I. Building Blocks

PROBLEM I.1: Analyzing Hazardous Materials Transportation

An electronics manufacturer is conducting a study for selecting possible treatment plants to ship its hazardous materials.

DESCRIPTION

An electronics manufacturer in Charlottesville, VA produces hazardous wastes as byproducts of its processes. These wastes must be shipped to appropriate treatment plants. There are three possible plants, located in N. Hornell, NY, Hot Springs, AR, and Jacksonville, IL. The plants have different per-tonnage processing fees as shown in Table I.1.1. The manufacturer needs to determine to which plant it should ship. The shipping arrangement shall be useful for a few years. The manufacturer is concerned about HazMat transport accidents, population exposure, costs, and distances (in decreasing order of importance).

METHODOLOGY

The objective of this exercise is to identify the building blocks of mathematical modeling to provide decisionmaking insights for selecting the optimal path for transporting hazardous materials.

TABLE I.1.1. Per-tonnage Processing Fees

Location of Plant	Per-tonnage Processing Fees
N. Hornell, NY	$250/ton
Hot Springs, AR	$100/ton
Jacksonville, IL	$150/ton

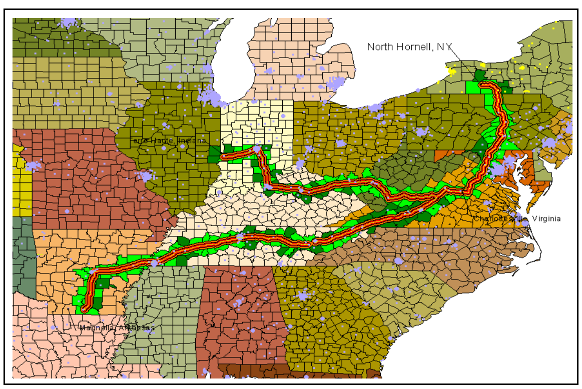

Figure I.1.1. GIS Map of Routes and Impact Areas

SOLUTION

Identifying the Different Variables

The variables below are defined based on the following parameters. Note that the designations of a specific variable type are not necessarily distinct and they may overlap:

Client	Private manufacturing company producing hazardous waste
Time Frame	Long-term
Objectives *(ordered from most important to least)*	**Z_1:** Minimize accidents during transport **Z_2:** Minimize population exposure **Z_3:** Minimize cost of transport **Z_4:** Minimize travel distance

TABLE I.1.2. Description of Variables

Variable Type	Index	
Decision Variable	d_1	Routes to be taken by transport vehicle – *will affect decision of which treatment plant j to select*
	d_2	Mode of transport (land, air, sea, rail, etc.)
	d_3	Other alternative (cleaner technologies, relocating plant, etc.)
Inputs	i_1	Population over time within impact radius of accident
	i_2	Cost of treatment process in plant j (j=NY, AR, IL)
	i_3	Cost of transport
	i_4	Existing road type (interstate, urban, rural, etc)
Random Variables	r_1	Weather conditions
	r_2	Road condition (accidents, traffic, etc.)
	r_3	Vehicle and driver condition
Exogenous Variable	α_1	Gasoline prices
	α_2	Transport worker union strike
Output	o_1	Production per unit time
	o_2	Profit
	o_3	Public perception/corporate image
State	S_1	Amount of chemicals transported per time period
	S_2	Number of available transport units

	S_3	Number and nature of transport incidents
Constraints	c_1 c_2 c_3	Existing road network Treatment plant location State and other local hazmat regulations (hazmat routes, volume, etc.)

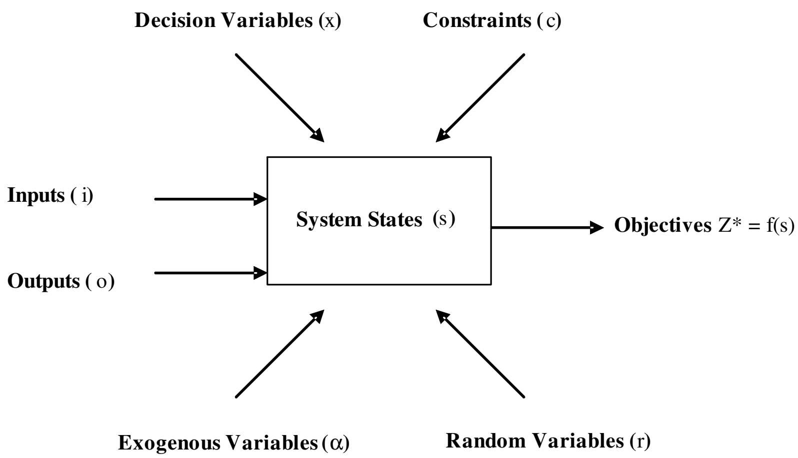

Figure I.1.2. Schematic Diagram of the Model Building Blocks

Mathematical Model

Parameters of System States:

$$s_1(x_1, x_2, x_3, i_2, i_3, i_4, o_2, o_3, \alpha_1, \alpha_2, r_1, r_2, r_3, c_1, c_2, c_3)$$
$$s_2(x_2, i_3, o_1, o_2, o_3, \alpha_2, r_1, r_2, r_3, c_3)$$
$$s_3(x_1, x_2, x_3, i_1, i_4, o_1, o_2, o_3, \alpha_2, r_1, r_2, r_3, c_1, c_2, c_3)$$

Multiple Objectives:

Min $\quad Z_1 = f_1(s_1, s_2, s_3)$
Min $\quad Z_2 = f_2(s_1, s_3)$
Min $\quad Z_3 = f_3(s_1, s_2, s_3)$
Min $\quad Z_4 = f_4(s_1, s_2)$

PROBLEM I.2: Preparing for Snowfall Removal Procedures

Examples of model variables are given in the following problem. An initial model is offered, demonstrating the relationships among the variables.

DESCRIPTION

You are the superintendent of a rural area headquarters for the Virginia Department of Transportation (VDOT). Your responsibilities include planning, scheduling, and supervising snow removal operations. You have four authorized crew member positions. Two positions are filled; two are open.

METHODOLOGY

The objective of this exercise is to use building blocks of mathematical modeling in planning, scheduling, and supervising snow removal operations.

The latest weather forecast for the upcoming weekend indicates that there is a 60% probability of 3 to 6 inches of snow falling in your area of snow removal responsibility sometime between Saturday at 6 pm and Sunday at 12 noon. The snow may be mixed with ice, depending on how the weather system develops.

Both crew members have already worked four 12-hour shifts on snow removal operations earlier this week. Their work week is Monday through Sunday; any weekend work is considered part of the current week's work and is categorized as "overtime."

You have three other sources of labor available for staffing snow removal operations this weekend: the headquarters' Management Operations Manager (MOM), a retired VDOT crew member, and a local contractor. However, you cannot spend more on these sources than the amount budgeted for the two open positions. You also have limited time to train and orient the chosen source(s) of labor.

Your problem/challenge/opportunity: Develop staffing and scheduling plans to perform snow removal operations for the upcoming weekend. Your goals are to minimize the operation's labor costs while fielding the most experienced crew possible and maximizing the efficacy and efficiency of snow removal operations.

SOLUTION

Note the close (and possibly overlapping) relationships among the state variables, the constraints, and the objective functions. The variables involved in this model include:

Decision Variables:

x_1: Crew Member 1
x_2: Crew Member 2
x_3: the MOM

x_4: the retired crew member
x_5: the local contractor

The above variables are binary decisions. A value of 1 means utilizing the services of a particular personnel, and a value of 0 means otherwise.

Exogenous Variables:

α_1: number of miles of roads in the snow removal operations area

α_2: number of pieces of equipment available for snow removal operations (e.g., plow/hopper spreader/liquid calcium chloride tank-equipped tandem dump trucks, plow/hopper spreader/liquid calcium chloride tank-equipped standard dump trucks, tractors with v-plow attachment, tractors with loader attachment, front end loaders, and motor graders)

α_3: time it takes to clear the roads once, per *VDOT Snow Removal Guidelines*

Inputs:

Cost per hour of using:
u_1: Crew Member 1 (overtime)
u_2: Crew Member 2 (overtime)
u_3: the MOM
u_4: the retired crew member
u_5: the local contractor

Time required to train and orient:
u_6: the MOM
u_7: the retired crew member
u_8: the local contractor

Outputs:

Number of hours worked:
y_1: by Crew Member 1
y_2: by Crew Member 2
y_3: by the MOM
y_4: by the retired crew member
y_5: by the local contractor

Total cost of using in this weekend's operations:
c_1: Crew Member 1 ($c_1 = u_1y_1$)
c_2: Crew Member 2 ($c_2 = u_2y_2$)
c_3: the MOM ($c_3 = u_3y_3$)
c_4: the retired crew member ($c_4 = u_4y_4$)
c_5: the local contractor ($c_5 = u_5y_5$)

Random Variables:

r_1: amount of actual snowfall
r_2: duration of the storm
r_3: number of miles of roads receiving enough snow to warrant snow removal operations

State Variables:

s_1: miles of roads that actually need to be cleared during and after the storm
s_2: pieces of equipment actually suitable for use given the amount of snow and the areas that must be cleared,
s_3: number of workers needed and available to clear area of responsibility during and after the storm according to *VDOT Snow Removal Guidelines*

Constraints:

g_1: number of additional hours Crew Member 1 can work this weekend according to fatigue level, contract provisions, and labor laws
g_2: number of additional hours Crew Member 2 can work this weekend according to fatigue level, contract provisions, and labor laws
g_3: total amount of money available to spend on overtime for crew members
g_4: total amount of money available to spend on outside labor forces
g_5: total amount of time available for training/orienting outside labor forces

Initial Model

The initial model addresses only the superintendent's goal of minimizing the cost of the weekend's snow removal operations. A goal-programming model or Pareto-optimization model would be the preferred method of finding a way to satisfy all of the superintendent's goals: minimize costs and maximize experience, efficiency, and efficacy.

Minimize $\Sigma^5_{i=1}\ c_i x_i$

s.t.

$y_1 x_1 \leq g_1$

Crew Member 1 can't work more than the allowed number of additional hours

$y_2 x_2 \leq g_2$

Crew Member 2 can't work more than the allowed number of additional hours

$c_1x_1 + c_2x_2 \leq g_3$	The overtime pay for Crew Members 1 and 2 can't be more than the budgeted/available amount
$c_3x_3 + c_4x_4 + c_5x_5 \leq g_4$	The pay for the "outside labor forces" can't be more than the budgeted/available amount
$u_6 + u_7 + u_8 \leq g_5$	Time spent on training and orientation for "outside labor forces" can't be more than time available for those activities
$x_i = 0$ or 1	Integer constraint on the decision variables
$\alpha_i, u_i, y_i, r_i, s_i, g_i \geq 0$ for all i	Non-negativity constraint on the other variables

Relationships among Variables

The state variables are a function of the decision variables, the exogenous variables, the inputs, and the random variables. That is, the number of miles of roads that need to be cleared of snow and the number of workers needed to clear those roads according to *VDOT Snow Removal Guidelines* depend on how much snow falls, where and how long it falls, and how long it takes to clear the snow from the roads, as well as the number of pieces of equipment available for use, and the number of workers participating in snow removal operations. Under this model, the workers are chosen based on the cost of using a particular worker, the time required to train a worker from an outside labor force, and the availability of crew members.

PROBLEM I.3: Opening a Corner Fruit Stand

A local supermarket owner wants to expand her business by opening a fruit stand on a busy downtown corner. Her son plans to run it.

DESCRIPTION

To help her son get started, the owner contacted a small consulting firm in town to model the various factors involved in making this venture successful.

METHODOLOGY

The consulting firm helped identify the components of the building blocks of modeling a corner fruit stand.

SOLUTION

There are two main objectives:

1) Maximizing profit
2) Reduce the risk of losing money due to the short shelf-life of fruit.

This problem can be modeled by identifying the relevant variables as below:

Decision variables:

• *The kinds of fruit to sell, and the price and quantity of each kind.*
Papayas, for example, could be sold at a higher margin, but may require special handling since they are not grown locally. Apples could be cheaper to stock, but may be sold only at low margins.

• *How often to place inventory orders*
The frequency of inventory orders is extremely important, because if orders are large and placed less frequently, some of the fruit may spoil. However, shorter inventory orders may incur larger procurement charges or may not be enough for demand.

Input variables:

• Quantity of fruit arriving from wholesaler
• Cash from customers buying fruit

Random variables:

• *Percentage of fruit possibly infected by bugs*
A shipment could be infected by a random level of bugs; this could be seasonal, weather related, or due to various other causes.

• *Number of customers (demand)*
The number of customers can vary depending on season and other temporal factors.

Exogenous variables:

- *Population growth*
The town could be growing due to added jobs in the area. This could increase the population and thus have an impact on the state variables.

- *Local regulation policies and events*
A fruit seller must obey all official regulations regarding food sales.
During the year, the town may schedule various events near the busy corner location. This could increase demand by drawing people into the fruit store.

Output variables:

- Fresh fruit sold to customers
- Spoiled fruit that must be thrown away
- Cash paid to wholesaler and also taken home as profit

State variables:

Identifying the state variables is critical in this modeling and the system can be monitored through them, the inventory level (quantity) and freshness level (quality of the fruit. State variables represent the entire system, since input, decision, random, and exogenous variables affect the levels of the state variables.

- Inventory level: the quantity of fruit available for purchase
- Quality level of the fruit at any specific time period

These objectives, constraints, and variables can be visualized in Figure I.3.1.

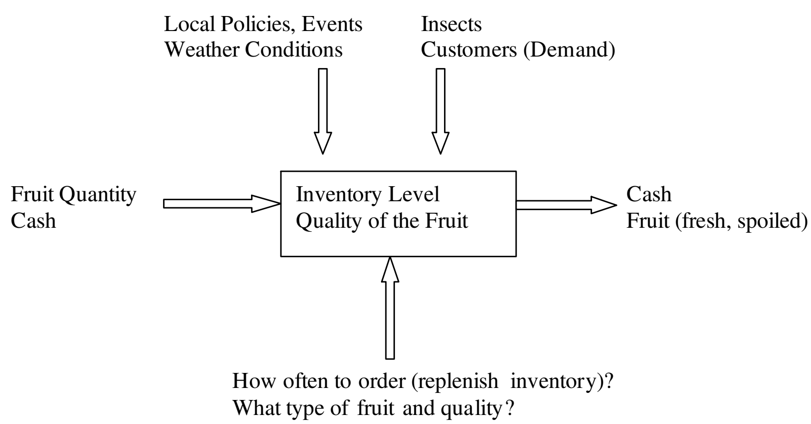

Figure I.3.1. A Block Diagram for a Fruit Stand

PROBLEM I.4: Florist's Valentine's Day Dilemma

For Valentine's Day, the only florist in town must decide on the number of red roses to order from the wholesale rose nursery as well as the price she will charge her customers.

DESCRIPTION

To make the problem a bit simpler, assume that the price the wholesale nursery charges the florist is independent of the total amount the florist purchases. Also assume that each order is for a dozen roses and each customer will buy precisely one dozen. Some people have pre-ordered roses for Valentine's Day at a previously determined price, and others will be purchasing them on February 14^{th}. The florist must fulfill the pre-orders, or those deprived customers will not only receive a full refund but will also be disappointed. If the florist runs out of roses for walk-in customers, then they will also be disappointed. We can assume that disappointed customers will turn to the Internet or other shopping malls for roses next Valentine's Day. Therefore, it is important to minimize the expected number of disappointed customers. If the florist has roses left at the end of the day, she will have to keep them fresh overnight and sell them at a lower price next day. Assuming that all roses will be sold, another goal is to maximize the expected total profit.

METHODOLOGY

This problem can be modeled using the building blocks of mathematical models:.

SOLUTION

Developing a model can be initiated by identifying the relevant variables and constraints, as follows:

State variables (S):

$S = (S_1, S_2)$

S_1: expected number of orders of roses sold

S_{1_1} is for pre-order, S_{1_2} for February 14^{th}, S_{1_3} for February 15^{th}

S_2: expected number of disappointed customers

S_{2_1} is for pre-order, S_{2_2} is for walk-in

Random variables (R):

$R = (R_1, R_2)$

R_1: number of walk-in customers on Valentine's Day

R_2: number of pre-orders that are not picked up

Decision variables (*X*):

$X = (X_1, X_2)$

X_1: number of orders to place

X_2: price per order to charge customers on Valentine's Day

Exogenous variables (A):

$A = (A_1, A_2)$

A_1: price per order wholesale charge

A_2: cost per order to maintain freshness for one night

Input variables (U):

$U = (U_1, U_2, U_3)$

U_1: price per order for pre-ordered roses (may also be considered as an exogenous variable)

U_2: regular price per order

U_3: number of pre-orders (also random variable)

Output variables (Y):

$Y = (Y_1, Y_2, Y_3, Y_4)$

Y_1: expected total revenue from selling roses

Y_2: expected total cost to maintain freshness for one night

Y_3: total cost of purchasing roses

Y_4: expected total number of disappointed customers (also random variable)

Constraints (G):

$G = (G_1, G_2)$

G_1: total number of orders the florist can handle

G_2: the upper limit of disappointed customers in order for the florist to survive

With these variables and constraints, the model can be solved as follows:

Objective functions :

Max $Y_1 - Y_2 - Y_3$

Min Y_4

Subject to:

$X_1 \leq G_1$ (total number of orders can't exceed what the florist can handle)

$Y_4 \leq G_2$ (expected total number of disappointed customers must be below the limit for florist's business to survive)

$X_1, X_2 \geq 0$ (nonnegativity)

where:

$A_1 * X_1 = Y_3$

(Price per order wholesale charge * number of orders purchased = total cost of purchase)

$S_{2\_1} + S_{2\_2} = Y_4$

(Expected number of disappointed pre-order customers + expected number of disappointed walk-in customers = total number of disappointed customers)

$U_1 * U_3 + X_2 * S_{1\_2} + U_2 * S_{1\_3} = Y_1$
(Expected total revenue from pre-orders + expected total revenue from February 14th + expected total revenue from February 15th = expected total revenue from selling roses)

$S_{1\_3} = \max(0, X_1 - U_3 + E[R_2] - E[R_1])$
(Expected roses left at the end of February 14th to be sold on the 15th)

$A_2 * S_{1\_3} = Y_2$
(Cost per order to keep freshness * the expected number of roses left over at the end of February 14th = expected total cost to maintain freshness)

$S_{1\_2} = E[R_1]$
$S_{2\_1} = \max(0, -X_1 + U_3 - E[R_2])$ (expected number of pre-orders not picked up)
$S_{2\_2} = \max(0, E[R_1] - X_1 + U_3 - E[R_2])$ (expected number of walk-ins not fulfilled)

The problem can be solved through multiobjective trade-off analysis, but without identifying pertinent variables in the system it is hard to obtain any specific solutions. Therefore, finding relevant components in each variable is the key to modeling the problem effectively.

PROBLEM I.5: Limiting Computer Browsing at Work

This problem analyzes the impact of Internet browsing on worker productivity.

DESCRIPTION

How to limit the amount of time employees spend on non-work-related sites while supposedly doing their jobs? This is one of the problems that companies face now more than ever because while the Internet is a valuable resource for increasing efficiency, it can also negatively affect worker productivity.

METHOLDOGY

Guided by the questions of risk assessment and management, the objective of this exercise is to identify the building blocks to support the extent to which companies can limit use of the internet for non-work-related activities.

Risk Assessment:

We can assess the risk associated with this problem by answering three questions:

What can go wrong?
What is the likelihood that it would go wrong?
What are the consequences?

Risk Management:

To manage the risk, we answer the following three questions:

What can be done and what options are available?
What are their associated tradeoffs in term of all costs, benefits, and risks?
What are the impacts of current management decisions on future options?

SOLUTION

Risk Assessment

What can go wrong?

Employees with wide open internet access could spend many hours of their day surfing sites that have nothing to do with their jobs, such as: Ebay.com, online shopping sites, and weather sites. In addition to a loss in productivity, there is also the chance that a virus could be transmitted to the employee's computer, which is inside the company network. Finally, surfing non-work related sites uses up valuable company bandwidth. This holds especially true for the streaming video and audio sites that many people enjoy.

What is the likelihood that it would go wrong?

The likelihood is near 100% that there would be a loss in productivity for an employee surfing non-work-related sites. As we know, time slips away when looking at topics of personal interest on the internet; this also affects other employees if content is shared among coworkers. The likelihood of an employee's computer contracting a virus depends on the type of site visited. Other sites may not be as harmful, but there is still a risk present. The likelihood of increased bandwidth utilization is 100%, and the usage can grow exponentially depending on the applications accessed over the web.

What are the consequences?

The consequences for each element that could go wrong range from an increase in monetary costs to the possibility of bringing down the entire network. The main consequence for a loss in productivity is that more people are needed to perform the job formerly done by one. This of course, will lead to an increase in costs. The consequences of contracting viruses involve spending man hours to remove them and damages ranging from incapacitating one computer to having the entire network brought down due to the virus replicating itself. There is also a possibility of a replicating virus attempting to broadcast out of the network onto the internet. A specific virus acting as a backdoor into the network could allow outside traffic to bypass the firewall due to its Trojan horse nature. Finally, the consequence of an increase in bandwidth utilization is very simply an increase in cost.

Risk Management

What can be done and what options are available?

The options are:

1. Shut down all internet usage.
2. Implement web-content filtering software.
3. Implement and publicize acceptable use policy.
4. Implement employee internet navigation-tracking software; publicize results.
5. No action.

What are their associated tradeoffs in terms of all costs, benefits, and risks?

	Option	Cost	Benefit	Risk
1	Shut down all internet usage	None	No loss of productivity	Employees may be unable to do all necessary tasks for job
2	Implement web-content filtering software	-Cost of software -Cost of man-hours to implement software	-Increased productivity -Decreased access to potentially harmful sites -Decreased network downtime -Decreased loss of bandwidth	Sites required to do work-related tasks could be blocked
3	Implement and publicize acceptable use policy	-Cost of man-hours to develop and communicate policy -Cost of man-hours to legally review policy	-Emphasizes good communication with employees since policies are clearly stated -Legal enforcement of policies -Increased productivity -Decreased access to potentially harmful sites -Decreased network downtime -Decreased loss of bandwidth	-Negative employee reaction to strict rules and perceived lack of trust -Lack of response by employees
4	Implement employee internet navigation- tracking software; publicize results	-Cost of software -Cost of man-hours to implement software	-Increased productivity -Decreased access to potentially harmful sites -Decreased network downtime -Decreased loss of bandwidth	-Negative employee reaction to strict rules and public disclosure of personal information -Negative employee reaction to perceived lack of trust -Lack of response by employees
5	No action	-No employee negative reaction -No cost for software application or implementation	-No improvement in employee productivity -No avoidance of harmful viruses or increased costs	-Lack of productivity -Harmful viruses -Network downtime

Overall recommendation is a combined strategy that implements Options 2, 3, and 4 to minimize risk.

What are the impacts of current management decisions on future options?

In this scenario, the impact of any or all of the possible options on future options is minimal. This is due to the fact that selecting any of these options does not eliminate or effectively change the available future options. This is unlike other scenarios where an engineering design results in a system that drives other decisions and eliminates options. Fortunately, for current managers this real-world scenario is less constraining in terms of future options.

PROBLEM I.6: Building a New Major League Baseball Stadium

The objective of this exercise is to identify the building blocks of mathematical modeling to evaluate the feasibility and cost-effectiveness of constructing a new stadium. A new stadium is needed to bring Major League Baseball (MLB) back to Washington, DC. Where should it be built to generate enough revenue to justify the initial capital investment?

The question is whether bringing professional baseball back to Washington, DC would generate enough revenue to justify the initial capital investment. The biggest issue associated with this question is long-term economic growth opportunity. At the forefront of this issue is the building of a new stadium, which MLB demanded. The Mayor of DC promised MLB that the city would build a new stadium complex for the right to have a team. He further promised to build the stadium on the Anacostia Waterfront; this would lead to considerable economic development, including residential and commercial real estate. According to some, this could translate into "billions of dollars of real estate investment and tens of thousands of new jobs." It would also mean the revitalization of an underdeveloped area of DC.

In order to build the new stadium at this site, a $440 million financing package would have to be approved by the DC City Council. At first glance, the Mayor appears to have the majority of the Board on his side. However, in public meetings there has been a strong backlash against the new stadium. Opponents argue that the public funding should go to schools and other social initiatives instead of wealthy major league owners.

The Council Chairperson has suggested an alternative to the Anacostia Waterfront site--build the new stadium right next to the Robert F. Kennedy (RFK) Stadium. Fewer dollars would be required to build it at this site, and thus more money could be used elsewhere. The RFK site cannot be expanded because it is located in a residentially dense area. Also, this site would not be open to new investors; thus real estate revenue and new jobs would be limited to the stadium itself. The generation of the building blocks for this problem requires recognition of the following questions of risk assessment and management:

Risk Assessment: (1) What can go wrong? (2) What is the likelihood that it would go wrong? (3) What are the consequences?

Risk Management: (1) What can be done and what options are available? (2) What are the associated tradeoffs in terms of all costs, benefits, and risks? (3) What are the impacts of current management decisions on future options?

(Note: This exercise does not require identification of the building blocks of mathematical modeling. Answers to the above questions of risk assessment and management will suffice.)

PROBLEM I.7: Controlling Tank Irrigation for Crops in India

A tank irrigation system predominates in south India, as there is no power plant and no long-distance water transportation there. Like a small-scale reservoir, the tank releases water to irrigate crops immediately downstream. Water from the tank is essential to the rice in the field. However, in the dry season, if water is evenly released to all villages, the rice would probably die.

The *Veeranam Tank* is the second-largest tank in south India. It provides water to 120 villages through multiple channels. Before 1994, the volume of water released was usually determined by expert experience. Arumugam and Mohan[1] developed an Integrated Decision Support System to help tank operation. The tank and the fields downstream form an integrated system here. Thus, we need to determine not only the amount of water to release, but also the crop area to be irrigated.

Identify all relevant building blocks in this problem.

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[1] Arumugam, M., Integrated decision support system (DSS) for tank irrigation system operation, 1997, *Journal of Water Resource Planning and Management* **Sept-Oct:** 266-273.

PROBLEM I.8: Marketing Lumber Ecologically

A logging company faces multiple decisions when managing its forests. The company wishes to maximize the amount of money made from cutting down trees, but has to balance that with keeping the forest healthy. This will ensure that the forest will produce a marketable product for years to come.

Using the building blocks methodology in formulating a mathematical model, define six basic groups of variables as follows:

- Decision variables
- Input variables
- State variables
- Exogenous variables
- Random variables
- Output variables

PROBLEM I.9: Controlling River Channel Overflow

The Marikina River in the Philippines has posed a big challenge to the city government in terms of controlling its channel overflow during monsoon season.

The Marikina River is the city of Marikina's main waterway. The river has supported the economic and social activities of the residents of the surrounding community. However, it has caused the city millions of pesos in terms of emergency response activities, economic losses, and the rehabilitation of affected communities, among others.

Identify the components of the building blocks of mathematical modeling to address the adverse effects of the river flooding scenario described above.

PROBLEM I.10: Designing a Car

A car designer wishes to develop a car prototype. Since the goal is to ultimately mass-produce this car design to a broad marketplace, several factors need to be considered including reliability, make, style, and other design attributes.

The functional and technical requirements of a car prototype are being developed from the standpoint of a designer. The design of the car should increase profit/market share and meet a variety of customer/government specifications.

The objective of this exercise is to use building blocks of mathematical modeling to enumerate multiple variables that represent considerations in designing a car prototype. These considerations range from corporate profitability to customer preferences.

PROBLEM I.11: Building a Light Rail System

The city council plans to build a light rail system to transport citizens within the city, reduce increasing automobile traffic, and help attract new residents.

The rail cars will be powered by electricity and the city plans to use funds that the federal government has promised to help cover the cost of construction. The council would like to optimize the locations of the stations in order to maximize the number of citizens that will use the rail system. In addition, they want it to be cost effective.

Identify all relevant building blocks of modeling for the above problem.

PROBLEM I.12: A Reliable School Transit Service

A School Transit Service (STS) handles much of the off- and on-grounds transit for students in a university area. STS handles over 3 million rides annually with a focus on service during the academic year. How can STS decisionmakers keep the buses running on schedule?

The overall goal of STS is to provide safe, reliable, and courteous transportation to university students, employees, and visitors. *Safety* is comprised of passenger security and health while in or around STS vehicles. *Reliability* refers to on-time service. *Courtesy* refers to having drivers treat customers with respect.

With these goals in mind, identify the relevant building blocks of modeling for a school transit service.