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Simulation of Adaptive Response: A Model of Drug Interdiction

Gordon B. Crawford, Peter Reuter,
with Karen Isaacson, Patrick Murphy

February 1988

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40 Years
1948-1988
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ACQUISITIONS

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PREFACE

This Note has been prepared for the Office of the Under Secretary of Defense for Policy, under RAND's National Defense Research Institute, a Federally Funded Research and Development Center supported by the Office of the Secretary of Defense. It is a product of RAND's program in International Security and Defense Policy and should be of interest to researchers and policymakers concerned with efforts to control drug smuggling. The Note presents the technical description of a simulation model of interdiction effects on smuggler costs where smugglers have the capacity to adapt. The major substantive results of the model are presented in Peter Reuter, Jonathan Cave, and Gordon Crawford, *Sealing the Borders: Effects of Increased Military Participation in Drug Interdiction*, R-3594-USDP, January 1988.

Of related interest is Jonathan Cave and Peter Reuter, *The Interdictor's Lot: A Dynamic Model of the Market for Drug Smuggling Services*, N-2632-USDP, February 1988.

SUMMARY

Concern about illicit drug use in America in the last decade has increased emphasis on interdiction of imported drugs. The seizure of drugs and smugglers as they travel from the source countries to the United States now accounts for 44 percent of federal drug enforcement expenditures. Although the interdiction effort has rapidly increased cocaine seizures since 1981, it has been ineffective at slowing cocaine imports, which have risen in quantity and declined in price.

This Note presents a simulation model of the effect of interdiction on smugglers called SOAR (Simulation of Adaptive Response); the model attempts to take into account smugglers' adaptations to the strategies of interdiction agencies. It traces how this adaptation affects increased interdiction efforts to reduce U.S. drug consumption.

In SOAR, increasing the risk of interdiction raises the cost of smuggling drugs. Increased smuggling costs, in turn, raise the wholesale price paid upon importation. The price increase is passed on through the chain of distribution to the retail level. Increased smuggling costs therefore should raise the retail price by an absolute amount that is somewhat larger than the rise in the import price, because domestic distributors' costs increase. This effect on retail price, modeled very simply in an extension to SOAR, leads from increased interdiction stringency to a reduction in consumption.

THE SOAR MODEL

Several studies for the federal government have developed models of drug smuggling and interdiction. They generally estimate the effect of additional assets on increasing the probability of interdiction in given geographical areas. The estimates of that effect, in terms of increased seizures, ignore the ability of smugglers to adapt and may overstate the effectiveness of additional assets.

The SOAR model has discarded this static approach in favor of a dynamic network model, which considers several routes from drug sources in Central and South America to the consumer in the United States. Because the pertinent data are not available, no effort is made to associate particular geographic routes with particular parameters. The model allows the smugglers to choose among these different routes and modes of transportation (air, sea, and land) and to change their choices as their perceptions of the risks change. In addition, the model allows major, predetermined shifts in the deployment of drug law enforcement assets, permitting interdictors to move resources and raise the risks associated with smuggling along a particular route.

SOAR is based on the assumption that smugglers have some perception of the probability of interdiction with each specific route and transportation method. The smugglers alter their perceptions of the probability of interdiction for the various routes as they accumulate experience. Interdiction of several successive shipments using a mode of transport along a particular route will indicate a higher probability of interdiction for that combination of route and mode. In the calculation of this perceived probability of interdiction, events in the recent past carry more weight than those occurring earlier. Costs along a particular route rise with the interdiction probability in part because agents require higher compensation for the higher risk of being arrested and imprisoned. The smugglers attempt to choose the combination of routes and modes that will minimize their expenses while maximizing their potential return.

The model user must enter several values into the model. These variables enable users to base their runs on their own estimates and assumptions. For example, the model operator must supply the export cost, desired shipment size, and average amount of the drug to be delivered in a day. Users also are able to input their own estimates of the amount of pay to personnel, the compensation for risk, the cost of interdiction (legal fees, loss of vessel, etc.), and the maximum shipment size. Other inputs include the cost and mode associated with a particular route and the time phased interdiction probabilities for each

route. This list of the user inputs to the SOAR model is not exhaustive but should provide some idea of the flexibility the model affords.

At the conclusion of a model trial, SOAR reports the number of attempts and successes for each route, the quantity lost and cost of unsuccessful attempts, the cost of transporting the landed drugs, and several other model results.

The model is necessarily imprecise; too little is known about smuggling markets to permit formal estimation of the important relations. Our decision to develop a simulation model, rather than estimate the parameters of a behavioral system, was made because of data constraints. The simulation model permits incorporation of several data sources of varying quality and the use of educated guesses where data are unavailable. We attempt to compensate for this uncertainty about parametric values by using a range of values where we are most uncertain. When presented with a choice among assumptions in the total absence of data, we have generally chosen the assumption that is most likely to produce a finding of effective interdiction.

APPLICATIONS OF THE MODEL

We have made three types of runs with SOAR. The first were simply intended to determine that the model functioned and that it did not produce obviously perverse results. These runs provided confidence that the results of the model were, within experimental error, equal to the answers that would result from a detailed analysis of the simplistic scenarios we created.

The second set of runs was our first exploration of the relevant policy question. What is the effect of smuggler adaptation? We chose a combination of air and sea routes, along with one safe but expensive land route, as possibilities for the smuggler. Each route was assigned a probability of interdiction representing a certain allocation of law enforcement resources. As time passes in the modeling, we introduced additional interdiction resources. In SOAR, this is simulated by raising the probability of interdiction on as many routes as desired. For example, in the first non-baseline run, the increase in interdiction resources was assigned to one fixed route where the interdiction

probability was raised from, say, .2 to .5; a given shipment now would have a one in two chance of being interdicted. Another possibility would be to increase the interdiction probability on a randomly chosen route. The randomness would affect the smugglers' perception of interdiction probabilities differently than would the resources being concentrated on one fixed route.

Output from the SOAR runs modeling cocaine smuggling provide an example of how changes in the probability of interdiction affect the smuggler. In the base case (run 1), the probability of interdiction was .2 for air routes, .23 for sea routes, and .1 for the one land route. In the second run, the probability of interdiction was raised to .5 on one fixed route; as a result, smugglers' costs increased 1.3 percent from the base scenario. In the fourth run, SOAR raised the probability of interdiction to .5 on a randomly chosen route (excluding the expensive land route), resulting in more cocaine being interdicted and a cost increase of 3.6 percent. By the seventh run, the probability of interdiction was raised to .5 on five randomly chosen routes, producing a dramatic increase in both quantity seized and the smugglers' costs of landing the given amount of cocaine. Costs increased 38 percent from the base scenario, and amount seized increased from 32.5 metric tons in the base case to 58.3 tons.

The third series of runs incorporated the cost-price driven feedbacks to consumption and production. This series differs from the second in that the quantity consumed in the United States varies from run to run, and that quantity is used as the criterion for judging the effectiveness of additional interdiction resources.

In the application incorporating elastic markets, the results were not encouraging. On the eighth run, when interdiction rates were set at 0.5 for 10 out of the 11 routes, cocaine consumption decreased approximately 25 percent. When only some of the routes were subject to higher interdiction rates, however, there was little effect on consumption. For example, when three randomly chosen routes were subject to interdiction probabilities of 0.5, total consumption was reduced by less than 9 percent.

Our application of the SOAR model provides a very mixed view of the effect of increased interdiction stringency. With respect to the cocaine runs, the results are generally unpromising. They suggest that unless almost all the routes available to smugglers are severely interdicted, there will be only modest reductions in total consumption.

For marijuana, we see rather different results. It is possible to drive down total marijuana imports substantially with sufficiently stringent interdiction. Raising the interdiction rate on a few routes has only modest effects; subjecting two and three random routes to the higher rates decreases imports by less than 15 percent. Raising interdiction on five random routes reduces imports by one-third. We could not explore with our models whether this would be mostly compensated for by increases in domestic production.

Two additional points emerge. First, raising interdiction rates on a few routes has little effect. In particular, raising the interdiction rate on a single route has almost no effect, especially if those efforts are concentrated on a fixed route rather than randomly chosen ones. Once smugglers identify a particular route as having a high interdiction rate, they will simply shift to other routes. A very large share of all routes have to be subjected to elevated interdiction before there is much effect.

Second, the random allocation of additional resources can substantially increase the effect of those resources. Smugglers can adapt efficiently only when they can form good estimates of the interdiction rates associated with particular routes. If they know only that three routes will have higher interdiction rates but not which three they are, then adaptation will be fairly ineffective.

ACKNOWLEDGMENTS

The most important and enjoyable part of this modeling effort is not explicit in this Note--it was the time spent with many civilian and military men and women who attempted to make clear the capabilities and limitations of the interdiction process, its resources, and the available data.

In the U.S. Customs Service, Bonnie Tischler, Director of Financial Investigations, shared her knowledge of the difficulties of interdiction and put us in contact with agents active in Custom's interdiction efforts. Among those who freely gave their time and understanding of smugglers and interdiction: Edmund (Red) Denmat, Chief of Miami Air Support Branch; Joe Maxwell, Director of Air Operations West; and Peter Kendig, Chief of San Diego Air Support Branch. Kathy Thodas of Air Operations has spent many hours retrieving data from the Air Operations Report system.

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RAND colleague Neal Thomas reviewed this Note and provided several helpful suggestions.

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I. INTRODUCTION

Drug interdiction, the seizing of drugs and smugglers as they travel from source countries to the United States, accounted for over $800 million of the nearly $1.9 billion spent on drug law enforcement by the federal government in fiscal year 1986. The interdiction budget has more than doubled since fiscal year 1981 (National Drug Enforcement Policy Board, 1986). Interdiction is carried out primarily by three agencies: the Coast Guard (within the Department of Transportation), the Customs Service (Treasury Department), and the Immigration and Naturalization Service (Department of Justice). The Department of Defense (DoD) has also been playing an increased role in providing support to these agencies. Recently, the Congress mandated that DoD acquire specific assets dedicated to supporting interdiction efforts.

This increase in interdiction resources has led to a dramatic increase in the amount of cocaine seized. In fiscal year 1981, federal agencies seized an estimated 1.7 metric tons of cocaine; in fiscal year 1986, 27.2 tons were seized. During this period, however, estimated cocaine consumption also has risen in the United States while the import price fell.

Factors other than the level of interdiction resources may account for the rise in cocaine seizures. For example, smugglers may be willing to risk larger shipments because the replacement cost in the source country has decreased. Or the preferred combination of drugs and other items in a smuggling shipment will have shifted to being more drug-intensive. The complex interactions among interdiction resources, the smuggling sector, and drug consumption require an analysis that incorporates all of these relationships. The dynamic model SOAR (Simulation of Adaptive Response) attempts to take into account adaptations by smugglers in response to changes in the strategies of interdiction agencies. The model traces how this adaptation then affects the ability of increased interdiction efforts to reduce drug use in the United States.

The rationale of the model is straightforward and ignores the complexity of market strategic behavior. As the perceived risks associated with particular routes and modes of smuggling a particular drug change, so does the smuggler's preference for how he brings his drugs into the country. His costs also change. Increasing the risks associated with one route and mode, leaving all other risks unchanged, changes the distribution of routes and modes by which the drug enters the United States and increases the cost of bringing in a given quantity.

Increased smuggling costs raise the retail price by an absolute amount that is somewhat larger than the rise in the import price, because increases in the import price raise certain costs for domestic distributors. This effect on retail price, modeled very simply in SOAR, ultimately reduces consumption.

We chose to develop a simulation model, rather than estimate the parameters of a behavioral system, simply because of data constraints. This simulation model permits us to incorporate many sources of data of varying quality and to fill in blanks where there just is no data, by using educated guesses. We shall attempt to compensate for this uncertainty about parametric values by using a range of values where we are most uncertain.

We have described the model and organized the Note to make the material accessible to readers having varying levels of interest and expertise. Section II presents the basic rationale of the model. Section III provides a nontechnical description of how the model operates. The fourth section presents the mechanics and theory of the program in greater detail. Sections V and VI discuss inputs to and outputs from SOAR. Both provide examples from model runs with explanations as to why we made certain choices. The final section presents a brief interpretation of the results of runs we have completed and a discussion of other possible applications of SOAR.

Appendix A lists the SOAR variable names with their explanations. Appendix B presents the SOAR model in the form of a Fortran program.

II. THE DYNAMIC NETWORK MODEL

Several studies for the federal government have developed models of drug smuggling and interdiction. A study by Boeing and one by the Center for Naval Analysis (Mitchell and Bell, 1979) could be considered as the starting points for our analysis. These models estimate the effectiveness of additional assets in increasing the probability of interdiction in given geographical areas where interdiction can be effective. Unfortunately, both these and the other models we have reviewed assume that the quantity smuggled and the means of smuggling through given areas remain constant, regardless of the level of interdiction.

In estimating the effect that particular assets could have in raising the amounts of drugs seized, or the effect of seizures and interdiction on the cost of smuggling drugs, these models disregard the ability of the smugglers to adapt and change their mode and locale of operation. This approach may therefore overstate the effectiveness of a given asset, and we have discarded the static approach in favor of a dynamic (not steady-state) network model.

The network model considers several routes from drug sources in Central and South America to the consumer in the United States. Because of the lack of route-specific data we treat routes as generic; no effort is made in the model to associate particular geographic routes with particular parameters. The model initially ignores all distribution costs within the United States; it is assumed that the smuggler's goal is merely to get the drugs into the United States. In a later section we add a very simple adaptation that infers increases in retail prices from increases in smuggler costs.

This model, like all models, is built around some simplifying assumptions, the most important of which we list here. The amount that the smuggler desires to send in any one shipment is fixed and is an input to the model. That is, we specify the amount that the smuggler wants to send each time; however, this still allows for variation in

actual shipment size for different modes of importation, because some modes do not permit the smuggler to dispatch as much in a single shipment as he would like.

The mean time between shipments is fixed and is also an input. The total quantity shipped and the quantity arriving varies from run to run. Initially our intent is to examine the increased costs to the smuggler that result from increased levels of interdiction. To make the results of a series of runs comparable, the initial model will also linearly extrapolate the results up or down to simulate a predetermined quantity successfully imported. Later, we consider the effect of allowing feedbacks to consumption and export prices that will lead to variation across runs in the total amount imported.

The availability of drugs in the source country is assumed to be unconstrained, but the export price is an input and may vary from run to run; the first set of runs ignores such variation. The smuggler's strategy is to get the total quantity of a drug from the source to the United States at the lowest cost. Cost is intended here to be a comprehensive measure. It includes risk compensation pay to agents; the replacement costs of the drugs, property, and trained people at risk; plus operating costs. The risk compensation pay required to smuggle drugs over a given route is driven by the smugglers' perception[1] of the risk on that route.

The model not only allows a choice among different routes and different modes (air, sea, or land) at any given time but also allows the modeling of the dynamic changes of smuggler preferences over time as perceptions of the risks associated with different routes and modes change. In addition, the model allows major but predetermined shifts in the deployment of Drug Law Enforcement (DLE) assets. That is, it is assumed that interdictors can move resources so that the risks associated with smuggling along a particular route (which we denote as the probability of interdiction, PI) can be raised for a period of time. Figure 1 presents the basic logic of the model.

---

[1]We are assuming here that agents are as well informed about the risks associated with particular routes as are smugglers.

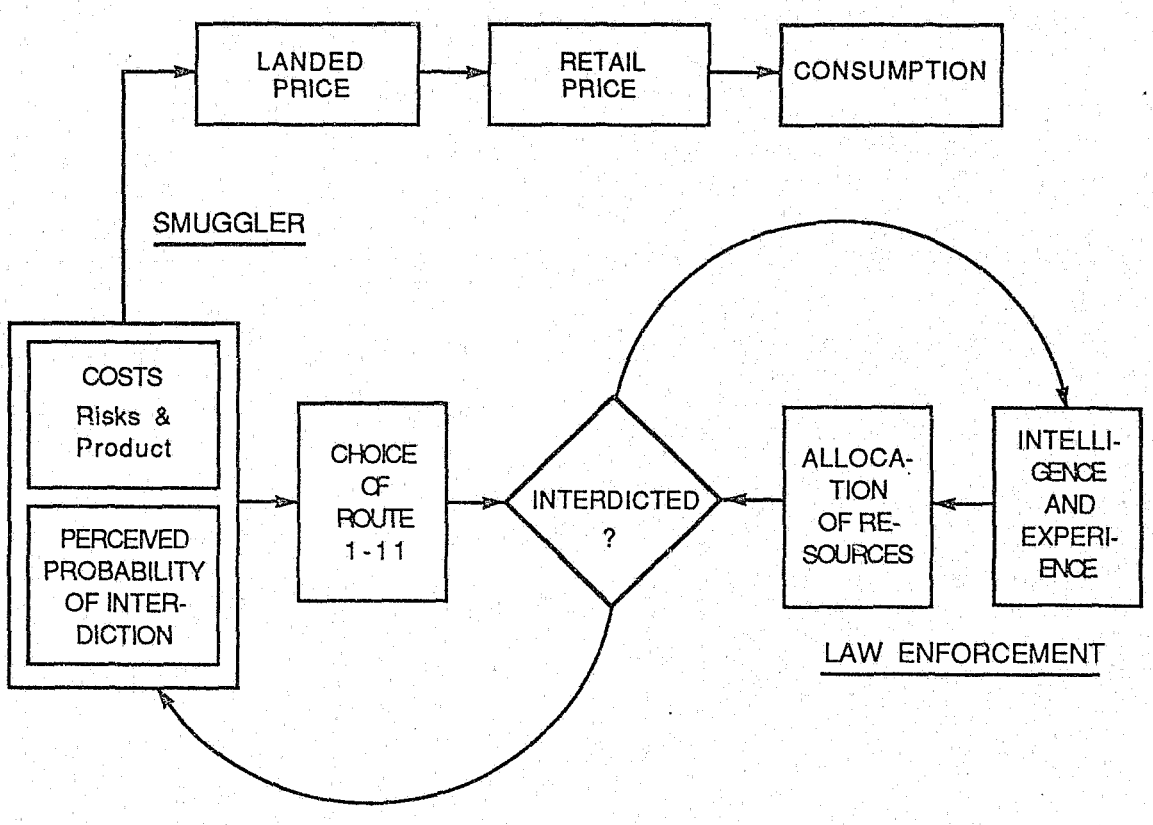

Fig. 1--The SOAR model

Minor shifts in the allocation of DLE forces are modeled with the assumption that the cost to ship a given quantity of drug over a given route is an increasing function of the total quantity shipped over that route (see the discussion below on the choice of the parameter "r"). The smuggler's observations of successful interdictions and shipments determine his perceptions of the risk along any given route. It is assumed that he has access to the experience of all smugglers in making that estimate.

The smuggler is faced with a version of what is known as the two-armed bandit problem, in which a gambler has the option of playing either arm of a two-armed slot machine (or, either of two one-armed slot machines), each one having an unknown, and different, probability of loss. The gambler's optimal strategy, given no information about the probability of loss for either arm, is to predominantly play the machine

that has given him the best ratio of winnings to attempts and occasionally play the other machine to insure that he is not being permanently misled by the luck of past plays.[2]

Mathematically, the smuggler faces a harder problem than the gambler: Not only does he have the option of multiple routes and methods of smuggling, but worse, as the DLE forces change the focus and deployment of their interdiction assets, the risks of interdiction are changing over time in ways unknown to the smuggler.

We have assumed a strategy for the smuggler that is in keeping with the spirit of the optimal solution to the two-armed bandit problem and with the dynamic nature of the problem: The smuggler computes time weighted estimates (more recent history is weighted more heavily than older history) of the probability of interdiction along every route and then randomly chooses a route on the basis of these estimates of interdiction--the seemingly safe routes are chosen more often than the seemingly more dangerous ones.[3]

The model is a Monte Carlo model with a randomized choice of routes for smuggling. In analogy with the gambler's choice of which slot machine arm to pull, the smuggler's random choice of routes will be tempered with observations of past successful and unsuccessful smuggling attempts along each given route. The model allows "safe" but expensive routes in an effort to model the likelihood that the DLE is unable to completely stop the flow of drugs despite any reasonable level of spending for interdiction. We would expect that these routes will become increasingly heavily used as other routes become riskier.

The inputs to the model include the Probability of Interdiction (PI) for each route. Varying these probabilities models the time phased placement of DLE interdiction assets--the movement of additional resources to particular smuggling routes. It is assumed that the location of DLE assets can be made known to smugglers either immediately

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[2]For a full exposition of this analysis see Berry and Friestedt, 1985.

[3]This simple scheme of incorporating feedback of past outcomes in such a way that it alters the likelihood of the future choices of routes is often referred to as "artificial intelligence."

through direct observation of DLE assets, such as a Coast Guard or Navy blockade,[4] or implicitly with a time lag, through the observation of successful and unsuccessful shipments.

Very little of the structure of the model is rigorously defensible; too little is known about the operation of smuggling markets to permit formal estimation of the important relations. The goal is to capture the important facets as well as possible. When given a choice among assumptions in the absence of data, we have generally chosen the one that is most likely to produce a finding of effective interdiction.

The model may be simplified when applied individually to marijuana or cocaine--some of the legs may be deemed unimportant for a particular drug. The intent is to build a general model and make it applicable to an individual drug by suitable choice of parameters.

The cost of shipping a quantity q of a drug through a given route is $aq + bq^r$, where a and b depend on the sector and the drug. We assume that a and b are nonnegative and r, the saturation factor, is greater than one. This implies that as a sector becomes more heavily traveled it will become increasingly well known and understood by the DLE forces. They will react[5] by attempting to stem the flow of drugs through that sector (by moving resources so as to maintain the specified probability of interception), and it is assumed that will increase the cost of smuggling a given marginal quantity of drugs through the sector.

Setting $r > 1$ models the idea that increasing the quantity moved over a route increases the per unit cost of smuggling over that route. It is an assumption biased toward showing effective interdiction. The alternative is to assume "flooding," in which fixed interdiction resources become less effective as smuggling along one channel increases.[6] We have chosen to increase the per unit smuggling costs as

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[4]Observation of a blockade, such as the Hat Trick operations off the coast of Colombia, is interpreted in the model as being equivalent to a route probability interception of 1 and leads to the closing down of that route during the period of the blockade.

[5]Regardless of the input variables that describe the time-phased deployment of DLE assets.

[6]There is no indication that flooding is a common strategy.

traffic increases for two reasons. First, the bias is appropriate (we should assume responsive enforcement), and second, it is mathematically convenient for the network approach: In a steady-state solution (where the DLE forces do not change in time) if $r \leq 1$ approach would result in all the drug traffic always going through one leg; clearly this does not describe reality. There are many routes.

When $r > 1$, this network model has the property that if the DLE forces do not change in time, then the smuggler's strategy will converge to a minimal cost solution, which also happens to be an equal cost per leg solution. The smuggler will face the same marginal cost to ship an additional small quantity of a drug through any leg. In the dynamic model, the smuggler's strategy is to move toward the perceived minimal cost solution, bearing in mind that the minimal cost solution is a moving target. The model assumes that the smuggler's cost of using a given route[7] is driven by several factors, including the capital cost of the mode of transportation (buying a vehicle, or compensation for stealing the vehicle), the marginal cost of transportation, the time and distance involved (at least to the extent that they effect the marginal cost of transportation), and the probability of interdiction.

The interdiction rate affects smugglers' costs in several ways. As the rate rises, agents (pilots, crewmen, etc.) will demand higher payments for incurring the greater risk of imprisonment. We have assumed that the actual risk compensation pay varies as the square of the perceived probability of interdiction (PPI). This probability is generated in the model through smugglers' weighting of past experiences. The assumption that the required payment rises with the square of the risk is consistent with risk aversion on the part of the agents. With this assumption increased interdiction will have more effect than it would if the agents were risk neutral.

Higher interdiction also may raise the replacement cost of seized drugs. Higher seizure rates, under quite plausible assumptions about the elasticity of demand for drugs, will lead to an increase in total

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[7]From this point we shall use the term *route* to describe a mode of transportation and geographic path from source country to the United States.

export demand. To persuade farmers to grow more and processors to refine more, it may be necessary for smugglers to offer higher prices at the point of export.

The other components of cost are not affected by the probability of interdiction. The "Cost to ship" includes the fixed costs other than risk compensation--for labor that is not at risk, for fuel, those associated with the use of a vessel, etc. The "Cost if interdicted" represents the legal fees and other costs to replace seized assets and personnel in the event that a shipment is interdicted. It does not include the cost of the drugs seized; that is computed from the shipment size and the export cost of the drug.

To implement the model we sought estimates of:

- Quantities shipped, by route, in a given year.
- Number of shipments, by route, in a given year.
- Number of vessels identified as suspicious, by route, in a given year.
  - -- Of those, the number pursued, by route, in a given year.
  - -- Of those, the number resulting in seizures, by route, in a given year.
- Estimates of the compensation resulting from the likelihood of prison.
- Estimates of smugglers' nonrisk compensation costs and profits.

We have been able to obtain data on only a few of these matters. The simulation results reported below use informed guesses for many parameters.

Existing estimates of the interdiction rate in a particular sector, regardless of the mode of smuggling, are of questionable accuracy. A good estimate of the interdiction rate along a route can be made only if there is good information about the amount of a drug being smuggled over the route. In the rare event that intelligence is available about the total flow through a sector, it is apt to be used to disrupt the smuggling along that route, hence ceases to be descriptive of activity there. For these reasons we have been forced to rely on global

estimates of the overall interdiction rate, based on seizure and estimated consumption. We have assumed in our base case (which provides the benchmark for evaluating the effect of additional interdiction resources) that the probability of interdiction is equal on all routes and modes, except the expensive but safe land route.

For our needs, estimates of the increases to interdiction rates that can be effected with the help of DoD assets are more important than precise estimates of current rates of interdiction. Such estimates were to be based on the data from Customs and the Coast Guard. It was our intent to make estimates from these data of the last two conditional probabilities in the chain of conditional probabilities that describe the interdiction process--the conditional probability of pursuit given that the vessel is suspicious, and the conditional probability of seizure given that the vessel was pursued. These estimates would then be used to judge the potential increase in PI that could be made on each route.

III. A NONTECHNICAL DESCRIPTION OF SOAR

The SOAR model is an attempt to create a self-documenting Fortran program (App. B) containing ample comments to explain the processing and input data. We chose variable names to be self-explanatory (App. A). This section is a brief overview for the interested analyst and provides background information making the Fortran code, with its comments, self-evident to the programmer. Some of the mathematical philosophy embodied in the model is not adequately explained by the code or the brief outlines in this section. Those aspects of the model will be addressed in detail in Sec. IV.

OVERVIEW

A "trial" is completed every time the computer replicates the smuggling and interdiction process for the time period specified. "Time," a user input, is measured in days and bounds the activity of the model; this Note describes runs of 365 days.

Simplified, there are three basic phases to a SOAR run:

Phase 1: Initialization,

Phase 2: Repeated replications of the smuggling and interdiction process, and

Phase 3: Summarizing the results.

The first phase is necessitated by a condition in the second. In Phase 2, smugglers make their decisions based on their historical knowledge of routes and methods that have been successful in the past. Because these decisions must be based on some accumulated knowledge, the model must be initialized with some historical insight in Phase 1. This initialization uses much the same logic as Phase 2, but the probabilities of interdiction remain constant. Once sufficient history has been accumulated, a new trial is begun (Phase 2).

The basic activities simulated in Phase 2 are:

(a) When will the next shipment take place, and what drug will be shipped?
(b) Based on history to date and input cost data, what route will be chosen?
(c) Will the DLE interdict the shipment?

Throughout Phase 2, time (days) continues to pass, during which the DLE may change their allocation of resources along each route (the probabilities of interdiction are no longer constant). The user determines these changes as time-phased interdiction probabilities. Given a specific interdiction probability for the route chosen by the smuggler, the computer (in a sense) rolls the dice to determine whether that shipment was interdicted. At the end of the time period, interdiction statistics are accumulated by internal bookkeeping procedures. Then Phase 2 repeats itself, beginning a new trial and making decisions and actions that will be different but governed by the same frequency distributions. This pattern is repeated until the prescribed number of trials have been executed. By making repeated trials we can compute average results that are not substantially affected by the random variations present in individual trials.

When the prescribed number of trials have finished, phase 3 summarizes the results, computes averages over the several runs, and prints them to an output file.

THE COMPUTATIONAL STEPS CONSTITUTING PHASES 1-3

In more detail, these phases are composed of the following steps. A flow-chart representation of these steps appears in Fig. 2.

Phase 1

(I) Initialize the data collection arrays used for bookkeeping.

(II) Read in the data.
- -- Check data for permissibility and bounds on indices
- -- Echo data
- -- Set up vector giving PI and whether blockaded, by day and for each route

(III) Monte Carlo the run in.
- -- Determine the time and type of drug of the next shipment
- -- If time of next shipment occurs after the end of the run-in period go to "Start a new trial"
- -- Select the route to be used based on history to date
- -- Compute the number of trips to be made on that route, based on desired shipment size and maximum shipment size on that route
- -- Get the numerator and denominator and compute the r-factor
- -- Compute the probability of interdiction
- -- Was the shipment interdicted?
- -- Do required bookkeeping
  - o perceived probability of interdiction
  - o amount attempted by route
- -- Go to "Monte Carlo the run in"

Phase 2

(IV) Start a new trial.
- -- If the desired number of trials have been executed go to "Summarize"
- -- Monte Carlo a new shipment
  - o set time to the time of the next shipment and determine the drug to be shipped
  - o if time of next shipment occurs after the last day of the run go to "End of trial"
  - o get the PIs for the drug and the time of day of the next shipment
  - o select the route for the next shipment
  - o compute the number of trips to be made on that route
  - o get the numerator and denominator and compute the r-factor
  - o compute the probability of interdiction
  - o was shipment interdicted?
  - o do required bookkeeping
    - -- perceived probability of interdiction
    - -- amount attempted by route
    - -- number of attempts
    - -- amount successfully shipped
    - -- amount seized
  - o go to "Monte Carlo a new shipment"

(V) End of trial
- -- Save the output data

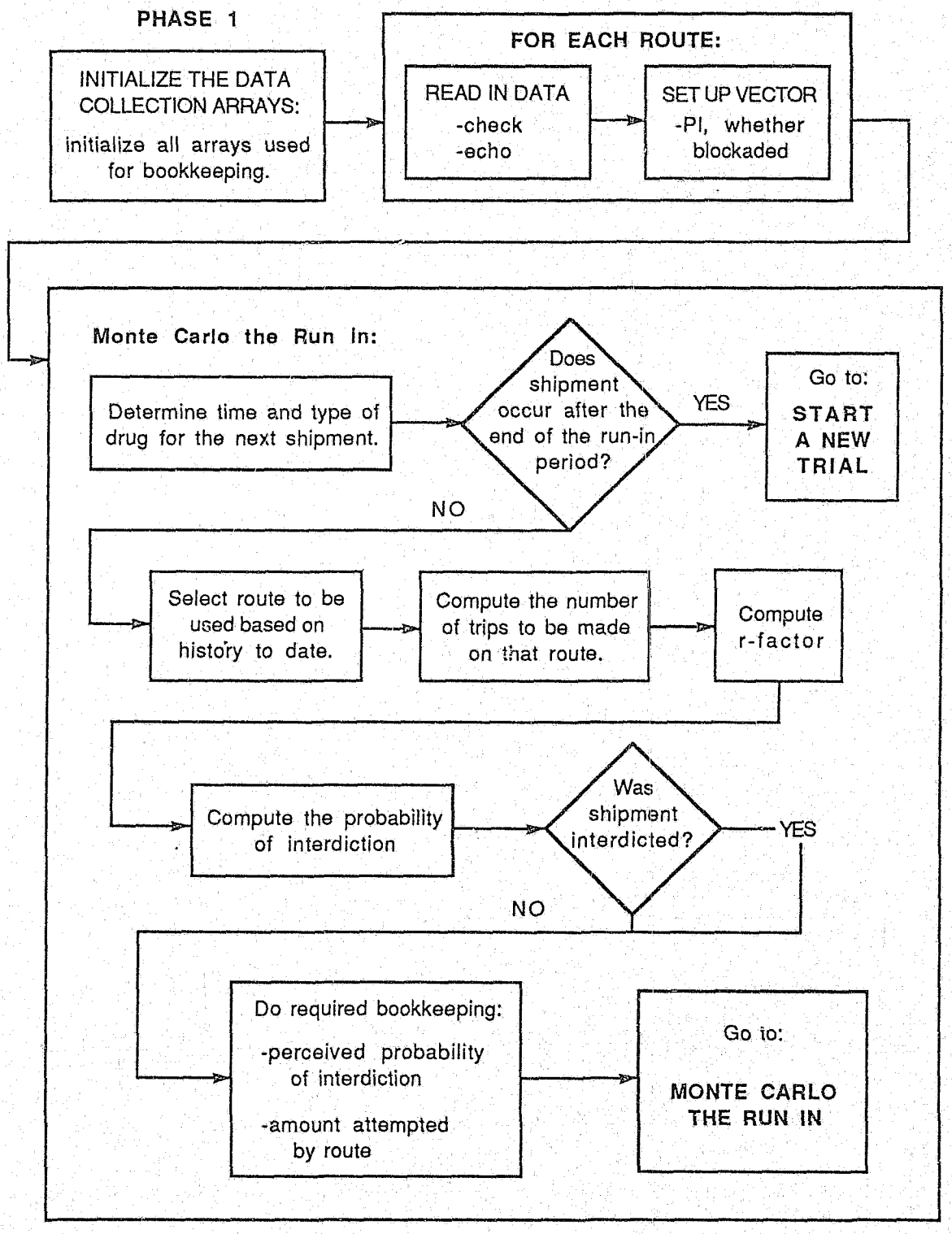
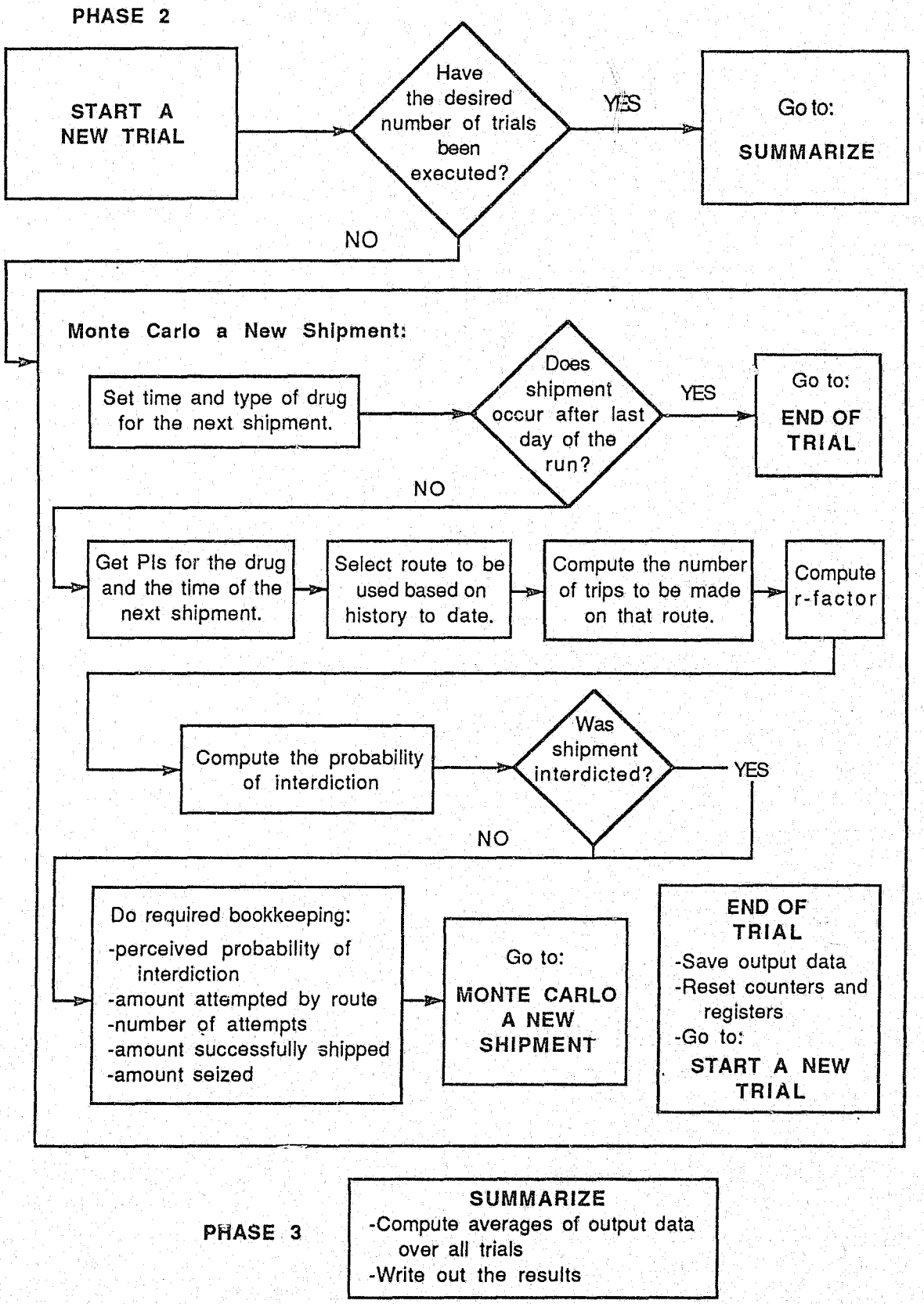


Fig. 2--Flow chart, phases 1-3



PHASE 3

SUMMARIZE
-Compute averages of output data over all trials
-Write out the results

-- Reset counters and cumulative registers
-- Go to "Start a new trial"

Phase 3

(VI) Summarize.
-- Compute averages of output data over all trials
-- Write out the results

NARRATIVE EXPLANATION OF THE STEPS

The following elaborates on each of the steps in the above outline and flow chart.

Phase 1

(I) Initialize the data collection arrays used for bookkeeping.

As the SOAR model Monte Carlos the smuggling and interdiction process, there is a substantial amount of bookkeeping, both to model the smuggler's knowledge of past events and to maintain records of the successes and failures of smuggling attempts for output. Many of these bookkeeping arrays are defined cumulatively and therefore must be initialized with proper values.

(II) Read in the data. Check data for permissibility and bounds on indices.

As the data are read, they are edited for obvious mistakes: Data fields must be positive or nonnegative. Where inputs define the dimension of arrays, these inputs must be no greater than the maximum allowable dimension specified in the program dimension statement.

Echo data. The input data are printed in the output file in the order they are read, with narrative titles. This provides a check on the format and reading of the input file as well as a reference to the parameters defining the run that produced the subsequent output.

Set up vector giving PI, and whether or not blockaded, by day for each route.

The program allows up to 12 epochs--time periods wherein probabilities of interdiction are constant--and allows these probabilities to change at the beginning of each new epoch. The program

also allows routes to be "blockaded" during one or more epochs. A route that is blockaded has probability of interdiction equal to 1, but that interdiction probability is assumed known to the smuggler. Smugglers do not attempt to ship on blockaded routes.

Two arrays are established for each route. One gives the PI for that route by day. The other tells whether or not the route is blockaded by day. A route may have PI = 1 without being blockaded; in this case the smugglers must learn of the perfect interdiction rate through experience.

(III) Monte Carlo the run in. Determine the time and type of drug of the next shipment.

The shipment size and average time between shipments are inputs. Utilizing these data and the output of a pseudo Random Number Generator (RNG) to generate an exponential random variable with the appropriate mean, the program schedules the time until the next shipment of each drug and finds the drug to be shipped next.

If time of next shipment occurs after the end of the run-in period, go to "Start a new trial."

The step above is repeated and time is incremented until the time of the next shipment exceeds the length of the run-in period. At this time, sufficient history has been accumulated and program control shifts to Phase 2.

Select the route to be used based on history to date.

If the time of the next shipment has not exceeded the run-in period, then a route is selected for that shipment. Throughout the run-in period the PIs are set to the values they assume on day 1. The selection of the route is based on the smuggler's perceived probability of interdiction, which is computed on the basis of history to date. At the beginning of the run-in period the smuggler has no information, except for where blockades exist. His early decisions may result in poor smuggling performance, and the run-in period should be long enough that subsequent informed decisions dominate the history at the beginning of Phase 2. In the 365 day runs reported below we have used a 120 day run-in period.[1]

[1]The program always computes time-weighted historical averages.

The selection of the route to be used is logically the same in the run-in period as it is in Phase 2. It is described in detail in the following section. The procedure computes the expected cost of using each route based on the input cost data and the perceived probabilities of interdiction. The probability of choosing a route is assumed to be inversely proportional to the expected cost of using the route. The RNG is used to draw a number that is compared with an array of accumulated expected costs by route.

Compute the number of trips to be made on that route, based on desired shipment size and maximum shipment size on that route.

The (desired) shipment size and the maximum shipment size by route are input. If the maximum size is smaller than the desired size, multiple shipments are scheduled until the total equals or exceeds the desired shipment size. These shipments are independently considered for interdiction.

Get the numerator and denominator and compute the r-factor.

The r-factor is used to model temporary or short term saturation of a route and the increased effect the DLE is assumed to have in interdicting drugs on a route that sees a substantial increase in use. This modeling philosophy and its implementation are explained in greater detail in the following section.

Compute the probability of interdiction. The input PI for the route and time of interest, in combination with the r-factor, determine the effective PI.

Was the shipment interdicted? An output of the RNG is compared with the effective PI to determine if the shipment was interdicted.

Do required bookkeeping: perceived probability of interdiction and amount attempted by route.

Bookkeeping arrays are augmented to keep track of the amount attempted, amount interdicted, and the historical number of attempts and successes, by route.

The weighting constants are a user input. In the runs reported below we have used exponential weighting where 90 day old data receive only 1/10th the weight of current data. Thus a 120 day run-in period will yield results that are dominated by informed decisions.

Go to "Monte Carlo the run in." Having completed the logic for one smuggling attempt during the run-in phase, program logic returns to another attempt.

Phase 2

(IV) Start a new trial: If the desired number of trials have been executed go to "Summarize."

A "trial" is completed every time the computer replicates the smuggling and interdiction process for the time period specified. (One year in the runs reported below.) By making repeated trials we can compute average results that are not substantially affected by the random variations present in individual trials.

The number of trials is an input. Because each trial contains a large number of Monte Carlo simulations, the number of trials necessary for the averages to settle down within several percent is fairly small. In the runs below we found 10 trials generally met this criterion for accuracy.

A trial is started by setting the time to day 1 and beginning the simulation process using the historical data accumulated during Phase 1, the run-in period. The run-in period is done only once for a given set of input parameters.

After the desired number of trials have been executed, program control shifts to Phase 3, "Summarize."

Monte Carlo a new shipment: Set time to the time of the next shipment and determine the drug to be shipped.

This is logically equivalent to the comparable step in Phase 1.

If time of next shipment occurs after the last day of the run in, go to "End of trial."

As in Phase 1, shipments are Monte Carlo'd until the user specified time. When the end of the time period has been reached control shifts to the bookkeeping described below.

- get the PIs for the drug and the time of the next shipment
- select the route for the next shipment
- compute the number of trips to be made on that route
- get the numerator and denominator and compute the r-factor
- compute the probability of interdiction
- was shipment interdicted?

The above six steps are as in Phase 1. During Phase 2 more bookkeeping is required to accumulate the additional program outputs.

Do required bookkeeping:

-- perceived probability of interdiction

-- amount attempted by route

-- number of attempts

-- amount successfully shipped

-- amount seized

go to "Monte Carlo a new shipment."

As in Phase 1, after the Monte Carloing of a smuggling attempt has been completed, program control returns to the start of another attempt.

(V) End of trial: Save the output data, reset counters and cumulative registers, and go to "Start a new trial."

The end of trial bookkeeping must save the output data in a file where it can be averaged with the output of other trials. Counters and registers that accumulated the data must be reset to zero for the start of the new trial. The files containing the output of the Phase 1 run in have been left unchanged and are used again.

Phase 3

(VI) Summarize: Compute averages of output data over all trials.

At this point, all trials have been run and the output data accumulated. These data are averaged and the output statistics shown in Sec. V are computed. The data are written to the output file mentioned above that contains an echo of the input data.

IV. TECHNICAL DETAILS

Listed below are several specific references to components of the SOAR model. This section expands further on some of the more subtle issues encompassed by the model and lays out the mathematical theory that provides the foundation for some of SOAR's calculations.

PROBABILITIES OF INTERDICTION

The user inputs the time phased conditional probabilities of interdiction for each route. The ability to define the changes to these probabilities as a function of time allows the user to model the dynamic ability of the DLE to change its strategy and emphasis over time. The inputs define the start and stop dates of epochs and the probabilities of interdiction that prevail on all routes during each epoch. All input probabilities of interdiction are constant during a given epoch. Up to 12 epochs are allowed. The number of days spanned by the sum of the epochs is also a user input; in the runs described below it is always one year.

CREATING A SCENARIO

The aggregate of the inputs, including the total collection of conditional probabilities by route and the start and stop dates of the epochs, as well as a description of the relevant costs and quantities of each drug, are referred to below as scenario S(t), where t is the time parameter. The S(t) scenario descriptions are stored as input data files. In our use of the model, they have been saved and used repeatedly with minor changes for subsequent Monte Carlo trials. Such a series of runs permits an investigation of the effects of changes of interdiction probabilities or the sensitivity of the results to cost (and other) inputs that are impossible to estimate with any degree of certainty.

NUMBER OF RUNS REQUIRED

Because each Monte Carlo trial is itself a result of a large number of Monte Carlo experiments, the run-to-run differences are usually small. We have empirically verified the run-to-run variation in the averages of the reported statistics by repeating 20 sets of 10 runs. Each run began with a different random number seed to insure randomness of the run-in results as well as randomness in the Monte Carloing of the smuggling and interdiction process.

These 20 sets of 10 runs yield 20 independent observations of the output measures. (The output measures are the means of the output of 10 runs.) We have looked explicitly at the following statistics: the average success rate, the average total cost to the smugglers, the average quantity interdicted, and the average number of attempts at route 11. Using the results of these 20 sets of runs, we have compiled statistics on the variation in the means of a set of 10 runs (see Table 1).

For the same reason that the variance of a Bernoulli random variable (which takes only the values of 0 and 1) increases as the probability of getting 1 increases from 0 to .5, we might expect the

Table 1

VARIATION IN THE MEANS OF A SET OF TEN RUNS

	Success Rate	Total Cost	Quantity Delivered	Average Attempts
Mean	0.76	1,948,525	59,504	538.9
Variance	2.4×10^{-5}	5.09×10^{8}	9.53×10^{5}	621.3
Standard deviation	.0049	2.26×10^{4}	976	24.9
Coefficient of variation	.006	.012	.016	.046

maximum run-to-run variation to occur when the probabilities of interdiction (which are never more than .5) are high. Accordingly, we have repeated cocaine run 088.5, an excursion around base case PIs of .30 and .345, 20 times. Run 5 in this scenario increased the PI to .5 on two changing and randomly chosen routes.

Among these statistics, the number of attempts on route 11 can be expected to have more variation than the other numbers, because the other outputs are the results of action on all routes. Still, the coefficient of variation for average attempts on route 11 is a modest .046, suggesting that a confidence band of $\pm$ 2 standard deviations around the mean would include less than $\pm$ 10 percent of the observed number of attempts on route 11.

As might be expected of a rate, the coefficient of variation of the run-to-run error in the overall success rate is the smallest. It is only .006; $\pm$ 2 standard deviations of this rate equates to less than $\pm$ 1 percent.

The other output measures also have modest run-to-run variation, and $\pm$ 2 standard deviations would equate to $\pm$ 2.4 and 3.2 percent in the total cost and quantity delivered respectively.

In summary, computing averages of the results of only 10 runs gives an adequately precise estimate of the overall means, especially compared with the imprecision of some of the input data and some of the assumptions incorporated in the model.

CHOOSING THE ROUTE FOR THE NEXT SHIPMENT

The choice of the route for the next shipment is based on the smuggler's perceptions of his cost of using a route. In SOAR, the likelihood of picking a given route is inversely proportional to the probable perceived cost on that route, which is a function of the input cost data and the perceived probability of loss on a route. The perceived probability of loss on a route is a time weighted average of past losses and attempts.

The mathematical calculations that affect the choice of route are performed in three subroutines or procedures, probloss, costrout, and pickrte.

Probloss gives the smuggler's estimate of the probability of interdiction based on recent experience along each route (recent experience being the contents of the file "route").

Probloss(i) is the smuggler's estimate of the probability of loss on route i at this time. It is computed from the contents of file route(i) (see bookkeeping) as follows: Suppose the entries in route(i) are t(j), t(j + 1),...,t(n) and I(j), I(j + 1),...,I(n). It is assumed that t(m - 1) < t(m). I(m) equals 0 or 1 depending on whether the mth smuggling attempt along the route was successful. If current time is T, set

probloss(i) = Sum{exp[-b(T - t(i))] x I(i)}/Sum{exp[-b(T - t(i))]}.

The constant "b" is chosen to give 90 day old data a fraction "f" of the weight of new data. That is: exp(-b*90) = f. The parameter f is an input labeled "Memory Value."

In costrout, the expected cost "expcost" to ship a quantity Q over a route is equal to fixed cost + probloss*(price of drug)*Q + probloss*(personnel pay factor + value of vehicle or vessel). The fixed cost could be a negligible component. The personnel pay factor is akin to the personal value attached to going to jail as a result of getting caught. (Inputs are discussed in more detail below.)

Pickrte makes a random choice of a route on the basis of the estimated cost of all routes as computed by procedure costrout. The probability of choosing a route is proportional to the reciprocal of the estimated cost of the route.

THE TIMING OF THE NEXT SHIPMENT

The time between shipments is an exponential random variable. Equivalently, the number of shipments in a given time interval is a Poisson random variable. The average number of shipments per time interval is chosen so that the expected shipments per day will be equal to the input value.

The size of the next shipment is fixed.

WAS THE SHIPMENT INTERDICTED?

An input to the model is the time phased conditional probabilities of interdiction. Suppose the product of the conditional probabilities of interdiction on this route at this time is P. We draw a uniform random number u on the unit interval. The shipment was interdicted if $u < P'$, where $P' = 1-(1 - P)^R$, and R is the saturation factor.

R is equal to the maximum of 1 and the ratio of the rate of shipments over the "recent past" to the rate of shipments over the "long past." Recent past is the last 20 days and long past is the last 120 days. The assumption here is that a smuggler's capacity along a route is his average rate of shipments over the last four months, and his costs go up as he exceeds this rate in the last three weeks running.

This method of calculating P' makes a low-risk route pretty safe even when it is oversaturated. It also allows the smuggler to build the capacity of a route at little increase in risk if he builds it slowly, but incurs a large increase in risk if he substantially increases throughput over a 20 day period.

This calculation has some disadvantages: If the capacity of a route is established, but the route is not often used for several months, a subsequent return to the previous capacity results in an increase in the probability of interdiction. If shipments are made often enough this is not a problem.

Letting R be no less than 1 keeps a route from getting safer when it is not used often.

Using P instead of P' in the test to see if a shipment was interdicted will result in approximately the right number of interdictions, where "right" is determined by input probabilities. Using P' will result in too many interdictions when judged by the interdiction probabilities, but the use of some kind of a saturation factor is important.

BOOKKEEPING

As the model runs and generates shipments along various routes that are interdicted or successful, the appropriate statistics must be collected so that the output summarizes all relevant information about the success of the DLE.

Procedure update stores the event outcomes (time of shipment and seized indicator = 1 if seized, 0 otherwise) in file "route(i)", i corresponding to the route chosen.

For each shipment the following information is stored in the file "shipment": route used, probloss for that route, quantity seized, quantity landed, and cost to ship as computed in the pickrte procedure.

THE SIMULATION OPERATION

For each trial, we simulate shipments during a run-in period and then for the number of days in the period of analysis.

Shipments occur according to a Poisson process. At the time of the shipment, the smuggler computes his perceived probability of interdiction on each route and then computes the expected cost of using each route. Suppose this is a shipment of drug N, and that the expected shipment size is not so large as to require multiple trips. Then the cost of an unsuccessful shipment using route K (implying method M) would be

```
Cost[K] = Route_cost[K] +
          Prob(caught) x Ex_shipment_size[N] x Drug_cost[N] +
          Prob(caught) x Cap_cost[M].
```

Let Inverse_cost be the sum of the terms 1/Cost[K]. The smuggler will then choose route K with probability

$$\frac{1/\text{Cost}[K]}{\text{Inverse_cost}}$$

This has the effect that routes with lower expected losses or costs will be chosen more frequently than routes with higher expected losses or costs.

Once the smuggler has committed to route K, the model computes the probability of interdiction, as described in Phase 2, part IV. The model then decides whether the shipment has been successful, based on that probability.

COMPUTATION OF R

R, the saturation factor, is used to model the fact that the probability of interdiction increases if the smugglers use a given route more than usual. In particular, if the probability of interdiction is p when the smuggler is using the route at normal capacity, then the probability of interdiction is increased to:

$$1.0 - (1.0 - p)^R$$

when the route is being used above normal levels. When R is one, the above simplifies to p.

We compute R as the max of 1.0 and

$$\frac{\text{6 times the number of shipments on the route in the past 20 days}}{\text{the number of shipments on the route in the past 120 days}}$$

The 20 and 120 are set when the model is compiled. The 6 is computed internally, and is just 120 ÷ 20. This should be adequate to capture the effect of the route being used above normal levels. Different values could be inserted before compilation if the 20 and 120 are unacceptable. For example, we might define R as the max of 1.0 and

$$\frac{\text{15 times the number of shipments in the past 10 days}}{\text{the number of shipments in the past 150 days}}$$

A problem with this approach is that, when we start simulating the period of interest, we don't know the normal rate of shipments on a given route. Hence, the run in. Before the model collects statistics for the output report (or starts the clock on the phased interdiction probabilities), the model is run so that it has a history of the past and can compute the R factor. The user specifies the number of days for which this is done in the input.

V. THE INPUT DATA

The following data, including a brief definition of the data fields, is taken from the model output. The echo of the inputs provides a check on the reading of the input file and a complete reference to the input parameters that defined the run-in question.

Following this extract from the output is an explanation of these input data and a discussion of the sources and choices of values that we have used in the runs described in this Note.

An actual input file is given at the end of this section. Except where changes in the ordering are obvious, the input data and the data echoed in the output occur in the same order.

THE INPUT DATA AS ECHOED IN THE OUTPUT

Smuggler's simulation parameters and input data:

```
 1 types of drugs,  3 allowed.
 3 smuggling methods,  3 allowed.
10 phases of interdiction, 12 allowed.
 3 routes considered, 20 allowed.
10 trials requested.

   120 days of initial run in (for initialization).
   365 days to be analyzed,  730 allowed.
   Memory value is   0.100
   Initial seeds for random number generator are  7243 and  3791

   Drug - Cocaine      : Export cost per kg =                        7500.00
                         Expected time between shipments =              0.71
                         Shipment size =                              250.00
                         Ave. amount to be delivered per day =        350.00

   Method   By air     : Risk compensation =                     1200000.00
                         Risk compensation exponent=                  2.00
                         Cost (if interdicted) =                 200000.00
                         Cocaine     - maximum shipment size =      2000.00

   Method - By sea     : Risk compensation =                     1600000.00
```

	Risk compensation exponent=	2.00
	Cost (if interdicted) =	40000.00
	Cocaine - maximum shipment size =	16000.00
Method - By land :	Risk compensation =	10000.00
	Risk compensation exponent=	2.00
	Cost (if interdicted) =	5000.00
	Cocaine - maximum shipment size =	50.00

Phase 1 lasts through day 1
Phase 2 lasts through day 41
Phase 3 lasts through day 82
Phase 4 lasts through day 122
Phase 5 lasts through day 163
Phase 6 lasts through day 203
Phase 7 lasts through day 244
Phase 8 lasts through day 284
Phase 9 lasts through day 325
Phase 10 lasts through day 366

Route - One :	Cost to ship =	20000.00
	Method = By air	
	Phase 1 interdiction probability =	0.50000
	Phase 2 interdiction probability =	0.20000
	Phase 3 interdiction probability =	0.20000
	Phase 4 interdiction probability =	0.50000
	Phase 5 interdiction probability =	0.20000
	Phase 6 interdiction probability =	0.20000
	Phase 7 interdiction probability =	0.50000
	Phase 8 interdiction probability =	0.20000
	Phase 9 interdiction probability =	0.20000
	Phase 10 interdiction probability =	0.20000
Route - Two :	Cost to ship =	16000.00
	Method = By sea	
	Phase 1 interdiction probability =	0.23000
	Phase 2 interdiction probability =	0.50000
	Phase 3 interdiction probability =	0.23000
	Phase 4 interdiction probability =	0.23000
	Phase 5 interdiction probability =	0.23000
	Phase 6 interdiction probability =	0.50000
	Phase 7 interdiction probability =	0.23000
	Phase 8 interdiction probability =	0.23000
	Phase 9 interdiction probability =	0.50000
	Phase 10 interdiction probability =	0.23000
Route - Three :	Cost to ship =	120000.00
	Method = By land	
	Phase 1 interdiction probability =	0.10000
	Phase 2 interdiction probability =	0.10000
	Phase 3 interdiction probability =	0.10000

```
Phase  4 interdiction probability =      0.10000
Phase  5 interdiction probability =      0.10000
Phase  6 interdiction probability =      0.10000
Phase  7 interdiction probability =      0.10000
Phase  8 interdiction probability =      0.10000
Phase  9 interdiction probability =      0.10000
Phase 10 interdiction probability =      0.10000
```

SEQUENTIAL LISTING OF THE INPUT DATA

The simulation first writes out the above file giving the input data that defines the run. Below we describe each data field and our reasons for the particular values used in the simulations described below.

Data Field 1: Type of Drug

The number of drugs being modeled and the maximum number allowed (3).

In the runs modeled below, we have concentrated on one type of drug per run. If more than one drug is modeled, say cocaine and marijuana, it is assumed that the smugglers share information and are aware of all the past histories of successes and interdictions along each route. Using two or more drugs in one run has the disadvantage that the PIs for each route are the same for all drugs. In the one-drug runs reported below we have assumed that on a given route marijuana shipments are more likely to be interdicted than cocaine shipments as a result of the added bulk and smell of the typical marijuana shipment.

Data Field 2: Smuggling Methods

The number of smuggling methods (air, land, sea) and the maximum number allowed (3).

Data Field 3: Phases of Interdiction

The number of phases or epochs wherein the PIs are constant and the maximum number allowed (12).

In runs where the DLE is aggressive in changing its emphasis, we have used nine epochs of approximately 40 days each. The first epoch, which gives the PIs used in the run in, ends on day 1 (giving a total of

10 epochs). It is expected that using more and shorter epochs will have little effect. In runs where the DLE does not change its emphasis and the PIs remain constant, the run may be set up with just one epoch.

Data Field 4: Routes Considered

The number of different routes considered and the maximum allowed (20).

In the runs described below, we have used 11 routes. That choice, rather than 10 or 12 or 17, was arbitrary. Our desire to make the set of options available to the smuggler sufficiently rich suggested that the number of routes be no less than 10.

Data Field 5: Trials Requested

The number of trials required. There is no maximum allowable number of trials; but if the number is large, substantially in excess of 100, some internal subscripts may exceed their bounds. If there is any question of this happening the program should be run with a compiler that checks for out-of-bound arrays.

The choice of the number of trials is a compromise between "many," which results in the computation of accurate averages with little statistical variation, and "few," which results in short computer run times. Because each run is composed of thousands of Monte Carlo'd decisions there is little run-to-run variation. We have found that 10 runs generally yield averages that are accurate to within a few percent. Compared with our knowledge of some of the input variables, this is close enough.

Data Field 6: Days of Initial Run

The number of days of run in. There is no maximum here, but if the run in or the number of days to be analyzed is more than 730 days and the time between shipments is less than .5 days, resulting in the possibility of several thousand shipments, some internal subscripts may exceed their bounds and the program should be run with a compiler that checks for out-of-bound arrays.

Earlier remarks regarding the number of trials also apply here: shorter is faster. The start of the run in is marred by smugglers' making decisions with no historical data. 120 days was chosen because that allows 30 days of history to build up before the bulk of the history data that will be passed to Phase 2 of the model run. (90 days is the length of time required for the value of historical information to decay to 1/10th the value of new information.) 120 days is arbitrary, but it seemed a reasonable compromise. The stability of the output measures mentioned in Sec. IV reinforces our belief that 120 days is adequate.

Data Field 7: Days to be Analyzed

The number of days to be analyzed (exclusive of the run in) in one trial and the maximum number allowed (730).

A time period of one year agrees with the common practice of fiscal evaluations.

Although the maximum allowable dimensions given above are generous, the concerned user could change the dimension statement and the data edits. This should be done with caution and all "do" loops over the effected subscripts indices should also be checked.

Data Field 8: Memory Value

The memory value that determines the decay rate of the value to the smuggler of old information. Setting the memory value to .10 results in 90 day old data having 1/10th the weight (importance) of new data.

Using a memory value close to 1 will result in old history having a value comparable to that of new history, an assumption that seems unreasonable in view of the likely occasional shifting of emphasis by the DLE. Using a memory value much closer to 0 will result in recent successes and failures dominating decisions. 1/10th seemed a reasonable compromise. Within reason, the model results are expected to be fairly insensitive to the memory value.

Data Field 9: Initial Seeds

The initial values used as seeds for the random number generator. If a given run seems to provide unreasonable values substituting new numbers here will give a run with the same defining parameters but a different random number string.

These values are arbitrary but must have 1 to 5 digits.

Data Field 10: Drug Related Data

For each drug, the drug related data:

(a) The export cost per kilogram.
(b) The expected time between shipments. When the exponential random variable that determines the random waiting time between shipments is generated, this input is used as scaling constant.
(c) The desired shipment size for this drug. (See comments below regarding shipment size for a given method.)
(d) The average amount to be delivered per day.

In attempting to find values for the above variables, we searched through a variety of information on drug trafficking and enforcement. There is no one source for these data; and in some cases, one can discover contradicting estimates made by different agencies. When choosing values, we attempted to be consistent in our decisionmaking and to use figures that did not appear to be completely at odds with what we already knew about drug markets.

The export price per kilogram was taken from an unpublished Drug Enforcement Agency (DEA) report. The expected time between shipments was computed so that the product of the expected number of shipments per year and the average shipment size (discussed below) equal the DEA estimates of the annual drug consumption plus the annual seizures. The shipment size was taken from a DEA report of average seizures by the Customs Air Support Branches. Examples of the actual numbers used appear in Section VII. In a model run the number of shipments will be a Poisson random variable whose expected value is given by the input

parameters. Given this random number of shipments, the number that are successful is also random and is driven by the PIs. If a series of runs are made to compare smugglers' costs of smuggling sufficient drugs to meet U.S. consumption in the face of, say, increasing interdiction probabilities, the unscaled results are misleading in the sense that increasing the PI will result in decreases in the amount of the drugs being successfully shipped. To rectify this and make the results within a series of runs compatible, the model also accepts an "average amount to be shipped per day." After all the unscaled results have been printed the model linearly scales all costs and quantities so that the average amount successfully shipped will agree with this input. The model output is then repeated using these scaled results, which may be compared with results of other runs having different parameters.

The 350 kg figure we chose is approximately the size of the average daily amount successfully smuggled in what was considered to be a likely base case run. The amount agrees with extrapolations of the U.S. consumption estimates in the National Narcotics Intelligence Estimate of the 1984 Narcotics Intelligence Consumers' Committee (NICC). The relative change in the run-to-run outputs is insensitive to the choice of this parameter. Only the absolute values and differences will be affected.

Data Field 11: Method Related Data

The method related data:

(a) The amount of pay to personnel.
(b) The risk compensation exponent.
(c) The cost of interdiction.
(d) The maximum shipment size.

The amount of pay to personnel that are at risk is assumed to vary as a function of the perceived risk. The amount entered here is the risk compensation pay that would be necessary if the Perceived Probability of Interdiction (PPI) is .5. Pay that does not vary as a function of risk, for instance pay to individuals not at risk, should be included in the cost to ship, which is part of the route information.

The risk compensation pay figure we estimated was based on the average sentence given to convicted smugglers, the average rate of conviction of drug smugglers, and our guess at the earnings potential of the people at risk. Some public sources are available that report information on sentencing and convictions, such as the U.S. Administrative Office of the Courts. Again, examples of the values we used in runs of the model appear in Sec. VII.

It is assumed that the necessary risk compensation will increase nonlinearly as a function of the perceived risk--that is, the PPI. Using a risk compensation exponent greater that one will result in risk compensation increasing superlinearly, an assumption that enhances the effectiveness of interdiction.

We used a risk exponent of 2, resulting in the risk compensation pay varying as the square of the PPI. This was assumed to be favorable to the DLE as it will enhance the value of increased interdiction by driving up the costs of smuggling.

The cost of interdiction should reflect all expected costs to the smuggler of establishing new personnel and contacts (where necessary), and of legal expenses associated with defending arrested personnel. It should also include the replacement costs of seized assets, not including seized drugs. (The model adds in the cost of seized drugs.)

The "cost if interdicted" for shipments by air were $200,000, $40,000 by sea, and $5,000 by land. These estimates reflect our belief that smugglers will make a substantially greater effort to try to release an experienced pilot, or incur substantially more costs in replacing him, than they would for a boat and ship's crew. By contrast, we have been told that the people used to carry drugs across land borders are generally considered expendable. These estimates include about $100,000 to cover the replacement cost of a light- to medium-weight, twin-engined aircraft, which seems ample in today's deflated market, and $20,000 to replace a boat. The latter figure may seem low--we have been influenced by Coast Guard observations that many smugglers' boats are barely seaworthy.

The maximum shipment size can vary for different methods and types of drugs. Where the maximum size is smaller than the desired shipment size given for the drug (which occurs in only one of the land routes in the runs below), the model schedules multiple shipments. The shipments are treated identically in the model logic that determines the expected cost to ship and computes the PPI. Although shipped simultaneously in the model, the shipments are treated independently in the portion of the model that determines whether each shipment is interdicted.[1]

The figure we chose as a maximum shipment size was intended to describe a typical professional shipment size, rather than a seizure of drugs that might be taken from a tourist or amateur smuggler. The data were taken from DEA and OTA reports giving sizes of seizures and adjusted as deemed necessary.[2]

Data Field 12: Ending Days of Each Epoch

The ending days of each epoch of constant PI. The next epoch starts on the following day.

Data Field 13: Route Related Data

The route related data:

---

[1]A cluster of simultaneous shipments could saturate the DLE in a given area, resulting in an overall decrease in the PI. However, we have not been informed that smugglers use this ploy; hence the independent treatment of the interdiction of multiple shipments seems justified.

[2]For instance, the OTA study reported that in 1986 Customs seized 24 aircraft containing 58.2 M-tons of marijuana, for an average of over 5,300 pounds per aircraft. This amount is slightly less than the useful load of a DC-3 with full fuel. We have been told that the typical large aircraft seizure of marijuana is a medium-weight, twin-engine craft with a useful load of 1,000 to 1,500 pounds. On the assumption that smugglers may not need a full load of fuel, we have used, OTA figures notwithstanding, a maximum size of 2,000 pounds for air shipments of marijuana.

(a) The cost to ship by this route.

(b) The method of shipping by this route, air or sea.

(c) The interdiction probabilities for each epoch.

The cost to ship by this route includes all operating expenses associated with shipping along a given route, except the risk compensation costs and the interdiction costs (which depend on the method).

In estimating operating cost by route, we assumed that the costs to ship by sea were to be less than by air. Route 11, the land route, was considered to be an expensive but safe route; hence its cost was much higher.

In our modeling, we used increasing values of PI in the different runs of a given series and different values in the base case run of different series. The values of PI ranged from .15 to .30 in the base case runs and were increased to .5 in the series of runs that were excursions from the base case run. The results of the model are clearly driven by this parameter, which cannot be very well known or estimated with existing data--hence the need for sensitivity studies. In the runs below, we have considered a PI of .5 to be very high in view of existing technology and the many options available to smugglers. If there is a safe but expensive route, raising PI above .5 has little effect because most traffic diverts to the safe route at that level of interdiction.

THE INPUT DATA FILE

The data in Fig. 3 are input and read by the program in the sequence described above with two exceptions. The names of the methods are given before their costs, and the method used on a given route is determined by the third field in the route-related data (1 if by air, 2 if by sea, and 3 if by land). Generally, the column number where a data field ends is a multiple of 5.

In the route-related data, the leading zeros imply that these routes are not blockaded. Replacing the zero with a one would cause the route to be blockaded, denying its use to smugglers.

```
    1     3    10     3    10   120   365         0.1 7243 3791
Cocaine          7500.0         0.71      250.0      350.0
By air        1200000.0          2.0   200000.0     2000.0
By sea        1600000.0          2.0    40000.0    16000.0
By land         10000.0          2.0     5000.0       50.0
   01
   41
   82
  122
  163
  203
  244
  284
  325
  366
  One           20000.0     1
    0          .15
    0          .15
    0          .15
    0          .15
    0          .15
    0          .15
    0          .15
    0          .15
    0          .15
    0          .15
  Two           16000.0     2
    0          .15
    0          .15
    0          .15
    0          .15
    0          .15
    0          .15
    0          .15
    0          .15
    0          .15
    0          .15
  Three        120000.0     3
    0          .10
    0          .10
    0          .10
    0          .10
    0          .10
    0          .10
    0          .10
    0          .10
    0          .10
    0          .10
```

Fig. 3--The input data file

The data must be consistent in that if one drug is specified (1st entry, 1st line), then there must be exactly one line of drug relevant data (2d line). Similarly, if three methods are specified (2d entry, 1st line) then there must be three lines of method-related data (lines 2 through 4). Both the number of ending days (the 10 lines following the method related data) and the number of PIs (the 10 lines following each line of route data) must agree with the number of epochs given in the 3d entry of the 1st line.

VI. THE OUTPUT FROM SOAR

This section describes the fields in the SOAR output and then gives a sample of the output to be expected from the input file described in Sec. V.[1]

The following section contains a discussion of a collection of runs describing the results of interdiction against cocaine smugglers, and a discussion of another collection of runs describing the results of interdiction against marijuana smugglers. Each collection of runs is composed of three baseline scenarios, one of which is designed to approximate the most commonly accepted set of seizure rates that have been operative over the last several years. The other two baseline runs use interdiction probabilities that are uniformly higher and uniformly lower than this seemingly most likely scenario. If the reader has opinions that the reported seizure rates are uniformly high or low, one of the other baselines may more nearly approximate the world as he sees it.

For each baseline run there is a set of seven variations showing the effect of systematically raising the interdiction rates on selected routes to levels that become very high. These seven variations are discussed in the next section.

The simulation first writes out the input values on which the results will be based. At the conclusion of all the trials, a report is written describing the following statistics:

1. Expected attempts per trial. The average number of shipments attempted during the period being analyzed.
2. Expected successes per trial. The average number of successful shipments during the analysis period.

---

[1]The following output resulted from a run on a COMPAQ PLUS personal computer. Runs on different computers may give slightly different results, as the precise output of the random number generator (but not the frequency distribution of this output) is hardware dependent.

3. Expected interdictions per trial. The average number of unsuccessful shipments during the analysis period. Expected attempts = Expected successes + Expected interdictions.
4. Success rate. The proportion of shipments that were successful.
5. Interdiction rate. The proportion of shipments that were unsuccessful.
6. Cost of incomplete shipments (in thousands). The average cost to the smuggler because of unsuccessful shipments, including the cost of the method (such as an airplane), the cost of the drug, and the cost of the route (such as gasoline.)
7. Cost of completed shipments (in thousands). The average cost to the smuggler because of successful shipments, including the cost of the drug and the cost of the route.
8. Total cost to smugglers (in thousands). The sum of the cost of incomplete shipments and the cost of completed shipments.
9. For each drug, the quantity that the smugglers attempted to ship.
10. For each drug, the quantity that the smugglers successfully shipped.
11. For each drug, the quantity that the smugglers lost because of unsuccessful shipments.
12. For each route, the expected attempts, successes, and failures are reported.
13. For each phase and each route, the expected attempts, successes, and failures are reported.
14. For each drug and each route, the expected quantities shipped, captured, etc.

Sample Output from the Input Data File Described in Sec. V

```
Smugglers simulation parameters and input data:

        1 types of drugs,  3 allowed.
        3 smuggling methods,  3 allowed.
       10 phases of interdiction, 12 allowed.
        3 routes considered, 20 allowed.
       10 trials requested.

      120 days of initial run in (for initialization).
      365 days to be analyzed,  730 allowed.
      Memory value is    0.100
      Initial seeds for random number generator are  7243 and  3791

      Drug - Cocaine       : Export cost per kg =                      7500.00
                             Expected time between shipments =            0.71
                             Shipment size =                            250.00
                             Ave. amount to be delivered per day =      350.00

      Method - By air      : Risk compensation =                    1200000.00
                             Risk compensation exponent=                2.00
                             Cost (if interdicted) =                  200000.00
                             Cocaine    - maximum shipment size =      2000.00

      Method - By sea      : Risk compensation =                    1600000.00
                             Risk compensation exponent=                2.00
                             Cost (if interdicted) =                   40000.00
                             Cocaine    - maximum shipment size =      16000.00

      Method - By land     : Risk compensation =                      10000.00
                             Risk compensation exponent=                2.00
                             Cost (if interdicted) =                  5000.00
                             Cocaine    - maximum shipment size =       50.00

      Phase  1 lasts through day    1
      Phase  2 lasts through day   41
      Phase  3 lasts through day   82
      Phase  4 lasts through day  122
      Phase  5 lasts through day  163
      Phase  6 lasts through day  203
      Phase  7 lasts through day  244
      Phase  8 lasts through day  284
      Phase  9 lasts through day  325
      Phase 10 lasts through day  366
```

Route - One	: Cost to ship =	20000.00
	Method = By air	
	Phase 1 interdiction probability =	0.15000
	Phase 2 interdiction probability =	0.15000
	Phase 3 interdiction probability =	0.15000
	Phase 4 interdiction probability =	0.15000
	Phase 5 interdiction probability =	0.15000
	Phase 6 interdiction probability =	0.15000
	Phase 7 interdiction probability =	0.15000
	Phase 8 interdiction probability =	0.15000
	Phase 9 interdiction probability =	0.15000
	Phase 10 interdiction probability =	0.15000
Route - Two	: Cost to ship =	16000.00
	Method = By sea	
	Phase 1 interdiction probability =	0.15000
	Phase 2 interdiction probability =	0.15000
	Phase 3 interdiction probability =	0.15000
	Phase 4 interdiction probability =	0.15000
	Phase 5 interdiction probability =	0.15000
	Phase 6 interdiction probability =	0.15000
	Phase 7 interdiction probability =	0.15000
	Phase 8 interdiction probability =	0.15000
	Phase 9 interdiction probability =	0.15000
	Phase 10 interdiction probability =	0.15000
Route - Three	: Cost to ship =	120000.00
	Method = By land	
	Phase 1 interdiction probability =	0.10000
	Phase 2 interdiction probability =	0.10000
	Phase 3 interdiction probability =	0.10000
	Phase 4 interdiction probability =	0.10000
	Phase 5 interdiction probability =	0.10000
	Phase 6 interdiction probability =	0.10000
	Phase 7 interdiction probability =	0.10000
	Phase 8 interdiction probability =	0.10000
	Phase 9 interdiction probability =	0.10000
	Phase 10 interdiction probability =	0.10000

Summary Report -- Unscaled Results

Ave(Attempts per trial)	=	954.90
Ave(Successes per trial)	=	839.20
Ave(Interdictions per trial)	=	115.70
Success rate	=	0.88
Interdiction rate	=	0.12

```
Cost of incomplete shipments (in thousands)  = 153963.50
Cost of completed shipments (in thousands)   = 941551.50
Total cost to smugglers (in thousands)       =1095515.00

                              Cocaine
Quantity attempted          =  128725.00
Quantity arrived            =  111180.00
Quantity Interdicted        =   17545.00
Cost of complete shipments
    (in thousands)          =  941551.50
Cost of incomplete shipments
    (in thousands)          =  153963.50
Total shipment costs
    (in thousands)          = 1095515.00

-------------------

Report for route  1 -   One      , Unscaled Results

Ave(Attempts per trial)     =    210.10
Ave(Successes per trial)    =    180.70
Ave(Interdictions per trial)=     29.40
Success rate                =      0.86
Interdiction rate           =      0.14

                    Phase 1  Phase 2  Phase 3  Phase 4  Phase 5  Phase 6  Phase
7  Phase 8  Phase 9  Phase10
Attempts          =     1.1     23.0     27.4     24.2     23.0     23.2     20
.8     20.8     23.5     23.1
Successes         =     1.0     20.6     23.7     20.9     20.3     18.7     17
.5     17.6     20.6     19.8
Interdictions     =     0.1      2.4      3.7      3.3      2.7      4.5      3
.3      3.2      2.9      3.3
Success rate      =    0.91     0.90     0.86     0.86     0.88     0.81     0.
84     0.85     0.88     0.86
Interdiction rate=    0.09     0.10     0.14     0.14     0.12     0.19     0.
16     0.15     0.12     0.14

                         Cocaine
Quantity attempted     =   52525.00
Quantity arrived       =   45175.00
Quantity Interdicted   =    7350.00

-------------------

Report for route  2 -   Two      , Unscaled Results

Ave(Attempts per trial)     =    194.80
Ave(Successes per trial)    =    165.40
Ave(Interdictions per trial)=     29.40
Success rate                =      0.85
Interdiction rate           =      0.15
```

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8	Phase 9	Phase10
Attempts =	1.2	22.2	18.0	20.3	25.8	22.4	20.9	21.5	21.9	20.6
Successes =	1.1	17.7	15.9	17.8	22.7	18.5	17.3	18.4	18.6	17.4
Interdictions =	0.1	4.5	2.1	2.5	3.1	3.9	3.6	3.1	3.3	3.2
Success rate =	0.92	0.80	0.88	0.88	0.88	0.83	0.83	0.86	0.85	0.84
Interdiction rate=	0.08	0.20	0.12	0.12	0.12	0.17	0.17	0.14	0.15	0.16

Cocaine

Quantity attempted = 48700.00
Quantity arrived = 41350.00
Quantity Interdicted = 7350.00

Report for route 3 - Three , Unscaled Results

Ave(Attempts per trial) = 550.00
Ave(Successes per trial) = 493.10
Ave(Interdictions per trial)= 56.90
Success rate = 0.90
Interdiction rate = 0.10

	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5	Phase 6	Phase 7	Phase 8	Phase 9	Phase10
Attempts =	3.5	60.5	63.0	56.0	46.0	62.0	65.5	70.5	65.0	58.0
Successes =	3.2	53.3	55.6	50.6	41.4	56.9	59.3	62.7	59.5	50.6
Interdictions =	0.3	7.2	7.4	5.4	4.6	5.1	6.2	7.8	5.5	7.4
Success rate =	0.91	0.88	0.88	0.90	0.90	0.92	0.91	0.89	0.92	0.87
Interdiction rate=	0.09	0.12	0.12	0.10	0.10	0.08	0.09	0.11	0.08	0.13

Cocaine

Quantity attempted = 27500.00
Quantity arrived = 24655.00
Quantity Interdicted = 2845.00

Summary Report -- Scaled Results

```
Ave(Attempts per trial)      =   1097.22
Ave(Successes per trial)     =    964.27
Ave(Interdictions per trial)=    132.94
Success rate                 =      0.88
Interdiction rate            =      0.12

Cost of incomplete shipments (in thousands)  = 176909.80
Cost of completed shipments (in thousands)   =1081878.00
Total cost to smugglers (in thousands)       =1258788.00

                             Cocaine
Quantity attempted          =  147909.90
Quantity arrived            =  127750.00
Quantity Interdicted        =   20159.86
Cost of complete shipments
    (in thousands)          = 1081878.00
Cost of incomplete shipments
    (in thousands)          =  176909.80
Total shipment costs
    (in thousands)          = 1258788.00
```

Report for route 1 - One , Scaled Results

```
Ave(Attempts per trial)      =    241.41
Ave(Successes per trial)     =    207.63
Ave(Interdictions per trial)=     33.78
Success rate                 =      0.86
Interdiction rate            =      0.14

                    Phase 1  Phase 2  Phase 3  Phase 4  Phase 5  Phase 6  Phase
7  Phase 8  Phase 9  Phase10
 Attempts          =     1.3     26.4     31.5     27.8     26.4     26.7     23
.9     23.9     27.0     26.5
 Successes         =     1.1     23.7     27.2     24.0     23.3     21.5     20
.1     20.2     23.7     22.8
 Interdictions     =     0.1      2.8      4.3      3.8      3.1      5.2      3
.8      3.7      3.3      3.8
 Success rate      =    0.91     0.90     0.86     0.86     0.88     0.81     0.
84     0.85     0.88     0.86
 Interdiction rate=    0.09     0.10     0.14     0.14     0.12     0.19     0.
16     0.15     0.12     0.14

                         Cocaine
 Quantity attempted     =  60353.20
 Quantity arrived       =  51907.77
 Quantity Interdicted   =   8445.43
```

```
Report for route  2 -   Two      , Scaled Results

Ave(Attempts per trial)      =    223.83
Ave(Successes per trial)     =    190.05
Ave(Interdictions per trial)=     33.78
Success rate                 =      0.85
Interdiction rate            =      0.15

                    Phase 1  Phase 2  Phase 3  Phase 4  Phase 5  Phase 6  Phase
 7  Phase 8  Phase 9  Phase10
 Attempts          =     1.4     25.5     20.7     23.3     29.6     25.7     24
.0     24.7     25.2     23.7
 Successes         =     1.3     20.3     18.3     20.5     26.1     21.3     19
.9     21.1     21.4     20.0
 Interdictions     =     0.1      5.2      2.4      2.9      3.6      4.5      4
.1      3.6      3.8      3.7
 Success rate      =    0.92     0.80     0.88     0.88     0.88     0.83     0.
83     0.86     0.85     0.84
 Interdiction rate=    0.08     0.20     0.12     0.12     0.12     0.17     0.
17     0.14     0.15     0.16

                        Cocaine
 Quantity attempted     =   55958.13
 Quantity arrived       =   47512.70
 Quantity Interdicted   =    8445.43


-------------------

Report for route  3 -   Three     Scaled Results

Ave(Attempts per trial)      =    631.97
Ave(Successes per trial)     =    566.59
Ave(Interdictions per trial)=     65.38
Success rate                 =      0.90
Interdiction rate            =      0.10

                    Phase 1  Phase 2  Phase 3  Phase 4  Phase 5  Phase 6  Phase
 7  Phase 8  Phase 9  Phase10
 Attempts          =     4.0     69.5     72.4     64.3     52.9     71.2     75
.3     81.0     74.7     66.6
 Successes         =     3.7     61.2     63.9     58.1     47.6     65.4     68
.1     72.0     68.4     58.1
 Interdictions     =     0.3      8.3      8.5      6.2      5.3      5.9      7
.1      9.0      6.3      8.5
 Success rate      =    0.91     0.88     0.88     0.90     0.90     0.92     0.
91     0.89     0.92     0.87
 Interdiction rate=    0.09     0.12     0.12     0.10     0.10     0.08     0.
09     0.11     0.08     0.13

                        Cocaine
 Quantity attempted     =   31598.53
 Quantity arrived       =   28329.52
 Quantity Interdicted   =    3269.01
```

VII. AN APPLICATION OF THE MODEL

We have made three types of runs with SOAR. The first were simply to determine that the model functioned and that it did not produce obviously perverse results. The process uncovered a few errors that caused the program not to execute; but with minor exceptions, the model logic seems to have been implemented as designed and the design seems complete, in the sense that it has not yielded counterintuitive answers in the contingencies and scenarios modeled.

Several SOAR runs were made in scenarios where all routes have identical interdiction probabilities and shipments were small, equal size, and frequent. In these runs shipments do not saturate routes (in the sense that the saturation factor "r" does not drive up the cost of using the route). In this case the proportion of shipments interdicted in the model should be close to the probability of interdiction, which is an input. These scenarios can be analyzed with back-of-the-envelope calculations; upper bounds on the experimental error are easy to compute. The differences between the proportions computed in the model and the input probabilities have been small and well within the range of expected experimental error.

Another of the exploratory series of runs held all parameters constant, except the mean time between shipments and the shipment size; the model dispatched a smaller number of larger shipments. Both the mean time between shipments and the shipment's size were increased by the same multiplicative factor. The results were as expected: Most output statistics remained fairly constant; but as shipment size gets bigger, the amount shipped over a route per unit time becomes more random. As this occurs, routes occasionally become randomly saturated, and the proportion interdicted rises. This reflects our assumption that interdiction agencies react positively to increased flow rather than being flooded.

In another series of runs the parameters describing different routes were varied to make individual routes advantageous or expensive. The resulting proportion of drugs shipped along each route was compared with the proportion before parameters were adjusted. The long term averages of the amount of drugs shipped, by route, were as expected--the more expensive routes were rarely used, the less expensive ones dominated.

These runs provided confidence that the results of the model are, within experimental error, equal to the answers that would result from a detailed analysis of these simplistic scenarios.

These initial proof-of-concept runs also included several runs to examine alternative methods of modeling smuggler adaptation. The method used in the model, and described in detail in this Note, assumes that smugglers have perfect historical recall of all past shipments, successes, and interdictions. This modeling assumption is clearly favorable to the smugglers. To some extent this assumption is mitigated by another assumption--the smuggler is forced to make a weighted random choice of routes rather than using routes clearly perceived to be cheaper. The degree to which these assumptions bias the results in favor of the smugglers or the DLE is unknown.

Because of our concern about the effects of these assumptions, we varied the extent to which past history influenced the random choice. By increasing the dispersion among the weights until one weighting constant is several orders of magnitude greater than the others, we modeled a strategy where the smuggler always uses the route perceived to be the cheapest. By shrinking all the weights toward an average value we were able to model strategies where historical attempts and successes and perceived costs had little effect on the choice of routes.

In the runs without randomization, where the smuggler always used the route perceived to be the cheapest, we found that the delay between the deployment of DLE forces and the predictable response of smugglers became too obvious; there were clear strategies for the DLE that took advantage of the unduly predictable timing of smuggler's reactions. The value of interdiction assets in these cases was seen to depend heavily

on the degree to which the DLE deployments took advantage of the almost deterministic smuggler's reactions. These scenarios lacked realism and robustness; small and seemingly inconsequential changes in DLE timing could have large effects.

Going to the other extreme and using randomizations where perceived costs have little effect in the selection of routes also gave unreasonable results. Smugglers continued to use routes regardless of the high interdiction rates and high costs.

There is a broad middle ground where changes in the degree of randomization, and minor changes in the scenario, had little effect. The model logic described here falls in this middle ground.

These first runs provided confidence in the model and some understanding of the consequences of our chosen method, and alternative methods, of modeling adaptation.

The second set of runs represents the first explorations of the policy relevant question, What is the effect of smuggler adaptation? Adaptation can be modeled in two dimensions, geography and time; we can also model adaptation of both the smugglers and the DLE. SOAR permits all of these adaptive strategies.

These SOAR runs incorporate 11 routes, representing different possible combinations of routes and modes of transportation for smugglers. The first ten routes are equally divided between air and sea routes for the cocaine runs. The preference of marijuana smugglers for sea and land routes is reflected in the choice of four air routes, five sea routes, and two land routes in the marijuana runs. In both sets of runs route 11 is an expensive land route with a PI of .10. PI on route 11 is not increased in any of the following runs. Route 11 is intended to model methods of smuggling that will probably remain viable regardless of the level of DoD participation in interdiction, such as smuggling through ports of entry or across remote areas of the Mexican border.

The third series of runs incorporated the feedbacks to consumption and production that would result from elastic markets, as described above. They differ from the second series in that the quantity landed varies from run to run, and this quantity is the prime criterion for judging the effectiveness of additional interdiction resources.

THE COCAINE RUNS

The Input Data

The inputs for the base case cocaine run are summarized in Table 2. In this table and others in this section, all costs are given in dollars and weights in kilograms except where noted. The average shipment was sized at 250 kg to approximate the average seizure as given in the data in Sec. V. Small seizures were excluded in an attempt to more accurately model the serious professional smugglers who bring in the bulk of imported drugs.

The mean time between shipments was set at .71 days, giving approximately 1.4 shipments a day, or 500 shipments per year. Because the model uses a Monte Carlo procedure, these inputs determine the average number of attempts, but the actual number of attempts and the amount delivered is random. To make the different runs in the initial set comparable, the model also scales the results; and for these cocaine runs the results are scaled to give an average of 350 kg successfully delivered per day, or 127.75 metric tons of cocaine per year. This figure is in agreement with the data of Sec. V., linearly extrapolated to 1986.

Assuming an air crew size of one, or occasionally two, people with reasonably high legitimate earning potential, the risk compensation was set at $1,200,000 for air shipments. Ship crews are larger; the data in Sec. V (admittedly dominated by marijuana smuggling) suggest that 4-5 is common. However, the potential earnings of most of the crew is much smaller, hence the risk compensation for the entire crew was set at $400,000 for sea shipments. Because of the lack of earning potential of the single smuggler who carries cocaine over the border, $10,000 was set as the risk compensation for land shipments. These figures are the totals that smugglers must pay their agents if PPI is 0.5, the norming factor for risk compensation throughout the analysis.

The model assumes that risk compensation pay varies as the square of PPI. For instance, if PPI is .25 for an air shipment, the risk compensation pay is $1,200,000 x $(0.25/0.5)^2$ or $300,000. If PPI is .10, then the risk compensation for air shipments is $48,000, or

Table 2

SUMMARY OF INPUTS FOR COCAINE RUN 1, THE BASE CASE

120 days of run in to initialize perceived probabilities of interdiction, 365 days to be analyzed. 127.75 metric tons of cocaine to be successfully imported.

Drug--Cocaine:	Export cost per kg =	$7,500.00
	Expected time between shipments =	0.71
	Shipment size (kg) =	250.00
	Ave. amount to be delivered per day (kg) =	350.00
Routes 1-5:	Cost to ship =	$20,000.00
Method--By air	Initial interdiction probability =	0.20
	Risk compensation =	$1,200,000.00
	Cost (if interdicted) =	$200,000.00
	Cocaine--maximum shipment size (kg) =	2,000.00
Routes 6-10:	Cost to ship =	$16,000.00
Method--By sea	Initial interdiction probability =	0.230
	Risk compensation =	$1,600,000.00
	Cost (if interdicted) =	$40,000.00
	Cocaine--maximum shipment size (kg) =	16,000.00
Route 11:	Cost to ship =	$120,000.00
Method--By land	Initial interdiction probability =	0.10
	Risk compensation =	$10,000.00
	Cost (if interdicted) =	$5,000.00
	Cocaine--maximum shipment size (kg) =	50.00

Summary of Inputs, Runs 2-8

Run 2, as in run 1, except P(int) = .5 on one fixed air route.
Run 3, as above, except P(int) = .5 on two fixed air routes.
Run 4, as in run 2, except P(int) = .5 on one random air or sea route.
Run 5, as above, except P(int) = .5 on two random air or sea routes.
Run 6, as above, except P(int) = .5 on three random routes.
Run 7, as above, except P(int) = .5 on five random routes.
Run 8, as above, except that P(int) = .5 on ten routes.

$\$1,200,000 \times (0.1/0.5)^2$. The assumption of such a relationship ensures that large increases in the risk of capture will have very large effects on smuggler labor costs. We believe that this is a reasonable assumption, particularly for pilots.

Inputs to the model include a maximum shipment size, by method of smuggling. If the maximum shipment size for a method is less than the shipment size specified for the drug, then multiple shipments are made when that method is chosen. We have chosen a maximum shipment size of 700 kg for air shipments as a reasonable approximation of the carrying capacity of the medium-weight, twin-engined aircraft that seems to be preferred for air smuggling. For sea shipments the maximum shipment size is set at 16 metric tons. Both of these limits exceed the shipment size for cocaine, hence do not effect the cocaine runs. The shipment size for smuggling across the Mexico land border may be approximated by a man's carrying capacity, over rough terrain and in a hostile environment. We estimated this capacity to be 50 kg. In this case, when land shipments were selected, the model made five individual shipments to achieve the desired shipment size.

The Base Case

There are actually two "probabilities of interdiction" that could be of interest in this problem. One is the probability that a randomly chosen *kilogram* of a drug is seized in the interdiction process. The other is the probability that a randomly chosen *shipment* gets seized in the interdiction process. If all shipments were the same size, or if all shipments incurred the same risk of interdiction, these probabilities would be the same, but in general they are different.

An estimate of PI is the interdiction rate as measured by the number of shipments interdicted divided by the number of shipments attempted. This is the more relevant interdiction probability for measuring the risk to which smugglers' agents are exposed, the number of individuals associated with a shipment being very insensitive to shipment size.

The other probability mentioned above would be estimated by the quantity seized divided by the quantity attempted. This will be referred to as the seizure rate. Since shipments are of different sizes and routes have different PIs, these probabilities will not be equal; and a disparity between the interdiction rates (as defined above) and the ratio of seized tonnage to attempted tonnage is to be expected.

The interdiction rate is likely to be lower than the seizure rate because larger shipments are more vulnerable than smaller shipments. Larger shipments tend both to be carried in more conspicuous vessels (using that term generically) and to be more readily found if a carrying vessel is searched. Large shipments, even though more vulnerable, may nonetheless be chosen because their transportation costs can be lower.

The PIs for the routes of the base case run, run 1, are shown in Table 2; they are .20 on the air routes, .23 on the sea routes, and .10 on the expensive land route. In the output of the base case run, the overall interdiction rate was .18, in reasonable agreement with current estimates of interdiction effectiveness. Also in agreement with extrapolations of the seizure data reported in the National Narcotics Intelligence Consumers Committee Report for 1984 (NNICCR), 31.4 metric tons were interdicted. Only 8 percent was shipped over the expensive land route; most of the total was shipped by air.

The value of these runs lies not in their ability to play back reasonable numbers, but in the capacity they provide to investigate the effects of reasonable changes in the probabilities of interdiction.

Increasing the Probability of Interdiction

A brief summary of the scenarios investigated in runs 2-8 is given at the bottom of Table 2. We looked at the consequences of raising the PI on one or more routes to .5. In run 2, PI was increased to .5 on one fixed route. In run 3, PI was increased to .5 on two fixed routes. To investigate the effectiveness of flexibly deploying interdiction assets and moving them from route to route, the PI was increased to .5 on one random air or sea route in run 4, and to .5 on two randomly selected routes in run 5. In this context "randomly selected" means the smuggler has no way of knowing when and where PI was going to be increased. Past experience about the interdiction rate on a particular route is not a good guide to the future rate.

We chose 0.5 as the ceiling rate, because it is unlikely that interdictors can achieve much higher interdiction rates along individual routes. Certainly this is a significantly higher rate than anyone estimates is being currently attained.

The result of these variations are given in Table 3. The increase in PI on one fixed route resulted in a small increase (1.3 percent) in smuggler's costs and a 3.1 percent increase in the amount of cocaine interdicted. There was a small shift to increased utilization of route 11. Comparing runs 2 and 4, where PI was also increased to .5 on one randomly selected route and varied over time, we notice a slight increase in the effectiveness of the interdiction assets when the randomization is allowed.

In run 3, PI was increased to .5 on two routes, and in run 5 it was increased to .5 on two randomly selected routes. Although 11 routes are available to smugglers, increasing PI on two routes begins to have substantial effect, especially if the routes are, from the smuggler's perspective, randomly selected. The increases are over twice as great when the two routes are randomly selected as when they are fixed. The increase in cost jumps to 2.3 and 12.0 percent in these two runs, and the amount interdicted increases by 6.8 and 27.7 percent. In these runs there is a continued increase in the utilization of route 11.

Runs 6 and 7 show the effect of further increases in the number of routes with enhanced PI. In run 6, PI was increased to .5 on three random routes, while in run 7 it was increased to that level on five

Table 3

SUMMARY OF SOAR OUTPUT, COCAINE RUNS 1-8

Run #	Total Cost (million $)	Drug $/ Total $	% Cost Increase	Inter-diction Rate	M-Tons Inter-dicted	Route 11	
						Landed Tons	% of Total
1	1408	.85	0	.18	32.5	10.2	8
2	1427	.85	1.3	.18	33.5	10.6	8
3	1440	.85	2.3	.19	34.7	11.5	9
4	1459	.84	3.6	.19	35.1	10.7	8
5	1572	.81	12.0	.21	41.5	14.8	12
6	1690	.78	20.0	.22	47.8	17.0	13
7	1938	.72	38.0	.24	58.3	24.3	19
8	2387	.65	70.0	.26	78.2	35.2	28

(out of 10) randomly chosen air and sea routes. These runs show substantially increased costs to the smuggler--increases of 38.0 percent and 70.0 percent. As the number of routes with enhanced PI increased in run 7, the utilization of route 11 doubles and is responsible for 19 percent of the delivered cocaine.

Finally in run 8 we allow for high interdiction rates on all the routes except route 11. The share of imports going through this route goes up dramatically, even compared with run 7, from 19 percent to 29 percent, as one might expect when it is so much safer than the other routes. Total importing costs go up substantially too, by about $450 million.

In these runs the obvious and tangible measure of success, the amount interdicted, increases at a much faster rate than does the measure that is more relevant to the overall effects of interdiction--the cost to the smuggler. Throughout these runs, increases in amount seized were about twice as large as the increases in cost to the smuggler. In run 7 the cost to the smuggler increased by 38 percent, but the amount interdicted increased by almost 80 percent. There are also changes in the discrepancies between the seizure and interdiction rates; the rate of interdiction rises much more slowly than the seizure rate. This reflects the fact that more of the drug is crossing the land border, route 11, in smaller bundles. In these runs the effectiveness of increased interdiction clearly depends on the choice of measure. Figure 4 graphs seizure quantities as a function of the number of routes with enhanced interdiction and Fig. 5 graphs smugglers' costs versus number of routes with enhanced interdiction.

Increasing the interdiction rate changes the structure of smugglers' costs. Whereas the replacement cost of cocaine accounts for 85 percent of total outlays for smugglers in the base case, this item accounts for only about 65 percent of the total in the 8th run, reflecting the effect of higher interdiction on risk compensation for pilots; on the air routes, with a perceived interdiction probability of 0.5, this now comes to $1,200,000 per shipment, rather than $192,000 for the base case, when the perceived air interdiction rate is about 0.2.

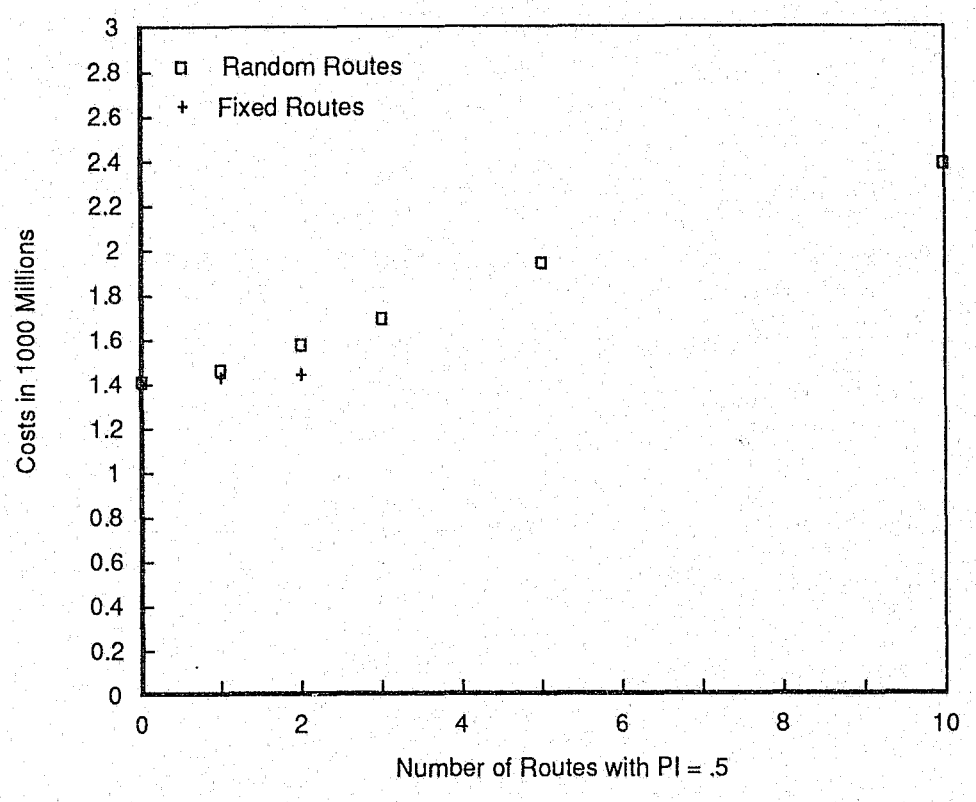


Fig. 4--Cocaine: M-tons interdicted vs. routes with enhanced interdiction

The increases in smuggler costs, when translated to a per kilogram basis, look quite modest compared with the final price of the drug, indeed even when compared with the wholesale price of cocaine. The total smugglers' cost in run 8 is only about $8,000 per kilogram higher than in the initial case; a nominal wholesale price is about $40,000 per kilogram.

Increased Interdiction: Feedbacks to Consumption and Production

The third set of runs allows for increased interdiction to affect the consumption level (as measured by the total deliveries) and the export price of the drug. The feedbacks are modeled very simply in the following equations.

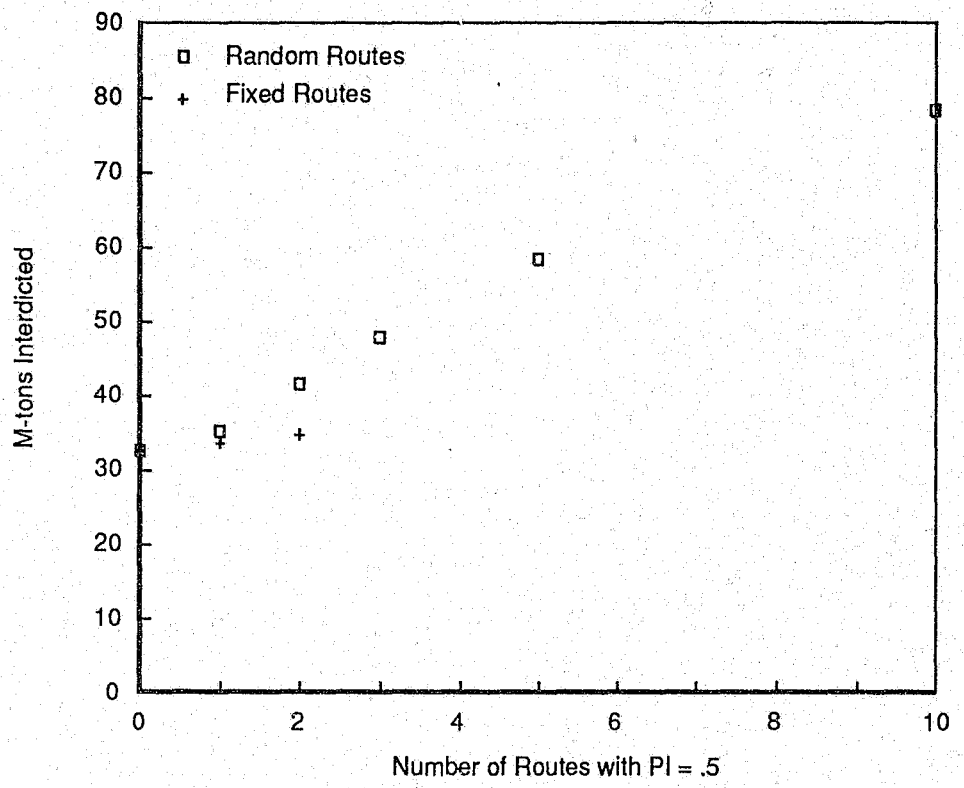


Fig. 5--Cocaine: Smugglers' costs vs. routes with enhanced interdiction

Eq. (1) ed = elasticity of demand with respect to retail price = -2.0

Eq. (2) ep = elasticity of retail price with respect to the import price = 0.2

Eq. (3) ex = elasticity of supply with respect to total shipments to the United States = 0.5

The first equation says that a 1 percent increase in the retail price of cocaine will result in a 2 percent decrease in cocaine consumption. As argued in Sec. III, this certainly overstates the elasticity of demand for cocaine in the short run, given the large share of the market that is addicted. It may be more reasonable in the long run.[1]

[1]This ignores shifts in tastes that might occur in the long run,

We have deliberately chosen an assumption that increases the likelihood that interdiction affects consumption, because the preliminary analysis suggested slight effect. If consumption is very insensitive to price, then even very large increases in costs and prices arising from interdiction will have little effect on consumption.

The same principle has guided our choice of the value in the second equation. Retail prices are currently approximately 10 times imported prices. This would suggest that, with competitive markets in the post-import distribution sectors, a $1 increase in the import price will raise retail price by only about $1.25, allowing generously for the additional domestic inventory costs. That would suggest an elasticity of retail to import price of only 0.125. We have increased that to account for nonenforcement risks that might be heightened by the raised value of the drugs when held in domestic transactions and have set it at 0.2. This will raise the likelihood that higher interdiction rates will have a large effect on domestic consumption. We have also assumed that increases in smugglers' costs are fully passed on in import prices.

The third equation captures the effect of seizures on the replacement cost of drugs for smugglers. If the higher seizures do not reduce consumption (demand) by as much or more, then total shipments from the source countries to the United States will rise. To obtain that larger quantity of drugs, smugglers will have to offer higher prices.

There is no basis for systematic estimation of this price elasticity. Discussions with officials suggest that they believe it to be very low. In the short run this perception is influenced by the apparent availability of very large inventories, which would dampen the price effect of increased U.S. demand. In the long run, the fact that U.S. cocaine consumption is less than half of total source country production and that the resources required for production (low productivity land and rural labor) are in ready supply make it unlikely

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for example if the drug acquires a reputation for being dangerous. The elasticity constitutes a statement about what would occur if the price increased and nothing else changed.

that prices would have to increase much to induce a higher supply of cocaine.

Our assumption about ex in Eq. (3) amounts to the assumption that a 1 percent increase in shipments to the United States requires a 2 percent increase in the export price. This is a much larger effect than we actually expect but is again intended to allow for the possibility that interdiction can have a large effect on export price, hence on domestic consumption, because the role of ex is to allow for an increase in another component of smugglers' costs as the result of interdiction.

These runs are created by a two step procedure. We start with the output created for each run in the previous set of runs, where there are no feedbacks. A second set of equations then incorporates the feedbacks. Implicit in these equations is the assumption that the elastic markets will not affect the seizure rate. This latter assumption simplifies the computation; it will provide trivial, if any, distortion when the initial SOAR runs show little increase in total smugglers' costs. When, as in runs 7 and 8, the smugglers' costs go up substantially, the assumption will induce some bias toward finding larger effects from increased interdiction.

With these additional feedbacks, we have a different output from the model. Instead of focusing on smugglers' total cost to ship, we give primary attention to the effect on total consumption. The effect of allowing for these feedbacks is captured in Table 4, which reports outputs from the same set of runs that were given in Table 3, so that, for example, the eighth and final run is one in which all routes, except land route 11, have a probability of interdiction of 0.5. The second column, metric tons landed, now shows total consumption (shipments less seizures).

The results are again somewhat disheartening. On the eighth run, when air and sea interdiction are very stringent, the net result is a reduction in total cocaine consumption of about 25 percent. That is indeed substantial, but when only some routes are subject to the higher interdiction rates, there is very little effect on total consumption. For example, when three randomly chosen routes are subject to interdiction probabilities of 0.5, total consumption is reduced by less

Table 4

SUMMARY OF OUTPUT WITH ELASTICITY FEEDBACK, COCAINE RUNS 1-8

Run #	M-Tons Landed	Total Cost (million $)	Interdiction Rate	M-Tons Interdicted	Route 11 M-Tons Landed	Export Price $ per kg
1	127.75	1408	.18	32.5	10.2	7500
2	127.02	1427	.18	33.5	10.6	7508
3	126.39	1440	.19	34.7	11.5	7544
4	125.83	1459	.19	35.1	10.7	7515
5	121.49	1572	.21	41.5	14.8	7566
6	117.18	1690	.22	47.8	17.0	7573
7	109.10	1938	.24	58.3	24.3	7373
8	95.18	2387	.26	78.2	35.2	6862

than 9 percent. Only when, in the seventh run, as many as five routes have the higher probability, does total consumption decrease by more than 10 percent. Figure 6 maps consumption against the number of routes with enhanced interdiction rates.

It is also of some interest to consider export prices and quantities. Seizures, though a positive measure for interdiction forces in the United States, do create a problem for the drug control forces in source countries, because they increase the demand for shipments and the income received by source country producers. Total export earnings can be calculated from Table 4 by multiplying total shipments (tons landed plus tons interdicted) by the export price. In the base case, export earnings are $1,202 million and rise to $1,249 million by run 6. In the final run, however, export earnings fall from the base case to $1,190 million, because other cost factors have been driven up so much that it is these expenses rather than drug replacement costs that lead to an increase in landed price and hence reduced consumption. Though the total quantity seized goes up, the sum of seizures and deliveries is now less than in the base case.

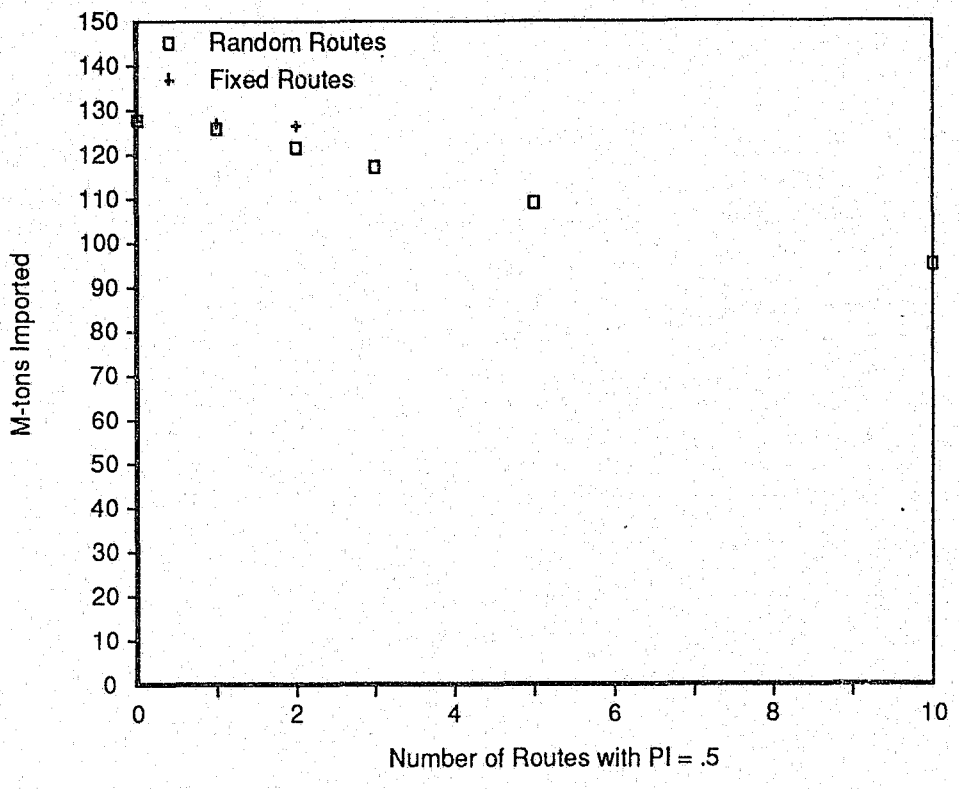

Fig. 6--Cocaine: imports with elastic markets vs. routes with enhanced interdiction

THE MARIJUANA RUNS

The Input Data

At an export price of $10 per kg, rather than $7,500 per kg for cocaine, the marijuana runs may be expected to show different trends as we increase the PI. The replacement cost of drugs is likely to be a much lower share of total smuggling costs. Indeed, this is consistent with the observation that for marijuana the ratio of import prices to export prices is vastly higher than for cocaine; perhaps 20 rather than 3.

Shipment sizes and mean time between shipments were chosen to be in agreement with an extrapolation of the low estimates for imports given in the NNICCR. The average amount to be delivered a day results in 6,500 metric tons of marijuana delivered per year. Risk compensation pay has been scaled down for marijuana, roughly in proportion to the

decrease in length of the average sentence for marijuana smugglers compared with cocaine smugglers.

The maximum shipment size for land shipments has been increased to reflect a shipment that may cross a port of entry in a vehicle, or be carried across the border by 10 people.

The Base Case

The amounts of marijuana delivered and seized agree with extrapolations of the NNICCR data. In comparison with the cocaine runs, route 11 sees more traffic, even in the base case, carrying 17 percent of the traffic, compared with 9 percent in the cocaine base case run. See Table 5. This accords with the observation that a considerable share of marijuana imports come across the Mexican land border. Because route 11 has a PI of .10, the overall seizure rate was reduced to .15.

The Results of Increasing the Probability of Interdiction

With the higher volume of traffic over route 11, increasing PI on one fixed route in run 2 had almost no effect. Traffickers were able to adapt very easily. Run 4, with PI increased on one random route, showed substantially more effect, increasing costs by 11 percent and increasing the amount interdicted by 12.1 percent. See Table 6.

Increasing PI on two routes showed again the great advantages of enhancing interdiction capability on random routes rather than fixed routes: Increasing PI on two fixed routes increased both costs and amount interdicted by less than 4 percent, while increasing PI on two random routes increased these measures of effectiveness by 24 to 29 percent.

Runs 6 and 7, where PI was increased to .5 on three and five random routes, show substantial increases in costs and amount interdicted. Finally, in run 8 we have truly large effects on smugglers' costs. The total cost is now 165 percent higher than the baseline cost; over half of the imports are forced over the land border.

In both the marijuana and the cocaine runs, the effectiveness of interdiction increased faster than did the number of routes affected, suggesting that if interdiction assets are randomly deployed, the per

Table 5

SUMMARY OF INPUTS FOR MARIJUANA RUN 1, THE BASE CASE

120 days of run in to initialize perceived probabilities of interdiction, 365 days to be analyzed. 6,500 metric tons of marijuana to be successfully imported.

Drug--Marijuana:	Export cost per kg =	$10.00
	Expected time between shipments =	0.28
	Shipment size (kg) =	5000.00
	Average amount to be delivered per day (kg) =	17808.00
Routes 1-4:	Cost to ship =	$10,000.00
Method--By air	Initial interdiction probability =	0.250
	Risk compensation =	$235,000.00
	Cost (if interdicted) =	100,000.00
	Marijuana--maximum shipment size (kg) =	700,000
Routes 5-9:	Cost to ship =	$10,000.00
Method--By sea	Initial interdiction probability =	0.250
	Risk compensation =	$300,000.00
	Cost (if interdicted) =	$20,000.00
	Marijuana--maximum shipment size (kg) =	50,000.00
Route 10:	Cost to ship =	$8,000.00
Method--By land	Initial interdiction probability =	0.30
	Risk compensation =	$7,000.00
	Cost (if interdicted) =	$5,000.00
	Marijuana--maximum shipment size (kg) =	500.00
	Method--By land	

Summary of Inputs, Marijuana Runs 2-8:

Run 2, as in run 1, except P(int) = .5 on one fixed air route.
Run 3, as above, except P(int) = .5 on two fixed routes.
Run 4, as in run 2, except P(int) = .5 on one random (air or sea) route.
Run 5, as in run 3, except P(int) = .5 on two random routes.
Run 6, as above, except P(int) = .5 on three random routes.
Run 7, as above, except P(int) = .5 on five random routes.
Run 8, as above, except P(int) = .5 on ten random routes.

Table 6

SUMMARY OF SOAR OUTPUT, MARIJUANA RUNS 1-8

Run #	Total Cost (million $)	Drug $/ Total $	% Cost Increase	Inter-diction Rate	M-Tons Inter-dicted	Route 11	
						Landed Tons	% of Total
1	229	.35	0.0	.15	1485	1085	17
2	236	.34	3.1	.15	1528	1124	17
3	237	.32	3.5	.16	1538	1150	18
4	254	.32	11.0	.16	1665	1202	18
5	285	.30	24.0	.16	1909	1398	22
6	329	.26	44.0	.17	2085	1658	26
7	418	.21	83.0	.17	2469	2316	36
8	608	.16	166.0	.17	2928	3462	53

unit effectiveness will not decrease as the number of deployments is increased (within the limits of these runs). The marijuana runs, even more than the cocaine runs, demonstrate the importance of flexibly deployed interdiction assets.

In the marijuana base case the smuggler delivered 6,500 metric tons and had 1,848 metric tons interdicted, for a total of 8,348 metric tons. At an export price of $10,000 per metric ton, that was only 35 percent of the smuggler's cost. As a result, the marijuana smuggler's costs are heavily driven by personnel cost, which increases faster as a function of interdictions than does the cumulative cost of the drug lost. In fact, the marijuana smuggler's costs actually increase faster than did the amount interdicted, increasing 83 percent in run 7, as opposed to a 66.3 percent increase in the amount interdicted. Initially, in runs 2-5, costs increase slower than amount interdicted, but as interdiction rates begin to get higher, costs begin to increase faster.[2] In run 8, with 10 routes subject to the high probability of interdiction, costs are driven up very substantially; they are now more than 1.5 times the baseline figure. The quantity interdicted is more than doubled.

[2]That is a result of using a quadratic in computing risk compensation pay.

The effect of the number of routes with enhanced PI on tons interdicted and smugglers' costs are shown in Figs. 7 and 8.

Increased Interdiction; Feedback to Consumption and Production

We now add to the SOAR model the same structure of feedbacks to consumption and production that we used for the cocaine model. Higher smuggling costs raise the landed price and then the retail price; that induces lower consumption. The replacement cost of marijuana for smugglers (the export price) rises if total shipments (quantity landed plus quantity seized) increases. We assume the same elasticities given in Eqs. (1)-(3) in the previous section. Demand is quite elastic with respect to the retail price (a 2 percent decline for each 1 percent increase in retail price). The elasticity of the retail with respect to

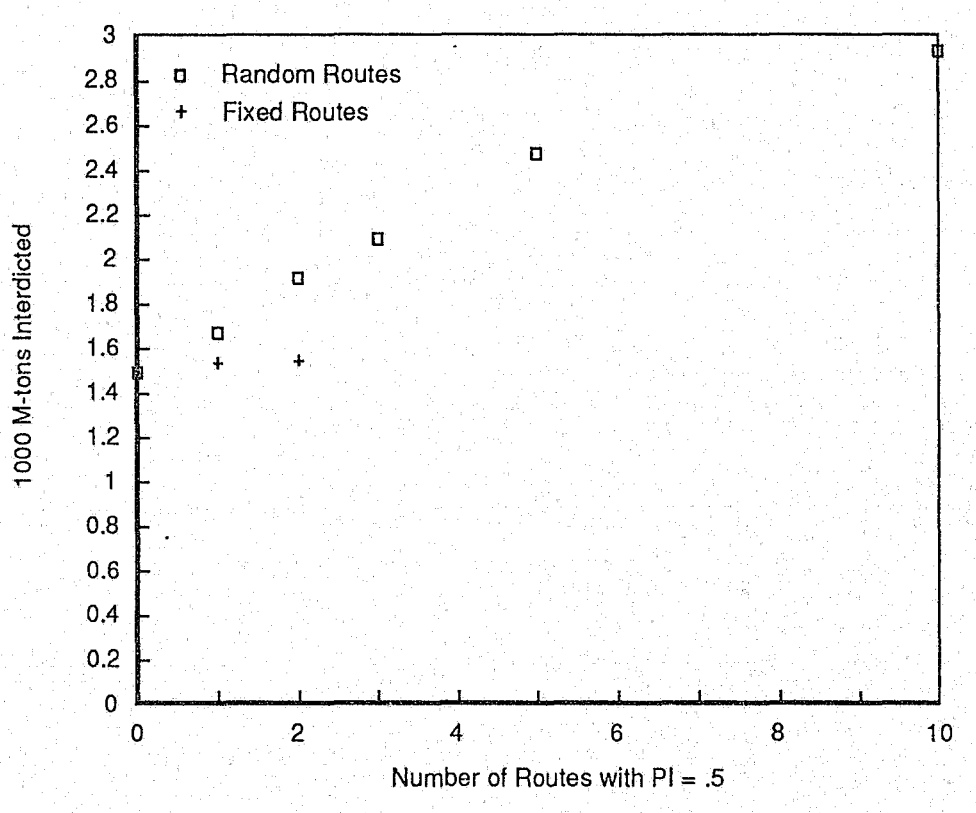

Fig. 7--Marijuana: M-tons interdicted vs. routes with enhanced interdiction

the import price is 0.2; a 1 percent increase in the landed price leads to a 0.2 percent increase in the retail price. We change ex from 0.5 to 1.0, so that a 1 percent increase in shipments can be obtained only at a 1 percent higher price. This is less favorable to the interdictors than ex = 0.5, but with the latter value the model generated implausibly low prices (50 cents per kilo) for the later SOAR runs, as total shipments declined. It still remains a more favorable assumption for interdiction effectiveness than is likely actually to be the case.

The assumptions about supply and demand elasticity need no further explanation beyond that given in the discussion of cocaine. However, the assumption about the elasticity of retail price with respect to the import price (ep) requires some discussion. For marijuana the landed price is a much higher percentage of the final price than is the case

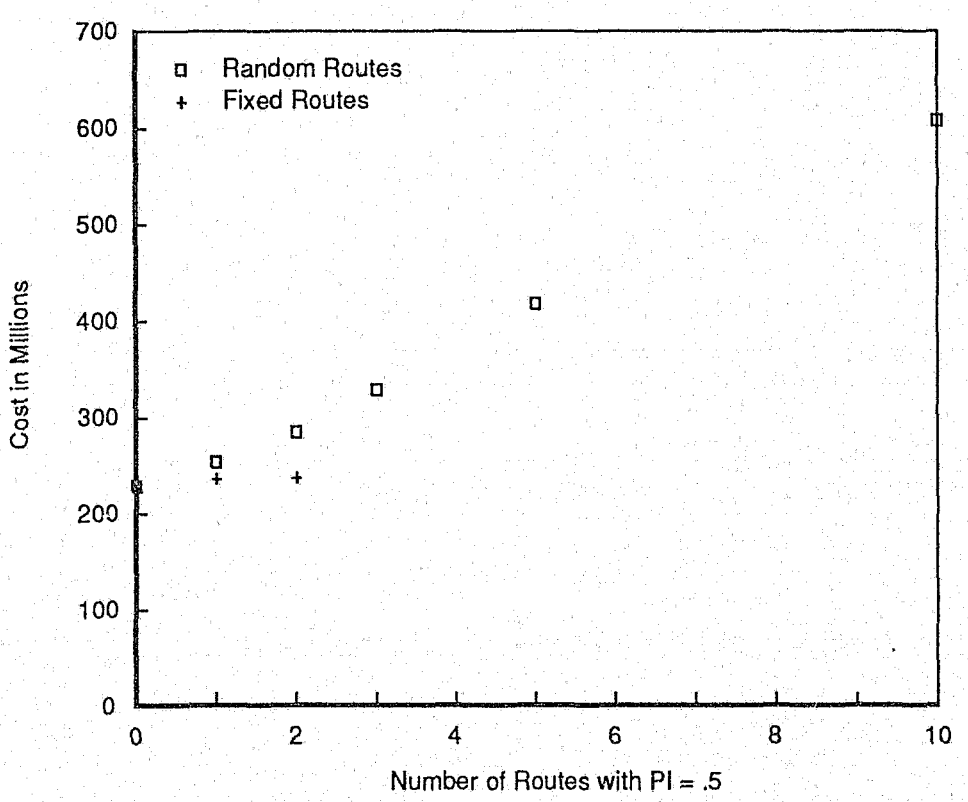

Fig. 8--Marijuana: Smugglers' costs vs. routes with enhanced Interdiction

for cocaine, about 25 percent rather than 10 percent. The existence of an increasing domestic sector suggests that the increase in smuggling costs cannot be fully passed on. Some of the market will be lost to domestic producers. Thus the model allows for only partial mark-up of the retail price.

These are arbitrary assumptions. But if they differ from the true values, they are likely to lead to a finding of a higher effect from increased interdiction than is actually the case.

The results with feedback are reported in Table 7 and graphed in Fig. 9. The results differ in some respects from those for cocaine. Raising the interdiction rate on a few routes has only modest effects, as reflected in runs 2 through 4. Runs 5 and 6, with two and three random routes subjected to the higher rates, show more substantial effects but still lower imports by less than 15 percent. The last two runs show very substantial effects indeed; with five random routes, imports are reduced by one-third. When all but one route is subject to an interdiction rate of 0.5, imports fall by fully two-thirds.

Table 7

SUMMARY OF OUTPUT WITH ELASTICITY FEEDBACK, MARIJUANA RUNS 1-8

Run #	M-Tons Landed	Total Cost Million $	Inter-diction Rate	M-Tons Inter-dicted	Route 11 M-Tons Landed	Export Price $ per kg
1	6500	229	.15	1485	1085	10.0
2	6425	236	.15	1528	1124	9.94
3	6414	237	.16	1538	1150	9.93
4	6231	254	.16	1665	1202	9.80
5	5897	285	.16	1909	1398	9.55
6	5439	329	.17	2085	1658	9.00
7	4516	418	.17	2469	2316	7.80
8	2588	608	.17	2928	3462	4.70

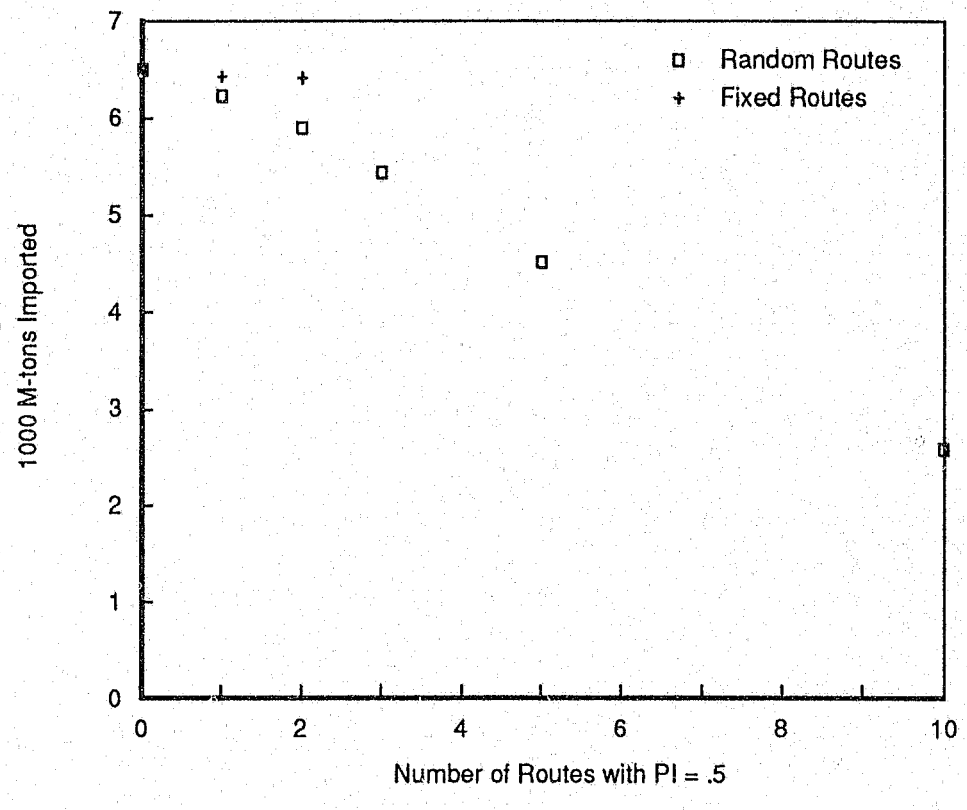

Fig. 9--Marijuana: Imports with elastic market vs. routes with enhanced interdiction

It is also interesting to note differences in the behavior of marijuana export prices compared with those for cocaine. The export prices here always fall when interdiction stringency increases because the risk compensation costs are a much higher share of smugglers' costs for marijuana.

CONCLUSIONS

The results here provide a very mixed view of the effect of increased interdiction stringency. With respect to cocaine the results suggest that unless interdiction severity can be raised on almost all the routes available to smugglers, only modest reductions in total consumption can be achieved.

For marijuana we see rather different results. It is possible to drive down total marijuana imports substantially with sufficiently stringent interdiction. The question, which could not be explored with our models, is whether this is mostly compensated for by increases in domestic production.

Three additional points emerge. First, raising interdiction rates on a few routes seems to have little effect. In particular, raising the interdiction rate on a single route has almost most no effect, particularly if it is a fixed route. Once smugglers identify a particular route as having a high interdiction rate, they will simply shift to other routes, resulting in a slight aggregate effect. A very large share of all routes have to be subject to elevated interdiction rates before there is much effect.

Second, the random allocation of additional resources can greatly increase the influence of more interdiction resources. Smugglers can adapt efficiently only when they can form good estimates of the interdiction rates associated with particular routes. If they know that some three routes will have higher interdiction rates but not which three they are, then their adaptation will be ineffective.

This second conclusion is not necessarily a strong recommendation that DLE resources be frequently shifted across routes. There are costs to such shifts that could not be incorporated into this analysis. Moreover, it is important not only to shift resources but to conceal the shift; this may be difficult to attain.

Third, the effect of increasing the number of routes with enhanced interdiction is almost linear on smugglers' costs and the amount imported with elastic markets. This suggests that the marginal return to the DLE does not diminish as it raises the interdiction rates on several routes.

We should end by reiterating certain methodological limitations of the model. We have not been able to directly incorporate a domestic production sector in the marijuana model. In order to prevent systematic underestimation of the effect on import prices we have used an elasticity of demand for imports that is probably greater than the

elasticity of demand for marijuana. This does not mean that the current runs underestimate the effect of interdiction on marijuana consumption; indeed quite the opposite. By assuming that smugglers can pass on most of the import cost increases, except as affected by the decline in aggregate demand for marijuana, the model will lead to overestimates of the effect of interdiction on marijuana consumption.

Equally troubling are assumptions about smuggler adaptation. Our model assumes that all smugglers share the same information and incorporate it rapidly into their estimates of the costs of smuggling by different means. We presented some evidence earlier that smuggler adaptation occurs. We have balanced this immediate and total historical recall by forcing smugglers to a weighted but randomized choice of routes. In this system, although smugglers may "know" a certain route to be the cheapest or safest, they will continue occasionally to use more expensive or more highly interdicted routes. In short, it is impossible to say how well or how poorly we have modeled smugglers' adaptive strategies.

SOAR and its variants constitute an early effort to systematically analyze how interdiction can raise smugglers' costs and lower consumption. More refined, data based versions of these models should be developed. The precise quantitative results presented in this section will certainly not be replicated. We do believe, however, that a more extensive effort will replicate the finding that interdiction must be very stringent indeed to greatly affect U.S. drug consumption.

Appendix A

VARIABLE NAMES AND DESCRIPTION

I. Parameters Selected When the Model is Compiled

Internal name	Value	Meaning
Long_past	120	See discussion of R in Sec. IV. This number is used in the denominator when computing the R factor. Also used when the smuggler is determining his perceived probability of interdiction on each route; he will consider shipments only over the past 120 days.
Recent_past	20	See discussion of R in Sec. IV. This number is used in the numerator when computing the R factor.
Max_days	500	Maximum number of days that may be analyzed. (Note: The run in is not analyzed in this sense, so Max_days need not be large enough to cover it in addition to the number of days to be analyzed.)
Max_drugs	2	The maximum number of drugs that can be analyzed.
Max_methods	2	The maximum number of methods for smuggling drugs. (Such as by air, by ship, etc.)
Max_phases	3	The time period under analysis may be divided into at most Max_phases epochs. Epochs do not have to have the same length. Probabilities of interdiction are constant during an epoch (except as potentially increased by the R factor, see Sec. IV.)
Max_routes	20	The maximum number of routes that can be analyzed.

Max_shipments	2000	The maximum number of shipments that will occur, including those that occur during the run in. Max_shipments should be comfortably larger than Expected Shipments per Day x (Days to be analyzed + Run-in Days).

II. Input Variables. (Data in the input data set.)

Internal name	Description
Num_drugs	Number of drugs to be analyzed. Cannot be larger than Max_drugs. Integer.
Num_methods	Number of methods for smuggling drugs. (Such as by air, by ship, etc.) Cannot be larger than Max_methods. Integer.
Num_phases	Number of phases. (See definition of Max_phases in Sec. IV for a description of "phase.") Cannot be larger than Max_phases. Integer.
Num_routes	Number of routes. Cannot be larger than Max_routes. Integer.
Num_trials	Number of times the analysis period is to be simulated. Results in the report will reflect the average behavior over these trials. Integer.
End_time	Number of days to be analyzed. Does not include the run-in period. Cannot be larger than Max_days. Integer.
Run_in	Number of days to run the simulation before commencing the analysis period. See Sec. IV for a discussion of why we need to do this. Should be at least as large as Long_past. Integer.
Inseed	Seed for the random number generator. Integer.
Drug_name[N]	The name of drug N. Up to ten characters.

Drug_cost[N]	The cost at the source of a kilogram of drug N. Real.
Ex_shipment_interval[N]	Expected time between shipments of drug N. Used as the parameter of a Poisson process. Real.
Ex_shipment_size[N]	Expected shipment size of drug N. Currently, this is not random. That is, any shipment of drug N will have size Ex_shipment_size[N]. If the shipment size exceeds the capacity (which you specify) of a method, multiple trips will be required. If the specified capacities are all sufficiently large, and so long as shipment sizes remain nonrandom, multiple trips will not be required. Real.
Method_name[M]	The name of drug smuggling method M. Such as "by air." Up to ten characters.
Cap_cost[M]	The cost incurred to the smuggler of an unsuccessful shipment using method M. Should not include the cost of the drug or the cost associated with the route (such as gasoline), which will be added in by the model. If method M is "by air," this might be the cost of the plane and crew. Real.
Capacity[M,N]	Maximum amount of drug N that may be shipped by method M. Real.
Last_day[P]	The last day on which phase P will be in effect. Integer.
Route_name[K]	The name of route K. Up to ten characters.
Route_cost[K]	The cost of using route K, incurred whether or not the shipment is successful. Real.
Route_method[K]	The index of the method that is used on route K. (If you have a real route that supports more than one method, set up two corresponding routes in the input, one per method.) Integer.
Blockaded[K,P]	One or true if route K is blockaded in phase P, zero or false if it is not. Integer.
Prob_interdict[K,P]	Probability that a shipment through route K during

phase P will be unsuccessful, assuming normal traffic levels. If traffic has been high, this probability will be increased as is discussed in Sec. IV.

Appendix B

THE FORTRAN CODE

The following code assumes the existence of an object module, RFORBN.OBJ, which will generate uniform random numbers on an IBM PC or compatible micro computer. The first author will supply the module for interested users.

```
      COMMON.FOR
C     DEFINE AND SET PARAMETERS:
      INTEGER*2       LONGPAST, RECENTPAST, MAXDAYS, MAXDRUGS,
     &                MAXMETHODS, MAXPHASES, MAXROUTES, MAXSHIPMENTS

      PARAMETER      (LONGPAST=120, RECENTPAST=20, MAXDRUGS=3,
     &                MAXDAYS=730,
     &                MAXMETHODS=3, MAXPHASES=12, MAXROUTES=20,
     &                MAXSHIPMENTS=10000)


C     REAL VARIABLES:
      REAL            AMOUNTATTEMPTED(MAXROUTES,MAXDRUGS),
     &                AMOUNTSUCCEEDED(MAXROUTES,MAXDRUGS),
     &                ATTEMPTS(MAXROUTES,MAXDRUGS),
     &                ATTEMPTSBYPHASE(MAXROUTES,MAXPHASES),
     &                CAPCOST(MAXMETHODS),
     &                CAPACITY(MAXMETHODS,MAXDRUGS),
     &                DAILYAMOUNT(MAXDRUGS),
     &                DRUGCOST(MAXDRUGS),EXPTABLE(0:LONGPAST),
     &                EXSHIPMENTINTRVL(MAXDRUGS),
     &                EXSHIPMENTSIZE(MAXDRUGS),
     &                FAILURECOSTS(MAXDRUGS),KMEMORY,MEMORYVALUE,
     &                NEXTEVENT,NEXTSHIPMENT(MAXDRUGS),
     &                PROBINTERDICT(MAXROUTES,MAXPHASES),
     &                RISKCOMP(MAXMETHODS),
     &                RISKCOMPEXP(MAXMETHODS),
     &                ROUTECOST(MAXROUTES),
     &                TIMESHIPPED(MAXSHIPMENTS),
     &                SUCCESSCOSTS(MAXDRUGS),
     &                SUCCESSES(MAXROUTES,MAXDRUGS),
     &                SUCCESSESBYPHASE(MAXROUTES,MAXPHASES)

C     LOGICAL VARIABLES:
      LOGICAL         BLOCKADED(MAXROUTES,MAXPHASES),GOODINPUT,
     &                SUCCESS(MAXSHIPMENTS)

C     INTEGER VARIABLES:
```

```
      INTEGER*2        CURRENTPHASE(0:MAXDAYS),DAYNOW,ENDTIME,NTRIAL,
     &                 NEXTEVENTTYPE,NUMDRUGS,NUMMETHODS,NUMPHASES,
     &                 NUMROUTES,NUMSHIPMENT,NUMTRIALS,
     &                 PASTSHIPMENTS(MAXROUTES,0:LONGPAST),
     &                 PASTFAILURES(MAXROUTES,0:LONGPAST),
     &                 ROUTEMETHOD(MAXROUTES),RUNIN,
     &                 ROUTEUSED(MAXSHIPMENTS),THISPHASE,
     &                 PEACESHIPMENTS(MAXROUTES,0:LONGPAST),
     &                 PEACEFAILURES(MAXROUTES,0:LONGPAST)

C       INTEGER VARIABLES:
        INTEGER          SEED1,SEED2

C       CHARACTER VARIABLES:
        CHARACTER*10     DRUGNAME(MAXDRUGS),METHODNAME(MAXMETHODS)

        CHARACTER*12     ROUTENAME(MAXROUTES)

        COMMON  AMOUNTATTEMPTED,AMOUNTSUCCEEDED,ATTEMPTS,
     &          ATTEMPTSBYPHASE,CAPCOST,CAPACITY,DRUGCOST,
     &          EXPTABLE,EXSHIPMENTINTRVL,EXSHIPMENTSIZE,KMEMORY,
     &          MEMORYVALUE,NEXTEVENT,NEXTSHIPMENT,PROBINTERDICT,
     &          ROUTECOST,TIMESHIPPED,SUCCESSES,
     &          SUCCESSESBYPHASE,BLOCKADED,GOODINPUT,SUCCESS,
     &          CURRENTPHASE,DAYNOW,ENDTIME,NTRIAL,NEXTEVENTTYPE,
     &          NUMDRUGS,NUMMETHODS,NUMPHASES,NUMROUTES,NUMSHIPMENT,
     &          NUMTRIALS,PASTSHIPMENTS,PASTFAILURES,ROUTEMETHOD,
     &          RUNIN,SEED1,SEED2,ROUTEUSED,THISPHASE,DRUGNAME,
     &          METHODNAME,ROUTENAME,PEACESHIPMENTS,PEACEFAILURES,
     &          RISKCOMP,SUCCESSCOSTS,FAILURECOSTS,RISKCOMPEXP,
     &          DAILYAMOUNT

      PROGRAM SOAR
C     SIMULATION OF ADAPATIVE RESPONSE--3/11/87

C*************************************************************************

C DATA STRUCTURES:

C       INCLUDE THE COMMON VARIABLES:
        IMPLICIT NONE
        INCLUDE 'COMMON.FOR'

C LOCAL INTEGER SCALARS:
        INTEGER M

C*************************************************************************

C       CALL THE SUBROUTINE TO INITIALIZE THE DATA COLLECTION ARRAYS.
        CALL INITIAL
```

```
C       CALL THE SUBROUTINE THAT READS IN THE DATA.
        CALL GETDATA

        WRITE(*,1234)
 1234   FORMAT(1X,'>>>>>>>>  THE INPUT DATA ARE OK.')
        IF (GOODINPUT) THEN
C           SET UP THE TABLE OF WEIGHTS FOR PAST SHIPMENTS.
            KMEMORY = ALOG(MEMORYVALUE)/(-LONGPAST)
            DO 10, M=0,LONGPAST
                EXPTABLE(M) = EXP(-KMEMORY*M)
   10       CONTINUE
            WRITE(*,1235)
 1235       FORMAT(1X,'>>>>>>>>  WEIGHTS FOR PAST SHIPMENT',
     &                 ' ARE COMPUTED.')

C           CALL THE SUBROUTINE THAT DOES THE RUN IN.
            CALL PEACE
            WRITE(*,1236)
 1236       FORMAT(1X,'>>>>>>>>  INITIAL RUN IN IS COMPLETE.')

C           DO EACH TRIAL.
            DO 20, NTRIAL=1,NUMTRIALS
                CALL SIMULATE
                WRITE(*,1237) NTRIAL
 1237           FORMAT(1X,'>>>>>>>>  SIMULATION RUN',I5,' IS COMPLETE.')
   20       CONTINUE

C           WRITE OUT THE RESULTS.
            CALL REPORT

        ENDIF
        STOP
        END


C*******************************************************************************
C*******************************************************************************
        SUBROUTINE COMPFACT(RNUMERATOR,RDENOMINATOR,R)
C       GET THE NUMERATOR AND DENOMINATOR OF THE "R" FACTOR, WHICH
C       WILL BE USED TO INCREASE THE PROBABILITY OF INTERDICTION
C       ON ROUTES WITH HIGHER THAN AVERAGE TRAVEL.

C*******************************************************************************

C DATA STRUCTURES:

C       INCLUDE THE COMMON VARIABLES:
        IMPLICIT NONE
        INCLUDE 'COMMON.FOR'

C       INTEGER SCALARS:
```

```
      INTEGER R,RNUMERATOR,RDENOMINATOR,S

C*************************************************************************************

      RNUMERATOR = 0
      RDENOMINATOR = 0
      DO 10, S=0,LONGPAST
          RDENOMINATOR = RDENOMINATOR + PASTSHIPMENTS(R,S)
10    CONTINUE
      DO 20, S=0,RECENTPAST
          RNUMERATOR = RNUMERATOR+PASTSHIPMENTS(R,S)
20    CONTINUE
      RETURN
      END


C*************************************************************************************
C*************************************************************************************
      SUBROUTINE GETDATA
C     READ IN THE INPUT DATA.

C*************************************************************************************

C DATA STRUCTURES:

C     INCLUDE THE COMMON VARIABLES:
      IMPLICIT NONE
      INCLUDE 'COMMON.FOR'

C     INTEGER SCALARS:
      INTEGER DAY1,DAY2,DAYN,D,M,N,R,TBLOCK,TEMP,TEMP2

C     LOGICAL SCALAR:
      LOGICAL TEMPIF

C*************************************************************************************

C     GOODINPUT WILL INDICATE WHETHER THE DATA WAS CLEAN AND THE
C     SIMULATION SHOULD BE RUN.
      GOODINPUT = .TRUE.

C     OPEN THE INPUT AND OUTPUT FILES AND SPECIFY THE UNIT NUMBERS
      OPEN(5, FILE='INPUT.DTA')
      OPEN(6, FILE='OUTPUT.DTA')


C     READ IN AND ECHO THE OVERALL DATA.
      READ (5,5001) NUMDRUGS,NUMMETHODS,NUMPHASES,NUMROUTES,
     &              NUMTRIALS,RUNIN,ENDTIME,MEMORYVALUE,SEED1,
     &              SEED2
5001  FORMAT (7I5,F10.5,2I5,F10.5)
```

```
      WRITE (6,6001)
      WRITE (*,6001)
 6001 FORMAT (' SMUGGLERS SIMULATION PARAMETERS AND INPUT DATA:')
      WRITE (6,6002)
      WRITE (*,6002)
 6002 FORMAT ()

C     CHECK WHETHER TOO MANY DRUG TYPES HAVE BEEN REQUESTED.
      TEMPIF = (NUMDRUGS .GT. MAXDRUGS)
      CALL WRTERROR(TEMPIF)

C     WRITE THE NUMBER OF DRUGS AND THE MAXIMUM ALLOWED.
      WRITE (6,6003) NUMDRUGS,MAXDRUGS
      WRITE (*,6003) NUMDRUGS,MAXDRUGS
 6003 FORMAT (8X,I3,' TYPES OF DRUGS, ',I2,' ALLOWED.')

C     CHECK WHETHER TOO MANY METHODS HAVE BEEN REQUESTED.
      TEMPIF = (NUMMETHODS .GT. MAXMETHODS)
      CALL WRTERROR(TEMPIF)

C     WRITE THE NUMBER OF METHODS AND THE MAXIMUM ALLOWED.
      WRITE (6,6004) NUMMETHODS,MAXMETHODS
      WRITE (*,6004) NUMMETHODS,MAXMETHODS
 6004 FORMAT (8X,I3,' SMUGGLING METHODS, ',I2,' ALLOWED.')

C     CHECK WHETHER TOO MANY PHASES HAVE BEEN REQUESTED.
      TEMPIF = (NUMPHASES .GT. MAXPHASES)
      CALL WRTERROR(TEMPIF)

C     WRITE THE NUMBER OF PHASES AND THE MAXIMUM ALLOWED.
      WRITE (6,6005) NUMPHASES,MAXPHASES
      WRITE (*,6005) NUMPHASES,MAXPHASES
 6005 FORMAT (8X,I3,' PHASES OF INTERDICTION, ',I2,' ALLOWED.')

C     CHECK WHETHER TOO MANY ROUTES HAVE BEEN REQUESTED.
      TEMPIF = (NUMROUTES .GT. MAXROUTES)
      CALL WRTERROR(TEMPIF)

C     WRITE THE NUMBER OF ROUTES AND THE MAXIMUM ALLOWED.
      WRITE (6,6006) NUMROUTES,MAXROUTES
      WRITE (*,6006) NUMROUTES,MAXROUTES
 6006 FORMAT (8X,I3,' ROUTES CONSIDERED, ',I2,' ALLOWED.')

C     WRITE THE NUMBER OF TRIALS REQUESTED.
      WRITE (6,6021) NUMTRIALS
      WRITE (*,6021) NUMTRIALS
 6021 FORMAT(7X,I4,' TRIALS REQUESTED.')
      WRITE (6,6002)
      WRITE (*,6002)

C     CHECK WHETHER TOO MANY DAYS HAVE BEEN REQUESTED.
```

```
        TEMPIF = (ENDTIME .GT. MAXDAYS)
        CALL WRTERROR(TEMPIF)

C       WRITE THE NUMBER OF RUNIN DAYS REQUESTED.
        WRITE (6,6008) RUNIN
        WRITE (*,6008) RUNIN
 6008   FORMAT (7X,I4,' DAYS OF INITIAL RUN IN (FOR INITIALIZATION).')

C       WRITE THE NUMBER OF DAYS AND THE MAXIMUM ALLOWED.
        WRITE (6,6007) ENDTIME,MAXDAYS
        WRITE (*,6007) ENDTIME,MAXDAYS
 6007   FORMAT (7X,I4,' DAYS TO BE ANALYZED, ',I4,' ALLOWED.')


C       WRITE OUT THE MEMORY VALUE (USED FOR DETERMINING WEIGHTS.)
        WRITE (6,6009) MEMORYVALUE
        WRITE (*,6009) MEMORYVALUE
 6009   FORMAT (8X,'MEMORY VALUE IS ',F7.3)

C       WRITE THE INITIAL RANDOM NUMBER SEEDS.
        WRITE (6,6010) SEED1,SEED2
        WRITE (*,6010) SEED1,SEED2
 6010   FORMAT (8X,'INITIAL SEEDS FOR RANDOM NUMBER GENERATOR ARE ',
     &          I5,' AND ',I5)
        WRITE (6,6002)
        WRITE (*,6002)

C       MAKE SURE THE FIRST SEED IS ODD.  (IN CASE WE RUN ON A SUN.)
        SEED1 = SEED1 / 2
        SEED1 = SEED1 * 2 + 1
C       CALL SETSD(SEED1,SEED2)

C       READ IN THE DRUG RELATED DATA RECORDS.
        TEMP = NUMDRUGS
        IF (TEMP .GT. MAXDRUGS) TEMP = MAXDRUGS
        DO 10, N=1,TEMP
            READ (5,5002) DRUGNAME(N),DRUGCOST(N),EXSHIPMENTINTRVL(N),
     &                    EXSHIPMENTSIZE(N),DAILYAMOUNT(N)
 5002       FORMAT (A10,4F10.5)
            WRITE (6,6011) DRUGNAME(N),DRUGCOST(N)
            WRITE (*,6011) DRUGNAME(N),DRUGCOST(N)
 6011       FORMAT (7X,' DRUG - ',A10,'    : EXPORT COST PER KG = ',
     &              17X,F10.2)
            WRITE (6,6012) EXSHIPMENTINTRVL(N)
            WRITE (*,6012) EXSHIPMENTINTRVL(N)
 6012       FORMAT (30X,'EXPECTED TIME BETWEEN SHIPMENTS = ',4X,F10.2)
            WRITE (6,6013) EXSHIPMENTSIZE(N)
            WRITE (*,6013) EXSHIPMENTSIZE(N)
 6013       FORMAT (30X,'SHIPMENT SIZE = ',22X,F10.2)
            WRITE (6,6024) DAILYAMOUNT(N)
            WRITE (*,6024) DAILYAMOUNT(N)
```

```
 6024       FORMAT (30X,'AVE. AMOUNT TO BE DELIVERED PER DAY = ',
     &             F10.2)
   10    CONTINUE
         WRITE (6,6002)
         WRITE (*,6002)
         IF (NUMDRUGS .GT. TEMP) THEN
             DO 20, N=TEMP+1,NUMDRUGS
                 READ (5,5002)
   20        CONTINUE
         ENDIF

C        READ IN THE METHOD RELATED RECORDS.
         TEMP = NUMMETHODS
         IF (TEMP .GT. MAXMETHODS) TEMP = MAXMETHODS
         TEMP2 = NUMDRUGS
         IF (TEMP2 .GT. MAXDRUGS) TEMP2 = MAXDRUGS
         DO 40, M=1,TEMP
             READ (5,5003) METHODNAME(M),
     &                     RISKCOMP(M),RISKCOMPEXP(M),CAPCOST(M),
     &                     (CAPACITY(M,D),D=1,TEMP2)
 5003        FORMAT(A10,100F10.5)
             WRITE (6,6014) METHODNAME(M),RISKCOMP(M)
             WRITE (*,6014) METHODNAME(M),RISKCOMP(M)
 6014        FORMAT(8X,'METHOD - ',A10,' : RISK COMPENSATION = ',
     &              18X,F10.2)
             WRITE (6,6023) RISKCOMPEXP(M)
             WRITE (*,6023) RISKCOMPEXP(M)
 6023        FORMAT(30X,'RISK COMPENSATION EXPONENT= ',10X,F10.2)
             WRITE (6,6022) CAPCOST(M)
             WRITE (*,6022) CAPCOST(M)
 6022        FORMAT(30X,'COST (IF INTERDICTED) = ',14X,F10.2)

             DO 30, D=1,TEMP2
                 WRITE (6,6015) DRUGNAME(D),CAPACITY(M,D)
                 WRITE (*,6015) DRUGNAME(D),CAPACITY(M,D)
 6015            FORMAT (30X,A10,' - MAXIMUM SHIPMENT SIZE =  ',F10.2)
                 WRITE (6,6002)
                 WRITE (*,6002)
   30        CONTINUE
   40    CONTINUE
         IF (NUMMETHODS .GT. TEMP) THEN
             DO 50, M=TEMP+1,NUMMETHODS
                 READ (5,5003)
   50        CONTINUE
         ENDIF

C        READ IN THE DAYS WHEN EACH PHASE ENDS.  SET UP THE VECTOR
C        INDICATING WHICH PHASE IS IN EFFECT FOR EACH DAY.
         DAY1 = 0
         TEMP = NUMPHASES
         IF (TEMP .GT. MAXPHASES) TEMP = MAXPHASES
```

```
      DO 70, N=1,TEMP
          READ (5,5004) DAY2
 5004     FORMAT (I5)
          TEMP2 = DAY2
          IF (TEMP2 .GT. MAXDAYS) TEMP2 = MAXDAYS
          IF (TEMP2 .GE. DAY1) THEN
              WRITE (6,6016) N,TEMP2
              WRITE (*,6016) N,TEMP2
 6016         FORMAT (8X,'PHASE ',I2,' LASTS THROUGH DAY ',I4)
              DO 60, DAYN=DAY1,TEMP2
                  CURRENTPHASE(DAYN) = N
   60         CONTINUE
              DAY1 = TEMP2 + 1
          ENDIF
   70 CONTINUE
      WRITE (6,6002)
      WRITE (*,6002)

C     READ IN THE ROUTE RELATED DATA.
      TEMP = NUMROUTES
      IF (TEMP .GT. MAXROUTES) TEMP = MAXROUTES
      TEMP2 = NUMPHASES
      IF (TEMP2 .GT. MAXPHASES) TEMP2 = MAXPHASES
      DO 100, R=1,TEMP
          READ (5,5005) ROUTENAME(R),ROUTECOST(R),ROUTEMETHOD(R)
 5005     FORMAT (A10,F10.5,I5)
          WRITE (6,6017) ROUTENAME(R),ROUTECOST(R)
          WRITE (*,6017) ROUTENAME(R),ROUTECOST(R)
 6017     FORMAT (8X,'ROUTE - ',A12,': COST TO SHIP =',24X,F10.2)
          WRITE (6,6018) METHODNAME(ROUTEMETHOD(R))
          WRITE (*,6018) METHODNAME(ROUTEMETHOD(R))
 6018     FORMAT (30X,'METHOD = ',A10)

C         READ IN THE PHASE RELATED DATA FOR THIS ROUTE.
          DO 80, N=1,TEMP2
              READ (5,5006) TBLOCK,PROBINTERDICT(R,N)
 5006         FORMAT (I5,F10.5)
              BLOCKADED(R,N) = (TBLOCK .EQ. 1)
              IF (BLOCKADED(R,N)) THEN
                  WRITE (6,6019) N
                  WRITE (*,6019) N
 6019             FORMAT (30X,'PHASE ',I2,' - BLOCKADED')
              ELSE
                  WRITE (6,6020) N,PROBINTERDICT(R,N)
                  WRITE (*,6020) N,PROBINTERDICT(R,N)
 6020             FORMAT (30X,'PHASE ',I2,' INTERDICTION ',
     &                        'PROBABILITY = ',2X,F10.5)
              ENDIF
   80     CONTINUE
          IF (NUMPHASES .GT. TEMP2) THEN
              DO 90, N=TEMP2+1,NUMPHASES
```

```
                READ (5,5005)
 90           CONTINUE
          ENDIF
          WRITE (6,6002)
          WRITE (*,6002)
100     CONTINUE
        RETURN
        END

C*******************************************************************************
C*******************************************************************************
        SUBROUTINE INITIAL
C       INITIALIZE THE ARRAYS THAT WILL BE USED WHEN WRITING THE
C       FINAL REPORT.

C*******************************************************************************

C DATA STRUCTURES:

C       INCLUDE THE COMMON VARIABLES:
        IMPLICIT NONE
        INCLUDE 'COMMON.FOR'

C       INTEGER SCALARS:
        INTEGER D,R

C*******************************************************************************

        DO 30, R=1,MAXROUTES
            DO 10, D=1, MAXDRUGS
                AMOUNTATTEMPTED(R,D) = 0.
                AMOUNTSUCCEEDED(R,D) = 0.
                ATTEMPTS(R,D) = 0.
                SUCCESSES(R,D) = 0.
 10         CONTINUE
            DO 20, THISPHASE = 1,MAXPHASES
                ATTEMPTSBYPHASE(R,THISPHASE) = 0.
                SUCCESSESBYPHASE(R,THISPHASE) = 0.
 20         CONTINUE
 30     CONTINUE

        DO 40 D=1,MAXDRUGS
            SUCCESSCOSTS(D)=0.0
            FAILURECOSTS(D)=0.0
 40     CONTINUE

        RETURN
        END
```

```
C*************************************************************************************
C*************************************************************************************
      SUBROUTINE INITSIM
C     INITIALIZE FOR THE CURRENT SAMPLE POINT.

C*************************************************************************************

C DATA STRUCTURES:

C     INCLUDE THE COMMON VARIABLES:
      IMPLICIT NONE
      INCLUDE 'COMMON.FOR'

C     INTEGER SCALARS:
      INTEGER D,R

C     REAL SCALARS:
      REAL RANDNM

C*************************************************************************************

C     SET THE SHIPMENT COUNTER TO ZERO.
      NUMSHIPMENT = 0

C     DETERMINE WHAT AND WHEN THE NEXT SHIPMENT WILL OCCUR.
      NEXTEVENT = ENDTIME + 1.0
      NEXTEVENTTYPE = 0
      DO 10, D=1,NUMDRUGS
          CALL RANDEX(RANDNM,EXSHIPMENTINTRVL(D),SEED1)
          NEXTSHIPMENT(D) = RANDNM
          IF (NEXTSHIPMENT(D) .LT. NEXTEVENT) THEN
              NEXTEVENT = NEXTSHIPMENT(D)
              NEXTEVENTTYPE = D
          ENDIF
   10 CONTINUE

C     GET THE PAST FROM THE LONG RUN IN.
      DO 30, D=0,LONGPAST
          DO 20, R=1,NUMROUTES
              PASTSHIPMENTS(R,D) = PEACESHIPMENTS(R,D)
              PASTFAILURES(R,D) = PEACEFAILURES(R,D)
   20     CONTINUE
   30 CONTINUE
      RETURN
      END


C*************************************************************************************
C*************************************************************************************
      SUBROUTINE PEACE
C     DO THE INITIAL RUN IN.
```

```
C*************************************************************************************

C DATA STRUCTURES:

C       INCLUDE THE COMMON VARIABLES:
        IMPLICIT NONE
        INCLUDE 'COMMON.FOR'

C       REAL SCALARS:
        REAL AMOUNT,PROBCAUGHT,RFACTOR,TEMPTIME,RANDNM,ACTUALRISKCOMP

C       INTEGER SCALARS:
        INTEGER D,R,RDENOMINATOR,RNUMERATOR,T,TRIPS

C       LOGICAL SCALAR:
        LOGICAL TRIPSUCCESS


C*************************************************************************************

C       DETERMINE THE TIME AND TYPE OF THE FIRST SHIPMENT.
        NEXTEVENT = RUNIN + 1.0
        NEXTEVENTTYPE = 0
        DO 210, D=1,NUMDRUGS
            CALL RANDEX(RANDNM,EXSHIPMENTINTRVL(D),SEED1)
            NEXTSHIPMENT(D) = RANDNM
            IF (NEXTSHIPMENT(D) .LT. NEXTEVENT) THEN
                NEXTEVENT = NEXTSHIPMENT(D)
                NEXTEVENTTYPE = D
            ENDIF
  210   CONTINUE

C       INITIALIZE THE ARRAYS DESCRIBING THE PAST.
        DO 230, D=0,LONGPAST
            DO 220, R=1,NUMROUTES
                PASTSHIPMENTS(R,D) = 0
                PASTFAILURES(R,D) = 0
  220       CONTINUE
  230   CONTINUE

C       FOR EACH DAY OF RUNIN...
        DO 100, DAYNOW=1,RUNIN
            THISPHASE = 1

C           SHIFT THE ARRAYS DESCRIBING THE PAST.
            DO 20, R=1,NUMROUTES
                DO 10, D=LONGPAST,1,-1
                    PASTSHIPMENTS(R,D) = PASTSHIPMENTS(R,D-1)
                    PASTFAILURES(R,D) = PASTFAILURES(R,D-1)
   10           CONTINUE
                PASTSHIPMENTS(R,0) = 0
```

```
                PASTFAILURES(R,0) = 0
   20         CONTINUE

C             LOOP THROUGH THE DAYS SHIPMENTS.
   30         IF (NEXTEVENT .GE. DAYNOW + 1.0) GO TO 100

C                 GET THE TYPE AND AMOUNT OF THE NEXT SHIPMENT.
                  D = NEXTEVENTTYPE
                  AMOUNT = EXSHIPMENTSIZE(D)

C                 SELECT THE ROUTE TO BE USED.
                  CALL SELROUTE(R,TRIPS,D,AMOUNT,ACTUALRISKCOMP)

C                 COMPUTE THE NUMERATOR AND DENOMINATOR OF THE
C                 "R" FACTOR.
                  CALL COMPFACT(RNUMERATOR,RDENOMINATOR,R)

C                 FOR EACH TRIP REQUIRED TO GET AMOUNT SHIPPED...
                  DO 70, T=1,TRIPS

C                     COMPUTE THE "R" FACTOR.
                      RFACTOR = 1.0
                      IF (RDENOMINATOR .GT. 0.0) THEN
                          RFACTOR = RNUMERATOR/RDENOMINATOR
                          TEMPTIME = NEXTEVENT
                          IF (TEMPTIME .GT. RECENTPAST) THEN
                              IF (TEMPTIME .GT. LONGPAST)
     &                            TEMPTIME = LONGPAST
                              RFACTOR = RFACTOR * TEMPTIME/RECENTPAST
                          ENDIF
                      ENDIF
                      IF (RFACTOR .LT. 1.0) RFACTOR = 1.0

C                     COMPUTE THE PROBABILITY OF INTERDICTION.
                     IF (PROBINTERDICT(R,THISPHASE).GE..9999) THEN
                         PROBCAUGHT = 1.0
                     ELSE
                          PROBCAUGHT = 1.0 - EXP(RFACTOR*ALOG(1.0 -
     &                                 PROBINTERDICT(R,THISPHASE)))
                     ENDIF

C                     DETERMINE WHETHER THE TRIP WAS SUCCESSFUL.
                      CALL RANDU(RANDNM,SEED1)
                      TRIPSUCCESS = (RANDNM .GE. PROBCAUGHT)

C                     DO THE BOOKKEEPING.  (NOT VERY EXTENSIVE
C                     DURING THE RUN IN.)
                      PASTSHIPMENTS(R,0) = PASTSHIPMENTS(R,0) + 1
                      IF (.NOT. TRIPSUCCESS)
     &                    PASTFAILURES(R,0) = PASTFAILURES(R,0) + 1
                      RNUMERATOR = RNUMERATOR + 1
```

```
                    RDENOMINATOR = RDENOMINATOR + 1
   70             CONTINUE

C                  GET THE TIME AND TYPE OF THE NEXT SHIPMENT.
                   CALL RANDEX(RANDNM,EXSHIPMENTINTRVL(D),SEED1)
                   NEXTSHIPMENT(D) = NEXTEVENT + RANDNM
                   NEXTEVENTTYPE = 0
                   NEXTEVENT = RUNIN + 1.0
                   DO 80, D=1,NUMDRUGS
                       IF (NEXTSHIPMENT(D) .LT. NEXTEVENT) THEN
                           NEXTEVENT = NEXTSHIPMENT(D)
                           NEXTEVENTTYPE = D
                       ENDIF
   80              CONTINUE
               GO TO 30
  100      CONTINUE

C          SAVE THE LAST LONGPAST DAYS FOR USE INITIALIZING EACH TRIAL.
           DO 130, D=0,LONGPAST
               DO 120, R=1,NUMROUTES
                   PEACESHIPMENTS(R,D)=PASTSHIPMENTS(R,D)
                   PEACEFAILURES(R,D)=PASTFAILURES(R,D)
  120          CONTINUE
  130      CONTINUE
           RETURN
           END


C*******************************************************************************
C*******************************************************************************
           SUBROUTINE RANDEX(SINTER,INTERA,SDNOW)
C          THIS SUBROUTINE RETURNS SINTER, AN EXPONENTIALLY DISTRIBUTED
C          RANDOM VARIABLE WITH MEAN INTERA.  SDNOW IS THE CURRENT SEED
C          FOR THE RANDOM NUMBER GENERATOR.

C*******************************************************************************

C DATA STRUCTURES:
           IMPLICIT NONE

C LOCAL INTEGER SCALARS:
           INTEGER SDNOW

C LOCAL REAL SCALARS:
           REAL INTERA,RTEMP,SINTER
C
C*******************************************************************************
C
           CALL RANDU(RTEMP,SDNOW)
           IF (RTEMP.LT..00001) RTEMP=.00001
           SINTER=-INTERA*ALOG(RTEMP)
```

```
      RETURN
      END

C*************************************************************************************
C*************************************************************************************
      SUBROUTINE RANDU(RANDNM,SDNOW)
C     THIS SUBROUTINE RETURNS AN UNIFORMALLY DISTRIBUTED
C     RANDOM VARIABLE (BETWEEN 0 AND 1).  CALLS RFORBN, THE ASSEMBLY
C     LANGUAGE IMPLEMENTATION OF L.W. MILLER'S PRIME MODULUS RANDOM
C     NUMBER GENERATOR.
C
C*************************************************************************************
C
C DATA STRUCTURES:
C
C LOCAL INTEGER SCALARS:
      INTEGER*4 RANDOMSTUFF(10), SDNOW
C
C LOCAL REAL SCALARS:
      REAL*8 REALSEED, TEMPRAND
      REAL   RANDNM

C FANCY STUFF:
      EQUIVALENCE (RANDOMSTUFF(9), REALSEED)
C     IF F77L -
          MS EXTERNAL RFORBN
C     IF RMFORT -
C         EXTERNAL RFORBN

C
C*************************************************************************************
C
C     SET RANDOMSTUFF(1) TO THE MULTIPLIER.  SET TO 630360016 FOR
C     SIMSCRIPT, 16807 FOR IMSL.
      RANDOMSTUFF(1) = 16807

C     SET THE SEED.
      RANDOMSTUFF(2) = SDNOW

C     SET THE MODULUS.
      RANDOMSTUFF(6) = 2147483647

C     CALL THE ASSEMBLY LANGUAGE MODULE.
C     IF F77L -
          CALL RFORBN(RANDOMSTUFF)
C     IF RMFORT -
C         CALL CALLMS(RFORBN,1,RANDOMSTUFF)

C     UPDATE THE SEED.
      SDNOW = RANDOMSTUFF(8)
```

```
C       GET THE REAL*8 RANDOM NUMBER.
        TEMPRAND = REALSEED / 2147483647.0

C       GET THE RANDOM NUMBER.
        IF (TEMPRAND .LT. 10E-30) THEN
            RANDNM = 0.0
        ELSE
            RANDNM = TEMPRAND
        ENDIF

        RETURN
        END

C*******************************************************************************
C*******************************************************************************
          SUBROUTINE REPORT
C         WRITE THE SUMMARY REPORTS.

C*******************************************************************************

C DATA STRUCTURES:

C         INCLUDE THE COMMON VARIABLES:
          IMPLICIT NONE
          INCLUDE 'COMMON.FOR'

C         REAL SCALARS:
          REAL    SUCCESSRATE,REALTEMP1,
     &            REALTEMP2,REALTEMP3,TOTATTEMPTED(MAXDRUGS),
     &            TOTCOSTS,TOTSHIPPED(MAXDRUGS),TOTATTEMPTS,TOTSUCCESSES,
     &            TEMPDVECT(MAXDRUGS),TEMPPVECT(MAXPHASES),
     &            TOTSUCCESSCOST,TOTFAILURECOST,SCALEFACTOR(MAXDRUGS),
     &            OLDATTEMPTS(MAXROUTES),OLDSUCCESSES(MAXROUTES),
     &            ATTEMPTSCALE,SUCCESSSCALE

C         INTEGER SCALARS:
          INTEGER D,N,R

C         CHARACTER SCALARS:
          CHARACTER*1 BLANK

C*******************************************************************************

C         BLANK WILL BE USED FOR FORMATTING PURPOSES.
          BLANK = ' '

C         INITIALIZE THE TOTALS.
          DO 10, D=1,NUMDRUGS
              TOTATTEMPTED(D)=0.
              TOTSHIPPED(D)=0.
```

```
   10   CONTINUE
        TOTATTEMPTS=0.
        TOTSUCCESSES=0.
        TOTSUCCESSCOST=0.
        TOTFAILURECOST=0.

C       COMPUTE THE TOTAL NUMBER OF ATTEMPTS, SUCCESSES, COSTS, ETC.
        DO 30, R=1,NUMROUTES
            DO 20, D=1,NUMDRUGS
                TOTATTEMPTS = TOTATTEMPTS + ATTEMPTS(R,D)
                TOTSUCCESSES = TOTSUCCESSES + SUCCESSES(R,D)
                TOTATTEMPTED(D) = TOTATTEMPTED(D) +
     &                           AMOUNTATTEMPTED(R,D)
                TOTSHIPPED(D) = TOTSHIPPED(D) + AMOUNTSUCCEEDED(R,D)
                SUCCESSCOSTS(D) = SUCCESSCOSTS(D) +
     &                           AMOUNTSUCCEEDED(R,D) * DRUGCOST(D)
                FAILURECOSTS(D) = FAILURECOSTS(D) +
     &                           (AMOUNTATTEMPTED(R,D)-
     &                                  AMOUNTSUCCEEDED(R,D)) *
     &                           DRUGCOST(D)
   20       CONTINUE
   30   CONTINUE
        DO 35 D=1,NUMDRUGS
            TOTSUCCESSCOST=TOTSUCCESSCOST+SUCCESSCOSTS(D)
            TOTFAILURECOST=TOTFAILURECOST+FAILURECOSTS(D)
   35   CONTINUE

C       COMPUTE THE SUCCESS RATE.
        IF (TOTATTEMPTS .GT. 0) THEN
            SUCCESSRATE = TOTSUCCESSES/TOTATTEMPTS
        ELSE
            SUCCESSRATE = 0.0
        ENDIF

C       GET THE AVERAGE NUMBER OF ATTEMPTS, SUCCESSES, COSTS, ETC.
C       PER TRIAL.
        TOTATTEMPTS = TOTATTEMPTS/NUMTRIALS
        TOTSUCCESSES = TOTSUCCESSES/NUMTRIALS
        TOTSUCCESSCOST = TOTSUCCESSCOST/NUMTRIALS
        TOTFAILURECOST = TOTFAILURECOST/NUMTRIALS
        TOTCOSTS = TOTSUCCESSCOST + TOTFAILURECOST

C       WRITE OUT THE REPORT HEADING.
        WRITE (6,6002)
 6002   FORMAT (' --------------------')
        WRITE (6,6001)
 6001   FORMAT ()
        WRITE (6,6003)
 6003   FORMAT (' SUMMARY REPORT -- UNSCALED RESULTS')
        WRITE (6,6001)
```

```
C       WRITE THE EXPECTED NUMBER OF ATTEMPTS PER TRIAL.
        WRITE (6,6004) TOTATTEMPTS
 6004   FORMAT (' AVE(ATTEMPTS PER TRIAL)     =',F10.2)

C       WRITE THE EXPECTED NUMBER OF SUCCESSES PER TRIAL.
        WRITE (6,6005) TOTSUCCESSES
 6005   FORMAT (' AVE(SUCCESSES PER TRIAL)    =',F10.2)

C       WRITE THE EXPECTED NUMBER OF FAILURES (INTERDICTIONS) PER TRIAL.
        REALTEMP1=TOTATTEMPTS-TOTSUCCESSES
        WRITE (6,6006) REALTEMP1
 6006   FORMAT (' AVE(INTERDICTIONS PER TRIAL)=',F10.2)

C       WRITE THE SUCCESS RATE.
        WRITE (6,6007) SUCCESSRATE
 6007   FORMAT(' SUCCESS RATE',16X,'=',F10.2)

C       WRITE THE FAILURE RATE.
        REALTEMP1=1.0-SUCCESSRATE
        WRITE (6,6008) REALTEMP1
 6008   FORMAT (' INTERDICTION RATE',11X,'=',F10.2)
        WRITE (6,6001)

C       WRITE THE COSTS OF INCOMPLETE SHIPMENTS.
        REALTEMP1=TOTFAILURECOST/1000.
        WRITE (6,6009) REALTEMP1
 6009   FORMAT(' COST OF INCOMPLETE SHIPMENTS (IN THOUSANDS)  =',F10.2)

C       WRITE THE COSTS OF COMPLETED SHIPMENTS.
        REALTEMP1=TOTSUCCESSCOST/1000.
        WRITE (6,6010) REALTEMP1
 6010   FORMAT(' COST OF COMPLETED SHIPMENTS (IN THOUSANDS)   =',F10.2)

C       WRITE OUT THE TOTAL COSTS.
        REALTEMP1=TOTCOSTS/1000.
        WRITE (6,6011) REALTEMP1
 6011   FORMAT(' TOTAL COST TO SMUGGLERS (IN THOUSANDS)       =',F10.2)
        WRITE (6,6001)

C       WRITE THE HEADINGS FOR THE TABLE BROKEN OUT BY DRUG TYPE.
        WRITE (6,6012) (DRUGNAME(D),D=1,NUMDRUGS)
 6012   FORMAT (29X,100(1X,A10))

C       FOR EACH DRUG, GET THE AVERAGE NUMBER OF ATTEMPTS, SUCCESSES,
C       ETC. PER TRIAL.
        DO 40, D=1,NUMDRUGS
            TOTATTEMPTED(D) = TOTATTEMPTED(D)/NUMTRIALS
            TOTSHIPPED(D) = TOTSHIPPED(D)/NUMTRIALS
            TEMPDVECT(D)=TOTATTEMPTED(D)-TOTSHIPPED(D)
   40   CONTINUE
```

```
C       FOR EACH DRUG, WRITE OUT THE AVERAGE QUANTITY ATTEMPTED
C       PER TRIAL.
        WRITE (6,6013) (TOTATTEMPTED(D),D=1,NUMDRUGS)
 6013   FORMAT (1X,'QUANTITY ATTEMPTED',9X,'=',100F11.2)

C       FOR EACH DRUG, WRITE OUT THE AVERAGE QUANTITY SUCCESSFULLY
C       SHIPPED PER TRIAL.
        WRITE (6,6014) (TOTSHIPPED(D),D=1,NUMDRUGS)
 6014   FORMAT (1X,'QUANTITY ARRIVED',11X,'=',100F11.2)

C       FOR EACH DRUG, WRITE OUT THE AVERAGE QUANTITY INTERDICTED
C       PER TRIAL.
        WRITE (6,6015) (TEMPDVECT(D),D=1,NUMDRUGS)
 6015   FORMAT (1X,'QUANTITY INTERDICTED',7X,'=',100F11.2)

        DO 45, D=1,NUMDRUGS
            SUCCESSCOSTS(D) = SUCCESSCOSTS(D)/(NUMTRIALS * 1000.)
            FAILURECOSTS(D) = FAILURECOSTS(D)/(NUMTRIALS * 1000.)
            TEMPDVECT(D)=SUCCESSCOSTS(D) + FAILURECOSTS(D)
   45   CONTINUE

C       FOR EACH DRUG, WRITE OUT THE AVERAGE COST FOR SUCCESSFUL
C       SHIPMENTS.
        WRITE (6,6033) (SUCCESSCOSTS(D),D=1,NUMDRUGS)
 6033   FORMAT (1X,'COST OF COMPLETE SHIPMENTS',/,
     &          1X,'    (IN THOUSANDS)',9X,'=',100F11.2)

C       FOR EACH DRUG, WRITE OUT THE AVERAGE COST FOR INCOMPLETE
C       SHIPMENTS.
        WRITE (6,6034) (FAILURECOSTS(D),D=1,NUMDRUGS)
 6034   FORMAT (1X,'COST OF INCOMPLETE SHIPMENTS',/,
     &          1X,'    (IN THOUSANDS)',9X,'=',100F11.2)

C       FOR EACH DRUG, WRITE OUT THE TOTAL SHIPMENT COSTS.
        WRITE (6,6035) (TEMPDVECT(D),D=1,NUMDRUGS)
 6035   FORMAT (1X,'TOTAL SHIPMENT COSTS',/,
     &          1X,'    (IN THOUSANDS)',9X,'=',100F11.2)

C       WRITE THE ROUTE BY ROUTE REPORTS.
        DO 130, R=1,NUMROUTES

C           WRITE OUT THE HEADING FOR THIS ROUTE.
            WRITE (6,6001)
            WRITE (6,6016)
 6016       FORMAT (' --------------------')
            WRITE (6,6001)
            WRITE (6,6017) R,ROUTENAME(R)
 6017       FORMAT (' REPORT FOR ROUTE ',I2,' - ',A10,
     &              ', UNSCALED RESULTS')
            WRITE (6,6001)
```

```
C           COMPUTE THE EXPECTED ATTEMPTS, SUCCESSES, ETC. FOR THIS
C           ROUTE.
            REALTEMP1=0.0
            REALTEMP2=0.0
            DO 55 D=1,NUMDRUGS
                REALTEMP1 = REALTEMP1 + ATTEMPTS(R,D)
                REALTEMP2 = REALTEMP2 + SUCCESSES(R,D)
   55       CONTINUE
            REALTEMP1=REALTEMP1/NUMTRIALS
            REALTEMP2=REALTEMP2/NUMTRIALS

            IF (REALTEMP1 .GT. 0) THEN
                SUCCESSRATE = REALTEMP2/REALTEMP1
            ELSE
                SUCCESSRATE = 0.0
            ENDIF

C           WRITE THE EXPECTED NUMBER OF ATTEMPTS PER TRIAL FOR THIS
C           ROUTE.
            OLDATTEMPTS(R)=REALTEMP1
            WRITE (6,6018) REALTEMP1
 6018       FORMAT (' AVE(ATTEMPTS PER TRIAL)     =',F10.2)

C           WRITE THE EXPECTED NUMBER OF SUCCESSES PER TRIAL FOR
C           THIS ROUTE.
            OLDSUCCESSES(R)=REALTEMP2
            WRITE (6,6019) REALTEMP2
 6019       FORMAT (' AVE(SUCCESSES PER TRIAL)    =',F10.2)

C           WRITE THE EXPECTED NUMBER OF INTERDICTIONS PER TRIAL
C           FOR THIS ROUTE.
            REALTEMP3=REALTEMP1-REALTEMP2
            WRITE (6,6020) REALTEMP3
 6020       FORMAT (' AVE(INTERDICTIONS PER TRIAL)=',F10.2)

C           WRITE THE SUCCESS RATE FOR THIS ROUTE.
            WRITE (6,6021) SUCCESSRATE
 6021       FORMAT (' SUCCESS RATE',16X,'=',F10.2)

C           WRITE THE INTERDICTION RATE FOR THIS ROUTE.
            REALTEMP3=1.-SUCCESSRATE
            WRITE (6,6022) REALTEMP3
 6022       FORMAT (' INTERDICTION RATE           =',F10.2)

C           WRITE THE HEADINGS FOR THE TABLE BROKEN OUT BY PHASE.
            WRITE (6,6001)
            WRITE (6,6023) (BLANK,N,N=1,NUMPHASES)
 6023       FORMAT (19X,100(A1,' PHASE',I2))

C           COMPUTE AND WRITE THE EXPECTED ATTEMPTS PER PHASE ON
C           THIS ROUTE.
```

```
            DO 50, N=1,NUMPHASES
               TEMPPVECT(N)=ATTEMPTSBYPHASE(R,N)/NUMTRIALS
   50       CONTINUE
            WRITE (6,6024) (TEMPPVECT(N),N=1,NUMPHASES)
 6024       FORMAT (1X,'ATTEMPTS',9X,'=',100F9.1)

C           COMPUTE AND WRITE THE EXPECTED SUCCESSES PER PHASE ON
C           THIS ROUTE.
            DO 60, N=1,NUMPHASES
               TEMPPVECT(N)=SUCCESSESBYPHASE(R,N)/NUMTRIALS
   60       CONTINUE
            WRITE (6,6025) (TEMPPVECT(N),N=1,NUMPHASES)
 6025       FORMAT (1X,'SUCCESSES',8X,'=',100F9.1)

C           COMPUTE AND WRITE THE EXPECTED INTERDICTIONS PER PHASE
C           ON THIS ROUTE.
            DO 70, N=1,NUMPHASES
               TEMPPVECT(N)=(ATTEMPTSBYPHASE(R,N) -
     &                     SUCCESSESBYPHASE(R,N))/
     &                     NUMTRIALS
   70       CONTINUE
            WRITE (6,6026) (TEMPPVECT(N),N=1,NUMPHASES)
 6026       FORMAT (1X,'INTERDICTIONS',4X,'=',100F9.1)

C           COMPUTE AND WRITE THE SUCCESS RATE FOR EACH PHASE ON
C           THIS ROUTE.
            DO 80, N=1,NUMPHASES
               IF (ATTEMPTSBYPHASE(R,N) .GT. 0) THEN
                  TEMPPVECT(N) = SUCCESSESBYPHASE(R,N)/
     &                           ATTEMPTSBYPHASE(R,N)
               ELSE
                  TEMPPVECT(N)=0.
               ENDIF
   80       CONTINUE
            WRITE (6,6027) (TEMPPVECT(N),N=1,NUMPHASES)
 6027       FORMAT (' SUCCESS RATE     =',100F9.2)

C           COMPUTE AND WRITE THE EXPECTED FAILURE RATE PER PHASE
C           ON THIS ROUTE.
            DO 90, N=1,NUMPHASES
               IF (ATTEMPTSBYPHASE(R,N) .GT. 0) THEN
                  TEMPPVECT(N) = 1. - SUCCESSESBYPHASE(R,N)/
     &                           ATTEMPTSBYPHASE(R,N)
               ELSE
                  TEMPPVECT(N)=0.
               ENDIF
   90       CONTINUE
            WRITE (6,6028) (TEMPPVECT(N),N=1,NUMPHASES)
 6028       FORMAT (' INTERDICTION RATE=',100F9.2)

C           WRITE THE HEADINGS FOR THE TABLE BROKEN OUT BY DRUG TYPE.
```

```
            WRITE (6,6001)
            WRITE (6,6029) (DRUGNAME(D),D=1,NUMDRUGS)
 6029       FORMAT (25X,100(1X,A10))

C           COMPUTE AND WRITE THE EXPECTED AMOUNT OF EACH DRUG THAT
C           WAS ATTEMPTED ON THIS ROUTE.
            DO 100, D=1,NUMDRUGS
                TEMPDVECT(D)=AMOUNTATTEMPTED(R,D)/NUMTRIALS
  100       CONTINUE
            WRITE (6,6030) (TEMPDVECT(D),D=1,NUMDRUGS)
 6030       FORMAT (1X,'QUANTITY ATTEMPTED',5X,'=',100F11.2)

C           COMPUTE AND WRITE THE EXPECTED AMOUNT OF EACH DRUG THAT
C           WAS SUCCESSFULLY SHIPPED ON THIS ROUTE.
            DO 110, D=1,NUMDRUGS
                TEMPDVECT(D)=AMOUNTSUCCEEDED(R,D)/NUMTRIALS
  110       CONTINUE
            WRITE (6,6031) (TEMPDVECT(D),D=1,NUMDRUGS)
 6031       FORMAT (1X,'QUANTITY ARRIVED',7X,'=',100F11.2)

C           COMPUTE AND WRITE THE EXPECTED AMOUNT OF EACH DRUG THAT
C           WAS INTERDICTED ON THIS ROUTE.
            DO 120, D=1,NUMDRUGS
                TEMPDVECT(D)=(AMOUNTATTEMPTED(R,D) -
     &                        AMOUNTSUCCEEDED(R,D))/
     &                        NUMTRIALS
  120       CONTINUE
            WRITE (6,6032) (TEMPDVECT(D),D=1,NUMDRUGS)
 6032       FORMAT (1X,'QUANTITY INTERDICTED',3X,'=',100F11.2)
            WRITE (6,6001)
  130   CONTINUE

C*******************************************************************************
C       NOW DO THE SCALED REPORT.

C       WRITE OUT THE REPORT HEADING.
        WRITE (6,6001)
        WRITE (6,6002)
        WRITE (6,6001)
        WRITE (6,6036)
 6036   FORMAT (' SUMMARY REPORT -- SCALED RESULTS')
        WRITE (6,6001)

        TOTATTEMPTS=0.0
        TOTSUCCESSES=0.0
        DO 140 D=1,NUMDRUGS
            SCALEFACTOR(D)=1.0
            IF (TOTSHIPPED(D) .GT. 0.0)
     &          SCALEFACTOR(D)=DAILYAMOUNT(D)*ENDTIME/TOTSHIPPED(D)
            DO 150 R=1,NUMROUTES
                ATTEMPTS(R,D)=ATTEMPTS(R,D)*SCALEFACTOR(D)/NUMTRIALS
```

```
                SUCCESSES(R,D)=SUCCESSES(R,D)*SCALEFACTOR(D)/NUMTRIALS
                TOTATTEMPTS=TOTATTEMPTS+ATTEMPTS(R,D)
                TOTSUCCESSES=TOTSUCCESSES+SUCCESSES(R,D)
  150       CONTINUE
  140   CONTINUE
        SUCCESSRATE = 0.0
        IF (TOTATTEMPTS .GT. 0.0)
     &      SUCCESSRATE = TOTSUCCESSES/TOTATTEMPTS

C       WRITE THE EXPECTED NUMBER OF ATTEMPTS PER TRIAL.
        WRITE (6,6004) TOTATTEMPTS

C       WRITE THE EXPECTED NUMBER OF SUCCESSES PER TRIAL.
        WRITE (6,6005) TOTSUCCESSES

C       WRITE THE EXPECTED NUMBER OF FAILURES (INTERDICTIONS) PER TRIAL.
        REALTEMP1=TOTATTEMPTS-TOTSUCCESSES
        WRITE (6,6006) REALTEMP1

C       WRITE THE SUCCESS RATE.
        WRITE (6,6007) SUCCESSRATE

C       WRITE THE FAILURE RATE.
        REALTEMP1=1.0-SUCCESSRATE
        WRITE (6,6008) REALTEMP1
        WRITE (6,6001)

C       WRITE THE COSTS OF INCOMPLETE SHIPMENTS.
        TOTSUCCESSCOST=0.0
        TOTFAILURECOST=0.0
        DO 160 D=1,NUMDRUGS
            SUCCESSCOSTS(D)=SUCCESSCOSTS(D)*SCALEFACTOR(D)
            TOTSUCCESSCOST=TOTSUCCESSCOST+SUCCESSCOSTS(D)
            FAILURECOSTS(D)=FAILURECOSTS(D)*SCALEFACTOR(D)
            TOTFAILURECOST=TOTFAILURECOST+FAILURECOSTS(D)
  160   CONTINUE

        WRITE (6,6009) TOTFAILURECOST

C       WRITE THE COSTS OF COMPLETED SHIPMENTS.
        WRITE (6,6010) TOTSUCCESSCOST

C       WRITE OUT THE TOTAL COSTS.
        REALTEMP1=TOTSUCCESSCOST+TOTFAILURECOST
        WRITE (6,6011) REALTEMP1
        WRITE (6,6001)

C       WRITE THE HEADINGS FOR THE TABLE BROKEN OUT BY DRUG TYPE.
        WRITE (6,6012) (DRUGNAME(D),D=1,NUMDRUGS)

C       FOR EACH DRUG, GET THE AVERAGE NUMBER OF ATTEMPTS, SUCCESSES,
```

```
C       ETC. PER TRIAL.
        DO 170 D=1,NUMDRUGS
            TOTATTEMPTED(D) = TOTATTEMPTED(D)*SCALEFACTOR(D)
            TOTSHIPPED(D) = TOTSHIPPED(D)*SCALEFACTOR(D)
            TEMPDVECT(D)=TOTATTEMPTED(D)-TOTSHIPPED(D)
  170   CONTINUE

C       FOR EACH DRUG, WRITE OUT THE AVERAGE QUANTITY ATTEMPTED
C       PER TRIAL.
        WRITE (6,6013) (TOTATTEMPTED(D),D=1,NUMDRUGS)

C       FOR EACH DRUG, WRITE OUT THE AVERAGE QUANTITY SUCCESSFULLY
C       SHIPPED PER TRIAL.
        WRITE (6,6014) (TOTSHIPPED(D),D=1,NUMDRUGS)

C       FOR EACH DRUG, WRITE OUT THE AVERAGE QUANTITY INTERDICTED
C       PER TRIAL.
        WRITE (6,6015) (TEMPDVECT(D),D=1,NUMDRUGS)

        DO 180 D=1,NUMDRUGS
            TEMPDVECT(D)=SUCCESSCOSTS(D) + FAILURECOSTS(D)
  180   CONTINUE

C       FOR EACH DRUG, WRITE OUT THE AVERAGE COST FOR SUCCESSFUL
C       SHIPMENTS.
        WRITE (6,6033) (SUCCESSCOSTS(D),D=1,NUMDRUGS)

C       FOR EACH DRUG, WRITE OUT THE AVERAGE COST FOR INCOMPLETE
C       SHIPMENTS.
        WRITE (6,6034) (FAILURECOSTS(D),D=1,NUMDRUGS)

C       FOR EACH DRUG, WRITE OUT THE TOTAL SHIPMENT COSTS.
        WRITE (6,6035) (TEMPDVECT(D),D=1,NUMDRUGS)

C       WRITE THE ROUTE BY ROUTE REPORTS.
        DO 230, R=1,NUMROUTES

C           WRITE OUT THE HEADING FOR THIS ROUTE.
            WRITE (6,6001)
            WRITE (6,6016)
            WRITE (6,6001)
            WRITE (6,6037) R,ROUTENAME(R)
 6037       FORMAT (' REPORT FOR ROUTE ',I2,' - ',A10,
     &              ', SCALED RESULTS')
            WRITE (6,6001)

C           COMPUTE THE EXPECTED ATTEMPTS, SUCCESSES, ETC. FOR THIS
C           ROUTE.
            REALTEMP1=0.0
            REALTEMP2=0.0
            DO 240 D=1,NUMDRUGS
```

```
                REALTEMP1=REALTEMP1+ATTEMPTS(R,D)
                REALTEMP2=REALTEMP2+SUCCESSES(R,D)
  240       CONTINUE

            IF (REALTEMP1 .GT. 0) THEN
                SUCCESSRATE = REALTEMP2/REALTEMP1
            ELSE
                SUCCESSRATE = 0.0
            ENDIF

C           WRITE THE EXPECTED NUMBER OF ATTEMPTS PER TRIAL FOR THIS
C           ROUTE.
            ATTEMPTSCALE=1.0
            IF (OLDATTEMPTS(R) .GT. 0.001)
     &          ATTEMPTSCALE=REALTEMP1/OLDATTEMPTS(R)
            WRITE (6,6018) REALTEMP1

C           WRITE THE EXPECTED NUMBER OF SUCCESSES PER TRIAL FOR
C           THIS ROUTE.
            SUCCESSSCALE=1.0
            IF (OLDSUCCESSES(R) .GT. 0.001)
     &          SUCCESSSCALE=REALTEMP2/OLDSUCCESSES(R)
            WRITE (6,6019) REALTEMP2

C           WRITE THE EXPECTED NUMBER OF INTERDICTIONS PER TRIAL
C           FOR THIS ROUTE.
            REALTEMP3=REALTEMP1-REALTEMP2
            WRITE (6,6020) REALTEMP3

C           WRITE THE SUCCESS RATE FOR THIS ROUTE.
            WRITE (6,6021) SUCCESSRATE

C           WRITE THE INTERDICTION RATE FOR THIS ROUTE.
            REALTEMP3=1.-SUCCESSRATE
            WRITE (6,6022) REALTEMP3

C           WRITE THE HEADINGS FOR THE TABLE BROKEN OUT BY PHASE.
            WRITE (6,6001)
            WRITE (6,6023) (BLANK,N,N=1,NUMPHASES)

C           COMPUTE AND WRITE THE EXPECTED ATTEMPTS PER PHASE ON
C           THIS ROUTE.
            DO 300 N=1,NUMPHASES
                TEMPPVECT(N)=ATTEMPTSCALE*ATTEMPTSBYPHASE(R,N)/NUMTRIALS
  300       CONTINUE
            WRITE (6,6024) (TEMPPVECT(N),N=1,NUMPHASES)

C           COMPUTE AND WRITE THE EXPECTED SUCCESSES PER PHASE ON
C           THIS ROUTE.
            DO 310 N=1,NUMPHASES
                TEMPPVECT(N)=SUCCESSSCALE*
```

```
     &                        SUCCESSESBYPHASE(R,N)/NUMTRIALS
  310        CONTINUE
             WRITE (6,6025) (TEMPPVECT(N),N=1,NUMPHASES)

C            COMPUTE AND WRITE THE EXPECTED INTERDICTIONS PER PHASE
C            ON THIS ROUTE.
             DO 320 N=1,NUMPHASES
                 TEMPPVECT(N)=(ATTEMPTSCALE*ATTEMPTSBYPHASE(R,N) -
     &                         SUCCESSSCALE*SUCCESSESBYPHASE(R,N))/
     &                         NUMTRIALS
  320        CONTINUE
             WRITE (6,6026) (TEMPPVECT(N),N=1,NUMPHASES)

C            COMPUTE AND WRITE THE SUCCESS RATE FOR EACH PHASE ON
C            THIS ROUTE.
             DO 250 N=1,NUMPHASES
                 IF (ATTEMPTSBYPHASE(R,N) .GT. 0) THEN
                     TEMPPVECT(N) = SUCCESSSCALE*SUCCESSESBYPHASE(R,N)/
     &                              (ATTEMPTSCALE*ATTEMPTSBYPHASE(R,N))
                 ELSE
                     TEMPPVECT(N)=0.
                 ENDIF
  250        CONTINUE
             WRITE (6,6027) (TEMPPVECT(N),N=1,NUMPHASES)

C            COMPUTE AND WRITE THE EXPECTED FAILURE RATE PER PHASE
C            ON THIS ROUTE.
             DO 260 N=1,NUMPHASES
                 TEMPPVECT(N) = 1. - TEMPPVECT(N)
  260        CONTINUE
             WRITE (6,6028) (TEMPPVECT(N),N=1,NUMPHASES)

C            WRITE THE HEADINGS FOR THE TABLE BROKEN OUT BY DRUG TYPE.
             WRITE (6,6001)
             WRITE (6,6029) (DRUGNAME(D),D=1,NUMDRUGS)

C            COMPUTE AND WRITE THE EXPECTED AMOUNT OF EACH DRUG THAT
C            WAS ATTEMPTED ON THIS ROUTE.
             DO 270, D=1,NUMDRUGS
                 TEMPDVECT(D)=SCALEFACTOR(D)*
     &                        AMOUNTATTEMPTED(R,D)/NUMTRIALS
  270        CONTINUE
             WRITE (6,6030) (TEMPDVECT(D),D=1,NUMDRUGS)

C            COMPUTE AND WRITE THE EXPECTED AMOUNT OF EACH DRUG THAT
C            WAS SUCCESSFULLY SHIPPED ON THIS ROUTE.
             DO 280, D=1,NUMDRUGS
                 TEMPDVECT(D)=SCALEFACTOR(D)*
     &                        AMOUNTSUCCEEDED(R,D)/NUMTRIALS
  280        CONTINUE
             WRITE (6,6031) (TEMPDVECT(D),D=1,NUMDRUGS)
```

```
C           COMPUTE AND WRITE THE EXPECTED AMOUNT OF EACH DRUG THAT
C           WAS INTERDICTED ON THIS ROUTE.
            DO 290, D=1,NUMDRUGS
                TEMPDVECT(D)=SCALEFACTOR(D)*
     &                       (AMOUNTATTEMPTED(R,D) -
     &                       AMOUNTSUCCEEDED(R,D))/
     &                       NUMTRIALS
  290       CONTINUE
            WRITE (6,6032) (TEMPDVECT(D),D=1,NUMDRUGS)
            WRITE (6,6001)
  230   CONTINUE


        RETURN
        END


C*************************************************************************************
C*************************************************************************************
        SUBROUTINE SELROUTE(RCHOSEN,TRIPS,D,AMOUNT,ACTUALRISKCOMP)
C       SELECT THE ROUTE FOR THE NEXT SHIPMENT.

C*************************************************************************************

C DATA STRUCTURES:

C       INCLUDE THE COMMON VARIABLES:
        IMPLICIT NONE
        INCLUDE 'COMMON.FOR'

C       REAL SCALARS:
        REAL AMOUNT,CUMPROB,ROUTEPROB,COSTROUTE(MAXROUTES),
     &       ACTUALRISKCOMP,PROBCAUGHT(MAXROUTES),
     &       TEMPNUMERATOR(MAXROUTES),TEMPDENOMINATOR(MAXROUTES),
     &       TOTCOST,WEIGHT,TEMPRISKCOMP(MAXROUTES)

C       INTEGER SCALARS:
        INTEGER RCHOSEN,TRIPS,D,RMETHOD,R,S

C*************************************************************************************

C       INITIALIZE THE NUMERATOR AND DENOMINATOR FOR EACH ROUTE.
        DO 10, R=1,NUMROUTES
            TEMPNUMERATOR(R) = 0.0
            TEMPDENOMINATOR(R) = 0.0
   10   CONTINUE

C       FOR EACH DAY TO BE CONSIDERED, ADD IN ITS CONTRIBUTION.
        DO 30, S=0,LONGPAST
            WEIGHT = EXPTABLE(S)
            DO 20, R=1,NUMROUTES
```

```
                TEMPDENOMINATOR(R) =
     &              TEMPDENOMINATOR(R) + WEIGHT*PASTSHIPMENTS(R,S)
                TEMPNUMERATOR(R) = TEMPNUMERATOR(R) +
     &              WEIGHT*PASTFAILURES(R,S)
    20      CONTINUE
    30  CONTINUE

C       FOR EACH ROUTE, COMPUTE THE PERCEIVED PROBABILITY OF BEING
C       CAPTURED AND HENCE THE EXPECTED COST OF USING THE ROUTE.
C       THE PROBABILITY A ROUTE WILL BE CHOSE WILL BE PROPORTIONAL
C       TO THE INVERSE EXPECTED COST OF USING THE ROUTE, SO GET THE
C       TOTAL OF THE INVERSE EXPECTED COSTS OF USING EACH ROUTE.
        TOTCOST = 0.0
        DO 40, R=1,NUMROUTES
            RMETHOD = ROUTEMETHOD(R)
            TRIPS = IFIX(AMOUNT/CAPACITY(RMETHOD,D) + 0.999)
            IF (TEMPDENOMINATOR(R) .GT. 0.001) THEN
                PROBCAUGHT(R) = TEMPNUMERATOR(R)/TEMPDENOMINATOR(R)
            ELSE
                PROBCAUGHT(R) = 0.0
            ENDIF
            IF (RISKCOMPEXP(RMETHOD) .LE. 0.0001) THEN
                TEMPRISKCOMP(R)=RISKCOMP(RMETHOD)
            ELSE
                TEMPRISKCOMP(R)=RISKCOMP(RMETHOD) *
     &                    ((2*PROBCAUGHT(R))**RISKCOMPEXP(RMETHOD))
            ENDIF
            COSTROUTE(R) = 1./
     &                    (TRIPS*(PROBCAUGHT(R)*CAPCOST(RMETHOD)+
     &                            ROUTECOST(R) + TEMPRISKCOMP(R))+
     &                    PROBCAUGHT(R)*AMOUNT*DRUGCOST(D))
            IF (.NOT. BLOCKADED(R,THISPHASE))
     &          TOTCOST = TOTCOST + COSTROUTE(R)
    40  CONTINUE

C       NOW CHOOSE THE ROUTE, WHERE THE PROBABILITY OF CHOOSING A
C       GIVEN ROUTE IS PROPORTIONAL TO THE INVERSE COST OF USING
C       THAT ROUTE.
        CALL RANDU(ROUTEPROB,SEED1)
        CUMPROB = 0.0
        DO 50, R=1,NUMROUTES
            RCHOSEN = R
            IF (.NOT. BLOCKADED(RCHOSEN,THISPHASE))
     &          CUMPROB = CUMPROB + COSTROUTE(RCHOSEN)/TOTCOST
            IF (CUMPROB.GE.ROUTEPROB) GO TO 60
    50  CONTINUE
    60  CONTINUE

        RMETHOD = ROUTEMETHOD(RCHOSEN)
        TRIPS = IFIX(AMOUNT/CAPACITY(RMETHOD,D) + 0.999)
        ACTUALRISKCOMP=TEMPRISKCOMP(RCHOSEN)
```

```
      RETURN
      END

C*************************************************************************************
C*************************************************************************************
      SUBROUTINE SIMULATE
C     THIS SUBROUTINE PERFORMS THE SIMULATION FOR A SINGLE SAMPLE
C     POINT.

C*************************************************************************************

C DATA STRUCTURES:

C     INCLUDE THE COMMON VARIABLES:
      IMPLICIT NONE
      INCLUDE 'COMMON.FOR'

C     REAL SCALARS:
      REAL AMOUNT,PROBCAUGHT,RFACTOR,TEMPTIME,RANDNM,ACTUALRISKCOMP

C     INTEGER SCALARS:
      INTEGER D,R,RDENOMINATOR,RNUMERATOR,T,TRIPS

C     LOGICAL SCALARS:
      LOGICAL TRIPSUCCESS

C*************************************************************************************

C     INITIALIZE FOR THIS TRIAL.
      CALL INITSIM

C     FOR EACH DAY...
      DO 100, DAYNOW=0,ENDTIME

C        GET THE POINTER INTO THE ARRAY OF INTERDICTION PROBABILITIES.
         THISPHASE = CURRENTPHASE(DAYNOW)

C        SHIFT THE PAST HISTORY ARRAYS.
         DO 20, R=1,NUMROUTES
            DO 10, D=LONGPAST,1,-1
               PASTSHIPMENTS(R,D) = PASTSHIPMENTS(R,D-1)
               PASTFAILURES(R,D) = PASTFAILURES(R,D-1)
10          CONTINUE
            PASTSHIPMENTS(R,0) = 0
            PASTFAILURES(R,0) = 0
20       CONTINUE

C        LOOP THROUGH THE EVENTS THAT HAPPEN TODAY.
30       IF (NEXTEVENT .GE. DAYNOW + 1.0) GO TO 100
```

```
C               DETERMINE THE NEXT TYPE OF DRUG TO BE SHIPPED AND
C               HOW MUCH.
                D = NEXTEVENTTYPE
                AMOUNT = EXSHIPMENTSIZE(D)

C               SELECT THE ROUTE.
                CALL SELROUTE(R,TRIPS,D,AMOUNT,ACTUALRISKCOMP)

C               GET THE NUMERATOR AND DENOMINATOR OF THE "R" FACTOR.
                CALL COMPFACT(RNUMERATOR,RDENOMINATOR,R)

C               MULTIPLE TRIPS MAY BE REQUIRED TO SHIP THE GIVEN
C               AMOUNT OF DRUG ON THE SELECTED ROUTE, DUE TO
C               CAPACITY CONSTRAINTS.  THE VARIABLE TRIPS CONTAINS
C               THE NUMBER OF TRIPS THAT WILL BE REQUIRED.  I EXPECT
C               THAT THIS VARIABLE WILL USUALLY BE EQUAL TO ONE
C               AND THAT AS A RESULT DO-LOOP 70 WILL USUALLY BE
C               EXECUTED ONLY ONCE.
                DO 70, T=1,TRIPS

C                   COMPUTE THE "R" FACTOR.
                    RFACTOR = 1.0
                    IF (RDENOMINATOR .GT. 0.0) THEN
                        RFACTOR = RNUMERATOR/RDENOMINATOR
                        TEMPTIME = NEXTEVENT
                        IF (TEMPTIME .GT. RECENTPAST) THEN
                            IF (TEMPTIME .GT. LONGPAST)
     &                          TEMPTIME = LONGPAST
                            RFACTOR = RFACTOR * TEMPTIME/RECENTPAST
                        ENDIF
                    ENDIF
                    IF (RFACTOR .LT. 1.0) RFACTOR = 1.0

C                   COMPUTE THE PROBABILITY OF INTERDICTION.
                    IF (PROBINTERDICT(R,THISPHASE).GE..9999 .OR.
     &                  BLOCKADED(R,THISPHASE)) THEN
                        PROBCAUGHT = 1.0
                    ELSE
                        PROBCAUGHT = 1.0 - EXP(RFACTOR*ALOG(1.0 -
     &                                 PROBINTERDICT(R,THISPHASE)))
                    ENDIF

C                   DETERMINE IF THE SHIPMENT WAS SUCCESSFUL.
                    CALL RANDU(RANDNM,SEED1)
                    TRIPSUCCESS = (RANDNM .GE. PROBCAUGHT)

C                   DO THE REQUIRED BOOKKEEPING.
                    NUMSHIPMENT = NUMSHIPMENT + 1
                    SUCCESS(NUMSHIPMENT) = TRIPSUCCESS
                    TIMESHIPPED(NUMSHIPMENT) = NEXTEVENT
                    ROUTEUSED(NUMSHIPMENT) = R
```

```
                    ATTEMPTS(R,D) = ATTEMPTS(R,D) + 1.0
                    AMOUNTATTEMPTED(R,D) =
     &                  AMOUNTATTEMPTED(R,D) + AMOUNT/TRIPS
                    ATTEMPTSBYPHASE(R,THISPHASE) =
     &                  ATTEMPTSBYPHASE(R,THISPHASE)+1
                    IF (TRIPSUCCESS) THEN
                        SUCCESSCOSTS(D)=SUCCESSCOSTS(D)+ACTUALRISKCOMP+
     &                                                  ROUTECOST(R)
                        SUCCESSES(R,D) = SUCCESSES(R,D) + 1.0
                        AMOUNTSUCCEEDED(R,D) =
     &                      AMOUNTSUCCEEDED(R,D) + AMOUNT/TRIPS
                        SUCCESSESBYPHASE(R,THISPHASE) =
     &                      SUCCESSESBYPHASE(R,THISPHASE) + 1
                    ELSE
                        PASTFAILURES(R,0) = PASTFAILURES(R,0) + 1
                        FAILURECOSTS(D)=FAILURECOSTS(D)+ACTUALRISKCOMP+
     &                                  ROUTECOST(R) +
     &                                  CAPCOST(ROUTEMETHOD(R))
                    ENDIF
                    PASTSHIPMENTS(R,0) = PASTSHIPMENTS(R,0) + 1
                    RNUMERATOR = RNUMERATOR + 1
                    RDENOMINATOR = RDENOMINATOR + 1
   70           CONTINUE

C                   DETERMINE WHEN THE NEXT SHIPMENT OF THIS DRUG WILL BE.
                    CALL RANDEX(RANDNM,EXSHIPMENTINTRVL(D),SEED1)
                    NEXTSHIPMENT(D) = NEXTEVENT +RANDNM

C                   DETERMINE WHAT THE NEXT SHIPMENT WILL BE.
                    NEXTEVENTTYPE = 0
                    NEXTEVENT = ENDTIME + 1.0
                    DO 80, D=1,NUMDRUGS
                        IF (NEXTSHIPMENT(D) .LT. NEXTEVENT) THEN
                            NEXTEVENT = NEXTSHIPMENT(D)
                            NEXTEVENTTYPE = D
                        ENDIF
   80               CONTINUE
                GO TO 30
  100   CONTINUE
        RETURN
        END

C*******************************************************************************
C*******************************************************************************
        SUBROUTINE WRTERROR(ERRORCONDITION)
C       THIS SUBROUTINE WRITES THE ERROR MESSAGE, IF NEEDED.

C*******************************************************************************

C DATA STRUCTURES:
```

```
C       INCLUDE THE COMMON VARIABLES:
        IMPLICIT NONE
        INCLUDE 'COMMON.FOR'

C       LOGICAL SCALAR:
        LOGICAL ERRORCONDITION

C*******************************************************************************

        IF (ERRORCONDITION) THEN
            WRITE (6,6001)
 6001       FORMAT (' ***ERROR***')
            GOODINPUT = .FALSE.
        ENDIF
        RETURN
        END
```

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