# OPTIMUM ENFORCEMENT LEVEL FOR TRAFFIC WEIGHT OPERATIONS

FINAL REPORT
October 31, 1968

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Conducted by the

Midwest Research Institute
Kansas City, Missouri

for the

Iowa State Highway Commission
Ames, Iowa

# PREFACE

This report describes the findings and recommendations to the Iowa State Highway Commission on "The Optimum Level of Enforcement of Regulations Governing the Size and Weight of Motor Vehicles Operated on Iowa Highways." It provides the Commission with guidance for future decisions on the number of officers to be assigned to traffic weight operations. The report contains details of the methodology so that forecasts of optimum levels of enforcement for future years can be easily established.

This project has utilized many specialized skills throughout Midwest Research Institute. The authors and main contributors to the development of the methodology and analysis are:

Mr. Walter Benson, Project Leader
Mr. Richard Cuthbert, cost benefit model and submodel development
Mr. Andrew St. John, road wear submodel
Mr. Marc Semanoff, data analysis
Mr. Frank Witte, computer programming

The success of the study was dependent upon the close cooperation of many ISHC personnel, especially the following:

Mr. Stephen Roberts, Research Engineer
Mr. Dennis Ehlert, Director, Traffic Weight Operations
Mr. Walter Fisher, Assistant Director, Traffic Weight Operations
Mr. Eugene Mills, Highway Planning Surveys Engineer

In addition to the above, the members of the study team are grateful to many other staff members of the Iowa State Highway Commission, Iowa Department of Public Safety, Iowa Reciprocity Board, and Midwest Research Institute for their advice and assistance in obtaining data.

Approved for:

MIDWEST RESEARCH INSTITUTE

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## A. The Problem

The enforcement of traffic weight and size regulations involves both benefits and costs to Iowa. The problem considered in the following study was a determination of the level and method of enforcement that would yield the greatest net benefits to Iowa. In other words, the objective of the study was to determine the "optimum" level and method of traffic weight and size regulation enforcement for the state of Iowa.

## B. Method of Analysis

The basic approach to the problem was to: (1) define the benefits and costs of Traffic Weight Operations (T.W.O.); (2) calculate the benefits and costs from various levels and methods of T.W.O.; and (3) pick the method and level of T.W.O. that maximized the difference of benefits and costs.

In step 1, the benefits from T.W.O. were defined as the sum of fines and additional license fees collected, the value of the uncompensated road wear avoided, and the increased registration revenue. The costs of T.W.O. were defined in terms of manpower, equipment, and materials utilized.

In step 2, computer models were developed to permit calculation of benefits and costs for a wide variety of inspection methods and levels of effort. The models were based on factors such as apprehension probability, fraction of the truck population complying with the law, and the average cost to Iowa from uncompensated road wear caused by overweight trucks.

In step 3, the computer models were applied to a set of proposed enforcement methods and levels of effort. The best resulting level and method of enforcement were chosen as optimum.

In addition to the above cost-effectiveness analysis (Steps 1-3), a series of side analyses was carried out to determine the feasibility as well as the effectiveness of various proposals. The methods used in these studies included: operational experiments, sampling of operational records, literature searches, surveys of other state T.W.O. operations, visits to scale research projects, etc.

## C. Results and Recommendations

The study has revealed that the Iowa State Highway Commission has progressively improved traffic weight operations by the addition of resources of enforcement personnel and conventional weighing equipment to the point where 89 percent of the trucks on Iowa's highways now comply with state weight and registration laws.

The interaction of the principal factors relating to the optimum staff level is shown in Figure 1. The shaded portion delimits the area of management flexibility.

The optimum point is that size staff which produces the maximum net revenue to the state. Assuming that current enforcement policies and practices would continue, a staff of 79 enforcement officers produces maximum net revenue, and can be considered to be the optimum level of enforcement. Adding another enforcement officer from this point would add slightly less benefit than his approximate $9,000 annual cost.

At this optimum point, a high degree of compliance--93 percent--with Iowa's truck-weight size and registration regulations could be obtained.

At the optimum enforcement level--79 men--Iowa would derive $6,480,000 in net benefits from traffic weight operations.

It is significant to note that the net revenue curve is very flat in the vicinity of the optimum staff level. From the viewpoint of management, this situation affords considerable latitude in staff manning levels without significant risk. For example, if current operating funds are the critical factor, then a staff level of 64 enforcement officers could be considered. This is the same as the 1967 average enforcement staff and would provide a net benefit to Iowa of $6,430,000, a reduction of less than 1 percent from the optimum net benefit. Eighty-nine percent of the trucks operating on Iowa's highways are caused to comply with truck-weight size and registration regulations at this staff level.

If increased compliance with the law is paramount, an increase of staff level to 95 field enforcement officers would reduce net revenue to the same level attainable at the 64-man level, but compliance would be increased to 95 percent. The operating budget would be higher at this staff level, but the increased compliance would mean an increase in the benefits from deferred violations.

Increased benefits from T.W.O. can also be realized for the near term by the application of newly developed management tools for the allocation of enforcement resources. Technological improvements in weighing and surveillance equipment now under development offer promise of further improvements for the long term.

The conclusions and recommendations of the study are in the following table:

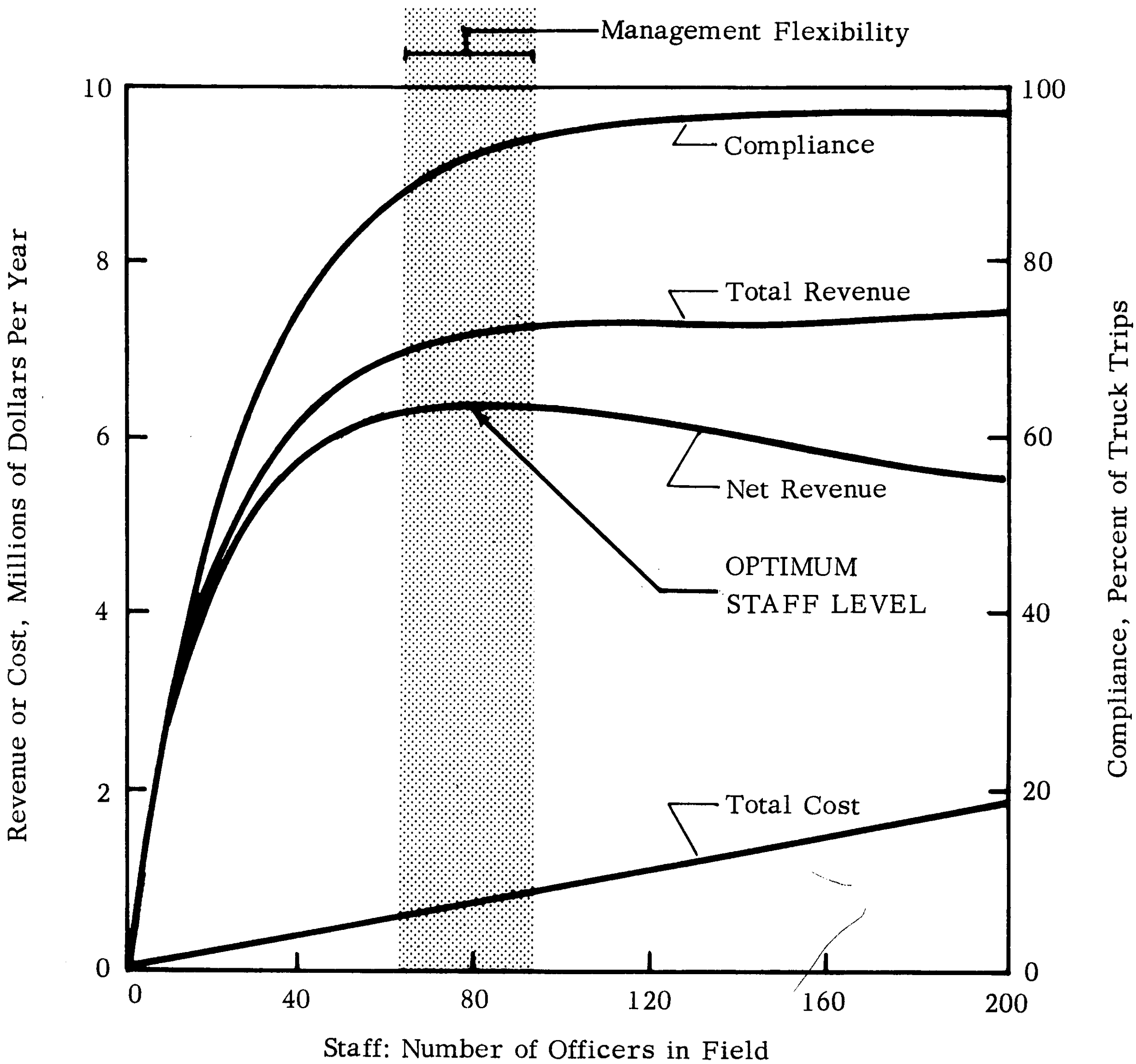


Figure 1 - Optimum Staff Level

## SUMMARY OF MAJOR CONCLUSIONS AND RECOMMENDATIONS

| Area of Investigation | | Conclusions | Recommendations and Comments | Report References |
|---|---|---|---|---|
| Staff Level | | Cost/Benefit analysis indicates that the optimum staff level is 79 field traffic weight officers. | Some staff expansion is needed to attain desired level. | Staff level Section III-B-1 pp. 38. |
| Number of Fixed Scales | | The construction of a new scale site can be justified only when the long run benefits are greater than the annual operating cost and the construction cost. | A detailed survey of prospective scale sites may justify some new construction. | Number of Scale Sites Section III-B-3 pp. 49. |
| Manpower Allocation | Fixed Versus Roving | Average fine collected per operating hour for roving patrol is greater than for fixed site operation. | Use of roving patrol should be increased. | Fraction of manpower devoted to fixed site operation versus roving patrol; Section III-B-4; pp. 57. |
| | Time of Day | The fraction of trucks in violation is significantly greater at night than during the day. | Nighttime enforcement should be increased. | Manpower allocation by time of day; Section III-B-5; pp. 60. |
| | Scale Location | Some fixed scale sites are more effective at enforcement and deterrence than other sites. | Manpower should be allocated to the fixed scale sites in proportion to contribution to the enforcement/deterrence effort. | Manpower allocation by Scale Site; Section III-B-6; pp. 54. |

## SUMMARY OF MAJOR CONCLUSIONS AND RECOMMENDATIONS (Concluded)

| Area of Investigation | Conclusions | Recommendations and Comments | Report References |
|---|---|---|---|
| Advanced Weighing Equipment | State of the art of scale research does not warrant wholesale replacement of current equipment. | Continue to operate conventional scales. Iowa should keep abreast of developments in scale research. | Use of Advanced Weighing Equipment; Section III-B-7; pp. 64. |
| | Use of Florida-type remote-weighing equipment may permit operation of two interstate scales by one crew. | Iowa should conduct a feasibility study to determine applicability. Feasibility has been proven in Florida, but significant differences in requirements for Iowa may exist. | |
| | Use of Lee-type scale as a screening device may make nighttime roving patrols feasible. | Iowa should test feasibility. | |
| Administrative/ Legal Procedures | Requirements for immediate trial places an undue burden on enforcement manpower. | Delayed court appearances should be adopted as standard procedure to eliminate escort of violators to court. | Procedural and Administrative Changes; Section III-B-8; pp. 70. |
| | Truck operators appear to use their knowledge of T.W.O. practices and schedules to avoid apprehension. | Enforcement schedules should be changed more frequently to prevent violators from becoming familiar with them. Implementation would require a computer program for scheduling or the addition of an administrative assistant. | |
| | Individual efficiency of roving patrol varies by a factor of 20 according to experience and training. | Roving patrol teams should receive uniform training. | |
| | A few companies may be committing a high percentage of Iowa's annual violations. Current files do not give definite information on companies involved. | A multiple-violator's file should be computer-maintained and made available to cognizant judicial authorities. | |

# II. INTRODUCTION

## A. Definition of Problem

The enforcement of traffic weight and size regulations involves both benefits and costs to Iowa. The problem considered in this study was the determination of the level and methods of enforcement that would yield the greatest net benefit to Iowa. Stated in another way, the solution of the problem--the objective--was to find the "optimum" level and methods of enforcement, "optimum" being defined as that which will produce the greatest difference between benefits and costs.

## B. Overall Approach

The study began with a literature search involving several state governments, federal agencies, manufacturers of weighing equipment, etc. This search sought information on other traffic weight operation studies, scale performance and cost, research on new methods of weighing, the relative effectiveness of various enforcement strategies, and the assessment of economic forces leading to the willingness of operators to risk violations.

Subsequent to this search, probably the first such ever conducted in this country and certainly the most extensive so far, MRI gathered data from the Iowa State Highway Commission on the costs of carrying out enforcement operations in terms of manpower and equipment used, salary rates, overhead costs, and equipment purchase costs. The Commission also provided factual data concerning truck traffic, weight regulations, apprehensions, and the amounts of fines resulting from enforcement.

Personnel from MRI inspected traffic weight stations observed the field operations of the traffic weight officers, and reviewed operational problems with the department head and his principal assistants. Records were obtained relative to assignment of crews to fixed stations and roving patrols, hours when fixed stations were operated, apprehensions per operating hour, and the variation in total truck traffic and apprehensions with respect to the hour of day or night.

## C. Study Plan

The relatively simple basic approach to the problem just outlined required a complex plan to implement. Figure 2 is a block diagram of the study plan.

The early part of the study was carried out along three major parallel paths. The upper path of the diagram began with a literature search. Many sources, including several state governments, federal agencies, scale manufacturers, and so on, were contacted.[1/] Information was sought concerning other studies done on traffic weight operations, scale performance and cost, research on new methods of weighing, relative effectiveness of various enforcement strategies, and economic forces tending to cause violation of overweight regulations. The information obtained from this search was not as complete as might have been desired, but did provide some insight into the problem (see pp. 64-70). It also became quickly established that the study being done was probably the first of its type.

The next step was to gather data from the Iowa State Highway Commission on the costs of carrying out enforcement operations: terms of the manpower and equipment used, salary rates, overhead costs, and equipment purchase costs.

Based on the cost information on current operations and the information on new equipment, it was possible to formulate the cost of carrying out enforcement on varying levels of effort, using new equipment and methods. This formulation is called the "cost model."

Meanwhile information was gathered from Iowa sources concerning truck traffic in Iowa, weight regulations, apprehensions, and fines collected by enforcement officers. These data were analyzed to provide a measure of success in enforcement efforts and a means of predicting the probable success of new enforcement efforts. This prediction method was formulated as an "Apprehension Model." In addition, from the analysis of enforcement data and an examination of the literature on new equipment there was developed a list of "Candidate Systems," i.e., a group of new inspection methods considered worthy of further investigation. Finally, analysis of the apprehension history of the enforcement group provided information on the ability of enforcement to deter violations from occurring. This information was formulated as a "Deterrence Model" which would predict how overweight regulation violators would respond to changes in enforcement policy.

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1/ A list of sources contacted is in Appendix 2.

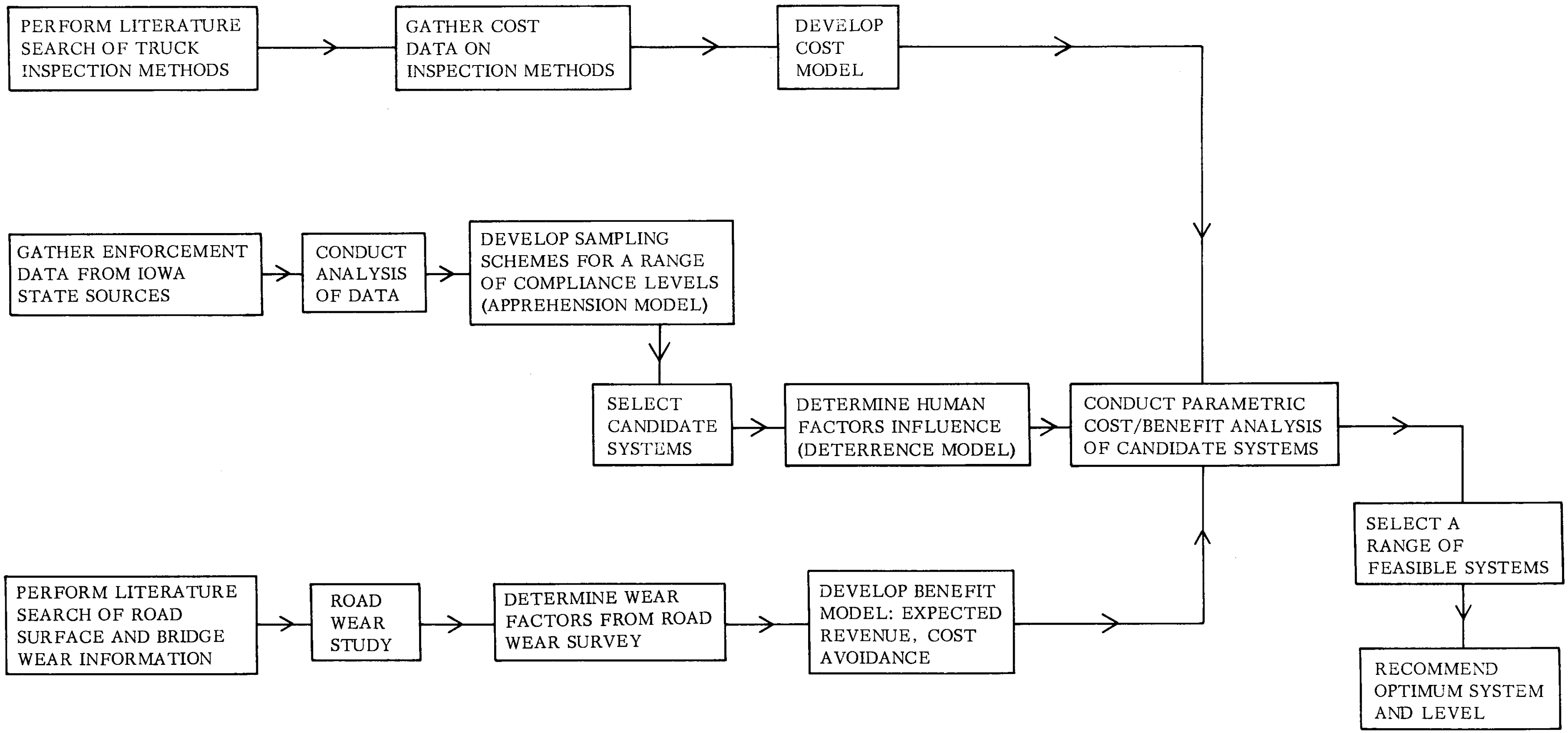



Figure 2 - Research Plan for a Study of the Optimum Level of Enforcement of Iowa State Motor Vehicle Size and Weight Regulations

A third major area of the study was to develop a method of measuring the benefits from enforcement operations. It was known from the outset that a major component of these benefits was the deterrence or prevention of uncompensated road wear by overweight trucks. It was also known that the evaluation of the magnitude of potential overweight uncompensated road wear would require an extensive substudy by itself. Hence, this part of the effort was begun early in the project. Further study of benefits from weight enforcement indicated that another major benefit is the collection of the fines and registration fees from apprehended violators. It is possible that enforcement of the oversize laws prevents a safety hazard, but no data on this effect are available. The road wear prevention and fine-collection benefits were formulated as a function of enforcement efficiency and deterrence efficiency, so that the benefits from new inspection methods could be predicted. This formulation is called the "Benefit Model."

All the study effort discussed above allowed the study team to calculate the benefits and costs from the list of candidate inspection systems and thereby determine the optimum level and type of enforcement. The calculations were carried out with a computer program which is documented in Appendix 8. The program was also used to study the effect of data errors on the results of the project, and to locate near optimum but more readily implemented or feasible alternatives.

The results of the study are outlined below in the discussion of the final report format.

## D. Alternatives Examined

Several alternative methods of enforcement were considered. The basic kinds of alternatives open to the inspection force are:

1. Reallocation of manpower in space or time;

2. Use of new types of equipment;

3. Hiring of more/fewer men;

4. Purchase of more scales; and

5. Changes in administrative procedures, such as elimination of the practice of immediate arrest and trial of violators.

Although the fundamental method of analyzing all of these alternatives was in terms of their cost/effectiveness, as previously discussed, other methods were also used:

1. Examination of technical feasibility of new equipment;

2. Consideration of legal/political constraints on changes in administrative procedures;

3. Direct measurement of performance of various alternatives by operational experiment; and

4. Statistical analysis of performance by sampling of operational records.

Some alternative methods of inspection were dismissed because of technical or legal infeasibility and their detailed cost-effectiveness analysis was not made.

Several of the results of procedures (3) and (4) are included in the report, along with results from the cost-effectiveness analysis.

## E. Scope and Limitations

Generally speaking, the study accepted without question the legal, economic and political environment in which traffic-weight operations are carried out. For example, there has been some controversy within transportation circles concerning the "fairest" way to allocate highway expenses to various users such as the general public and truckers. The study accepted the current truck registration structure as reasonably well reflecting economic realities. Similarly, the fine structure of the overweight regulations was accepted without further analysis. Such assumptions do not affect the validity of the results so much as their range of applicability. If the laws relating to fines are changed drastically, parts of the study may have to be revised to cover the new situation.

The subject of weight enforcement itself has also been a matter of some controversy in Iowa. In the light of this fact, an attempt was made to make the analysis as clear cut and well defined as possible. The benefits attributed to T.W.O. activities were those that could be firmly identified and measured. Safety benefits and bridge-damage prevention were not included in the formal analysis, and the recommended scale of T.W.O. operations is slightly conservative as a consequence.

The validity of the analysis was not restricted adversely by lack of data. As might be expected, all the information necessary for the study was not readily at hand. However, sampling of operational records, operational experiments and other methods of gathering information satisfactorily filled the gaps. The report format described below will enable the reader to determine the source of each piece of data used in the analysis, so that he can verify its adequacy for himself.

However, even complete data often have measurement and other errors that are extremely difficult to evaluate. The sensitivity of the conclusions of the study to such errors was examined, and forms an important part of the report.

## F. Organization of the Report

The report is organized for use by the Iowa State Highway Commission to aid in developing current and future budgetary requirements for traffic weight operations.

The Summary gives MRI's conclusions and recommendations for the operation of traffic weight enforcement for Fiscal Year 1969.

The Body of the Report relates in detail the Results of the study and the Methodology for obtaining them. The recommendations made in the Summary cannot be properly understood and implemented without full understanding of these matters.

Appendices to the report provide complete data on all of the study's technical inputs: computer programs, statistical information, bibliography, etc. Should ISHC personnel need to carry out a similar study for future budget requests, all the necessary materials are available.

## III. BODY OF REPORT

### A. Methodology

#### 1. Cost Effectiveness Analysis

Background and assumptions: The basic objectives of the project were to (1) find the optimum level of overweight regulation enforcement by using various methods of enforcement; and (2) find ways of improving the efficiency of such enforcement methods so that the net benefit to Iowa would be as great as possible.

The fulfillment of these objectives requires in turn:

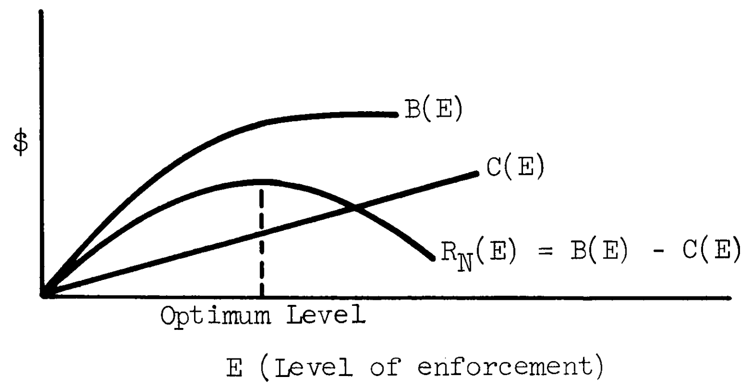
1. Acceptable definitions of the terms "optimum," "benefit," and "cost" as applied to traffic weight operations (T.W.O.).

2. A means of measuring benefits and costs of present and alternative T.W.O. methods.

Definition of terms: Level of enforcement is taken to mean the level of effort put into traffic weight operations as measured in terms of manpower and equipment. If this level is too low, then violations will increase, causing excessive road wear or other losses to Iowa. If the level is too high, then the cost of enforcement may exceed the benefits to the state. The enforcement effort results in both benefits (fines collected and road wear and registration losses prevented) and costs (enforcement officer salaries, equipment costs). The optimum level of enforcement for any given method of operation is that level resulting in a maximum in the difference in benefits and costs. Symbolically, the best level of enforcement, $E$ , is one such that

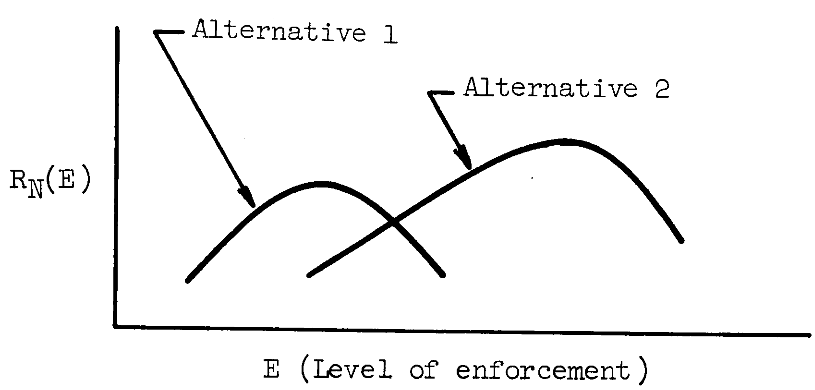
$$R_N(E) = B(E) - C(E)$$

is maximum, where $R_N(E)$ is the net revenue or "profit," $B(E)$ is the benefit or revenue, and $C(E)$ is the cost. $R_N$ , $B$ , and $C$ are all written as being dependent on $E$. The general situation can be depicted graphically as below:




Both costs and benefits would probably increase with an expanded level of effort, but typically costs continue to rise rapidly while benefits tend to increase more slowly because of "diminishing returns." The best or optimum level is the point shown where the distance between the two curves is the greatest, since this results in the maximum possible difference between costs and revenue.

<u>Evaluation of alternatives</u>: Various alternative or candidate methods of carrying out weight regulation enforcement may have different cost and benefit curves because of differing efficiencies. Hence, even if the optimum level for a given method is employed, it may not result in the maximum net benefit or revenue to Iowa because another alternative may be intrinsically more efficient. This comparison can be shown graphically as follows:




Alternative 2 is better because it results in greater net revenue at its optimum level.

Alternatives cannot be compared fairly unless they are both at their best levels. In addition, such comparisons should be made only for alternatives that are feasible, regardless of their revenue and cost.

Alternatives involving the use of equipment that is beyond the technical sophistication of enforcement officers[1] or of methods that unduly harass honest truckers cannot be justified in terms of revenue and cost.

Measuring benefits and costs: The above discussion provided a logical framework for deciding on the optimum level and means of enforcement given that we have measures of benefits and costs. These measures are provided by what are called cost and benefit models, which are simply mathematical relations predicting the outcome of enforcement efforts in terms of benefits obtained and costs expended.

Figure 3 shows the structure of the cost effectiveness analysis used in the study. The cost and benefit models provide the net revenue, $R_N(E)$ , to be maximized for each alternative considered. Legal, technical, and other practical constraints limit the choice of alternatives. The best alternative is both feasible, and provides the maximum net revenue.

Details on the cost and benefit models are provided in subsequent sections of the methodology. It is appropriate to point out here, however, that "Models" of the apprehension effort, deterrent effects of apprehension, uncompensated road wear due to violation, cost expended by apprehension, and benefits obtained from enforcement are necessary because we must predict what will happen under changes in hypothetical enforcement policies. We need a model or simulation of reality with which to try out experimental ideas. Experimentation with real inspection methods, personnel and equipment is usually not feasible, or at best, very expensive. Theoretical models combined with limited operational experimentation can often provide relatively quick insight into ways of improving even the most complex operations.

## 2. Benefit Model

Purpose: The purpose of the benefit model is to provide a means of determining the benefits or return to Iowa from the Iowa State Highway Commission's Traffic Weight Operations.

Background and assumptions: The state of Iowa derives several benefits from its traffic-weight operations. First of all, there is the very tangible and easily measured benefit of the money collected in fines and increased registration fees from apprehended weight regulation violators. However, since the primary purpose of the enforcing effort is not to collect fines but rather to deter violations in the first place, the success of the enforcement unit should be measured not only in terms of the money it

1/ E.g., oscilloscopes and laboratory-type electronic equipment.

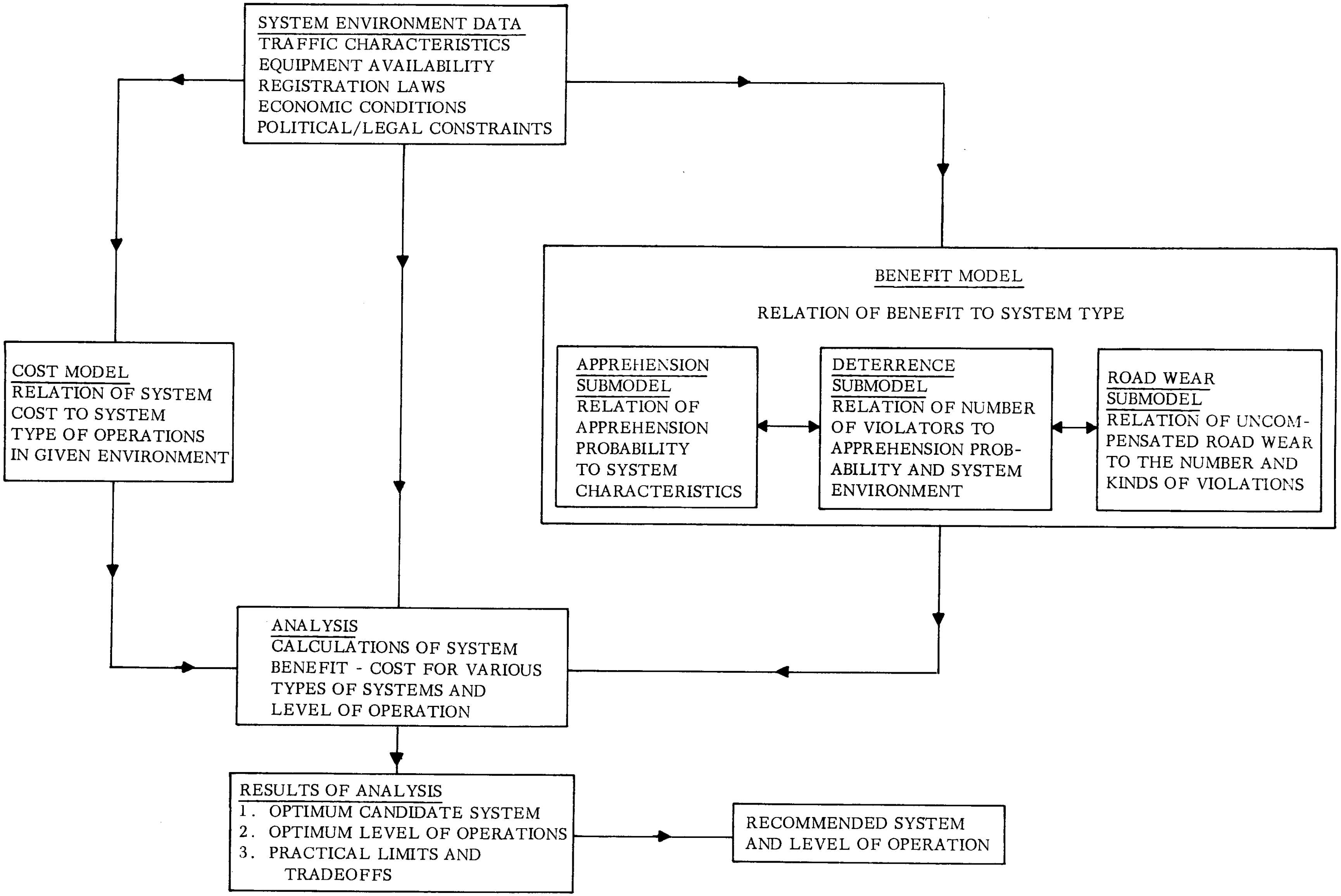



Figure 3 - Overall Logic of the Cost Effectiveness Analysis of Weight Enforcement Methods

actually collects but also in terms of the money or other values it saves Iowa by prevention or deterrence of violations.

Violators of weight regulations cause two kinds of losses to Iowa. First, registration violators withhold from the state their fair share of registration fees. Second, overweight violators extract from Iowa's roads a portion of their useful life that is uncompensated by registration fees. Prevention of such violations results in a real but difficult-to-measure savings to Iowa.

It is also very possible that overweight or oversize violations result in a safety hazard to the Iowa motoring public. However, preliminary investigation indicated that no valid accident rate statistics were available which would allow evaluation of the magnitude of this hazard. Hence, potential safety benefits were not included in the benefits attributed to Traffic Weight Operations. Interpretation of the results from the benefit model should take this omission into account.

Measurement of benefits: In order to quantify the benefits we need the following notation:

Let $B$ = Yearly dollar benefit to Iowa from T.W.O.

$B_c$ = Total fines and registration increases collected for the year.

$B_p$ = Total uncompensated road wear and withheld fees prevented for the year.

$F_{vf}$ = Fine per violating vehicle apprehended by a fixed site.

$F_{vr}$ = Fine per violating vehicle apprehended by a roving patrol.

$f_{vw}$ = Fraction of violators overweight.

$f_{v\ell}$ = Fraction of violators committing registration violations.

$L_{vw}$ = Loss per violator due to uncompensated road wear.

$L_{v\ell}$ = Loss per violator due to withheld registration fees.

$P_f$ = Probability of apprehending a violator during a single trip by a fixed site.

$P_r$ = Probability of apprehending a violator during a single trip by a roving patrol.

$T$ = Number of trips per year in Iowa by vehicles covered by overweight regulations.

$V$ = Fraction of vehicle trips made in violation of one or more T.W.O. enforced regulations.

$V_u$ = Fraction of vehicle trips made in violation of one or more T.W.O. enforced regulations if T.W.O. did not exist.

The total benefit $B$ is the sum of the fines and registration increases collected, $B_c$, plus the prevented road wear and withheld registration fees, $B_p$. Symbolically:

$$B = B_c + B_p$$

$B_c$, the dollar value of fines and registration increases collected per year is the product of truck trips per year times the fraction of these truck trips in violation times the probability of apprehension times the average fine collected per violator apprehended for each method of apprehension.

$B_c$ is given by the following expression:

$$B_c = TV\left[P_f F_{vf} + P_r F_{vr}\right]$$

$B_p$, the dollar value of increased compliance is the number of truck trips per year times the increase in the fraction complying with the law times a weighted average loss prevented per trip.

$B_p$ is expressed as follows:

$$B_p = T(V_u - V)\left[f_{vw} L_{vw} + f_{v\ell} L_{v\ell}\right]$$

<u>Source of values</u>: The values used for each term in the above equations come from a variety of sources. The sources for $T$, $F_{vf}$ and $F_{vr}$, $f_{vw}$ and $f_{v\ell}$ are discussed in Appendix 1, Tabs B, E, and C, respectively. The values used for $P_f$ and $P_r$ were obtained from the Apprehension Submodel discussed in Section 4 of the methodology, pp. 21. combined with some apprehension rate data used for calibration purposes as discussed in Appendix 1, Tab D. The values used for $V$ were obtained

from the Deterrence Submodel discussed in Section 5, p. 26 of the methodology. The values for $L_{vw}$ were obtained from the Road Wear Submodel in Section 6, p. 28 of the methodology. The values of $L_{v\ell}$ for registration violators are discussed in Appendix 1, Tab. J.

Method and scope of calculations: The benefit model or equation in combination with the various submodels supplying values to it was coded in FORTRAN IV for the IBM 360 computer. Documentation on the program is provided in Appendix 8. The program was exercised using inputs describing various alternative or candidate methods of carrying out T.W.O.'s duties. The alternative methods considered are discussed in Section 7, p. 38 of the methodology.

## 3. Cost Model

Purpose: The purpose of the cost model is to provide a means of determining the expected capital outflow necessary to finance a given level of enforcement for the Iowa State Highway Commission Traffic Weight Operations.

Background and assumptions: The annual operating budget to be expected for T.W.O. is dependent on a given level of enforcement. For example, as more enforcement officers are employed to enforce the traffic weight regulations, the total operating cost or outflow of capital can be expected to increase.

The rate at which the operating cost changes depends mostly on variable cost and to a lesser degree on incremental fixed costs. A variable cost is defined as those costs which change directly with the level of enforcement. Direct salary expenses for a traffic weight officer compose the largest component of the variable cost. Other variable costs include travel costs, a portion of the miscellaneous budget, and the employer's share of employee benefits.

A fixed cost, by definition, is a cost factor which remains relatively constant over a range of operating levels. For example, the present administrative staff consists of eight persons: a director of traffic, an assistant director of traffic, a mechanic, and three clerks.

If the enforcement level is increased so would the volume of administrative duties. However, the administrative staff should be able to operate effectively within a range of volumes. Above this range in work load, which is a function of the enforcement level, additional administrative staff would be required. The result would be an incremental increase to the fixed cost portion of the total operating cost.

The administrative costs for the traffic director and his staff is a major percentage of the total fixed cost. Some of the other fixed costs are data processing, reproduction, electricity, heat, and water, janitorial supplies, office supplies and repairs. These costs do not vary directly with changes to the enforcement level and are considered fixed costs over a range of manpower.

The cost of depreciation for fixed-site operations--scales, building structures, and other equipment--is not included in the operating cost model. As the value of equipment depreciates, it may be desirable to allocate capital to replace this equipment. However, the optimum staff level is only affected by those operating costs and revenues which change with the level of enforcement. Because depreciation of equipment is not affected by the staff level, the depreciation cost is not included in the cost model.

Land, from an economic viewpoint, does not have an economic life; for this reason, land values do not normally depreciate with time. Therefore, the economic value of land is not affected by the enforcement level. Consequently, an annual cost equivalent to the purchase cost for land is not included in the cost model.

In summary, the cost model consists of two types of costs, variable and fixed (see Figure 4). The direct salary costs for traffic weight officers and travel costs are the major variable costs. The fixed costs are the administrative costs and a portion of the miscellaneous budget. The cost of land and the depreciation of equipment is not affected by the enforcement level; therefore, these costs are not included in the cost model.

Symbolically, the cost model can be written in the form:

$$C = C_V S + C_F$$

where $C$ is the annual operating budget for Traffic Weight Operations, $C_V$ is the average annual variable cost associated with the effort of each enforcement officer, $S$ is the number of enforcement officers in the field, and $C_F$ is the fixed cost associated with the administrative overhead required to maintain and direct an enforcement staff of size, $S$ .

The values used in the study for the various factors of the cost model are developed in Appendix 1, Tab K.

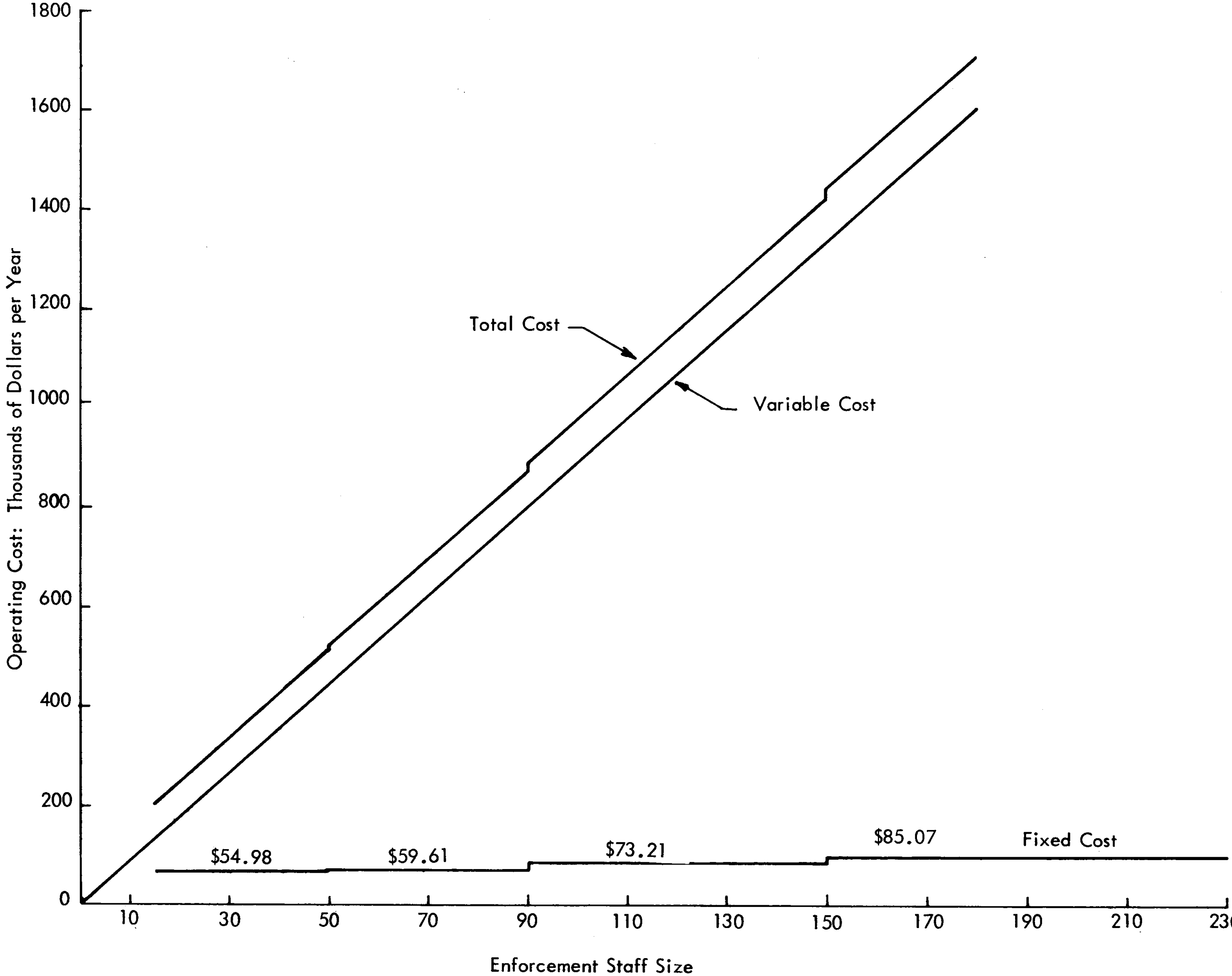



Figure 4 - Cost Model: Cost Versus Staff Level

## 4. Apprehension Submodel

Purpose: The purpose of the apprehension submodel is to mathematically relate the probability of apprehending a weight-regulation violator with the level and efficiency of weight-enforcement operations. The equation representing this relation will be used to predict the increase in the apprehension probability resulting from increased expenditures on inspection activities.

Background and assumptions: The actual search for violators carried out by the weight-enforcement force is a complex process involving many factors. These factors include: the manpower available, the number and types of scales available, the total length of road network under surveillance, the length of the trips taken by violators, the concentration of traffic on various areas of road network, the efficiency of manpower utilization, and the ability of violators to detect and avoid inspection sites. The ability to apprehend violators as measured by the probability of apprehension would be increased by more manpower, more traffic concentration, better manpower utilization, and so on. On the other hand, an increase in the length of road network to patrol or in the intelligence activities of the violators would decrease the apprehension probability.

The overall approach taken to determine the mathematical relation between the apprehension probability and the various factors listed above was successive approximation and evaluation. The theoretical model was initially very simple, and was gradually increased in complexity until it provided an adequate representation of the known facts about Iowa's traffic weight operations. This method is best understood by following through the actual derivation of the various forms of the apprehension equation.

Consider first a simple inspection activity in which there is only one inspection method--fixed scales.

Single inspection method - random site location: Let

$D$ = Days worked per week

$f_s$ = Fraction of sites that can be manned at once

$H$ = Hours worked per day

$M_I$ = Length of road under surveillance in miles

$M_T$ = Trip length in miles

$N$ = Number of inspection sites

$P$ = Probability of being caught violating weight regulations

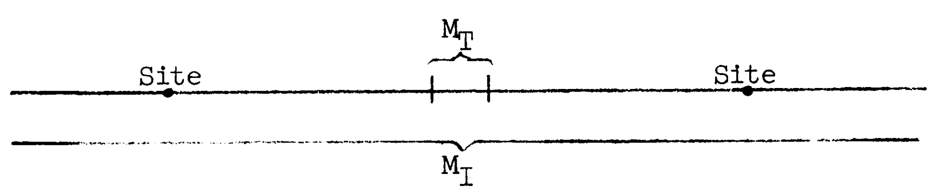
$P_I$ = Probability of being inspected at a site given that a violator passes it; i.e., the probability that the site is open

$P_o$ = Probability of being apprehended at any one site

$S$ = Total staff available for enforcement

$s$ = Size of crew for each site

Consider the road under surveillance as one long stretch of length $M_I$




Assume that the inspection sites are randomly located and open at random intervals, and that the person making the trip is starting from a random point, has no intelligence concerning the operation of the sites, and hence cannot deliberately avoid them. Then: the probability of being apprehended at any one site = the probability of going by the site times the probability the site is open, or

$$P_o = (M_T/M_I)\ f_s P_I$$

but

$$f_s = \left[(S/s)/N\right]\ (H/24)(D/7)$$

$$= SHD/168sN$$

i.e., the fraction of the sites that can be manned is the number that can be manned divided by the total number of sites. The number of sites that can be manned is the total staff available divided by the number of crewmen per site, reduced by the fractions of a day and week that are worked, e.g., 1/3 and 5/7, respectively. Thus:

$$P_o = M_T\ SHDP_I/168M_IsN$$

The probability of being apprehended at at least one of $N$ sites is given by

$$P = 1 - (1-P_o)^N$$

which can be approximated (for moderate $P_o$ ) as

$$P = 1 - e^{-NP_o}$$

Hence:

$$P = 1 - \left[1 - (M_T SHDP_I/168M_I sN)\right]^N$$

or approximately, for moderate $P_o$.

$$P = 1 - e^{-(M_T SHDP_I/168M_I s)}$$

This applies when $f_s < 1$ or

$$SHD/168sN < 1$$

i.e.,

$$S < (168sN/HD)$$

Thus as long as the sites are not staff-saturated, there is no value in increasing $N$ since it does not appear in the above formula[1/] for $P$ . When the sites are saturated, we have to increase $S$ when we increase $N$ in order to gain in $P$ .

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1/ Increasing the number of sites without adequate manpower to man them simply lowers the fraction of time any one site can be manned, canceling out any increase in $P$ .

For the saturated region:

$$S = 168sN/HD$$

and so

$$f_s = 1$$

Therefore:

$$P_o = (M_T/M_I)P_I$$

or

$$P = 1 - e^{-(M_T/M_I)NP_I}$$

<u>Multiple inspection methods</u>: Suppose there are two or more methods of inspection, e.g., fixed site operation and "roving" patrols that differ in manpower allocation, working schedule, probability of apprehension and so on. If there are two teams operating in the same state the probability of apprehending a violator can in general be expressed as:

$$P = P_1 + P_2 - P_{12}$$

where $P_{12}$ is the probability associated by both teams or methods. The probability that a violator will be apprehended by both teams practically is zero. (In order to maximize the probability of apprehension, an effort is made to keep various teams from inspecting the same traffic.) Hence, the probability of apprehension for $n$ teams or methods is additive, i.e.:

$$P = P_1 + P_2 + \cdots + P_n$$

where $P_1$, $P_2$, . . . , $P_n$ are the probabilities associated with each method.

Currently, there are two methods of apprehension, fixed sites and roving patrols. We will refer to $P_r$ and $P_f$ as the probabilities of apprehension by roving patrol and fixed site, respectively. Thus,

$$P = P_r + P_f \quad .$$

Effect of nonrandom site location: Suppose that fixed sites or temporary "roving" patrol sites can be located in high traffic areas, i.e., we can make the probability of a scale being in a region the same as the probability that a trip will be made in the same region. Then the probability of a violator going by a site can be significantly increased over the random-site derived value. We can evaluate the magnitude of this increase in the following fashion:

Divide the total road length into K equal-length subregions. Let the probability that a trip will occur in the $j^{th}$ region be $P_{tj}$ . The probability of being caught by any one scale in the $j^{th}$ region = the probability that the scale will be placed in the region times the probability that the trip will take place in the region times the probability of going by the site and being inspected if both site and violator are in the region.

Prob(being apprehended in $j^{th}$ region) = Prob(scale in $j^{th}$ region) x
Prob(trip in $j^{th}$ region) x
Prob(passing scale and being inspected)

$$P_o'(j) = (P_{tj})(P_{tj})\left(\frac{M_T P_I}{M_I/K}\right) = K(P_{tj})^2(M_T/M_I)P_I$$

Since any one site can be in only one region, we can add the probabilities in all K regions to obtain the probability of apprehension by one scale:

$$P_o' = \sum_{j=1}^{K} P_o'(j) = \left[K \sum_{j=1}^{K} (P_{tj})^2\right](M_T/M_I)P_I = \left[K \sum_{j=1}^{K} (P_{tj})^2\right]P_o$$

where $P_o'$ is the new nonrandom $P_o$ . For example, if we can divide the road net into two pieces and $P_{t_1} = 1$ and $P_{t_2} = 0$ , then $P_o' = 2P_o$ , i.e., we effectively cut the distance to be searched by 2. If we divide the road net into two pieces with $P_{t_1} = P_{t_2} = 0.5$ , then $P_o' = P_o$ ; that is, we gain nothing as would be expected.

Effect of violator intelligence activities: Up until this point, we have assumed that the violators have had no knowledge of the activities of the inspection force. Based on initial discussions with T.W.O. personnel, MRI determined that the truckers do have information on scale location and general scale-scheduling practices. It was decided that explicit modeling of the intelligence activities of the truckers was not feasible. The approach taken was to measure the actual apprehension probability achieved by the inspection force under current operating policies and under some reasonable alternative policies (for example, an increase in "roving patrol" operations). This probability was used to calibrate the apprehension model. Effectively, this means rewriting the apprehension model in the form:

$$P = 1 - e^{-K_s N P_o'}$$

and solving the equation for K which is a constant reflecting the "leakage" of scale location and scheduling information to potential violators. In general, $0 < K_s < 1$ ; i.e., there is a degradation in apprehension. The details of these calculations are recorded in Appendix 1.

Summary: An equation has been developed which relates the probability of apprehension of a violator to the scope of the inspection activity and to characteristics of potential violators. The effects of nearly all known factors related to apprehension are modeled by their explicit appearance in the probability of apprehension equation. However, insufficient detailed information exists on the methods used by truckers to acquire information on inspection activities and to thus avoid apprehension. The degrading effect of such methods on apprehension was measured indirectly and lumped into a constant $K_s$ in the apprehension equation.

## 5. Deterrence Submodel

Purpose: The purpose of the deterrence submodel is to provide a mathematical relation that will predict the violation behavior of the trucking population in Iowa as changes are made in regulation-enforcement level and method.

Background and assumptions: Preliminary investigation quickly indicated the general behavior that could be expected. The carrying of overly large loads potentially results in an increased profit per run for almost any truck operator.[1] There are practical limitations on the size and number of the resulting violations: the design maximum load of the truck, the density of the material being carried, time schedules to be met, and so on. As soon as regulations are enforced, another factor comes into the picture: the chance of being apprehended and thus delayed and fined. If the probability of being apprehended is significant, the potential profits from violations become less attractive due to the risks. Even efforts at evading the law can be expensive because of the value of time to the truck operator. Exactly who will violate the law and when in such circumstances is very difficult to evaluate.

In summary, we can generally expect that violations will drop off as enforcement is increased, but precise predictions depend on the development of statistical information in the fields of psychology and economics unavailable at present.

A proposed method of measuring deterrence: Since economic analysis did not yield definitive data on deterrence, it was proposed that the effect might be observed indirectly by studying the apprehension rate of actual traffic weight operations. For example, different states invest widely differing amounts in weight-regulation enforcement and hence presumably achieve various levels of deterrence. Their operational records might shed some light on the problem.

An inquiry was made to the Highway Commissions of every state concerning their weight-regulation enforcement. In general, they responded generously by providing operational records. However, examination of this information, although it yielded some useful insights into the problems of weight enforcement, did not provide useful data on deterrence. The administrative practices, laws, and economics of the various states vary too much to allow measuring their deterrent effects on a common scale.

The only reasonable alternative remaining was to use the operational records of Iowa itself to provide data on deterrence. Examination of Iowa records revealed that over the last several years traffic-weight operations had greatly increased its probability of apprehending vehicles and hence achieved increased deterrence. This fact provides information that can form the basis of a deterrence model.

Calculation of deterrence from apprehensions: Deterrence is measured by $V$ , the fraction of trucks that travel in violation of overweight regulations. Assume that the truck traffic, $T$ , and the probability

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1/ Some of the economic forces operating in the trucking industry are discussed in the sources indicated in Appendix 2, Bibliography.

of apprehension, $P$, are constant. As the fraction of truck trips in violation increases, so will the number of apprehensions, $A$. This is expressed by the following relationship:

$$A = T V P$$

Hence, when the values for $T$, $A$, and $P$ are known, $V$ can be determined; $V$ is equal to:

$$V = A / T P$$

The number of apprehensions and traffic were taken for each year from 1950-1967 from ISHC records. The probability of apprehension was determined from the number of enforcement personnel for those years using the Apprehension Submodel.

The details of these calculations are recorded in Appendix 1, Tab C. Figure 5 graphically depicts the deterrence model. The general shape of the curve is as expected: the fraction of the truck population in violation, $V$, drops quickly as the probability of apprehension, $P$, increases.

The data were necessarily extrapolated in the area of higher P's than the one obtained in 1967. The region shown on the graph at $P = 0.05$ and above was obtained by professional judgment of the Captains of the Iowa's T.W.O. force who indicated that 15 to 20 percent of the current violators were in violation by accident and would continue to be so independent of the probability of apprehension. A violator who does not know he is in violation cannot be deterred. Since the 1968 level of $V$ was approximately 10 percent or 0.10, the value at $P = 1$ would be $(0.15 \longrightarrow 0.20)$ of 0.10 or 0.015 - 0.02.

## 6. Road-Wear Submodel

An unapprehended overweight vehicle operating on a public road causes road wear for which incomplete compensation is made to the state. This section presents a philosophy for defining the uncompensated road wear (or cost), and also the general procedure used to calculate uncompensated costs.

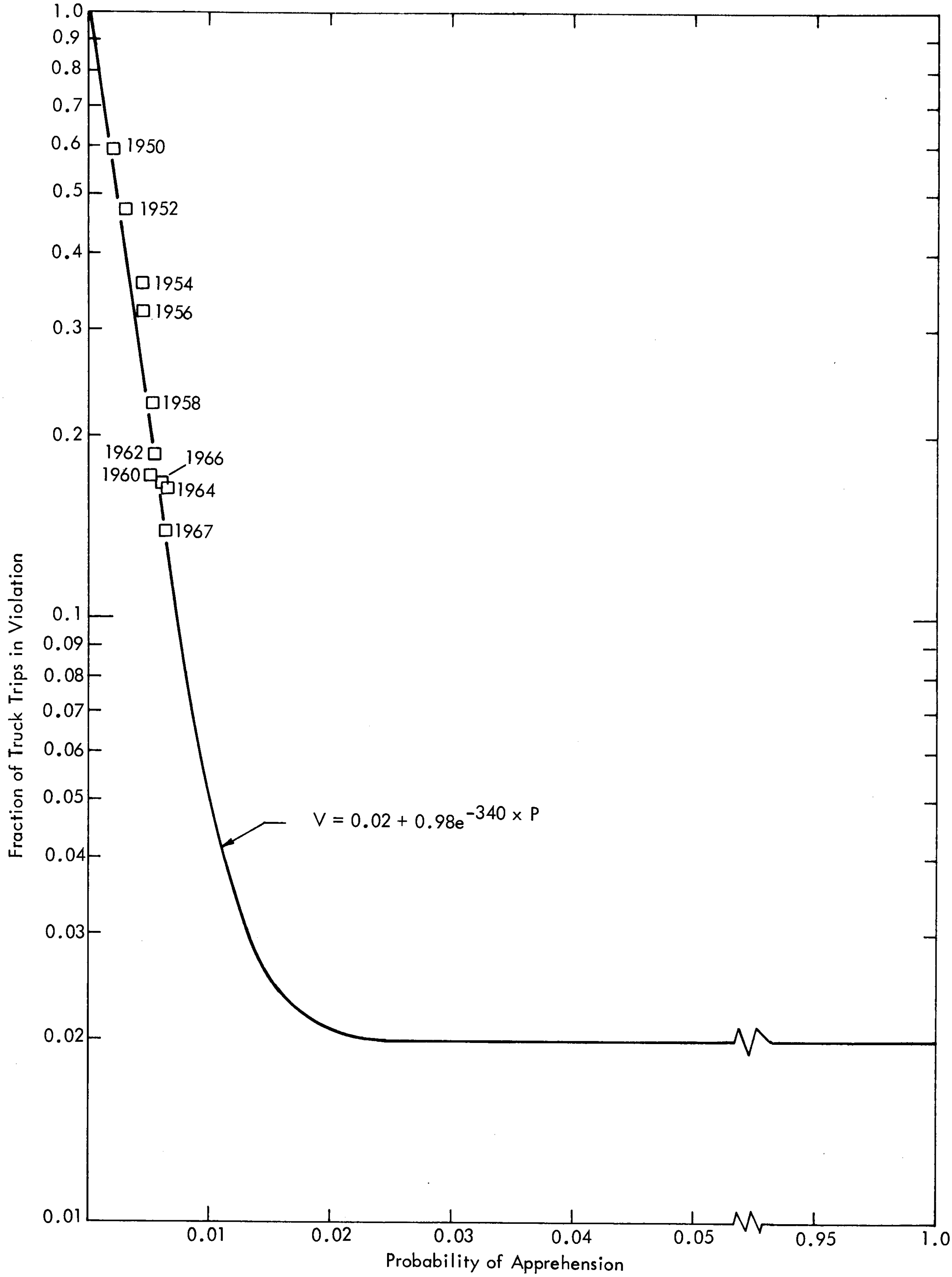


Figure 5 - Deterrence Model

Philosophy of definition: Road systems are designed to expedite the transport of goods and people with efficiency and safety. These systems serve a wide spectrum of users or other beneficiaries is a highly controversial matter. The problem of apportionment is complicated by expensive features which make the roadway suitable for use by the mixture of passenger and commercial vehicles.

It is important to recognize that the present analysis is not concerned with the subject of road-cost apportionment. Such apportionments may be guided by direct benefits, but will also be influenced by indirect benefits and policies. In Iowa, part of the ultimate apportionment lies in the schedule of vehicle-registration fees and fuel taxes. This leads to an important point of the philosophy used here. A vehicle operating within both maximum weight limits and its own current registration limit is compensating for road use in a way that is acceptable to the state governing and regulatory bodies.

When a vehicle weight exceeds maximum or registration limits, it is using the road in excess of the compensation returned to the state. In evaluating the excess, or uncompensated use, we will not establish credit for indirect benefits which may have been considered when the schedule of fees and taxes were devised. This still leaves the question; what feature(s) and associated roadway cost(s) are used by the increment of overweights? A number of things are clearly not used up by the overweight. The right-of-way, a significant part of initial road cost, is not affected by the overweight, nor is the extensive grading to minimize grades and provide long sight distances.

The item which is clearly used up by the overweight increment is the pavement. Some of the pavement life is used, and some additional increment of maintenance is probably incurred. Even here, if the vehicle is registered, it is legally entitled to use some of the pavement life and maintenance. The increment of use above the legal provision is uncompensated, and if evaluated in dollars, is an uncompensated cost to the state. The calculation of uncompensated pavement costs is outlined below.

Unquantified considerations: A number of probable uncompensated costs arise from overweight-vehicle operations which cannot be quantified on the basis of currently available knowledge.

Just as pavement structures have a useful life, so do the steel and concrete elements of bridges. Repeated loadings use up this life; increments of life-use increase with the load magnitudes. Current design practice is very conservative, and should lead to lives of several hundred years for the main steel elements.[1] The increments of life use are so small that they often lie outside the range of direct test and engineering experience. This situation is partially refuted by other findings.[2] The bridge research in the AASHO road tests showed that load distributions both dead (structure weight) and live could be significantly different than anticipated, so that some structural members loafed while others carried larger loads than anticipated. Also, in some few cases the dynamic effects from load motion were larger than is assumed in design practice. The question of bridge life is further confounded by the use of older structures which may have been conservatively designed for traffic weights and volumes of earlier years.

Vehicles which are overweight may cause uncompensated bridge expense to the state in three principal ways:

1. By uncompensated use of the fatigue life of the bridge major structural elements.

2. By uncompensated use of the bridge pavement life.

3. By incurring uncompensated additions to the bridge pavement maintenance.

With regard to fatigue life, design practice both past and present has attempted to be conservative in the allowable stress levels. As a result the fatigue lives of bridge major elements should be extremely long. The results of this conservatism are cast partly in doubt by recent findings that show load distributions to bridge elements may be quite different than anticipated in design. However, failures in major elements of bridges are very infrequent so that the expectation of long lives seems confirmed by experience. As a result the uncompensated costs due to major element life use should be small. It should be added that an attempt to evaluate such uncompensated life use is a project equal to or greater in magnitude and cost than the reference project in which the results would be applied. Part of the project cost would arise in the analyses of this variety of bridge designs which are in use and the equally varied traffic to which they are subjected.

The bridge pavement life use and maintenance use bear some resemblance to the life and maintenance relations for highway pavement. In each case the pavement is supported by an elastic structure or base. A major engineering analysis would be required to extend this comparison

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1/ "The Effects of Loadings on Bridge Life," by G. R. Cudney, Michigan Department of State Highways, January 1968.

2/ "The AASHO Road Test," Report 4, Bridge Research, HRB Special Report 61D.

to reasonably supported, quantitative relations. However, if one is willing to accept the general similarity, there are several ways to derive estimates of the average uncompensated bridge pavement costs per overweight vehicle.

One approach would select a pavement type (ground supported) simulating the primary highway bridge pavement. The average uncompensated fractions of life and maintenance use per overweight vehicle are available for the selected pavement. The original cost and maintenance cost per bridge-lane-mile would need to be obtained from state records. Multiplication of these quantities would provide products which could be used as average uncompensated cost per overweight vehicle for a bridge-lane-mile. Overall average uncompensated cost per overweight vehicle mile could then be formed by using bridge lane miles in proportion to their extent in the highway system. A similar calculation could be made for the secondary bridge and system.

The values obtained from the approximations described above would give some insight as to the relative importance of bridge pavement uncompensated costs. However, due to the technical assumptions employed, the results would be difficult to defend in comparison to the well documented values which have been used in this report.

In summary, bridge life is shortened by overloads. It is, however, not possible to define this life use and associated uncompensated cost by proven methods. This lack of definition arises largely from the incomplete state of knowledge about the actual loading and performance of bridge elements. Current investigations are attempting to clarify the situation so that economic and judicious design can replace possible overconservatism.

The overweight vehicle may overuse the road in the sense that it prevents timely use of the road by others. In calculations of traffic flow it is conventional to treat heavy commercial vehicles as though they were more than single passenger vehicles. The equivalent number of passenger vehicles depends on road grades and the like. When the commercial vehicle is above legal weight, its performance will be reduced, and it will offer a higher impedance to the traffic flow. The power available is just as important as the weight; in fact, the most significant single measure of potential performance is the ratio of weight to net horsepower. A vehicle with undersized or poorly tuned engine may offer greater impedance to traffic flow than the well-proportioned and well-maintained overweight vehicle.

Low-performance vehicles may increase the accident potential of the roadway. Like many accident-related considerations, statistical evidence is incomplete. However, it is certain that the presence of low-performance vehicles in a mixed traffic flow leads to maneuvers, conflicts, or "friction" (a term used by various investigators), and the evidence points to a connection between these situations and accident potential. Here again, overweight would tend to reduce performance and presumably augment the undesirable road situations.

None of the considerations discussed here has been explicitly included in the calculations of uncompensated costs arising from overweight vehicle operation. Some of these considerations--e.g., bridge life--might be evaluated and included. However, an extensive data collection and analysis effort would be required. Because of the incomplete state of knowledge, these costly results would be highly controversial and, when combined with better defined data, would cast doubt on the value of the results. For these reasons the explicit uncompensated costs used here have been restricted to the costs associated with pavement life and maintenance use.

Methodology for calculating uncompensated road wear costs: A road pavement is a structure designed to carry certain numbers, types, and weights of axles during its useful life. Each axle which is imposed on the pavement uses some of the available life and apparently contributes to the cost of pavement maintenance.

An axle may impose an over-legal load on the pavement because it exceeds the maximum permitted load, or because it exceeds proportionately the load for which the vehicle is registered. In either case, part of the pavement life and maintenance is used without compensation to the state. A dollar value can be assigned to the uncompensated use by employing the pavement cost and maintenance cost. This section of the report presents the methodology used in calculating average uncompensated pavement life and maintenance cost per violating vehicle mile. Major data items and distributions are identified. The individual items are treated in more detail in the Appendices.

The expression for average uncompensated cost per violating vehicle[1/] mile can be constructed to start with the smallest element, an axle traveling over a pavement. The axle passage uses some part of the

1/ "A violating vehicle is one which has axle(s) over legal weight for one of the reasons listed above. The methodology can be applied to vehicles over maximum weights or over-registration weights simply by using data from these violation types. The results presented in this report state the type or types of weight violations which were included."

the pavement life. It is conventional and convenient to express this life use in terms of reference axle applications $W_{rx}$ .[1] This equivalent number of reference axle applications depends on the axle configuration, the pavement, and the load.

$$W_{rx} = W_{rx}(\text{config., pave., load})$$

If the load imposed is over a legal limit two measures of life use are associated with its passage. The legal, or compensated, life use is given by

$$W_{rx}(\text{config., pave., legal load}) .$$

And the actual life use is given by

$$W_{rx}(\text{config., pave., actual load}) .$$

The difference is the uncompensated life use in equivalent reference axle applications,

$$\begin{aligned} W_{ru}(\text{config., pave., } L_{legal}, L_{actual}) \\ = W_{rx}(\text{config., pave., actual load}) \\ - W_{rx}(\text{config., pave., legal load}) . \end{aligned}$$

Now consider a large number of vehicles, $V_v$ , with violations involving weight. There will be an associated set of axles which are over legal limits.[2] Each of these axles can be indicated by its properties of interest, which are configuration, legal weight, and actual weight. All axles of like configuration, legal weight and actual weight can be grouped together. One number of axles in a group is A . Thus, there is a sequence of these numbers, each indicated by

$$A(\text{config., } L_{legal}, L_{actual}) .$$

Each of these numbers can be divided by $V_v$ to provide

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1/ The reference axle is a single axle of 18,000 lb.

2/ Not all axles in these vehicles will be over appropriate legal limits.

$$\frac{A(\text{config.}, L_{legal}, L_{actual})}{V_v}$$

which is the average number of such axles per violating vehicle.

The average uncompensated life use per violating vehicle, $\bar{W}_{ru}$(pave.), can now be obtained for a specified pavement. This average is formed by a sum in which each axle group contributes a term. The sum is

$$\bar{W}_{ru}(\text{pave.}) = \sum_{\text{config.}, L_{legal}, L_{actual}} \left[A/V_v\right]\left[W_{ru}\right]$$

where $A = \left[A(\text{config.}, L_{legal}, L_{actual})\right]$ and $W_{ru} = \left[W_{ru}(\text{config.}, L_{legal}, L_{actual})\right]$.

The units of the results are equivalent reference axle applications.

The useful life of the pavement is calculated in equivalent reference axle applications, $W_{tr}$(pave.). A ratio can be formed

$$\frac{\bar{W}_{ru}(\text{pave.})}{W_{tr}(\text{pave.})}$$

which is the average uncompensated life fraction used per violating vehicle. Subsequent multiplication by $C_p$(pave.), the pavement cost per lane mile, provides

$$\bar{C}_p(\text{pave.}) = C_p(\text{pave.}) \frac{\bar{W}_{ru}(\text{pave.})}{W_{tr}(\text{pave.})}$$

which is the average uncompensated pavement life cost per violating vehicle mile. The units are \$/(violating vehicle mile).

A parallel development is made for the uncompensated maintenance costs. The development and forms differ in two ways. First, the analytical forms for equivalent reference axle applications, $W_{rx}$, differ from those used for life calculations. (The denominator $W_{rt}$(pave.) is unchanged since the total <u>life</u> in reference axle applications is required.) Second, maintenance costs are generally available as yearly costs so that $C_p$(pave.)

is replaced by $C_{my}(\text{pave.}) \cdot Y$ , where $C_{my}(\text{pave.})$ = Yearly maintenance cost per lane mile.

Y = the number of calendar years of useful pavement life. The product of these quantities is, of course, the maintenance cost per lane mile during the pavement useful life.

The average uncompensated pavement maintenance cost per violating vehicle mile is then

$$\bar{C}_m(\text{pave.}) = C_{my}(\text{pave.}) \cdot Y \frac{\bar{W}_{rmu}(\text{pave.})}{W_{tr}(\text{pave.})}$$

where $\bar{W}_{rmu}$ is the average uncompensated maintenance use per violating vehicle. The units of $\bar{W}_{rmu}$ are equivalent reference axle applications.

As indicated by the pave., in parenthesis, the values $\bar{C}_p(\text{pave.})$ and $\bar{C}_m(\text{pave.})$ are calculated for, and apply to, a specific pavement structure. When added they provide for the specified pavement

$$\bar{C}_{p+m}(\text{pave.}) = \bar{C}_p(\text{pave.}) + \bar{C}_m(\text{pave.})$$

which is the average uncompensated cost, pavement life and maintenance, per violating vehicle mile.

In order to obtain an average over a road system, it is nesessary to sum, in proper proportion, uncompensated costs which are incurred by violating vehicles on all pavements in the road system. The emphasis to be given each pavement must account for the road miles of the pavement and the quantity of traffic which traverses those miles. The weight factors used here are

$$F(\text{pave.}) = \frac{M(\text{pave.}) \cdot W_{tr}(\text{pave.})}{\sum_{\text{pave.}} \left[M(\text{pave.}) \cdot W_{tr}(\text{pave.})\right]}$$

where $M(\text{pave.})$ = Miles of road in the analyzed system with specified pavement.

$W_{tr}(\text{pave.})$ = Number of reference axles which the pavement should carry in its useful life.

This formulation assigns quantity of traffic according to total traffic for which the pavement is designed. An alternate form for the weight factors is

$$F'(\text{pave.}) = \frac{M(\text{pave.}) \cdot \left[W_{tr}(\text{pave.})\right]^n}{\sum_{\text{pave.}} \left\{ M(\text{pave.}) \cdot \left[W_{tr}(\text{pave.})\right]^n \right\}}$$

where the exponent $n$ lies in the range $0. \leq n \leq 1.0$. A value of $n$ less than 1.0 has the effect of de-emphasizing roads designed for large traffic lifetimes and emphasizing roads designed for lesser traffic lifetimes. The appropriate value of $n$ will generally be less than one since new highway construction is designed for projected traffic which may not exist yet while older roads may be carrying a volume of traffic larger than their design basis. The $n$ less than one will cause an increase in uncompensated costs. The value $n = 1.0$ is used in reported numerics and should provide conservatively low uncompensated costs.

A final summation provides a system-wide, average-uncompensated-cost-per-violating-vehicle-mile. The sum employs the weight factors and pavement related costs which have been presented. The sum is

$$\bar{C}_s = \sum_{\text{pave.}} \left[F(\text{pave.}) \cdot \bar{C}_{p+m}(\text{pave.})\right]$$

<u>Consideration in employment</u>: There is some flexibility in the definition of violating vehicles. If violating vehicles are restricted to those which are over legal maximum weights in some respect (as opposed to over-registration limits), then the number $V_v$ will include only those vehicles which meet this definition. Likewise, the set of axle characteristics $A(\text{config.}, L_{legal}, L_{actual})$ will include only those which were obtained for vehicles which qualified as violators. The calculations could also be carried out for vehicles which were over their registration limits. A different value $V_v$ and set of values $A(\text{config.}, L_{legal}, L_{actual})$ would be extracted from weight-station measurements and employed.

To be meaningful, results must be accompanied by statements describing the data and definition employed.

7. Alternative Enforcement Systems Considered

There are many possible ways in which weight enforcement might be improved. Based on analysis of information obtained from a variety of sources, a list was compiled of such alternative methods or systems of enforcement.1/

Figure 6 lists the alternatives considered in the study. The performance achieved by such candidates are discussed later in the report.

## B. Results

### 1. Staff Level

Introduction: As discussed in Section III-A-1, the staff level chosen as the best or "optimum" should be based on, at least initially, the manning that would produce the maximum benefit to Iowa. The value arrived at in this manner should then be reviewed for feasibility of implementation.

The optimum staff level based on current manpower efficiency is considered first.

Method of data acquisition and analysis: The cost-effectiveness methodology was implemented by coding it on a 360/30 computer, and the inputs were obtained from the sources described in the various Appendices. The program was run using the traffic conditions forecast for Iowa for Fiscal Year 1968 with the current methods of T.W.O. enforcement. The benefit and costs to Iowa of operating T.W.O. with staff levels ranging from 15 - 400 were calculated. The computer results are shown as actually printed out in Figure 7. Figures 8, 9, and 10 are graphical displays of the same results.

Results: The optimum staff level for Iowa T.W.O., using current apprehension methods, is 79 men.

Interpretation of the results: The interpretation of the above results requires a clear understanding of the methodology. Our basic decision rule can be stated in this manner: Add one additional man if the additional benefit he contributes is at least as much as his cost to the system. At a staff level of 78 men, one additional man adds slightly more benefit than his cost of approximately $9,000 per year.

1/ See Appendix 2, Bibliography and Data Sources.

| System No. | Short System Name or Description | Full Description and Comments |
|---|---|---|
| 1 | Present System | 64 men and 31 inspection sites. Fixed stations and some roving patrol to cover station by passing and absence of sites in some areas. No communication equipment. |
| 2 | Personnel Expansion/ Contraction | Reliance on current methods and equipment but increase or decrease in enforcement personnel. No increase in inspector sites. |
| 3 | Personnel Expansion & New Fixed Sites | Use of current methods, but expansion of operations by addition of proposed sites and increase of staff to man them. |
| 4 | Addition of Lee Type Inspection Sites | Use of Lee scales to improve effectiveness of roving patrols. Probable increase in roving patrol efforts. Lee type scales are small load cell type scales imbedded under surface of highway to weigh moving trucks. |
| 5 | Major Procedural (Legal?) Changes | Adoption of more random schedules, shorter fixed site operating periods, smaller site crews, delayed and wholesale prosecution, radio communications, simpler reciprocity and prorata processing, better violator identification. |
| 6 | Major Equipment Changes & Some Procedural Changes | Use of Lee Sites, Michigan Sites, automatic data recording, new communication equipment, aircraft, etc., to stretch manpower. |
| 7 | Combination of Best Features | Use of best features of Systems 1 - 6. |

Figure 6 - List of Candidate Enforcement Systems

COST - BENEFIT MODEL

| Staff | Net Revenue (thousand $) | Revenue Registration (thousand $) | Revenue Fixed Sites (thousand $) | Revenue Roving Patrol (thousand $) | Revenue Road Wear Prevented (thousand $) | Total Revenue (thousand $) | Operating Cost (thousand $) | Probability Apprehension | Fraction Violating |
|---|---|---|---|---|---|---|---|---|---|
| 15 | 3517. | 803. | 399. | 185. | 2318. | 3706. | 189. | .0017 | .5779 |
| 20 | 4245. | 985. | 445. | 206. | 2842. | 4478. | 233. | .0022 | .4825 |
| 25 | 4814. | 1135. | 464. | 215. | 3277. | 5092. | 278. | .0028 | .4034 |
| 30 | 5258. | 1260. | 467. | 216. | 3637. | 5580. | 322. | .0033 | .3378 |
| 35 | 5600. | 1363. | 457. | 212. | 3935. | 5967. | 367. | .0039 | .2835 |
| 40 | 5863. | 1449. | 439. | 203. | 4183. | 6274. | 411. | .0044 | .2385 |
| 45 | 6062. | 1520. | 417. | 193. | 4388. | 6517. | 456. | .0050 | .2012 |
| 50 | 6205. | 1579. | 392. | 181. | 4557. | 6709. | 505. | .0055 | .1702 |
| 55 | 6312. | 1628. | 366. | 170. | 4698. | 6861. | 549. | .0061 | .1446 |
| 60 | 6387. | 1668. | 340. | 158. | 4815. | 6981. | 594. | .0066 | .1233 |
| 65 | 6438. | 1702. | 316. | 146. | 4912. | 7076. | 638. | .0072 | .1057 |
| 70 | 6468. | 1730. | 293. | 136. | 4992. | 7151. | 683. | .0077 | .0911 |
| 75 | 6482. | 1753. | 272. | 126. | 5059. | 7210. | 727. | .0083 | .0790 |
| 80 | 6485. | 1772. | 253. | 117. | 5114. | 7256. | 772. | .0088 | .0689 |
| 85 | 6477. | 1788. | 237. | 110. | 5160. | 7293. | 816. | .0094 | .0606 |
| 90 | 6462. | 1801. | 222. | 103. | 5198. | 7323. | 861. | .0099 | .0537 |
| 95 | 6428. | 1812. | 209. | 97. | 5229. | 7347. | 919. | .0105 | .0479 |
| 100 | 6403. | 1821. | 198. | 92. | 5255. | 7366. | 964. | .0110 | .0432 |
| 105 | 6374. | 1828. | 189. | 88. | 5277. | 7382. | 1008. | .0116 | .0392 |
| 110 | 6343. | 1834. | 182. | 84. | 5295. | 7395. | 1053. | .0121 | .0360 |
| 115 | 6309. | 1840. | 175. | 81. | 5310. | 7406. | 1097. | .0127 | .0333 |
| 120 | 6274. | 1844. | 171. | 79. | 5322. | 7416. | 1142. | .0132 | .0310 |
| 125 | 6238. | 1847. | 167. | 78. | 5332. | 7424. | 1186. | .0138 | .0291 |
| 130 | 6201. | 1850. | 164. | 76. | 5341. | 7432. | 1231. | .0143 | .0276 |
| 135 | 6164. | 1853. | 163. | 76. | 5348. | 7439. | 1275. | .0149 | .0263 |
| 140 | 6126. | 1855. | 162. | 75. | 5354. | 7446. | 1320. | .0154 | .0252 |
| 145 | 6088. | 1857. | 162. | 75. | 5359. | 7452. | 1364. | .0160 | .0243 |
| 150 | 6050. | 1858. | 162. | 75. | 5363. | 7458. | 1409. | .0165 | .0236 |
| 155 | 6000. | 1859. | 163. | 76. | 5366. | 7464. | 1465. | .0170 | .0230 |
| 160 | 5961. | 1860. | 165. | 77. | 5369. | 7470. | 1509. | .0176 | .0225 |
| 165 | 5923. | 1861. | 167. | 77. | 5371. | 7476. | 1554. | .0181 | .0221 |
| 170 | 5884. | 1862. | 169. | 79. | 5373. | 7482. | 1598. | .0187 | .0217 |
| 175 | 5845. | 1862. | 172. | 80. | 5375. | 7488. | 1643. | .0192 | .0214 |
| 180 | 5807. | 1863. | 174. | 81. | 5376. | 7494. | 1687. | .0198 | .0212 |
| 185 | 5769. | 1863. | 178. | 83. | 5377. | 7500. | 1732. | .0203 | .0210 |
| 190 | 5730. | 1863. | 181. | 84. | 5378. | 7506. | 1776. | .0209 | .0208 |
| 195 | 5692. | 1863. | 184. | 86. | 5379. | 7512. | 1821. | .0214 | .0207 |
| 200 | 5653. | 1864. | 188. | 88. | 5379. | 7519. | 1865. | .0220 | .0206 |

Figure 7 - Calculation of Optimum Staff Level

| Staff | Net Revenue (thousand $) | Revenue Registration (thousand $) | Revenue Fixed Sites (thousand $) | Revenue Roving Patrol (thousand $) | Revenue Road Wear Prevented (thousand $) | Total Revenue (thousand $) | Operating Cost (thousand $) | Probability Apprehension | Fraction Violating |
|---|---|---|---|---|---|---|---|---|---|
| 205 | 5615. | 1864. | 192. | 89. | 5380. | 7525. | 1910. | .0225 | .0205 |
| 210 | 5577. | 1864. | 196. | 91. | 5380. | 7531. | 1954. | .0230 | .0204 |
| 215 | 5539. | 1864. | 200. | 93. | 5381. | 7537. | 1999. | .0236 | .0203 |
| 220 | 5501. | 1864. | 204. | 95. | 5381. | 7544. | 2043. | .0241 | .0203 |
| 225 | 5462. | 1864. | 208. | 97. | 5381. | 7550. | 2088. | .0247 | .0202 |
| 230 | 5424. | 1864. | 212. | 99. | 5381. | 7557. | 2132. | .0252 | .0202 |
| 235 | 5386. | 1864. | 216. | 101. | 5382. | 7563. | 2177. | .0258 | .0202 |
| 240 | 5348. | 1865. | 220. | 103. | 5382. | 7570. | 2221. | .0263 | .0201 |
| 245 | 5310. | 1865. | 225. | 105. | 5382. | 7576. | 2266. | .0269 | .0201 |
| 250 | 5272. | 1865. | 229. | 107. | 5382. | 7583. | 2310. | .0274 | .0201 |
| 255 | 5234. | 1865. | 233. | 109. | 5382. | 7589. | 2355. | .0279 | .0201 |
| 260 | 5196. | 1865. | 238. | 111. | 5382. | 7596. | 2399. | .0285 | .0201 |
| 265 | 5158. | 1865. | 242. | 113. | 5382. | 7602. | 2444. | .0290 | .0201 |
| 270 | 5120. | 1865. | 247. | 115. | 5382. | 7609. | 2488. | .0296 | .0200 |
| 275 | 5082. | 1865. | 251. | 117. | 5382. | 7615. | 2533. | .0301 | .0200 |
| 280 | 5044. | 1865. | 255. | 119. | 5382. | 7622. | 2577. | .0307 | .0200 |
| 285 | 5006. | 1865. | 260. | 121. | 5382. | 7628. | 2622. | .0312 | .0200 |
| 290 | 4968. | 1865. | 264. | 123. | 5382. | 7635. | 2667. | .0317 | .0200 |
| 295 | 4930. | 1865. | 269. | 126. | 5382. | 7642. | 2711. | .0323 | .0200 |
| 300 | 4893. | 1865. | 273. | 128. | 5382. | 7648. | 2756. | .0328 | .0200 |
| 305 | 4855. | 1865. | 278. | 130. | 5382. | 7655. | 2800. | .0334 | .0200 |
| 310 | 4817. | 1865. | 282. | 132. | 5382. | 7661. | 2845. | .0339 | .0200 |
| 315 | 4779. | 1865. | 287. | 134. | 5382. | 7668. | 2889. | .0344 | .0200 |
| 320 | 4741. | 1865. | 291. | 136. | 5382. | 7674. | 2934. | .0350 | .0200 |
| 325 | 4703. | 1865. | 296. | 138. | 5382. | 7681. | 2978. | .0355 | .0200 |
| 330 | 4665. | 1865. | 300. | 140. | 5382. | 7688. | 3023. | .0361 | .0200 |
| 335 | 4627. | 1865. | 305. | 142. | 5382. | 7694. | 3067. | .0366 | .0200 |
| 340 | 4589. | 1865. | 309. | 144. | 5382. | 7701. | 3112. | .0371 | .0200 |
| 345 | 4551. | 1865. | 314. | 147. | 5382. | 7707. | 3156. | .0377 | .0200 |
| 350 | 4513. | 1865. | 318. | 149. | 5383. | 7714. | 3201. | .0382 | .0200 |
| 355 | 4475. | 1865. | 322. | 151. | 5383. | 7721. | 3245. | .0388 | .0200 |
| 360 | 4437. | 1865. | 327. | 153. | 5383. | 7727. | 3290. | .0393 | .0200 |
| 365 | 4399. | 1865. | 331. | 155. | 5383. | 7734. | 3334. | .0398 | .0200 |
| 370 | 4362. | 1865. | 336. | 157. | 5383. | 7740. | 3379. | .0404 | .0200 |
| 375 | 4324. | 1865. | 340. | 159. | 5383. | 7747. | 3423. | .0409 | .0200 |
| 380 | 4286. | 1865. | 345. | 161. | 5383. | 7753. | 3468. | .0415 | .0200 |
| 385 | 4248. | 1865. | 349. | 163. | 5383. | 7760. | 3512. | .0420 | .0200 |
| 390 | 4210. | 1865. | 354. | 166. | 5383. | 7767. | 3557. | .0425 | .0200 |
| 395 | 4172. | 1865. | 358. | 168. | 5383. | 7773. | 3601. | .0431 | .0200 |
| 400 | 4134. | 1865. | 363. | 170. | 5383. | 7780. | 3646. | .0436 | .0200 |

Figure 7 - (Concluded)

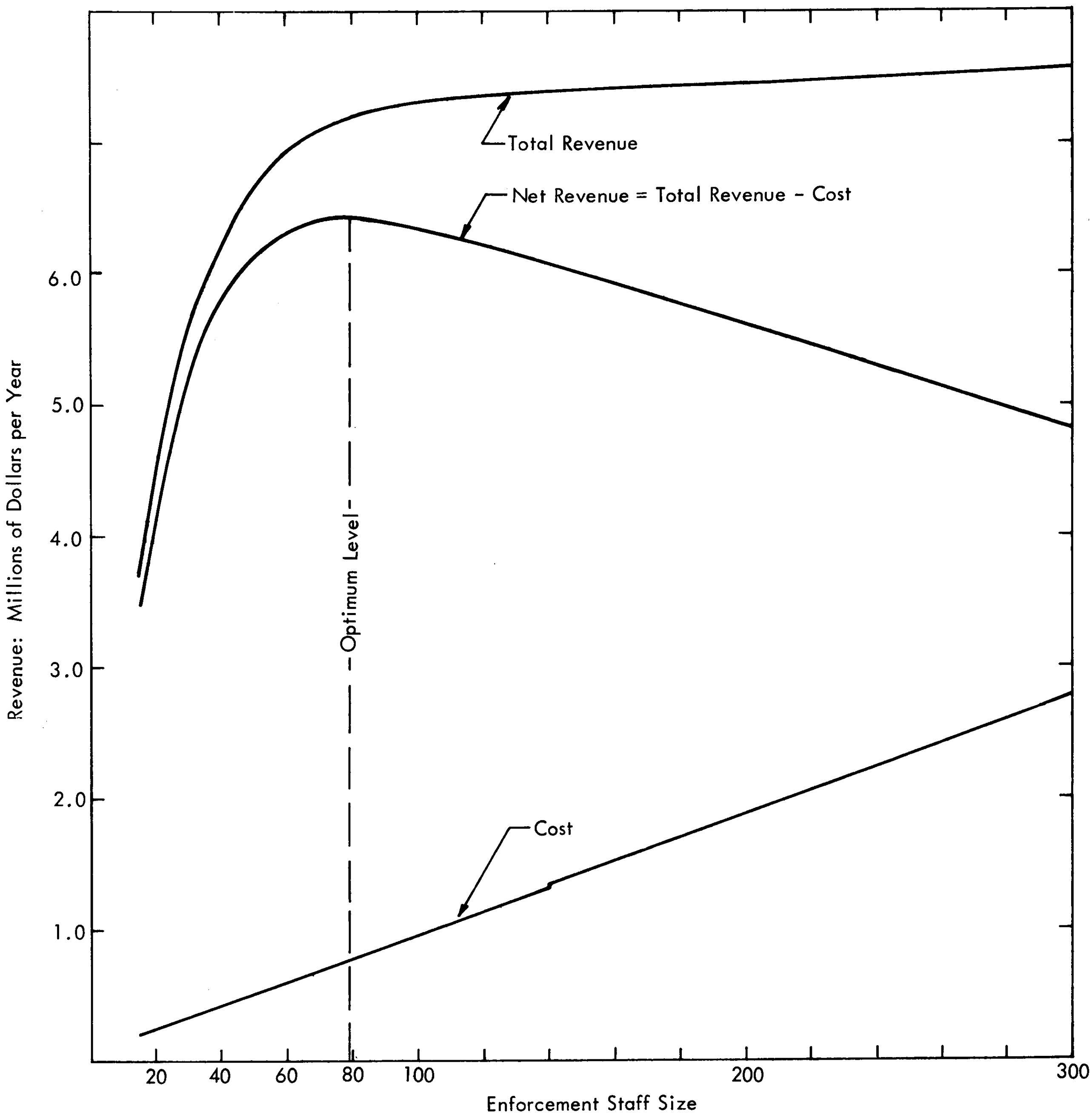


Figure 8 - Total Revenue, Net Revenue, and Cost
Versus Staff Level

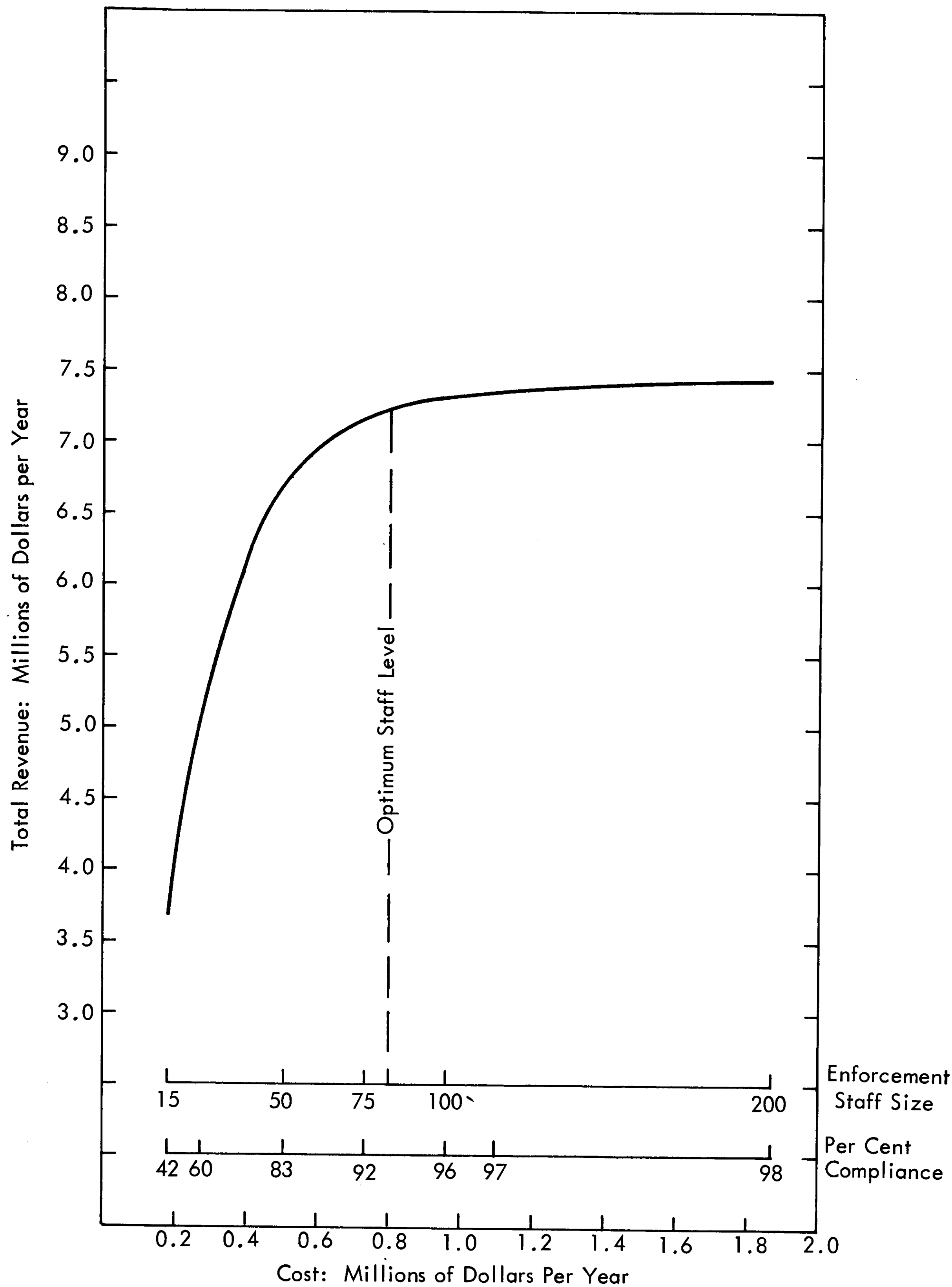


Figure 9 - Total Revenue Versus Cost

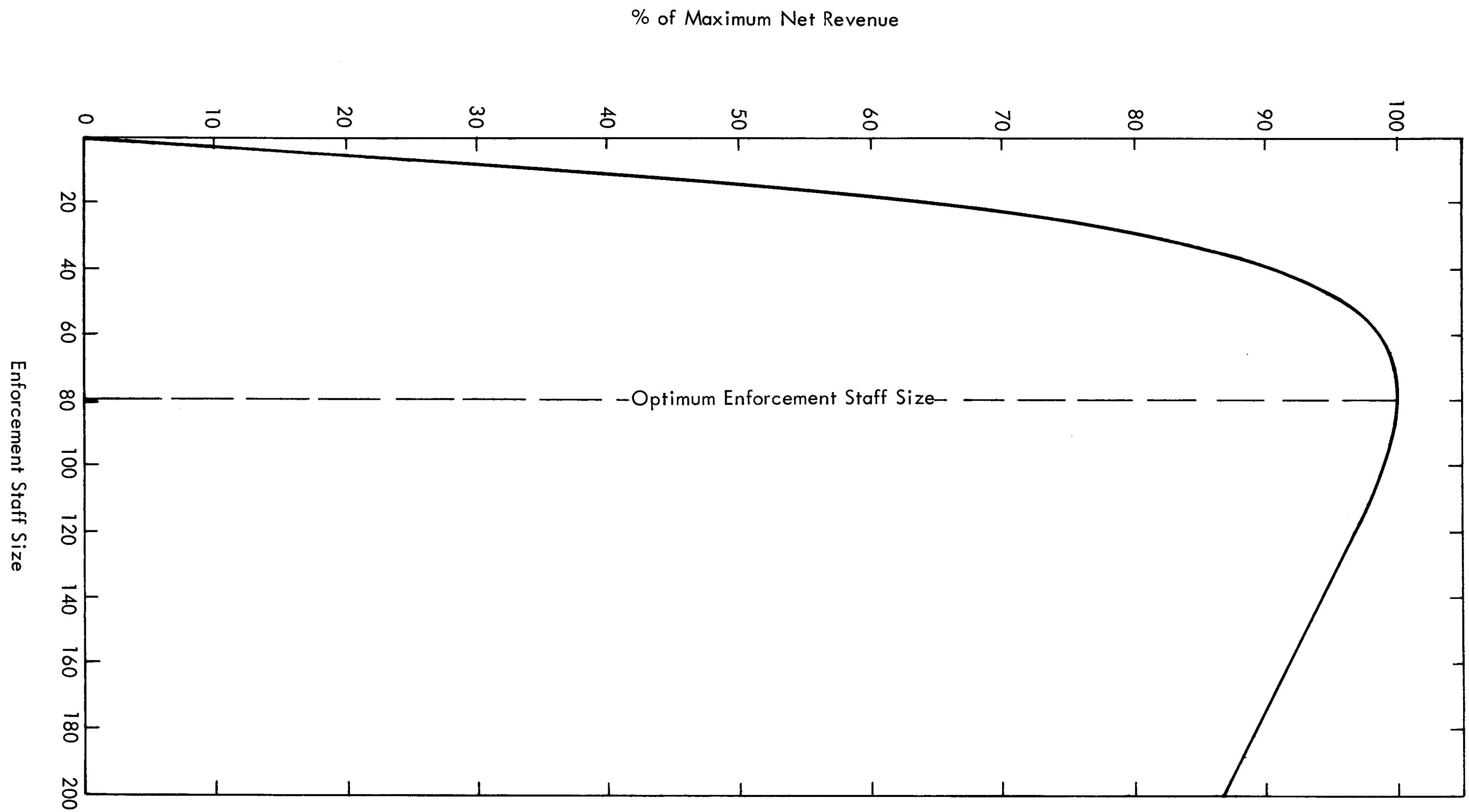


Figure 10 - Percentage of Theoretical Maximum Profit Obtained at Various Staff Levels

When the staff is 79 men, adding another employee would add less than $9,000 benefit. While T.W.O. would continue to have a positive net revenue when the enforcement level is greater than the optimum, the net benefit would continually decrease. The optimum enforcement level, 79 men, yields $6,480,000 in benefits from T.W.O. At a 200-man staff level, the net revenue would be $830,000 per year less.

Figure 9 shows that the percent compliance at the optimum staff level of 79 is about 93 percent. In Figure 9, Total Revenue vs. Cost, it can also be seen that a dollar of investment in T.W.O. returns a dollar in revenue at 79 men. Dollars invested beyond 79 men do not bring in a return to cover the extra investment. It should be recalled that revenue credited to T.W.O. for increased compliance includes a credit for the reduction of road wear. Further staff increases would improve compliance as shown in Figure 9, but the cost would not be commensurate with the benefit.

Figure 10 shows that the current staff level of 64 is very close to optimum in the sense that it results in Iowa obtaining more than 99 percent of the profit associated with the optimal level. Raising the staff level by 15 men will result in a profit increase of about $50,000 per year.

## 2. Sensitivity of Staff Level Results to Data Errors and Assumption

Introduction: Every method of study is subject to limitations. Two major limitations of quantitative analyses are: (1) that they can be no more accurate than the data used to make them, and (2) they necessarily must make assumptions about the state of the real world that are sometimes only partially true. The results of the study, therefore, apply fully only in the circumstances postulated in the analysis.

As long as these two restrictions are kept in mind, there is little danger that the results of this or of similar studies will be misinterpreted and misapplied.

In order to give some insight into how sensitive the results of the study are to data errors and assumptions, a series of sensitivity analyses were prepared.

Method of data analysis: The cost/effectiveness program was modified to cycle through a series of values for each major parameter influencing the optimum staff level. These included the following:

a. Apprehension Efficiency (as measured by the Apprehension Constant $K_A$ )

b. Deterrence Efficiency (as measured by the Deterrence Constant $K_D$ )

c. Average Fine or Registration Increase per Violator Apprehended

d. Average Loss to Iowa Due to a Violation

The effect of apprehension and deterrence efficiency on optimum staff level is shown together on Figure 10. The apprehension constant, $K_A$ , is a direct measure of the efficiency of personnel at apprehending violators. If the efficiency of personnel at apprehending violators could be increased by 10 percent, $K_A$ would increase from $1.58 (10)^{-4}$ to $1.74 (10)^{-4}$ . This improvement would mean that the same apprehension performance could be obtained with five fewer men, i.e., the optimum staff level would be 75 men. The optimum staff level is fairly sensitive to the efficiency of the operating personnel, as might be expected. The optimum staff level has been calculated based on current efficiency as determined from T.W.O. records, however, and is appropriate for this study.

The other curves on Figure 11 indicate the sensitivity of the optimum staff level to deterrence efficiency. The two curves use different values of an exponential coefficient to fit to the deterrence data. These parametric deterrence curves are shown in Figure 12. The bigger the deterrence constant, the more easily would violators be deterred by the threat of apprehension, and the fewer men are needed to achieve a satisfactory level of compliance. The upper and lower curves represent an arbitrary 20 percent increase and decrease in the fraction of trips in violation (V). These variations produced a variation in manpower required of four men. The deterrence constant is one of the parameters probably most prone to errors because of the indirect method of its calculation (Appendix 1, Tab D). However, a 20 percent error would probably be larger than anticipated even under these circumstances.

The effect of variation in average fine on staff size is shown in Figure 12. Data on average fine per violation have been gathered for many years, with ten's of thousands of cases being handled and accounted for by automated accounting machinery. Thus, it should be anticipated that there is little likelihood of errors associated with this number. In addition, Figure 12 shows that the optimum staff level is relatively insensitive to changes in the average fine.

The average loss associated with a violation is another parameter that is the result of a complex analysis and is, therefore, relatively prone to error. The average loss per violator ($0.37) is a function of both the loss due to uncompensated road wear ($0.16) and the average increase in vehicle registration per violation($0.70).

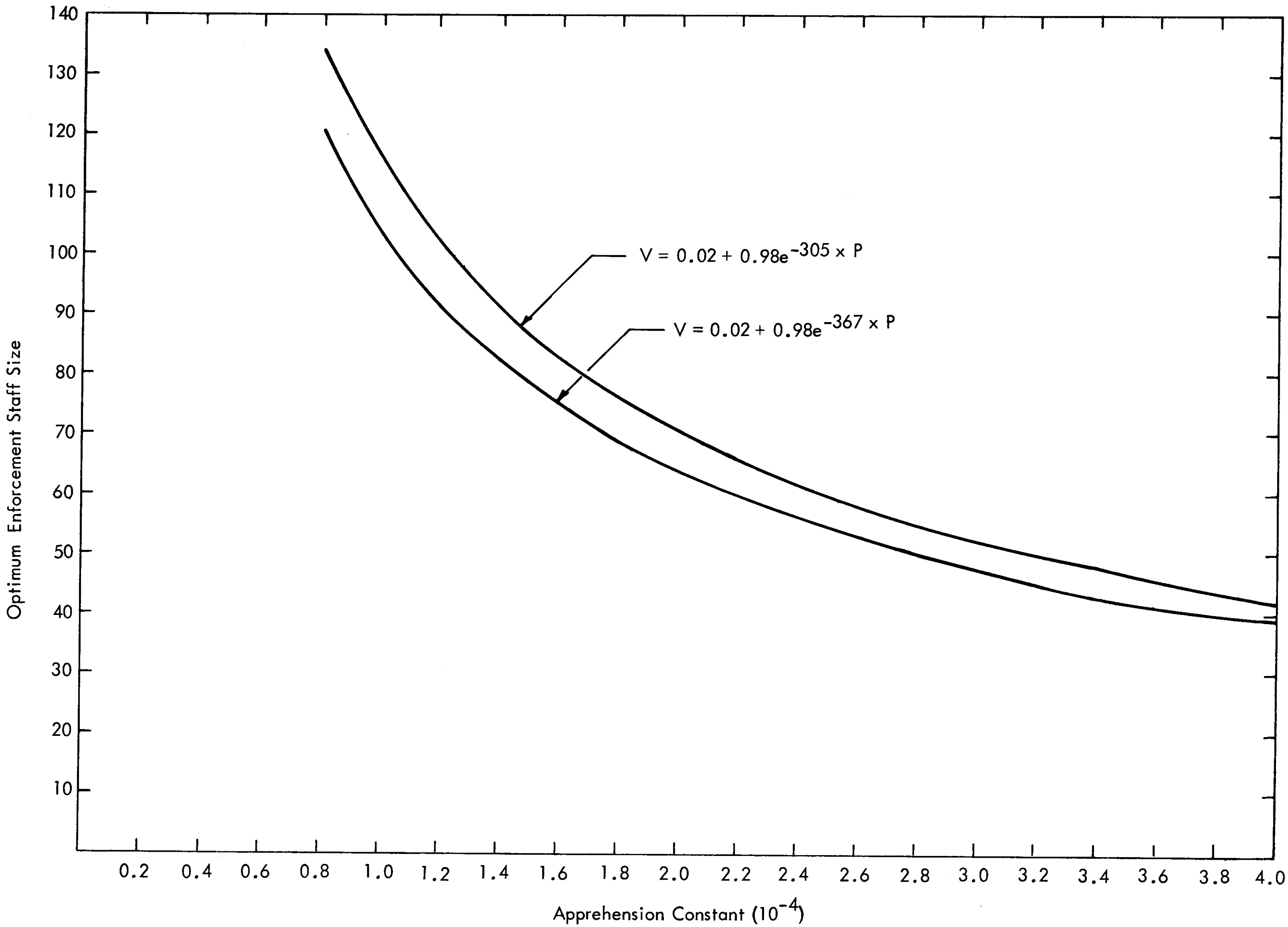


Figure 11 - Sensitivity of Optimum Staff Size to Apprehension and Deterrence Efficiency

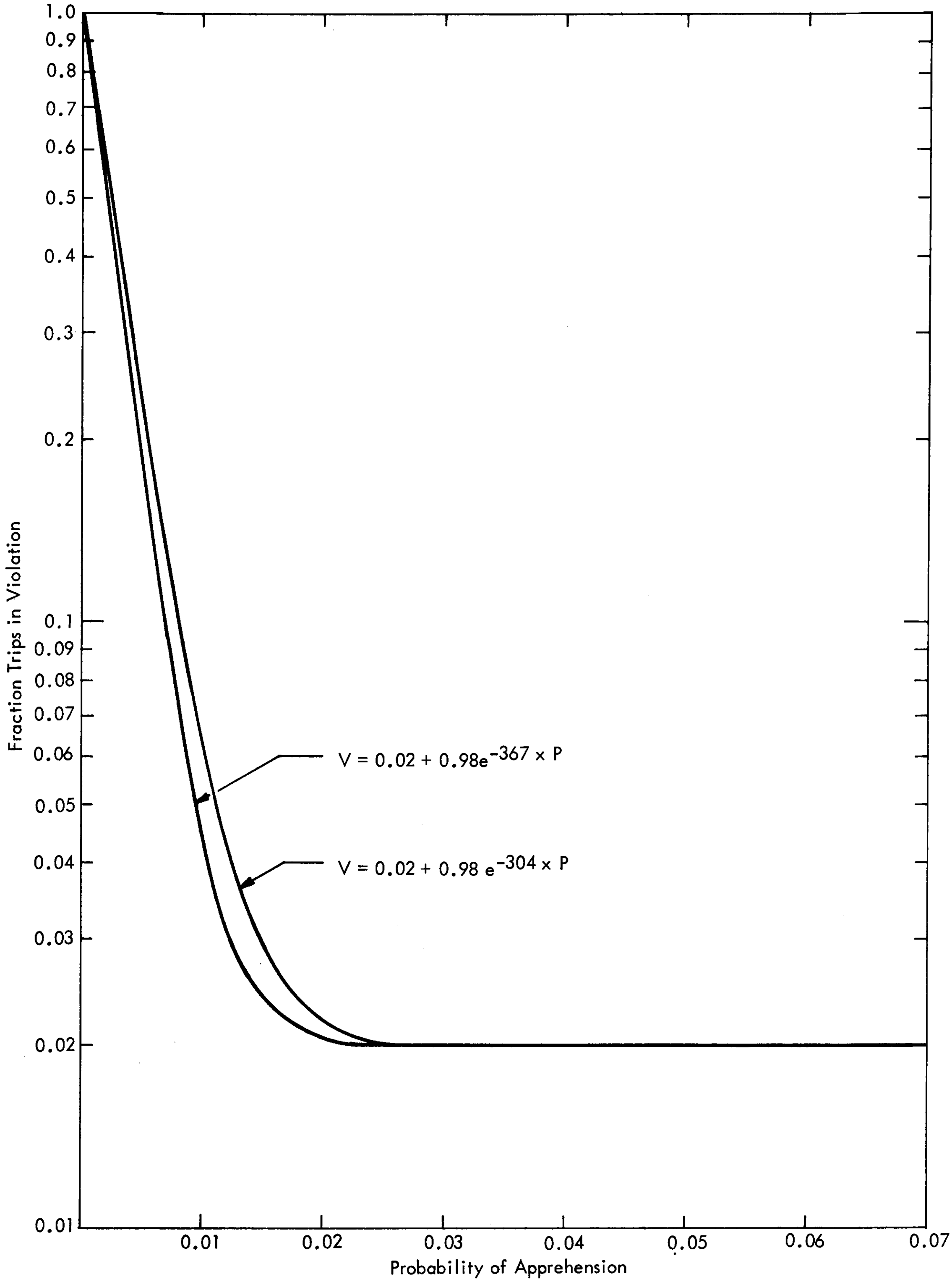


Figure 12 - Parametric Deterrence Curves

The average loss per violation can also be viewed as a credit if the violation is detained. Figure 13 shows the relationship between this benefit and the optimum staff level.

It is very likely that weight regulation enforcement has some value in preventing accidents and bridge deterioration. These factors were not included in the derivation of the $0.37 average value per trip for increased compliance because of lack of data. Addition of these factors into the analysis would have increased the average value of compliance somewhat. As can be seen on Figure 14, this would in turn have increased the optimum staff level.

## 3. Utilization of Fixed Scale Sites

Introduction: Iowa already has made a very large investment in fixed scale sites. The state now owns 31 such installations which, if purchased at today's prices, would cost in the neighborhood of $5 million.

Traffic weight enforcement operations are returning to Iowa over $6 million a year in benefits. There is little question that Iowa's fixed scales are valuable assets.

For this reason alone, an attempt to calculate after the fact an "optimum" number of scales would not seem inappropriate. The investment has already been made. The question now should be how best to utilize it. The two main factors influencing the efficiency of scale utilization are scale location and manpower allocation.

### Manpower Allocation by Scale Site

Method of analysis: This section develops rules for allocation of manpower to each fixed site location. Our approach was to develop a relative index, based on past performance, which can be used to allocate manpower in proportion to each site's benefit contribution. The net effect of the recommended strategy will be to focus the limited manpower where it is most needed, without encouraging violations in lightly traveled areas.

The method of analysis does not include any residual deterrent effect when the scale is not in operation. Any residual effect is assumed to be proportional to the total contribution per operating hour shown in Figure 14.

Figure 14 shows the dollar value of fines collected per operating hour for each site. Note that these values range from $19.10 to $2.80 per operating hour. The individual differences in traffic volume, fraction of trips in violation and the average fine per violation account for this wide and significant range in fines collected per operating hour.

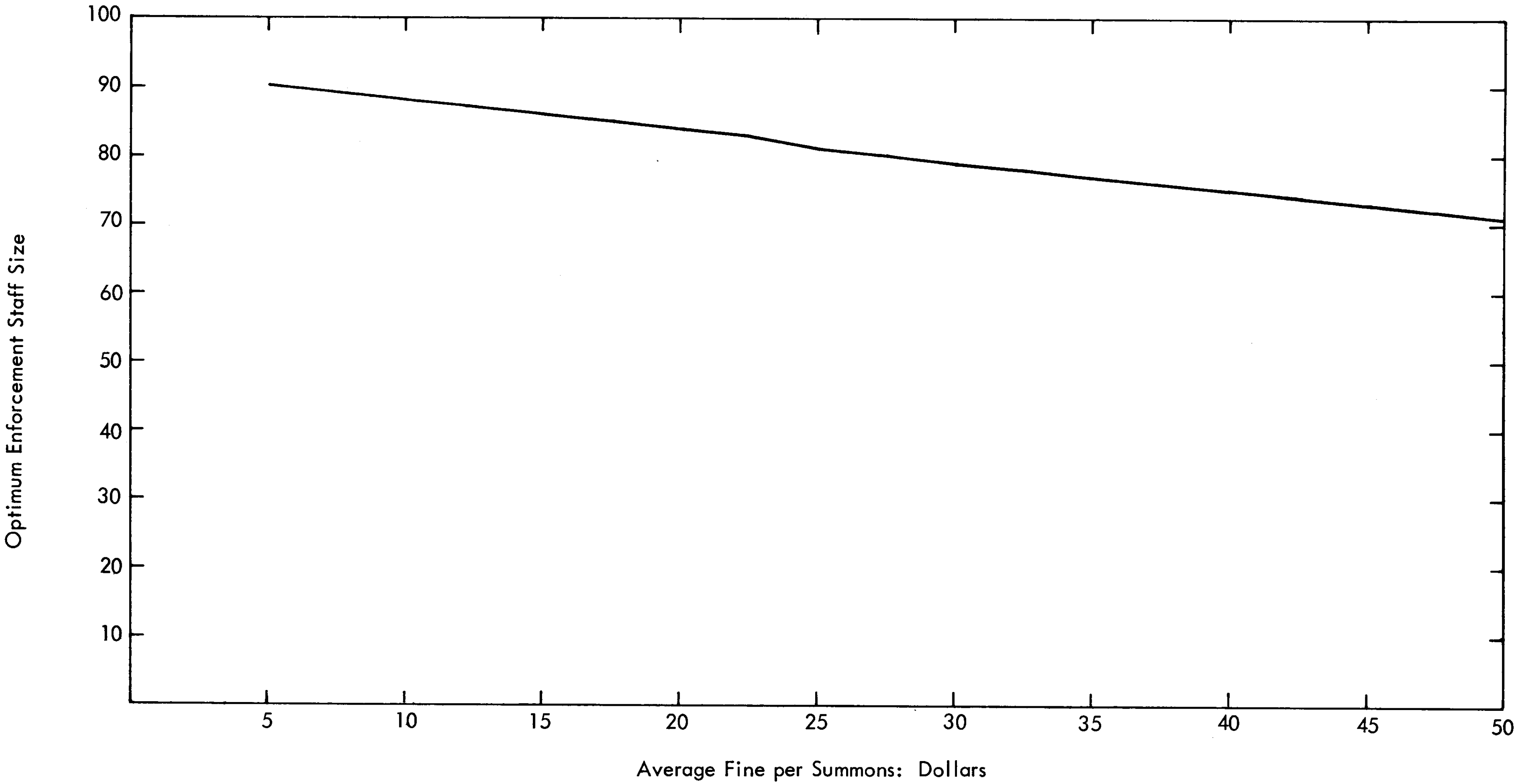


Figure 13 - Sensitivity of Optimum Enforcement Staff to Average Fine per Summons

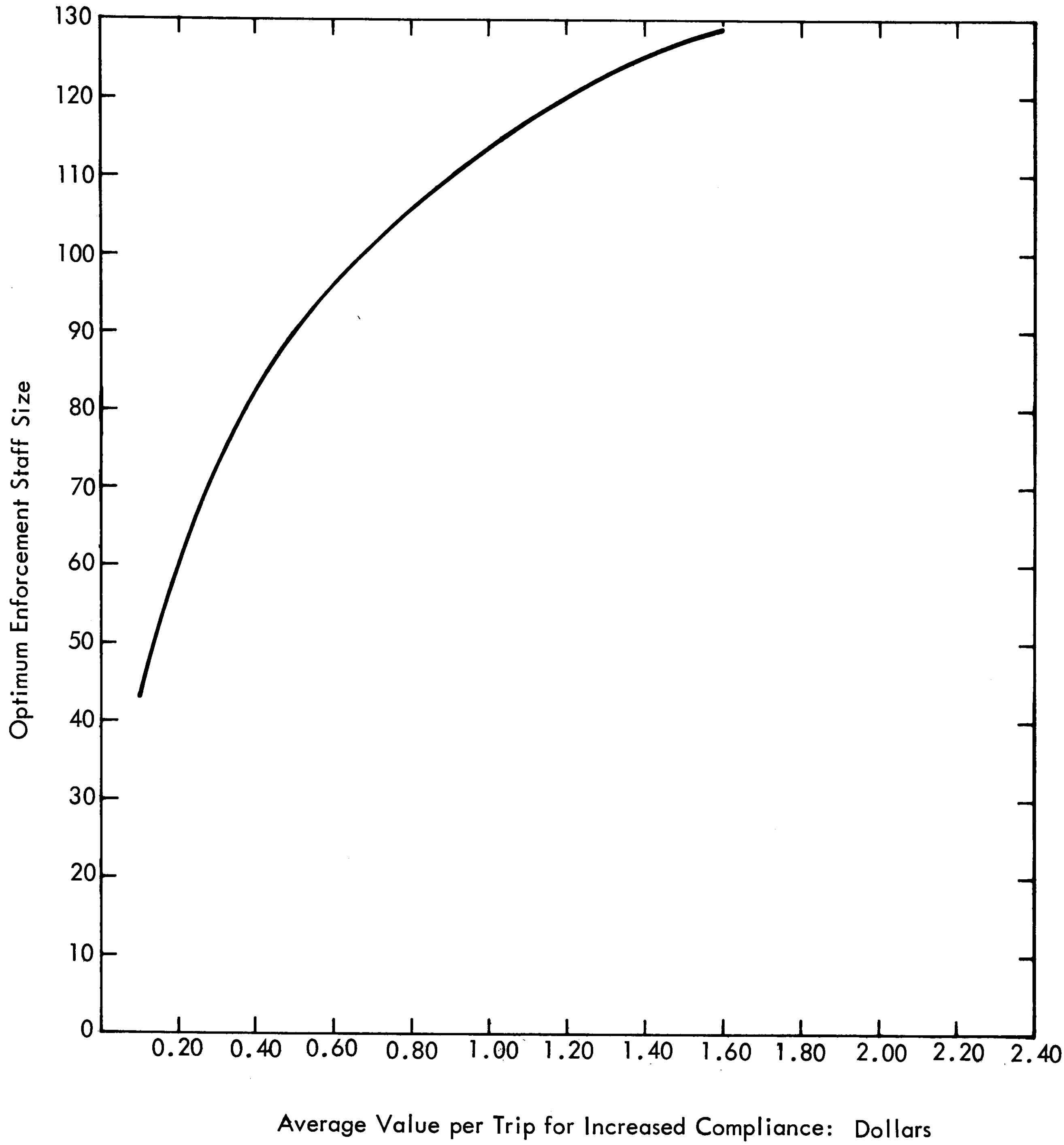


Figure 14 - Sensitivity of Optimum Enforcement Staff to Average Value Per Trip for Increased Compliance

Besides fines collected per operating hour the index also includes a value earned from increased compliance. The observed fraction of trips in violation at individual sites is about 2 percent compared to a statewide average of 14 percent. The 1967 Loadometer Survey provided a basis for calculating an estimate that 14 percent of the truck traffic was in violation of one or more of the regulations enforced by T.W.O. This indicated that the general compliance level on Iowa highways was 86 percent. The deterrence model used in this study recognizes the increased compliance effect of increased enforcement effort. In 1968, the enforcement staff was increased which causes the general compliance level to rise to approximately 90 percent. The average observed compliance at traffic weight stations was 98 percent. These weight stations observe approximately 5 percent of the annual truck trips on Iowa highways. Since no decay either in violations or in rate of traffic flow could be observed from the experiment designed to test this phenomenon, it is likely that the fraction of violators in traffic passing a fixed weight station remains largely the same whether the scale is opened or closed, and consists primarily of accidental violators. It may be concluded that intentional violators of T.W.O. enforced regulations deliberately avoid passing fixed scale site locations.

The value of the increased local compliance is the product of the traffic ($T_h$), times the local increase in compliance ($V-V_s$) and the average loss to Iowa per overweight or oversize vehicle ($L_v$). The total hourly contribution, $B_h$, of a scale is the sum of the dollar value of fines collected per operating hour, $F_h$, and the value of increased compliance per operating hour.

<u>Sample calculation of benefits due to scale operation</u>: Station 245N has the following characteristics:

$F_h$ = \$18.20 average revenue collected from fines per operating hour

$L_v$ = \$0.37 average loss per violator (see Appendix 1)

$T_h$ = 41.7 vehicles inspected per operating hour

$V_s$ = 0.017, the fraction of vehicles inspected which are in violation

$V$ = 0.14, the 1967 fraction of vehicles in violation

$$B_h = T_h L (V-V_s) + F_h$$

$$B_h = 41.7 (0.37)(0.14 - 0.017) + 18.20$$

$B_h$ = \$20.10 total benefit earned per operating hour for station 245N

<u>Results of the analysis</u>: Similar calculations were performed for each fixed-weight station in order to determine the benefits earned. Figure 15 presents the results of the analysis.

The recommended allocations of manpower per fixed site location is expressed as a percentage of the manpower available for fixed site operation. For example, at the present enforcement level of 64 men, with 53 percent (34 men) allocated to fixed site operation, station 245N should receive 5.59 percent of the available manpower. This is equivalent to about 80 man-hours per week.

The manpower allocation should be periodically reviewed to reflect changes in traffic patterns. These changes may be a direct response to the allocation of manpower. In any case, the objective is to cause the maximum deterrent effect. By allocating manpower in proportion to the fines, value of fines, and value of increased compliance, this objective will be approached.

<u>New scale construction</u>: As traffic patterns change, shifts in manpower allocation may not be enough to maintain efficient utilization of manpower and scales. In these circumstances new scale construction and/or old scale elimination should be considered. The two basic factors to consider when evaluating a proposed scale site are the following:

a. Purchase cost

b. Benefit

If the purchase cost of a new site exceeds the anticipated benefit, a proposed site should not be built. The purchase cost is generally a known factor based on a construction bid. Current estimates range from $80,000 to about $225,000. The cost to Iowa may be reduced in some cases by federal government contributions totaling about 80 percent of the cost.

The benefits from owning a scale accrue during the life of the site which is approximately that of the road it protects. Twenty years is a good planning figure. Care should be taken whenever possible to anticipate future shifts in traffic patterns which might shorten the useful life of a proposed scale.

The decision whether to build a new scale involves determining what is economical in the long run. In such problems it is necessary to recognize the time value of money. Because of the existence of interest a dollar now is worth more than the prospect of a dollar next year or at some future time. Given an interest rate, we may say that any payment or series of payments that will repay a present sum of money with interest at that rate is equivalent to the present value.

Figure 15

RECOMMENDED MANPOWER ALLOCATION TO TRAFFIC WEIGHT STATIONS

| Weight Station | Rank | Traffic Per Operating Hour, $T_h$ | Fraction Violating ($V_s$) | Fines Collected/ Hour ($), $F_h$ | Loss Prevented/Hour ($) $L_v$ | Total Contribution ($)1/, $B_h$ | Recommended Manpower Allocation (%)2/ |
|---|---|---|---|---|---|---|---|
| 246 S | 1 | 39.7 | 0.032 | 19.10 | 1.57 | 20.67 | 5.74 |
| 233 | 2 | 34.4 | 0.016 | 19.00 | 1.58 | 20.58 | 5.72 |
| 245 N | 3 | 41.7 | 0.017 | 18.20 | 1.90 | 20.10 | 5.59 |
| 232 | 4 | 27.2 | 0.020 | 18.80 | 1.21 | 20.01 | 5.56 |
| 243 | 5 | 27.8 | 0.021 | 18.60 | 1.22 | 19.82 | 5.51 |
| 239 | 6 | 10.6 | 0.037 | 19.00 | 0.40 | 19.40 | 5.39 |
| 240 | 7 | 33.3 | 0.021 | 15.40 | 1.46 | 16.86 | 4.69 |
| 246 N | 8 | 38.5 | 0.031 | 14.20 | 1.55 | 15.75 | 4.38 |
| 238 | 9 | 30.8 | 0.015 | 13.70 | 1.42 | 15.12 | 4.20 |
| 222 | 10 | 36.8 | 0.019 | 11.40 | 1.64 | 13.04 | 3.62 |
| 244 | 11 | 12.7 | 0.036 | 12.10 | 0.49 | 12.59 | 3.50 |
| 249 N | 12 | 25.4 | 0.027 | 11.00 | 1.06 | 12.06 | 3.35 |
| 226 | 13 | 30.8 | 0.015 | 10.40 | 1.42 | 11.82 | 3.29 |
| 245 S | 14 | 40.3 | 0.017 | 9.40 | 1.83 | 11.23 | 3.12 |
| 249 S | 15 | 25.0 | 0.031 | 9.50 | 1.00 | 10.50 | 2.92 |
| 229 | 16 | 14.8 | 0.039 | 9.40 | 0.55 | 9.95 | 2.77 |
| 221 | 17 | 39.6 | 0.015 | 8.00 | 1.83 | 9.83 | 2.73 |
| 223 | 18 | 17.7 | 0.038 | 8.80 | 0.67 | 9.47 | 2.63 |
| 250 E | 19 | 16.4 | 0.024 | 8.70 | 0.70 | 9.40 | 2.61 |
| 242 | 20 | 34.8 | 0.019 | 7.40 | 1.56 | 8.96 | 2.49 |
| 228 | 21 | 31.0 | 0.010 | 7.40 | 1.49 | 8.89 | 2.47 |
| 247 E | 22 | 16.8 | 0.031 | 7.80 | 0.68 | 8.48 | 2.36 |
| 230 | 23 | 22.1 | 0.024 | 7.50 | 0.95 | 8.45 | 2.35 |
| 224 | 24 | 17.9 | 0.019 | 7.40 | 0.80 | 8.20 | 2.28 |
| 227 | 25 | 14.7 | 0.016 | 7.40 | 0.67 | 8.07 | 2.24 |
| 247 W | 26 | 15.7 | 0.029 | 7.40 | 0.64 | 8.04 | 2.24 |
| 250 W | 27 | 13.3 | 0.022 | 7.10 | 0.58 | 7.68 | 2.13 |
| 234 | 28 | 13.6 | 0.031 | 5.50 | 0.55 | 6.05 | 1.68 |
| 241 | 29 | 13.9 | 0.028 | 4.80 | 0.58 | 5.38 | 1.49 |
| 237 | 30 | 13.0 | 0.013 | 2.80 | 0.61 | 3.41 | 0.95 |
| Total | | | | | | 359.81 | 100.00 |

1/ Sum of fines collected and loss prevented per operating hour.

2/ Recommended manpower allocation is based on fraction individual site contributes to total contribution.

A proposed site should be built if the present value of the series of annual benefits is equal to or greater than the purchase cost. The proposed scale should not be built if the present value is less than the purchase cost.

The present value is the product of the expected annual benefits times a present value factor which converts all future benefits to a present sum. Present value factors for a given interest rate and expected life can be obtained from any annuity table. The annual net benefit from a new scale depends on four factors:

a. Fines and registration fees collected

b. Dollar value received from increased compliance

c. Operating cost

d. Total number of annual hours of operation

The annual benefit from a new scale $(B_s)$ is the product of the hourly benefit $(B_h)$ times the total number of annual operating hours; where $(B_h)$ is expressed by the following equation:

$$B_h = T_h L_v (V - V_s) + T_h V_s F - C_o$$

where

$B_h$ = Benefit from scale operation: dollars per operating hour

$T_h$ = Traffic going by site per hour

$L_v$ = Loss to Iowa from each violation: dollars

$V$ = Average fraction violating in Iowa

$V_s$ = Fraction violating at site

$F$ = Average fine collected per violator: dollars

$C_o$ = Scale operating cost, includes personnel, heat, electricity, dollars per operating hour

When a scale site is operated, fines are collected from apprehended violators. The expected dollar value of fines collected at a site per hour of operation is the product of the truck traffic $(T_h)$, times the fraction of trips by the site in violation $(V_s)$, times the average fine per violator, $(F)$.

The dollar value from increased compliance by a proposed scale is the product of the average truck traffic $(T_h)$, times the increase in local compliance from the statewide average, $(V-V_s)$, times the value of compliance per trip, $(L_v)$.

A sample calculation to evaluate a hypothetical scale site is shown below to demonstrate the application of the method.

The traffic, $T_h$, is the expected average traffic rate over a 20-year period with a 3 percent growth factor. The 1967 value for truck traffic for all interstate traffic weight stations ranges from 40 to 13 trucks per hour, and the average value is 27.3 trucks per hour. Using the 27.3 trucks per hour as a base, and applying the growth factor, the 20-year average value would be 38.4 trucks per hour.

The 1967 value for the average fine per violator, the direct operating cost, and the value for increased compliance per violator have been assumed to be constant over the 20-year life of a traffic weight station. Actually, the operating cost will increase; however, the average fine per violator and the cost of road maintenance will also increase. Changes in these values would tend to compensate each other, and have little effect on the net benefit to the scale.

$L_v$ = \$0.37 per deterred violator

$F$ = \$26.95 per apprehended violator

$C_o$ = \$16.35 per site operating hour

The local fraction of trips in violation at a fixed site $(V_s)$ is about 2 percent and these are primarily accidental violators. This value should not change during the life of a site. The statewide average fraction of trips in violation $(V)$ is the expected fraction in violation at the recommended staff level, 0.07.

The average operating cost $(C_o)$ is the product of the average variable operating cost per enforcement officer (\$8,903), times the average crew size for fixed site operation (2.64 men), divided by the average number of man-hours per man-year (1,455 hours), plus \$0.20 for power and other miscellaneous costs. Therefore, the average operating cost per operations hour is equal to:

$$C_o = \frac{(\$8,903)(2.64)}{1,455} + 0.20 = \$16.35$$

$$B_h = 38.5(0.37)(0.07 - 0.02) + 38.5(0.02)(26.95) - 16.35$$

$$= \$5.11 \text{ per operating hour net benefit.}$$

The number of annual hours of operation is an important factor in the calculation. It should inflect reasonably attainable levels of operation, assuming counseling manpower is available. For this sample calculation, a figure of 1,400 operating hours per year is assumed. For 1,400 operating hours this site would contribute annually $7,154 (5.11 x 1,400 hours). Since there are two sites at each interstate traffic weight station the total dollars received from an interstate complex is $14,308, per year, or $286,000 during the 20-year expected lifetime. Assuming the time value of money to be zero, a two scale interstate site costing Iowa less than $286,000 would be feasible, based on the values assumed for this example. If the time value of money to T.W.O. is 8 percent, a two scale interstate site costing less than 140,000 (14,308 x 9.81[1]) would be feasible.

There are three factors which are variable with respect to the selected scale locations: (1) expected truck traffic, (2) hourly operating cost, and (3) the total number of annual operating hours. Increased value of new scale sites can be obtained by: (1) locating traffic weight stations on roads with a high expected traffic count; (2) reduce the crew size and operating costs by improving operating efficiency; and (3) increase the annual operating hours of the new scale by reallocating manpower from low contribution sites. Any positive change in these three factors increases the expected annual contribution from the proposed site, the expected value, and therefore improves the economical justification for constructing a traffic weight station.

4. <u>Fraction of Manpower Devoted to Fixed Site Operation vs. Roving Patrol Operation</u>

General method: During the fiscal year of 1967, on the average, 29.8 traffic weight enforcement officers were devoted to fixed site operations, 9.4 men to roving patrol, and 16.8 men were either on vacation; escort duty; attending staff meetings; or sick. The present strategy for allocating manpower is then: 75 percent of the available manpower to fixed site operations and 25 percent to roving patrol.

1/ A series of $1 annual payments over a 20-year period with an 8 percent interest rate is equivalent to $9.81.

Data collected from a sample of T.W.O. operational records for 1967,[1] and shown in Figure 16 in Columns 1 and 2, indicated that roving patrol was much more effective than fixed sites in the collection of revenue.[2]

Based on these results, an operational experiment was conducted to determine the effect of increasing the fraction of manpower devoted to roving patrol.

Our procedure was to conduct two experiments during successive weeks beginning April 18, 1968. In the first experiment, 50 percent of the available manpower was devoted to roving patrol; during the second experiment 75 percent of the available manpower was devoted to roving patrol.[3] The results of these experiments are shown in Figure 16 in Columns 3 - 6. The intent of this table is to compare fixed and roving patrol operations on a cash flow income basis ignoring the total benefit from increased compliance.

Results of the analysis:

1. Roving patrol was better than fixed site operation in income production in all three manpower mixes.

2. Roving patrol was much more variable in its income production per operating hour. Roving patrol varied over a range of $16.07 to 22.63 while fixed sites varied only from $13.16 to 13.57.

3. Costs per operating hour for both fixed sites and roving patrol varied because the crew sizes were not kept constant from experiment to experiment.

4. Performance of both fixed sites and roving patrols dropped markedly during the first week of experimentation (Mix 2) and then improved during the second week (Mix 3).

Conclusions:

1. The results from the sample and operational experiments are not sufficient to define an "optimum" roving patrol vs. fixed site manpower mix.

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1/ Sampling instructions are documented in Appendix 4.

2/ This comparison includes fines and registration increases collected, but not any credit for increased compliance.

3/ The ratios were only roughly approximated because of operational constraints.

| Operating Ratios<br>Operational Performance | Mix 1[1/]<br>75% Fixed | Mix 1[1/]<br>25% Roving | Mix 2[2/]<br>50% Fixed | Mix 2[2/]<br>50% Roving | Mix 3[2/]<br>25% Fixed | Mix 3[2/]<br>75% Roving |
|---|---|---|---|---|---|---|
| Summons per Site Operating Hour | 0.584 | 0.505 | 0.576 | 0.445 | 0.603 | 0.517 |
| Summons per Man-Hour | 0.223 | 0.205 | 0.181 | 0.172 | 0.201 | 0.187 |
| Average Team Size | 2.640 | 2.460 | 3.180 | 2.590 | 3.000 | 2.770 |
| Cash Income per Summons | $22.7 | $35.8 | $22.8 | $36.1 | $22.5 | $43.7 |
| **Cash Income Statistics** | | | | | | |
| Cash Income per Site Operating Hour | $13.25 | $18.08 | $13.16 | $16.07 | $13.57 | $22.63 |
| Cost per Site Operating Hour | $14.12 | $13.34 | $16.28 | $13.55 | $15.36 | $14.74 |
| Net Income per Site Operating Hour | $(0.87) (loss) | $ 4.74 | $(3.12) (loss) | $ 2.52 | $(1.80) (loss) | $ 7.98 |
| Net Cash Income per Site Operating Hour for Mix as a Whole | $0.553 | | $0.015 | | $4.04 | |

1/ Based on 1/19 sample of full year 1967 operating statistics.
2/ Based on 1 week operational experiment.

Figure 16 - Effect of Roving Patrol vs. Fixed Site Manpower Mix on Operating Statistics

2. The operational experiments were not of long enough duration or sufficiently well controlled to establish the long term effect of shifts in the roving patrol vs. fixed site manpower mix. In particular the crew sizes were allowed to vary in order to meet short term scheduling problems, and there was a noticeable learning effect during the course of the experimentation.

3. An improvement probably would result from increased roving patrol, but a long term well controlled experiment will be necessary to establish the desired manpower mix.

4. The performance of roving patrols is currently highly variable and subject to improvement through training and practice. If care is taken to improve roving patrol training, the value of increased roving patrols would be enhanced.

Recommendations:

1. A long term experiment should be carried out to determine the best ratio of roving pertinent to fixed site operation. A stability point of 50 percent of available manpower devoted to each type is recommended.

2. Training of officers in roving patrol operations should be increased.

5. Manpower Allocation by Time of Day

Introduction: One potential area of improvement in enforcement policy is a better allocation of manpower by time of day. For example, it might be better to devote more manpower to night operations in order to apprehend violators who are trying to avoid apprehension by driving at night. It could be advantageous to change the time pattern of operation by shortening the periods open. This section of the report discusses the results of investigations into these questions.

Method of data acquisition: Current practice does not record the time of day at which a violator is apprehended.[1/] MRI therefore designed a special form to acquire this information, which is shown in Appendix 9. Trucks counted and apprehensions vs. time of day were recorded for a two-week operating period in an operational experiment which did not otherwise change enforcement policies.

1/ However, a code is used to indicate whether the apprehension occurred during the day or at night.

Method of data analysis: A computer program documented in Appendix 7 accumulated traffic and apprehensions or violations from all scale sites, and grouped them by the time period in which they occurred.[1] The program also calculated the "fraction violating" for each time period by dividing the number of apprehensions or violations by the traffic counted.

Results: The results of the analysis are displayed in two sets of graphs as in Figures 17 and 18.

Figure 17 shows fraction apprehended violating, apprehensions per scale hour, and vehicles per scale hour as a function of time of day on a 24-hour scale beginning at midnight.

Truck traffic is heaviest during the middle of the day, and drops off sharply at night.

The fraction of trucks in violation follows an almost reverse pattern. The fraction violating is heaviest at night. Also shown in Figure 17 is the number of violators per hour. Although statistically noisy, it is fairly constant with a slight peaking during the daylight hours while the fraction of violators at night is higher, the heavier traffic during the day offsets this fact, and produces slightly more violators per hour during the day.

Figure 18 shows what were called "decay curves" in anticipation of a decrease in violations after the scale is opened. As can be seen from the fraction violating curve, there is no significant "decay" or drop-off of fraction violating after a scale is opened.

This is an important result, and apparently contrary to the common belief that truckers warn each other that a scale has just opened.

Conclusions:

1. If truckers do attempt to communicate to each other on the road that a scale is open it has little or no effect on traffic characteristics.

2. The truckers knowingly in violation avoid routes which have fixed sites whenever possible.

3. The deliberate violators know the schedule of openings of the scales, and adjust their own time of travel accordingly as evidenced by the fact that the fraction violating is greatest during the night, while the level of enforcement is greatest during the day.

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1/ Generally the time periods were 1 hour long, but shorter periods (15 minutes) were used for the first hour after a scale opened.

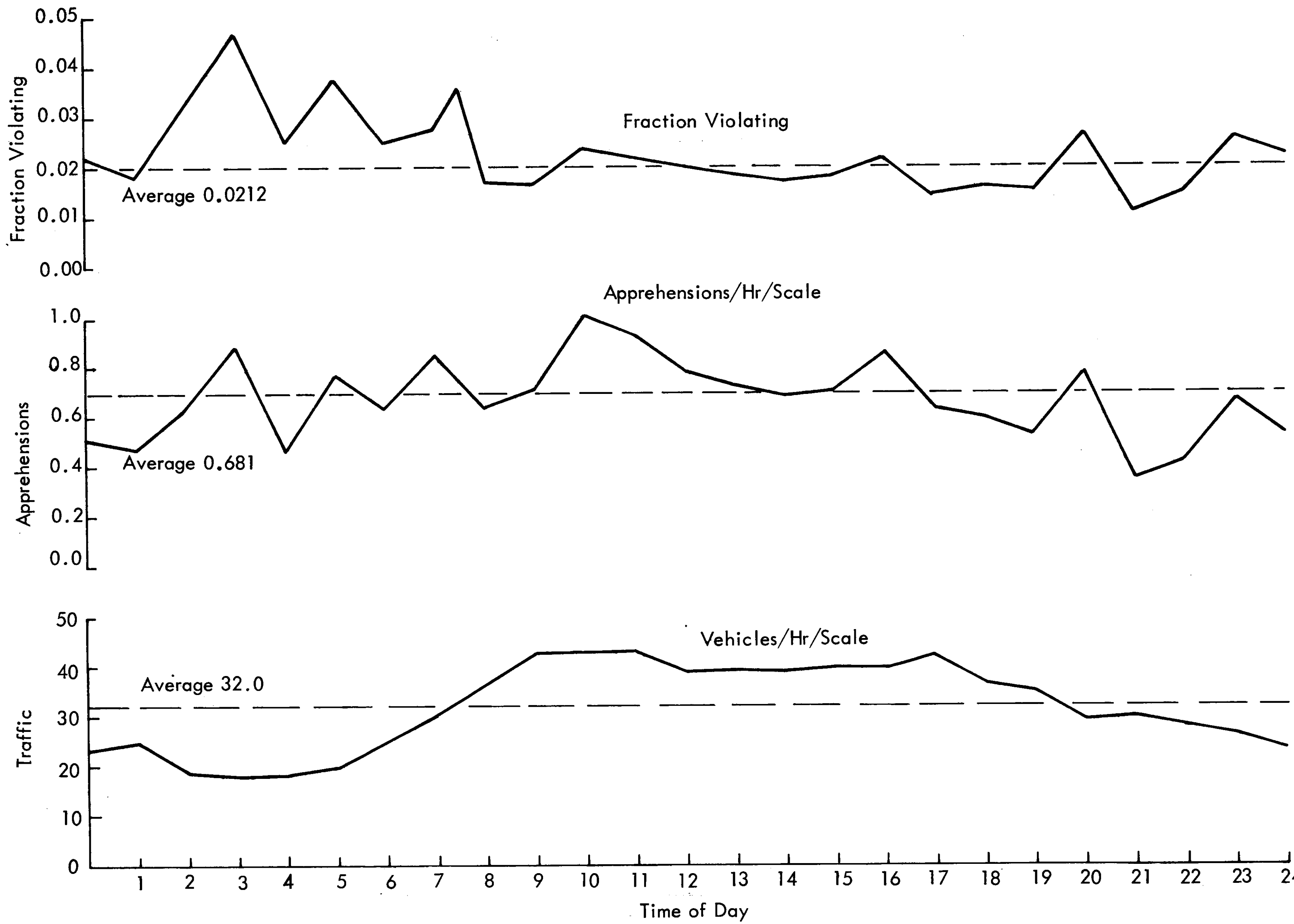


Figure 17 - Fraction Violating, Apprehensions Per Scale Hour
and Vehicles Per Scale Hour Versus Time of Day

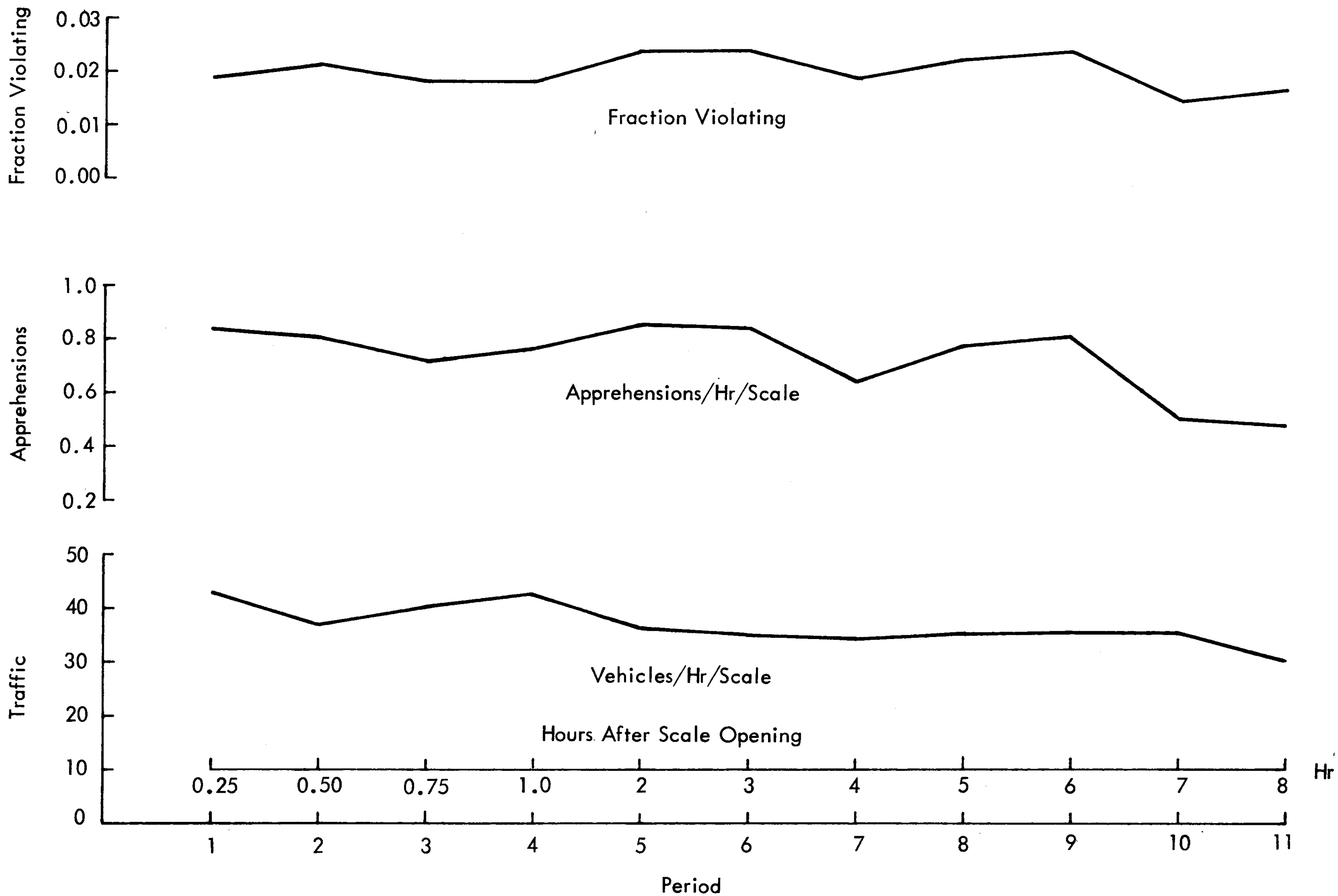


Figure 18 - Fraction Violating (At Scale), Apprehensions Per Scale Hour, and Vehicles Per Scale Hour Versus Hours After Time of Opening

Recommendations: It would seem to be possible to boost the enforcement efficiency of Iowa T.W.O. by efforts to decrease the ability of truckers to anticipate enforcement activities. These might include:

a. Increased use of roving patrol, so that the violators cannot plan on easily avoiding apprehension.[1/]

b. Increased use of night operations to deter the running of scales at night. As discussed above, this will not result in apprehending numerically more violators, but in apprehending and deterring a subgroup of violators who try to "run" the scales at night.

c. More frequent changes in scale scheduling.

The measures recommended above all have some difficulties associated with their implementation. For example, roving patrol is currently unsafe at night because of risks of stopping trucks along an unlit road. Hence, recommendations (a) and (b) conflict to a certain extent. For this reason, it is believed that a major effort to find a safe method of roving at night is worthwhile. Two approaches that might be considered are: (1) the use of advanced in-motion weighing methods to identify probable violators combined with use of public or fixed scales to verify, or (2) portable lighting along primary and secondary roads to make night use of conventional loadometers safe and practical.

Frequent schedule changes and intermittent shifts in manpower are difficult to handle administratively. A computer program should be developed to assist the Director of Traffic Weight Operations in carrying out this difficult task. This program could be combined with MRI's violation-analysis programs to indicate when violators are aware of the current schedules.

## 6. Use of Advanced Weighing Equipment

Introduction: Early in the study we decided that use of advanced weighing equipment might result in significant improvements in weight-enforcement operating efficiency. Therefore, some research in this area fell within the scope of the project contract.

Since the use of advanced equipment often involves practical problems that make achieving theoretical improvements difficult, research on such equipment focused on its feasibility.

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1/ As discussed in Section II-B-4.

Method of data acquisition: A review was made of the literature, including publications of highway-related organizations, trucking associations, and so on. A bibliography of this material is in Appendix 2. A letter of inquiry was also sent to state organizations responsible for traffic-weight operations, concerning their research programs and other activities of interest.

Finally, field trips were made to two experimental installations as discussed below.

Method of data analysis: No experiments on advanced equipment were carried out by MRI. The results were obtained by review and comparison of the various data sources outlined above. The results discussed below should therefore be interpreted only as informed technical opinion.

## Results of the Analysis

a. Research programs under way: There are research programs going on in several states on improved weighing methods. These states include: Texas, Michigan, Pennsylvania, Oregon, New York, and Iowa itself. In addition, several foreign governments including England, Germany, Sweden, and South Africa, have programs under way.

b. Directions of research: The principal direction that scale research is taking is the development of weighing in motion. Equipment has been developed that will weigh trucks at full highway speeds of 60 - 70 mph. Such equipment would be valuable in two respects; it would permit traffic surveys to be carried out at a great number of locations without construction of expensive ramps, parking facilities, and so on; and it would permit sorting out of violators from the general truck population without stopping all vehicles and creating waiting lines.

A second major area of development is scales that require less manpower to operate. One design permits a single operator to control two interstate scales simultaneously.

Characteristics of sample equipment are discussed in more detail below.

c. State of the art: No one is known to be using weighing in motion for weight-limitation enforcement. However, Germany and Sweden are now using dynamic weighing for generating highway-survey data.

The chief limiting factor on the use of dynamic weighing appears to be accuracy. The University of Texas Center for Highway Research has a portable scale which can produce gross weight reading with an accuracy of ± 10 percent.[1] Exact weight distributions of trucks are not available, but it is believed that many trucks operate relatively close to the legal limits both above and below. This means that with ± 10 percent accuracy it would be difficult to distinguish violators.

Dynamic weighing involves the use of electronics with attendant maintenance and reliability problems. Michigan has had a site in being for over five years, and has not been able to bring it out of the research phase and into routine operation.[2]

Despite these problems dynamic weighing is regarded as promising as witnessed by the many programs that are under way. It is still definitely in the research phase, however.

d. Possible Applications in Iowa: Two possible applications of new weighing concepts appear to warrant further investigation by Iowa.

(1) Florida remote weighing installation for better manpower utilization: "The Florida State Road Department has installed a truck weighing system by which a vehicle on either side of a divided four-lane highway can be weighed from the control house on one side."[3] The article continues with the following description of this system:

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1/ Below speeds of 15 mph dynamic weighing equipment is as accurate as conventional methods, according to Dr. C.E. Lee of the University of Texas. Dr. Lee was contacted by MRI on a field trip to the University.

2/ An MRI staff member visited Michigan's experimental installation at Grass Lake, Michigan, and discussed the project with Mr. Leo De Vogel, Project Engineer.

3/ Engineering News-Record, August 6, 1964, "Weighing Station Does Double Duty."

"The equipment on each side of the highway comprises two sets of three scale platforms. The mechanical lever system of each platform has a capacity of 30 tons. One platform is 34 x 10 ft. wide; the others are 10 x 10 ft. The platforms were installed end to end. The big platform weighs tandem rear axles of a tractor-trailer combination, the middle scale weighs the drive axle and the remaining scale the front axle."

Each platform is connected through a load cell to a separate chart digital output (CDO) electronic instrument. Each chart is graduated 12,000 x 20 lb. (to 12,000 lb. in 20-lb. increments) with five automatic ranges to give a total chart reading of 62,000 x 20 lb. Automatic ranging is done so rapidly that the weight of each axle or tandem can be read on the chart by the time the truck comes to a complete stop on the scale platforms.

If the three indicated weights indicate a possibility of a gross or axle overload, the operator can press a "Print" button on the control panel, which is desk mounted. This results in the printing by the adding machine on a ticket or tape of each of the scale weights and their sum. These figures are printed out in four seconds.

Using a switching system controlled from the same panel, the operator on one side of the highway can read into the CDO instruments and get readout from the adding machine on his side, the weights of a truck on the scales on the opposite side. Warning lights mounted on the control panel tell the operator if one or more of the truck wheels is not positioned properly on the scale platforms.

During peak traffic periods, the twin control arrangement still requires an operator on each side. Even then, SRD engineers say the capability of switching from one side to the other serves a very useful purpose. If there is a violation, the patrolman-operator takes about 10 minutes to complete his citation ticket. Meanwhile, the operator on the far side may switch over and weigh incoming vehicles, which otherwise would stack up until the patrolman could return to his weighing station.

In off-peak periods, the switching system allows one operator to handle traffic from both directions with little or no delay."

This system might also be applicable in Iowa with some modifications. For example, it would be desirable to add a closed-circuit television-monitoring system to enable the operator to remotely scan vehicle licenses and driver papers. Detailed costing information on such a system was not cited in the article. Conversion to such a system for an already constructed site would probably be about $10,000. This includes about $5,000 to convert the scales to remote readout, $4,000 for TV equipment, and some installation expenses.

Iowa currently uses about five men to operate two interstate scales 1,000 hours at a cost of $6 per man-hour. If manpower requirements could be reduced to two men, a direct savings of $18,000 per year might be realized.

(2) Texas (Lee) Dynamic Scales for Nighttime Roving Operations: Dr. Clyde E. Lee of the University of Texas has developed a portable scale as described in the following abridgement of one of his papers:

> "Lee, Clyde E., "A Portable Electronic Scale for Weighing Vehicles in Motion." Presented at 45th Annual Meeting of the Highway Research Board, Washington, D.C., January 17-21, 1966. Manuscript copy consists of 19 pages of text, 9 pages of illustrations, and 16 references.
>
> Descriptors: scales; electronic scales; portable electronic scales; loadometer; weighing vehicles in motion; transducer, load; classification, vehicle; Lee, Clyde E.
>
> A portable electronic scale consisting of a pair of special wheel load transducers and conventional electronic recording instruments and capable of weighing each wheel of vehicles moving at speeds up to 70 mph has been developed at the Center for Highway Research, The University of Texas. The transducers, each of which is 50 x 20 in. in plan dimensions and slightly over 1 in. thick, utilize resistance strain gages. They are simple in design, rugged, portable, and relatively inexpensive. Electrical output signals result only from loads applied normal to the surface of the transducer. The signals are not affected by tractive forces, tire contact pressure or area, position of the load on the transducer, temperature, nor moisture. Inertial effects in the transducer are negligible.
>
> Since only 1-1/2 in. of pavement material must be removed, the portable scale can be installed in any smooth roadway surface including rigid pavements and bridge decks. Initial installation requires about 3 hours, but installation at a previously occupied site requires only about 30 minutes. Pre-mix asphalt has been used quite successfully to fill the grout-lined depression left in the pavement when the transducers are removed.
>
> Analysis of data on nearly 300 different vehicles, each of which was weighed both statically by a conventional loadometer and while moving at normal road speed by the portable electronic scale, demonstrates that static vehicle weight can be estimated from wheel weights obtained by a single pair of transducers on the portable electronic scale with precision sufficient for

planning and design purposes. Variation in the gross vehicle weight obtained by the two weighing methods was only about plus or minus 10 percent even though individual wheel weights varied considerably more than this. A more precise estimate of static vehicle weight can be obtained by using several pairs of wheel load transducers to sample the dynamic wheel forces at different points as the vehicle moves along the traffic lane.

Engineers with imagination will find many uses for the portable dynamic weighing device. It is a new tool for research into traffic operations and structural design to include the effects of repeated dynamic loads."

The above described system might be used to carry out nighttime roving patrol operations. Roving patrols are not currently feasible at night because of the accident risks associated with stopping a truck in the dark. The Lee site could be used as a screening device to select trucks for escort to a state-owned fixed site, a commercial scale, or a prepared parking area. The trucks would thus not have to be stopped at a busy, unsafe location.

Dr. Lee's transducers may be purchased for $1,600, and are available commercially; however, no standard instrumentation is available for purchase, but must be assembled from available devices.

It is difficult to estimate the potential benefits from the introduction of such a system. It was shown earlier in this report that there is a marked increase in fraction violating at night, apparently because of the smaller enforcement effort during those hours. A system to make nighttime roving patrol operations possible would therefore seem to be a worthwhile objective.

e. Points of contact: Should Iowa be interested in further pursuing research programs in methods of weighing, the following points of contact should be useful:

Dr. C. E. Lee
The Center for Highway Research
University of Texas
Austin, Texas 78712

Mr. T. W. Jennings
Assistant State Highway Engineer (Structures)
State Road Department
Tallahassee, Florida 32304

Mr. Leo De Vogel
Project Engineer, Grass Lake Project
Michigan Department of State Highway
Stephens T. Mason Building
Lansing, Michigan 48926

7. Procedural and Administrative Changes

Introduction: The main objective of this study is to find the optimum level of traffic weight enforcement. Since this level and the associated net benefit to Iowa depend on the efficiency of the enforcement methods used, a secondary objective of the study is to improve Iowa's T.W.O. efficiency.

Based on the quantitative analyses discussed in relation to T.W.O. elsewhere in this report, our observations of other state T.W.O. operations, and our general systems experience, MRI does have some suggestions for improving the efficiency of traffic-weight operations in Iowa.

Delayed versus immediate prosecution: The practice in Iowa of immediate prosecution may not be necessary. Summonses could be issued and violators required to post bond, as is done quite successfully in other states such as Michigan. If immediate prosecution is not required, it would be possible to reduce the weighing crew size and thus operate more scale sites with the same staff. An escort--i.e., one of the field enforcement offices--would not be required to take violators to court. Investigation by the Director of Traffic Weight Operations indicated that no more weight cases are lost in court with delayed appearance than with immediate appearance. Michigan's experience with bonding is that fewer than 1 percent of the violators forfeit bond. Immediate prosecution and attendant delay does have a deterrent effect. However, in the absence of quantitative data, it is our opinion that the advantages of decreased staff costs would likely outweigh the possible deterrent effect of delay for immediate prosecution.

Computer analysis of violation history/computer scheduling of scale operations: Currently it is the responsibility of the Assistant Director of Traffic Weight Operations to review when and where violations are occurring, and to recommend appropriate changes in scale schedules. This is a difficult and time-consuming manual process. We suggest that computer programs be developed to assist him. These programs combine routines to analyze violation history with procedures that would allocate manpower properly, with practical limitations (such as limitations on continuous night work) being taken into account. The output from the computer would be operational schedules and work assignments. The use of such a program would permit more frequent change of schedules that should help prevent violators from learning scale schedules.

Inspection team training: T.W.O. records indicate that some teams are much more effective in roving operations than others, varying from 0.043 to 0.985 apprehension per hour. This variation may be attributed in part to local traffic characteristics, but patrol efficiency appears to be an important factor. The results of the roving patrol vs. fixed patrol analysis indicated that the average roving patrol apprehension rate was actually lower than that for fixed sites. We recommend that increased emphasis be placed on training of enforcement officers in roving patrol operations. Such training should emphasize site selection, e.g., operations on routes which complement active fixed scale operation. Such measures should improve the overall apprehension rate for roving patrols.

Multiple violator file: Several states maintain a file of very heavy violators. Iowa's violation tape file is printed out for use by the Director of T.W.O., but not much field use seems to be made of the information. One problem in dealing with this file is that the names of truck owners are not uniquely defined. A violator may appear under a dozen different names. Computer analysis of the file to determine the owner responsible for violations is therefore infeasible.[1] It should be possible to maintain a central file of unique owner names associated with their vehicle license numbers. Periodically, a list of major violators could be distributed to inspection teams and to courts of jurisdiction. Inspection effort could be focused on repeat violators and judges would be aware of the same information.

It is our opinion that the distribution of the list of major violators to T.W.O. officers would improve enforcement. Similarily, this same information distributed to courts of jurisdiction could influence the severity of the fine imposed after the determination of guilt or innocence, and act as an increased deterrent to repeat violators. The driver's license traffic violation point system used in several states is a precedent in this area. The legal procedures to be followed, however, can best be determined by ISHC's own representatives of the State Attorney General's office.

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1/ The 1967 Iowa violation file was reviewed in part. Companies were found that had received as many as 50 summonses in one year. Since the probability of apprehension was only 0.0062 in 1967, such a company might have committed an additional 8,000 violations without being apprehended.

Use of television scanners and remote weighing equipment: A combined television scanner and remote weighing equipment that can be used to operate two interstate scales simultaneously from one side of the highway offers promise in reducing manpower requirements. This should make it possible to operate both interstate scales with two men. Such a system also should alleviate the prorata/reciprocity identification problem by allowing scanning of papers by television.

Summary - probable effects of proposed changes: It is difficult to predict the cumulative effect of all the above changes. In general, improvements in efficiency will result in more benefit to Iowa from T.W.O. The benefit curve in Figure 11 shows that a 10 percent increase in manpower efficiency, as measured by the apprehension constant, would result in $18,000 of increased revenue per year to Iowa. The cost to attain this increase should be less than the revenue that would result. It is believed that each of the above procedural changes would cost significantly less than the benefit from improvement in apprehension efficiency.

## 8. Effect of Traffic Increases

Introduction: Truck traffic in Iowa is forecast to increase at an annual rate of 3 percent for the next several years. The general effect of this increase on the present study is that there will be more potential violators, and a larger apprehension force may be necessary to prevent increased road wear. It should not be anticipated, however, that the recommended or optimum staff level will grow in direct proportion to increases in truck traffic. The new trucks will still use the same road network. The probability of their being apprehended is a matter of manpower and geography, not a function of the number of trucks.[1/]

Method of analysis: The cost-effectiveness program was rerun with traffic in trips steadily increased from the 1968 value. The program was adjusted to print out only the optimum staff level for each traffic volume.

Results of the analysis: Figure 19 is a graph showing the optimum staff level versus traffic. Assuming a 3 percent annual traffic growth rate, we see that the requirement for T.W.O. personnel will increase as indicated below.[2/]

1/ Assuming that scales are not so saturated that they fail to inspect all passing trucks.

2/ It is possible that the increases in personnel efficiency obtainable from the methods outlined elsewhere in this report will obviate the need for some of these manpower increases.

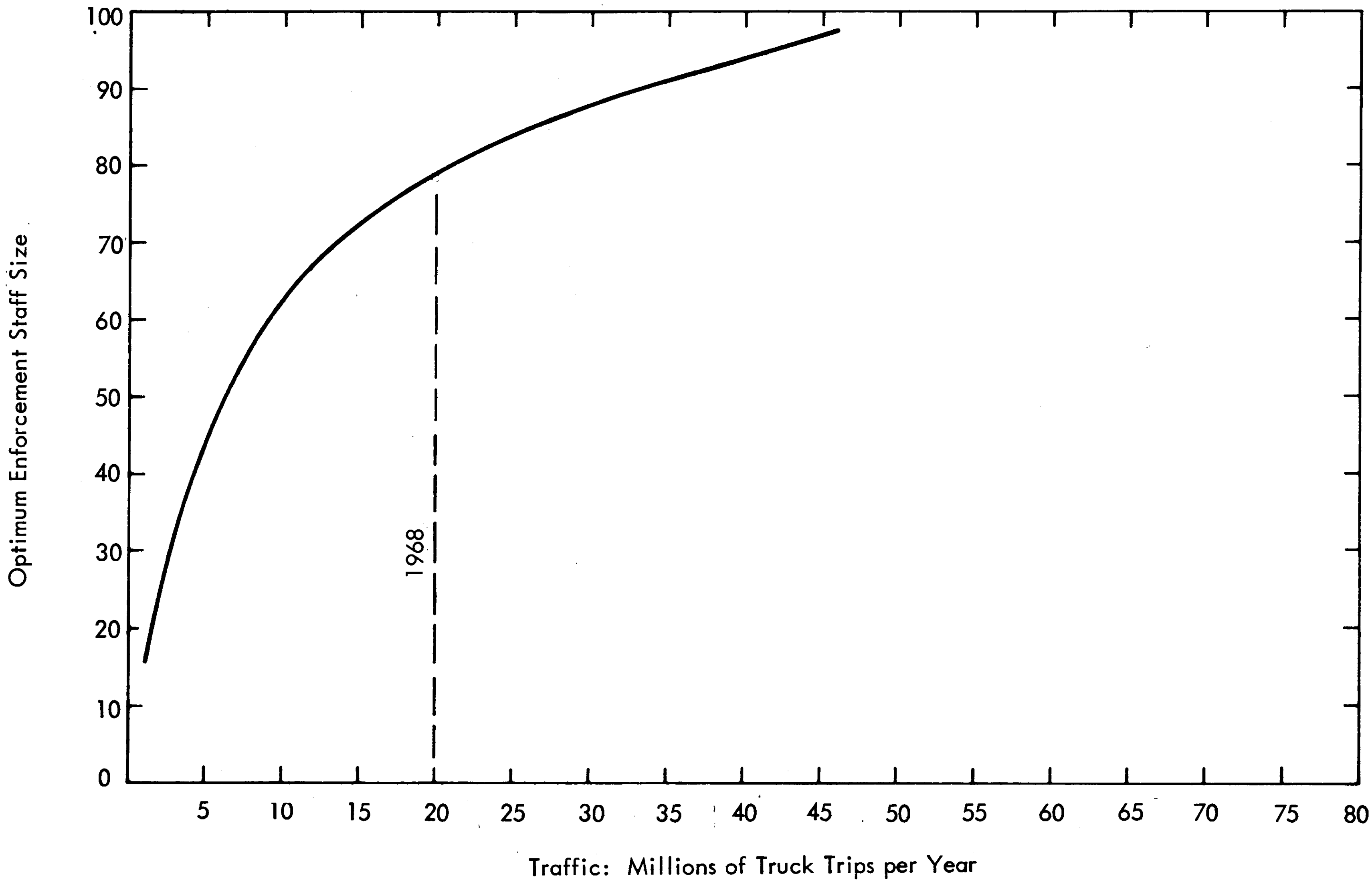


Figure 19 - Sensitivity of Optimum Staff Size to Truck Traffic

| Year | Optimum Staff |
|---|---|
| 1968 | 79 |
| 1973 | 83 |
| 1978 | 86 |
| 1983 | 89 |
| 1988 | 92 |

Sensitivity of optimum staff level to traffic volume: The value obtained for optimum staff is dependent upon traffic volume. Since the traffic volume figures used in the study were obtained by sampling methods as discussed in Appendix 1, Tab B, they are subject to statistical errors. The table below shows the effect on staff level of possible error in traffic estimates:

| Percent Possible Error in Traffic Estimate | Resulting Percent Error Estimate of Optimum Staff Level |
|---|---|
| 5 | 1 |
| 10 | 3 |
| 20 | 4 |
| 50 | 9 |

## 9. Comparison of Selected State Traffic Weight Operations

Introduction: Traffic weight operations differ widely from state to state. These differences reflect not only varying circumstances but divergent philosophies of operation. Direct comparison of T.W.O. activities in one state with those of another is therefore difficult. Moreover, the relative "efficiencies" or "performance" of such operations are nearly impossible to evaluate even if such an evalution had any real meaning.

However, it is possible that, by examining various approaches to T.W.O., we may obtain some insights into how other states have approached enforcement.

Method of data acquisition: A letter request for information was sent to the office responsible for T.W.O. in each state.

Method of data analysis: Although many of the states did not reply in sufficient detail to warrant analysis, 13 of the replies were quite informative, and provided sufficient indication that Iowa's practices are in consonance with national norms.

Figure 20 is a table summarizing traffic weight statistics in these states. Many comments were also recorded on the "philosophy" of traffic weight enforcement which will be discussed below.

Statistical results:

Staff size - The enforcement staff size varied from 42 to 160. Of the 13 states, all but one had larger staffs than Iowa. It will be recalled that the optimum staff size depends on several factors, including traffic volume in the state. On a traffic weight enforcement staff per state-trucks-registered basis, Iowa ranked third lowest in the states examined.

In interpreting this result, it should be noted that in many states enforcement personnel have more responsibilities than those in Iowa, such as enforcing gasoline tax laws. These states therefore require more manpower.1/

Number of scales - The number of fixed scale sites varied from 7 to 31. Iowa ranked first in number of sites, and first in number of sites per trucks registered.2/ Iowa, as well as the other states, use these sites for enforcing all kinds of truck regulations including gas-tax laws. The scale sites are thus probably used in a more directly comparable manner than is the manpower.

Operating budget - Iowa ranked lowest, but only four states reported this figure.

Performance statistics - As previously noted, it is difficult to compare state to state performance because of differences in traffic volume and other factors. However, Iowa achieved the second lowest (best) value of percent violations observed by the loadometer survey, a measure of compliance with state weight regulations. This statistic is fairly comparable from state to state, since it is based on a common report prepared for the Bureau of Public Roads by all state highway commissions.

Operating practices:

Enforcement responsibility - Several states such as Arkansas and North Dakota give traffic weight enforcement personnel additional responsibilities. These include gas tax enforcement, driver's license enforcement,

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1/ Iowa uses an additional 29 personnel for such duties, bringing its comparable total inspection force to 93 men.

2/ Oregon reported number of scales, not number of scale sites, and uses more than one scale per site. The number of sites was not determined for Oregon.

SUMMARY OF TRAFFIC WEIGHT OPERATIONS
FOR SELECTED STATES

| | Truck Registrations[a] (1963) x 1000 | Operating Budget (1967) $ x 1000 | Number of Fixed (Roving) Scales (1967) | Staff (1967) | Number of Trucks Weighed (1967) x 1000 | Number of Violations Apprehended (1967) x 1000 | Percent Violations of Trucks Weighed (1967) | Number of Overload Violations Apprehended (1967) | Percent Overload Violations of Trucks Weighed (1967) | Percent Overload Violations from Loadometer Survey | Amount of Fines Charged (1967) $ x 1000 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Arkansas | 231 | - | 15 (22) | 129 | 2,615 | 17.5[b] | 0.67 | 2,780[c] | 0.1 | - | 183[d] |
| Indiana | 386 | - | 29 (104) | - | 325 | 42.1[b] | 12.9 | 2,750[c] | 0.8 | - | 403[e] |
| Iowa | 264 | 486 | 31 (1) | 64 | 800 | 19.0[f] | 2.4 | 7,500[g] | 0.9 | 6.1 (1966) | 416 |
| Kansas | 320 | - | 17 (4) | 42 | 931 | 4.2[h] | 0.5 | 3,780[c] | 0.4 | 9.8 (1966) | 167[i] |
| Michigan | 406 | 1,400 | 19 | 124 | 3,240 | 10.0[f] | 0.3 | - | - | 11.3 (1967) | 521[i] |
| Missouri | 383 | 1,000 | 28 (15) | 160 | 1,042 | 18.4[h] | 1.8 | 6,170[c] | 0.6 | 4.4 (1967) | 566 |
| Nebraska | 192 | - | 16 (6) | - | 640 | 6.4[j] | 1.0 | 4,090[j] | 0.6 | - | 158 |
| North Dakota | 119 | - | 9 (24) | 81 | - | 1.8[j] | - | 1,630 | - | - | 1,134[k] |
| Oregon | 176 | 510 | 61[l] (30) | 73 | 600 | 7.8[m] | 1.3 | 7,200 | 1.2 | - | - |
| Utah | 97 | - | 9 (2) | - | 904 | 2.7[f] | 0.3 | 1,140 | 0.1 | - | 62 |
| Virginia | 237 | - | 7 (5) | 80 | 3,033 | - | - | 9,700[g] | 0.3 | - | 500[n] |
| Washington | 273 | - | - | - | 2,101 | 33.5[m] | 1.6 | 3,500 | 0.2 | - | 524 |
| Wisconsin | 272 | - | - | - | 671 | 50.7[m] | 7.7 | 9,500[o] | 1.4 | 13.0 (1964) | - |

a Total commercial and private truck registrations--Truck Inventory and Use Survey, 1963 Census of Transportation. U. S. Dept. of Commerce.
b Arrests, summonses, and warnings.
c Overload arrests.
d Fines, court costs, and axle overload penalties.
e All fines except for P.S.C. violations.
f Total citations.
g Summonses issued.
h Total arrests.
i Fines and court costs.
j Total cases.
k All revenues, including license fees and fuel tax.
l Number of stationary platform scales.
m Total violations.
n Liquidated damages and fines.
o Overload and over licensed weight.

Figure 20

and even livestock inspection. In some states the responsibility lies with the state highway patrol, who, of course, have many other police functions.

The advantage of such multiple responsibilities is that a man who has stopped a truck for one kind of inspection can inspect it more efficiently than two men stopping it at different times.

However, a disadvantage to this method was cited by members of enforcement organizations that believe in specialization such as Iowa and Michigan. The more items inspected the more time and knowledge are required. It may be inefficient or impractical to combine responsibilities in Iowa without significantly simplifying inspection procedures. A more detailed study of this matter should be worth pursuing.

Fixed vs. roving - All states agreed that both modes of operation are necessary. Most states tended toward a larger portion of roving patrol than practiced in Iowa. They also usually used a smaller number of fixed sites, but operated them 24 hours a day, 7 days a week.

Crew size - Several states such as Michigan and Virginia used smaller crew sizes than Iowa for fixed site operation. Michigan used one man, Virginia two, and Iowa 2.5-3.0. The third man in Iowa is used primarily as a pickup man to take violators to court for immediate prosecution. Other states eliminate this requirement by issuing all delayed-appearance tickets. Out-of-state violators post bonds.

Communication facilities - Several of the states equip their stations or cars with special radios. Michigan also authorizes its weight officers general police powers. These officers are then useful in state emergencies. (They were mobilized and sent to Detroit during recent racial disorders.)

Site preparation - At least one state, Virginia, prepares "cutoffs" beside roads to facilitate roving patrol operations.

Research programs - Several states, including Texas, Michigan, Pennsylvania, Oregon and Iowa itself, have experimented with weighing in motion. Results to date have been meager, but appear promising enough for work to continue. This research is discussed elsewhere in this report.

Summary: Other states have some interesting operating practices and programs that deserve further examination by Iowa. However, Iowa operations seem to compare favorably.