特別寄稿

Similarity Between Computer Control Systems and Community Planning

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Abstract

The planning of a community's development and operations, whether for a small town or an international project, requires the allocation of resources to various areas of endeavor. This can best be done if a reasonably accurate estimate is made of the needs for corrective action and the effectiveness of it as a function of type and amount of expenditure. An estimate may be made of the amount of pollution and social conflict which may develop and of the effectiveness of various physical and human countermeasures (sewage disposal facilities, air pollution control, police, hospitals, etc.); on this basis a reasonable allccation may be made. Such a procedure forces one to establish value systems in order to ascertain social costs on comparable bases with each other. This is difficult. Few planners understand the philosophical implications of their actions. This approach, which bears great similarity to optimal process control by computer, will not solve the problems unless value systems can be established. Even when values cannot be adequately established, however, this approach to examining community problems allows decision makers to understand better the implications of their actions. This approach helps educators to better plan programs different from the traditionally narrow engineering curricula, and introduce the concept that technical tools and techniques have important applications at political and philosophical levels.

Introduction

We have on numerous occasions discussed, with various groups of people the ideas of community modeling. Frequently we have been asked why engineers and mathematicians are concerning themselves with such matters. This question is fairly easy to answer. As members of the human race, we are highly concerned with the rapid deterioration of our environment and of the relatively uplanned efforts to combat it. As scientists, we recognize that we have certain tools and knowledge which may be of assistance in analyzing and understanding our environmental and growth problems. Finally, as educators we feel we should aid in the development of programs which will in turn help the next generation of engineers to become better trained in the social and biolo-

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gical scienecs, leading to more intelligent and effective approaches to problems and their solutions.

One of the tools which has been developed fairly recently, but has now become almost standard in large chemical engineering facilities, (especially refineries) is sophisticated automation. This includes not just sensors, control elements, and instruments, but also an oranizing computer designed to carry out more intricate, rapid and sophisticated control maneauvers. This automation also inserts the economic factors directly and automatically into the control loop. Such a tool, it seems to us, has far wider utility than the automation of inanimate physical facilities such as a chemical plant. It is this tool which we specifically believe has an application in a field as unrelated to process control as community planning.

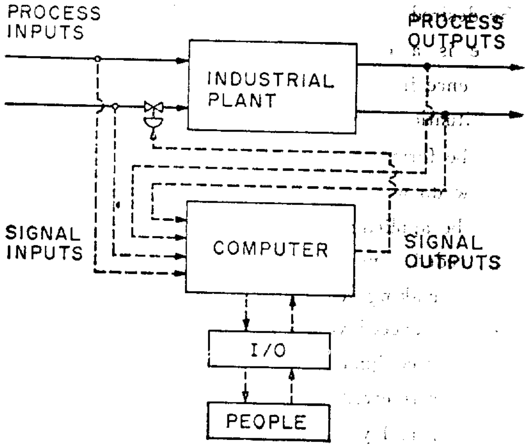

Fig. 1 Relationship between Computer and plant

Figure 1 shows the relationship between the computer and an industrial plant. Information from both input and output of a process is fed in to a computer; resulting output signals are fed back to control valves or mechanisms in the plant. Through the use of various input/output devices, people are able to communicate with the computer.

Let us examine some of the philosophy of a computer control system in terms of work which is carried out. (Figure 2) Input information and the desired performance are used, in an appropriate model, to determine suitable control variables. In most cases plants may be operated satisfactorilly at a variety of conditions. For example, a given throughput and temperature in a certain reactor will

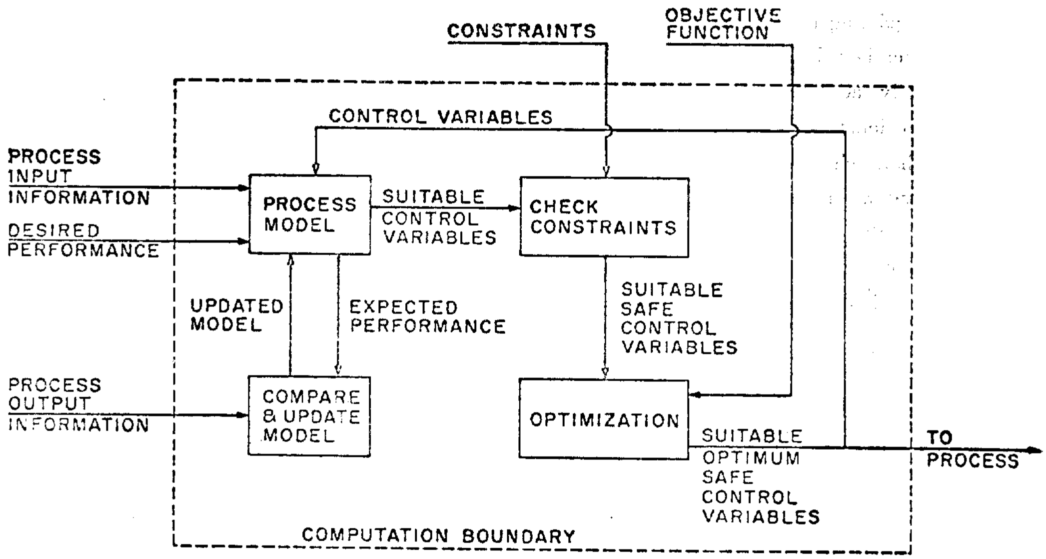

Fig. 2 Logic of Computer Control Calculations

yield the desired amount of a product. A higher throughput and a higher temperature may also yield the desired amount of product, but in the two cases there is a difference in costs. There may be a difference in conditions, making it safe to operate in one situation and not in the other. Different byproducts may be formed in the two cases.

How do we then decide what set of conditions must be applied? Two further areas of calculation are needed. One is the checking of constraints, which means making certain that no temperatures or pressures exceed values so that there is danger to people or equipment. In our example, both of the situations referred to might very well be both suitable and safe, and yet one will be better than the other. How do we decide this? We usually apply an objective function and go through a process of optimization which will determine suitable, safe and optimum control variables.

In the industrial plant the objective function or statement is almost always either, a) maximize profit, b) achieve the largest benefit-to-cost ratio, or c) under fixed production, minimize operating costs. In all cases, however, a unit of currency is the measure of the objective, thus the yardstick by which the optimization is carried out.

Also, on figure 2, there is a block that deals with comparing and updating the model. A model of a process, no matter how hard one tries, is not going to be a completely accurate representation of that process. We still don, t know enough about processes. In addition to that, changes can occur within the process itself, and we must continually update the model to reflect these changes. Comparing actual output information with the perdicted performance is a suitable way of determining the type and amount of updating necessary.

The logic then, is to predict the performance, determine whether it is safe and optimum, and keep refining the calulcations until there is no further improvement (while continually checking the prediction with real values to refine the model as necessary).

From this simple statement of logic, we realize that there is nothing exclusive about philosophy of a computer control system. Ever since man has been able to think, he has carried out this type of logic in determining what his actions should be. The only reason a computer control system should appear different, or amaze people in any way, is that it is extremely fast, and is automatically hooked into the process. Actually the wonder of the whole process is that man has been able to develop his analytical capabilities to the point of understanding the physics and chemistry of processes, and also to the points of understanding the design and construction of computers and control mechanisms.

This same sort of procedure is applied in almost every example of decision making. The situation which we compare with the computer control process is that of community planning. Certainly, when we realize that the output may be a decision concerning tax dollars, or expenditures on new facilities, we realize that an on-line, closed-loop computer system is not at all necessary. What is important is that we still have the same process of collecting information, determining several possible paths which meet the objectives, trying to decide what is safe and optimum, and finding a procedure for recycling through the process until we come to some satisfactory conclusions. We also recognize that, if it is difficult to make a model a real physical and chemical process, it is an order of-magnitude more difficult to do this for a social-biological system Thus, we realize that there is the opportuntity, and even the necessity, for collectiong data and comparing actual system performances with that expected from mathematical models. Table 1 illustrates parallels between the various plant variables and those terms which relate to a city. A chemical plant is frequently subjected to such disturbances as

Table I. Examples of Variables

Type	Chemical Plant	Social System
Disturbance	Change in Feedstock	Change in Population
Performance	Quantity and Purity of Products	Quality of Life
Constraint s	Pressure And Temperature Limits	Water Supply
Objective	Maximize Profit	Minimize Social Cost
Manipulated	Flow (Valve Position)	Tax Dollars
Intermediate	Condition of Equipment	Condition of Facilities

changes in feedstock, a social system to changes in population. The performance of a chemical plant is measured by the quantity and purity of its products, the measure of a social system by the less tangible "quality of life". The constraints in a chemical plant are usually physical, such as pressure and temperature values which should not be exceeded. In the social system the constraint may not be physical; coming from Boulder, Colorado, we know one of our biggest constraints to growth is our supply of water. The objective in a chemical plant is fairly simple-to make the most money or the best return on investment. In a social system it is again much more difficult, because this will relate to the quality of life. For lack of better terminology, we say "minimize social cost." The variable which we manipulate in both cases is a flow-physical flows in one case, currency in another. Intermediate variables are somewhat more difficult to establish. We list two rather vague terms-the condition of equipment vs. the condition of facilities.

It is relatively simple to make some comparisons between the two types of systems. It is reasonable to assume, then, that close parallels also exist for methods of data gathering, model formulation, and optimization.

Mathematical Modeling

At this point it is necessary to make some comments regarding models in general, because there is much confusion about the mathematical model and what it means. Any situation of any degree of complexity might be rather well-described by dozens of different models; the question which must necessarily arise is, which model is the best one to use, if indeed, there is a "best" model? Consider population models. A very simple model is

$$p_{n+1} = (1.0x)p_n$$

The population in the $(n+1)$st year is proportional to the population in the nth year, where the proportionality factor is $1.0X$, with X being the percent growth per year (i. e., 1.05 for 5 % annual growth). This is a very good model which will fit many cases with sufficient accuracy to do at least reasanable projections into the future. Here is another model:

$$p_{n+1} = p_n + \text{Births} - \text{Deaths} + \text{Migration (in-out)}$$

This is fundamentally perfect, stating that the population in the $(n+1)$st year is equal to the population in the nth year plus the number of births, minus the number of deaths, plus net migration during the year. It is possible to model the individual terms, births, deaths, and migration, and to make them functions of many social and economic factors. The equation is perfect, but reliable data may be very hard to get, so the accuracy of the results may turn out to be very bad.

One question one should ask regarding population models is, "for what do you wish to use the information?" because this in turn will tell one both how complicated the model must be and also what type of input information one should prepare. For example, one may wish to categorize the population by age. If we want to know something about the number of voters in a community in the U.S., we need a break point at age 18; if we want to know something about the number of retired people, we need one at age 65. For estimates of our enrollment in schools, we might need breaks at ages 3, 5, 6, 11, 14, 18 and 22. In order to comply wtih our nondiscrimination regulations we might need tabulations according to sex and racial background as well.

All of these breakdowns are possible. The more complicated the categorization, the more difficult it is to manipulate, the more complicated the mathematics necessary, and the more computer memory needed. The more complex the model, the greater are the chances for errors. Thus, it is essential that an intelligent evaluation be made of the real need for information, before spending a large amount of time obtaining data, writing models, and testing computer programs, all of which might turn out to be unsuitable for the desired situation.

Community Modelling

As depicted in Fig. 3 a city may be considered as having three major parts; resources, people, and a society in which these two are allowed to interact. This combination of human action upon nature and nature's counteraction upon man, results in many varied problems. Obviously, in the application of man's ignorance, many types of physical degradaton have occured: air, water. land, pesticide, thermal, noise, and radiation pollution have invaded our ecology. Accompanying these are less tangible types, such as aesthetic pollution. During this confrontation of man and nature, society sees man interacting with himself as well, to create an assortment of social conflict problems which parallel the environmental crises-social problems such as crime, mental and physical disease, and legal conflicts. These latter problems are much different than their physical counterparts, and require a much different approach for solution. (In fact each of the pollution types requires its own type of solution, as does each of the social conflicts.) Thus society employs countermeasures to try to rectify the problems it has created. Examples are sewage treatment plants for water purification, hospitals for the diseased, police forces to combat crime, and a court system to decide legalities. These, of course, cost money to implement, and this is where the city spends its budget. More dramatic costs, however, are those of the irreparable damages done to the ecology--the social costs to the community. These include the "worth" to the community of disease downstream, lives, lost to murder, daughters raped, mental disorder, scarring of environmental

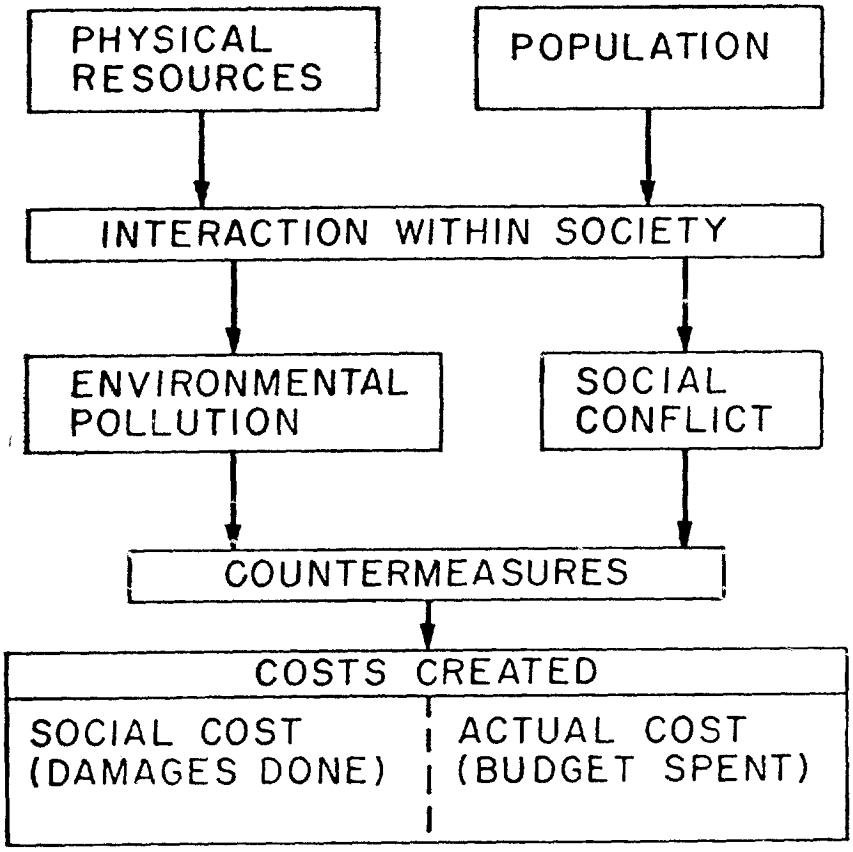

Fig. 3 Simplified operation of a City

beauty, and many such intangible but very real losses to the community as a living whole.

So we see the city's three parts creating problems to solve, implementing solutions to these problems, and, in the process, incurring costs.

Naturally the city would like to minimize these costs-both social costs and the actual budget expenditures. To do this the city must have a value system in which to evaluate the social costs incurred. With a value system, one can optimize the expenditure of the budget so as to minimize the total cost to the community. Figures 4 and 5 show how this works. (The significance of Figure 5 will become more clear through the discussion of the later example.)

The result of this is a rather large and complicated diagram (Figure 6), which is far from complete, but at least it begins to put the total picture together. This diagram shows how a city creates the two problems of pollution and social conflict. It shows eight possible types of pollution along with three areas of conflict. The block labeled factual output' indicates that, if we know enough about a community, and we have appropriate models, and we know something about methods of attempting to combat these ills, we should be able to process the data so as to predcit the levels of pollution and social conflict as functions of expenditure for countermeasures.

Up to this point, the treatment of the information is strictly factual. For example, knowing something about the effectiveness of our police force, we can relate the expected number of crimes to the amount of money we are willing to spend on the police force as a preventive countermeasure. Similarly we should be able to predict something about the amount of disease in the community as a function of both the community and of how much we are willing to spend on doctors, hospitals and the like. We repeat: up to this point the output is totally objective, though the reliability of results may suffer because of incomplete modeling, poor data, or lack of information on which to update the model.

The last block, which has to do with the value system, is strictly subjective. We may perform a scientific analysis of what man spends, but the arbitrarily established values can completely determine where the optimum solution will lie.

A Two-dimensional Decision Process

We have created a small example model which demonstrates how these principles are applied. The simulation conisders one resource, water, and its

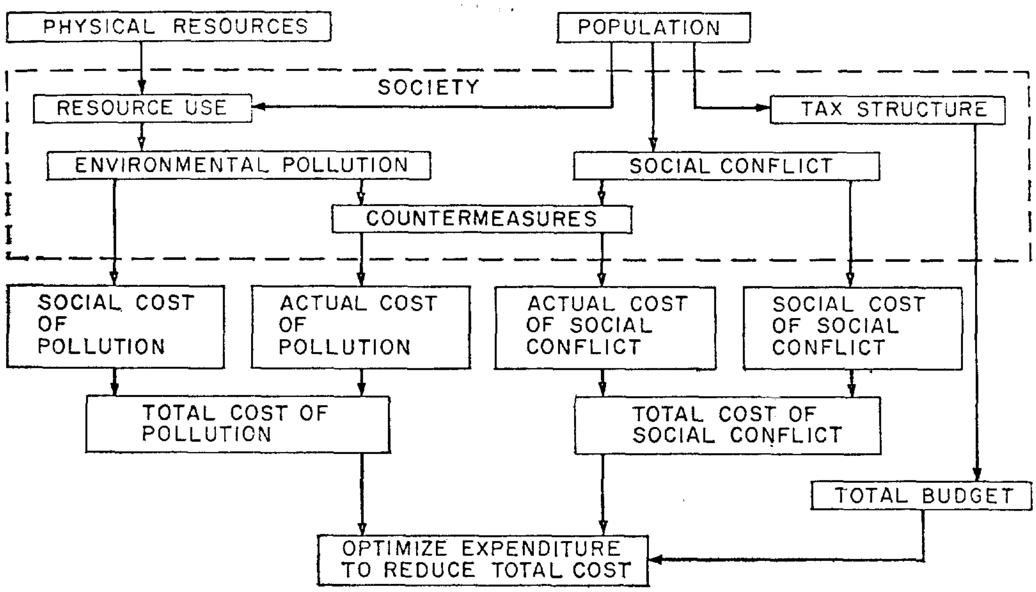

Fig. 4 Expanded Operation of a City-I

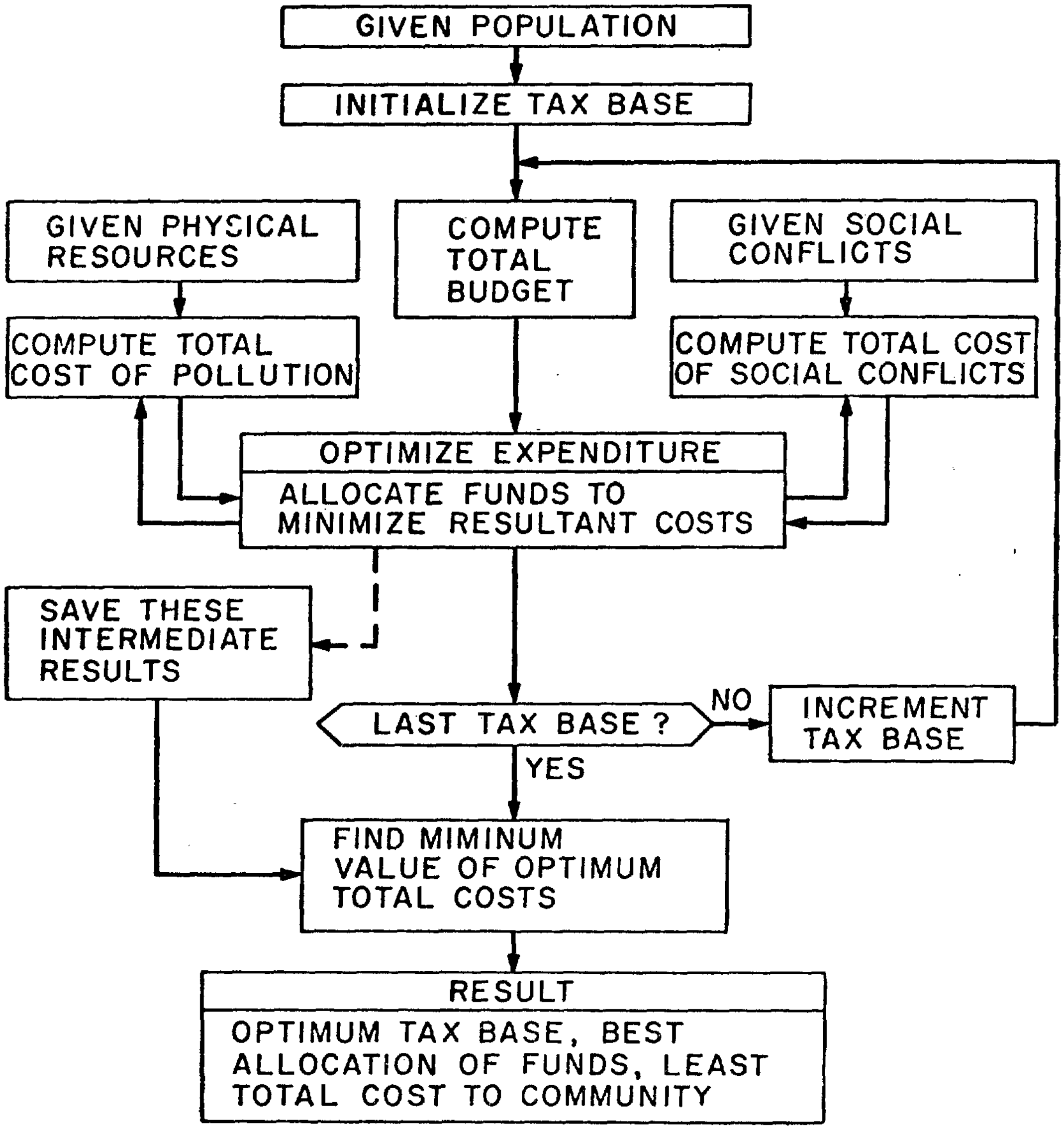

Fig. 5 Logic of Computations

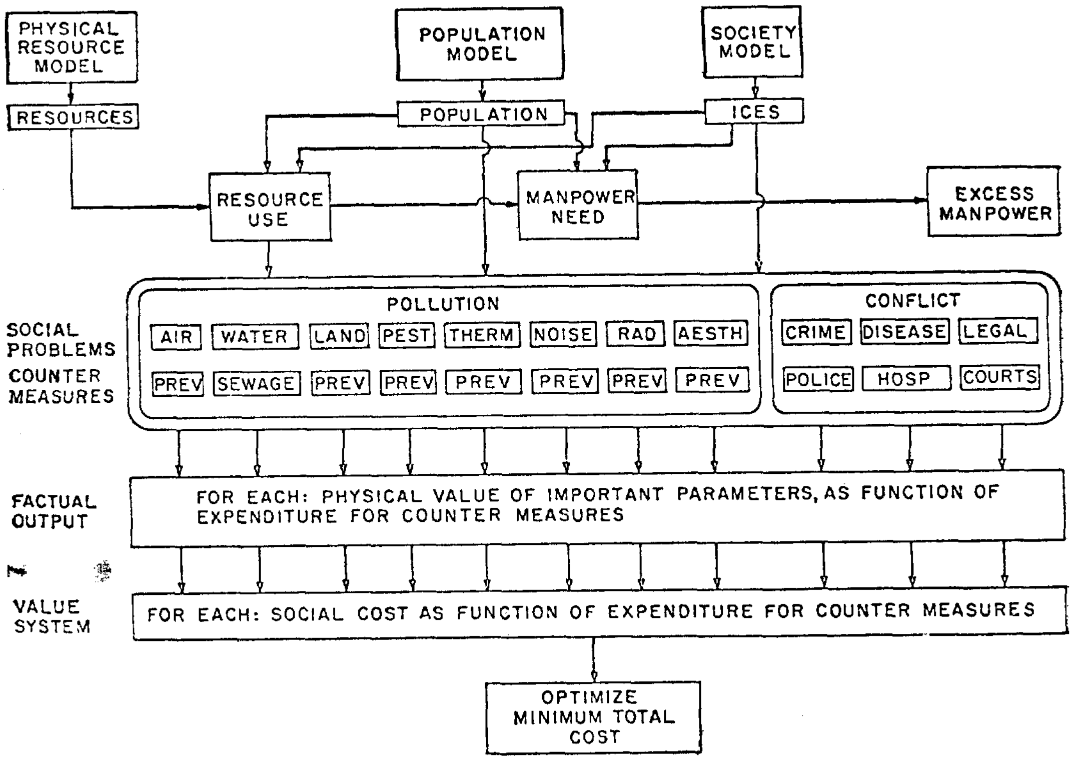

Fig. 6 Expanded Operation of a dity-II

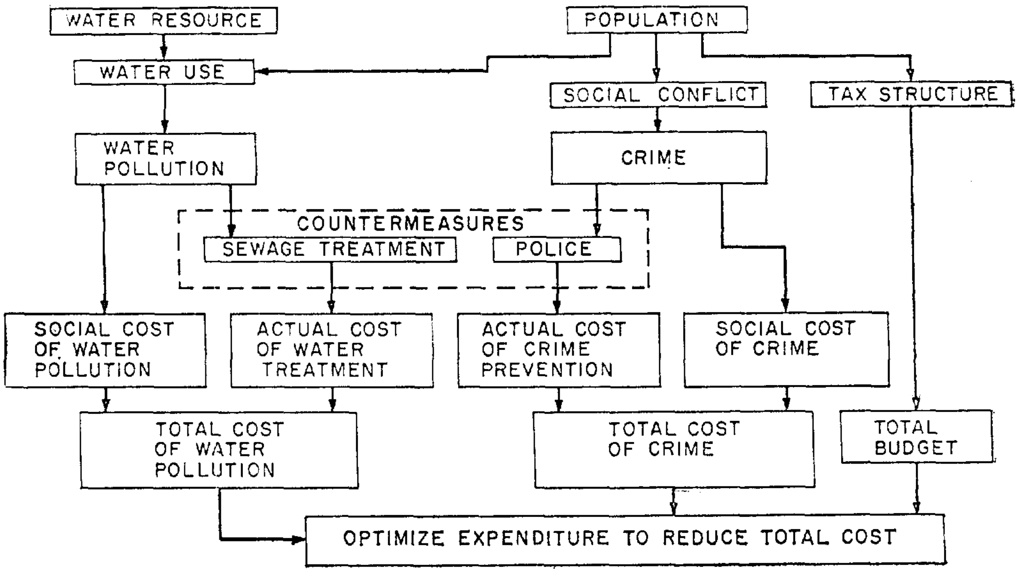

Fig. 7 Diagram of Example Model

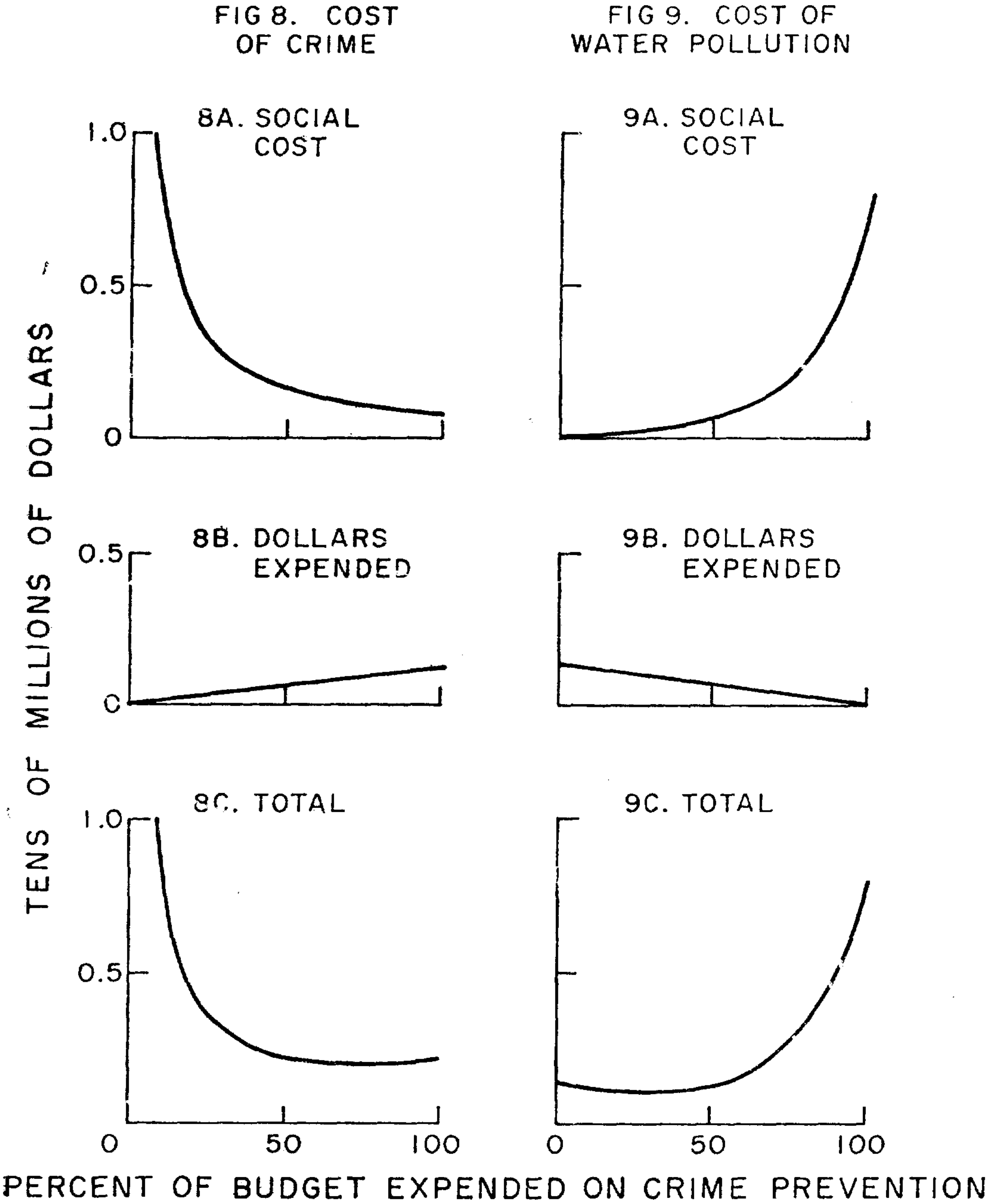
FIG 8. COST OF CRIME
FIG 9. COST OF WATER POLLUTION
8A. SOCIAL COST
9A. SOCIAL COST
8B. DOLLARS EXPENDED
9B. DOLLARS EXPENDED
8C. TOTAL
9C. TOTAL
1.0
0.5
0
TENS OF MILLIONS OF DOLLARS
0
50
100
PERCENT OF BUDGET EXPENDED ON CRIME PREVENTION

resultant pollution with the countermeasure of sewage treatment; and one social conflict, crime, with its law enforcemet countermeasure. (Figure 7) These seemingly unrelated problems are then related through the dollars spent for crime prevention. This can be easily understood graphically since we are considering only two opposing countermeasures, each desiring funds, on which the entire budget is to be spent. Concsider Figure 8. The first curve (8a) shows the social cost of crime as a function of the amount spent for crime prevention. Here the social cost incurred is inversely related to the amount of prevention. The second relation (8b) is linear and depicts that, for a larger budger tax base must be employed. And as a result, more money is spent for solutions of problems. The city, in fact, cannot better solve its troubles by merely spending more money. The concept of diminishing returns has shown, at some point, that the benefits do not continue to increase with increased expenditure. Rather, a dramtic reverse effect is observed. We simulate this hidden concept by viewing the total cost of crime as the sum of the social cost function and the linear tax dollar relaton, both as functions of the amount spent for crime prevention. (Figure 8c)

In a like manner, the total cost of water pollution is shown as the sum of two functions; the linear relation of tax dollars to total budget[1], and the exponential relation of pollution social cost to the amount spent for crime prevention (and therefore not spent on water improvement). The latter function is of the form $ke^{\alpha(1-r)}$, where k and α are constant coefficients, and r is the fraction of the budget spent for crime prevention. (Figure 9)

The total cost to the city can thus be considered as the sum of two total cost functions. As shown in Figure 10, this total cost will have a minimum value at some point. This indicates, for that particular allocation of funds, R_0, that the total cost to the community is minimized. The key here is that these curves are dependent upon the given population, the

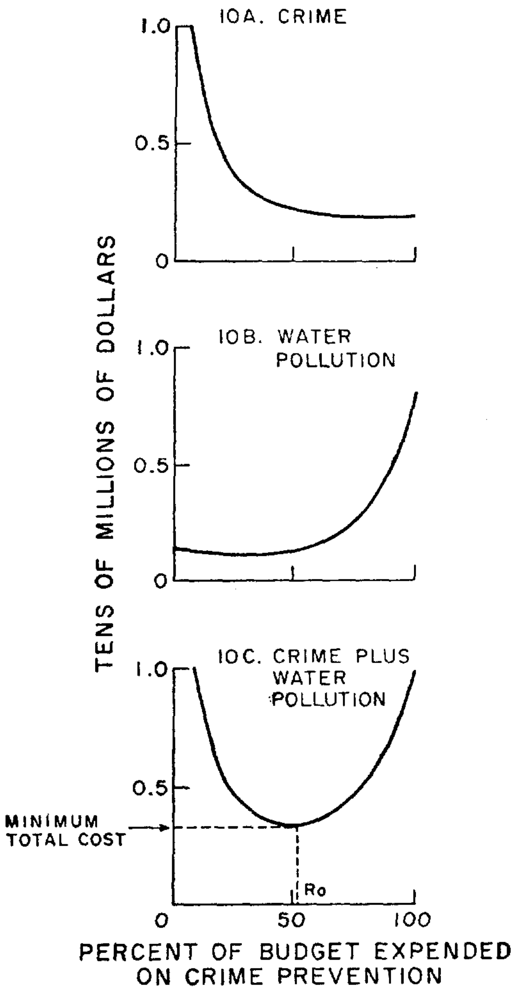

Fig. 10 Total Costs and optimum

tax base used, and the value system imposed. Hence, by varying these, one gets an assortment of differing minima. The desired result is to find which tax base gives the least total cost for a given population. Therefore, while holding the population constant, one computes a minimum curve (total coat curve) for each of seveal tax bases. Then, finding the minimum of these minima gives the optimum tax base for that population and value system.

Figur 11 shows how different tax bases move the minima curves up and down. These curves used a base population of 100, 000. A different base value would give similar results proportional to the change

1. It is worth noticing that the linear function depicting diminishing returns may also represent the idea that larger populations create more pollution, and as well, give birth to more crime.

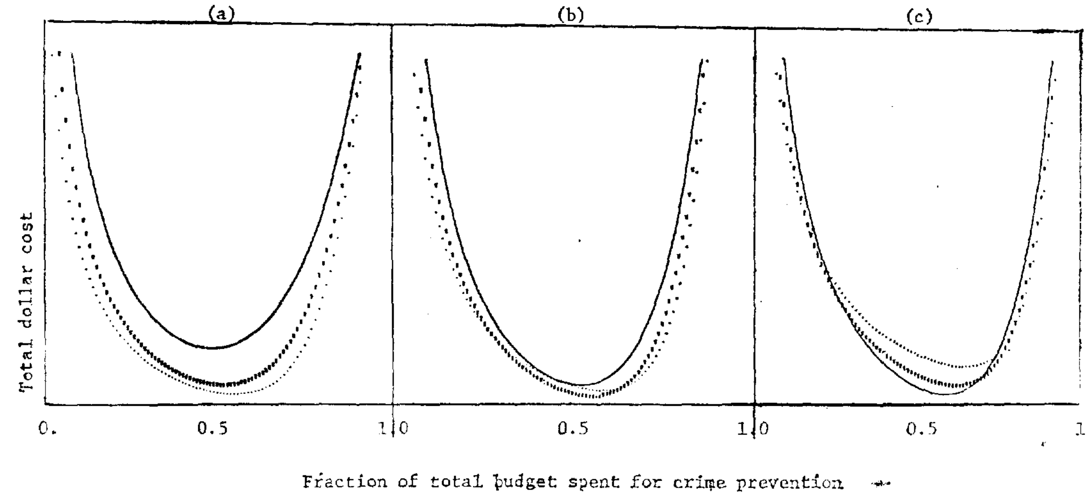

Fig. 11 Variation of Total Cost Curves for Several Tax Bases

The following per-capita tax bases were used for the respective plots:

Line	Frame(a)	Frame(b)	Frame(c)
———	$ 100	$ 140	$ 180
XXXX	$ 140	$ 180	$ 220
· · ·	$ 180	$ 220	$ 260

(Note: These plots are direct reproductions of actual microfilm computer output, with axis labels removed. There is some vartical scale for each frame, since the model was written to create the most readable scale for each frame.)

in population. That is, a population of 200, 000 would give minima with higher absolute values; a figure of 50, 000 would lower the minmima curves.

Underlying all of this is the ominous value system which completely dictates where the optimum expenditure should occur. In this example the value system is relatively simple, consisting of four coefficients. Two of these regulate the water pollution values and two relate the dollar value placed upon violent and non-violent crime. Figure 12 shows three minimum curves for the same tax base ($100). These were generated while holding the population at 100, 000, and the pollution value system constant; and then varing the dollar vaues of violent and nonviolent crime. The upper curve employed the values of $50, 000 per violent crime and $5, 000 per non-violent crime, and gave the optimum amount for crime prevention to be 74 percent of the total budget, leaving only 26 percent for sewage treatment(see Fig. 13a). The middle curve (Fig. 13b) depicts the

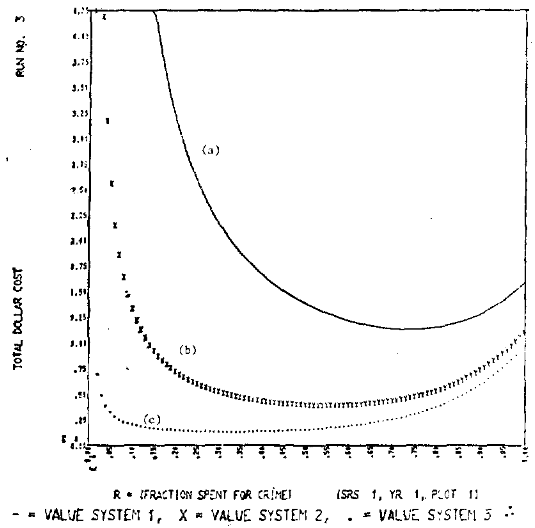

Fig. 12 Variation of Total Costs and Optima as Influenced by Value System

(Note: This plot is a direct reproduction of actual microfilm computer output, including scales and labels.)

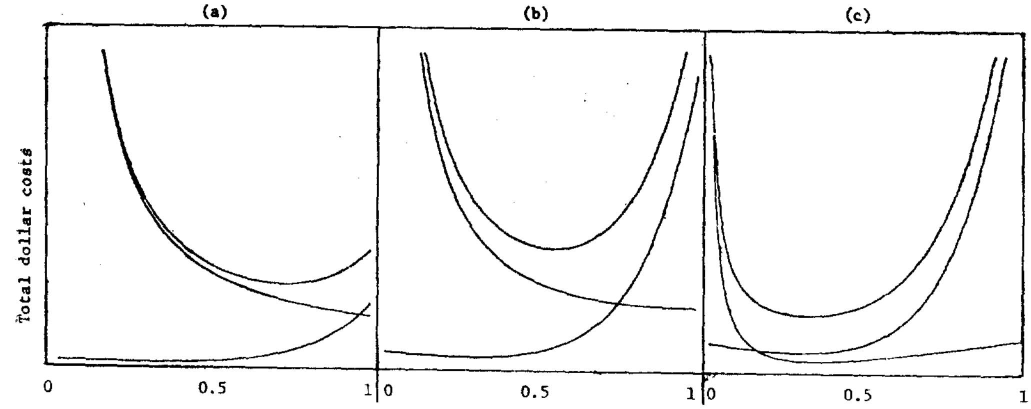

Fig. 13 Computer Outputs Summarized In Fig. 12

The following value systems were used:

	Frame(a)	Frame(b)	Frame(c)
Cost of violent crime	$50,000	$10,000	$1,000
Cost of nonviolent crime	$ 5,000	$ 1,000	$ 100
Optimum percent expended on crime prevention	74%	56%	33%

(Note: These plots are direct reproductions of actual microfilm computer output, with axis labels removed. There is some variation in vertical scale for each frame, since the model was written to create the most readable scale for each frame.)

values of $10,000 per violent crime and $1,000 per violent crime and $1,000 per nonviolent crime. This one optimized at 56 percent, indicating 44 percent should be spent for treatment of water pollution. The third cuve (Fig. 13c) used $1,000 per violent crime and $100 per nonviolent crime, and gave the optimum expenditure as 33 percent for crime prevention and 67 percent to be spent on sewage treatment. This phenomenon of optimum expenditure variance is less obvious than the change in actual minimum total cost values. As one would expect, the less value placed upon crime, the lower the social cost incurred, and hence the total cost to the community is decreased.

From these (and others like them) one can see the importance of the value system and how much control it really exerts over city's expenditures. The members of the city government are faced with the subtle but dramatic task of defining their value system through the allocation of funds. When deciding where to spend the budget, most city councilmen are unaware that they are actually dictating the dollar value of a human life, a rape, a sickness downstream. When allocating expenditures for the community, these people designate a certain percentage of the budget for crime prevention, Compared to the projected occurrence of crime for the city's population, this fundage, in fact, represnts dollars per crime. For example, a city of 100,000 population might allocate $2,000,000 for crime prevention, of which perhaps half might be "assigned" to violent crime prevention. If about 1,000 violent crimes are expected per year, these figures suggest thas the city council has declared the value of a human life to be merely $1,000!

The Real Problem

In this paper we have first laid out the general model, then showed, for a specific 2-dimensional case, that the computed results conform with logic.

The real world of decision-making is multi-dimensional. The council for even a small city may have 20 or more major money alloctions to make every year. How can this work be of aid? Several points need to be stressed:

(1) It is imperative that, whatever is done, a clear demarcation must exist between, (a) the factual calculations and presentation of data, and (b) the optimization of expenditure based upon a subjective value system.

(2) It is better to do something on all levels-to model every important situation, even the models are too simple-than to carry out sophisticated modelling of parts of the system and ignore other parts.

(3) Models and simlations are never, in themselves, harmful. Only blind and uninformed acceptance-or total rejection-of computer output is foolish. In fact, the modeling process itself forces one to organize his facts and thought processes, and to develop awareness of the limitations of both.

This work must proceed, methodically but not too slowly, in a well-planned, interdisciplinary effort. Our results to date show only the close working relationships that must exist between the disciplines, and the physical and phiosophical components of the decision-making process.

The problem is 99 % unsolved. The accomplishment of projects such as those listed in Table 2 will at least move us toward some degree of solution.

Table2. A Few Sample Projects

Given "enough" information about the nature of a community-its people, resources, business, history, etc. estimate

1) Levels of air pollution, when and to what extent lung disease will be significant.
2) Use of water, when it will become scarce, and desirbility of a complete recycling plant.
3) Buildup of solid trash in landfills, related air and water pollution, and evaluation of alternate methods of treating solid waste.
4) Loss of agricultural land as a function of urbanization and population concentration; reduction of food availabiability, and resultant increase in crime and disease.

Acknowledgements

Many students and faculty have contributed ideas through discussions and wark on this project. Among the students involved have been Charles Dietz, Steven Goering, Don Hedden, Michael Henderson, Mary Beth Kelley, John Nicol, Jay Sherritt, and Gary Svoboda.

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Appendix
Modeling Example-Crime Model*

Before we can predict future costs of crime we need a suitable model with which to predict the incidence of crimes. Generially the model should mathematically represent meaningful concepts which physically affect the crime rate. The illustrative model was determind largely through the use of curve-fitting methods. It is not the appropriate model perfectly illustrating the crime incidence-enforcement relationships; it is useful, however, in that it does fit some sample data reasonably well and illustrates a probable casual-effect relationship between crime and police. Statistical data for confirmation are not readily available.

The number of crimes should be dependent, among other things, on the number of people who reside in a certain locale. As more people live in close proximity to each other, the possible interactions between different personalities susceptible to criminal motivations increase; the targets of crimes such as business establishments, residences, and automobiles increase also. Thus crimes should be some function of the population:

$$C=f(P)$$

where P = population

C = crimes

Since the possible interactions increase faster than with just simple addition, because every person can meet more than one other person, a possible equation describing this probability is:

$$C/P \propto P! = P(P-1)(P-2) \quad (1)$$

*Much of this material is abstracted from a study by Steven Goering, Chemical Engineering Department, University of Colorado.

This allows essentially for everyone to interact with all others, which becomes highly improbable as P becomes large. It seems reasonable to approximate the incidence of undeterred crime by an exponential form, rather than a factorial:

$$C/P = k \times P^N$$

where K & N = constants and P is in thousands.

The effect of law enforcement officers might logically be expressed mathematically be either a subtraction or division. Since subtraction could lead to a negative dependent variable, it seemed more reasonable to divide the above crime-to-population ratio by the ratio E/P where E equals the number of police (enforcement) and P the population in thousands. The final trial equation describing the crime rate is:

$$C/P = \frac{k \times P^N}{E/P}$$

The variables $C, E,$ and P were obtained from local police department files and a separate population model; k and N were then determined graphically and also by computer using a non-linear regression program. Note that N and k vary with the type of crime committed. For violent crimes $kl = 1.37 \times 10^{-8}$ and $Nl = 4.83$; the property (nonviolent) crime coefficients were $k2 = 2.47 \times 10^{-9}$ and $N2 = 5.38$. Therefore assuming we can adcequtely predict population, there should be no problem in also projecting the number of crimes likely to occur during a certain year as a function of the number of policemen.

$$\text{Number of violent crimes} = \text{NVC} = \frac{(1.37 \times 10^{-8})p^{6.83}}{E}$$

Number of nonviolent crimes

$$= \text{NNVC} = \frac{(2.47 \times 10^{-9})p^{7.38}}{E}$$

$$\text{Also } E = \frac{r(\text{Population})(\text{per capita tax})}{\$ \text{ per policeman}}$$

and r = fraction of budget spent for police

Before this crime model could be used in an optimization routine, a social cost must be specifically designated for the various crimes. The social cost of these crimes would be additive.

Crime social cost=CSC=KVC*NVC+KNVC*NNVC

where KVC and KVC and KNVC are "value system" coefficients

Crime total cost=CSC= \$ expendend for crime prevention

Thus the social cost which is used comparatively in the optimization routine can be either increased or decreased by weighting the different constants, KVC and KNVC.