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STRATEGIC INDUSTRY ATTACK

The BDM Corporation
7915 Jones Branch Drive
McLean, Virginia 22102

15 January 1980

Final Report for Period 1 July 1978—15 January 1980

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This report describes an industrial simulation model, INDATAK, which has been developed by The BDM Corporation for the Defense Nuclear Agency. The INDATAK model provides a quantitative means of estimating the impact of interruption or destruction of one or more critical elements of a major Soviet industry. Thus, INDATAK can be used to measure the economic impact and estimate the effect on Soviet war fighting capability of an attack on the industrial installations and/or the

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supporting transportation network.

PREFACE

The BDM Corporation is pleased to submit this report to the Defense Nuclear Agency, Washington, D.C., 20305 as required by Contract Number DNA001-78-C-0323. The purpose of this study is to develop, debug and test an industrial simulation model (INDATAK) using the LOGATAK model as a point of departure. The copper processing industry is researched to define all activities and other relationships which must be simulated in the model. The data base describing the characteristics of all significant processes in the copper industry, including the transportation network connecting the processing elements, have been formatted for use in the model. The model was then tested for operational validation using the copper industry as the test case. A corollary purpose was to develop a means of determining the relative importance of various factors and parameters which would influence the successful prosecution of a strategic attack on the industry and how these factors affect the ability of the industry to recover to a reasonable production rate after the attack.

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SECTION 1
EXECUTIVE SUMMARY

1-1 INTRODUCTION

In July 1977, the BDM Corporation (BDM) began a program for the Defense Nuclear Agency (DNA) as a part of an overall Target Damage Requirement Study (TDRS) in support of the Supreme Headquarters, Allied Powers in Europe (SHAPE). During this effort, a LOGATAK simulation model has been developed. This is a transportation interdiction model based on the MAWLOGS (Model of Army Worldwide Logistics) modeling system. It models the movement of forces and logistics along railroad and highway networks and measures the delays caused by congestion and interdiction. It was recognized by DNA that the LOGATAK simulation model had a potential as an analytical tool to develop an industrial model which would evaluate the impact of interruption or destruction of critical elements of industrial processes. This resulted in a requirement for the development of an INDATAK model which would simulate major industries. Accordingly, in September 1978, BDM began the research necessary for this development using the LOGATAK model as a point of departure. The Soviet copper industry was selected as the industry to simulate for this effort.

1-2 INDATAK MODEL

The INDATAK Model is a flexible simulation designed to model one or more large strategic industries, to measure the impact of interdiction on key processing elements of the industrial network, and to aid in developing viable attack strategies on the candidate industries. The model represents geographically dispersed and interdependent manufacturing or producing facilities connected by a transportation network. Product demands, manufacturing and transportation shipments are simulated over time to permit analysis of production levels, material flows between processing sites and transportation network loading. The model can represent attack against production facilities and subsequent rebuild and contains logic that allows the industry to adapt to the destruction or disruption of key elements in the production chain.

The model was designed to measure industrial production over time under varying conditions of demand, material availability, and attack and thus can be used to determine the relative merit of different targets and to compare the effectiveness the relative merit of different targets and to compare the effectiveness of different targeting strategies.

1-3 SOVIET COPPER INDUSTRY

For the purpose of demonstrating the viability of the INDATAK model, it was necessary to select an industry to simulate which was sufficiently complex to properly exercise the model and yet one which could reasonably be analyzed by other methods in order to validate the results. The Soviet copper industry had these characteristics and was therefore selected for the purpose of exercising the model.

The Soviet copper industry has experienced a rapid growth rate since the New Economic Policy (NEP) was issued in 1921. At that time, no copper was being produced as a result of the Russian Revolution. Today the Soviets are the world's second largest copper producer with an output of about 1.5 million metric tons per year. Recent high-production mining of copper ore has shifted to open-pit operations. This was made possible by the development of suitable machinery for this type of ore removal and by the discovery of large new ore bodies. There are seven widely dispersed geographical areas in which copper is produced in the Soviet Union. This is discussed briefly in Section 4 and in more detail in Appendix A of this report.

1-4 MODEL APPLICATION

The Soviet copper industry was analyzed in detail in order to provide the necessary industry data input to the model. For the purposes of exercising the model, the entire industrial array of 35 ore concentrators, 13 smelters and 8 refineries was used in the model application. The specific materials input, product output and location by geographical coordinates of each facility was entered into the model. The estimated restart times after short shutdowns were also entered. The 44 mines were not included in the exercise. The reasons being: (1) the relative target hardness of the mines compared with the related industrial facilities make them unlikely targets; and (2) appreciably savings in computer time was gained.

The core of the INDATAK effort is the transportation network which services the copper industry. Because of the magnitude of the Soviet land mass and the widely separated copper producing installations, the model was confined to the major rail links and the terminals which are integral parts of the industry. This model accurately assesses the present copper transportation network. It permits an analysis of the industrial crippling effects of the combined destruction of copper production facilities and transportation links.

1-5 SIMULATION RESULTS

The INDATAK model of the copper industry was run under two ırget-ing situations devised to determine: (1) the amount of productic loss which would result from a limited number of weapons used against sı cific facilities; and (2) the usefulness of the model in the determinatic of the ability of the industry to overcome the loss of a single large production plant.

It was found that when a limited number of weapons are available, the maximum production loss was achieved when all the available weapons were applied against one production tier or plant category of the industry, and when this tier represented the narrowest point in terms of numbers of plant locations. In the copper industry case te best attack strategy would be to concentrate the attack on the refineries. The results are shown graphically in Figure 6-3.

In order to determine the model's ability to adapt the industry to changing conditions, four model runs were made. Each of these runs assumed one plant was destroyed. Two of the runs assumed separate attacks on each of the two largest refineries. The other two runs attacked each of the two largest smelters separately. A comparison analysis of the results of these four model runs shows the ability of the model to adapt the industry to changing conditions. When one large plant is destroyed, the other plants pickup a part of the lost production. However, as shown in Figures 6-6 and 6-7 there is a net loss in production over the 28 weeks simulated.

These runs also provided insights into the transportation problems associated with raw material and product distribution when an intermediate processor (smelter in this case) is destroyed.

1-6 CONCLUSIONS AND RECOMMENDATIONS

1-6.1 Conclusions

The INDATAK model has demonstrated the feasibility of using simulation as a tool which can be used to estimate the impact of strategic strikes on an industry.

Valuable insights have been gained into the roles of inventories and transportation capacity in post-attack recovery.

1-6.2 Recommendations

Based on the INDATAK model study of the copper industry, it is recommended that:

(1) INDATAK be expanded to multiple industries to further address the questions of geographic distribution, inter-industry competition for resources, and the value of bonus effects on collocated industrial facilities.

(2) Th industries selected for this expansion be the steel and chemical industries. These could be used in conjunction with the copper industry to investigate the questions noted in (1) above. The Soviet steel industry is similar in nature to the copper industry and will demonstrate the flexibility of INDATAK to model similar industries. The Soviet chemical industry would provide INDATAK with a more complex modeling situation. This study will show the interaction between the three industries and the collective effect of their competition for transportation resources.

SECTION 2
INTRODUCTION

2-1 BACKGROUND, OBJECTIVE AND WORK STATEMENT

2-1.1 Background

The problem of selecting the best set of targets to attack in order to achieve a desired reduction in the output of an enemy industry has been of importance to U.S. strategic planners for several decades. A considerable amount of information on the strategic industries of potential adversaries has been collected, econometric models of the operation of these industries have been developed, and many target plans have been prepared. For many years the targets, which would be attacked in the event of war, have been identified by these methods. In the past one type of useful tool has not been available for the preparation of these plans. This is a computerized simulation which models the detailed operation of a complete strategic industry system in such a way that the contribution of individual elements of an industry to the entire industrial operation can be readily varied and studied. This report describes the results of a research effort to develop such a model.

In July 1977, BDM began a program for DNA as a part of the overall Target Damage Requirement Study (TDRS) in support of the Supreme Headquarters, Allied Powers in Europe (SHAPE). The objective of that study was to examine SHAPE doctrines for interdiction of railroad and highway lines-of-communication in Central Europe, and to recommend useful modifications of the doctrines, as well as desirable alternative approaches for efficiently achieving the overall objective. A logistics simulation model called LOGATAK developed by BDM for DNA was used as an analytical tool in the initial effort. The importance of this initial approach was the determination of the feasibility (value) of such a network analysis tool to the overall development of interdiction on strategy against the Warsaw Pact.

LOGATAK is a transportation/interdiction model, based on the MAWLOGS (Model of the Army Worldwide Logistics) modeling system. It models the movement of forces and logistics along a railroad and highway network, and measures the delays caused by congestion and interdiction. The most significant result of the initial effort was a recommended alternative approach to interdiction in Central Europe which SHAPE felt could form the basis for future SHAPE targeting activities.

A follow-on research program (currently in process) is designed to refine the interdiction strategy against Warsaw Pact second echelon forces in the Central and Southern European Regions which allows for improved peacetime planning and, if required, more efficient time-phased allocation of NATO resources during war time operations. The present approach uses the fundamental methodology developed in the initial effort in which the LOGATAK simulation is a critical analytical tool.

The LOGATAK simulation model was developed for DNA to assess the impact of interdiction on a logistics network and to aid in developing attack strategies on the network. The model represents a multi-echelon supply system connected by a multi-mode transportation network. The movement of shipments throughout the network is simulated over time to permit the analysis of traffic flows and overloads. The model utilizes the available transportation capability to move all shipments and chooses alternative routes if overloads or attacks reduce the capability.

The model was designed to handle a wide range of scenarios and transportation networks. The user can select any geographic area that is covered by the data base and specify the location of supply bases and the movement units over the area selected. Varying demand patterns may be specified to represent changing conditions on the battlefield. The demands from units in different locations drive the model to satisfy the movement requirements over the transportation network.

The normal mode of operation for the LOGATAK model is a baseline run where no interdiction is performed, followed by a series of runs to test the effect of various attack strategies. A comparative analysis can then be performed on the system response under varying conditions.

It was recognized by the DNA that the LOGATAK simulation model contained most of the logical features required for the needed strategic industry attack model (INDATAK). It, therefore, had a good potential to serve as a point of departure in the development of a simulation model which would be used in the evaluation of the economic and strategic impact resulting from the interruption or destruction of one or more critical elements or processes in major industries. There is, in fact, a considerable amount of commonality between industrial processes and the elements used in the LOGATAK model. They both have material demands and supplies. They both require utilization of transportation networks. Scheduling of various events or processes is critical for efficient operation of both. Accordingly, many of the functions necessary to develop the INDATAK model are taken from the LOGATAK model and its predecessor, the MAWLOGS systems. The major new add-on functions required for the INDATAK program are modules to represent industrial production activities.

2-1.2 Objective

The principal objective of developing the INDATAK model is the selection of a set of geographic target points which constitute a highly efficient attack plan capable of imposing a desired reduction in the output of a strategic industry. These target points may consist of factory locations, nodes or links in the transportation network connecting factories, utility installations which service factories, or combinations of these three classes of targets. A corollary objective is an understanding of the importance of the various factors and parameters which influence the successful prosecution of a strategic industry attack, and how these factors affect the ability of the industry to recover to a reasonable production rate after the attack.

2-1.3 Work Statement

The following tasks outlined the scope of work and the parameters used to accomplish the above objective.

(1) TASK 1. Define Hierarchy of Candidate Industry

The selected industry, copper processing, will be researched to define all activities and other interrelationships which must be simulated in the model.

(2) TASK 2. Prepare Data Base

A data base, describing the characteristics of all significant processing elements of the copper industry including the transportation network connecting the processing elements will be prepared. The information will be formatted for use in the model. Inclusion of the supporting utility systems (electricity and gas) in the data base will be done if time and resources permit.

(3) TASK 3. Develop INDATAK Model

Using LOGATAK as a point of departure, the INDATAK model will be developed, debugged, and validated. Provision of logic, to include supporting utility systems, will be made in the mode but will be validated and exercised only if time and resources are available.

(4) TASK 4. Operational Demonstration

After validation of the model, an Operational Demonstration of satisfactory operation will be made to DNA.

(5) TASK 5. Model Exercise

The model will be exercised to gain insights into the response of the copper industry to various types of strategic attack, and to select preferred alternatives. Sensitivity of results to uncertainties in the data base will also be investigated.

2-2 SIMULATION

The purpose of the INDATAK simulation is to attempt to represent a complete industry (or group of industries through the use of a mathematical model. The model developed for this purpose is a large computer program written in the FORTRAN language and operates on a Control Data Corporation CYBER 1976 computer system. The simulation is designed to simplify an extremely complex task by removing as many variables as possible, generalizing those that remain, and combining them into a model that represents the real industry relatively accurately.

2-3 USE OF THE SIMULATION TECHNIQUE

Once the model is constructed a number of adjustments must be made to some of the variables. This is necessary in order to obtain results which correspond to the real-life situation.

The first useable product of the simulation model is the baseline case. This is a paper representation of the normal industrial operation without attacks on any of supply, transportation or production elements. The baseline is the output to which all subsequent model exercises are compared. It is, where possible, compared with similar information from other sources in order to assure the reliability of the results. Once a valid baseline is established, perturbations may be introduced into the simulation and the effects of these perturbations can be measured. In the INDATAK simulation model, the perturbations are attacks which impair or halt key industrial processes for periods of time required for repair or rebuild a plant or reestablish a supply source.

The INDATAK simulation model serves as a tool to aid a targeting analyst in assessing the changes imposed on the industry being studied by attacks on elements of the industry. It can assist in the determination of the most profitable industrial targets to strike with limited attack resources.

2-4 COPPER INDUSTRY TEST CASE

A number of factors were carefully considered in the process of selecting the copper industry as a "test case" strategic industry for exercising the INDATAK model. The strategic industries of Soviet Russia can be described or identified in several ways. One fundamental categorization is the relative importance of the steps in the industrial process from a finished product back to the raw materials from which the product is obtained. This general concept can be further extended according to the immediacy of the effect of damage upon the Soviet war effort. The following list defines six levels of this categorization:

(1) War consumable items, e.g., ammunition of POL,

(2) Finished equipment, e.g., aircraft or ships,

(3) Semi-finished productions or components, e.g., aluminum extrusions, sulfuric acid or aircraft engines,

(4) Raw materials, e.g., copper or sulfur,

(5) Factory equipment, e.g., electric transformers or machine tools, and

(6) Utilities, e.g., electricity or natural gas.

With the exception of item (6), items high in the list have a more immediate effect on war making capability, and items low on the list have a more futuristic effect. Utilities, of course, can influence any other items in the list. In considering the breadth of influence of these items, the effect will spread laterally as one goes either up or down the list; that is, a finished equipment item, such as an aircraft, will draw from many raw materials and a single raw material, such as copper, will be used in many different finished items.

Another industrial characteristic to consider in the test case selection is the number of locations occupied for the industry. For example, there are many steel rolling mills in the Soviet Union but only a handful of factories that build light automatic cannons. Still another factor to consider is the geographic network complexity of an industry. For example, the steel industry makes use of widely scattered iron ore and coal mines from which materials must be taken to a large number of widely scattered blast furnaces and then to a different set of steel fabrication plants. As an opposite extreme, the plants which produce sulfuric acid are almost completely self-contained. Many of these plants make use of waste sulfur dioxide gas produced by another facility such as a copper smelter and are localized with minimal needs for a transportation network.

It was considered desirable that the strategic industry selected to initially exercise the INDATAK model should have the following characteristics:

(1) It should be a target system of significant military importance;

(2) It should be representative of a rather complex Soviet industry having the following features:

(a) several hierarchial levels of processing,

(b) geographical diversity,

(c) dependent on at least one significant utility, and

(d) either a basic industry or a finished product of wide diversity;

(3) It should be "not too complex but not too simple;" that is, it should be a good hard workout without exceeding contract resources.

Inasmuch as the purpose of producing a model like INDATAK is to solve the hard problems rather than the easy problems, the candidate industry should preferably be typical of the more complex members of the Soviet industrial society rather than an average of all such establishments. An industry with many levels of functions and widespread geographical diversity is desirable because it is this type of industry which returns the biggest payoff from analytical solutions.

A number of different industries were considered as candidates to be modeled by INDATAK. Some of these, such as the steel industry and the POL industry, are excellent, sophisticated examples but were considered to be too complex and widespread to be affordable within the initial contract resources. Other industries such as electric transformer production are very attractive military targets in that they have very few fabrication plants and a widespread impact on the economy, but such examples are not considered to be the best to exercise INDATAK because the proper attack strategy is too simple and too obvious. Still other industries like sulfuric acid have great industrial importance but are too simple in their network structure and too diverse in their geographic distribution to hope for key target sets which have high payoff. In considering various potential industries, the copper producing industry was selected as the best candidate.

The copper industry is similar to the steel industry in the diversification of its processing functions; it has mines, smelters, electrolytic refining plants, and fabrication plants such as wire-producing plants. Copper also has a critical and widespread military importance to the economy. Copper is the basic material for all electric equipment and has no good substitute. Copper is used in the production of sophisticated electronic equipment such as guidance systems and radars, in the production and distribution of electric power. It is widely used in the production of ammunition, particularly the cartridge cases and bullet jackets of small arms ammunition and the driving bands of artillery ammunition. Because there are significantly fewer copper processing plants in the Soviet Union than steel plants, the data base of the copper industry was more amenable to the resources of this program. It was, therefore, selected and used as the test case industry for exercising the INDATAK simulation model.

2-5 DATA BASE

The data base required for the development and exercise of the INDATAK model on the copper industry is quite exacting and extensive. It involves detailed information on the mines, the processing plants, and the utilities and transportation networks supporting the industry. The specific data collected and analyzed on each significant processing plant in the industry included:

(1) Name and types of activity,

(2) Geographical coordinates,

(3) Types of inputs required,

(4) Output as a function of input levels,

(5) Process delay times, and

(6) Inventory and storage.

These data were obtained from various economic open literature sources.

In a number of instances, precise input data was unavailable. As a result, some estimates were required in order to fulfill the input requirements for the model exercise. In order to compensate for these uncertainties, sensitivity analyses were performed during the model run to determine the significance of variations in the input data to the final results. The insights obtained will be useful in future applications of the model.

SECTION 3
INDATAK MODEL

3-1 PURPOSE AND USE

The INDATAK simulation model has been developed to analyze large multi-echelon industrial production systems, assess the impact of attack on key production facilities in these systems, and aid in developing attack strategies against industrial targets.

A considerable amount of work has gone into macro-economic studies of the Soviet economy, the interdependence between economic sectors, and the importance of different sectors in a post attack recovery situation. While these analyses provide valuable insight into the relative merit of different economic sectors as targets, they do not provide the tools necessary to make individual targeting decisions.

The INDATAK simulation is designed to model large industrial production systems with sufficient resolution to represent individual targetable production faclities, and to measure the effect of destruction of these facilities on the output of the industry. Thus INDATAK may be used to develop the marginal value of individual targets as well as assess the effects of alternative targeting strategies.

The normal mode of operation for the INDATAK model is a baseline run (without attack) to establish pre-attack levels of production. This is normally followed by series of runs with attacks on various components to test the effect of various attack strategies. A comparative analysis can then be performed on the industry response under varying conditions.

3-2 GENERAL CHARACTERISTICS

The INDATAK model is a discrete-event simulation model of an industrial process or series of processes. It consists of a multi-echelon industrial production network and a multi-node transportation network. The production network consists of demand generation nodes and material supply nodes linked in such a manner as to represent the structure of the industry.

INDATAK operates as a demand pull model where production is based on plant capacities, product demand, and the availability of raw materials. The flow of shipments of finished products and semi-manufactures from production nodes to the users (in response to user demands) is simulated over time on the transportation network. Attacks against production and supply nodes can reduce both production capacity and inventories. The resultant losses and impairments in the production chain hamper the ability of the system to respond to demands at higher levels and ultimately force closings of plants down the chain due to lack of materials. Plant repair or rebuild and its return to a production status is modeled over time. This provides a way to measure the effectiveness of the attack. The model attempts to meet production demands and to rebuild inventories in the minimum possible time. Thus orders are routed to suppliers based on expected delivery times and transportation routing is selected (subject to capacity constraints) to minimize time in transit. When attacks cause delays in delivery from normal supply sources, orders will be routed to alternative sources of supply and, where feasible, plants may be converted to use alternative types of materials. The measures of effectiveness determined by the model are the reduction in production levels, the drawdown of inventories, and the delays in demand satisfaction.

Figure 3-1 shows schematically, the basic inputs and outputs for the INDATAK model (see Section 3-4 for more detail). The user defines the transportation and production networks, the production relationships, the initial inventory levels, and the level of demand. The model can then be run to determine the output of the industry over time. Model outputs include individual and aggregate plant production, inventory statistics, transportation loading, and the rate of demand satisfaction. Attacks against production facilities may be scheduled at any time during a model run. The effects of the attacks on the industry output and other dependent production processes are measured.

INDATAK is a sophisticated simulation with complex logic to handle many decisions involving production, inventory maintenance, demand, and transportation routing. The model allows the user to study the interactions and interdependencies between the facilities in a complex and

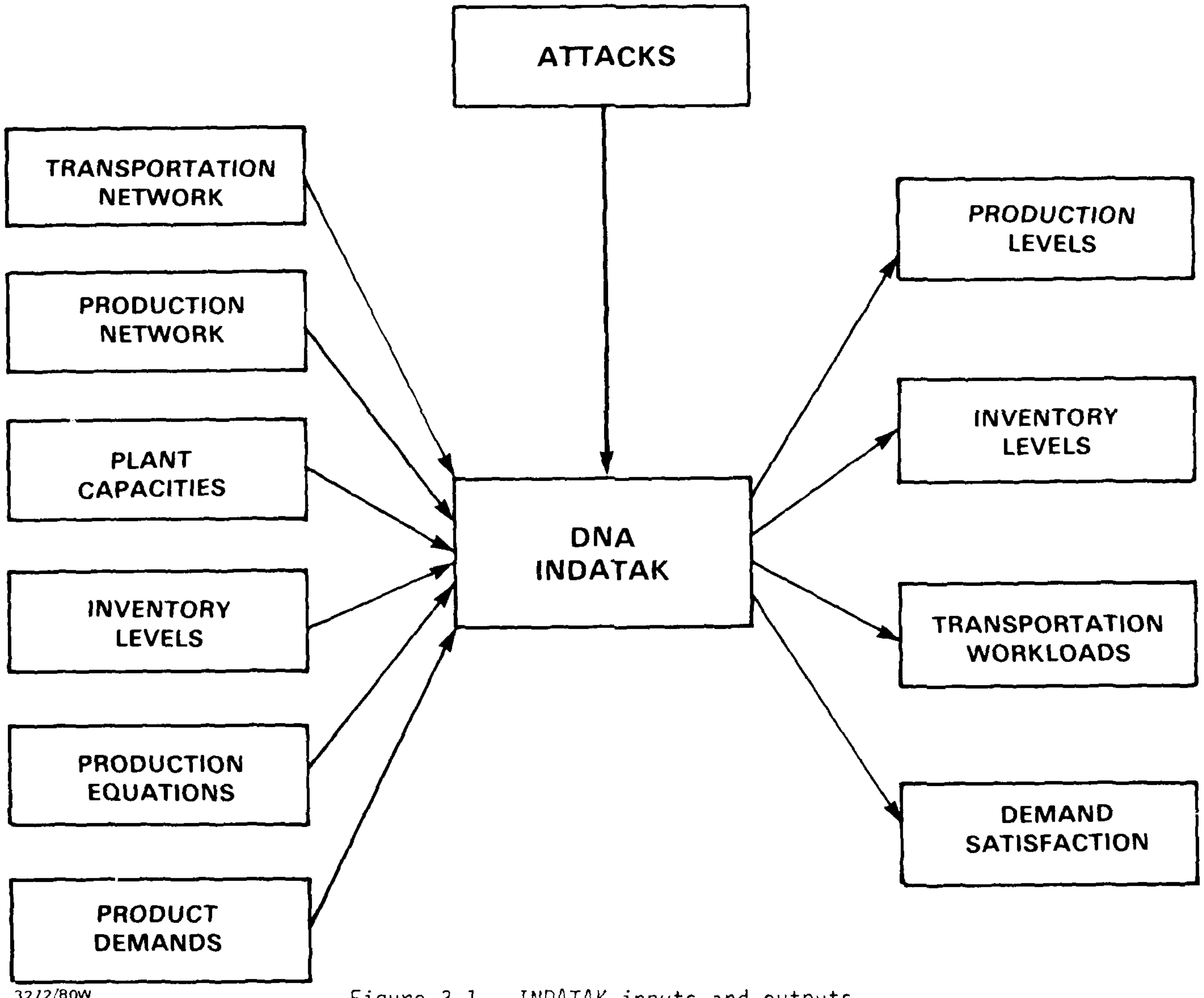

Figure 3-1. INDATAK inputs and outputs

geographically dispersed production network. The model has been designed to allow the study of a wide variety of industries and combinations of industries.

3-3 ACTIVITIES SIMULATED

In the INDATAK simulation, discrete events and activities representative of industrial processes are modeled and simulation time is advanced based on the next event scheduled to occur. Activities such as ordering, order processing, inventory maintenance, production, and shipping are each contained in separate program modules which are collected and linked at nodes used to represent specific processing or production facilities. The nodes are linked together to represent the industrial structure located by map coordinates and are connected to the transportation network that serves the industry.

The principal activities simulated by the model are demand generation, production, supply, selection of supply services, transportation routing and control, attack, and rebuild. Figure 3-2 is a simplified representation of the nodes in the industry model and their relationship to one another. The supply, production and demand nodes are representative of actual industrial plant locations. Production control is functional and controls the routing of material orders to the best source of supply. Transportation control handles route selection and the movement of materials through the transportation network. Attacks and rebuilds (not shown) are exogenous to the industry operation. They can change capacities and the operational status of production facilities. They also affect inventory levels but are not represented as operational parts of the industry being modeled.

3-3.1 Demand Generator Node

The demand generator is used to load the simulation model with demands; controling the frequency and quantities of demands for one or more products. It can be used to represent an aggregate demand for the entire industry where specific product use is unimportant or to represent individual users where the amount of a product available to individual users is important. Figure 3-3 lists the functions of the demand generator

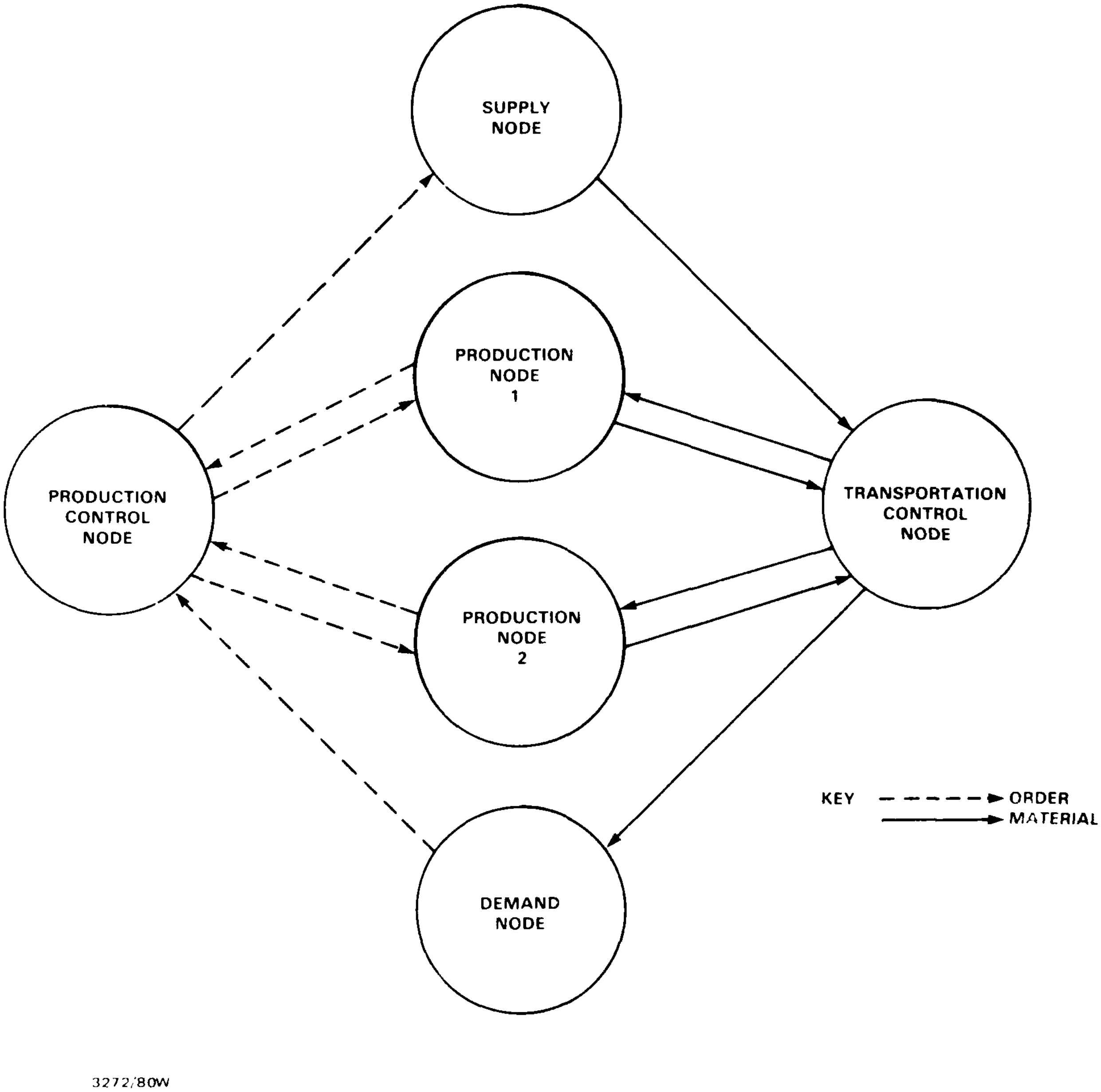

Figure 3-2. Industry node relationships

- Generates Demands for End Products
  - Product Type
  - Demand Frequencies
  - Demand Quantity
- Receives End Products
- Represents
  - Aggregate Demand Function
  - Individual Product Users

Figure 3-3. Demand generator node functions

3-3.2 Production Node

A production node is used to represent a manufacturing facility. It includes a range of activities necessary to accurately portray the operation of an industrial plant. It is represented in sufficient generality so that different types of manufacturing can be modeled. The functions of a production node include the following:

(1) Process and fill demands for finished goods,

(2) Cancel demands if unfillable,

(3) Schedule and issue raw material orders,

(4) Stock raw materials,

(5) Schedule production,

(6) Produce products,

(7) Stock finished goods, and

(8) Convert to alternate raw materials if necessary.

The operation of the plant can be briefly described beginning with the receipt of demands for materials or supplies. Demands for finished plant products are filled from plant inventories as the demands are received. When demands for products cannot be filled from inventory stocks, they are queued by assigned priority to await future production. Production is scheduled and the production rate is varied based on material availability, plant capacity and demand. Production reduces input inventories and increases output inventories based on a production equation expressing the input/output ratios for the particular plant, process, and material involved. The plant is shut down when input materials are exhausted, when there is insufficient demand for output products, or when an attack destroys or damages it. After the production cycle is started, input inventories are checked and orders for additional materials are issued if the inventory has dropped below the reorder point. New output production is added to output inventories. Pending demand orders are filled and shipped. Materials arriving from suppliers are added to raw material (input) inventories. Cancelled orders are reissued in the next ordering cycle. If the plant has been shut down for lack of raw materials, the receipt of a new shipment will restart production. If shutdown occurs because of insufficient demands, production will be restarted when new orders have reduced the ouput inventory enough to sustain at least the minimum production rate for the next production cycle.

A final function of the production node is the selection of the source of supply for raw materials. A production node can usually select from among a number of alternative suppliers of the same raw material. The choice of the best supplier or suppliers is based on a calculated fill time. For each potential supplier, the production node collects data on inventory balance, back order level, production usage rate, material arrival rate, and transportation time. The fill time calculated from these data is a prediction of the amount of time it will take to receive a shipment from the supplier. The order will be sent to the supplier with the shortest fill time or the order may be split between two or more suppliers with approximately equal fill times. By selecting suppliers based on the current conditions in the production and transportation networks, material flows and production relationships are dynamically adjusted when normal supply channels have been disrupted by attacks on the industry or by transportation bottlenecks.

3-3.3 Supply Node

The supply node is the source of basic raw materials for the industry model. It is similar in function to a production node without input inventory maintenance. Demands are processed in a similar manner, i.e., filled when possible and queued otherwise. Scheduling of output inventory is analagous to that of the production node and is used to limit the capacity or delivery rate of basic supplies to the industry. The functions of the supply node are as follows:

(1) Process and fill demands for raw materials,

(2) Maintain material inventories,

(3) Schedule inventory restocking, and

(4) Control rate of material delivery.

A supply node can be attacked and rebuilt in the same manner as a production node.

3-3.4 Transportation Network

The transportation function in INDATAK is simulated by following the movements of discrete shipments over time on a terminal/link network. Up to five modes of transportation can be included in a network (air, rail, road, inland waterway, and transhipment between modes). Shipments are routed through the network from source to user terminals based on current operational status of the network, the priority of the shipment, and the size of the shipment. The loading on the terminals, and links is measured and the delays associated with travel time and terminal operations are used to determine delivery time.

The links in the network represent sections of existing transportaion facilities (highway, rail, waterway) within the geographic area being studied. Data describing the link characteristics are used to provide accurate simulation of transportation through the links. These data include: the mode (highway, rail, etc), length, expected rate of travel, and capacity. The terminals in the network represent points at which divergent flows may intersect. Data describing the terminals are used to provide accurate simulation of delays associated with terminal operations. These data include terminal type (highway, rail, air, port), capacity, and the delays associated with off-loading and reloading of shipments.

In the INDATAK model, transportation may be simulated at two levels of detail.

(1) The less detailed of the two operates as described above but does not account for queuing at the terminals and does not permit attacks on the transportation network. This is the preferred level when the industrial operation is to be simulated over a long period of time. The rebuild times for production facilities are normally much greater than the rebuild times for transportation facilities. For large industry simulations, the less detailed transportation model may be preferred, particularly if computer time and memory resources are at a premium.

(2) The more detailed transportation model includes queuing due to terminal and link overloading. The terminals and links of the transportation network are assigned vulnerability factors and rebuild times. Any element of the network can be attacked at any time during the model run. The model calculates the reduction in capacity and the time required to rebuild the element. Shipments are rerouted by the model, using the remaining capacity of the network after an attack. This level of detail is more useful for short time frames and where attacks on the transportation network may be as disruptive as attacks on the plants that can be rebuilt quickly. This level may also be more useful where a single transportation link serves several colocated industries.

3-3.5 Attacks

The user can schedule attacks against industrial production facilities at any time during the model run. Attacks against plants and supply sources may result in complete destruction o. the targeted facilities or may reduce plant capacity. Inventories and warehousing facilities can also be destroyed. Plant rebuild is scheduled at attack time in one or more stages and the user can specify a rebuild capability which differs from the original if desired.

Attacks will cause disruptions of the normal flows of orders and materials within the industry as dependent plants are forced to use alternative sources for raw materials inputs. Additional demands will cause undamaged facilities to increase production if extra capacity is available and inventory drawdown will occur if added capacity is not possible. Ultimately, production plants may be forceu to close because input materials are not available. At that point in time, the output of the industry will drop.

The effects on industrial output by an attack will not always be in direct relation to the capacity of the attacked plants. This is due to underutilization of some plants, existing inventory levels, strategic stockpiles and the possibility of using substitute materials. Thus, an attack against one or more plants in a large industry may be less than the reduction in output capacity which simple subtraction would imply. The INDATAK model allows the industry to adapt to changing conditions in supply and demand. This permits the study of effects of different attack plans under different assumptions regarding plant capacity, inventory levels and strategic stockpiling.

3-4 INPUTS AND OUTPUTS

Figure 3-1 provided a schematic of the base's inputs and outputs of the INDATAK simulation model. This section provides a more detailed coverage.

3-4.1 Inputs

The industry production network requires four major categories on input data, i.e., the industry structure, demand generation, production, and supply. Each of these data categories are further broken down into a number of specific items as shown in Figure 3-4.

Figure 3-5 shows the data inputs used in the transportation simulation network and Figure 3-6 indicates the data inputs required for the analysis of the effects of attacks designed to impede the output of an industrial facility.

3-4.2 Outputs

The INDATAK model produces a series of reports during and after the conclusion of the model run. Also, reports can be scheduled at any

- Industry Structure
  Plant location, material suppliers, material consumers.

- Demand Generation
  Material type, demand frequency, demand quantity.

- Production
  Production equation, (materials consumed, materials produced), plant capacity, production time, initial inventory stockage, inventory stockage objectives, plant vulnerability, inventory vulnerability, repair or rebuild time, alternative material types, plant conversion time.

- Supply
  Material types, delivery dates, initial inventory, stockage objectives, vulnerability, rebuild time.

Figure 3-4. Production network data input

- Terminals
  Type, capacity, location, loading delay, unloading delay, throughput delay, vulnerability and rebuild time*.

- Links
  Type, terminals connected, length, rate of travel, capacity, vulnerability*, rebuild time*.

* used for the more detailed transportation scenario.

Figure 3-5. Transportation network data inputs

- Plant Number
- Plant Location
- Time Of Attack
- Attack Effects On Plant Capacity
- Attack Effects On Inventory
- Capacity After Rebuild
- Number Of Rebuild Increments

Figure 3-6. Attack and rebuild data inputs time by the user. These are helpful during the debugging/validation process. The various reports discussed below become final outputs of the industry analysis.

The Production Status Report is scheduled at periodic intervals. It provides the current inventory levels and the due-in/due-out levels for each production facility in the system. It also provides the total tonnage of material shipped and received, orders sent and received, orders cancelled, quantities of raw material consumed, and finished product produced since the previous report was printed. This report is the basis for determining the weekly, monthly, or quarterly production of each plant and the effects of inventory drawdown during post-attack recovery.

At the end of the model run, a series of reports are produced which provide average plant characteristics. The type of information given in the Production Status Report is repeated, but is presented as an overall average, both for individual facilities and for the industry as a whole. For example, the mean weakly production of smelted copper is given for each smelter and for the entire industry. A listing of the normal industrial network is produced. This report gives the plant locations and a list of the normal suppliers of raw materials for each plant. This provides a quick reference between model "shorthand" and actual facilities. A transportation network is also produced. It lists the various components of the network which services the industry and the links and terminals actually used to transport materials. The mean usage of each element during the model run is also listed.

In addition to the above, a report dealing with computer core storage is produced. This report is useful for planning the sizing requirements of the model for follow-on exercises rather than information required by the analyst.

3-5 COMPUTER SYSTEM REQUIREMENTS

The INDATAK model program is coded in the FORTRAN language and is operational on a Control Data Corporation CYBER 176 computer system. The current model version requires approximately 260,000 words of small core memory and 60,000 words of large core memory. Exact storage requirements and running times will depend on the complexity of the industry being simulated, the number of discrete sites represented, the complexity of the transportation network used, and the amount, size or detail of the activity being represented.

The current pilot model of the Soviet copper industry contains a simple demand generator, fourteen production nodes and nineteen supply nodes. The transportation network contains 170 terminals and 130 links. Studies of larger industries and multiple industries will increase the number of nodes and size of the transportation net. Both storage requirements and run times can be expected to increase as a result.

3-6 INDATAK ANCESTRY

3-6.1 Background

The INDATAK simulation model was developed using the MAWLOGS (Models of the Army Worldwide Logistics System) modeling system. MAWLOGS is a highly modular system of computer programs which permits automated assembly of simulation models and facilitates their application. Until recently, MAWLOGS was used primarily to develop models of military logistics systems including transportation networks.

In an earlier contract with DNA, BDM added to the MAWLOGS system a capability to simulate the effects of attacks on the transportation network. This effort called LOGATAK is being used to simulate the imposition of interdiction lines in the Central and Southern European regions. The INDATAK simulation model developed for DNA under this contract adds to the LOGATAK system the capability to model industrial production networks and attacks against these networks.

3-6.2 MAWLOGS

The components of the MAWLOGS modeling system include a transportation network data base program, a model definition language, a model assembler, a library of programs for simulating different activities, and an output data postprocessor system. Figure 3-7 shows a graphical representation of the relationship of these components to one another and the general process of building and using a specific application model. The following paragraphs briefly describe these components.

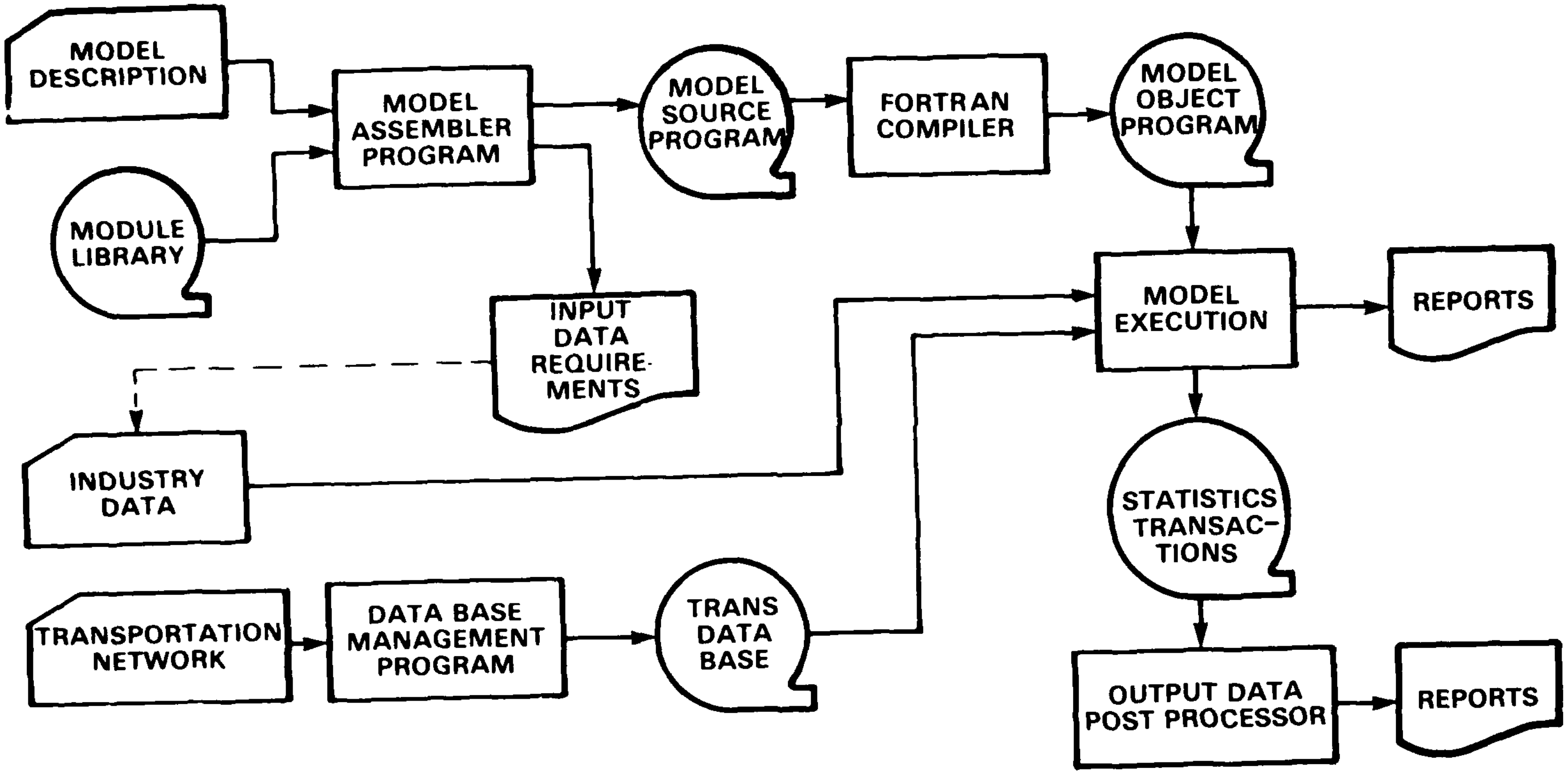

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Figure 3-7. MAWLOGS simulation system flow

3-6.2.1 Transportation Data Base Program. The transportation data base resides in a Data Management Selection system called DAMSEL. This system is used to prepare the transportation network data base and to select suitable parts of the existing data base library for input to the model under consideration. The program reads data describing the attributes (location, capacity, speed, distance, etc.) of the links and terminals in a multimode transportation network, and adds these data to the existing network data base. When run in the selection mode, the program extracts a selected subset of the network data by map sector number and formats it for use by the model.

3-6.2.2 Model Description Language. The model description language is a formal, high level language used to describe the context and structure of a model. With this language, the model builders can describe how different activities are grouped and linked to form nodes in a network and how these nodes are interrelated and linked to represent the network.

3-6.2.3 Model Assembly Program. The model assembly program processes the model description and selects from a library modules of computer code that are appropriate to the activities described in the nodes of the model definition. The assembler program then writes linkage subroutines to combine the modules and link them to represent the structure contained in the model description. The output of the assembler is a linked set of computer subroutines that may properly be called the model. At this point, a listing of the data necessary for the proper execution of the routines that have been included in the model is produced.

3-6.2.4 Module Library. The module library is an extensive set of subroutines which can be selected by the assembler to perform the various functions necessary to the simulation. Some of these modules perform simultaneous control fucntions such as event sequencing, time stepping, statistics collection, etc. Other moduels are used to simulate the activities performed at the various nodes such as production, supply, shipping, and order processing. The combination of model description language, model assembler, and module libarary provides a flexible and powerful tool with which a wide variety of models can easily be built.

3-6.2.5 Output Data Postprocessor. The postprocessor program is used to analyze data file output of the model and to print graphs and reports resulting from this analysis. Sequences of events in the model execution and statistics describing levels and flows can be aggregated and graphed to assist in the analysis of the results of the simulation.

3-6.3 LOGATAK

The DNA LOGATAK simulation model was developed by BDM to simulate the logistics, supply demand functions, and the movement of ground combat units. This was a natural follow-on to the MAWLOGS modeling system. It is used to develop interdiction strategies and measure the relative effectiveness of these strategies in terms of delays.

The LOGATAK model simulates the movement of force units and supplies over a multi-mode transportation network as functions of time. This permits the analysis of traffic flows and the identification of overloads and bottlenecks in the transportation network. The model determines the optimum routes from the starting locations to the final destinations. It changes the routing as necessary to reduce congestion caused by overloads or interdictive attacks.

The model was designed to accept a wide range of scenarios and transportation networks. It was made flexible to permit the user to select any geographical area which is covered by the data base. The locations of the supply bases and the assembly areas as well as the weight quantities of the units represented in the scenarios are specified in the area selected for study. The logistics scenario includes the varying demand patterns for a variety of supply classes.

The LOGATAK model required considerable expansion of the MAWLOGS module library. New modules were designed and incorporated into the model. This permits a detailed analysis of the results of interdictive strikes on the supply system and/or the transportation network. The model is particularly useful in the evaluation and comparison of various interdictive attack strategies aimed at the establishment of barrier lines against force and logistics movements.

It was recognized by DNA that the LOGATAK model had a good potential for use as a tool to develop a simulation model for major industries. A model which would evaluate the impact of interruption or destruction of critical elements of industrial processes. This led to the study discussed in this report.

3-7 EXPANSION AND APPLICATION TO OTHER INDUSTRIES

The initial INDATAK model was developed to simulate a random major industry or combination of related industries. It is therefore adaptable and expandable to other industries. The current version of INDATAK has now been used successfully to model the copper industry. Other base metal industries can be modeled with the current version of LOGATAK since most of the processes in these industries are similar to the copper industry. It would, however, be necessary to collect the required input data on the new industry and expand the transportation network to include the locations of the selected industry.

Some industries will require additional modeling. For example, electric power is not distributed in the same manner as other raw materials. Therefore, the servicing power grid would require modeling in case this is needed.

The present model allows for some degree of substitution of materials. This may need improvement in some industries in order to assure quality of production.

Another consideration in the selection of an industry or group of related industries would be the size of the required model and its execution time. It is axiomatic that, as the number of installations grows, the size of model also grows. This may entail a requirement for more data, additional subroutines and statistics collection locations. This would occur in any major expansion effort. It would therefore appear prudent to phase-in other industries in such a manner that the required modeling efforts could move forward without making the expansion task unreasonable. For example, the chemical, steel and possibly the electric power industries would require data collection and modest modeling efforts.

SECTION 4

THE SOVIET COPPER INDUSTRY - SUMMARY

4-1 INTRODUCTION

The INDATAK simulation model has been designed to simulate a major industry or combination of related industries. It has sufficient flexibility to model and thus measure the production of the industry over time under varying conditions of product demands, material availability and damage or destruction of key industrial elements by attack.

For the purpose of demonstrating the viability of the INDATAK model, it was necessary to select an industry to simulate which was sufficiently complex to properly exercise the model and yet one which could reasonably be analyzed by other methods in order to validate the results. The Soviet copper industry was selected for the purpose of exercising the model. This section provides a brief summary of the copper industry in the Soviet Union. More detailed information is continued in Appendix A.

4-2 BRIEF HISTORY

Archeologic studies in the Middle East and in the Valley of the Tigris and Euphrates Rivers indicate that copper mining in the Caucasus Mountains, Central Asia and the Ural Mountains had its genesis as early as the Third or Fourth Milleniums B.C. Copper production remained at a low level until the 17th Century A.D. A period of rapid expansion took place during the reign of Peter the Great in the 18th Century. This expansion continued until World War II. However, the industry was severely damaged to a point where production was stopped completely during the Russian Revolution.

The New Economic Policy (NEP) established in 1921 started a series of drives to expand the industry. The success of the NEP is evident from the fact that the USSR is now the World's second largest copper producer with an annual output of about 1.5 million metric tons of refined copper.

At the present time, there are six geographical areas within the Soviet Union where new copper is produced from ore mined nearby. One of these areas, Kazakhstan, has three separate smelter locations as shown on Figure 4-1. One additional area, European Russia, produces refined copper recovered from scrap. Each of these areas are discussed individually in Appendix A.

4-3 COPPER PRODUCTION

New copper is produced from ores, generally oxides or sulfides, which exist in ore bodies in the areas indicated on Figure 4-1. Most ore bodies now being worked yield rock with a copper content of one to two percent. In order to produce usable copper, these ores must go through a series of industrial processes; i.e., ore concentration, smelting and refining. The ore concentration process results in a copper content of between 20 and 30 percent, suitable for smelting. The smelting process transforms the ore concentrates into a complex material containing metallic copper and copper-sulfide compounds called a matte. The matte is then melted and converted to almost pure metallic copper called "blister copper". The next process involves refining. This consists of fire refining where the remaining sulfur and oxygen is removed from molten copper. The copper is then cast into anodes. These anodes become inputs to an electrolyte process wherein pure copper is deposited on the cathodes. It is then ready for processing into its final product.

4-4 BYPRODUCTS

In addition to copper, there are two major groups of industrial products obtained during the extraction of copper from ores. The first is a group of important allied metals including nickel, zinc, lead, molybdenum, gold, silver, platinum, palladium and rhenium. Most of these are separated during the ore concentration stage and processed separately. Some of the rare metals have high monetary values. The second major byproduct is sulfur dioxide gas which is used to make sulfuric acid.

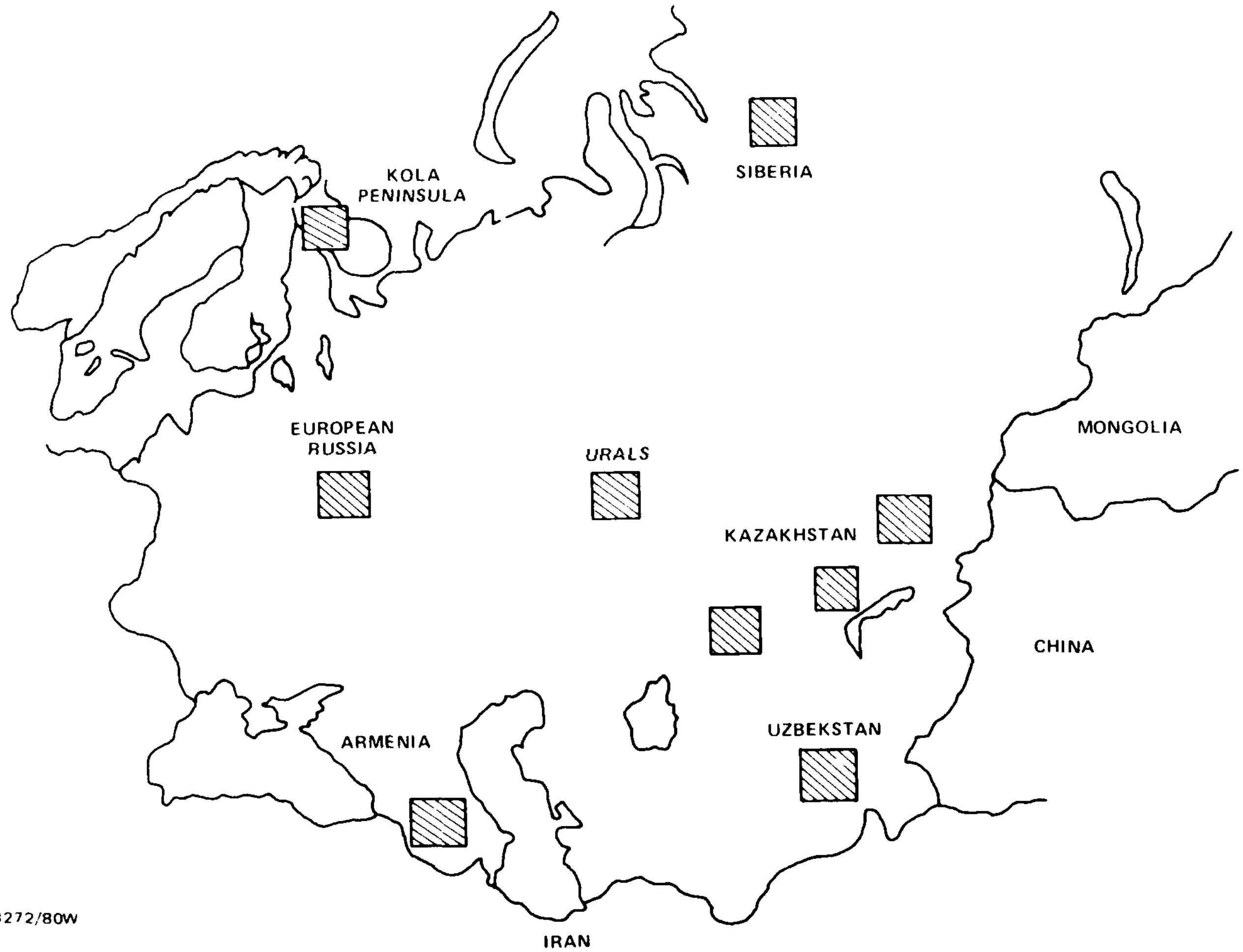

Figure 4-1. Major Soviet copper processing areas

SECTION 5
MODEL APPLICATION

5-1 DATA BASE

5-1.1 Industry Data Inputs to INDATAK Model

Figures 5-1 through 5-6 show the estimated materials enrichment and annual metric tonnage input and output capacities by locality of the industrial installations used in the INDATAK model. In these figures, the types of installations or facilities are indicated by M (mines), C (concentrators), S (smelters), and R (refineries). The various processes of these facilities are discussed in Appendix A.

AREA: Armenia

TYPE	Place Name	Cu Out	% Cu Content	Material Out	% Cu Recvy	Cu In	% Cu Cont.	Material In
R	Alaverdi	80,000	100	80,000	100	80,000	100	80,000
S	Alaverdi	80,000	100	80,000	98	81,600	16	510,300
C	Agarak	6,800	17	40,000	78	8,720	1.5	581,000
M	Agarak	8,720	1.5	581,000				
C	Akhtala (1)	6,800	16	42,500	80	8,500	1	850,000
M	Akhtala	8,500	1	850,000				
C	Akhtala (2)	6,800	16	42,500	85	8,000	1.5	533,000
M	Shamlug	8,000	1.5	533,000				
C	Alagyaz	6,800	16	42,500	80	8,500	1	850,000
M	Alagyaz	8,500	1	850,000				
C	Dastakert	6,800	16	42,500	80	8,500	1	850,000
M	Dastakert	8,500	1	850,000				
C	Kadzharan	6,800	15	45,300	80	8,500	1.5	567,000
M	Kadzharan	8,500	1.5	567,000				
C	Kafan	20,400	16	127,500	80	25,500	1	2,550,000
M	Kafan	25,500	1	2,550,000				
C	Kazreti	6,800	16	42,500	80	8,500	1	850,000
M	Madneuli	8,500	1	850,000				
C	Urup	13,600	16	85,000	80	17,000	1	1,700,000
M	Urup	17,000	1	1,700,000				

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Figure 5-1. Material enrichment and metric tonnage figures for Armenia

AREA: Kazakhstan								
TYPE	Place Name	Cu Out	% Cu Content	Material Out	% Cu Recvy	Cu In	% Cu Cont.	Material In
R	Balkhash	280,000	100	280,000	100	280,000	100	280,000
S	Balkhash	250,000	100	250,000	96.7	258,500	20.8	1,244,400
C	Balkhash	148,500	23.5	631,900	85	174,700	1	17,470,000
M	Vostochno-Kounradskiy (Open Pit)	58,200	1	5,820,000				
M	Sayak-Pervyy (Open Pit)	116,500	1	11,650,00				
C	Uspenskiy	60,000	20	300,000	85	70,600		7,060,000
M	Uspenskiy	70,600	1	7,060,000				
C	Bozshakol'	50,000	16	312,500	85	58,800	.6	9,800,000
M	Bozshakol'	58,800	.6	9,800,000				
R	Dzhezkazgan	310,000	100	310,000	100	310,000	100	310,000
S	Dzhezkazgan	300,000	100	300,000	98.5	304,500	25	1,218,400
C	Dzhezkazgan (1)	100,000	25	400,000	94	106,400	1.2	8,866,700
M	Zlatoust-Belovskiy	106,400	1.2	8,866,700				
C	Dzhezkazgan (2)	204,600	25	818,400	94	217,700	1.7	12,805,900
M	Dzhezkazgan (Several Mines)	217,700	1.7	12,805,900				
S	Glubokoye	40,000	100	40,000	98.5	40,600	23.6	172,200
C	Orlovka	7.120	23.6	30,200	72	9,890	2	494,500
M	Orlovka	9,890	2	494,500				
C	Ust'Talovka	7,120	23.6	30,200	72	9,890	2.5	395,600
M	Ust'Talovka	4,000	2.5	160,000				
M	Nikolayevka	5,890	2.5	235,600				
C	Verkhnebere Zovskiy	7,120	23.6	30,200	72	9,890	2	494,500
M	Verkhnebere Zovskiy	9,890	2	494,500				
C	Belousovka	7,120	23.6	30,200	72	9,890	2	494,500
M	Belousovka	9,890	2	494,500				
C	Zolotukha	7,120	23.6	30,200	72	9,890	2	494,500
M	Zolotukha	9,890	2	494,500				
C	Zyryanovsk	5,000	23.6	21,200	72	6,940	1	694,000
M	Zyryanovsk	6,940	1	694,000				

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Figure 5-2. Material enrichment and metric tonnage figures for Kazakhstan

TYPE	Place Name	Cu Out	% Cu Content	Material Out	% Cu Recvy	Cu In	% Cu Cont.	Material In
AREA: Uzbekstan								
R	Almalyk	200,000	100	200,000	100	200,000	100	200,000
S	Almalyk	200,000	100	200,000	98.5	203,000	16.5	1,230,300
C	Almalyk	203,000	16.5	1,230,300	77	263,600	1.5	17,574,000
M	Kalmakyr (Several Mines)	263,600	1.5	17,574,000				

Figure 5-3. Material enrichment and metric tonnage figures for Uzbekstan

TYPE	Place Name	Cu Out	% Cu Content	Material Out	% Cu Recvy	Cu In	% Cu Cont.	Material In
AREA: Kola Peninsula								
R	Monchegorsk	20,000	100	20,000	100	20,000	100	20,000
S	Monchegorsk	5,000	100	5,000	95	5,260	15	35,070
S	Nikel	15,000	100	15,000	95	15,790	15	105,270
C	Zapolyarnyy	21,050	15	140,340	80	26,300	1	2,630,000
M	Zapolyarnyy	26,300	1	2,630,000				

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Figure 5-4. Material enrichment and metric tonnage figures for Kola Peninsula

AREA: Siberia

TYPE	Place Name	Cu Out	% Cu Content	Material Out	% Cu Recvy	Cu In	% Cu Cont.	Material In
R	Noril'Sk	100,000	100	100,000	100	100,000	100	100,000
S	Noril'Sk	100,000	100	100,00	91	109,890	15	732,600
C	Noril'Sk	109,890	15	732,600	80	137,360	1	13,736,000
M	Medvezhiy Ruchey (Open Pit)	34,340	1	3,434,000				
M	Zapolyarnyy (Underground)	34,340	1	3,434,000				
M	Mayak (Underground)	34,340	1	3,434,000				
M	Khara-Yelakh	34,340	1	3,434,000				

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Figure 5-5. Material enrichment and metric tonnage figures for Siberia

AREA: Urals								
TYPE	Place Name	Cu Out	% Cu Content	Material Out	% Cu Recvy	Cu In	% Cu Cont.	Material In
R	Verkhnyaya Pyshma	272,000	100	272,000	100	272,000	100	272,000
S	Krasnoural'Sk	80,000	100	80,000	98.5	81,220	17.7	457,870
C	Krasnoural'Sk No. 1	52,220	19.2	271,980	87.6	59,610	1	5,961,000
M	III International	59,610	1	5,961,000				
C	Krasnoural'Sk No. 2	9,000	15.6	57,690	88.9	10,120	1	1,012,000
M	Krasnogvardelsk	10,120	1	1,012,000				
C	Krasnoural'Sk No. 3	9,000	15.6	57,690	88.9	10,120	1	1,012,000
M	Kabansk	10,120	1	1,012,000				
C	Turinsk	11,000	15.6	70,510	88.9	12,370	1	1,237,000
M	Turinsk	12,370	1	1,237,000				
S	Kirovgrad	96,000	100	96,000	99 Tot.	96,970	100	Scrap 58,000
						38,970	15.4	253,000
C	Kirovgrad (4 Sections)	38,970	15.4	253,000	86.1	45,260	1	4,526,000
M	Levikhinsk	11,000	1	1,100,000				
M	Lomovsk	11,000	1	1,100,000				
M	Belorechensk (Separate Conc.)	12,000	1	1,200,000				
M	Novoyezhovsk	11,260	1	1,126,000				
S	Sredneural'Sk	96,000	100	96,000	98.5	97,460	23.6	412,280
C	Degtiarsk	29,200	19.5	149,740	80	36,500	1	3,650,000
M	Degtiarsk	36,500	1	3,650,000				
C	Pyshma	68,260	26	262,540	90	75,840	1	7,584,000
M	Kliuchevski	60,670	1	6,067,000				
M	Gumeshevski	15,170	1	1,517,000				
R	Kyshtym	190,000	100	190,000	100	190,000	100	190,000
S	Karabash	130,000	100	130,000	98.5	132,000	20.2	652,500
C	Karabash	80,000	22	363,600	89	89,900	1.5	5,993,000
M	Karabash	89,900	1.5	5,993,000				
C	Uchaly	52,000	18	288,900	79	65,800	1.5	4,387,000
M	Uchaly	65,800	1.5	4,387,000				
S	Mednogorsk	60,000	100	60,000	98.5	60,900	7.5	817,450
M	Bliavinski (Open Pit, No Conc.)	13,400	2.5	536,000				
C	Gay	26,800	18	149,000	84	31,900	5	638,000
M	Gay	31,900	5	638,000				
C	Sibay	13,400	16	83,750	80	16,750	2.5	670,000
M	Sibay	16,750	2.5	670,000				
C	Buribai	7,300	15	48,700	91	8,020	2.5	320,800
M	Makanski	8,020	2.5	320,800				

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Figure 5-6. Material enrichment and metric tonnage figures for Urals

Figure 5-7 shows the estimated restart times after a short shutdown for each of the types of installations used in the INDATAK model.

Installation	Time (Days)
Mine	10
Concentrator	3
Smelter	5
Refinery	3

Assume: 6 days/week
50 weeks/year
300 days/year

Figure 5-7. Restart time

5-1.2 Industry Data Assumptions

In order to operate the INDATAK model, a number of data types are required. Some of the data on the copper industry are not readily available from the open literature. In general, these involve such items as excess plant capacities, inventory and stockpile levels, damage estimates, rebuild times, and post attack copper demand. For example: inventory levels vary from day-to-day; rebuild times depend upon the availability of manpower, building materials and equipment as well as post attack recovery priority; the level of damage is dependent upon the hardness of the target and its proximity to the point of burst; and the number of plants attacked is dependent upon the number of weapons available. In order to overcome these uncertainties, a number of assumptions as discussed below were made for inputs to the model. Should any of these assumptions prove unreasonable they can be easily changed. This flexibility was a design requirement for INDATAK and it permits sensitivity analyses to be performed quickly and efficiently.

(1) Inventory Levels. It was assumed that inventory levels equivalent to one week of plant output and three weeks of required materials input would be maintained at each

facility. These levels are considered adequate to provide a buffer against random transportation and production delays. The are consistent with levels maintained for similar domestic industries.

(2) Plant Capacities. It was estimated that plant capacities could be increased by about 22 percent above normal production levels. This would result from possible production shortcuts and extended hours of operation. In this regard, it should be noted that extending the operating hours from 16 to 24 will not necessarily increase output by 33 percent. The reason being the continuous use of plant machinery will result in additional breakdowns and repairs would need to be done during working hours.

(3) Damage Estimates. It was assumed that six weapons would be available for attacking the copper industry and that each weapon resulted in complete shutdown of the attacked plant thus reducing its production and inventories to zero. The bonus effects obtained by damage to other plants in the target area were not modeled.

(4) Rebuild Times. The assumed rebuild times for each type of plant were developed separately. The concentrator rebuild was assumed to be a one step operation. No production capacity would exist until the rebuild is completed in one year at which time it would achieve 100 percent capacity. Three smelters which were known to have multiple production lines were assumed to reach 50 percent capacity in one-half year and full capacity in one year. Three of the smelters were assumed rebuilt in one step to full capacity in one year. In the case of refineries which consist of a number of low capacity electrolytic vats run off one or more power sources were assumed to return to production on a multi-step basis. The refineries were assumed to be rebuilt on a schedule which permitted a return to full production by

increments over a two year period. Three of the refineries were assumed to gain 10 percent of maximum capacity every two-tenths of a year. The other three were assumed to gain 17 percent of maximum capacity every one-third of a year. In all cases it was assumed that adequate manpower, materials, equipment and energy were available and rebuild began immediately after the attack at or near their original locations.

(5) Post Attack Copper Demand. It was assumed that the overall demand for copper would remain unchanged in the post attack environment.

5-1.3 INDATAK Transportation Network Model

A second major data input to the INDATAK model is the transportation network which services the Soviet copper industry. This is a terminal - link network connecting the major copper producing areas with sufficient redundancy to allow both primary and alternate routings between different plant locations. For the copper industry model, this network consists of 187 rail terminals, 220 rail links, and 3 water links.

The sheer magnitude of the Soviet land mass and its rail network has imposed limitations on the size of the network used in the model. Since the model would be incapable of including the entire Soviet rail system, the model has been limited to the major rail links and terminals that are integral parts of the industry. The network is an accurate assessment of the present copper transportation network. Minor links with negligible roles as transportation aids have been deleted.

5-2 COPPER INDUSTRY ATTACK SCENARIO

This section of the report will first discuss some of the factors to be considered when developing attack scenarios against the Soviet copper industry and will then present some typical attacks developed to meet specific criteria.

5-2.1 Duration of Attack Elements

It must be assumed that the USSR has a large strategic stockpile of refined copper. The amount of this stockpile has not been estimated in the unclassified literature. Attack scenarios which halt or reduce copper production for only a short period, i.e., one or two months, are not likely to have any effect on the warfighting ability of the Soviets. Any needs for refined copper to support short term conflicts can be supplied from stocks on hand. In general, over these very short time periods, the military must depend on materiel already on hand and cannot expect resupply from new manufacture of goods. This further reduces the effects on warfighting capabilities of an attack on the copper production industry.

Mid-term effects can be thought of in terms of an output reduction time which is sufficient to exhaust the strategic stockpile by the time the industry has been rebuilt and is once more beginning to produce refined copper. This time period will be of the order of one to three years. To maintain any degree of effective military force during the restoration of production will require careful central planning of resource allocation and would undoubtedly require cutting the output of consumer goods to a minimum. Mid-term effects can be obtained with attacks only upon the copper production industry. Plant rebuild times for only partial damage can well stretch to several years. Some of the current installations within the USSR did not come into useful production for 5 to 7 years after construction began.

Any major attack designed to eliminate the ability of the USSR to produce copper will undoubtedly extend its effects for a period of 5 to 8 years and can be classed as one with long-term strategic effects. These long-term effects can be obtained by destroying the production nodes which are expensive to build and which require long lead-times. Full industry destruction will also produce problems associated with obtaining copper and wire for use in generating, transmitting, and distributing electric power. All phases of the copper producing industry are heavily dependent on electric power for their operation.

5-2.2 Installation Capacity Effects

The obvious points to destroy in the succession of processes necessary to produce copper are those in which materiel flow is concentrated, i.e., the traditional "choke points." In the copper production industry, these are the refineries and the smelters. There are nine refineries and twelve smelters in the USSR. There are also about 35 concentrators in the Soviet Union which concentrate the ore in preparation for the smelters.

Figure 5-8 presents the estimated drawdown curve which shows the reduction of smelter production of copper in metric tons per year for the 12 USSR smelters. A similar drawdown curve for the 9 Soviet refineries is presented in Figure 5-9. It should be pointed out that these drawdown curves do not accurately predict the loss in copper production of the industry as a whole unless all of the like facilities are destroyed. The reason for this is that some of the lost production from one destroyed plant, say a refinery, can be overcome by utilizing the extra production capabilities of other refineries. This effect will be shown in Section 6. There would be an overall efficiency loss however because the smelted copper would need to be transported to other refineries some distance away.

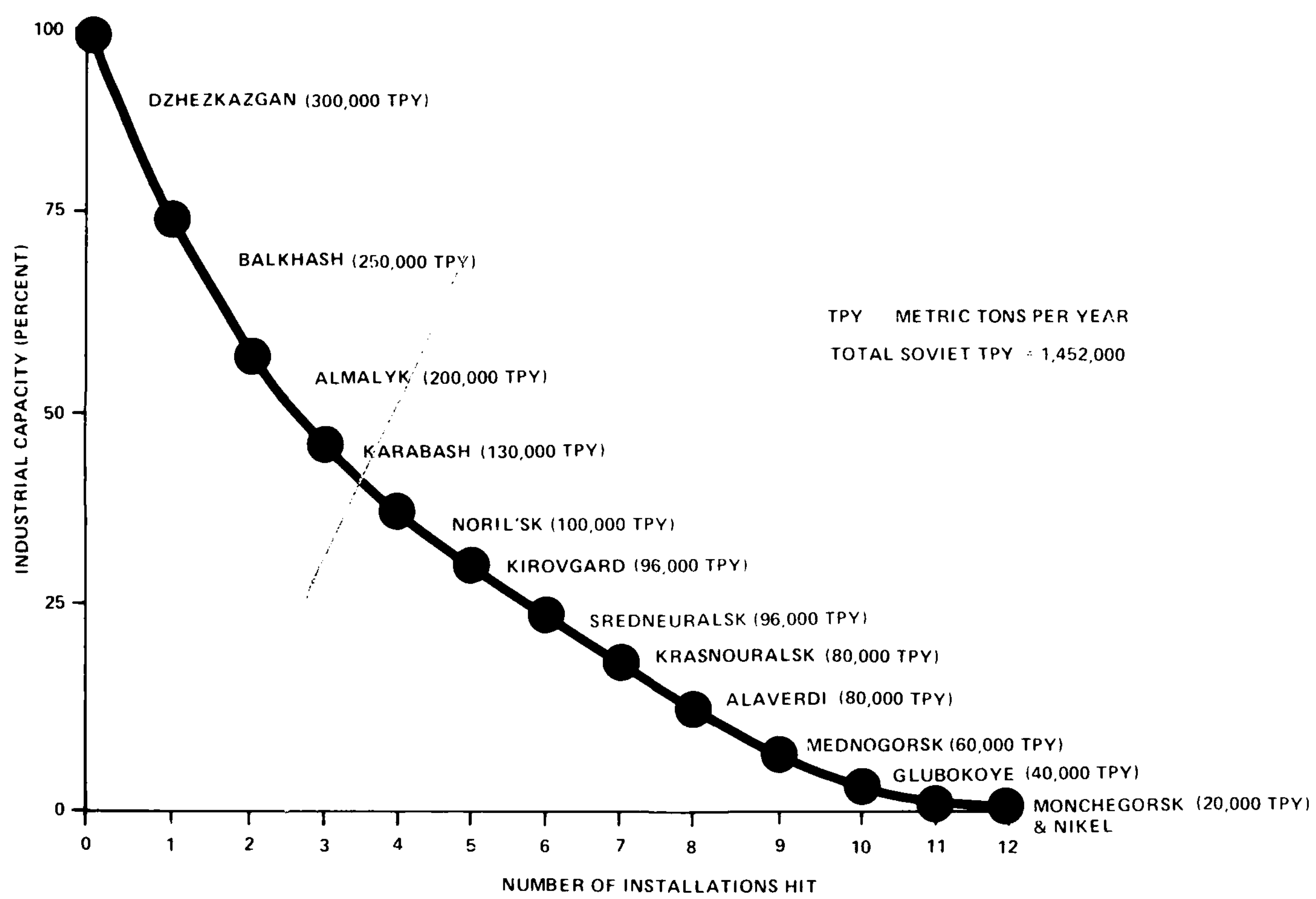

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Figure 5-8. USSR copper production (smelter drawdown curve)

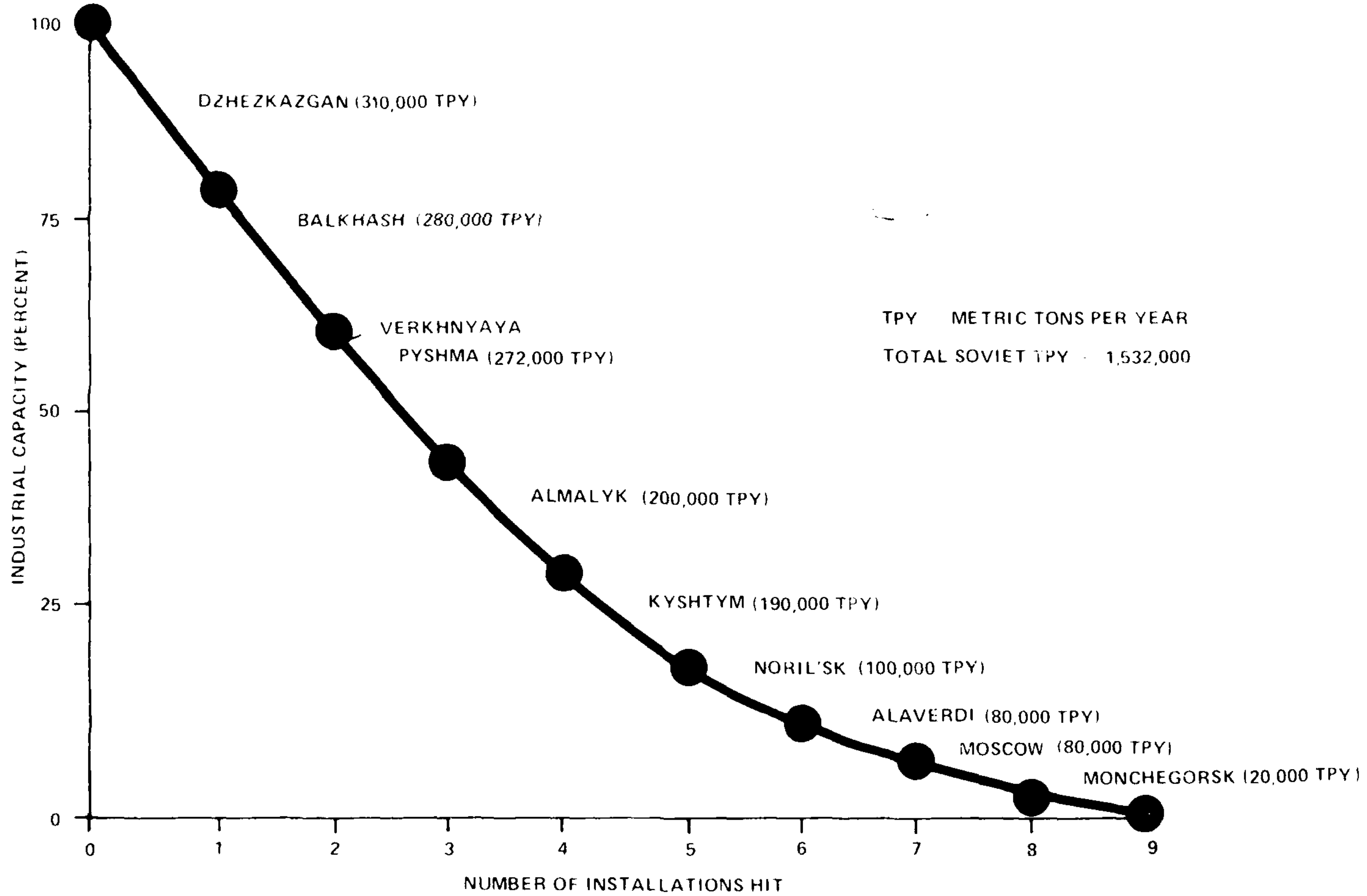

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Figure 5-9. USSR copper production (refinery drawdown curve)

SECTION 6
SIMULATION RESULTS

6-1 BASELINE ANALYSIS

The first INDATAK model run is the baseline case. This establishes the normal output of the various industrial facilities over time without attacks on any of the components of the industry. The purpose of the baseline run is twofold: (1) to verify that the model's prediction of industrial production over time is the same as the actual production; and (2) to provide a basis for comparison with the model's prediction of production under various attack situations. Figure 6-1 provides a summary of the annual baseline copper production levels for the Soviet smelters and refineries.

The inputs to the models were prepared from the best available data. Where specific data was lacking, estimates were made of the current level of production for the various facilities. An assumption was made that each of the facilities modeled was producing at an average of 82.2 of capacity. This provides 17.8 percent production capacity available to counter the effects of attacks on other facilities. Figure 6-2 gives the industry wide plant utilization as a function of capacity for the various facilities after steady state production has been reached. These utilization rates were developed by the model. The differences in utilization are a result of the model's attempt to minimize transportation time. Thus, when there is sufficient production capacity to meet demands, closer plants will receive more orders than distant plants. The distribution is considered to be within tolerable statistical limits.

The model inputs on inventory sizes and purity are estimates of the normal levels found at each location. At the beginning of the run, the model attempts to achieve a stable steady state. Inventory and production levels will vary until this state is reached and may stabilize at levels slightly different from the input data. These differences are the result of the model's attempt to minimize production and transportation time. This initial warmup period was determined to be eight months.

REFINERIES			SMELTERS		
NODE	LOCATION*	COPPER OUTPUT (TPY)	NODE	LOCATION	COPPER OUTPUT (TPY)
1	BALKHASH	280,000	1	BALKHASH	250,000
2	DZHEZKAZGAN	310,000	2	DZHEZKAZGAN	300,000
3	ALMALYK	200,000	3	GLUBOKOYE	40,000
			4	ALMALYK	200,000
4	ALAVERDI	80,000	5	ALAVERDI	80,000
5	NORILSK	100,000	6	NORILSK	100,000
6	MONCHEGORSK	20,000	7	MONCHEGORSK	5,000
			8	NIKEL	15,000
7	KYSHTYM	190,000	9	KARABASH	130,000
			10	MEDNOGORSK	60,000
8	VERKHNYAYA PYSHMA	272,000	11	KRASNOURALSK	80,000
			12	KIROVGRAD	96,000
			13	SREDNEURALSK	96,000
	TOTAL	1,452,000	TOTAL		1,452,000

*MOSCOW REPROCESSING REFINERY NOT MODELED

Figure 6-1. Soviet baseline copper production

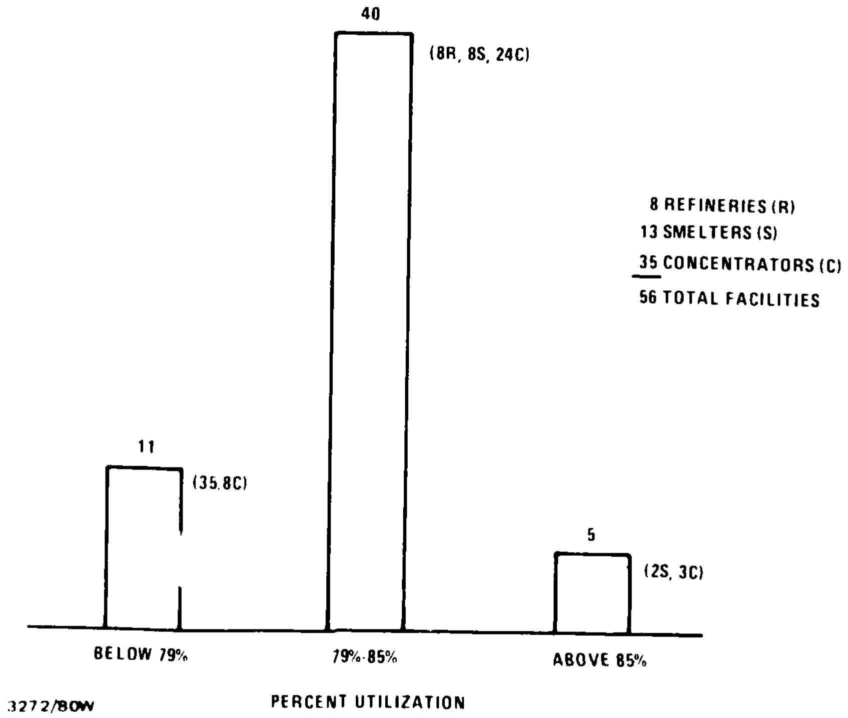

Figure 6-2. Baseline plant utilization

However, it was found that the fluctuations in production levels was less than 0.1 percent per month after the second month. For this reason, a two month period was allowed for internal model warmup before attacks were allowed. This was considered sufficient for comparative purposes. At this point in time, there were minor changes in distribution occurring but the total quantities of materials produced no longer varied.

6-2 MODEL EXERCISES

Having established a valid baseline run, the INDATAK model was used to analyze the effect, in terms of production loss, which would be expected from a variety of attack strategies. Two separate experiments were devised to show the potential usefulness of INDATAK in solving problems addressed were:

(1) Given a fixed number of available weapons, what will be the effects of various targeting strategies on the availability of refined copper during post-attack recovery; and

(2) Can INDATAK be used to evaluate the relative worth of individual plant facilities to overall industrial production.

6-2.1 Industry Denial Attack

6-2.1.1 Attack Strategies. With the assumption that six weapons were available for nuclear attack on the Soviet copper industry, four attack strategies were evaluated to measure their effect on the total copper production capacity. These strategies included strikes on:

(1) The six largest refineries;

(2) The six largest smelters;

(3) The six largest concentrators;

(4) The three largest refineries; and the three largest smelters.

6-2.1.2 Attack Results. The results of the four attack strategies on Soviet refined copper production are shown on Figure 6-3. In this Figure, four week months were used.

In the refinery attack, the effect on production is immediate. Refined Copper production is reduced to about 8 percent of the normal

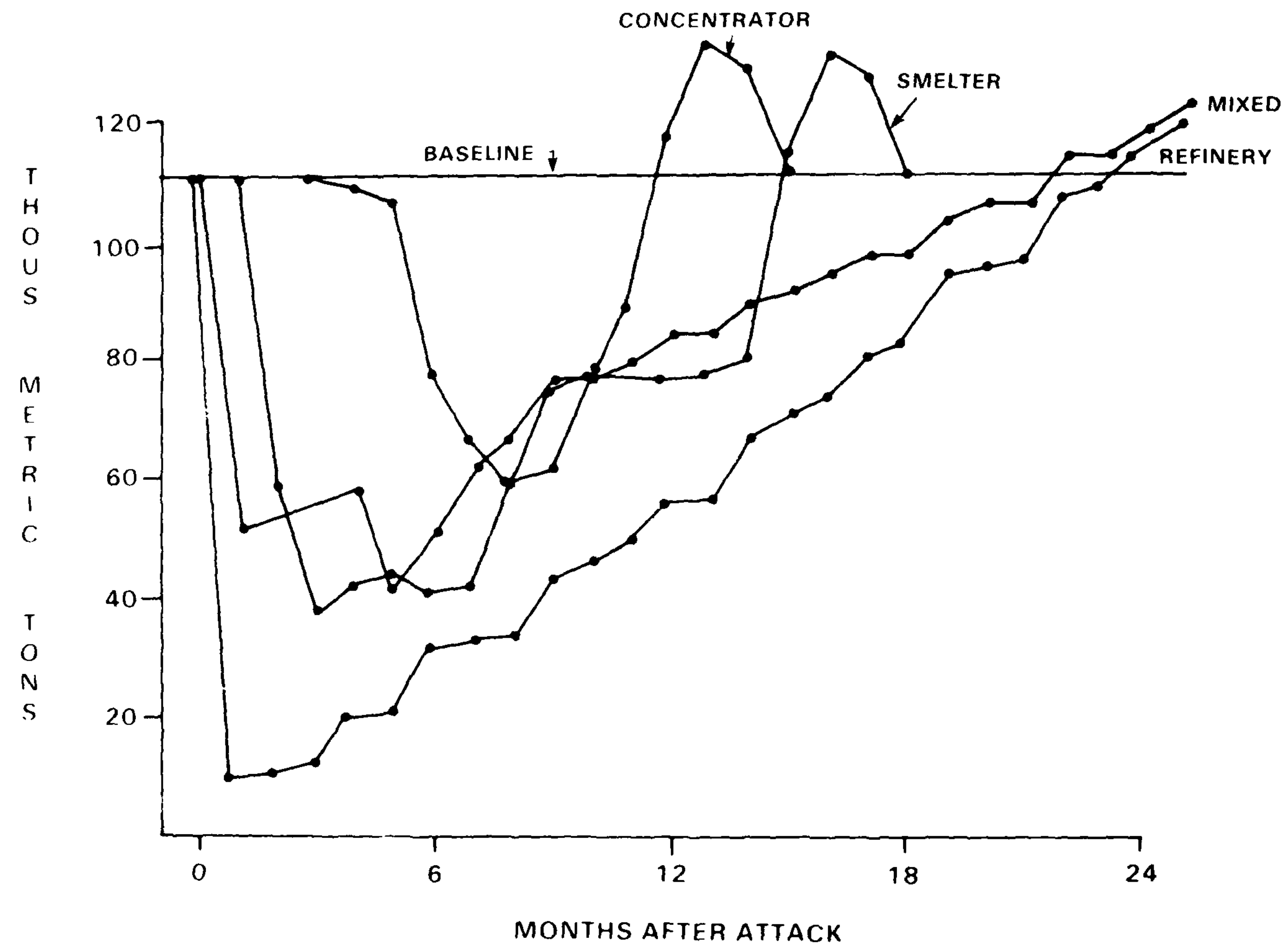

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Figure 6-3. Total monthly refined copper production level. Recovery begins within two months and extends over a two year period. This recovery is based on the rebuild assumptions put into the model.

When the six largest smelters are the targets, the decline in production is delayed one month. This delay results from the inventory of smelted copper at each refinery. A minor recovery occurs during the following six months as smelted copper is redistributed from surviving plants. At eight months, some smelting capacity is regained as a result of partial rebuild of three of the destroyed plants. At fifteen months, full production capacity is restored and production exceeds baseline levels to fill back orders and inventories. After eighteen months the output reverts to the steady state baseline level.

The attacks on the ore concentrators proved to be the least effective strategy in reducing copper production. The maximum effects of the attacks were delayed nine months due to the inventories of ore concentrates at the smelters and smelted copper at the refineries. By twelve months, the industry was back at baseline production levels. Again, production above baseline levels occurred for about three months to rebuild inventories. An experimental run was conducted assuming a concentrator rebuild time of six weeks. In this case the only effect on copper production was a reduction of inventories.

When the six attacks were applied against the three largest refineries and three largest smelters, the immediate effect was less than when the six attacks were concentrated on the refineries. The loss of three refineries caused an immediate effect on refined copper production which declined to about 50 percent of the baseline level during the first month. A modest recovery occurred over the following three months. This resulted from redistribution of smelted copper inventories. The loss of smelted copper inventories caused a further reduction in production of refined copper during the fifth month. This was followed by increased production until the ninth month as a result of partial recovery of smelter output. At that time, the reduced refinery capacity became the limiting factor. The excess capacity of the unattacked refineries allowed the recovery to reach the baseline level two months earlier than when the six attacks were concentrated on the largest refineries.

Figure 6-4 shows a breakdown of copper production at each of the eight refineries after the six largest smelters were destroyed. These are smelters numbered 1, 2, 4, 5, 9 and 12 at locations shown on Figure 6-1. Smelters 1, 2, and 4 serving refineries 1, 2, and 3 rebuild to half their capacity in six months (four week months) and all smelters are at full production after thirteen months. The model chose to operate refineries 1, 4, and 6 above baseline levels during the recovery period whereas refineries 5, 7, and 8 were essentially shut down and did not come back on the line to full production until the fifteenth or sixteenth month after the attack. Refinery 2 was returned to maximum capacity during the seventh through ninth month after the attack. The minor rises and drops in production from month-to-month are the result of transportation and distribution effects within the system.

Figure 6-5 shows a similar breakdown of refined copper production by the mixed attack case. The targeted refineries were 1, 5, and 8 and the targeted smelters were 1, 2, and 4 at locations shown on Figure 6-1. In this case, the attacked refineries gradually returned to full production over a 2 year period. All other refineries increase their production to the maximum level over the first two months after the attack. They rapidly use their smelted copper inventories and the output of the unattacked smelters. During the fourth month, the effect of inventory drawdown becomes apparent. By the sixth month, refinery 3 production drops to about 30 percent of normal and refinery 6 is forced to close. Soon after the three attacked refineries reach full capacity and the inventories and back orders are filled, all refineries return to normal baseline operation.

6-2.2 Individual Plant Attack

In order to determine the usefulness of INDATAK in the evaluation of the relative value of attacking individual plants, four model runs were made. Each of these runs assumed one plant was destroyed. Two of the runs assumed separate attacks on each of two largest refineries. The other two runs attacked each of the two largest smelters separately. These runs

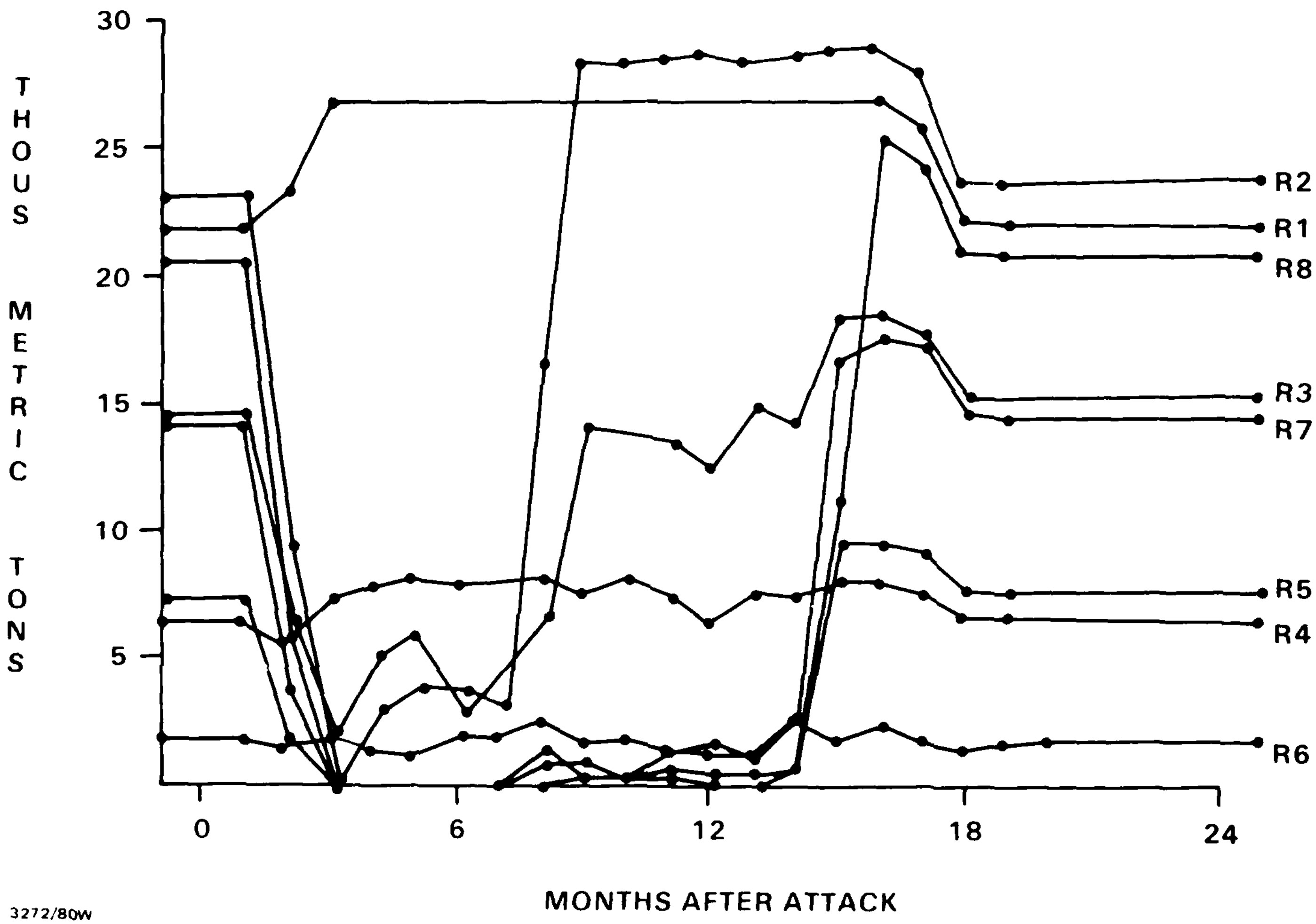

Figure 6-4. Monthly refined copper production (six smelter attack case)

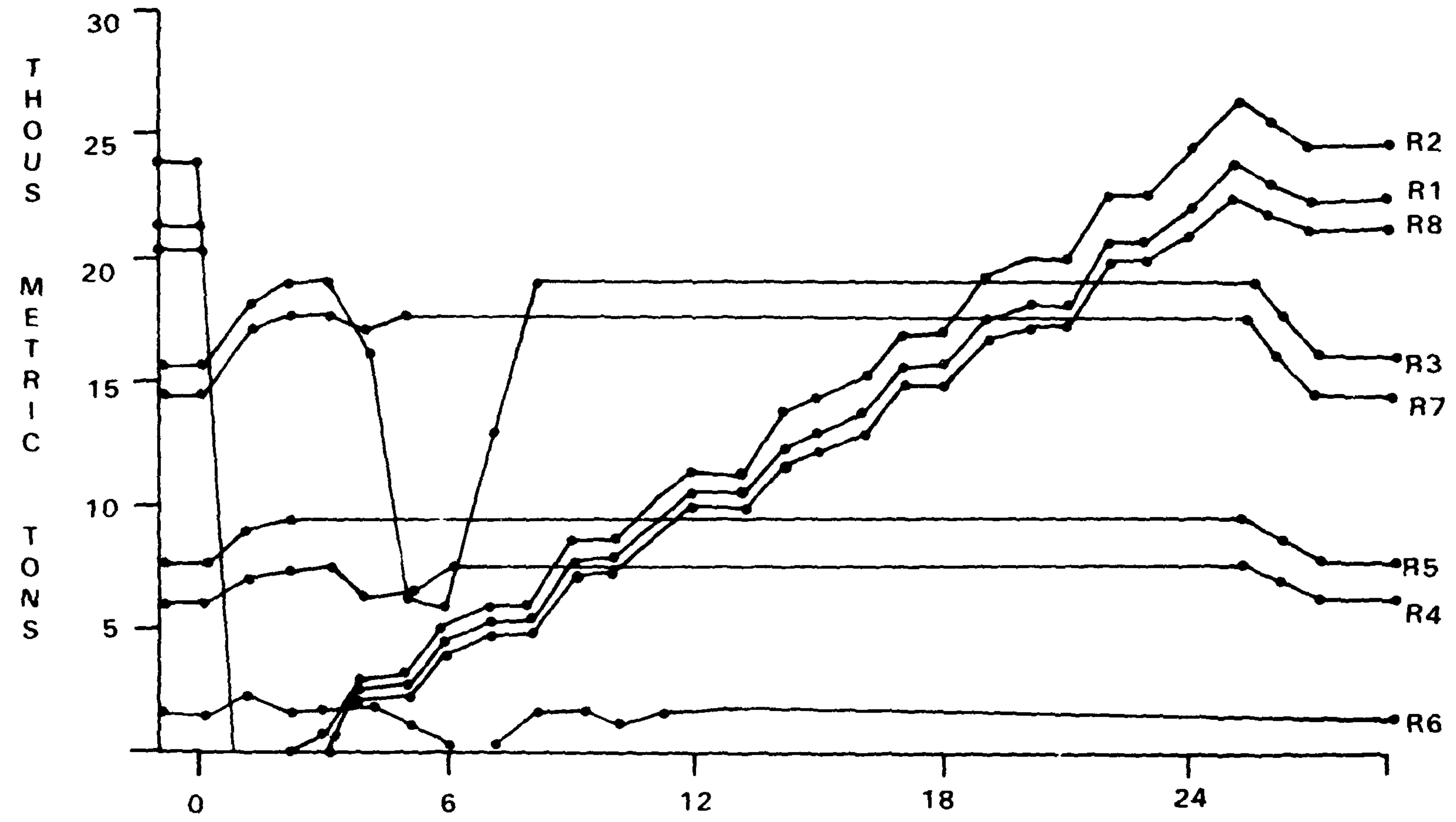

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Figure 6-5. Individual refinery monthly copp er production mixed attack case permitted a comparison of the effects on the other plants and the overall production capacity of the industry.

6-2.2.1 Comparison of Attacks on the Two Largest Refineries. When only one refinery is removed from the industry, the remaining refineries, increase production in an attempt to compensate for the loss. The model does not consider the geographical distribution of refined copper as a result, the redistribution was fairly uniform.

Figure 6-6 shows the results of these attacks on refined copper production over a 28 week period (seven-four week months). The production changes, both industry wide and at each refinery, are presented in terms of metric tons and percentages. The amount of lost production picked up by the remaining plants varied for the two attack cases, amounting to a total of 17,932 metric tons over the 28 week period. The refinery locations were shown in Figure 6-1.

6-2.2.2 Comparison of Attacks on the Two Largest Smelters. Figure 6-7 shows a comparison of the results of attacks on each of the two largest smelters over a 28 week period (See also Figure 6-1 for smelter locations). In this case, the distribution of smelted copper users was considered by the model. In the event that orders for smelted copper would result in excession transportation requirements, the orders are cancelled and reorders submitted at a later time. The results show that smelter 2 can pick up a significant portion of the lost production of smelter 1. However, smelter 1 cannot receive enough ore concentrate to do the reverse when smelter 2 is attacked. In the baseline analysis, the model showed smelter 1 operating at 92 percent capacity and smelter 2 operating at 75 percent capacity. This is due to refinery demands on the smelters and relative transportation difficulties in moving ore concentrates and smelted copper. It is noted that all unattacked smelters increased their production in an attempt to counter the results of the attack. However, the net loss of smelted copper is significantly greater in both cases than the loss of refined copper when the refineries were attacked.

REFINERY	BASELINE PRODUCTION METRIC TONS	% OF TOTAL CHANGE	AFTER ATTACK 1 PRODUCTION METRIC TONS	% OF TOTAL CHANGE	AFTER ATTACK 2 PRODUCTION METRIC TONS	% OF TOTAL CHANGE
1	150,335	19.31	0	-19.31	181,204	+ 3.96
2	166,437	21.38	200,348	+ 4.36	0	-21.38
3	107,370	13.79	129,255	+ 2.81	129,429	+ 2.83
4	42,965	5.52	51,705	+ 1.12	51,774	+ 1.13
5	53,728	6.90	64,634	+ 1.40	64,720	+ 1.41
6	10,763	1.38	11,079	+ 0.04	11,562	+ 0.10
7	102,032	13.10	122,797	+ 2.67	122,962	+ 2.69
8	144,998	18.62	174,502	+ 3.79	174,737	+ 3.82
TOTAL	778,628	100.00	754,320	- 3.12	736,388	- 5.44

Figure 6-6. 28 week refined copper production

SMELTER	BASELINE PRODUCTION METRIC TONS	% OF TOTAL CHANGE	AFTER ATTACK 1 PRODUCTION METRIC TONS	% OF TOTAL CHANGE	AFTER ATTACK 2 PRODUCTION METRIC TONS	% OF TOTAL CHANGE
1	150,335	19.31	0	-19.31	162,405	+ 1.55
2	146,909	18.87	193,574	+ 5.99	0	-18.87
3	19,528	2.51	25,730	+ 0.79	25,899	+ 0.82
4	107,370	13.79	107,704	+ 0.04	112,087	+ 0.61
5	42,966	5.52	43,099	+ 0.02	46,952	+ 0.51
6	53,728	6.90	53,896	+ 0.02	54,086	+ 0.05
7	2,193	0.28	2,862	+ 0.09	2,933	+ 0.01
8	8,570	1.10	9,152	+ 0.07	9,130	+ 0.07
9	69,842	8.97	82,777	+ 1.66	83,316	+ 1.73
10	32,190	4.13	38,200	+ 0.77	38,450	+ 0.80
11	42,679	5.48	50,554	+ 1.01	50,897	+ 1.06
12	51,159	6.57	60,656	+ 1.22	61,069	+ 1.27
13	51,159	6.57	60,656	+ 1.22	61,069	+ 1.27
TOTAL	778,628	100.00	728,860	- 6.39	708,293	- 9.03

Figure 6-7. 28 week smelted copper production

SECTION 7
FINDINGS, CONCLUSIONS AND RECOMMENDATIONS

7-1 FINDINGS AND CONCLUSIONS

The INDATAK model has demonstrated the feasibility of using simulation as a tool to estimate the impact of strategic strikes on major sectors of an industry and to analyze the post-attack recovery. It is suitable for use in the development of targeting strategies that would minimize the number of weapons needed to achieve a particular level of damage or maximize rebuild times. The model can be used to evaluate the production contribution of individual plants when other industry components are destroyed. It can also be used to measure the impact on the transportation network which serves the industry.

Use of the INDATAK methodology requires a thorough understanding of the industry being analyzed and the interactions of the various industrial components. Therefore, detailed data must be gathered for input into the model. However, the relative worth of missing data on the overall results can be readily determined by use of sensitivity analyses.

The limited use of the copper industry model has shown that the geographical distribution of an industry impacts quite heavily on its ability to adapt to crisis situations. This is due primarily to transportation network constraints. It was found that, when a limited number of weapons are allocated (six for the copper industry), the maximum production loss was achieved when all the weapons were applied against one production tier (plant category) and when this tier represented the narrowest point in terms of number of plant locations. In the copper industry case, the best attack strategy would be to concentrate the attack on the refineries. In general, if the tier or echelon level of plants in the production chain are above those attacked, their production would be inhibited by the lack of raw materials. On the other hand, if they were below the attacked plants they would suffer from lack of market for their products. This would force them to retard or cease their operations until the market was reestablished.

This model exercize has demonstrated clearly that limited attacks on the largest plants in an industry does not result in the proportional reduction in production that would be implied from normal drawdown curves shown in Figures 5-8 and 5-9. For example, the destruction of the largest refinery at Dzhezkazgan (310,000 TPY output) does not reduce the industry capacity by over 20 percent as would be implied by the drawdown curve in Figure 5-9. The model shows that the total reduction would be about 5.4 percent as shown in Figure 6.6. The reason being that the remaining refineries would use their surplus capacity to make up part of the loss. This would however impose an additional burden on the transportation network serving the industry.

7-2 RECOMMENDATIONS

It is recommended that:

(1) INDATAK be expanded to multiple industries to further address the questions of geographic distribution, inter-industry competition for resources, and the value of bonus effects on colocated industrial facilities.

(2) The industries selected for this expansion be the steel and chemical industries. These could be used in conjunction with the copper industry to investigate the questions noted in (1) above. The Soviet steel industry is similar in nature to the copper industry and will demonstrate the flexibility of INDATAK to model similar industries. The Soviet chemical industry would provide INDATAK with a more complex modeling situation. This study will show the interaction between the three industries and the collective effect of their competition for transportation resources.

SECTION 8

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APPENDIX A
THE SOVIET COPPER INDUSTRY

A-1 DEVELOPMENT OF THE COPPER INDUSTRY

A-1.1 Early History to 1918

Archeologic studies in the Middle East and in the valley of the Tigris and Euphrates Rivers indicate that man was using copper and bronze in the Third and Fourth Milleniums B.C. Some of these materials probably came from the Caucasus Mountains in the region now known as Armenia. By the Third Millenium, mining areas in Central Asia, the Ural Mountains, and parts of Siberia had been developed and were supplying small amounts of copper. Both mining and smelting continued at a very low level until the 16th Century when Ivan the Terrible put down the Tartar tribes and opened the country between Moscow and the Ural Mountains to exploration and colonization by the Russians. By the 17th Century, the Russians were bringing in foreign geologists to locate sources of raw materials and to teach the Russians the method for exploiting these resources. The first period of rapid expansion occurred during the reign of Peter the Great in the 18th Century; at the end of this period, Russian copper production had reached 3000 metric tons per year (TPY). Production of sulfuric acid as a by-product of copper smelting, and the introduction of many improved methods of ore treatment originated in the 19th Century. These resulted in a production rise to about 6500 TPY by the end of the century. Continued rapid expansion brought the industry to a level of about 35,000 TPY at the start of World War I. Production dropped during the war and was severely curtailed in 1918 at the time of the Revolution.

A-1.2 History Since 1918

During the Russian Revolution there was widespread damage to the copper industrial works and flooding and burning of the mines. The state of the copper industry was so bad that in the period 1919 to 1922, no copper was produced. Skilled personnel involved in this industry were widely scattered, and it has been said that at the time the New Economic Policy (NEP) was issued in 1921, only 58 metallurgists and technicians with over three years' experience in non-ferrous materials were still to be found in Russia.

The NEP started a series of drives to upgrade and expand industry throughout Russia. Its concentration on the electrification of Soviet manufacturing led to a requirement for a large increase in copper production. By 1930, copper output had risen to 34,000 TPY and by the start of World War II the output stood at about 180,000 TPY. This was not enough to reach self-sufficiency, however.

Further efforts to increase production after World War II resulted in reaching self-sufficiency in the late 1960's at a level of about 700,000 TPY. Estimated production in the early 1970's was about 1.2 million TPY, with current levels probably about 1.5 million. Russia is now the world's second largest producer of copper and is an exporter of the metal.

A-2 COPPER PRODUCTION METHODOLOGY

A-2.1 Ores and Mining

Important ores of copper are of two main types, oxides and sulfides. The oxide ores are easier to smelt, but are not as plentiful or as widespread as the sulfide ores. Figure A-1 shows the chemical composition of most of the important copper ores now being mined throughout the world, as well as some of the important allied metals found primarily in conjunction with the sulfide copper ores. Almost all Soviet copper is now obtained from sulfide ores, the main oxide deposits having been exhausted by the end of the 19th Century.

Initially, large-scale ore production was obtained from underground mines, and many of these are still in use, primarily in the Ural Mountains and in Armenia. Most recent high-production mining has been shifted to open-pit operations. This has been made possible by the development of suitable machinery for this type of ore removal and by the discovery of large new ore bodies which make it economical to develop such operations. Many of these new ore bodies were located as a result of the exhaustion of many of the underground mining areas, some of which have been worked for centuries.

ORES

Type		World Production (%)
Sulfides		90
Chalcopyrite	$CuFeS_2$	
Bornite	Cu_5FeS_4	
Chalcocite	Cu_2S	
Covellite	CuS	
Oxides		10
Cuprite	Cu_2O	
Tenorite	CuO	
Malachite	$CuCO_3Cu(OH)_2$	
Native Copper		Very Small

Important Allied Metals -

Nickel	Molybdenum	Platinum
Zinc	Gold	Palladium
Lead	Silver	Rhenium

Figure A-1. Copper ores

Most ore bodies now being worked yield rock with a metallic copper percentage of about 1 to 2 percent. Some ores bearing as little as 3/4 percent are also mined. A few underground deposits in heavily mineralized zones can have up to approximately 20-30 percent copper content, but veins such as these are now rare.

A-2.2 Ore Concentration

Ores are difficult to smelt when the metallic copper content is below 20 percent. Since most of the mineable ores today are much below this figure, the ores must be concentrated to remove some of the matrix rock, or gangue, so a smeltable material can be obtained. There are three main steps in this process:

(1) Crushing,

(2) Milling, and

(3) Flotation beneficiation.

Large pieces of ore are reduced in size in a jaw crusher until all the ores may be fed into a cone crusher. The particle size resulting from this step is about 1 to 2 cm. in diameter. These pieces are then sent through rod and ball mill processing to grind the ore to very fine particles between 10 and 75 micrometers in diameter. The size range is important in the flotation process which follows. If the pieces are too small, they will form a slime in the flotation liquid, and if they are too large, they will not float, and copper will be lost.

After grinding to suitable size, the powdered ore is mixed with water which has had butyl xanthate and pine oil added. The mixture is then stirred, and air is blown through the slurry. The butyl xanthate acts to cause the surfaces of the copper ore particles to capture air bubbles. These then float to the surface and are skimmed off while the gangue falls to the bottom of the flotation tanks. The pine oil in the mix acts to control frothing at the surface of the liquid. By these means, the resultant ore will have a copper concentration of between 20 and 30 percent, suitable for smelting.

A-2.3 Smelting

The purpose of smelting is to transform the copper ore into a complex material containing metallic copper and copper-sulfur compounds, called a "matte." In the process the gangue is melted, combined with fluxing materials, and removed as slag. In the second phase of smelting, the molten matte is converted into almost pure metallic copper by the Pierce-Smith process. The resulting output, ready for refining, is characterized as "blister copper" because the sulfur content is still high enough (up to two percent) that, if an attempt to cast the material is made, the sulfur will combine with oxygen in the air at the melt surface and form blisters containing sulfur dioxide gas.

Smelting is done in three types of furnaces:

(1) Reverberatory,

(2) Electric, and

(3) Flash.

Reverberatory and electric furnaces are essentially the same except for the energy source used to raise the temperature of the ore. In both of these furnaces, the input material is usually roasted prior to being fed to the smelter. Roasting dries and partially processes the ores, thus making the smelting more efficient.

Flash smelters were introduced in the 1930's and are used primarily when an autogenous (self-heating) process is desired and recovery of the maximum amount of sulfur dioxide is needed. The input material for a flash smelter must be dried, but should not be roasted.

The final step in the smelting process uses retorts similar to Bessemer converters used in steel making. The molten matte is injected with air or oxygen-enriched air under pressure, and the sulfur remaining in the melt is oxidized and removed as sulfur dioxide gas. The product is blister copper of 98 to 99.5 percent purity.

A-2.4 Refining

Essentially, all copper used in the world today is refined from the blister copper produced by the smelting process. Since blister copper is not easily castable, the first step in the refining of copper is called fire refining. In this process, air is bubbled through the molten copper to remove as much of the remaining sulfur as possible, and then hydrocarbon gases are injected to remove the oxygen left from the sulfur-removal process. The end result is a castable copper from which anodes are made to be used as input to an electrolytic process.

In the final step of copper production, anodes and cathodes are suspended in tanks containing an electrically-conductive liquid, and electric current is used to remove metallic copper from the impure anodes and deposit it on the cathodes. After 20 to 30 days, the cathodes are removed for shipment. They are now copper containing only about .005 percent impurities.

A-2.5 Economic Factors

A-2.5.1 Energy Usage

One of the controlling factors in the cost of copper extraction is the energy consumed by the process. A typical energy budget is shown in Figure A-2. Most of this energy is obtained from natural gas and electricity, with much smaller usage of oil and coal. A major problem in the exploitation of some of the more remote ore bodies in the USSR has been the difficulty of furnishing sufficient energy in the proper form.

A-2.5.2 Capital Investment

A continuing problem in the Soviet economy has been a lack of capital. This has limited the growth of the copper industry during most of its history. A single large processing center containing a smelter and refinery may cost approximately $100 million to get into operation. Relative capital costs obtained from United States figures are shown in Figure A-3.

A-2.5.3 Transportation

The primary transportation method used for material transfer within the copper extraction industry is rail shipment. Trucks are probably used only locally for short haul links when rail is impractical due to low flexibility of route change and large turning radius of the cars. Most of the copper industry is located in areas of the USSR where no

ENERGY REQUIREMENTS FOR THERMAL EXTRACTION OF COPPER	
OPERATION	ENERGY PER METRIC TON OF COPPER (KCAL X 10^5)
Mining	13
Milling	9
Smelting	20
Converting	0.0
Anode Preparation	0.5
Refining	3
Cathode Melting	4
Total --	49.5

Figure A-2. Energy requirements

CAPITAL COSTS (1975) COPPER EXTRACTION COMPLEX	
OPERATION	FIXED CAPITAL COST ($ U.S./TON OF COPPER/YEAR)
Mine (Underground)	2,000
Concentrator	800
Smelter	1,200
Refinery	300
Total --	4,300

Figure A-3. Capital costs per metric ton per year waterways are available. Only one sea link is known to carry bulk material within the industry.

A full discussion of the transportation methods and network is given in Section 5-1.2.

A-2.5.4 Auxiliary Industry Outputs

There are two prime allied outputs resulting from the processing of materials in the extractive copper industry. The first is a group of allied metals (see Figure A-1), most of which are separated during the ore concentration stage and processed separately. In the case of nickel, zinc, and lead, these other metals may have as great a concentration in the ore as the copper minerals. For some of the rare metals, the monetary value of the materials recovered may be quite large. Thus, great emphasis is placed on the design of copper extraction processes to recover all possible materials of value.

The second bulk output obtained as a by-product is sulfur dioxide gas which is made into sulfuric acid. Roughly 40 percent of all sulfuric acid produced in the USSR is used to make agricultural fertilizers, and the copper smelters and refineries furnish about 15 percent of all sulfuric acid made in the USSR. Rock with a high phosphate content is shipped from the Kola Peninsula as far away as Armenia for conversion into superphosphate fertilizer.

A-3 SOVIET COPPER PRODUCTION

Within the USSR there are seven main geographical areas in which copper is produced or recovered from scrap. Six of these areas are producers of new copper, and one, European Russia, is only a scrap refiner. These areas are shown in Figure A-4.[1] The estimated yearly output of new copper for each producing area in the mid-1970's is shown in Figure A-5. Each of these areas will be discussed individually in the following paragraphs.

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1. One of these areas, Kazakhstan, has three separate smelter locations.

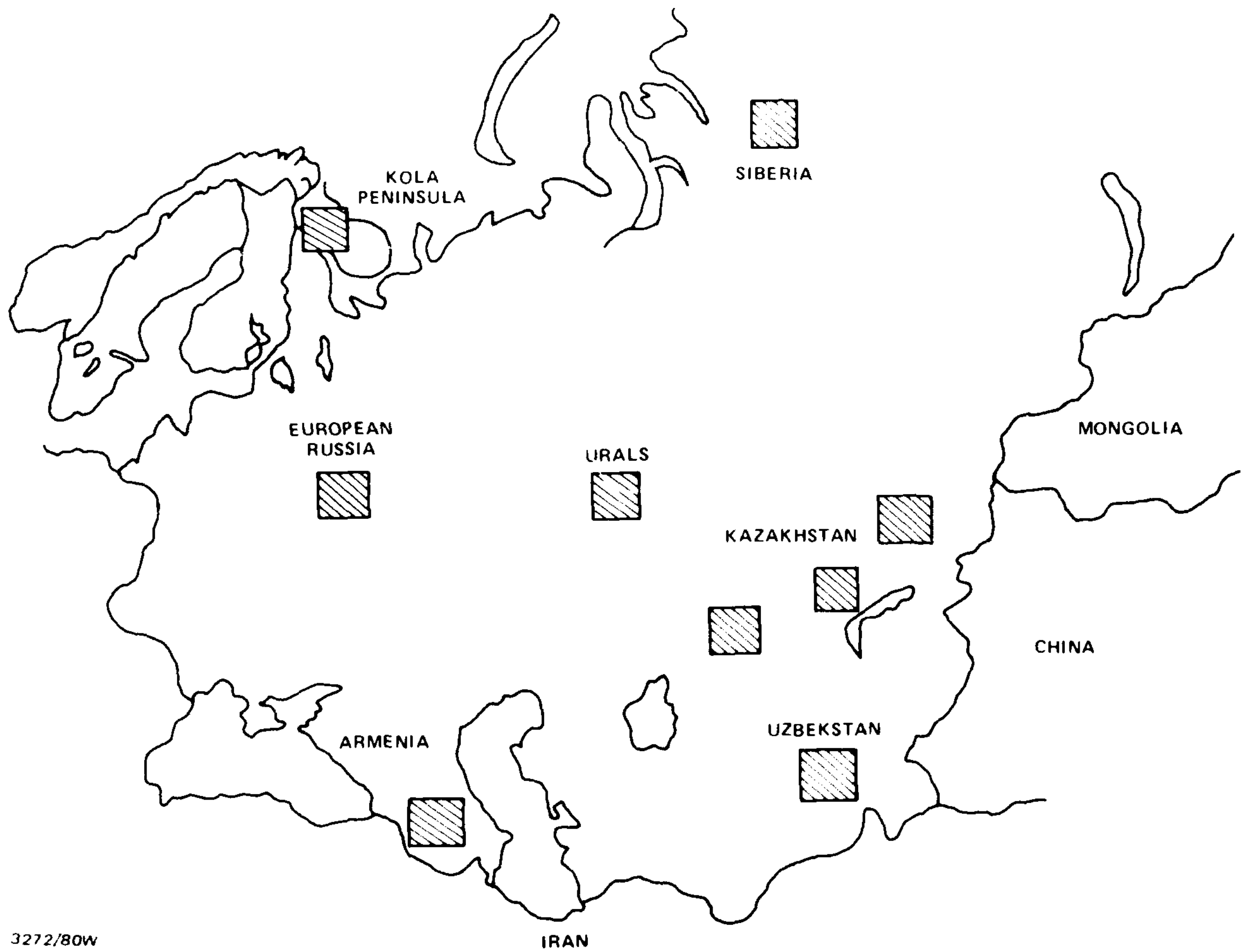

Figure A-4. Major Soviet copper processing areas

SOVIET COPPER PRODUCTION ESTIMATED YEARLY PRODUCTION	
GEOGRAPHIC AREA	YEARLY OUTPUT (METRIC TONS)
Armenia	80,000
Kazakhstan	590,000
Kola Peninsula	200,000
Siberia	100,000
Urals	460,000
Uzbekstan	200,000
Total --	1,450,000
World Rank: 2	

Figure A-5. Soviet copper production

A-3.1 Armenia

The Caucasus Mountains contain some of the oldest mining areas in the USSR. Most of the mines are underground, with a few open-pit workings being developed. All smelting and refining in Armenia is done at Alaverdi. Recent upgrades of the smelting facility at Alaverdi have led to the installation of modern electric arc furnaces to supplement the older reverberatory furnaces. Alaverdi is also a large manufacturer of sulfuric acid and of superphosphate fertilizer. Mines in the southeastern part of the area yield a complex ore with significant deposits of molybdenum, which is separated at the concentrators and smelted at other locations.

Figure A-6 shows the site locations and material flow paths for this area.

A-3.2 Kazakhstan

With the development of the large complex at Dzhezkazgan, this area has become the largest copper producer in the USSR. An older installation at Karsakpay, west of Dzhezkazgan, was used as an experimental producer for many years, but is probably closed now.

Dzhezkazgan and Balkhash have problems in obtaining industrial quantities of water. Dzhezkazgan is in an arid plain with no rivers and little rainfall. Balkhash is situated on the north shore of Lake Balkhash, but its waters are salty and difficult to use in most industrial processes, particularly ore concentration for the copper plants.

The area in East Kazakhstan around Glubokoye is similar to the mining areas of the Urals, in that complex ores are found. In many of these mines, zinc and lead are the primary metals found. The Glubokoye smelter/refinery is the smallest of the three [illegible] this region.

Figure A-7 gives the site lo[illegible] [illegible]d material flow paths for this area.

A-3.3 Kola Peninsula

The Kola Peninsula is primarily a producer of nickel, but commercial quantities of copper and other metals are also found. Old mines a[illegible] Zapolyarnyy are supplemented in the summer by imports from Noril'sk (Siberia) and are divided among the small smelting operations at Nike[illegible], Zapolyarnyy and Monchegorsk.

AREA: Armenia				ESTIMATED RESERVES: 1.5 x 10^6 Metric Tons		
Mine	Lat.	Long	Sec. Ore(s)	Concentrator	Smelter	Refinery
Agarak	38-52	46-11	Mo	Agarak	Alaverdi (41-08, 44-34)	Alaverdi 80,000 TPY
Akhtala	41-09	44-46		Akhtala (1)		
Shamlug	41-10	44-43		Akhtala (2)		
Alagyaz	40-41	44-17		Alagyaz		
Dastakert	39-23	46-02	Mo	Dastakert (?)		
Kadzharan (Open Pit)	39-10	46-08	Mo	Kadzharan		
Kafan	39-12	46-24		Kafan		
Madneuli (West of Marneuli R.R. Station at 41-27, 44-48)				Kazreti (41-23, 44-25)		
Urup	43-51	41-09		Urup		

(1) 1 Concentrator
(2) 2 Concentrators
(?) unknown number of Concentrators

Figure A-6. Site locations and material flow paths for Armenia

AREA: Kazakhstan				ESTIMATED RESERVES: 10^7 Metric Tons		
Mine	Lat.	Long	Sec. Ore(s)	Concentrator	Smelter	Refinery
Vostochno-Kounradskiy	47-00	75-03		Balkhash	Balkhash	Balkhash
Sayak-Pervyy	47-00	77-24	Mo, Re	"	"	"
Uspenskiy	48-40	72-43		Uspenskiy	"	"
Bozshakol'	51-50	74-20		Bozshakol'	"	"
Zlatoust-Belvskiy (at Nikol'Skiy) Open Pit				Dzhezkazgan (1)	Dzhezkazgan	Dzhezkazgan
Dzhezkazgan (several underground mines)	47-58	67-28	PB	Dzhezkazgan (?)	"	"
Orlovka	50-58	81-23		Orlovka	Glubokoye	
Nikolayevka	50-35	81-42	Zn	Ust'Talovka	(50-08, 82-18)	"
Ust'Talovka	50-35	81-42	Zn	"	"	"
Verkhnebere Zovskiy	50-18	82-13	Zn	At Mine	"	"
Belousovka	50-08	82-33	Zn	At Mine	"	"
Zolotukha	50-47	81-32	PB, Zn	At Mine	"	"
Zyryanovsk (Open Pit)	49-43	84-20	PB, Zn	Zyryanovsk	"(?)	"
					(?) = Unknown	

Figure A-7. Site locations and material flow paths for Kazakhstan

The Kola Peninsula is also the source of the high-quality apatite used in the manufacture of superphosphate fertilizer.

Figure A-8 shows the site locations and material flow paths within the area.

A-3.4 Siberia

The only known copper producing area in Siberia is the large complex in and around the city of Noril'sk. The ores are complex in this region, and several rare metals are produced. Recent enlargements of the complex have seen the installation of flash smelters. During the summer, both ore and concentrates are shipped by sea to the Kola Peninsula.

A huge new ore body in the Udokan Mountains in Eastern Siberia has been explored but is not yet developed. It lies some 200 miles north of the nearest railhead on the Trans-Siberian railroad and the terrain is very difficult. Plans for mining in this area are not known.

Figure A-9 gives the sites and material flow in Siberia. The mines in this area cannot be precisely located by map coordinates.

A-3.5 Ural Mountains

The Ural Mountains' area is still a large producer of copper even though many of the mines have been worked for many decades. Most of the mining in the northern and central zones is underground, and complex ores are recovered. The newer deposits in the south, such as those at Bliavinsk and Gav, are open-pit mines with the copper minerals finely dispersed in a base porphyry. The ore dispersal in the Bliavinsk mine is so fine that concentration is not possible, and the crushed ore is smelted directly.

Many of the ores contain a high percentage of iron pyrite, which is processed both for the iron content and for the sulfur. The roasted sulfur produces sulfur dioxide gas to feed the sulfuric acid plants in the area.

Figure A-10 gives some of the site locations and the material flow for this region. Many of the mines in this area cannot be located by map coordinates because the names are unplotted local minehead positions.

A-5.6 Uzbekstan

Only one producing center is located in Uzbekstan. The Kalmakyr mines are just east of the town of Almalyk which contains the rest of the

AREA: Kola Peninsula				ESTIMATED RESERVES: Unknown		
Mine	Lat.	Long	Sec. Ore(s)	Concentrator	Smelter	Refinery
Zapolyarnyy (Nickel is primary ore)	67-25	30-50	Ni Se Te Rl	(67-56, 32-58)	Monchegorsk	Monchegorsk
				(69-25, 30-16) Zapolyarnyy (also feeds Nikel' smelter)	Nickel'	

Figure A-8. Site locations and material flow paths of Kola Peninsula

AREA: Siberia				ESTIMATED RESERVES: Unknown		
Mine	Lat.	Long	Sec. Ore(s)	Concentrator	Smelter	Refinery
Medvezhiy Ruchey (Open Pit)				Noril'sk (?) (69-20, 88-06)	Noril'sk	Noril'k
Zapolyarnyy						
Mayak (Talnakn deposit)						
Khara-Yelakh (Oktyabr'skoye deposit)						
				(?) = Unknown number		

Figure A-9. Site locations and material flow paths for Siberia

AREA: Urals				ESTIMATED RESERVES: Unknown		
Mine	Lat.	Long	Sec. Ore(s)	Concentrator	Smelter	Refinery
III International				Krasnouralsk (1)	Krasnouralsk (58-21, (60-03)	Pyshma (56-55, 60-37)
Krasnogvardelsk				Krasnouralsk (2)		
Kabansk						
Turinsk	59-46	60-12		Turinsk		
Levikhinsk	57-36	59-55		Kirovgrad (57-26, 60-04)	Kirovgrad	
Lomovsk	57-40	58-34		"		
Beldrechensk				"		
Navoyezhovsk				" (?)		
Degtiarsk	56-42	60-06		Degtiarsk	Sredne Uralsk (56-59, 60-28)	
Kliuchevsk	57-07	60-56		Kliucnevsk, Pyshma		
Gumeshevsk				Pyshma		
Karabash	55-29	60-14		Karabash	Karabash	Kyshtym (55-42, 60-34)
Bliavinsk (Open Pit)	51-24	57-44		None	Mevnogorsk (51-24, 57-37)	
Uchaly	54-15	59-15		Uchaly		
Gay (Open Pit)		51-27	58-27	Gay		
Sibay	54-42	58-39		Sibay		
Makanski orebody @ Buribai	51-57	58-10		Buribai		

Figure A-10. Site locations and material flow paths for Urals industrial installation. Molybdenum is a side product of the copper extraction process.

Figure A-11 shows the locations of the sites for this center.

A-3.7 European Russia

This region is industrialized but not heavily mineralized. Only Moscow is included here, as the location of a scrap recovery and refining operation. These processes may also be conducted at Leningrad and at Kol'chuginc, but the certainty of these plants and their probable contributions to the Soviet refined copper output are not sufficiently large to include them here.

Figure A-12 is included for completeness in tabulating all areas involved.

AREA: Uzbekstan				ESTIMATED RESERVES: 3 x 10^6 Tons		
Mine	Lat.	Long	Sec. Ore(s)	Concentrator	Smelter	Refinery
Kalmakyr Area (Several Mines)	40-50 (40-50,	69-35 69-37)	Mo	Almalyk	Almalyk	Almalyk

Figure A-11. Site location and material flow paths for Uzbekstan

AREA: European Russia				ESTIMATED RESERVES: None		
Mine	Lat.	Long	Sec. Ore(s)	Concentrator	Smelter	Refinery
None				None	Moscow (scrap remelt)	Moscow

Figure A-12. Site locations and material flow paths for European Russia

APPENDIX B
SAMPLE INDATAK OUTPUT REPORTS

B-1 PRODUCTION STATUS REPORT

Figure B-1 shows a sample Production Status Report. Scheduled once a month, this report provides a snapshot of the functions that have taken place at each production facility. Each page is marked with the name of the run, the data and the simulation time at which the report was taken. The report lists, from left to right:

- The production facility identification code
- The internal model node number
- The item code of each material stocked at this node
- The item's use
- Quantity currently on hand and the fraction of the maximum allowable inventory that this represents.
- Quantity of raw material received or finished good shipped since the last report.
- Amount due in or due out
- Amount cancelled since last report
- Orders for finished goods sent and raw material received
- Tonnage consumed or produced and the fraction of maximum production that this represents.

B-2 DETAILED STATISTICS REPORT

Figure B-2 provides and example of the Detailed Statistics Report which is produced at the end of the model run. This report provides aggregate statistics on inventories, plant disposition and production for each plant over the course of the entire simulation. These data are also compiled for each item in the entire industry.

Each statistic has listed for it, the mean value, standard deviation, minimum, and maximum. The total and weighted sum columns also contain

** INDATAK MODEL **

SUMMARY OUTPUT
RUN NO. 1

ANALYST..THE BDM CORP
DATE. 12/ 6/ 197[illegible]
RUN NAME.3 SCONDATACK (FULL
TNOW 5376.010

PRODUCTION STATUS REPORT

PLANT	ITEM		USAGE	BAL ON HAND		REC/SHPD	DUE IN/OUT	CANCELLED	PROD SN/RC	CNSMD/PROD	
R01	1	1300	RAW MATERIAL	15101.7	(.750)	21525.[illegible]	5379.3	0.0	21526.1	21526.1	
		1400	FINISHED GOOD	555[illegible].3	(.4[illegible])	21526.2	0.0	0.0	21526.2	21525.1	(.824)
R02	2	1300	RAW MATERIAL	1782[illegible].7	(.750)	23[illegible]31.2	5[illegible]54.3	0.0	23831.5	23831.5	
		1400	FINISHED GOOD	5935.0	(.4[illegible])	23831.7	0.0	0.0	23831.7	23831.5	(.[illegible]24)
R03	3	1300	RAW MATERIAL	11493.3	(.750)	15373.[illegible]	3[illegible]41.2	0.0	15374.0	15374.0	
		1400	FINISHED GOOD	3827.1	(.4[illegible])	15374.1	0.0	0.0	15374.1	15374.0	(.[illegible]24)
R04	4	1300	RAW MATERIAL	4602.9	(.750)	51[illegible]2.0	1537.1	0.0	6152.1	6152.1	
		1400	FINISHED GOOD	1532.2	(.4[illegible])	51[illegible]2.1	0.0	0.0	6152.1	6152.1	(.[illegible]24)
R05	5	1300	RAW MATERIAL	3794.9	(.4[illegible])	76[illegible].9	3[illegible]5.1	0.0	7693.2	7693.2	
		1400	FINISHED GOOD	1917.0	(.4[illegible])	76[illegible]3.3	0.0	0.0	7693.3	7693.2	(.[illegible]24)
R06	6	1300	RAW MATERIAL	3[illegible].1	(.025)	12[illegible].	1501.[illegible]	0.0	1282.8	1282.8	
		1400	FINISHED GOOD	394.0	(.512)	12[illegible].	0.0	0.0	1283.9	12[illegible]2.8	(.697)
R07	7	1300	RAW MATERIAL	1092[illegible].8	(.750)	14[illegible]0[illegible].4	3[illegible]50.[illegible]	0.0	1459[illegible].6	145[illegible].6	
		1400	FINISHED GOOD	363[illegible].2	(.4[illegible])	1460[illegible].7	0.0	0.0	1460[illegible].7	146[illegible].6	(.[illegible]24)
R08	8	1300	RAW MATERIAL	15532.7	(.750)	20761.5	51[illegible]7.3	0.0	20761.7	20761.7	
		1400	FINISHED GOOD	5170.4	(.4[illegible])	20761.[illegible]	0.0	0.0	20761.9	20761.7	(.[illegible]24)
S01	9	1200	RAW MATERIAL	56493.4	(.714)	10452[illegible].0	25620.6	0.0	[illegible]3490.0	110275.3	
		1300	FINISHED GOOD	4211.7	(.43[illegible])	21526.1	0.0	0.0	21526.1	[illegible]2517.7	(.[illegible]65)
S02	10	1200	RAW MATERIAL	71753.3	(.757)	373[illegible]7.5	21736.7	0.0	[illegible]7374.1	[illegible]7374.1	
		1300	FINISHED GOOD	6254.3	(.543)	21035.4	0.0	0.0	21035.4	21035.1	(.751)
S03	11	1200	RAW MATERIAL	10110.4	(.76[illegible])	123[illegible]0.3	3952.6	0.0	12295.4	122[illegible]5.4	
		1300	FINISHED GOOD	831.4	(.543)	27[illegible]6.2	0.0	0.0	2796.2	27[illegible]5.1	(.747)
S04	12	1200	RAW MATERIAL	70664.3	(.747)	[illegible]4[illegible]4.5	23726.0	0.0	[illegible]4535.3	[illegible]4535.9	
		1300	FINISHED GOOD	382[illegible].8	(.4[illegible])	15374.0	0.0	0.0	15374.0	15373.8	(.[illegible]24)
S05	13	1200	RAW MATERIAL	[illegible]3314.0	(.7[illegible])	3724[illegible].4	[illegible]346.0	0.0	39252.3	39252.3	
		1300	FINISHED GOOD	1532.9	(.4[illegible])	5152.1	0.0	0.0	6152.1	6152.0	(.824)
S06	14	1200	RAW MATERIAL	[illegible]2134.5	(.747)	5[illegible]3[illegible]2.2	14135.[illegible]	0.0	[illegible]5155.2	[illegible]5[illegible]2	
		1300	FINISHED GOOD	492[illegible].4	(1.2[illegible]3)	76[illegible]3.1	3009.5	0.0	7693.2	7693.1	(.[illegible]24)
S07	15	1200	RAW MATERIAL	2670.0	(1.000)	2144.0	0.0	0.0	2144.0	2144.0	
		1300	FINISHED GOOD	6[illegible].5	(.1[illegible]5)	305.5	0.0	0.0	305.5	3[illegible]5.5	(.[illegible]55)

3272/80W

Figure B-1. Sample production status report

DETAILED STATISTICS REPORT TAKEN AT TIME = 14795.000

	TOTAL	WGTD SUM	MEAN	STD DEV	MIN	MAX
FOR NODE 1 R01						
STATISTICS FOR RAW MATERIAL ITEM NO. 1300						
NUMBER OF ORDERS AND QUANTITY PER ORDER	.88000E+02	.47333E+06	.53788E+04	.11409E+02	.53674E+04	.54101E+04
MEAN QUANTITY DUE-IN	.14795E+05	.50631E+06	.34245E+02	.17595E+03	0.	.53392E+04
MEAN DURATION OF DUE-IN	.47333E+06	.69259E+03	.14634E-02	.19755E-01	.47874E-05	.29571E+00
NUMBER AND QUANTITY OF SHIPMENTS RECEIVED	.93000E+02	.47333E+06	.50896E+04	.19425E+04	.56250E+03	.54101E+04
MEAN BALANCE ON HAND	.14795E+05	.31708E+09	.21445E+05	.17595E+03	.11251E+05	.21480E+05
NUMBER AND QUANTITY OF CANCELLATIONS	NOT YET COLLECTED					
DURATION OF CANCELLATIONS	NOT YET COLLECTED					
PLANT DISPOSITION STATISTICS						
TOTAL AND PERCENT OF TIME IN OPERATION	.14795E+05	.14617E+05	.98864E+00	.10593E+00	0.	.10000E+01
TIME STOPPED WAITING FOR RAW MATERIALS	NOT YET COLLECTED					
TIME STOPPED WAITING FOR ORDERS	.14795E+05	.16800E+03	.11363E-01	.10599E+00	0.	.10000E+01
TIME STOPPED WHILE CONVERTING	NOT YET COLLECTED					
TIME STOPPED DUE TO ATTACK	NOT YET COLLECTED					
PRODUCTION STATISTICS FOR ITEM NO. 1400						
MEAN QUANTITY IN PRODUCTION	NOT YET COLLECTED					
NUMBER OF BATCHES AND QUANTITY PER BATCH	.87000E+02	.46796E+06	.53789E+04	.11435E+02	.53674E+04	.54101E+04
QUANTITY OF FINAL PRODUCT PER BATCH	.87000E+02	.46796E+06	.53789E+04	.11435E+02	.53674E+04	.54101E+04
PRODUCTION INVENTORY AND DEMAND STATISTICS FOR ITEM NO. 1400						
MEAN BALANCE ON HAND	.14795E+05	.43927E+08	.29643E+04	.25368E+04	.17317E+01	.10740E+05
NUMBER OF AND QUANTITY PER ORDER RECEIVED	.88000E+02	.47334E+06	.53789E+04	.11572E+02	.53674E+04	.54101E+04
MEAN TOTAL QUANTITY DUE OUT	.14795E+05	.31949E+07	.21609E+03	.27353E+03	0.	.55250E+03
MEAN QUANTITY PER DUE OUT	.60000E+02	.33250E+05	.55250E+03	0.	.55250E+03	.55250E+03
MEAN DURATION OF DUE OUTS	.33250E+05	.31949E+07	.83527E+02	.27959E+00	.83004E+02	.83394E+02
NUMBER OF AND QUANTITY PER SHIPMENT	.15600E+03	.47334E+06	.30342E+04	.21797E+04	.55250E+03	.53691E+04
NUMBER AND QUANTITY CANCELLED	NOT YET COLLECTED					
MEAN DURATION OF CANCELLATIONS	NOT YET COLLECTED					
FOR NODE 2 R02						
STATISTICS FOR RAW MATERIAL ITEM NO. 1300						
NUMBER OF ORDERS AND QUANTITY PER ORDER	.88000E+02	.52154E+05	.59265E+04	.18977E+03	.42545E+04	.59773E+04
MEAN QUANTITY DUE-IN	.14795E+05	.33957E+07	.22967E+03	.45139E+03	0.	.79924E+04
MEAN DURATION OF DUE-INS	.52332E+05	.50610E+04	.96709E-02	.29252E-01	.49090E-05	.34545E+00
NUMBER AND QUANTITY OF SHIPMENTS RECEIVED	.13200E+03	.59332E+06	.23754E+04	.22253E+04	.51890E+03	.52760E+04
MEAN BALANCE ON HAND	.14795E+05	.34853E+09	.23573E+05	.49215E+03	.15798E+05	.25470E+05
NUMBER AND QUANTITY OF CANCELLATIONS	NOT YET COLLECTED					
DURATION OF CANCELLATIONS	NOT YET COLLECTED					

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Figure B-2. Sample detailed statistics report information that may be useful. Statistics that are not needed (such as cancellations) are listed as not yet collected.

B-3 ATTACK REPORT

Each attack produces a list of those plant attributes that have been changed because of the attack. Production rates, balance on hand and scheduled rebuilds are given for the production node attacked. Figure B-3 shows an example of this report.

```
  1. REBUILDS OCCURING AT 1008.0 HOUR INTERVALS
     CAPACITY INCREASE =   14744.3
     FINAL CAPACITY =      14744.3


  PRODUCTION NODE 25  C04     ATTACKED AT TIME  1345.000

VALUES CHANGED                                 FROM          TO

MAXIMUM PRODUCTION RATE                       9333.3         0.0
CURRENT PRODUCTION RATE                       5995.8        41.5
BALANCE ON HAND-ITEM    1200                  8354.2         0.0

  1. REBUILDS OCCURING AT 1008.0 HOUR INTERVALS
     CAPACITY INCREASE =    9333.3
     FINAL CAPACITY =       9333.3


  PRODUCTION NODE 26  C0[illegible]     ATTACKED AT TIME  1345.000

VALUES CHANGED                                 FROM          TO

MAXIMUM PRODUCTION RATE                      19096.0         0.0
CURRENT PRODUCTION RATE                      14310.7        85.2
BALANCE ON HAND-ITEM    1200                 17039.3         0.0

  1. REBUILDS OCCURING AT 1008.0 HOUR INTERVALS
     CAPACITY INCREASE =   19096.0
     FINAL CAPACITY =      19095.0


  PRODUCTION NODE 43  C22     ATTACKED AT TIME  1345.000

VALUES CHANGED                                 FROM          TO

MAXIMUM PRODUCTION RATE                      17094.0         0.0
CURRENT PRODUCTION RATE                      14057.7        83.7
BALANCE ON HAND-ITEM    1200                 14042.3         0.0

  1. REBUILDS OCCURING AT 1008.0 HOUR INTERVALS
     CAPACITY INCREASE =   17094.0
     FINAL CAPACITY =      17094.0


  PRODUCTION NODE 45  C24     ATTACKED AT TIME  1345.000

VALUES CHANGED                                 FROM          TO

MAXIMUM PRODUCTION RATE                       8484.0         0.0
CURRENT PRODUCTION RATE                       6973.4        41.5
BALANCE ON HAND-ITEM    1200                  6976.6         0.0

  1. REBUILDS OCCURING AT 1008.0 HOUR INTERVALS
     CAPACITY INCREASE =    8484.0
     FINAL CAPACITY =       8484.0
```

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Figure B-3. Sample attack report

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