summary of the transportation system vulnerability and the remedial actions that were identified in each of the individual mode studies is presented in this section. No attempt has been made in any of the studies to evaluate the cost or the effectiveness of remedial actions. However, in each particular problem situation, an attempt has been made to identify what appeared to be the most appropriate remedial action.

Railroad Freight Transportation

In analyzing all of the components of the railroad transportation system, no evidence was found to suggest that any single component would be the most limiting component for a wide variety of attack conditions. In some geographical areas, the lack of adequate classification yards would limit the system capability; in other areas, the lack of rail lines would be a limiting factor. In still other situations, train crews might be the limiting portion of the system, and in still other situations, freight cars might be the limiting component.

The capability of the system would be sensitive to the manner in which the system was managed. Substantial physical resources of all types needed to operate a rail system would survive. In any attack that included large cities as targets, the normal patterns of railroad operations would be disrupted. Postattack managements would have to improvise to re-establish efficient system operations. Unless provisions were made to assure efficient management in the postattack period, the capability of the railroad system could be greatly reduced below what it would be for an efficiently operated system. Remedial actions for this particular problem would include training of key personnel and planning for actions to be taken in the event that key facilities or services were lost.

Fallout hazards for railroad workers would be serious in the case of attacks on cities. For the Early 1960s Military and Population Attack, good fallout shelter could approximately double the number of available workers following an attack compared to those that would be available if no special provisions were made for shelter. Following the Late 1960s Military and Population Attack, approximately 4 to 5 times as many workers would be available if good shelter were available compared to no special shelter provisions. The remedial action in this case is obvious--provide fallout shelter with a suitable protection factor. Provisions for decontamination of key control centers and other facilities would make it possible to resume operations sooner after an attack than if no such provision were made.

Loss of electric power would hamper or prevent operations in most industries including the railroads. Power would be particularly vital for classification yards and signaling systems if rail operations are to be continued. Most classification yards and signaling systems are critically dependent on electric power. Loss of electric power will prevent operation of most classification yards and will render signaling systems inoperative as soon as the battery power is consumed. Remedial action in this case would be the provision of means to supply standby power to key classification yards and signaling systems in the event of electric power failure.

Switching locomotives tend to be concentrated in metropolitan areas. As a result, in an attack on cities, more switching locomotives would be damaged, proportionate to their numbers, than other rolling stock. Should there be adequate warning of an impending attack a remedial action could be the evacuation of switching locomotives to sidings outside the metropolitan areas.

The problem of loading and unloading freight cars could be a very serious one if terminals are badly damaged or destroyed in an attack on cities. Remedial action for this problem would include planning for makeshift terminals in areas outside expected targets, devising means to provide materials handling equipment for loading and unloading.

Spare parts and maintenance capability for locomotives has become concentrated in a few locations. These appear to be vulnerable to an attack on metropolitan areas. While this problem may not be serious immediately following an attack, it will become progressively more serious as locomotives become inoperative for lack of maintenance. A remedial action for this situation would be the stockpiling of spare parts and maintenance manuals outside target areas.

In most target areas, rail lines would be blocked by debris or rubble at many locations where the rail line itself would probably be undamaged. In the attacks on metropolitan areas, it appeared that large sections of undamaged track would be closed because of debris. A remedial action for this situation would be the provision of equipment for the removal of debris from track.

Motor Truck Transportation

Significant fractions of the physical resources needed for postattack truck transportation would survive even the most damaging attack. The productiveness of trucking operations in unfamiliar postattack conditions would clearly depend upon the quality of the management of the operation. As was the case for rail transportation, a remedial action for this situation would be training and planning for emergency situations.

As is the case for any system involving personnel, trucking operations would be vulnerable to the effects of fallout. Remedial action, of course, is the provision of fallout shelter. It was estimated that if good fallout shelter were available to personnel in the trucking industry, approximately 1.3 times as many workers would be available following the Early 1960s Military and Population Attack and approximately 2.7 times as many workers would be available following the Late 1960s Military and Population Attack as would be available if no provision were made for special fallout shelter.

Roadways appeared to be most vulnerable to blockage by debris. Remedial action in this case would be the provision of equipment for debris removal. In almost all metropolitan areas studied it appeared highly desirable to have at least some limited capability to remove debris using equipment that provided radiation protection for the operator.

In this way critical roadway sections having light debris could be cleared for traffic even if the fallout intensity were high.

Water Transportation

Unlike other transportation networks, the inland waterways of the United States form "tree" networks. Therefore, a blockage of the channel at any point tends to isolate the portion of the network above the point from the portion below the point. Because of the tree character of the network, with few exceptions, there is no way to use alternative water routes for circumventing a particular channel blockage. This particular characteristic represents the most vulnerable aspect of the inland water transportation system.

There are many bridge spans across navigable waterways in the United States and many dams and locks essential to maintaining proper water depths for navigation. In any general nuclear attack against cities in the United States, the probability is high that long bridge spans will be dropped into navigable waterways and will block the waterway. Similarly, blast damage to locks or dams could prevent navigation. An obvious remedial action in this case would be to construct bridges that are more difficult to knock down; however, a more practical remedial action would be the development of efficient methods to remove bridge sections from channels or efficient means to transfer barge cargoes, either by land or by water, around blockages. In the long term, new construction of bridges, dams, and locks could be designed or located to reduce their vulnerability to damage or destruction by nuclear blast.

The vulnerability of vessels to damage or destruction in a nuclear attack could be reduced by establishing operating procedures that would permit rapid vessel dispersal from target areas upon warning of impending attack. Training civilian vessel crews in ship decontamination methods and providing instrumentation on ships to assist in maneuvering to avoid the more serious fallout areas would be useful vulnerability reduction techniques. The U.S. Navy has already done considerable work on ship operations both during and after attack.

Skilled personnel in the marine transportation industry, particularly longshoremen, appear to be considerably more vulnerable to a nuclear attack on cities than would be the general population in the United States. This is so because a large majority of the longshoremen tend to be concentrated in a relatively small number of large port cities. Remedial action on this point would include the development of plans for training workers in a short time to augment the surviving workers in the marine transportation industry. A preattack measure could be the provision of adequate shelter for these personnel.

Air Transportation

The vulnerability of common carrier aircraft can be considered in two parts. One part is concerned with the problem of retrieving aircraft in flight when an attack occurs or is impending. The other problem is concerned with the fact that normal aircraft overnight parking patterns place a substantial fraction of the total fleet at airports and major metropolitan areas. Remedial action for reducing the vulnerability of aircraft in flight would include more effective programs for diverting such aircraft to airfields that are less likely to be in target areas. For aircraft that are parked overnight in large metropolitan areas, alternative standby plans could be developed so that aircraft could be moved to less vulnerable locations during periods of impending crisis.

Regarding the fallout hazards to air transportation systems, it appears that all efforts directed at reducing vulnerability to fallout should be directed toward reducing fallout intensities (e.g., by decontamination) or providing additional protection to key terminal and servicing facilities.

Air carrier support facilities, such as maintenance facilities and spare parts inventories, tend to be located in large metropolitan areas and are thus vulnerable to an attack on cities. Without adequate maintenance and spare parts, the aircraft inventory would very rapidly dwindle. A remedial action to reduce the vulnerability in this case might be to locate one or more pools of spare parts and maintenance equipment at airports expected to be safe havens.

General aviation, when considered as a whole, represents a substantial air transportation capability. The aircraft, personnel, and facilities associated with general aviation are distributed widely throughout the country. From this standpoint, they are relatively less vulnerable to nuclear attack than are the common carrier systems. However, because of their diffuse nature, the general aviation system might be considered vulnerable from the standpoint of a lack of plans to organize and use the surviving capability. Remedial action in this case would consist of planning and organizaing for the efficient use of surviving general aviation equipment, personnel, and facilities.

Mode Interaction

As in the individual modes, good management will be important if the operations of two or more modes are to be integrated. In particular, makeshift terminals may need to be established and materials handling equipment acquired to permit efficient load transfer operations. Remedial actions in this case would be training key personnel, identifying locations outside likely target areas that could be used as terminals, identifying materials handling equipment that could be used, and planning for the postattack operations. Such plans should include emergency-type procedures and provision for redundancy of key functions.

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13. ABSTRACT

The operations and equipment used in transferring vehicle loads between two vehicles or between a vehicle and a terminal are examined for seven different classes of cargo. For each of these classes, the usual method of load transfer is discussed, and expedient methods that could be used in a postattack situation are suggested.

St. Louis, Missouri is used to illustrate the problem of moving cargo through a damaged area after a nuclear attack. Several alternative methods of moving cargo via multiple transportation modes are analyzed, and a simple procedure for determining the minimum-time route among the alternatives is proposed.

The transportation resources required to deliver the minimum supplies for survivor support in the St. Louis area are analyzed for different mixes of trains and trucks and for movements of the supplies over a range of distances.

A general summary of the vulnerability of each transportation mode to nuclear attack is provided, and the remedial actions that might be taken in the preattack period to enhance postattack capability are discussed.

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