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Dennis E. Ihlert

OPTIMUM LEVEL OF ENFORCEMENT OF REGULATIONS GOVERNING THE SIZE AND WEIGHT OF MOTOR VEHICLES OPERATED ON IOWA HIGHWAYS

PRELIMINARY COPY.

FINAL REPORT
July 3, 1968

Project No. 3158-P

For

Iowa State Highway Commission
Ames, Iowa 50010

MRI

MIDWEST RESEARCH INSTITUTE
425 VOLKER BOULEVARD/KANSAS CITY, MISSOURI 64110/AC 816 LO 1-0202

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PREFACE

This report describes research done for the Iowa State Highway Commission on the optimum level of traffic weight-regulation enforcement.

The work was carried out during the spring of 1968 in preparation for submissions of budget requests to the 1968 session of the Iowa State Legislature.

The project was authorized by Mr. J. R. Coupal, Director of Highways, Iowa State Highway Commission as Research Project HR-138. It was designated as Project 3158-P by Midwest Research Institute. The attached report constitutes the total written product of the work described therein. No other general reports were or are planned to be submitted.

The success of the study was dependent on the close collaboration of many Highway Commission personnel, especially Messrs. Dennis Ehlert and Walter Fisher, Director and Assistant Director of Traffic Weight Operations, Mr. Eugene Mills, Highway Planning Surveys Engineer, and Mr. Stephen Roberts, Research Engineer.

The weight-enforcement agencies of several other states furnished additional assistance.

Within MRI the project was also the product of several people. Mr. Walter Benson provided the Senior management and review. Mr. Richard Cuthbert developed the overall logic of the study. Mr. Andrew St. John performed the highway-damage study, a major subsection of the project. Messrs. Marc Semanoff and Frank Witte did most of the detailed data analysis and computer programming. In addition, Mr. Semanoff in cooperation with Mr. William Park developed the cost model, another major subsection of the study. MRI's transportation studies group also provided assistance concerning characteristics of the trucking industry.

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I. SUMMARY

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 (TWO); (2) calculate the benefits and costs from new levels and methods of TWO; and (3) pick the method and level of TWO that maximized the difference of benefits and costs.

In step 1, the benefits from TWO were defined as the sum of fines and additional license fees collected, the value of the road damage avoided and the increased registration revenue. The costs from TWO 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 loss to Iowa from road damage 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 were 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 TWO 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 weighting equipment to the point where ~~90~~ 89 percent of the trucks on Iowa's highways now comply with state weight and registration laws. In general further increases of this routine would result in increased compliance, but at a cost incommensurate with the benefits. As traffic patterns shift with major improvements in the primary road system, new scale sites may become necessary.

Increased benefits from TWO can best be realized for the 4 year term by the application of newly developed management tools for the allocation of reinforcement 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:

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 64 field traffic weight officers.	No staff changes are needed to attain desired level.	Staff level Section III-B-1 pp. III-39
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.
		Some scale sites do not contribute sufficient benefits to meet annual operating costs.	Some low traffic count sites should be abandoned or put to other uses.	
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.
	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.
	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.

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.
	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 of 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.
	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 problem under study was to determine the optimum level and method of enforcing traffic weight and size regulations in Iowa. Part of the study itself was to formulate definitions of terms like "optimum," "level" and "method of enforcing" as applied to traffic-weight operations, T.W.O.

B. Overall Approach

The basic approach of the study is described in the following steps:

1. Determine the benefits to Iowa from traffic-weight operations.

2. Determine the costs to Iowa from traffic-weight operations.

3. Determine the optimum level and method of enforcement as the level and method of enforcement that produce a satisfactory relation between benefits and costs. Specifically, the level and method chosen was that which maximized the difference between benefits and costs, i.e., produced the greatest net gain to Iowa.

C. Study Plan

The relatively simple basic approach to the problem just outlined required a complex plan to implement. Figure 1 is a block diagram of the study plan.

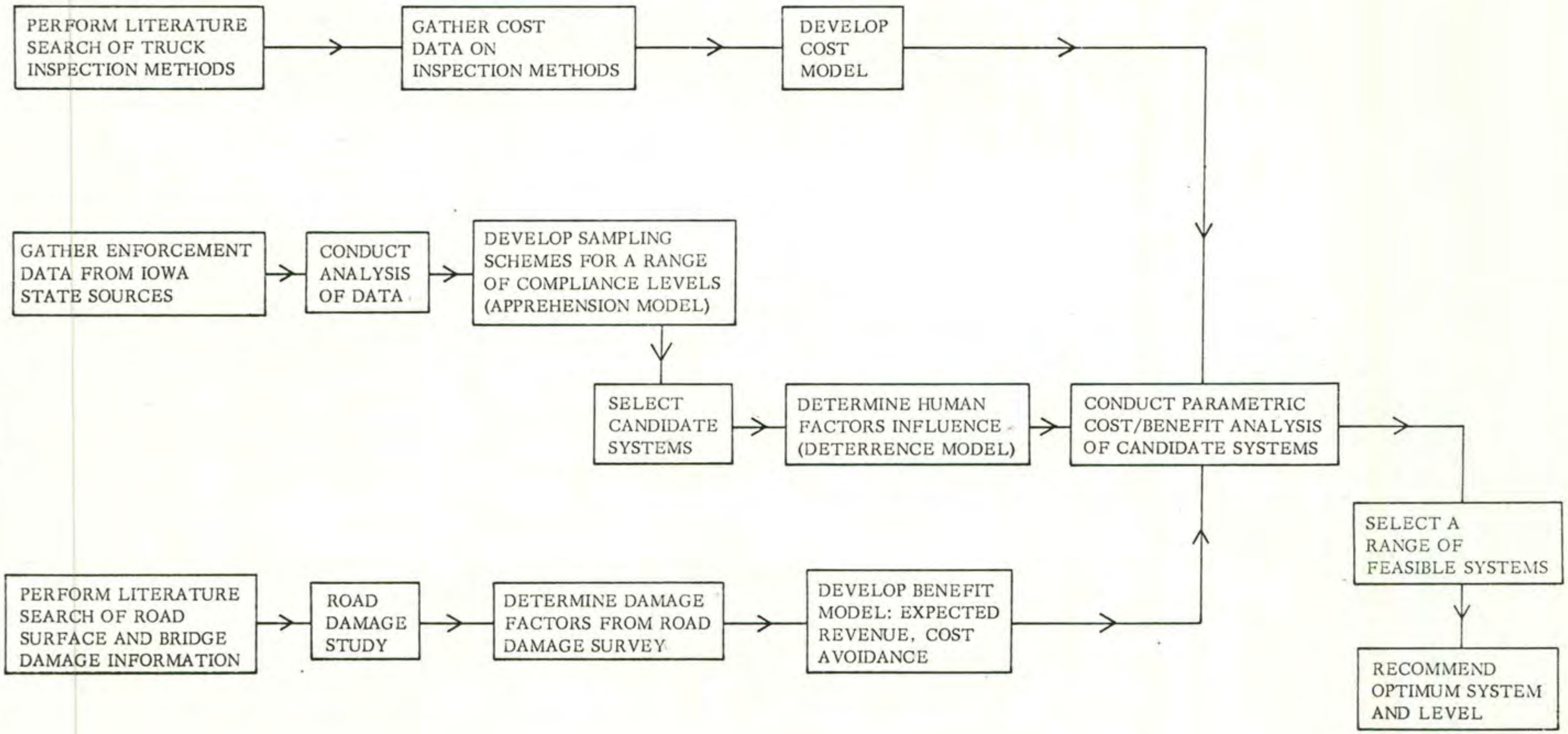

Figure 1 - Research Plan for a Study of the Optimum Level of Enforcement of Iowa State Motor Vehicle Size and Weight Regulations

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.* 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.). 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

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* A list of sources contacted is at Appendix 2.

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.

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 one major component of these benefits was the deterrence or prevention of uncompensated road wear or damage by overweight trucks. It was also known that the evaluation of the magnitude of potential overweight damage would require an extensive substudy by itself. Hence, this part of the effort was begun early in the project. Further study of benefits from weigth enforcement indicated that the other major benefit besides damage prevention was the fines and registration fees collected from apprehended violators. It is possible that enforcement of the oversize laws prevents a safety hazard, but no data on this effect were found to be available. The damage-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 was 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. A full list is included in Section III-A-7 of the report. 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 procedure;

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 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. An acceptable clear definition of what is meant by the terms "optimum," "benefit," and "cost" as applied to traffic weight operations (T.W.O.).

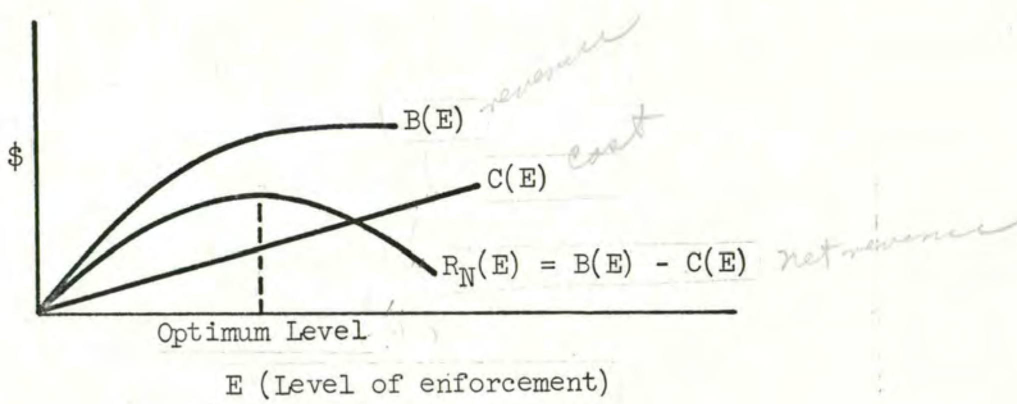
2. A means of measuring benefits and costs of present and alternative T.W.O. methods.

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 damage 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

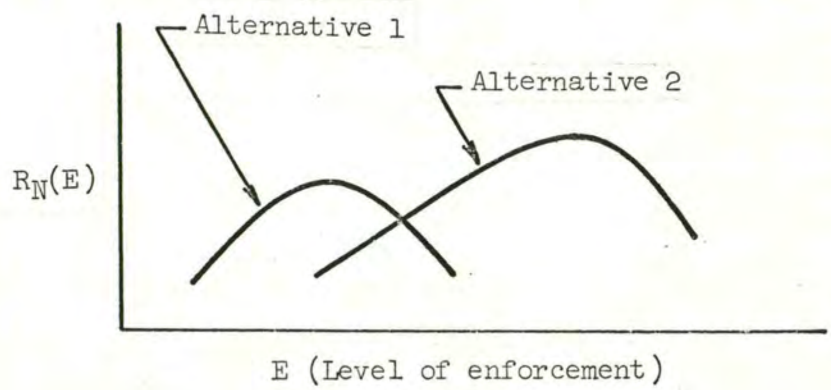
$$R_N(E) = B(E) - C(E)$$

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 return." For example, the initial enforcement effort may deter the majority of violators, so that most of the road-damage prevention possible is accomplished. 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.

Evaluation of Alternatives: 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 costs. Alternatives involving the use of equipment that is beyond the technical sophistication of enforcement officers1/ or of methods that unduly harass honest truckers cannot be justified in terms of revenue and cost.

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

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 2 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, road damage 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.

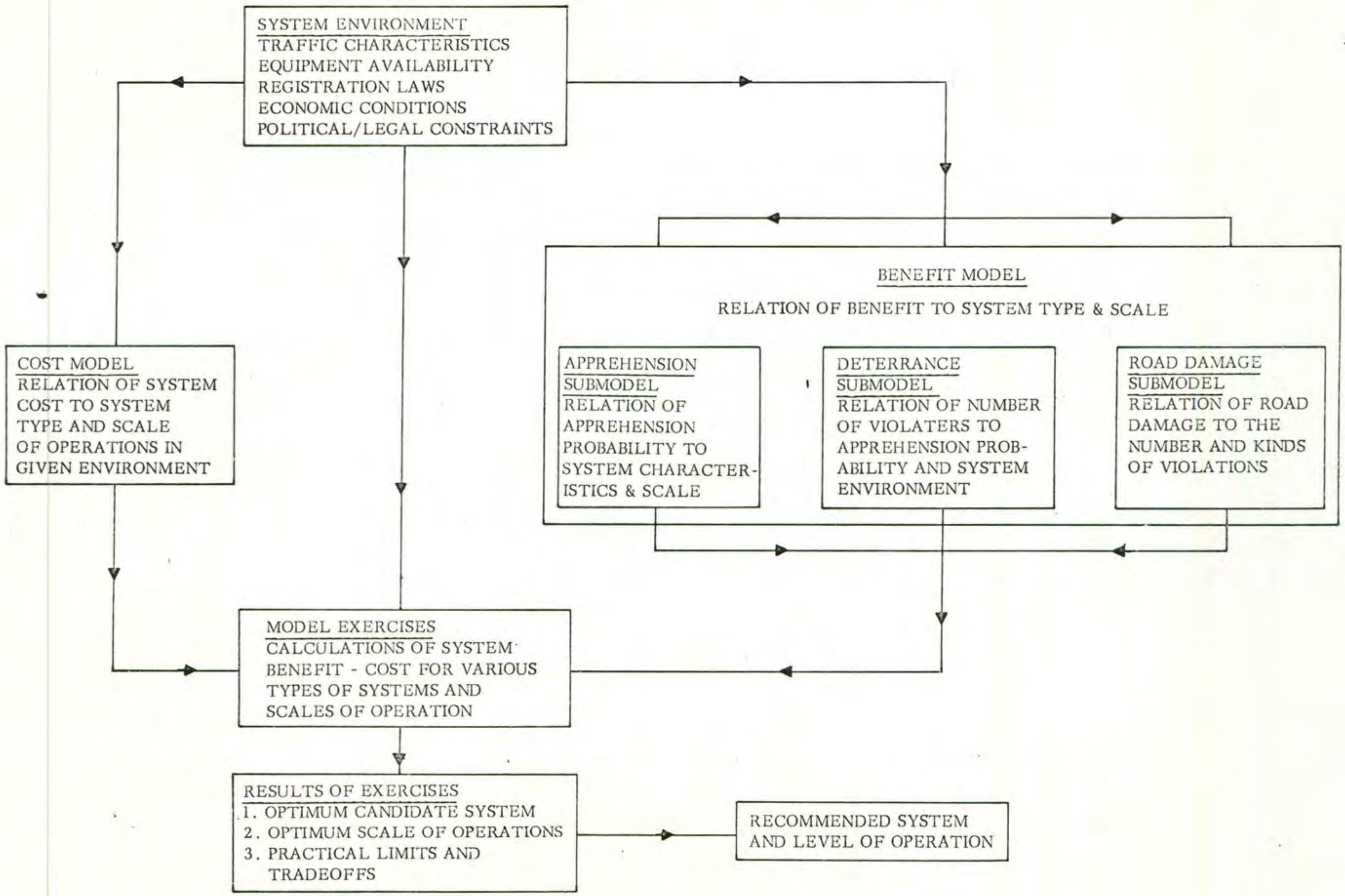


Figure 2 - Overall Logic of The Cost Effectiveness Analysis of Weight Enforcement Methods

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 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 overweight regulations.

V_u = Fraction of vehicle trips made in violation of one or more overweight regulations if no T.W.O. existed.

The total benefit B is the sum of the fines and registration increases collected plus the uncompensated road wear and withheld fees that are prevented. Symbolically:

$$B = B_c + B_p$$

B_c is given by the following expression:

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

B_p is expressed as follows:

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

Source of Values: 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, 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 of the methodology. The values for L_{vw} were obtained from the Road Damage Submodel in Section 6 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 of the Methodology.

A sample output from the program is at Figure 6 in Section III-B-1, p. III.39 The various revenue categories shown there are based on the benefit equation. The actual fines or registration increases collected from apprehended violators are shown under two column headings, one for fixed sites and one for roving patrols. The column marked REVENUE DAMAGE PREVEN shows the savings to Iowa from uncompensated road wear prevented, and the column marked REVENUE REGISTRATION shows the expected savings resulting from deterring failure to pay full registration fees. The figure marked NET REVENUE shows the difference of benefit and cost in dollars. The staff level at which this difference is maximum is best for this particular apprehension method.

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, two permit officers, 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 3). The direct salary costs for traffic weight officers

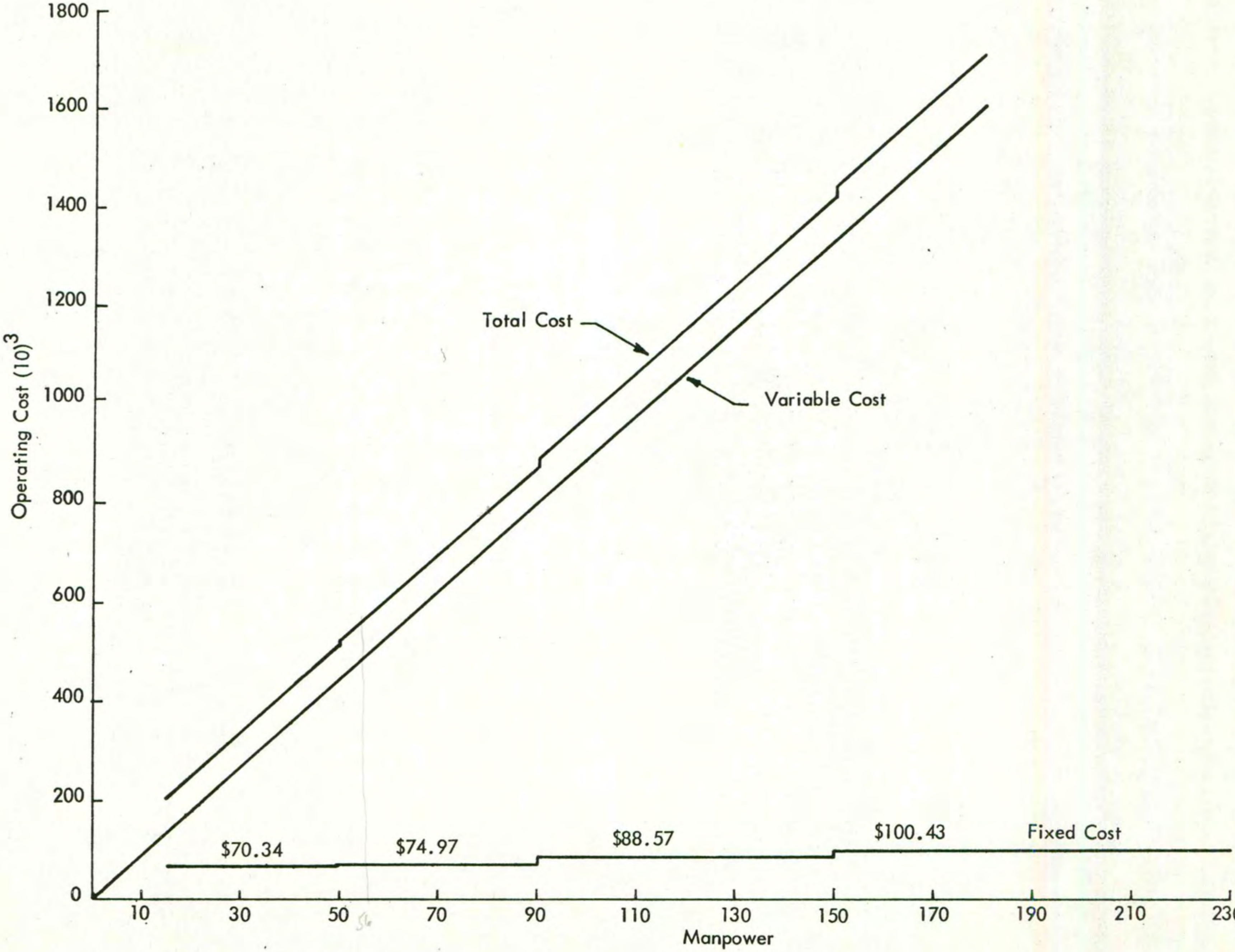


Figure 3 - Cost Model: Cost Versus Staff Level

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.

Cv = 8,903
S = 56
CF = 74.97
C = 498,642.97

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

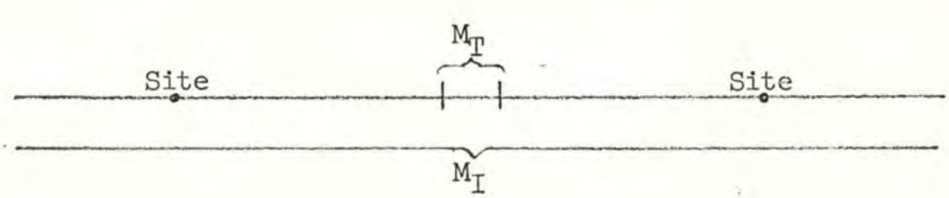
P_I = Probability of being inspected at a site given that a violator passes it; i.e., the probability that the site is open

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:

$$P_o = M_T\ SHDP_I/168M_I sN$$

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

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

7

Hence:

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

or approximately, for moderate P_O,

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

?

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* for P. When the sites are saturated, we have to increase S when we increase N in order to gain in P.

For the saturated region:

$$S = 168sN/HD$$

and so

$$f_s = 1$$

---

* 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.

Therefore:

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

or

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

Multiple Inspection Methods - Random Site Location: 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 inspecting and so on. An effort is normally made to keep the various teams from operating in the same geographic area, so that their chances of apprehending a violator are additive, i.e.:

$$P = P_1 + P_2 + \ldots + P_N$$

where $P_1, P_2, \ldots, P_N$ are the probabilities associated with each method.

Currently, there are only two methods of apprehension, fixed sites and roving patrols. Hence, we will refer to P_r and P_f, probability of apprehension by roving patrol and fixed site, respectively. Hence,

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

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 trucker.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 trucker. 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.

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

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,[1/] 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 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 4 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 judgement 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 $(0.15 \rightarrow 0.20)$ of 0.10 or 0.015 - 0.02.

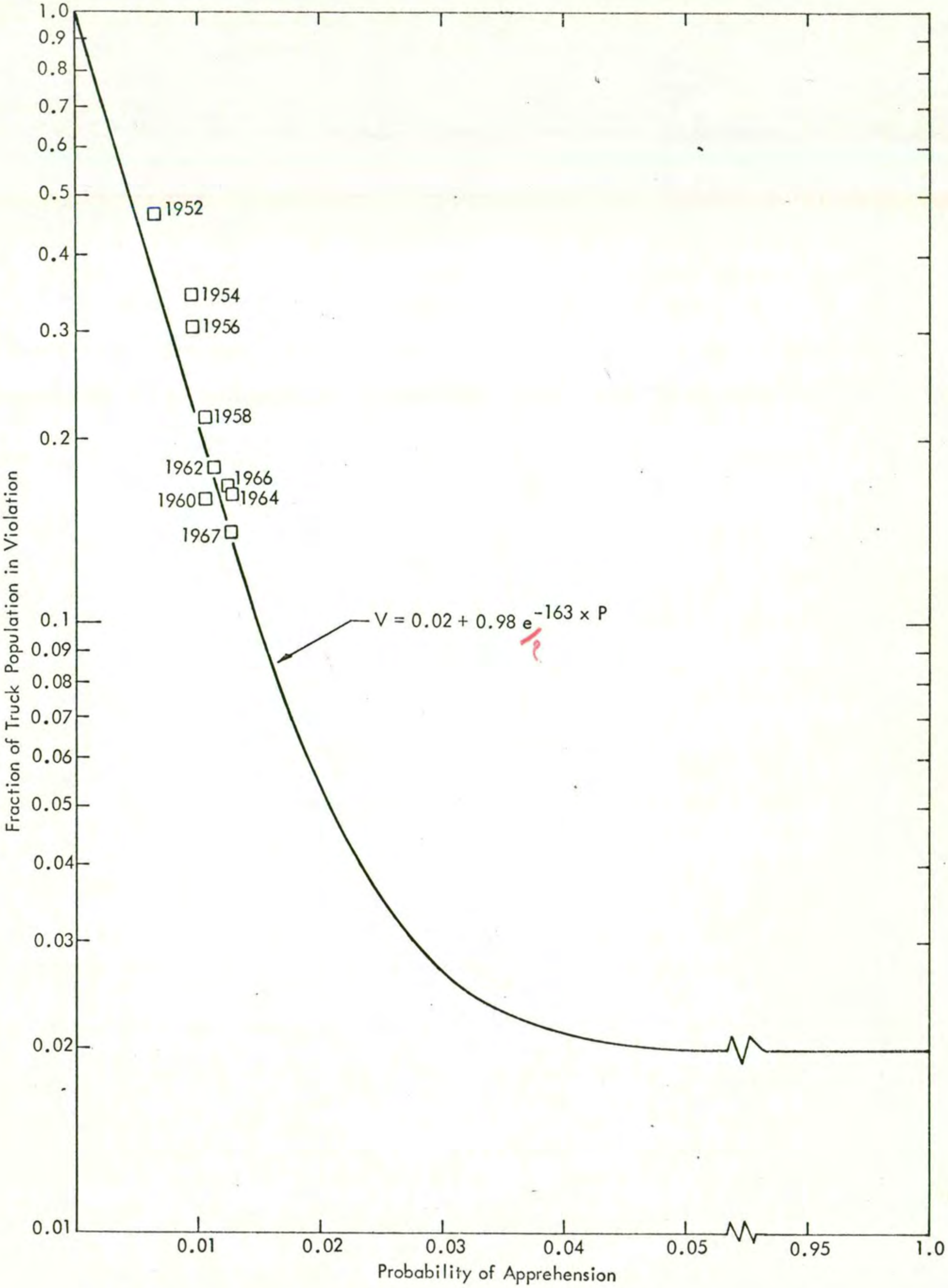


Figure 4 - Deterrence Model

6. Road-Damage Submodel

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

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. The equitable apportionment of the system costs among 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.* The increments of life-use are so small that they often lie outside the range of direct test and engineering experience. This situation

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

is partially refuted by other findings.* 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.

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 over-conservatism.

The overweight vehicle may over-use 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 ofer a higher impedance to the traffic flow. The power available is just as important as the

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

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 Pavement 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 mile can be constructed to start with the smallest element, an axle traveling over a pavement. The axle passage uses some part of the pavement life. It is conventional and convenient to express this life-use in terms of reference axle applications W_{rx}.* 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,

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

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.** 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

* The reference axle is a single axle of 18,000 lbs.

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

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

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

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

The average uncompensated life use per violating vehicle, $\overline{W}_{ru}(\text{pave.})$, 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

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

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, $W_{tr}(\text{pave.})$. A ratio can be formed

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

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

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

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 life 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}(pave.) $\cdot$ Y. Where C_{my}(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

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

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 $\bar{C}_p$(pave.) and $\bar{C}_m$(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 necessary 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(pave.) = Miles of road in the analyzed system with specified pavement.

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

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* 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

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

Consideration in Employment: 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 $A(\text{config.}, L_{lega}, L_{actual})$ 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 5 lists the alternatives considered in the study. The performance achieved by such candidates are discussed in Sections B and C of the body of the report.

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 effort. 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 5 - List of Candidate Enforcement Systems

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 developed in Section A 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 6. Figures 7 and 8 are graphical displays of the same results.

Results: The optimum staff level for Iowa T.W.O., using current apprehension methods, is 64 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 63 men, one additional man adds slightly more benefit than his

SYSTEM INPUT DATA

TRAFFIC 12060000. FRACTION VIOLATING 0.140 PROBABILITY OF APPREHENSION0.013
ALLOCATION OF MANPOWER: FIXED 0.532, ROVING 0.168, OTHER 0.300

STAFF	NET REVENUE	REVENUE REGISTRATION	REVENUE FIXED SITES	REVENUE ROVING PATROL	REVENUE DAMAGE PREVEN.	TOTAL REVENUE	OPERATING COST	P	V
15	2644.	732.	499.	231.	1385.	2848.	204.	.0034	.5774
20	3160.	897.	556.	257.	1698.	3408.	248.	.0046	.4820
25	3547.	1034.	580.	268.	1958.	3840.	293.	.0057	.4029
30	3835.	1148.	583.	270.	2172.	4172.	337.	.0069	.3375
35	4044.	1242.	570.	264.	2350.	4426.	382.	.0080	.2832
40	4192.	1319.	548.	254.	2497.	4518.	426.	.0092	.2333
45	4294.	1384.	520.	241.	2620.	4765.	471.	.0103	.2010
50	4354.	1437.	489.	227.	2721.	4874.	520.	.0114	.1702
55	4390.	1482.	457.	212.	2805.	4955.	565.	.0126	.1446
60	4406.	1518.	425.	197.	2874.	5015.	609.	.0137	.1234
65	4405.	1549.	395.	183.	2932.	5058.	654.	.0148	.1058
70	4392.	1574.	366.	170.	2980.	5090.	698.	.0160	.0912
75	4370.	1595.	340.	158.	3019.	5112.	743.	.0171	.0791
80	4341.	1612.	317.	147.	3052.	5128.	787.	.0183	.0691
85	4308.	1627.	296.	137.	3080.	5140.	832.	.0194	.0607
90	4271.	1639.	277.	129.	3102.	5147.	876.	.0205	.0538
95	4218.	1649.	262.	122.	3121.	5153.	934.	.0217	.0481
100	4178.	1657.	248.	115.	3137.	5157.	979.	.0228	.0433
105	4136.	1664.	237.	110.	3150.	5160.	1023.	.0239	.0394
110	4095.	1670.	227.	106.	3160.	5162.	1068.	.0250	.0361
115	4052.	1674.	219.	102.	3169.	5165.	1112.	.0262	.0334
120	4010.	1678.	213.	99.	3177.	5167.	1157.	.0273	.0311
125	3969.	1681.	209.	97.	3183.	5170.	1201.	.0284	.0292
130	3927.	1684.	205.	96.	3188.	5173.	1246.	.0296	.0277
135	3886.	1686.	203.	95.	3192.	5176.	1290.	.0307	.0264
140	3845.	1688.	202.	94.	3196.	5180.	1335.	.0318	.0253
145	3805.	1690.	202.	94.	3199.	5184.	1380.	.0329	.0244
150	3765.	1691.	202.	94.	3201.	5189.	1424.	.0340	.0237
155	3713.	1692.	204.	95.	3203.	5194.	1480.	.0352	.0231
160	3674.	1693.	205.	96.	3205.	5199.	1525.	.0363	.0225
165	3635.	1694.	208.	97.	3206.	5204.	1569.	.0374	.0221
170	3596.	1694.	210.	98.	3207.	5210.	1614.	.0385	.0218
175	3558.	1695.	214.	100.	3208.	5216.	1658.	.0396	.0215
180	3520.	1695.	217.	101.	3209.	5223.	1703.	.0408	.0212
185	3482.	1696.	221.	103.	3210.	5229.	1747.	.0419	.0210
190	3444.	1696.	225.	105.	3210.	5236.	1792.	.0430	.0208
195	3407.	1696.	229.	107.	3211.	5243.	1837.	.0441	.0207
200	3369.	1696.	234.	109.	3211.	5250.	1881.	.0452	.0206

Figure 6 - Calculation of Optimum Staff Level

SYSTEM INPUT DATA
TRAFFIC 12060000. FRACTION VIOLATING 0.021 PROBABILITY OF APPREHENSION0.013
ALLOCATION OF MANPOWER: FIXED 0.532, ROVING 0.168, OTHER 0.300

STAFF	NET REVENUE	REVENUE REGISTRATION	REVENUE FIXED SITES	REVENUE ROVING PATROL	REVENUE DAMAGE PREVEN.	TOTAL REVENUE	OPERATING COST	P	V
205	3332.	1697.	238.	111.	3211.	5258.	1926.	.0463	.0205
210	3295.	1697.	243.	114.	3212.	5265.	1970.	.0475	.0204
215	3258.	1697.	248.	116.	3212.	5272.	2015.	.0486	.0203
220	3221.	1697.	253.	118.	3212.	5280.	2059.	.0497	.0203
225	3184.	1697.	258.	121.	3212.	5288.	2104.	.0508	.0202
230	3147.	1697.	263.	123.	3212.	5295.	2148.	.0519	.0202
235	3111.	1697.	268.	126.	3213.	5303.	2193.	.0530	.0202
240	3074.	1697.	273.	128.	3213.	5311.	2237.	.0541	.0201
245	3037.	1697.	278.	131.	3213.	5319.	2282.	.0552	.0201
250	3001.	1697.	284.	133.	3213.	5327.	2326.	.0563	.0201
255	2964.	1697.	289.	136.	3213.	5335.	2371.	.0574	.0201
260	2927.	1697.	294.	138.	3213.	5343.	2415.	.0585	.0201
265	2891.	1697.	300.	141.	3213.	5351.	2460.	.0596	.0201
270	2854.	1697.	305.	143.	3213.	5359.	2504.	.0607	.0200
275	2818.	1697.	310.	146.	3213.	5367.	2549.	.0618	.0200
280	2781.	1697.	316.	148.	3213.	5375.	2593.	.0629	.0200
285	2745.	1697.	321.	151.	3213.	5383.	2638.	.0640	.0200
290	2708.	1697.	327.	154.	3213.	5391.	2682.	.0651	.0200
295	2672.	1697.	332.	156.	3213.	5399.	2727.	.0662	.0200
300	2636.	1697.	338.	159.	3213.	5407.	2771.	.0673	.0200
305	2599.	1697.	343.	161.	3213.	5415.	2816.	.0684	.0200
310	2563.	1697.	348.	164.	3213.	5423.	2860.	.0695	.0200
315	2526.	1697.	354.	167.	3213.	5431.	2905.	.0706	.0200
320	2490.	1697.	359.	169.	3213.	5439.	2949.	.0717	.0200
325	2453.	1697.	365.	172.	3213.	5447.	2994.	.0728	.0200
330	2417.	1697.	370.	175.	3213.	5455.	3038.	.0739	.0200
335	2380.	1697.	376.	177.	3213.	5463.	3083.	.0750	.0200
340	2344.	1697.	381.	180.	3213.	5471.	3127.	.0761	.0200
345	2307.	1697.	386.	182.	3213.	5479.	3172.	.0772	.0200
350	2271.	1697.	392.	185.	3213.	5487.	3216.	.0783	.0200
355	2234.	1697.	397.	188.	3213.	5495.	3261.	.0794	.0200
360	2198.	1697.	403.	190.	3213.	5503.	3306.	.0805	.0200
365	2161.	1697.	408.	193.	3213.	5511.	3350.	.0815	.0200
370	2125.	1697.	413.	195.	3213.	5519.	3395.	.0826	.0200
375	2088.	1697.	419.	198.	3213.	5527.	3439.	.0837	.0200
380	2052.	1697.	424.	201.	3213.	5535.	3484.	.0848	.0200
385	2015.	1697.	430.	203.	3213.	5543.	3528.	.0859	.0200
390	1979.	1697.	435.	206.	3213.	5551.	3573.	.0870	.0200
395	1942.	1697.	440.	209.	3213.	5559.	3617.	.0880	.0200
400	1906.	1697.	446.	211.	3213.	5567.	3662.	.0891	.0200

Figure 6 (Concluded)

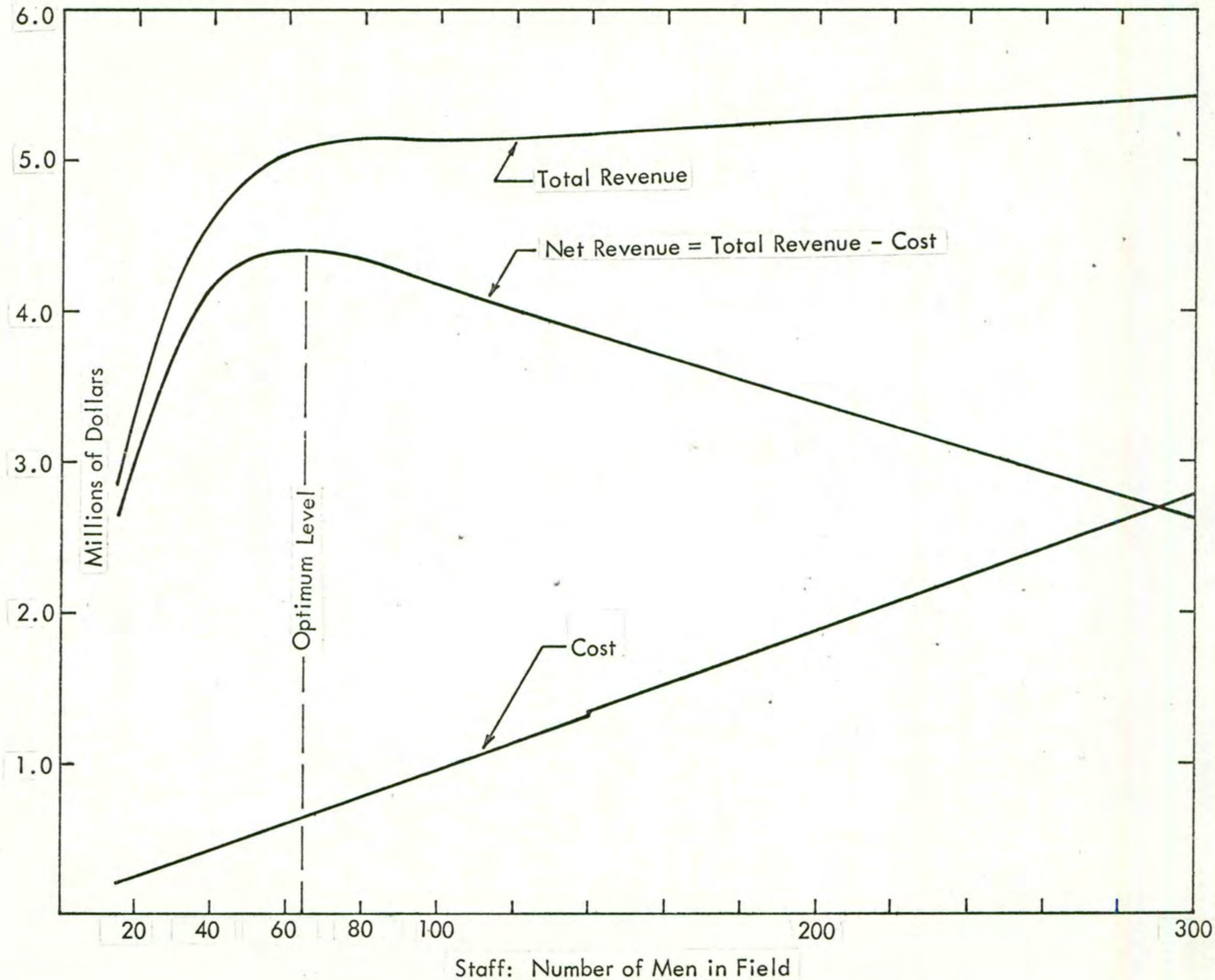

Figure 7 - Total Revenue, Net Revenue, and Cost Versus Staff Level

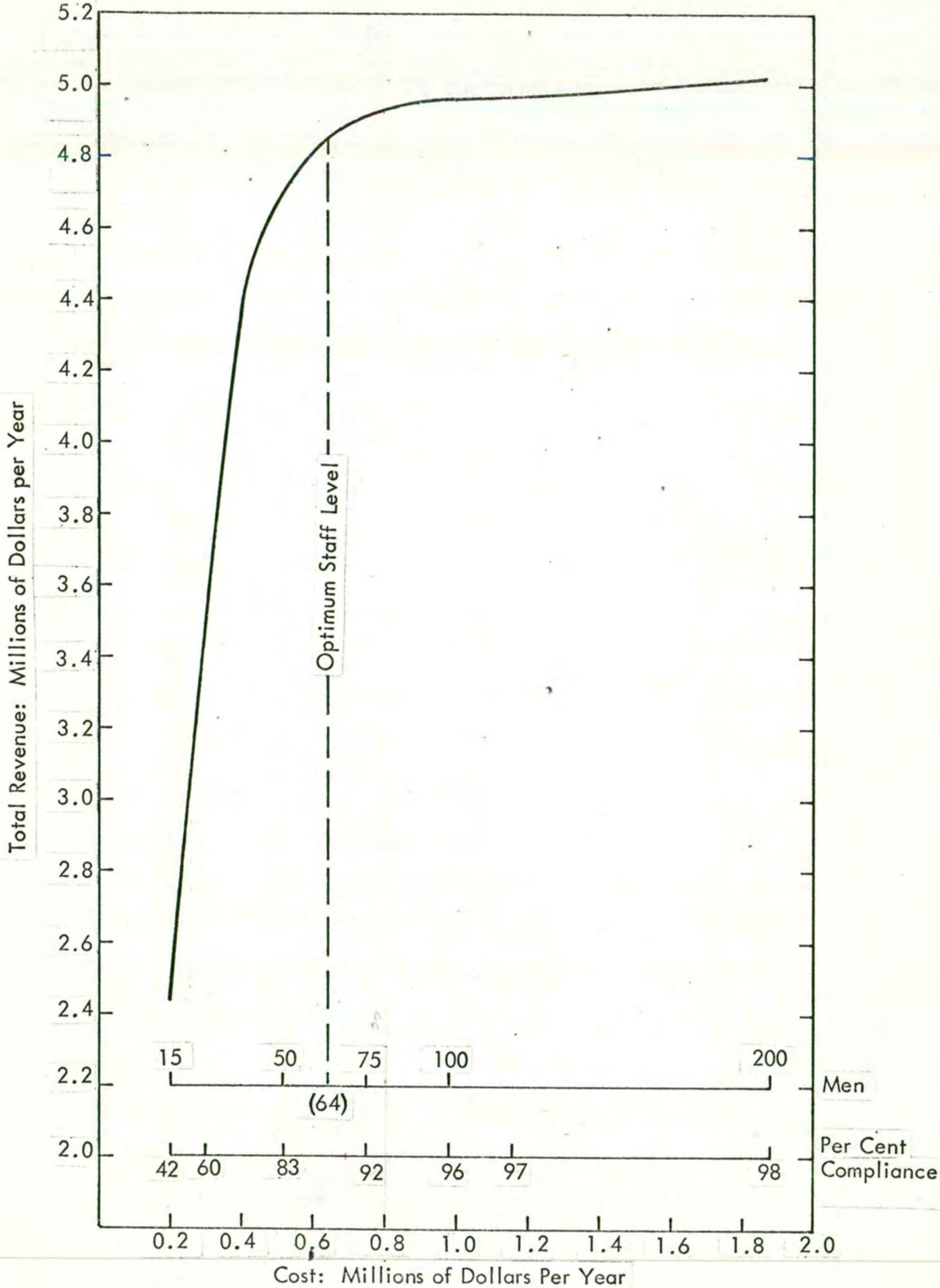

Figure 8 - Total Revenue Versus Cost

cost of approximately $9,000 per year. When the staff is 64 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, 64 men, yields $4,400,000 in benefits from T.W.O. At a 200-man staff level, the net revenue would be $1 million per year less.

Figure 8 shows that the percent compliance at the optimum staff level of 64 is about 90 percent. The fact that the optimum staff level is 64 men implies that a high degree of compliance (90 percent) can be obtained at a commensurate cost of enforcement. On Figure 8, Total Revenue vs. Cost, it can also be seen that a dollar of investment in T.W.O. returns a dollar in revenue at 64 men. Dollars invested beyond 64 men do not bring in a return to cover the extra investment. It should be recalled that revenue credited to T.W.O. includes prevention of road damage obtained by compliance with the law. Further staff increases would improve compliance as shown in Figure 8, but the cost would not be commensurate with the benefit.

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 9. 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 $3.3\ (10)^{-4}$ to $3.63\ (10)^{-4}$. This improvement would mean that the same apprehension performance could be obtained with five fewer men, i.e., the optimum staff level would be 59 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 9 indicate the sensitivity of the optimum staff level to deterrence efficiency. The three curves use different values of an exponential coefficient to fit to the deterrence data. These parametric deterrence curves are shown in Figure 10. 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 deterrence constant. These variations produced a variation in manpower required of five 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.

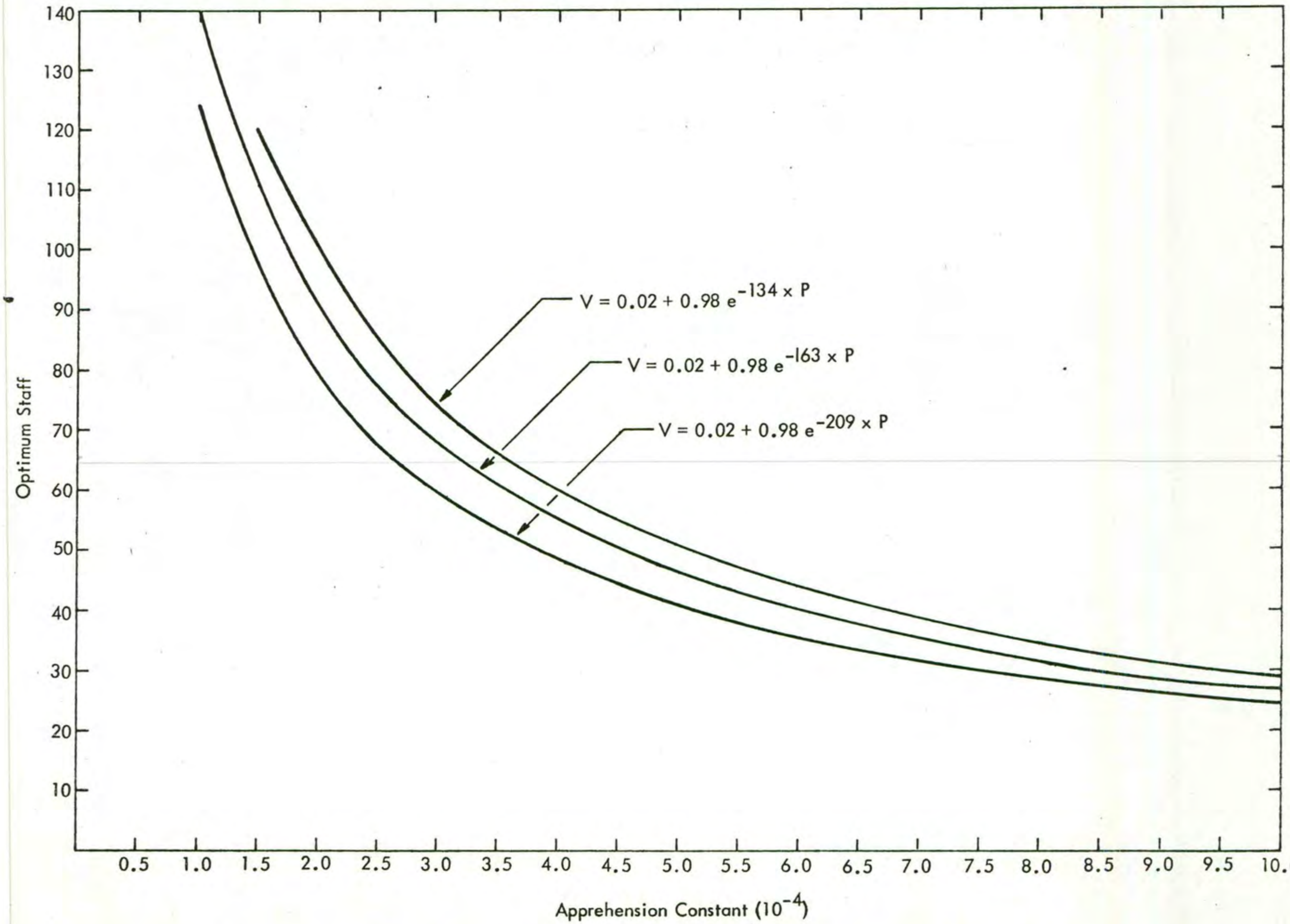

Figure 9 - Sensitivity of Optimum Staff to Apprehension and Deterrence Efficiency

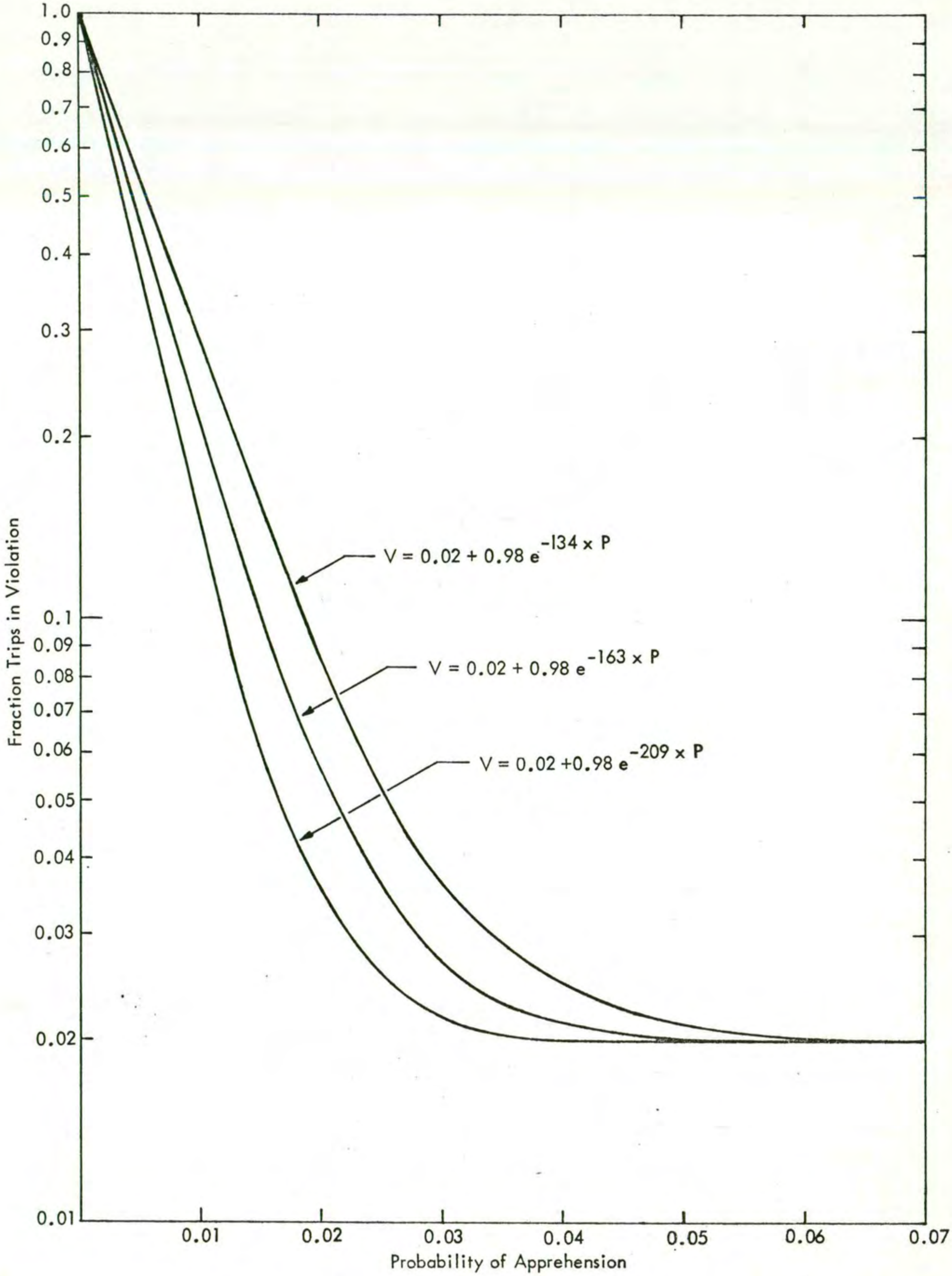

Figure 10 - Parametric Deterrence Curves

The effect of variation in average fine on staff size is shown in Figure 11. 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 11 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 was the result of a complex analysis, and is therefore probably relatively prone to error. The engineer in charge of developing this figure, Mr. Andrew St. John, calculated the average damage per violator per mile for the primary system only, and for the primary and paved secondary roads taken together. The average damage per violation on the primary system only is $.19 compared to $.42 per violator on the primary and secondary roads together. As can be seen on Figure 12, use of $.19 as the average damage would reduce the optimum staff level to 43 men.*

It is very likely that weight regulation enforcement has some value in preventing accidents and bridge damage. These factors were not included in the derivation of the $.42 average damage figure because of lack of data.

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* The study originally considered only the damage to primary roads. Further analysis, however, indicated that neglecting the secondary roads would have been a major error since these roads also are protected from damage from overweight vehicles by T.W.O.

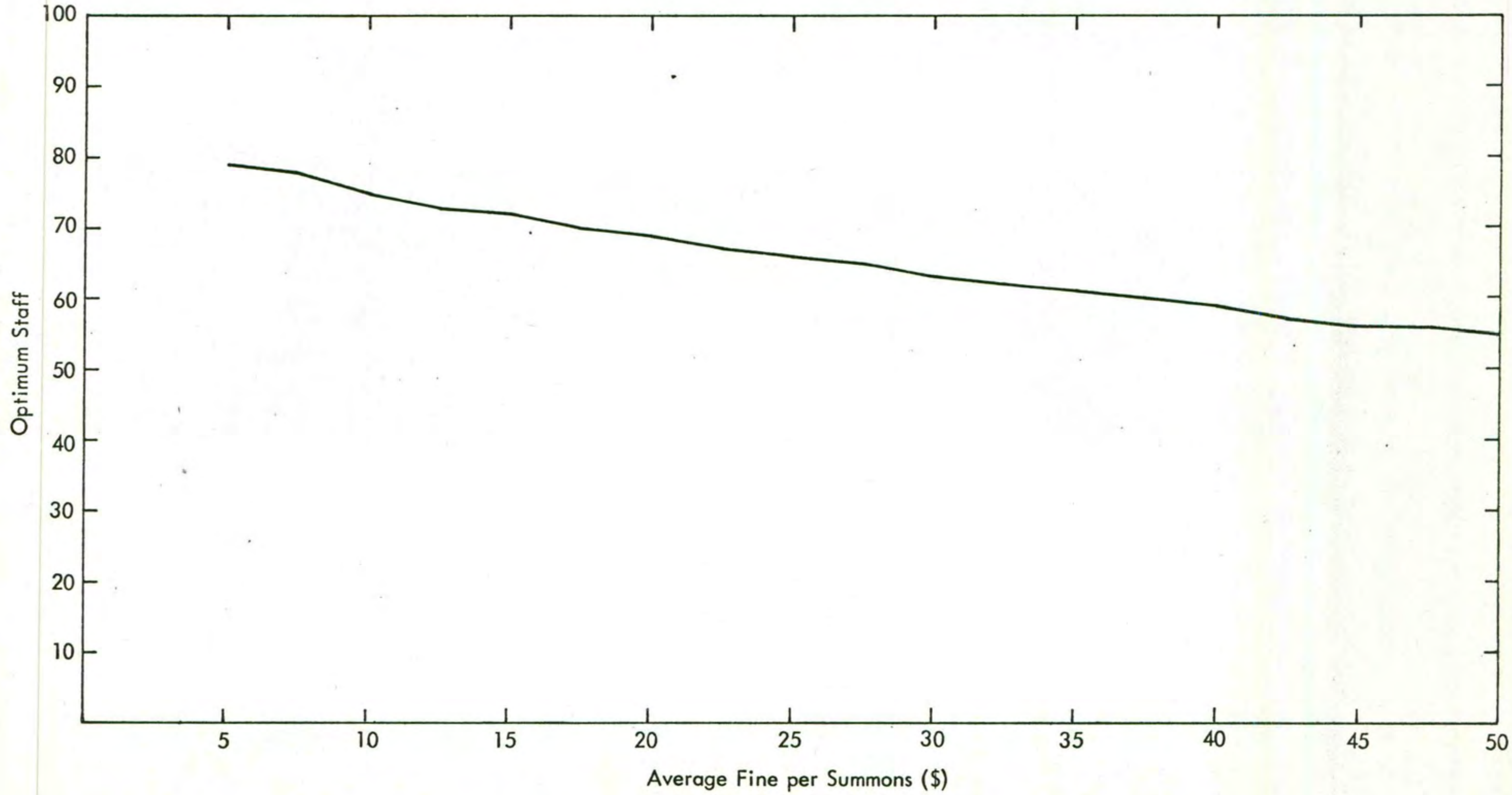

Figure 11 - Sensitivity of Optimum Staff to Average Fine per Summons

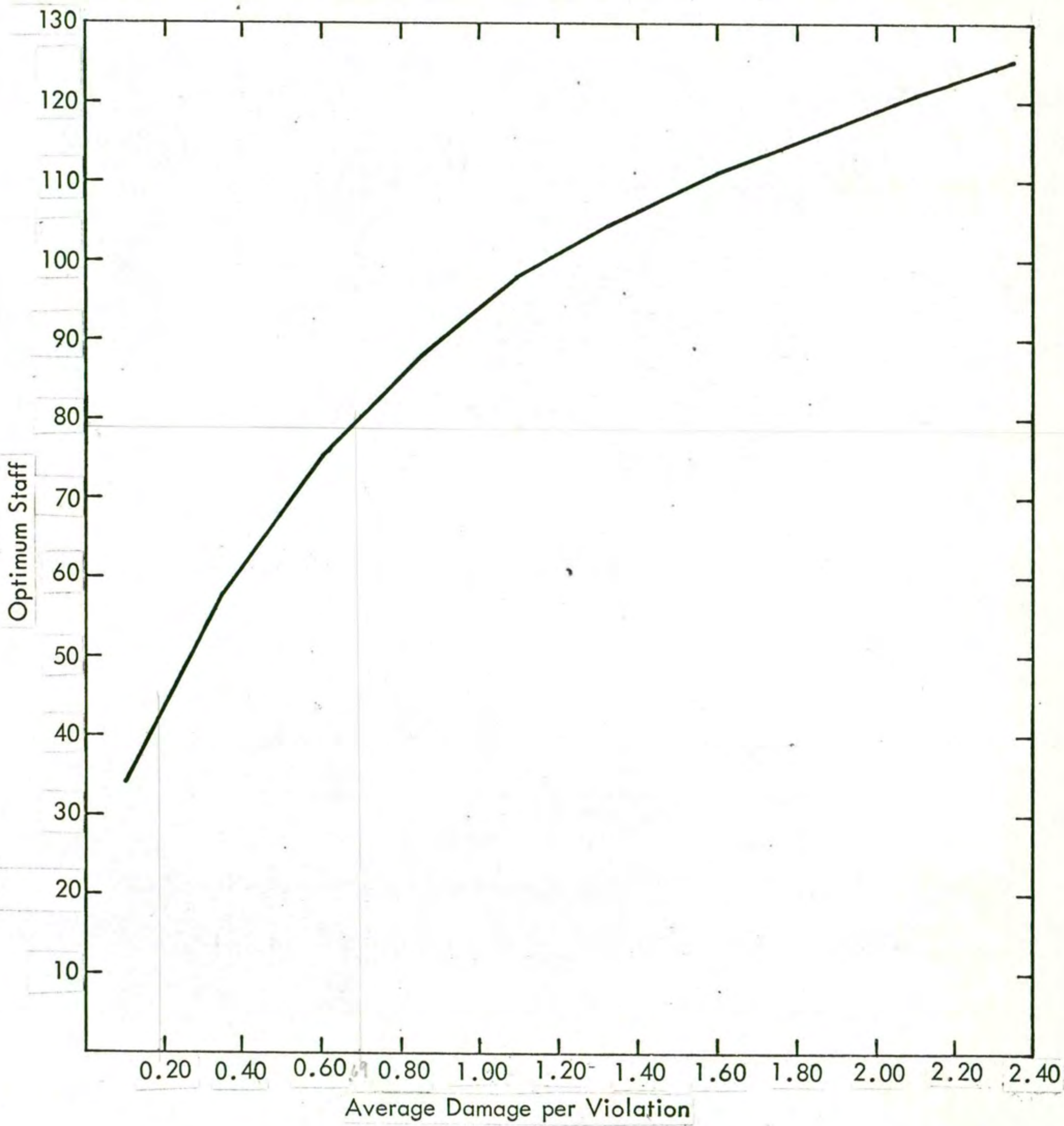

Figure 12 - Damage Versus Optimum Staff

Addition of these factors into the analysis would have increased the average damage figure somewhat. As can be seen on Figure 12, this would in turn have increased the optimum staff level.

Even considering the necessary assumptions and approximations, it is almost certainly true that Iowa traffic weight operations have reached a level where increased enforcement through personnel expansion is not remunerative. Efforts to increase enforcement through more efficient allocation of present resources should yield compliance improvements at lower cost.

5. Number 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 $4 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.

Manpower Allocation by Scale Site

Method of Analysis: This section of the report presents a general methodology for the allocation of manpower to individual traffic weight stations. Our approach is to rank each traffic weight station by the total revenue earned per operating hour, and to allocate manpower to sites in proportion to their earning power. Total revenue consists of the fines collected from summonses, and an implicit value for road damage and other losses prevented.

The revenue collected from summonses issued varies considerably among the 31 existing stations, as shown on Figure 13, Recommended Manpower Allocation by Scale Site. Seven stations receive $28.40 per summons and collect $15 to $20 per operating hour. Six other stations average $18.20 per summons and collect $10 to $15 per operating hour. There are 18 stations in the

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	Damage Prevented/Hour (\$)	Total Contribution (\$)[1/], B_h	Recommended Manpower Allocation (%)[2/]
246 S	1	39.7	0.032	19.10	17.20	20.23	7.25
233	2	34.4	0.016	19.00	16.10	20.21	7.20
232	3	27.2	0.020	18.80	14.20	19.71	6.80
245 N	4	41.7	0.017	18.20	11.20	19.66	6.14
243	5	27.8	0.021	18.60	11.40	19.52	6.14
239	6	10.6	0.037	19.00	15.60	19.28	6.10
240	7	33.3	0.021	15.40	13.70	16.50	5.95
246 N	8	38.5	0.031	14.20	15.20	15.31	5.45
238	9	30.8	0.015	13.70	12.70	14.80	5.40
222	10	36.8	0.019	11.40	16.60	12.65	5.32
244	11	12.7	0.036	12.10	16.40	12.44	4.79
249 N	12	25.4	0.027	11.00	4.28	11.67	4.76
226	13	30.8	0.013	10.40	12.70	11.50	4.73
245 S	14	40.3	0.017	9.40	14.30	10.80	4.44
249 S	15	25.0	0.031	9.50	10.40	10.22	4.38
229	16	14.8	0.039	9.40	12.90	9.78	4.16
221	17	39.6	0.015	8.00	10.20	9.42	4.03
223	18	17.7	0.038	8.80	5.14	9.26	3.52
250 E	19	16.4	0.024	8.70	9.06	9.22	3.40
242	20	34.8	0.019	7.40	7.15	8.58	99.87
228	21	31.0	0.010	7.40	6.72	8.57	
247 E	22	16.8	0.031	7.80	5.97	8.29	
230	23	22.1	0.024	7.50	7.37	8.21	
224	24	17.9	0.019	7.40	6.84	8.01	
227	25	14.7	0.016	7.40	6.40	7.92	
247 W	26	15.7	0.029	7.40	6.07	7.86	
250 W	27	13.3	0.022	7.10	5.46	7.54	
234	28	13.6	0.031	5.50	5.54	5.89	
241	29	13.9	0.028	4.80	5.68	5.22	
237	30	13.0	0.013	2.80	5.39	3.19	
Total						351.46	

Missouri Valley Interstate not included

1/ Sum of fines collected and damage prevented per operating hour.
2/ Recommended manpower allocation is based on fraction individual site contributes to total contribution.

Figure 13

lowest group, where the average summons is $13.95 and $1 to $10 is collected per operating hour. These differences can be attributed to local differences in traffic volume, fraction of traffic in violation, and the average fine per summons. Figure 13 shows, by station, the expected cash revenue as fines collected per operating hour.

The fixed site scales which Iowa now owns are all part of the system of T.W.O. which has encouraged compliance with the law to the point where 90 percent of the trucks on Iowa's highways obey the laws and regulations pertaining to registration, weight, and size of vehicle. Each scale station, therefore, can be considered to have contributed to the system compliance level of 90 percent and also to the local level of compliance as measured at the scale site. The local compliance averages 98 percent, and can be calculated for each scale from Figure 13 as $1 - V_s$. The damage prevention value associated with each scale is the product of the traffic per operating hour T_h, the local degree of compliance, $(1 - V_s)$, and the average loss to Iowa per overweight or oversize vehicle, L_v (as discussed in Appendix 1, Tabs L and M).

The total hourly contribution, B_h, of a scale is the sum of the damage prevented and fines collected:

$$B_h = T_h L_v (1-V) + F_h$$

<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 = \$0.42 average damage 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.

$$B_h = T_h L(1-V_s) + F_h$$

$$B_h = 41.7(0.42)(1-0.017) + 18.20$$

B_h = \$35.40 total benefit earned per operating hour for station 245N.

Results of the Analysis: Similar calculations were performed for each fixed-weight station in order to determine the benefits earned. Each station was then ranked according to its benefits earned per operating hour. Figure 13 presents the results of this analysis.

Manpower to operate fixed sites is a limited resource. Therefore, it is necessary to find the best means to allocate the manpower.

If manpower is allocated in direct proportion to the revenue contribution per hour of a given fixed site, near optimum total benefits can be attained. This strategy tends to improve revenue in the long run. When more manpower is allocated to station 245N, the probability of apprehending a violator who passes this station increases. This policy should cause greater compliance at this station, since truck traffic is sensitive to the increased probability of apprehension. At the same time, the compliance may decline at another station which is now operated fewer hours. The total benefits from enforcement are based on the traffic level, degree of compliance, and the average revenue collected from fines at all stations. The net effect of the recommended strategy will be to focus the limited number of men where they are most needed, without encouraging violations in lightly traveled areas.

The total contribution for each fixed station is also shown in Figure 13. There is some question whether the continued operation of the last 11 stations is economically justified; it costs more to operate each station than the station contributes. With the current operating procedure, the direct variable cost is $16.30 per operating hour.* An additional $.20 per hour is required for heat, electricity, etc., for a total operating cost of $16.50 per hour. For example, if the operating costs are $16.50 per hour and the site collects only $2.80 per hour in fines, then the scale loses $13.70 per hour of operation. If the scale is operated 100 hours per year, this "loss" is $1,370 which must be offset by the increased compliance. If the traffic is only 13 trucks per hour and a violation prevention is worth $.42, then a 10 percent

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* Direct variable operating cost per man per year =	$8,903
Man-hours per man-year	1,455
Average crew on fixed sites	2.64

$$\text{Average variable operating cost} = \frac{(8.903)\ (2.64)}{1{,}455}$$

$$= \$16.20 \text{ per operating hour.}$$

increase in compliance is worth only $.55 per hour or $55 per year. Continued operation of the scale in such circumstances does not appear to be worthwhile.

In Figure 13 we have presented a recommended manpower allocation to those stations that had total contribution greater than the operating cost. In some cases a station may be operated more than 8 hours during any one day. We think this is a feasible and possibly an advantageous strategy in light of our findings concerning the higher fraction of violators apprehended during the evening hours.

.02 in violation

At the present time 98 percent of the vehicles which are inspected at the traffic weight stations do comply with the law. An important question to answer is: what would happen to the compliance on the roads by the 11 weight stations whose continued operation is questionable? These stations could be operated as locations for roving patrol, thus maintaining the level of compliance through periodic inspections. Although compliance might decline somewhat at these marginal sites, the increased damage to the road would be offset by gains in other areas with a higher traffic count.*

Another alternative would be to reduce the operating cost by reducing the necessary crew size to 2 men. The average hourly operating cost would then become $12.30, and the continued operation of all but seven weight stations would be justified.

* The present analysis assumes that all roads are equally vulnerable to damage. If a site is marginal on a revenue basis, but protects some extraordinarily vulnerable roads, it should be given additional consideration for retention.

<u>New Scale Construction:</u> There are two basic factors to be considered in evaluation of a proposed scale site:

a. Cost

b. Benefit

If the cost of a new site exceeds the anticipated benefit, a proposed site clearly should not be built.

The cost of owning a scale site in turn depends on three factors:

a. Purchase price

b. Useful life

c. Cost of capital

The purchase price is generally a known factor based on a construction bid. Current estimates run from $80,000 to about $225,000.*

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

Scale construction ties up capital for long periods of time. Interest costs effectively increase the purchase cost of a scale. Allowance for this effect should be made if it is anticipated that scale construction

* The cost to Iowa may be reduced in some cases by federal government contributions totaling about 80 percent of the cost. The federal government's intention is to protect its investment in the Interstate Highway system, so that it contributes only to interstate scales.

funds would be borrowed rather than financed out of current taxes. The effective annual cost to Iowa of owning a scale can be calculated by the formula:

$$C_s = C_P/Y$$

where C_s = Effective annual cost of scale ownership in dollars per year

C_P = Scale purchase price in dollars

Y = Useful life of scale in years

The benefits from owning a scale depend on two factors:

a. Fines and registration fees collected

b. Local road damage prevented

When a scale site is operated, some fines are collected from violators. There is no good theoretical way to predict how much money this will be. There is a large body of experience from other sites, however. Figure 13 shows the fines collected per hour from current sites. In evaluating a new scale the best approach appears to be to set the constraint that the fines collected per hour must cover the operating cost per hour. Otherwise there would be no value in allocating manpower to the scale. This effectively sets a lower limit on the traffic going by a proposed site.

The damage prevented by a proposed scale can be evaluated from the improvement in compliance obtained from its presence, times the amount of traffic in which this improvement is obtained, times the value of compliance per trip. The current general level of compliance throughout Iowa is about

90 percent. When a site is open the traffic going by it has a compliance of about 98 percent. Thus, the new site would produce an improvement in compliance of about 8 percent for the traffic going by when it is open.* In Appendix 1, Tabs L and M, it is shown that every truck trip made in Iowa in compliance with the regulation saves the state about $.42.

42¢ is total primary + secondary however scales are located on primary only.

All of the various quantitative factors pertaining to the benefit obtained from a new scale are combined in the following formulas:

$$B'_s = B'_h A'_h$$

$$B'_h = T_h L_v (V - V_s) + F_h - C_o$$

$$C_o = 16.50$$

If B'_h is negative, reject the scale without further analysis

where B'_s = Annual benefit from new scale

B'_h = Hourly benefit from scale operation

A'_h = Annual number of operating hours of new scale

T_h = Traffic going by site per hour

L_v = Loss to Iowa from each violation

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* A proposed scale site is not given credit for contributing to the system compliance level of 90 percent, but only for the effect it would have in increasing compliance above the 90 percent level for the traffic passing by the proposed site.

V = Current average fraction violating in Iowa

V_s = Fraction violating at site

F_h = Fines collected per hour

C_o = Hourly scale operating cost, includes personnel, heat, electricity, etc.

A proposed site should be built if the annual benefit, B_s' , from the scale is significantly greater than its annual cost of ownership, C_s . If the annual cost is significantly greater than the annual benefit, the scale should not be built. If the annual cost and benefit are nearly equal, the non-quantitative factors discussed below should be used to make the final decision.

Some Nonquantitative Factors: If a scale proposal appears doubtful on the basis of the above quantitative analysis, the following factors should also be given some consideration.

Roving patrols cannot safely operate on interstate highways. Full protection of these roads therefore requires a fixed site.

Roving patrols cannot safely operate at night. Operation of fixed sites is the only way to protect roads at night.

The federal government derives a benefit from site operation not included in the above benefit calculation which was based on Iowa truck mileage only.

Fixed sites may produce some improvement in compliance even when they are not open.

Example of Application of Methodology: Consider a proposed scale with the following characteristics:*

$$C_P = 225,000$$

$$Y = 20 \text{ years}$$

and

$$C_s = 225,000/20 = 11,200 \text{ dollars per year}$$

Also

A_h = 1,500 hours

T_h = 40

L_v = \$.42

V = 0.90

V_s = 0.980

F_h = \$19.00

C_o = \$16.50

* These characteristics represent a composite of well located interstate scales.

Hence,

$$B_h = 40(0.42)(0.08) + 19.00 - 16.50 = \$3.85 \text{ per hour}$$

and

$$B_s = (3.85)(1{,}500 \text{ hours}) = \$5{,}800 \text{ per year}$$

but

$$C_s = \$11{,}200 \text{ per year}$$

Since $B_s < C_s$, it would be recommended that the site should not be built.* (Figure 14 shows this method applied to Fiscal Year 1969 proposed scale construction.)

There are basically three ways that Iowa's return from its fixed scale installations can be maintained and improved. First, the operating schedules of the scales should be planned as carefully as possible and updated frequently to meet changing patterns of traffic and violations. Second, the scale installations themselves should not be allowed to become outdated. As new equipment and operating procedures are developed, they should be applied as soon as feasible. Third, new scales should be built to protect newly constructed roads, and scales protecting roads whose traffic has greatly diminished should be shut down. As new roads are built in Iowa, traffic patterns change.

* If the federal government would contribute to the construction of this scale site, as in the case of some interstate highways, C_s would be reduced to approximately 20 percent of 11,200 to 2,240, and the construction would be economically feasible.

Proposed Scale Site	Estimated Traffic per Hour	Annual $ Benefit to Iowa	Annual $ Cost to Iowa	Nonquantitative Factors	Purchase Recommendation
Interstate Traffic Weight Stations					
Fremont County - Construction of weight stations and related facilities including two buildings and scales adjacent to I-29 north of Iowa 2. Estimated Cost = $125,000	76	9300	6250	Further consideration not necessary.	Yes
Clarke County - Construction of weight stations and related facilities including two buildings and scales adjacent to I-35 south of US 34. Estimated Cost = $125,000	76	9300	6250	Further consideration not necessary.	Yes
Worth County - Construction of weigh stations and related facilities including two buildings and scales adjacent to I-35 north of Iowa 9. Estimated Cost = $125,000	76	9300	6250	Further consideration not necessary.	Yes
Primary Traffic Weight Stations					
Woodbury County - Construction of a weigh station and related facilities including land and all items necessary for a complete installation adjacent to US 20 near Correctionville. Estimated Cost = $185,000 (less $80,000 already in 65-67 approp.) $105,000	33	2040	5250	Roving patrol cannot operate at night.	No
Clayton County - Construction of a weigh station and related facilities including land and all items necessary for a complete installation adjacent to US 18 near McGregor. Estimated Cost = $150,000	33 ?	2040	7500	Extra compliance may be obtained even when scale is not open.	No
Cerro Gordo County - Construction of a weigh station including a building, scale, and approach paving adjacent to US 65 north of Mason City. Estimated Cost = $80,000	33	2040	4000		Yes

ASSUMPTIONS

Traffic based on averages of current interstate and primary scales taken separately and projected over 20 year life.
Benefit based on following factors: Compliance increase, 8 percent; hours operated per year, 1000; loss prevented per deterred violator, 42 cents; average fine paid by apprehended violator, $26.08.
Cost based on purchase price of scale site with no interest costs and a 20 year useful life.

Figure 14 - Application of Scale Evaluation Methodology to 1967-1969 Building Program

Scales which formerly protected principal routes of travel may become much less important. The only response to this problem is the gradual relocation of Iowa's system of scales.

In conclusion, we recommend that manpower be allocated to each traffic weight station in direct proportion to the demonstrated earning ability of the station. In the long run this should provide improved benefits from T.W.O. in terms of cash collected from summonses, road-damage prevented, and increased license registration. The continued operation of certain stations is questionable unless the cost of an operating hour can be reduced, or the stations can be justified as protecting unusually vulnerable roads. Finally, the allocation of manpower must be reviewed and updated periodically to reflect changes in traffic volume, degree of compliance, and the average fine collected per summons. This updating procedure might best be implemented by use of a computer program.

4. Fraction of Manpower Devoted to Fixed Site Operation versus Roving Patrol Operation

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; escorting; attending staff meetings; or out on sick leave. The present strategy for allocating manpower is then: 75 percent of the available manpower to fixed-site operations and 25 percent to roving patrol.

Data collected from a sample of T.W.O. operational records for 1967,* and shown on Figure 15 in columns 1 and 2, indicated that roving patrol was much more effective than fixed sites in the collection of revenue.**

Based on these results, we decided to conduct an operational experiment 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. The results of these experiments are shown in Figure 15 in columns 3 - 6.

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* Sampling instructions are documented in Appendix 4.

** This includes fines and registration increases collected, but not damage prevention credits.

Performance	Mix 1*		Mix 2**		Mix 3**	
Operational Efficiency	75% Fixed	25% Roving	50% Fixed	50% Roving	25% Fixed	75% Roving
Summons/Operating Hour	0.584	0.505	0.576	0.445	0.603	0.517
Summons/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
Income/Summons	22.680	35.810	22.830	36.080	22.500	43.730
Cost/Effectiveness						
Income/Operating Hour	13.25	18.08	13.16	16.07	13.57	22.63
Cost/Operating Hour	14.12	13.34	16.28	13.55	15.36	14.74
Net Income/Operating Hour	(0.87)	4.74	(3.12)	2.52	(1.80)	7.89
Net Income/Operating Hour For Mix As A Whole	0.548		(.300)		5.47	

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

Figure 15 - Effect of Roving Patrol/Fixed Site Manpower Mix on Operating Statistics

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 markedly apparently 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 picked up 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/fixed site manpower mix.

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/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 noticable 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 by raising roving patrol manpower to 50% and carefully controlling and observing the resulting performance.

2. More effort should go into training of officers in roving patrol operations.

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. For example, an increased apprehension rate might result from operating at one site for only 4 hours and then moving to another site for 4 hours, instead of operating one scale 8 hours (as is currently the practice). 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.* 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.

Method of data analysis: A computer program documented in Appendix 11 accumulated traffic and apprehensions or violations from all scale sites, and grouped them by the time period in which they occurred.** The program also calculated the "fraction violating" for each time period by dividing

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

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

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 16 and 17.

Figure 16 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 16 is the number of violators per hour, though statistically noisy, is rather constant with a slight peaking during the daylight hours, because, even though 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 17 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:

a. The truckers' attempt to communicate to each other on the road that a scale is open has little or no effect on traffic characteristics.

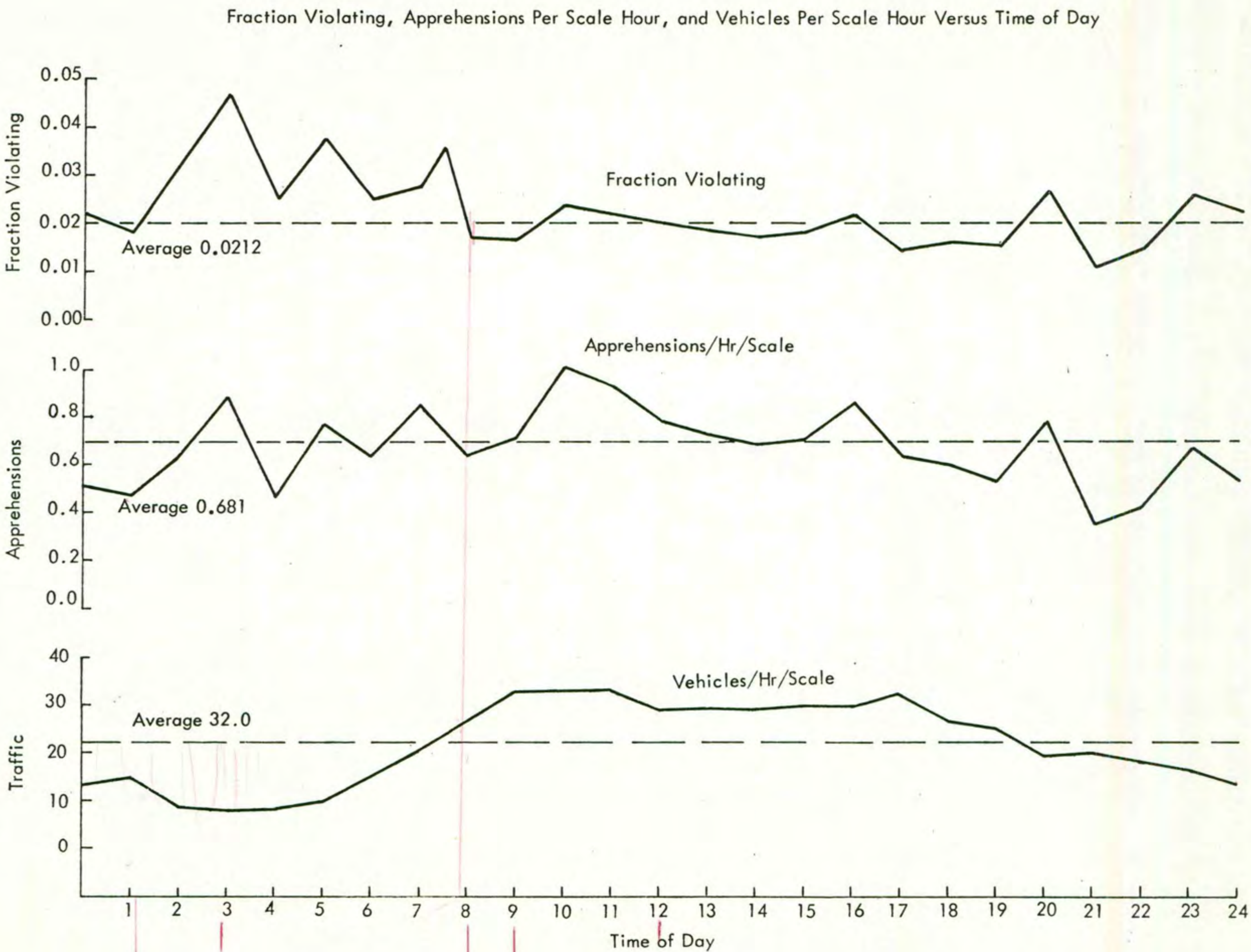

Figure 16 - Fraction Violating, Apprehensions Per Scale Hour and Vehicles Per Scale Hour Versus Time of Day

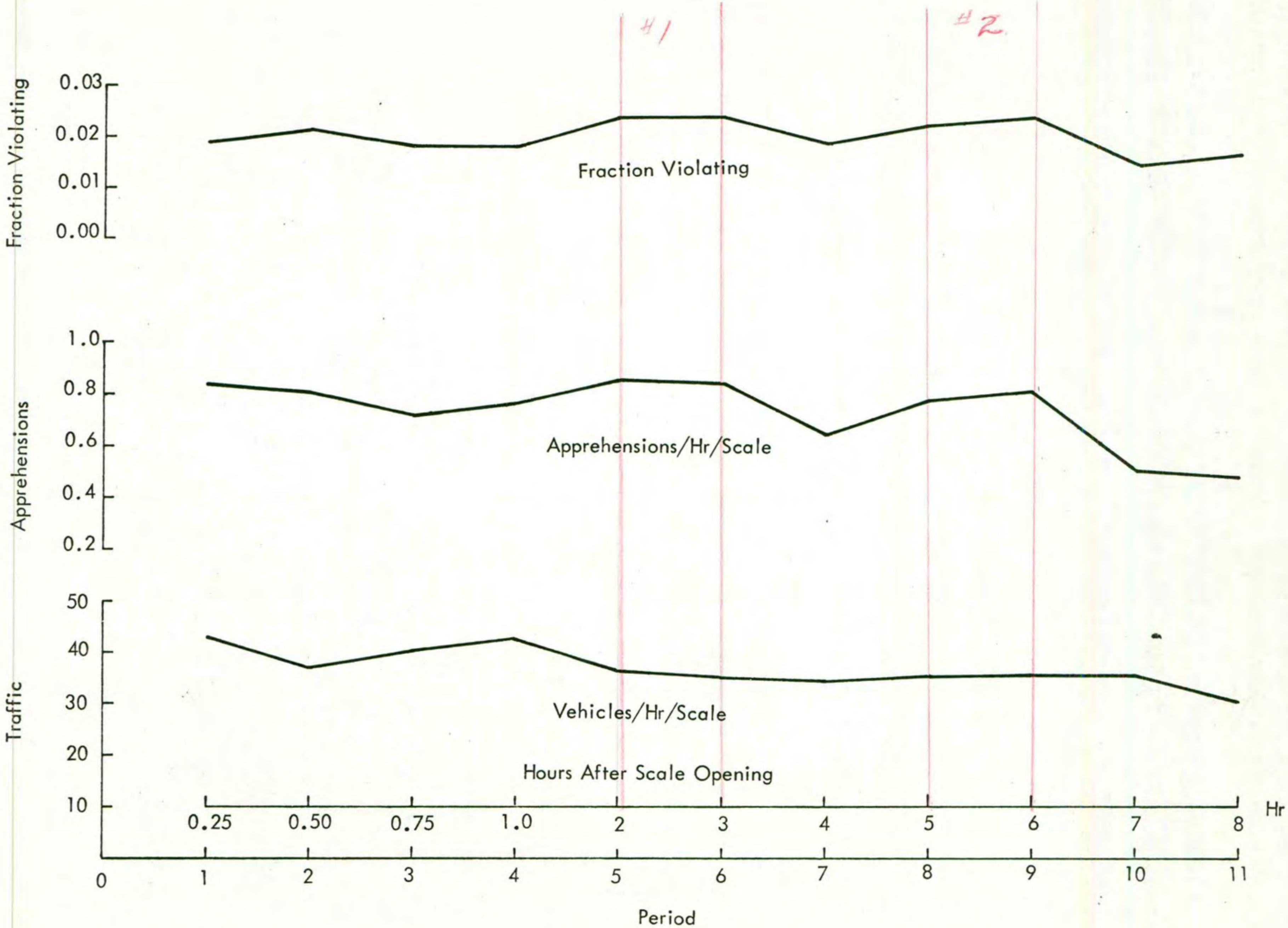

Figure 17 - Fraction Violating, Apprehensions Per Scale Hour, and Vehicles per Scale Hour Versus Hours After Time of Opening

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

c. 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.

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.*

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

* As discussed in Section II-B-3.

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 warn when the 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.

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

- 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/]

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.

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.1/

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."2/ The article continues with the following description of this system:

1/ The author visited Michigan's experimental installation at Grass Lake, Michigan, and discussed the project with Mr. Leo De Vogel, Project Engineer.
2/ 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 make 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. In Section III-B-4, it was shown 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 TWO efficiency.

Based on the quantitative analyses discussed in relation to TWO elsewhere in this report, our observations of other state TWO 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 escost--i.e., one of the weighing crew--would not have 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.

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 would 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: TWO records indicate that some teams are much more effective in roving operations than others varying from 0.043 to 0.985 apprehension per hour. The results of the roving patrol versus fixed patrol analysis performed in Section III B-3 indicated that the average roving patrol apprehension rate was actually lower than that for fixed sites. We recommend that some of the more experienced and successful roving personnel be temporarily transferred to the less successful teams and vice versa, in order to 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 TWO, but not much field use seems to be made of the information. One problem in dealing with this file 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.* 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.

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 TWO. The benefit curve in Figure 10 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.

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* The 1967 Iowa violation file was reviewed by a quick sight check. Companies were found that had received as many as 50 summonses in one year. Since the probability of apprehension was only 0.015 in 1967 such a company might have committed any additional 3,300 violations without being apprehended.

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 damage. 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.*

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

Results of the Analysis: Figure 18 is a graph showing the optimum staff level versus traffic. Assuming a 3 percent annual traffic growth rate, we see that the requirement for TWO personnel will increase as indicated below.**

Year	Optimum Staff
1968	64
1973	65
1978	67
1983	69
1988	72

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

** 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.

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 I, Tab A, 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	Less than 1
10	1
20	3
50	8

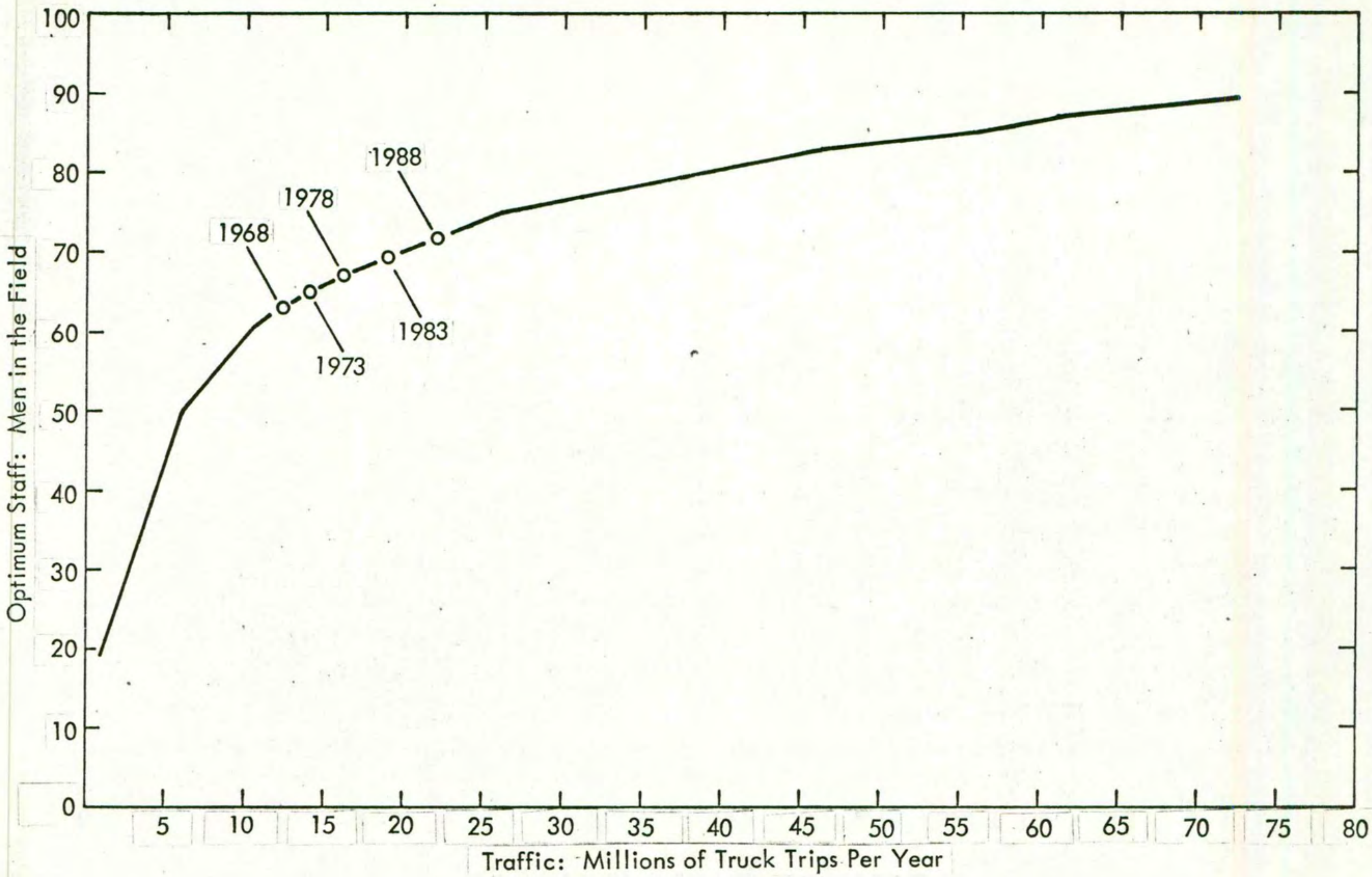

Figure 18 - Optimum Staff Level Versus Volume of Traffic

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 "performances" of such operations are nearly impossible to evaluate even if such an evaluation 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 form letter 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 warrent analysis, 13 of the replies were quite informative, and provided sufficient indication that Iowa's practices are in line with national norms.

Figure 19 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 from Section III-B-3 of this report that the optimum staff size depends on

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 19

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

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

2/ It is believed that Oregon reported number of scales, not number of scale sites, and uses more than one scale per site. Oregon was not counted in the above rankings.

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-licence enforcement, 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 immediately. 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 there.)

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 enought for work to continue. A separate report on this research is in Section II-B-6.

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

10. Average Uncompensated Pavement Costs per Violating Vehicle Mile

The calculated values are summarized in Table 1 below.

TABLE 1

AVERAGE UNCOMPENSATED PAVEMENT COSTS PER VIOLATING VEHICLE MILE

Uncompensated Costs per Violating Vehicle Mile ($)	Type Violators	Highway System*	Comments
0.002246	Overweight	Primary (01 and 03)	Conservatively low value obtained using high quality pavement emphasis and overload distribution from well policed routes.
0.012531	Overweight	Primary (31)	Upper bound value using pavements with emphasis on lighter structures and overload data from lightly policed routes.
0.021205	Overweight	Secondary (paved)	Average value based on distribution of commercial vehicle types found on secondary roads.
0.001227	Overweight and over-registration taken together	Primary (01 and 03)	Conservatively low value for combined violation types.
0.00809	Overweight and over-registration taken together	Primary (01 and 03) and secondary (paved)	Average value based on distribution of truck traffic on primary roads (69%) and paved secondary roads (31%).

* Classifications obtained from Analysis of Traffic Volume and Weight Study, Iowa, 1966, Table W-6.

Each entry in Table 1 is derived through consideration of road pavement types, their costs, and the uncompensated use per violating vehicle.

Summary tables which follow indicate the magnitude of these considerations and the manner in which they are combined. The tables contain the major items which are described under Methodology, Road-Damage Submodel. The more detailed considerations and numerics appear in the appendices.

Tables 2, 3 and 4 show the assembly of the conservatively low value for the primary system.* Here, in the class 5 and 6 pavements, the mileage (extent factor) is divided equally between the extreme pavement thicknesses.

Tables 5, 6, and 7 show the assembly of the upper bound value for the primary system.** Here, added emphasis is given to the thinner pavement structures, the distribution of violations is taken from a highway section with no permanent (enforcement) weight station; and lower physical properties are used for the rigid pavements. The increase in uncompensated costs here is due mainly to the distribution of violations and the emphasis on thinner pavement structures.

Tables 8, 9, and 10 show the assembly of the uncompensated cost value for secondary roads.

The uncompensated cost value for secondary roads is higher than the comparable value for the primary system. This increase arises primarily from

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* Rigid pavement calculations here used: modulus of rupture - 650 psi, soil coefficient = 150 psi/in, and modulus of elasticity = 4.2×10^6 psi.

** Rigid pavement calculations used: Modulus of rupture = 500 psi, soil coefficient = 100 psi/in, and modulus of elasticity = 4.2×10^6 psi.

the lower structural properties of the secondary pavements. (The low structural property pavements have a higher cost per reference axle served during their useful life.)

The vehicle distribution by type is changed here to reflect the higher proportion of single unit trucks on secondary roads. Associated with this change is a reduction in large overweights applied by heavy vehicles.

The regional factor is reduced here to 1.0. (The value 3.0 is used for all primary roads.) The final serviceability index is left at 2.5 although design practice in Iowa uses 2.0 as a final value for secondary roads.

For secondary road rigid pavement the physical properties used are: modulus of rupture = 690 psi, soil coefficient = 100 psi/in, and modulus of elasticity = 4.2×10^6 psi. The total rigid pavement life calculated in reference axle applications is reduced by the factor 0.68 to account for the lack of sub-base in pavement construction. The corrected life appears in the tables.

Tables 11 and 12 show the assembly of the uncompensated cost value for over-registration and overweight violators taken together. Table 3 is also applied in this calculation. The overweight values and pavement emphasis correspond to those used for the conservatively low uncompensated costs on primary systems 01 and 03. The over-registration violators contribute less to uncompensated costs than do the overweight violators. As a result, the average uncompensated cost per violator mile is reduced.

TABLE 2

AVERAGE UNCOMPENSATED COST PER MILE FOR OVERWEIGHT VEHICLES
(Primary System 01 and 03)

Road	Average Cost per Violation Mile ($)	Road Extent & Traffic Dist. Weight Factor	Contribution to State-Wide Average ($)
Class 1	40.020	0.000 000 7	0.000 028 0
2	0.595 6	0.000 020 8	0.000 012 4
3	0.492 7	0.000 081 0	0.000 039 9
4 (8 in. pcc)	0.005 275	0.108 047 6	0.000 570 0
5 (8 in. pcc)	0.002 578	0.234 707 4	0.000 605 1
5 (9 in. pcc)	0.001 568	0.479 735 2	0.000 752 2
6 (SN = 5)	0.008 047	0.013 176 5	0.000 106 0
6 (SN = 7)	0.000 807 0	0.164 230 8	0.000 132 5
			0.002 246 1

TABLE 3

ROAD EXTENT AND TRAFFIC DISTRIBUTION WEIGHT FACTORS

Road	Extent Factor	Reference Axles $\times 10^{-6}$	Product $\times 10^{-6}$	Weight Factor
Class 1	0.03	0.000 138	0.000 004 1	0.000 000 7
2	0.01	0.012 800	0.000 128 0	0.000 020 8
3	0.03	0.016 600	0.000 498 0	0.000 081 0
4 (8 in. pcc)	0.41	1.619 400	0.663 954 0	0.108 047 6
5 (8 in. pcc)	0.21	6.868 00	1.442 280 0	0.234 707 4
5 (9 in. pcc)	0.21	14.038 000	2.947 980 0	0.479 735 2
6 (SN = 5)	0.05	1.619 400	0.080 970 0	0.013 176 5
6 (SN = 7)	0.05	20.184 000	1.009 200 0	0.164 230 8
			6.145 014 1	

TABLE 4

PRIMARY ROAD PAVEMENTS, THEIR UNCOMPENSATED USE BY OVERWEIGHT VEHICLES FROM SYSTEMS 01 AND 03

Road Class No.	Pavement	Structural No. Coef.	Structural No.	Reference Axles During Life	Average Uncompensated Ref. Axles per Violating Vehicle (overweight)		Average Uncompensated Fraction Used per Violating Vehicle (overweight)		Pavement Cost per Lane Mile ($)	Maintenance Cost per Lane Mile Year ($)	Average Uncompensated Cost per Mile per Violating Vehicle (overweight)		
					Life	Maintenance	Life	Maintenance			Life ($)	Maintenance ($)	Total ($)
1	$\frac{1}{4}$ in. invert pene. 7 in. rolled stone	0.20 0.12	0.89 (1.00 used)	0.13762×10^{3}	0.259 39	0.174 73	$0.188\ 49 \times 10^{-2}$	$0.126\ 97 \times 10^{-2}$	17,500	277	32.986	7.034 1	40.020
2	2 in. asph. conc. 7 in. bit.tr.soil ag.	0.44 0.22	2.28 (2.3 used)	0.128×10^{5}	0.242 0	0.174 73	1.891×10^{-5}	1.365×10^{-5}	27,500	277	0.520 0	0.075 6	0.595 6
3	3 in. asph. conc. 8 in. rolled stone 2 in. soil - aggr.	0.44 0.12 0.05	2.38 (2.4 used)	0.166×10^{5}	0.240 4	0.174 73	1.448×10^{-5}	1.053×10^{-5}	30,000	277	0.434 4	0.058 3	0.492 7
4	4 in. asph. conc. 8 in. pcc	0.44 0.40	4.96 (5.00 used)	$1.619\ 4 \times 10^{6}$	0.241 27	0.174 73	$0.148\ 99 \times 10^{-6}$	$0.107\ 90 \times 10^{-6}$	34,000 (asph. re- surface of pcc)	97	0.005 066	0.000 209 3	0.005 275
4	4 in. asph. conc. 9 in. pcc	0.44 0.40	5.36 (5.4 used)	2.81×10^{6}	0.244 47	0.174 73	0.87×10^{-7}	0.63×10^{-7}	34,000 (asph. re- surface of pcc)	97	0.002 958	0.000 012 2	0.002 97
5	8 in. pcc	-	-	6.868×10^{6}	0.342 12	0.204 26	$0.498\ 14 \times 10^{-7}$	$0.297\ 41 \times 10^{-7}$	50,000	147	0.002 491	0.000 087 44	0.002 578
5	9 in. pcc	-	-	14.038×10^{6}	0.357 09	0.197 98	$0.254\ 37 \times 10^{-7}$	$0.141\ 03 \times 10^{-7}$	60,000	147	0.001 526	0.000 041 46	0.001 568
6	3 in. asph. conc. 10 in. asph.tr.c.stone 6 in. soil aggr.	0.44 0.34 0.05	5.02 (5.00 used)	$1.619\ 4 \times 10^{6}$	0.241 27	0.174 73	$0.148\ 99 \times 10^{-6}$	$0.107\ 90 \times 10^{-6}$	50,000	277	0.007 450	0.000 597 8	0.008 047
6	4.5 in. asph.conc. 14 in. asph.tr.c.stone 6 in. soil aggr.	0.44 0.34 0.05	7.04 (7.00 used)	20.184×10^{6}	0.255 35	0.174 73	$0.126\ 51 \times 10^{-7}$	$0.865\ 69 \times 10^{-8}$	60,000	277	0.000 759 1	0.000 047 96	0.000 807 0

TABLE 5

AVERAGE UNCOMPENSATED COST PER MILE FOR OVERWEIGHT VEHICLES
(Primary System 31)

Road	Average Cost per Violation Mile ($)	Road Extent & Traffic Dist. Weight Factor	Contribution to State-Wide Average ($)
Class 1	70.373 9	0.000 000 8	0.000 056 3
2	1.091 64	0.000 026 7	0.000 029 1
3	0.915 08	0.000 103 8	0.000 095 0
4 (8 in. pcc)	0.010 67	0.138 341 7	0.001 476 1
5 (8 in. pcc)	0.016 23	0.457 926 2	0.007 432 1
5 (9 in. pcc)	0.009 85	0.292 496 4	0.002 881 1
6 (SN = 5)	0.015 73	0.026 993 5	0.000 424 6
6 (SN = 7)	0.001 63	0.084 110 9	0.000 137 1
			0.012 531 4

TABLE 6

ROAD EXTENT AND TRAFFIC DISTRIBUTION
WEIGHT FACTORS FOR UPPER BOUND ON PRIMARY ROADS

Road	Extent Factor	Reference Axles $x 10^{-6}$	Product $x 10^{-6}$	Complete Weight Factor
Class 1	0.03	0.000 138	0.000 004 1	0.000 000 8
2	0.01	0.012 800	0.000 128 0	0.000 026 7
3	0.03	0.016 600	0.000 498 0	0.000 103 8
4 (8 in. pcc)	0.41	1.619 400	0.663 954 0	0.138 341 7
5 (8 in. pcc)	0.32	6.868 00	2.197 760 0	0.457 926 2
5 (9 in. pcc)	0.10	14.038 000	1.403 800 0	0.292 496 4
6 (SN = 5)	0.08	1.619 400	0.129 552 0	0.026 993 5
6 (SN = 7)	0.02	20.184 000	0.403 680 0	0.084 110 9
			4.799 376 1	1.000 000 0

TABLE 7

PRIMARY ROAD PAVEMENTS, THEIR UNCOMPENSATED USE BY OVERWEIGHT VEHICLE FROM SYSTEM 31

Road Class No.	Pavement	Structural No. Coef.	Structural No.	Reference Axles During Life	Aveg. Uncompensated Ref. Axles per Violating Vehicle (overwt. on System 31.) Life	Maintenance	Average Uncompensated Fraction Used per Violating Vehicle (overwt. on System 31) Life	Maintenance	Pavement Cost per Lane Mile ($)	Maintenance Cost per Lane Mile Year ($)	Average Uncompensated Cost per Mile per Violating Vehicle Life ($)	Maintenance ($)	Total ($)
1	½ in. invert pene. 7 in. rolled stone	0.20 0.12	0.89 (1.00 used)	1.376 2 x 10^{2}	0.537 82	0.358 72	0.390 81 x 10^{-2}	0.260 67 x 10^{-2}	17,500	277	69.651 8	0.722 1	70.373 9
2	2 in. asph.conc. 7 in. bit.tr.soil ag.	0.44 0.22	2.28 (2.3 used)	1.271 9 x 10^{4}	0.501 30	↓	0.394 12 x 10^{-4}	0.282 03 x 10^{-4}	27,500	277	1.083 83	0.007 81	1.091 64
3	3 in. asph. conc. 8 in. rolled stone 2 in. soil aggr.	0.44 0.12 0.05	2.38 (2.4 used)	1.641 4 x 10^{4}	0.497 57	↓	0.303 01 x 10^{-4}	0.218 54 x 10^{-4}	30,000	277	0.909 03	0.006 05	0.915 08
4	4 in.asph.conc. 8 in. pcc	0.44 0.40	4.96 (5.00 used)	1.619 4 x 10^{6}	0.507 43	↓	0.313 35 x 10^{-6}	0.221 51 x 10^{-6}	34,000	97	0.010 65	0.000 02	0.010 67
4	4 in.asph.conc. 9 in. pcc	0.44 0.40	5.36 (5.40 used)	2.801 8 x 10^{-6}	0.514 71	↓	0.183 71 x 10^{-6}	0.128 03 x 10^{-6}	34,000	97	0.006 25	0.000 01	0.006 26
5	8 in. pcc	–	–	2.438 8 x 10^{-6}	0.789 63	0.651 79	0.323 77 x 10^{-6}	0.267 25 x 10^{-6}	50,000	147	0.016 19	0.000 04	0.016 23
5	9 in. pcc	–	–	5.064 3 x 10^{-6}	0.829 53	0.560 25	0.163 80 x 10^{-6}	0.110 63 x 10^{-6}	60,000	147	0.009 83	0.000 02	0.009 85
6	3 in. asph.conc. 10 in. asph.tr.c.stone 6 in. soil aggr.	0.44 0.34 0.05	5.02 (5.00 used)	1.619 4 x 10^{6}	0.507 43	0.358 72	0.313 35 x 10^{-6}	0.221 51 x 10^{-6}	50,000	277	0.015 67	0.000 06	0.015 73
6	4.5 in. asph.conc. 14 in. asph.tr.c.stone 6 in. soil aggr.	0.44 0.34 0.05	7.04 (7.00 used)	20.184 x 10^{6}	0.531 75	0.358 72	0.263 45 x 10^{-7}	0.177 73 x 10^{-7}	60,000	277	0.001 58	0.000 005	0.00163

TABLE 8

AVERAGE UNCOMPENSATED COST PER MILE FOR
OVERWEIGHT VEHICLES ON SECONDARY ROADS

Road	Average Cost per Violation Mile ($)	Road Extent & Traffic Dist. Weight Factor	Contribution to State-Wide Average ($)
47,48	13.081 0	0.000 123 0	0.001 609
44,46,57, & 58	1.727 2	0.001 922	0.003 320
56	0.340 1	0.032 752	0.011 139
54	0.055 55	0.001 526	0.000 085
55 (6 in. pcc)	0.008 54	0.291 928	0.002 493
55 (7 in. pcc)	0.003 81	0.671 749	0.002 559
			0.021 205

TABLE 9

ROAD EXTENT AND TRAFFIC DISTRIBUTION
WEIGHT FACTORS FOR SECONDARY ROADS

Pavement	Extent Factor	Reference Axles x 10^3	Product x 10^{-3}	Weight Factor
47,48	0.085 9	0.412 85	0.035 46	0.000 123
44,46,57 & 58	0.171 6	3.228 5	0.554 01	0.001 922
56	0.567 4	16.636	9.439 27	0.032 752
54	0.004 4	99.970	0.439 87	0.001 526
55 (6 in. pcc)	0.085 8	980.62	84.137 20	0.291 928
55 (7 in. pcc)	0.084 9	2280.4	193.605 96	0.671 749
			288.211 77	1.000 000

TABLE 10

SECONDARY ROAD PAVEMENTS, THEIR UNCOMPENSATED USE BY OVERWEIGHT VEHICLES ON SECONDARY ROADS

Pavement Codes	Pavement	Reference Axles During Life	Ave. Uncompensated Ref. Axles per Violating Vehicle (overweight, secondary road) Life	Maintenance	Average Uncompensated Fraction Used per Violating Vehicle (overweight, secondary road) Life	Maintenance	Pavement Cost per Lane Mile ($)	Maintenance Cost per Lane Mile Year ($)	Average Uncompensated Cost per Mile per Violating Vehicle (overweight, secondary road) Life ($)	Maintenance ($)	Total ($)
47,48	Flexible SN = 1.0	$4.128\,5 \times 10^2$	0.267 61	0.172 29	$0.648\,20 \times 10^{-3}$	$0.417\,32 \times 10^{-3}$	17,000	247	11.019 4	2.061 6	13.081 0
44,46 57,58	Flexible SN = 1.5	$3.228\,5 \times 10^3$	0.262 51	↓	$0.813\,10 \times 10^{-4}$	$0.533\,65 \times 10^{-4}$	18,000	247	1.463 6	0.263 6	1.727 2
56	Flexible SN = 2.0	$1.663\,6 \times 10^4$	0.252 92	↓	$0.152\,04 \times 10^{-4}$	$0.103\,57 \times 10^{-4}$	19,000	247	0.288 9	0.051 2	0.340 1
54	Flexible SN = 2.7	$9.997\,0 \times 10^4$	0.235 14	↓	$0.235\,20 \times 10^{-5}$	$0.172\,34 \times 10^{-5}$	20,000	237	0.047 04	0.008 51	0.055 55
55	pcc 6 in.	$0.980\,62 \times 10^6$	0.304 00	0.316 15	$0.310\,00 \times 10^{-6}$	$0.322\,40 \times 10^{-6}$	25,000	122	0.007 75	0.000 79	0.008 54
		$\frac{1.442\,1 \times 10^6}{0.68}$			$\frac{0.210\,80 \times 10^{-6}}{0.68}$	$\frac{0.219\,23 \times 10^{-6}}{0.68}$					
55	pcc 7 in.	$2.280\,4 \times 10^6$	0.303 65	0.269 99	$0.133\,16 \times 10^{-6}$	$0.118\,40 \times 10^{-6}$	26,400	122	0.003 52	0.000 29	0.003 81
		$\frac{3.353\,5 \times 10^6}{0.68}$			$\frac{0.905\,47 \times 10^{-7}}{0.68}$	$\frac{0.805\,09 \times 10^{-7}}{0.68}$					

TABLE 11

AVERAGE UNCOMPENSATED COST PER MILE
FOR OVER-REGISTRATION AND OVERWEIGHT VEHICLES
(Primary Systems 01 and 03)

Road	Average Cost per Violation Mile ($)	Road Extent & Traffic Dist. Weight Factor	Contribution to State-Wide Average ($)
Class 1	22.02	0.000 000 7	0.000 015 4
2	0.3315	0.000 020 8	0.000 006 9
3	0.274 2	0.000 081 0	0.000 022 2
4 (8 in. pcc)	0.002 802	0.108 047 6	0.000 302 7
5 (8 in. pcc)	0.001 426	0.234 707 4	0.000 334 7
5 (9 in. pcc)	0.000 863	0.479 735 2	0.000 414 0
6 (SN = 5)	0.004 463	0.013 176 5	0.000 058 8
6 (SN = 7)	0.000 441	0.164 230 8	0.000 072 4
			0.001 227 1

TABLE 12

PRIMARY ROAD PAVEMENTS, THEIR UNCOMPENSATED USE BY OVER-REGISTRATION AND OVERWEIGHT VEHICLES

Road Class	No.	Pavement	Structural No. Coef.	Structural No.	Reference Axles During Life	Avg. Uncompensated Ref. Axles per Violating Vehicle (overwt. & over-reg.) Life	Maintenance	Average Uncompensated Fraction Used per Violating Vehicle (overwt. and over-registration) Life	Maintenance	Pavement Cost per Lane Mile ($)	Maintenance Cost per Lane Mile Year ($)	Average Uncompensated Cost per Mile per Violating Vehicle (Both overweight and over-reg.) Life ($)	Maintenance ($)	Total ($)
FLEXM FLEXL	1	¼ in. invert.pene. 7 in.rolled stone	0.20 0.12	0.89 (1.00 used)	$0.137\ 62 \times 10^{3}$	0.140 68	0.102 48	$0.102\ 23 \times 10^{-2}$	$0.744\ 68 \times 10^{-3}$	17,500	277	17.89	4.13	22.02
	2	2 in.asph.conc. 7 in. bit.tr.soil ag.	0.44 0.20	2.28 (2.3 used)	0.128×10^{5}	0.133 6	0.102 48	1.044×10^{-5}	$0.800\ 6 \times 10^{-5}$	27,500	277	0.287 1	0.044 4	0.331 5
	3	3 in.asph.conc. 8 in.rolled stone 2 in.soil aggr.	0.44 0.12 0.05	2.38 (2.4 used)	0.166×10^{5}	0.132 8	0.102 48	$0.800\ 0 \times 10^{-5}$	$0.617\ 3 \times 10^{-5}$	30,000	277	0.240 0	0.034 2	0.274 2
	4	4 in.asph. conc. 8 in.pcc	0.44 0.40	4.96 (5.00 used)	$1.619\ 4 \times 10^{6}$	0.133 18	0.102 48	$0.822\ 40 \times 10^{-7}$	$0.632\ 82 \times 10^{-7}$	34,000 (asph.resurface of pcc)	97	0.002 796	0.000 006	0.002 802
	4	4 in.asph.conc. 9 in.pcc	0.44 0.40	5.36 (5.4 used)	2.81×10^{6}	0.132 1	0.102 48	0.470×10^{-7}	0.365×10^{-7}	34,000 (asph.resurface of pcc)	97	0.001 598	0.000 004	0.001 602
RIGDM RIGDL	5	8 in.pcc 9 in.pcc	-- --	-- --	6.868×10^{6} 14.038×10^{6}	0.188 79 0.196 14	0.122 28 0.118 67	$0.274\ 88 \times 10^{-7}$ $0.139\ 72 \times 10^{-7}$	$0.178\ 04 \times 10^{-7}$ $0.845\ 34 \times 10^{-8}$	50,000 60,000	147 147	0.001 374 0.000 838	0.000 052 0.000 025	0.001 426 0.000 863
FLEXM FLEXL	6	3 in.asph conc. 10 in. asph.tr.c. stone 6 in. soil aggr.	0.44 0.34 0.05	5.02 (5.00 used)	$1.619\ 4 \times 10^{6}$	0.133 18	0.102 48	$0.822\ 40 \times 10^{-7}$	$0.632\ 82 \times 10^{-7}$	50,000	277	0.004 112	0.000 351	0.004 463
	6	4.5 in.asph.conc. 14 in. asph.tr.c. stone 6 in. soil aggr.	0.44 0.34 0.05	7.04 (7.00 used)	20.184×10^{6}	0.138 99	0.102 48	$0.698\ 64 \times 10^{-8}$	$0.507\ 73 \times 10^{-8}$	60,000	277	0.000 413	0.000 028	0.000 441

APPENDIX 1, TAB A

AVERAGE IOWA MILEAGE PER TRUCK TRIP

Basic Information Source

1963 Iowa State Highway Commission Loadometer Survey Records 1/

Form of Data

Individual trip distances are recorded in miles. The origin and destination of each trip and the state of registration of the vehicle are recorded in a coded form.

Method of Analyzing Data

The number of vehicles originally surveyed were far more than needed for the purpose of estimating a gross average mileage per trip. The records were therefore sampled systematically using every nineteenth trip. A total of 503 trips were sampled.

For trips within Iowa the trip mileage was simply recorded for each trip record. For trips that originated or terminated out of state, only the estimated portion of the trip that occurred within Iowa was recorded. The estimate of mileage in Iowa was made by examining the probable route taken on a map of Iowa highways.

Results of the Analysis

GENERAL TRUCK POPULATION

Trip Location	No. of Trips	Mileage	Average Mileage
Iowa only	382	27,623	72.3
Partial out of state	121	29,005	240.0
All	503	56,628	112.3

1/ 1963 data was most recent Origin-Destination survey available. It is not believed that average trip mileage would change greatly in a few years.

Estimate For the Violator Population

The above average mileage estimate applies to the general population of trucks. A mileage figure is also needed for weight regulation violators. The Loadometer Survey provides no direct information on mileage of violators. It was not believed that violators travel greater or less distances than non-violators per trip. However, it is possible that violations are more frequent per vehicle on out-of-state trucks than in-state trucks. Hence, the average distance might be shifted towards the 240-mile trip distance of out-of-state vehicles.

A tape record of all 1967 violations was used to determine the fraction of violations committed by in/out-of-state vehicles as follows:[1/]

VIOLATORS ONLY

Registration	Percent of Violators	Average Mileage
Iowa	78.8	72.3
Other	21.2	240.0
All	100.0	108.0

The density of violations does not seem to depend significantly on state of registration since 108.0 is so close to 112.3. (However, out-of-state violators travel about three times farther per violation and thus may cause three times as much road damage per violation.) ?

1/ The program used to process the tape is at Appendix 6.

APPENDIX 1, TAB B

NUMBER OF TRUCK TRIPS PER YEAR IN IOWA

Basic Information Sources

1. ISHC Planning Division: "Estimated Annual Vehicle Miles of Travel In Iowa In 1968 By Road System and Vehicle Type."

2. Appendix 1, Tab A of this Report (Average Iowa Mileage Per Truck Trip).

3. ISHC Planning Department: "Registration of Motor Vehicles, Trailers, etc. Classified by Vehicle Type" (1967 Automobile Registration).

Method of Processing Data

Item 1, supplied an estimate of 1.375 billion truck miles for 1968 on the primary and secondary rural roads of Iowa. We are interested in fiscal year 1968, so that we must correct this figure for a 3 percent annual growth rate.

Now

$$T = M/m$$

where: T is number of annual truck trips, M is total annual truck mileage and m is average distance traveled per truck trip.

Results of Analysis

$$T = 1.375(10)^9/112.3(1.015)$$

$$T = 12.06(10)^6$$

APPENDIX 1, TAB C

FRACTION OF TRUCK TRIPS IN VIOLATION

Basic Information Sources

1. ISHC T.W.O. "Summary of Results of Traffic Weight Operations" (Attached).

2. ISHC Planning Department "Analysis of Traffic Volume and Weight Study--1966", Table W-7, p. 67.

3. ISHC T.W.O. Communication to MRI: Number of Traffic Weight Officers by Year (Attached).

4. Appendix 1, Tabs A,B of this Report.

5. ISHC T.W.O. "Summonses Issued by Traffic Weight Officers July 1, 1966 through June 30, 1967 (Attached).

6. Tape File of 1967 Violation Records.

7. ISHC Planning Department Motor Vehicle Traffic Data.

Method of Processing Data

Item 2 indicated that 6.05 percent of the truck trips in Iowa were made in violation of overweight or oversize regulations. Item 5, attached below, indicated that out of 19,084 summons issued only 7,513 or 39.4 percent were overweight or oversize violation. Hence, a rough estimate of the percent violating would be 6.05 percent/0.394 or 15.5 percent. However, an analysis of item 6 indicated that about 10 percent of these violations belong to both the overweight/oversize category and the registration violation category. Hence, 1.5 percent of the violations would be double counted by the above calculation; the actual percent violating in 1967 was 15.5-1.5 percent or 14.0 percent. This is the percent of traffic violating one or more of the laws enforced by T.W.O.

As explained in Section III A of the report the number of summons in any given year is proportional to the traffic T , the fraction violating V , and the probability of apprehension, P. Hence, the change of V with P can be obtained by scaling from the number of apprehensions and correcting for growth in probability of apprehension, and truck trips (measured by registration R) over a number of years. In other words:

$$V = KA/PR$$

where

$$K = (V'P'R'/A')$$

and V', R', T', and A' are the values for 1967. K = 0.00324.

Below is a table showing the results of these calculations for Iowa.

	Average Staff	Estimated[2/] P (P)	Truck[3/] Registration (thousands) (R)	Summonses[4/] (thousands) (A)	Fraction Violating (V)
1950	19	0.0043	190	14.9	0.585
1952	28	0.0064	205	18.8	0.465
1954	42	0.0096	216	22.0	0.342
1956	41	0.0094	228	20.4	0.308
1958	46	0.0105	238	16.9	0.218
1960	45	0.0103	248	13.4	0.170
1962	49	0.0112	256	16.2	0.181
1964	57	0.0130	282	18.2	0.161
1966	54	0.0123	334	21.2	0.166
1967	56	0.0128	345	19.1	0.140

1/ Item 3.

2/ 1967 value taken from Appendix 1, Tab D. Other values were taken as linearly proportional to staff. (Apprehension model is linear for small P.)

3/ Item 7.

4/ Item 1 (Attached below).

SUMMONSES ISSUED BY TRAFFIC WEIGHT OFFICERS

July 1, 1966 through June 30, 1967

Also Completion of Summonses Issued in Prior Period

Type of Violation	No. of Summonses Issued	Fine and Court Costs Paid	Increased Registrations
WEIGHT			
Overload of Registrations	3,498	$ 39,647.29	$ 83,168.44
Single Axle Overloads	2,384	77,425.27	125.00
Two Axle Tandem Overloads	2,263	61,516.85	
Three Axle Tandem Overloads	11	3,390.14	
Gross Overloads	1,339	66,906.27	75.00
Improper Registration	7,897	118,150.51	16,993.95
Other Violations	176	3,567.50	131.25
Subtotal	17,568	$ 370,603.83	$ 100,493.64
DIMENSIONS			
Width	816	$ 13,362.75	
Length	626	14,401.50	
Height	16	245.00	
Front-End Projection	58	1,310.00	
Sub-Total	1,516	$ 29,319.25	
TOTALS	19,084	$ 399,923.08	
Cases prior to July 1, 1966 now complete (454)		$ 15,989.70	$ 8,296.43
Registration increases due to Warnings			5,199.14
GRAND TOTALS	19,084	$ 415,912.78	$ 113,989.21

SUMMARY OF RESULTS OF TRAFFIC WEIGHT OPERATIONS

Fiscal Year	No. of Summonses Issued	Total Paid Fines & Costs	Total Paid Registration	Cost of Operation
1941-42	8,320	$ 70,270.55	$ 173,685.60	$ 61,559.91
1942-43	7,820	49,683.66	186,637.40	70,040.49
1943-44	7,507	54,862.80	157,365.11	72,598.96
1944-45	7,383	64,740.50	154,283.41	83,276.37
1945-46	10,009	87,640.90	183,300.08	81,296.99
1946-47	10,125	104,245.45	174,096.52	82,902.94
1947-48	9,784	128,650.20	212,263.91	85,545.13
1948-49	9,479	130,715.15	267,667.20	80,454.60
1949-50	10,505	109,543.69	310,810.61	80,599.24
1950-51	10,474	151,887.87	268,225.35	86,467.15
1951-52	13,324	221,364.06	268,205.32	156,220.75
1952-53	16,805	272,586.41	341,300.55	197,862.66
1953-54	15,605	241,039.18	314,305.22	221,700.75
1954-55	14,739	259,717.35	439,629.28	225,392.79
1955-56	14,444	263,134.82	402,759.49	229,135.08
1956-57	13,692	256,941.42	336,703.83	236,373.96
1957-58	11,952	279,741.95	235,956.70	234,867.14
1958-59	12,565	294,485.66	247,389.00	249,217.64
1959-60	13,370	340,422.59	136,336.11	228,584.23
1960-61	14,247	356,523.12	134,674.91	332,832.70
1961-62	16,177	416,031.55	177,444.87	342,176.67
1962-63	16,819	406,576.74	238,170.56	360,704.14
1963-64	18,196	433,559.23	214,568.07	387,971.59
1964-65	22,796	525,546.38	183,268.66	433,650.39
1965-66	21,213	481,548.21	168,942.41	477,089.26
1966-67	19,084	415,912.78	113,989.21	485,668.76
TOTAL	346,434	$ 6,417,362.22	$ 5,861,979.38	$ 5,584,190.29

NOTE: Figures shown under "Registration" show only the amount of additional registration fees paid on vehicles actually found to be under registered.

Results of the Analysis

The results of the analysis are shown graphically in Section III A5 of the report. pp III 25

The following function was fitted to the data for calculation purposes:

$$V = 0.02 + 0.98e^{-163\ P}$$

APPENDIX 1, TAB D

PROBABILITY OF APPREHENSION

Basic Information Sources

1. ISHC T.W.O.: "Summary of Results of Traffic Weight Operations, July 1, 1966, through June 30, 1967."

2. Appendix 1, Tab B of this report.

3. Appendix 1, Tab C of this report.

4. ISHC Planning Division: "Volume of Traffic on the Primary Road - 1965."

5. Tape File of 1967 violations.

6. Appendix 1, Tab A of this report.

7. ISHC Planning Division: "Highway Mileage in Iowa by Surface Type, January 1, 1967."

8. Section III-B-3 of this report.

Method of Data Analysis

Apprehension rate method: One method of determining apprehension probability is to determine the number of apprehensions per violating trip.

For example: In fiscal year 1967, according to item 2, there were $12.06(10)^6$ trips of which, according to item 3, 14 percent involved one or more violations. Computer analysis of item 5 indicated there were 0.88 violators per violation (because of multiple violations by one violator on one trip). Item 1 indicated there were 19,084 apprehensions during the same period.

We may assemble these facts as follows:

Probability of apprehension = Apprehensions/violating trips

or

$$P = (19{,}084)(0.88)/(12.06)(10)^6(0.14)$$

Results of the Analysis

$$P = 0.0128 \text{ for } 1967$$

Application of the Results

From Section III-A-4 of the report we know that P can be related to staff level, S , by a relation of the following general form:[1/]

$$P = 1 - e^{-K_A S}$$

where K_A is a lumped constant depending on such factors as length of trip, number of miles of road being patrolled, etc. We may solve the above equation for K_A :

$$K_A = - \ln(1-P)/S$$

This method was used to find K_A's for conventional fixed sites and for roving patrols using loadometers for the scheduling and other management techniques employed in 1967.

Site Type	Apprehension Constant (1967)
Fixed site	$3.32(10)^{-4}$
Roving Patrol	$3.09(10)^{-4}$

These K_A values were in turn inserted into the Apprehension Model to obtain P's for a range of new S's .

1/ Assuming that the size of the staff is not sufficient to fully man all available inspection sites.

Theoretical Analysis Method

Another method of estimating P is by theoretically calculating K_A from the factors known to compose it.

Under the assumption of random scale location:

$$P = 1 - e^{-(MHDP_S/168LC)S}$$

Hence,

$$K_A = MHDP_S/168LC$$

where M , etc., are defined in Section III-A-4 of the report as:

M = trip length of vehicles in violation

H = hours worked per day

D = days worked per week

P_S = probability of inspecting vehicles going by site

L = length of road under surveillance

C = crew per site (average)

We estimate these values as follows (for 1967 average):

Parameter	Value	Source or Method
M	108	Item 6
H	8	Nominal
D	5	Nominal
P_S	1	Assumed (true for fixed sites)
L	17,931 1/	Item 7
C	2.58	Item 8

1/ Rural primary and paved secondary only.

Thus $K_A = 108(8)(5)(1)/168(17,931)(2.58) = 4.33(10)^3/7.78(10)^6$.

$$K_A = 5.56(10)^{-4}$$

However, it is known that the inspection sites are not placed randomly, but are placed in regions of high traffic density. This effectively boosts P and K_A by a factor related to the traffic concentration. The more traffic is concentrated on a few miles of roads the better the chance of properly locating a scale, and the better the probability of apprehension.

Figure 1-D-1 shows the traffic concentration of the Primary Road System. This information was processed to produce the graph in Figure 1-D-2 by plotting the fractional cumulative mileage traveled versus the cumulative amount of highway used in traveling.

Figure 1-D-3 shows how the information from Figure 1-D-2 is processed to produce P_j's , probabilities that traffic will be located in regions 1,000 miles in length. The primary road information was combined with information on secondary roads that added to a truck mileage of 1.15 million truck miles per day.

As discussed in Section III-A-4 of the report and displayed on Figure 1-D-3, P_j's can be used to calculate a "boost factor" on the probability of apprehension calculated using the random site location method. This factor for Iowa is 1.41.

Since the single site probability of apprehension is proportional to the apprehension constant K_A we can boost K_A to 1.41 K_A to accommodate this effect.

Results of the Analysis

The theoretical value for P may now be calculated as

$$P = 1 - e^{-1.41\left[(5.56)(10)^{-4}\right]S}$$

or

$$P = 1 - e^{-1.41(5.56)(10)^{-4}(39.2)}$$

AVERAGE DAILY TRAFFIC COUNT*

Cell	Midpoint	Section Length	Total Distance Traveled	Cumulative Distance Traveled
0 - 49.9	25	683.2	17,000	17,000
50 - 99.9	75	929.6	70,000	87,000
100 - 199	150	1,900.6	280,000	367,000
200 - 299	250	2,925.2	733,000	1,100,000
300 - 399	350	1,093.1	382,000	1,482,000
400 - 499	450	724.4	326,000	1,808,000
500 - 699	600	1,491.7	900,000	2,708,000
700 - 899	800	0.0	0	2,708,000
900 - 1,099	1,000	288.9	288,900	2,996,900
	TOTALS	10,036.0	2,996,900	

Miles traveled in a day - 2.997×10^6
Miles traveled in a year - 109.0×10^7

* 1965 Iowa Volume of Traffic on Primary Road System.

Figure 1-D-1 - Traffic Concentration on Iowa Primary Road System

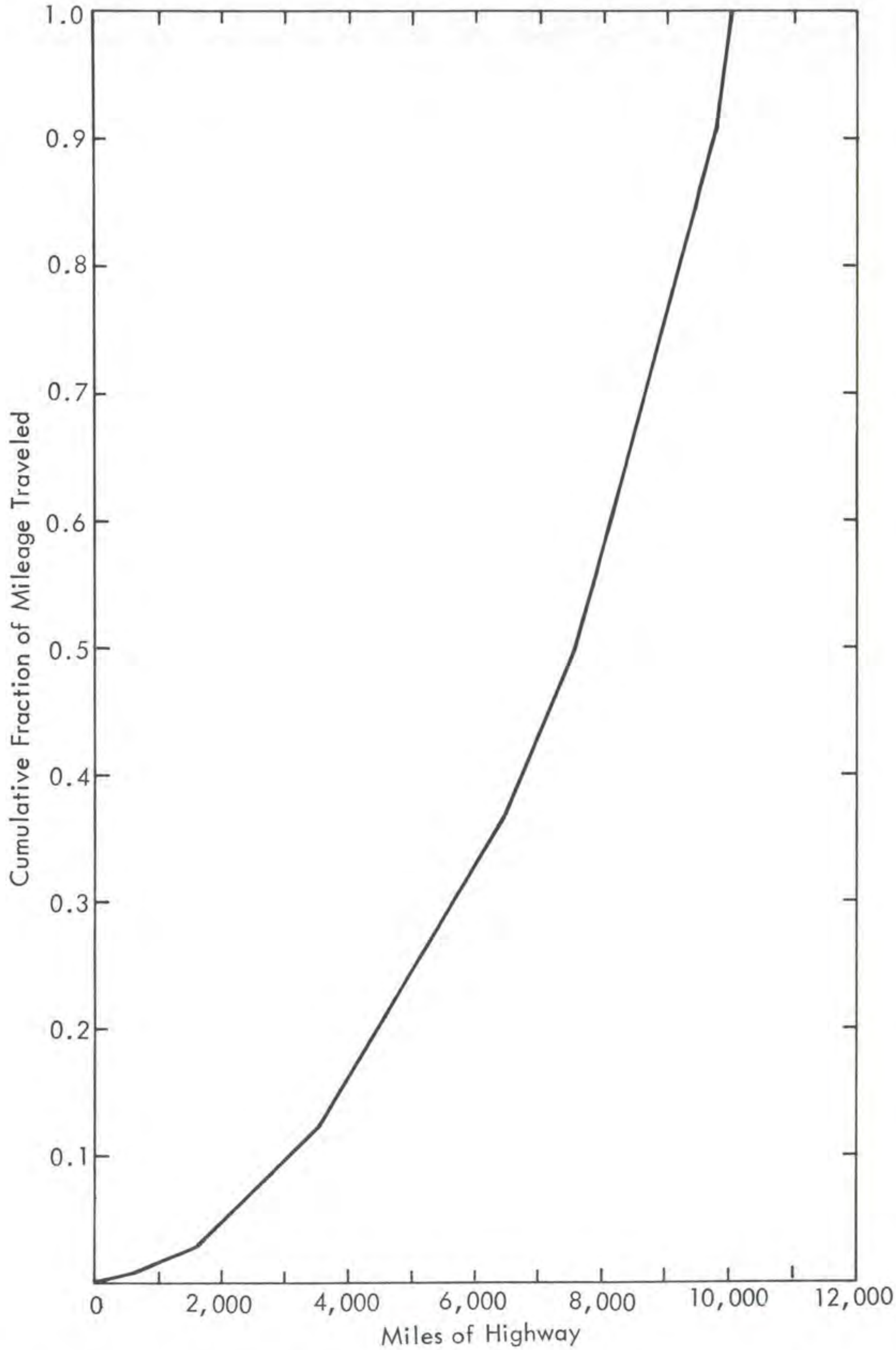

Figure 1-D-2, Cumulative Fraction of Mileage Traveled vs. Miles of Primary Road Used

PRIMARY

Mileage Region (J)		Cumulative Fraction of Miles Traveled	Fractional Increase = P_j	P_j^2
1)	0 - 999.9	0.0067	0.0067	0.000045
2)	1,000 - 1,999.9	0.0343	0.0267	0.001706
3)	2,000 - 2,999.9	0.0705	0.0362	0.001310
4)	3,000 - 3,999.9	0.117	0.0465	0.002162
5)	4,000 - 4,999.9	0.178	0.0610	0.003721
6)	5,000 - 5,999.9	0.239	0.0610	0.003721
7)	6,000 - 6,999.9	0.3110	0.0720	0.005702
8)	7,000 - 7,999.9	0.4160	0.1050	0.011025
9)	8,000 - 8,999.9	0.5530	0.1370	0.018769
10)	9,000 - 9,999.9	0.7230	0.1700	0.028900
		PAVED SECONDARY		
11)	10,000 - 10,999.9	0.7576	0.0346	0.001197
12)	11,000 - 11,999.9	0.7922	0.0346	0.001197
13)	12,000 - 12,999.9	0.8268	0.0346	0.001197
14)	13,000 - 13,999.9	0.8614	0.0346	0.001197
15)	14,000 - 14,999.9	0.8960	0.0346	0.001197
16)	15,000 - 15,999.9	0.9306	0.0346	0.001197
17)	16,000 - 16,999.9	0.9652	0.0346	0.001197
18)	17,000 - 17,999.9	0.9998	0.0346	0.001197

Cumulative Fraction Mileage	Sum P_j	Sum P_j^2
1.000	1.000	0.078258

Boost Factor = Number of 1,000 mile segments x sum $\left[P_j^2\right]$

Boost Factor = 18 x 0.078258 = 1.41

Figure 1-D-3 - Calculation of Boost Factor on Apprehension Probability Due to Scale Location Along High Traffic Density Roads

$$P = 1 - e^{-0.0550}$$

$$P = 1 - 0.9465$$

$$P = 0.0530$$

It should be noted that the apprehension rate method, which is a more direct method, yielded a value of 0.0128 or about 24 percent of the theoretical value based on the apprehension model.

The difference between the two figures was attributed to the "leakage" of information on scale schedules and other enforcement practices to violators. This leakage was assumed to be independent of slow changes in staff size, so that the apprehension rate calculated value for K_A would be insensitive to staff size. The leakage rate would change if ways could be found to prevent violators from finding out about enforcement practices.

APPENDIX 1, TAB E

AVERAGE FINE PER VIOLATING VEHICLE

Basic Information Sources

1. Tape file of 1967 Violation Records.

2. Sample of 1967 scale operation reports.

Method of Analyzing Data

A sample was made of T.W.O.'s own 1967 scale operation reports. The instructions for carrying out the sample are at Appendix 8. The fines and/or registration increases (both referred to as a "fine" herein) for each day's operations in the sample were recorded. The average fine per violation was calculated by simply totaling the dollars collected and dividing by the total violations recorded.

A computer analysis of Item 1 (simply tabulating the number of violations committed for each violator apprehended)1/ indicated that there are 1.135 violations per violator. This fact can be used to determine the average amount paid by each violator as follows:

Results of Analysis

Mode of Apprehension	Percent of Apprehensions	Average Fine Per Violation	Average Fine Per Violator 2/
Fixed Sites	77.4 67% Walt	23.70	26.95
Roving Patrol	22.6 33% ''	37.50	42.60
All	100.0	26.80	30.40

1/ The computer program is documented at Appendix 10.
2/ Taken equal to 1.135 times the average fine per violation.

APPENDIX 1, TAB F

DISTRIBUTION OF PAVEMENT TYPES AND COSTS IN IOWA
(Primary System)*

Basic Information Sources

The information on pavement types and costs in the Iowa primary road system was obtained from the Iowa State Highway Commission. The information was forwarded by Mr. Stephen E. Roberts, Research Engineer.

In a telephone discussion with Mr. Roberts on May 21, 1968, two pavement properties were confirmed. The bituminous treated soil aggregate is no longer used and current standards provide no structural coefficient. A structural coefficient of 0.20 was chosen based on the similarity to currently employed cold laid bituminous concrete base. Also, it was agreed to treat the asphalt treated crushed stone in pavement class 6 as asphalt treated base class I with a structural coefficient of 0.34.

A majority of the pavement courses are types in current use. The structural coefficients for these courses are obtained from "Guide for Primary and Interstate Road Pavement Design," Design Department, Soils, January 1968.

Data Processing and Application

The calculation of uncompensated pavement costs per violating vehicle mile requires the following inputs discussed here:

1. Pavement structure sufficiently well defined to calculate useful life in terms of reference axle applications.

2. The number of miles of each pavement structure (or the percent of total miles).

3. The cost of the pavement per lane mile.

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* Distribution of Pavement Types and Costs for paved secondary roads is contained in Appendix 1, Tab M.

The pavement structures are well defined by the information provided by the ISHC. However, for class number 5 two thicknesses are indicated and for class 6 a range of thicknesses is indicated. For the class 6 pavements the extremes are used so that there are in the distributions two type 5 and two type 6 pavements. The percent miles within these classes are presented later in this section.

A range of costs is given for the class 5 and 6 pavements. The extreme values are used. The minimum value is associated with minimum thickness and maximum value is associated with maximum thickness.*

Careful consideration has been given to portland cement concrete slabs covered with an asphalt concrete course. In effect, these pavements have two lives, first as a rigid pavement with pcc surface, and then as a flexible pavement with pcc base course. From this point of view these pavements could be considered as possessing a life which is the sum of the two separate lives and a total cost which is the sum of original pavement plus asphalt surfacing. In the same light one might project current pcc pavements as possessing the potential of second life as a flexible pavement. However, not all pcc pavements will be used since marginal soil support or altered alignment and grade requirements may reduce the desirability of the second life. Thus at any time the primary road system will contain these pavements in their first and second life states. The current state on the Iowa primary system is defined by the supplied data.

It appears that a pcc pavement (in first life) should be evaluated as a rigid pavement with one useful life. The associated pavement cost is for the pcc structure. A pavement which consists of an asphaltic concrete surface course over an old pcc slab should be treated as a single life flexible pavement. However, the cost applied here should cover only the expense of adding the asphaltic concrete surface course. This procedure accounts for the possibility of a second pavement life and proportions first and second lives according to the state of the highway system.

The cost of the asphaltic concrete surface course (over pcc base) is estimated from the data supplied by the ISHC. The current

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* It is recognized that factors other than thickness do affect pavement costs. However, for average correlations the chosen assignments seem most logical.

pcc slab pavements cost $100,000 to $120,000 per two lane mile. Currently an 8 in. pcc base with asphalt surface would cost $168,000 per two lane mile. The cost of the asphaltic surface course is taken as $68,000 per two lane mile or $34,000 per lane mile.*

Results

Two pavement distributions are presented and used in the calculations of uncompensated costs per violation vehicle mile. The first distribution uses equal amounts of the two different pavement thicknesses in class numbers 5 and 6. This distribution emphasizes thick, high capacity pavements and tends to hold uncompensated costs to a minimum. The second distribution contains a higher proportion of the thinner pavements and is used in calculations which attempt to locate an upper bound on uncompensated costs per violating vehicle mile on the primary system. These distributions are given in Table 1-F-1 together with structure and cost values used.

The class 4 pavement with 9 in. pcc is not used in the current system. It has been carried through the calculations to indicate the second life potential of currently employed 9 in. pcc pavements.

* The figure used is the largest of the possible differences. However, it is a conservatively low estimate since resurfacing requires shoulder and entrance rework.

TABLE 1-F-1

PAVEMENT CHARACTERISTICS, COST AND DISTRIBUTION IN THE IOWA PRIMARY SYSTEM

Class No.	Structural Elements	Structural Coef.	Structural No.	Pavement Cost per lane mile($)	Decimal Percent of total Primary miles Distribution 1	Distribution 2
1	$\frac{1}{4}$ in. invert. penetration 7 in. rolled stone	0.20 0.12	0.89 (1.00 used)	17,500	0.03	0.03
2	2 in. asph. concrete 7 in. bitum. treat. soil aggr.	0.44 0.22	2.28 (2.3 used)	27,500	0.01	0.01
3	3 in. asph. concrete 8 in. rolled stone 2 in. soil aggr.	0.44 0.12 0.05	2.38 (2.4 used)	30,000	0.03	0.03
4	4 in. asph. concrete 8 in. pcc	0.44 0.40	4.96 (5.00 used)	34,000 (for asph. resurface)	0.41	0.41
4	4 in. asph. concrete 9 in. pcc	0.44 0.40	5.36 (5.40 used)	34,000 (for asph. resurface)	0.00	0.00
5	8 in. pcc	NA	NA	50,000	0.21	0.32
5	9 in. pcc	NA	NA	60,000	0.21	0.10
6	3 in. asph. concrete 10 in. asph. treat. crush. stone 6 in. soil aggregate	0.44 0.34 0.05	5.02 (5.00 used)	50,000	0.05	0.08
6	4.5 in. asph. concrete 14 in. asph. treat. crush stone 6 in. soil aggregate	0.44 0.34 0.05	7.04 (7.00 used)	60,000	0.05	0.02

APPENDIX 1, TAB G

PAVEMENT MAINTENANCE COST DATA
(Primary Roads)*

Source of Information

The basic data are obtained from the Statistical and Financial Reference ISHC (66-67) and from the Summary, Maintenance Control Sections, ISHC 1966.

Data Requirements, Processing and Results

The data needed are the annual cost of pavement maintenance per lane mile as a function of pavement type. These specific costs are used in the calculation of uncompensated costs per violating vehicle mile. Since maintenance cost data are recorded per roadway mile, it is necessary to determine the average number of lanes per roadway mile. Then the annual specific cost can be found as

$$\text{Annual pavement maintenance cost per lane mile} = \frac{\text{Annual pavement maintenance cost per mile}}{\text{Average lanes per road mile}}$$

Table 1-G-1 presents the (1966) proportions of two- and four-lane pavements in the Iowa primary system.

Portland cement concrete and asphalt pavements constitute 91.9% of two-lane and 99.8% of four-lane pavements. Table 1-G-2 presents average lanes per road miles. Table 1-G-3 presents maintenance costs per mile.

* Pavement Maintenance Cost for Paved Secondary Roads are contained in Appendix 1, Tab M.

TABLE 1-G-1

MILES OF TWO- AND FOUR-LANE PRIMARY HIGHWAYS

Pavement	Miles: Two-Lane	Miles: Four-Lane
Portland Cement Concrete	4,303	417
Asphalt material over pcc	3,114	32
Asphalt	1,541	70
Other (extensions omitted)	790	1
	9,748	520

TABLE 1-G-2

AVERAGE LANES PER ROAD MILE

Pavement	Lanes Per Mile
Portland cement concrete	2.177
Asphalt material over pcc	2.020
Asphalt over flexible base	2.087
All asphalt	2.043

TABLE 1-G-3

ANNUAL SURFACE MAINTENANCE COSTS PER MILE

Pavement	Costs ($/mile) Routine	Special	Shoulders & Approaches	Total
Portland cement concrete	283	37	391	711
Asphalt material over pcc	171	24	396	591
Asphalt	313	266	226	805
Asphalt surface treated	1,269	272	116	1,657
Gravel or crushed stone	625	322	36	983
Extensions (maintained by cities)	891	44	22	957

Only the routine and special costs are appropriate to the calculation of uncompensated costs per violating vehicle mile. The sum of these two quantities is used together with average lanes per road mile to compute the costs in Table 1-G-4.

TABLE 1-G-4

PRIMARY ROADS ANNUAL SURFACE MAINTENANCE COSTS PER LANE MILE

Pavement	Annual Cost Per Lane Mile (dollars)
Portland cement concrete	147.0
Asphalt material over pcc	97.0
Asphalt over flexible base	277.0

APPENDIX 1, TAB H

DISTRIBUTION OF AXLE WEIGHTS FOR OVER-REGISTRATION AND OVERWEIGHT VEHICLES

Source of Information

Data used in the development of these distributions are taken from tables in the 1966 Iowa Analysis of Traffic Volume and Weight Study. The specific tables used are identified in subsequent descriptions of procedures. The combined distribution of over-registration and overweight vehicles uses the summonses issued by traffic weight officers, July 1, 1966, through June 30, 1967.

Required Data

The data discussed here are used in the calculation of uncompensated cost per violating vehicle mile. For each violating group (over-registration or overweight) the following information on each violating axle is required:

1. The axle configuration (single or tandem)
2. The legal weight
3. The actual weight (or amount over legal)
4. The average number of such violation axles per violating vehicle

Over-Registration Vehicles

The over-registration vehicles are those whose gross weights exceed the weight for which they are registered. They do not include vehicles which are over maximum allowable weight limits on a single axle, more than one axle, or on the entire vehicle.

In order to obtain the four required data items, it is necessary to determine the distribution of axle weights for commercial vehicles and to assign the over legal weight increment to the axles. The data from Table W-4, All Main Rural, are used. Also used are the implications of the "Summonses Issued by Traffic Weight Officers," July 1, 1966, through June 30, 1967.

The data on summonses show that for overload of registrations the increased registration per summons is $23.78. This implies that the average registration increase is one increment or about 2,000 lb.* It follows that the average over legal (registration weight) amount is one-half the weight increment or 1,000 lb. This average is used here and is distributed over the axles of the violating vehicle.

Axle weight distributions are obtained from Table W-4, All Main Rural. Each type of vehicle is treated separately in initial data processing although in some cases similar types are grouped together. Where axle weights are over legal maximums the axles are dropped together with associated weights which constitute the entire vehicle set. (These eliminated axles and vehicles are over maximum weight limits as opposed to over-registration vehicles.) The values in the W-4 table are classified in weight ranges. The central value of the interval is used for all the axles in the indicated range.

The distribution of axle weights for each vehicle type is used as a guide for the distribution of the average 1,000 lb. over-registration load among the vehicle axles. These assignments are shown with other features of the data reduction in Table 1-H-1. Distributions of Legal and Actual Axle Weights for Over-Registration Vehicles by Vehicle Type.

As shown in Table 1-H-1 a large proportion of the panels and pickups are not capable of violating registration weight limits. This situation occurs when both axles are in the 2,000-lb. range.

The last column in Table 1-H-1 provides average numbers of the indicated axle per over-registration vehicle of the type. The next step uses these values to generate a distribution of axle types and weights applicable to the entire population of vehicles which are over their registration weights. The relative frequencies of over-registration violations by vehicle type are obtained from the summonses issued by traffic weight officers, July 1, 1966, through June 30, 1967.

The summarization of summonses by type indicates that approximately 0.218 of the violations are for, or involve, over-registration weight. (The value 0.218 consists of 0.183 for over-registration directly plus 0.035 from other violations which involve added registration fees.)

The distribution of commercial vehicles by type is obtained from the W-4 table, All Main Rural.

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* At weights less than 24,000 lb. the weight and fee increments are not uniform. However, most weight increments are 2,000 lb. and the average fee increase for 2,000 lb. is approximately $25.

TABLE 1-H-1

DISTRIBUTIONS OF LEGAL AND ACTUAL AXLE WEIGHTS FOR OVER-REGISTRATION VEHICLES BY VEHICLE TYPE

Vehicle Type	Vehicles Weighed	Axles Over Max. Weights	No. Vehicles Eligible for Over-Reg.	Distribution of Weight Increase	Axle, or Set, Type	Axle Wt. (legal) (lb.)	No. Axles Available for Over-Reg.	Over-Reg. Axle Wt.	Axles per Vehicle of Indicated Type
Panel & Pickup	1,306	0	293	300 lb. on front	Single	2,000	293	2,300	1.0
				700 lb. on rear	Single	5,000	293	5,700	1.0
2 Axle, 4 & 6 Tire	1,045	3 Singles	1,037	300 lb. on front	Single	2,000	205	2,300	0.198
				700 lb. on rear	Single	5,000	832	5,300	0.802
					Single	5,000	484	5,700	0.467
					Single	7,500	143	8,200	0.138
					Single	10,000	251	10,700	0.242
					Single	14,000	137	14,700	0.132
					Single	17,000	22	17,700	0.021
3 Axle Single Unit	390	14 Tandems	376	300 lb. on front single	Single	2,000	5	2,300	0.013
				700 lb. on tandem	Single	5,000	180	5,300	0.479
					Single	7,500	42	7,800	0.112
					Single	10,000	107	10,300	0.285
					Single	14,000	42	14,300	0.112
					Tandem	4,000	4	4,700	0.011
					Tandem	9,000	153	9,700	0.407
					Tandem	15,000	70	15,700	0.186
					Tandem	21,000	35	21,700	0.093
					Tandem	27,000	95	27,700	0.253
					Tandem	31,000	19	31,700	0.051
Tractor Semitrailer 3 Axle	169	2 Singles	167	200 lb. on front axle	Single	5,000	165	5,200	0.988
				400 lb. on each of	Single	7,500	2	7,700	0.012
				other singles	Single	7,500	55	7,900	0.329
					Single	10,000	150	10,400	0.898
					Single	14,000	102	14,400	0.611
					Single	17,000	27	17,400	0.162
Tractor Semitrailer 4 Axle	647	37 Singles 27 Tandems	610	200 lb. on front single	Single	5,000	313	5,200	0.513
				500 lb. on tandem	Single	7,500	180	7,700	0.295
				300 lb. on rear single	Single	10,000	117	10,200	0.192
					Single	10,000	304	10,300	0.498
					Single	14,000	182	14,300	0.298
					Single	17,000	124	17,300	0.203
					Tandem	4,000	1	4,500	0.0016
					Tandem	9,000	170	9,500	0.279
					Tandem	15,000	137	15,500	0.225
					Tandem	21,000	141	21,500	0.231
					Tandem	27,000	124	27,500	0.203
					Tandem	31,000	37	31,500	0.0607

TABLE 1-H-1 (Continued)

Vehicle Type	Vehicles Weighed	Axles Over Max. Weights	No.Vehicles Eligible for Over-Reg.	Distribution of Weight Increase	Axle, or Set, Type	Axle Wt. (legal) (lb.)	No. Axles Available for Over-Reg.	Over-Reg. Axle Wt.	Axles per Vehicle of Indicated Type	
Tractor	2,110	384 Tandems	1,918	200 lb. on front single	Single	5,000	216	5,200	0.1126	
Semitrailer				400 lb. on tridems and	Single	7,500	333	7,700	0.1736	
5 Axle				tandems.(Total 1,000 lb.	Single	10,000	1,372	10,200	0.7153	
				incremental increase	Single	14,000	0		0	
				per vehicle.)	Tridem	17,000	3	17,400	0.0016	
					Tandem	9,000	623	9,400	0.3248	
						15,000	622	15,400	0.3243	
						21,000	609	21,400	0.3175	
						27,000	1,330	27,400	0.6934	
						31,000	649	31,400	0.3384	
Tractor	10	3 Tandems	8	100 lb. on front single	Sgl & Tdm	5,000	2	5,100	0.25	
Semitrailer				200 lb. on tridems	Sgl & Tdm	7,500	4	7,600	0.50	
6 Axle				350 lb. on tandems	Sgl & Tdm	10,000	2	10,100	0.25	
					Sgl & Tdm	10,000	5	10,200	0.625	
					Sgl & Tdm	14,000	3	14,200	0.375	
					Tandem	9,000	1	9,350	0.125	
					Tandem	15,000	4	15,350	0.500	
					Tandem	21,000	4	21,350	0.500	
					Tandem	27,000	7	27,350	0.875	
Truck & Trailer	152	12 Singles	144	For 3 Axle --	Single	2,000	42	2,200	0.2916	0.2884*
Combinations				200 lb. on front	Single	5,000	36	5,100	0.2500	0.2000
(6, 6 Axle Units				400 lb. on each	Single	5,000	59	5,200	0.4097	0.4855
Omitted)				other single.	Single	5,000	11	5,300	0.0764	0.0724
					Single	5,000	46	5,400	0.3194	0.2875
				For 4 Axle --	Single	7,500	9	7,600	0.0625	0.0500
				200 lb. on front	Single	7,500	13	7,700	0.0903	0.1548
				300 lb. on other	Single	7,500	7	7,800	0.0486	0.0461
				single and	Single	7,500	4	7,900	0.0278	0.0250
				500 lb. on tandem.	Single	10,000	110	10,200	0.7638	0.6492
					Single	10,000	18	10,300	0.1250	0.1185
				For 5 Axle --	Single	10,000	12	10,400	0.0833	0.0875
				200 lb. on front	Single	14,000	60	14,200	0.4166	0.3525
				200 lb. on other	Single	14,000	5	14,300	0.0347	0.0329
				singles & tridem	Single	14,000	12	14,400	0.0833	0.0750
				400 lb. on tandems.	Single	17,000	19	17,200	0.1319	0.1055
					Single	17,000	1	17,300	0.0069	0.0066
				For 5 Axle - 2 Trailer	Single	17,000	4	17,400	0.0278	0.0250
				100 lb. on front	Tandem	4,000	1	4,400	0.0069	0.0119
				200 lb. on each	Tandem	4,000	5	4,500	0.0347	0.0329
				other axle.	Tandem	9,000	15	9,400	0.1042	0.1786

TABLE 1-H-1 (Concluded)

Vehicle Type	Vehicles Weighed	Axles Over Max. Weights	No. Vehicles Eligible for Over-Reg.	Distribution of Weight Increase	Axle, or Set, Type	Axle Wt. (legal) (lb.)	No. Axles Available for Over-Reg.	Over-Reg. Axle Wt.	Axles per Vehicle of Indicated Type	
Truck & Trailer Combinations (6, 6 Axle Units Omitted) (concluded)	512	12 Singles	144	For 5 Axle - 2 Trailer 100 lb. on front 200 lb. on each other axle. (concluded)	Tandem	9,000	17	9,500	0.1180	0.1119
					Tandem	15,000	7	15,400	0.0486	0.0833
					Tandem	15,000	7	15,500	0.0486	0.0461
					Tandem	21,000	2	21,400	0.0139	0.0238
					Tandem	21,000	6	21,500	0.0417	0.0395
					Tandem	27,000	5	27,400	0.0347	0.0595
					Tandem	27,000	2	27,500	0.0139	0.0132

* In the original reduction the truck trailer units were treated separately according to vehicle configuration and then combined giving equal emphasis to each configuration. This procedure produced these values for number of axles per over-registration vehicles of the truck-trailer types.

Table 1-H-2 presents the factors discussed above and used in developing the weight factor for over-registration vehicles in a sample of 1,000 trucks of all types on primary roads.

The distribution of axle characteristics for over-registration vehicles is obtained by applying the weight factors for specific vehicle types to the over-registration axle characteristics for the vehicle type. This procedure entails multiplying the last columns in Tables 1-H-1 and 1-H-2. The results have been regrouped and several axles with nearly equal characteristics have been combined. The results are presented in Table 1-H-3.

Vehicles Over Maximum Legal Weights

Maximum legal limits can be exceeded on a single axle, a tandem set, an axle group or on the entire vehicle. In order to obtain the four required data items, it is necessary to determine the legal weight and overweight for each axle (or tandem set) which is in violation. The basic data are obtained from the Iowa W-6 tables, 1966. Here the data are given for individual, type identified, vehicles with violations in percent over state law. Violations are recorded for individual axles, axle groups and total weights.

The first step in processing the data is to determine the primary violation type for each vehicle which is indicated with more than one violation. Four overweight violation types are used, (1) single axle, (2) tandem set, (3) axle group (more than tandem), and (4) vehicle gross. In selection of a primary violation type the intent is to describe most accurately the extra legal axles, their legal loads, and their average. The selection rules use the percent over state law values given in W-6. The rules are:

Single axle of tandem in violation--Treat as a single axle.

Single axle of tandem and tandem set in violation--Treat as tandem if tandem percent violation is largest.

Single(s) in group and group in violation--Use singles if there are two or more. Use the one violation single if it is twice or more in violation compared to group.

Group and gross in violation--Use the gross unless gross violation is one-half or less of group.

TABLE 1-H-2

DEVELOPMENT OF WEIGHT FACTORS FOR OVER-REGISTRATION VEHICLES

(1) Vehicle Type	(2) No. in Sample of 1,000 Trucks	(3) Violations per Vehicle of Specified Type	(4), (2)·(3) Violations in Specified Type per 1,000 Trucks of All Types	(5) Over-Reg. Violations per Total Violations	(6) Other Factor (= 1.0 if not indicated)	(7), (2)·(3)·(5)·(6) Over-Reg. Vehicles of Specified Type per 1,000 Trucks of All Types	(8), (7)/$\sum$(7) Weight Factor for Over-Reg. Vehicles of Specified Type
Panel & pickup	272	0.00261	0.71	0.218	293/1306*	0.0347	0.00790
2 axle	154	0.0238	3.665			0.7990	0.18200
3 axle	54	0.02385	1.288			0.2810	0.06400
2S1	31	0.02666	0.826			0.1512	0.03444
2S2	100	0.02833	2.833			0.6176	0.14068
3S2 & 3	364	0.0300	10.92			2.3806	0.54224
Truck + trailer(s) & others	25	0.02316	0.579			0.1262	0.02874
						$\sum$(7) = 4.3903	1.00000

* The factor 293/1306 accounts for the proportion of these light units which are capable of being over registration by having one axle above the 2,000 lb. classification.

TABLE 1-H-3

AXLE CHARACTERISTICS OF OVER-REGISTRATION VEHICLES ON PRIMARY ROADS

Single Axles			Tandem Sets		
Legal Weight (Kips)	Amount Over Legal Weight (Kips)	Average Number of Axles Per Over-Reg. Vehicle	Legal Weight (Kips)	Amount Over Legal Weight (Kips)	Average Number of Sets Per Over-Reg. Vehicle
2.000	0.200	0.0083	4.000	0.400	0.0003
	0.300	0.0447		0.500	0.0012
5.000	0.100	0.0057		0.700	0.0007
	0.200	0.1877	9.000	0.400	0.1812
	0.300	0.1787		0.500	0.0425
	0.400	0.0083		0.700	0.0261
	0.700	0.0929	15.000	0.400	0.1782
7.500	0.100	0.0014		0.500	0.0330
	0.200	0.1406		0.700	0.0119
	0.300	0.0085	21.000	0.400	0.1728
	0.400	0.0142		0.500	0.0336
	0.700	0.0251		0.700	0.0049
10.000	0.200	0.4335	27.000	0.400	0.3673
	0.300	0.0917		0.500	0.0289
	0.400	0.0390		0.700	0.0162
	0.700	0.0440	31.000	0.400	0.1835
14.000	0.200	0.0101		0.500	0.0085
	0.300	0.0500		0.700	0.0033
	0.400	0.0272			
	0.700	0.0239			
17.000	0.200	0.0030			
	0.300	0.0287			
	0.400	0.0082			
	0.700	0.0039			

Single and gross in violation--Use the gross unless gross violation is one-half or less of single.

Tandem and gross in violation--Use the gross unless gross violation is one-half or less of tandem.

Single, a separate tandem, and gross all in violation--Use the gross unless its percent violation is smaller than the other two taken individually.

After the selection of a primary violation, the primary violation within each vehicle type are listed and grouped in classes of 3 percent violation increments.* The center value of each class increment is assigned for all class members.

All violations are converted to single and tandem axle form. For gross vehicle weight violations the conversion uses the axle weight distributions found for specific vehicle types in the over-registration analysis. The legal weights distributed on the axles are for 3 axle trucks 450,000 lb., and for semi-trailer and trailer units 72,000 lb. The percent violation figures are used with these values to obtain gross overweight in pounds. The gross overweight is then divided among the axles according to the weight distributions previously determined.

The axle group violations are first converted to gross violations by retaining the percent violation but reducing the number of violating axles to one-half the vehicle axles. The conversion to singles and tandems then follows as a conversion from gross load violation.

Overweight data from Table W-6 1966 have been processed as described above. One data set was obtained from the tables for highway system (01) with added data on vehicle types 2D, 3A, 252 and truck-trailers from system (03). These data should be representative of weight violations on the heavily traveled, highly enforced part of the primary system. The axle characteristics are given in Table 1-H-4.

The weight factor for each vehicle type is found by procedure similar to that used for the over-registration vehicles. The distribution of types is obtained from the W-4 table, All Main Rural: the summonses issued by traffic weight officers indicate that 0.3143 of the summonses are

* The 3 percent class interval grouping are not used for the three-axle single units where the small sample (9) and distribution of values would be poorly represented by the 3 percent class intervals. Values within 3 percent of one another are grouped and averaged for the three-axle vehicles.

TABLE 1-H-4

DISTRIBUTIONS OF LEGAL AND ACTUAL AXLE WEIGHTS FOR OVER LEGAL WEIGHT VEHICLES BY VEHICLE TYPE
(For Highway Systems 01 and 03)

Vehicle Type	No. Vehicles in Sample	Axle Type	Legal Weight (lb.)	Amount Over Legal (lb.)	Number of Axles Per Overweight Vehicle of Specified Type
2A	4	Single	18,000	900	1.0
3A	9	Single	13,500	500	0.333
		Single	18,000	300	0.111
		Single	18,000	2,600	0.111
		Tandem	31,500	1,200	0.333
		Tandem	32,000	1,400	0.333
		Tandem	32,000	4,600	0.111
2S2 & 1	49	Single	18,000	300	0.3470
		Single	18,000	800	0.1021
		Single	18,000	1,350	0.1633
		Single	18,000	2,400	0.0204
		Tandem	32,000	500	0.1429
				1,450	0.0816
				2,400	0.1021
				3,400	0.0204
				5,300	0.0204
3S2	201	Single	14,000	200	0.1791
				650	0.1692
				1,100	0.0398
				1,500	0.0448
				1,950	0.0100
				2,400	0.0050
				3,200	0.0100

TABLE 1-H-4 (Concluded)

Vehicle Type	No. Vehicles in Sample	Axle Type	Legal Weight (lb.)	Amount Over Legal (lb.)	Number of Axles Per Overweight Vehicle of Specified Type
3S2 (Concluded)	201	Single	18,000	300	0.0945
				800	0.0348
				1,350	0.0299
				2,400	0.0100
				3,000	0.0050
		Tandem	29,000	450	0.3582
				1,300	0.3383
				2,200	0.0796
				3,000	0.0896
				3,900	0.0199
				4,800	0.0100
				6,500	0.0199
			32,000	500	0.1343
				1,450	0.0498
				2,400	0.0149
				3,400	0.0348
				4,300	0.0100
				5,300	0.0100
				6,200	0.0149
				8,200	0.0050*
				10,000	0.0050*
Truck-trailer combinations	8	Single	7,000	100	0.5000
				300	0.2500
				1,000	0.6250
				1,200	0.2500
			18,000	300	0.1250
		Tandem	29,000	400	0.5000
				1,300	0.2500
				3,900	0.6250
				4,800	0.2500

* These two values were omitted in the calculation of the final distribution which was subsequently used to obtain a minimum value for uncompensated life and maintenance use.

for overweight. The overweight violations from highway system 01 show 386 violations by 231 overweight vehicles. These data are dominated by the four-axle and more, semi- and truck-trailer units, and indicate that for these units there are approximately 0.60 weight violating vehicles per weight violation summons. These values are used to calculate weight factors as shown in Table 1-H-5.

The distribution of axle characteristics for overweight vehicles is obtained by applying the weight factors for specific vehicle types to the overweight axle characteristics for the vehicle type. This procedure entails multiplying the last columns in Tables 1-H-4 and 1-H-5. The results have been regrouped and axles with nearly equal characteristics have been combined. The results are presented in Table 1-H-6.

Over-Registration and Overweight Vehicles

A combined distribution of axle characteristics for over-registration and overweight vehicles can be formed from tables prepared separately for these two violation types. The combined distribution is obtained by using revised weight factors for each combination of vehicle type and violation type. The denominator of the revised weight factor is 4.3903 + 3.8112 = 8.2015, the number of violating vehicles, over-registration and overweight, in the sample of 1,000 trucks of all types. The numerators of the weight factors are over-registration or overweight vehicles of the specified type per 1,000 trucks of all types. These latter quantities are listed in column 7 of Tables 1-H-2 and 1-H-5.

Vehicles Over Maximum Legal Weight Limits on System 31

An additional distribution is obtained to be used in setting an upper bound for uncompensated life and maintenance use per overweight violating vehicle. The data in Table W-6 for highway system 31 were chosen. This highway system contains roads which are being replaced by interstates so that current traffic runs partially on older roads which may be underdesigned for current usage. In addition, the W-6 data for this system are obtained on a road which currently has no permanent enforcement weight station.

The processing of data from the W-6 table parallels that described previously except that the weight factor for vehicle type is derived directly from the overweight data sample. (There is no attempt or need in this case to obtain violator frequency for a 1,000 truck sample of all types.) The results are presented in Table 1-H-7 and 1-H-8.

TABLE 1-H-5

DEVELOPMENT OF WEIGHT FACTORS FOR OVERWEIGHT VEHICLES

(1) Vehicle Type	(2) No. in 1,000 Truck Sample	(3) Violations Per Vehicle Of Specified Type	(4), (2).(3) Violations (Total) in Specified Type Per 1,000 Trucks of All Types	(5) Overweight Violations Per Total Violations	(6) Weight Violating Vehicle Per Overweight Violation	(7), (2).(3).(5).(6) Overweight Vehicles of Specified Type Per 1,000 Trucks of All Types	(8), (7)/$\sum$(7) Weight Factor For Overweight Vehicles Of Specified Type
Panel & pickup	272	0.00261	0.71	0.0000 (by inference)		0.0000*	0.0000
2 axle	154	0.02380	3.665	0.1210 (by inference)	1.00	0.4440*	0.1165
3 axle	54	0.02385	1.288	0.3143**	1.00	0.4048	0.1062
2S1	31	0.02666	0.8264	↓	1.00	0.2597	0.0681
2S2	100	0.02833	2.8330	↓	0.60	0.5342	0.1402
3S2 & 3	364	0.0300	10.9200	↓	0.60	2.0593	0.5403
Truck + trailer(s) & others	25	0.02316	0.5790	↓	0.60	0.1092	0.0287
						$\sum$(7) = 3.8112	1.0000

* Indicated by the ratio of overweight to legal weight axles for this type in the W-4 Table, All Main Rural.

** Ratio is overweight to total summonses.

TABLE 1-H-6

AXLE CHARACTERISTICS OF OVERWEIGHT VEHICLES ON PRIMARY ROADS
(Systems 01 and 03)

Single Axles			Tandem Sets		
Legal Weight (Kips)	Amount Over Legal Weight (Kips)	Average Number of Axles Per Overweight Vehicle	Legal Weight (Kips)	Amount Over Legal Weight (Kips)	Average Number of Sets Per Overweight Vehicle
7.000	0.100	0.0143	29.000	0.400	0.2079
	0.300	0.0072		1.300	0.1900
	1.000	0.0179		2.200	0.0430
	1.200	0.0072		3.000	0.0484
13.000	0.500	0.0354		3.900	0.0287
14.000	0.200	0.0968		4.800	0.0126
	0.650	0.0914		6.500	0.0108
	1.100	0.0215	32.000	0.500	0.0926
	1.500	0.0242		1.200	0.0354
	1.950	0.0054		1.400	0.0737
	2.400	0.0027		2.400	0.0224
	3.200	0.0054		3.400	0.0217
18.000	0.300	0.1151		4.300	0.0054
	0.800	0.0162		4.600	0.0118
	0.900	0.1977		5.300	0.0083
	1.300	0.0390		6.200	0.0081
	2.400	0.0083		8.200	0.0027*
	2.600	0.0118		10.000	0.0027*
	3.000	0.0027			

* These two contributions were omitted in calculations designed to provide a minimum value for uncompensated life and maintenance use.

TABLE 1-H-7

DISTRIBUTIONS OF LEGAL AND ACTUAL AXLE WEIGHTS FOR OVER LEGAL WEIGHT VEHICLES BY VEHICLE TYPE
(For Highway System 31)

Vehicle Type	Number of Vehicles	Axle Type	Number of Axles or Sets	Legal Weight (Lb.)	Amount Over Legal (Lb.)	Axles per Violating Vehicle of Specified Type
3A	3	Tandem	2	32,000	2,400	0.6666
			1		5,300	0.3333
2S2 & 1	7	Single	4	18,000	300	0.5714
		Tandem	1	32,000	3,400	0.1429
			1		4,300	0.1429
			1		5,300	0.1429
3S2 & 2-2	73	Single	12	14,000	200	0.1644
			10		600	0.1370
			11		1,100	0.1507
			5		1,500	0.0685
			4		1,900	0.0548
			2		2,400	0.0274
			1		2,800	0.0137
			1		5,400	0.0137
			1	18,000	1,350	0.0137
			1		1,900	0.0137
			1		2,400	0.0137
			1		3,500	0.0137
		Tandem	24	29,000	500	0.3288
			20		1,300	0.2740
			22		2,200	0.3014
			10		3,100	0.1370
			8		3,900	0.1096
			4		4,800	0.0548
			2		5,600	0.0274
			2		10,800	0.0274
			4	32,000	500	0.0548
			2		1,450	0.0274
			2		2,400	0.0274
			2		3,400	0.0274
			3		4,300	0.0411
			2		5,300	0.0274
			2		7,200	0.0274
			2		9,100	0.0274

TABLE 1-H-8

AXLE CHARACTERISTICS OF OVERWEIGHT VEHICLES ON PRIMARY ROADS
(For Highway System 31)

Single Axles			Tandem Sets		
Legal Weight (Kips)	Amount Over Legal Weight (Kips)	Average Number of Axles Per Overweight Vehicle	Legal Weight (Kips)	Amount Over Legal Weight (Kips)	Average Number of Axles per Overweight Vehicle
14.000	0.200	0.1446	29.000	0.500	0.2892
	0.600	0.1205		1.300	0.2410
	1.100	0.1325		2.200	0.2651
	1.500	0.0602		3.100	0.1205
	1.900	0.0482		3.900	0.0964
	2.400	0.0241		4.800	0.0482
	2.800	0.0120		5.600	0.0241
	5.400	0.0120		10.800	0.0241
18.000	0.300	0.0482	32.000	0.500	0.0482
	1.350	0.0120		1.450	0.0241
	1.900	0.0120		2.400	0.0482
	2.400	0.0120		3.400	0.0361
	3.500	0.0120		4.300	0.0482
				5.300	0.0482
				7.200	0.0241
				9.100	0.0241

APPENDIX 1, TAB I

UNCOMPENSATED ROAD LIFE AND MAINTENANCE USAGE

Source of Basic Analytical Relationships

The basic analytical relationships are taken from Highway Research Board Special Report 61E, "The AASHO Road Test, Report 5, Pavement Research," and from two design guides. The design guides, prepared by the AASHO Committee on Design, are: "AASHO Interim Guide for the Design of Rigid Pavement Structures," April, 1962, and "AASHO Interim Guide for the Design of Flexible Pavement Structures," October 12, 1961.

Flexible Pavement Life Use

The relation between pavement condition, pavement structures, and loads carried is given by

$$W = \frac{1}{R}\left(\frac{C_0-p}{C_0-C_1}\right)^{1/\beta}\rho ,$$

where

W = Number of axle applications

R = Regional factor (to account for environment and environment-soil interactions)

C_0 = Initial serviceability index (new pavement value)

= 4.2 in AASHO tests, a value applicable to Iowa pavements

p = Present serviceability index (after the W axle applications)

C_1 = Final serviceability index in AASHO tests

= 1.5

β and ρ are functions which contain the axle configurations, axle weight, and the pavement structural property.

$$\beta = 0.4 + \frac{0.081(L_1+L_2)^{3.23}}{(S_n+1)^{5.19}L_2{}^{3.23}} \quad \text{, and}$$

$$\rho = \frac{10^{5.93}(S_n+1)^{9.36}L_2{}^{4.33}}{(L_1+L_2)^{4.79}} \quad ,$$

where

L_1 = Load carried by a single axle or tandem pair (kips)*

L_2 = 1.0 for single axle; = 2.0 for tandem pair

S_n = Structural number, a property of the pavement given by

$$S_n = A_1D_1 + A_2D_2 + A_3D_3$$

D_1, D_2, D_3 = Thickness in inches of the surface course, base course, and subbase, respectively

A_1, A_2, A_3 = Coefficients of load carrying capacities of the courses.

---

* 1.0 kip = 1000. pounds.

Total Life

When S_n is given or calculated the total useful life of a pavement is calculated using the equation for W. In this calculation (p) is set equal to 2.5, the final value for primary roads. According to Iowa practice the regional factor R is set equal to 3.0 for Classes I, II and III, and 2.0 for Class IV. (The value $R = 3.0$ has been used in calculations for this report.) The axle configuration and load are set equal to reference values, $L_1 = 18.0$ and $L_2 = 1.0$. The resulting value of W is written W_{tr} and is the number of reference axle load applications which the pavement should sustain during its useful life.

Reference Axle Equivalences

With the total pavement life available in terms of reference axle applications it is necessary to define life usage by every axle in these same units, i.e., reference axle applications. The equivalence value sought is the number of reference axle applications which would use the same amount of pavement life as one application of the nonreference axle. It is given by

$$W_{rx} = \frac{W_{tr}}{W_{xr}} = \frac{\rho_r}{\rho_x} \left(\frac{4.2-2.5}{4.2-1.5} \right)^{\left(\frac{1}{\beta_r} - \frac{1}{\beta_x} \right)}$$

Here the subscripts r and x on ρ and β indicate that they are evaluated with the reference axle values and nonreference values respectively.

The value W_{rx} is a measure of life use by the nonreference axle in terms of reference axle applications. The equation for W_{rx} is applied twice for each violation axle. In one calculation the legal weight of the axle is used; in the second calculation the actual weight is used. The difference of these two values is the uncompensated life use by the violation axle, in units of reference axle applications.

Rigid Pavement Life Use

The relations for the rigid pavement and their applications are similar to the flexible pavement case. The fundamental relation is

$$W = \rho\left(\frac{C_0-p}{C_0-C_1}\right)^{1/\beta}\left(\frac{S_c\sigma'}{S_c\sigma'}\right)^{(4.22-0.32p_t)},$$

where as before

W = Number of axle applications

C_0 = Initial serviceability index

- (but = 4.5 for rigid pavements)

C_1 = Terminal serviceability index in AASHO tests

= 1.5

p = Present serviceability index (after W applications)

The β and ρ have generally the same forms but different coefficients and exponents.

$$\beta = 1.0 + \frac{3.63(L_1+L_2)^{5.20}}{(D_2+1)^{8.46}L_2^{3.52}}$$

$$\rho = \frac{10^{5.85}(D_2+1)^{7.35}L_2^{3.28}}{(L_1+L_2)^{4.62}}$$

L_1 = Axle load or tandem set load (kips)

L_2 = 1.0 for single axle; = 2.0 tandem set

D_2 = Concrete slab thickness (inches)

The factor with S_c, S_c' σ, and σ' is used to compensate for material and soil differences between the analyzed pavement and the AASHO test pavements.

p_t = Terminal value of serviceability index, = 2.5 for Iowa primary roads

S_c = Modulus of rupture for concrete (28 day) in the AASHO test (psi)

= 690 psi

S_c' = Modulus of rupture for concrete (28 day) in analyzed pavement (psi)

$$\frac{\sigma}{\sigma'} = \frac{\left\{\left[\frac{(E/k)D_2^3}{12(1-\mu^2)}\right]^{1/4} - a_1\right\}(E'/k')^{1/4}}{\left\{\left[\frac{(E'/k')D_2^3}{12(1-\mu^2)}\right]^{1/4} - a_1\right\}(E/k)^{1/4}},$$

where

E = Modulus of elasticity for concrete in AASHO test

= 4.2×10^6 psi

E' = Modulus of elasticity for concrete in analyzed pavement (psi)

μ = Poisson's ratio = 0.2

a_1 = 10.0 inches, a load distribution measure

k = The soil support value in the AASHO test (psi/in)

= 60.0 psi/in

k' = Soil support value for analyzed pavement (psi/in)

Total Life

Total pavement life is calculated using the expression for W with $L_1 = 18.0$ and $L_2 = 1.0$, and $p = 2.5$. The result is denoted as W_{tr} reference axle applications.

Reference Axle Equivalences

As in the case with flexible pavement calculations the life used by a nonreference axle is calculated in terms of equivalent reference axle applications. The life use by axle sub x is

$$W_{rx} = \frac{W_{tr}}{W_{tx}} = \frac{\rho_r}{\rho_x}\left(\frac{4.5-2.5}{4.5-1.5}\right)^{(1/\beta_r - 1/\beta_x)} ,$$

where the subscripts r and x indicate the use of reference and nonreference axle properties.

The equation for W_{rx} is applied twice for each violation axle. The actual weight is used in one calculation, the legal weight in the other. The difference in W_{rx} values is the uncompensated life use in the units (reference axle applications).

Load - Maintenance Relations

There are no explicit data which identify the relations between loads and pavement maintenance costs. There are, however, some data which provide a basis for estimating these relationships. In the AASHO road tests the pavements were inspected and their states recorded at closely spaced intervals. The history of pavement states and the history of load passages were used to derive relations between cracking and load applications. Cracking is probably the best single measure of pavement maintenance requirements. It is used here to establish the uncompensated maintenance use per lane mile which arises from the passage of an over legal axle load.

Flexible Pavement Cracking

The AASHO road test results indicated that the first appearance of class two cracking was related to pavement design, loads, and load applications. The class two cracking is likely to require patching or sealing and is considered here as an indication of the design-load-maintenance relationship.

The relation has the form

$$W_c = \frac{A_0(a_1D_1+a_2D_2+a_3D_3+a_4)^{A_1} L_2^{A_3}}{(L_1+L_2)^{A_2}} \quad ,$$

where

W_c = Number of load applications to first appearance of class two cracking.

(weighted to smooth seasonal variations)

L_1 = Load carried by single axle or by tandem pair (kips)

L_2 = 1.0 for single axle, = 2.0 for tandem pair

D_1 = Surfacing thickness (inches)

D_2 = Base thickness (inches)

D_3 = Subbase thickness (inches)

The capital and lower case A's were chosen by AASHO investigators to fit the test results.

Table 1-I-1 presents the values of the coefficients.

TABLE 1-I-1

COEFFICIENTS FOR FLEXIBLE PAVEMENT CRACKING

Coefficient	Value
A_0	0.3048×10^5
A_1	7.275
A_2	3.136
A_3	2.947
a_1	0.33
a_2	0.10
a_3	0.08
a_4	1.0

The number of reference load applications to class two cracking forms the basis for calculating maintenance use. This value is obtained using the equation for W_c with $L_1 = 18.0$ and $L_2 = 1.0$. The result is denoted W_{rm} . For a nonreference axle the equivalent use of maintenance is obtained as the ratio W_{rmx}.

$$W_{rmx} = \frac{W_{rm}}{W_{xm}} = \left(\frac{1.0}{L_{2x}}\right)^{2.947} \left(\frac{L_{1x}+L_{2x}}{19.0}\right)^{3.136}$$

where

L_{1x} = Nonreference axle load (kips)

L_{2x} = 1.0 for single nonreference axle

= 2.0 for tandem nonreference axle set,

and the reference values 18.0 and 1.0 have been inserted together with the exponents. W_{rmx} is the maintenance use by the nonreference axle x in terms of equivalent applications of reference axles. (Notice that the parameters relating to the flexible pavement structure cancel out.)

Application to Maintenance Use

The equation for W_{rmx} is applied twice for each violation axle. In one calculation the legal load is used; in the second calculation the actual load is used. The difference of the resulting values is the uncompensated maintenance use in reference axle applications.

Rigid Pavement Cracking

The AASHO road test results provide the following relation between cracking and load applications for rigid pavements.

$$C' = \frac{A_0 L_1^{A_1} W^2}{D_2^{A_2}}$$

where

C' = cracking index, linear feet of cracks per 1000 square feet of pavement.*

L_1 = Axle load or tandem set load (kips)

W = Number of applications

* It was noted by the AASHO investigators that $C' = 100$ constituted a substantial amount of structural deterioration.

D_2 = Pavement thickness (inches)

A_0, A_1, and A_2 = coefficients dependent on the pavement reinforcement and axle configuration.

The relation can be written

$$W = \left[\frac{C' D_2^{A_2}}{A_0 L_1^{A_1}} \right]^{1/2} .$$

We chose a single axle load of 18.0 kips as a reference and any convenient amount of cracking, C^1 , to form a basis for maintenance use. This basis is a number of reference axle applications given by

$$W_{rm} = \left[\frac{C' D_2^{A_{2r}}}{A_{0r} L_{1r}^{A_{1r}}} \right]^{1/2} ,$$

where the subscript r is used to indicate that the values and exponents are selected for the single axle, reference load.

The application of a nonreference axle will promote cracking equivalent to some applications of the reference axle. We interpret this as equivalent maintenance use. The equivalence is given by

$$W_{rmx} = \frac{W_{rm}}{W_{xm}} = D_2^{\left(\frac{A_{2r}-A_{2x}}{2}\right)} \left(\frac{A_{0x}}{A_{0r}}\right)^{1/2} \frac{L_{1x}^{(A_{1x}/2)}}{L_{1r}^{(A_{1r}/2)}} .$$

This is the maintenance use by nonreference axle x in terms of equivalent reference axle applications. The coefficients and exponents depend on pavement and axle configuration as shown in Table .

TABLE 1-I-2

RIGID PAVEMENT CRACKING COEFFICIENTS AND EXPONENTS

Pavement	Axle Configuration	$A_0^{1/2}$	$\frac{A_1}{2}$	$\frac{A_2}{2}$
nonreinforced	single	1.995×10^{-5}	2.62	4.84
nonreinforced	tandem	2.455×10^{-7}	4.38	6.33
reinforced	single	1.122×10^{-5}	2.30	3.57
reinforced	tandem	4.266×10^{-7}	3.13	3.96

Application to Maintenance Use

The equation for W_{rmx} is applied twice for each violation axle. In one calculation the legal load is used; in the second calculation the actual load is used. The difference of the resulting values is the uncompensated maintenance use in reference axle applications.

APPENDIX 1, TAB J

AVERAGE LOSS PREVENTED FOR DETERRED REGISTRATION VIOLATORS

Basic Information Sources

1. ISHC: "Summary of Traffic Weight Operations for the Period July 1, 1966, through June 30, 1967.

2. ISHC Planning Division: "Truck and Bus Registration in Iowa For 1966."

3. Appendix 1, Tab B of this Report.

Method of Analyzing Data

Item 3 indicated that $12.06(10)^6$ truck trips occurred in Iowa in 1968. Item 2 indicated that there were 299,000 vehicles registered in Iowa in 1966.

This implies that $12.06(10)^6/326{,}000 = 37.0$ trips per year were taken by the "average" vehicle.[1/]

Item 1 indicated that registration violations[2/] brought in $100,161 for 11,395 violations or $8.79 per violation. Once a violator is apprehended he must pay the registration increase and cannot pay the increase twice. Hence, the most Iowa can lose from such a violation if it goes unapprehended for a full year is $8.79/. We prorate this over the 37.0 trips to obtain an average loss per trip of $8.79/37.0 = $.237 per trip.

Results of Analysis

Average loss for Iowa per trip of a registration violator = $0.237.

1/ These are 112.3 mile "average" trips. Shorter trips are more frequent.
2/ As measured by apprehended registration violators.

APPENDIX 1, TAB K

FIXED AND VARIABLE COSTS OF ENFORCEMENT

Basic Information Sources

1. ISHC: "Budget Status Report," July 1, 1966 to July 14, 1967.

2. ISHC: "Table of Organization and Manning-Traffic Weight Operation," dated January 11, 1968.

Method of Data Analysis

Item 2 provided information on the number of men on the T.W.O. staff and their salaries. This was developed into an average salary figure.

Item 1 provided information on the other types of expenditures necessary to support T.W.O. These were divided according to whether they would vary with staff, i.e., whether they were fixed or variable.

Some costs were considered semi-fixed, i.e., would increase in steps once manpower passed certain fixed levels. These are associated with hiring more administrative personnel.

The calculations and assumptions are displayed in Figure 1-K-1.

Result of Analysis

Shown in Figure 1-K-1, and in Section III-A-3 of the Report.

VARIABLE OPERATING COSTS (Thousands)

Salary (1967 average salary and benefits for enforcement officers):[1]	$6.813
Vehicle Operation ($104,284 per year (1967)); per enforcement officer, $104,284/56):	1.862
Miscellaneous Budget (variable portion):	0.228
Total Variable Operating Cost per Enforcement Officer	$8.903

FIXED OR SEMI-VARIABLE OPERATING COSTS (Thousands)

Enforcement Level	20-49		Current 50-90		91-150		151-210	
Administrative Salary:[2]								
Director	(1)	$10.70	(1)	$10.70	(1)	$10.70	(1)	$ 10.70
Assistant Director	(1)	11.00	(1)	11.00	(2)	20.60	(2)	20.60
Permit Officer	(2)	15.36	(2)	15.36	(2)	15.36	(2)	15.36
Stenographer	(1)	4.63	(2)	9.26	(2)	9.26	(2)	9.26
Clerk	(2)	8.00	(2)	8.00	(3)	12.00	(4)	16.00
Mechanic	(1)	7.86	(1)	7.86	(1)	7.86	(2)	15.72
Total Administrative Salary		$57.55		$62.18		$75.78		$ 87.64
Miscellaneous Budget		12.79		12.79		12.79		12.79
Total Fixed and Semi-Variable Operating Costs		$70.34		$74.97		$88.57		$100.43

1/ Average 1967 enforcement level = 56, final staff level 1967 = 64.
2/ Numbers in parentheses indicate number of administrative personnel in each capacity.

Figure 1-K-1 - Variable and Fixed Operating Costs of T.W.O.

APPENDIX 1, TAB L

AVERAGE LOSS PREVENTED FOR DETERRED OVERWEIGHT AND OVERSIZED VIOLATORS

Basic Information Sources

1. Table 1, Section III-B-10 of this Report.

2. Appendix 1, Tab A of this Report.

3. ISHC T.W.O.: "Summonses Issued by Traffic Officers, July 1, 1966 through June 30, 1967."

Method of Data Analysis

Item 1 indicates that overweight violators cause \$0.00809 worth of uncompensated wear per mile of travel. Item 2 indicates that violators travel on the average 108. miles. Hence overweight violators cause 0.00809(108.) = \$0.869 damage per trip in violation.

Item 3 indicates that oversize violators which cause no damage make up 20.5 percent of both oversize and overweight violators taken together.

Hence the weighted average damage for overweight and oversize violators is:

$$0.869(0.795) + 0(0.205) = \$0.690$$

Results of Analysis

Average loss for Iowa per trip of an overweight or oversized violator = \$0.690.

APPENDIX 1, TAB M

CALCULATIONS FOR UNCOMPENSATED COSTS ON SECONDARY ROADS

General

These calculations require the same types of information and computations as are required for the primary roads. The same road life and maintenance use relations are applied here. This Tab M presents the sources, logic and procedures used for the paved secondary roads.

Distribution of Road Types and Costs

A representative sample of secondary road pavements and the general characteristics of the pavements were supplied by Mr. Eugene Mills, ISHC, in telephone calls. General pavement characteristics are shown in Table 1-M-1.

The structural characteristics for the flexible pavements are assigned and calculated as shown in Table 1-M-2. The nearly equal types are combined with rounded structural numbers as will be shown in Table 1-M-3.

Pavement Costs

Guidance in pavement cost is obtained from "Secondary Structures Cost Assignment," Table 1 and 2. These tables refer to

Trunk Class Codes 1, 2, 3, 4, 5, and 6

Feeder Class Codes 1, 2, 3, and 4

Local Class Codes 1, 2, 3, and 4

The average cost for new pavement construction per two-lane mile varies from $37,000 to $42,000. The average for all four cost areas is $39,750. Using comparable primary road pavement costs a range of costs per lane mile is selected as $17,000 to $26,400, as will be shown in Table 1-M-3.

TABLE 1-M-1

SECONDARY ROAD PAVEMENT CHARACTERISTICS

Code	Type	Base + Surface	Surface
44	asphalt	less than 8 in.	road or plant mix $\geq$ 1.0 in.
46	"	"	plant mix asphalt $\geq$ 1.0 in.
47	"	"	plant mix asphalt $<$ 1.0 in.
48	"	"	inverted penetration $\geq$ 1.0 in.
54	"	greater than or equal to 8 in.	road or plant mix $\geq$ 1.0 in.
55	pcc	–	6 in. or 7 in. with no reinforcing or sub base
56	asphalt	greater than or equal to 8 in.	plant mix asphalt $\geq$ 1.0 in.
57	"	"	plant mix asphalt $<$ 1.0 in.
58	"	"	inverted penetration $\geq$ 1.0 in.

TABLE 1-M-2

ESTIMATED TYPICAL STRUCTURAL NUMBERS FOR PAVED, FLEXIBLE SECONDARY ROADS

Code No.	Structure	Coefficient	Contribution to Structural No.	Structural Number
44 & 46	2 in. asph. conc.	0.44	0.88	
	4 in. crushed stone	0.12	0.48	
	3 in. soil aggr.	0.05	0.15	1.51
47	½ in. asph. conc.	0.44	0.22	
	4 in. crushed stone	0.12	0.48	
	3 in. soil aggr.	0.05	0.15	0.85
48	1½ in. invert. pene.	0.20	0.30	
	4 in. crushed stone	0.12	0.48	
	3 in. soil aggr.	0.05	0.15	0.93
54	2½ in. asph. conc.	0.44	1.11	
	6 in. asph. tr. base II	0.23	1.38	
	4 in. soil aggr.	0.05	0.20	2.68
56	2½ in. asph. conc.	0.44	1.10	
	6 in. crushed stone	0.12	0.72	
	4 in. soil aggr.	0.05	0.20	2.02
57	½ in. asph. conc.	0.44	0.22	
	8 in. crushed stone	0.12	0.96	
	4 in. soil aggr.	0.05	0.20	1.38
58	1½ in. invert. pene.	0.20	0.30	
	7 in. crushed stone	0.12	0.84	
	4 in. soil aggr.	0.05	0.20	1.34

Table 7 in the above reference provides estimated annual maintenance costs per mile as follows for Trunk and Feeder secondary roads.

Surface Type	Cost per Mile ($)
1 paved	325
2 paved	660
3 dustless	790

On primary roads over one-half of surface maintenance costs go to pavement surface work. On secondary roads the fraction should be somewhat larger. Seventy-five percent is chosen so that pavement maintenance costs per lane mile year are taken as:

Pavement	Cost per Lane Mile Year
pcc	122
asphalt	247

Table 1-M-3 summarizes the secondary road pavements, extent and costs.

TABLE 1-M-3

PAVED SECONDARY ROAD PAVEMENTS AND COSTS

				Pavement Costs ($)	
Code No.	Thickness or Structural No.	Road Miles	Fraction of Miles	Construction Lane/mile	Maintenance Lane/(Mile Year)
47 & 48	SN = 1.0	678	0.0859	17,000	247
44,46,57, & 58	SN = 1.5	1,355	0.1716	18,000	247
56	SN = 2.0	4,480	0.5674	19,000	247
54	SN = 2.7	35	0.0044	20,000	247
55	T = 6 in.	677	0.0858	25,000	122
55	T = 7 in.	670	0.0849	26,400	122

With the pavement construction costs in Table 1-M-3 the average cost per lane mile is $19,800, in agreement with the data from secondary structures cost assignment.

Distribution of Axle Weights

The axle weight data for the primary roads are modified to account for the different vehicle mix which is observed on the secondary roads. Data from three sources are used to establish the distribution of vehicle types on paved secondary roads. The sources are:

1. "Creston Origin and Destination Traffic Report," Iowa, 1961 (Data from external station on FAS 807 South, for July average weekday traffic, Table 3-1)

2. "Buena Vista Country Paved Secondary Road Origin and Destination Traffic Study," August 1961. (From the table, Vehicle Classification, Traffic passing through Buena Vista County Interview Stations, 1961 August average weekday traffic).

3. Telephone conversations with Mr. Eugene Mills, ISHC (From a traffic survey with two stations in Polk County and one station in Stafford County. These were only counts over a 24-hour period.

Table 1-M-4 presents the data from these three sources. The commercial vehicle counts are extracted and compared with data from the primary system in Table 1-M-5. This latter table shows a substantial difference in the primary and secondary road traffic. On the primary system the single units constitute 48 percent of the total commercial; on the secondary system the single units constitute 91 percent of the total commercial. The distribution (from W-4 table) for primary roads is modified to the secondary distribution as shown in Table 1-M-6. The distribution by type is then used to develop weight factors for overweight vehicles on paved secondary roads as shown in Table 1-M-7. These weight factors are then applied to the overweight axle characteristics for highway systems 01 and 03. The results are presented in Table 1-M-8.

TABLE 1-M-4

VEHICLE TYPE DISTRIBUTION ON PAVED SECONDARY ROADS

	Source					
	1		2		3	
	No. Vehicles	% of Total	No. Vehicles	% of Total	No. Vehicles	% of Total
Passenger Cars			5,094	78.19	1,009	77.85
Panels & Pickups			690	10.59	176	13.58
Passenger Cars & Panels & Pickups	346	91.05	5,784	88.78	1,185	91.43
2 Axle - 4 Tire					22	1.70
2 Axle - 6 Tire					78	6.02
3 Axle					3	0.23
Total Single Unit Trucks	31	8.16	652	10.01	103	7.95
Buses			3	0.05		
4 Axle Semi					1	0.08
5 Axle Semi					2	0.15
Total Semi's	3	0.79	75	1.15	3	0.23
Double Bottoms					5	0.39
Total Multiple Unit Trucks	3	0.79	75	1.15	8	0.62
Total Commercial	34	8.95	730	11.21	111	8.56
Total	380	100.00	6,514	100.00	1,296	100.00

TABLE 1-M-5

COMPARISON OF TRUCK TYPES ON SECONDARY AND PRIMARY ROADS

	Source							
	1 (secondary)		2 (secondary)		3 (secondary)		4 (primary)*	
	No.	% of Commercial	No.	% of Commercial	No.	% of Commercial	No.	% of Commercial
Total single unit trucks and buses	31	91.18	655	89.73	103	92.79	4,086	48.09
Total semi's and multiple units	3	8.82	75	10.27	8	7.21	4,410	51.91
Total commercial	34	100.00	730	100.00	111	100.00	8,496	100.00

* Source No. 4 is the Table W-4: All Main Rural for 1966.

TABLE 1-M-6

DISTRIBUTION BY TYPE ON SECONDARY ROAD

Vehicle Type	Number in 1000 Truck Sample on Primary Road	Factor for Conversion to Secondary Road	Calculated Number in 1000 Truck Sample on Secondary Road
Panel & pickup	272	91/48	516
2 axle	154	"	292
3 axle	54	"	103
3 axle semi	31	9/52	5
4 axle semi	100	"	17
5 and 6 axle semi	364	"	63
Truck & trailer(s) & others	25	"	4

TABLE 1-M-7

DEVELOPMENT OF WEIGHT FACTORS FOR OVERWEIGHT VEHICLES ON PAVED SECONDARY ROADS

(1) Vehicle Types	(2) Calculated Number in 1000 Truck Sample on Paved Secondary Road	(3) Violations per Vehicle of Specified Type	(4), (2)·(3) Violations (Total) in Specified Type Per Thousand Trucks of All Types	(5) Overweight Violations Per Total Violations	(6) Weight Violating Vehicle Per Over-Weight Violation	(7),(2)·(3)·(5)·(6) Overweight Vehicle of Specified Type Per Thousand Trucks of All Types	(8),(7)/$\sum$(7) Weight Factor for Overweight Vehicles of Specified Types on Secondary Road
Panel & Pickup	516	0.00261	1.34676	0.0000 (by inference)*		0.0	0.0
2 axle	292	0.02380	6.9496	0.1210 (by inference)	1.0	0.84090	0.3967
3 axle	103	0.02385	2.45655	0.3143	1.0	0.77209	0.3643
3 axle semi	5	0.02666	0.13330		1.0	0.04190	0.0198
4 axle semi	17	0.02833	0.48161		0.6	0.09082	0.0428
5 and 6 axle semi	63	0.03000	1.89000		0.6	0.35642	0.1682
Truck + trailer(s) and others	4	0.02316	0.09264		0.6	0.01747	0.0082
						(7) = $\sum$ 2.1196	1.0000

* The inferred values are derived from W-4 data applied to the primary road vehicle distribution.

TABLE 1-M-8

CHARACTERISTICS OF OVERWEIGHT VEHICLES ON SECONDARY PAVED ROADS

Single Axles			Tandem Sets		
Legal Weight (Kips)	Amount Over Legal Weight (Kips)	Average Number of Axles Per Overweight Vehicle	Legal Weight (Kips)	Amount Over Legal Weight (Kips)	Average Number of Sets Per Overweight Vehicle
7.000	0.100	0.004100	29.000	0.400	0.064349
	0.300	0.002050		1.300	0.058952
	1.000	0.005125		2.200	0.013389
	1.200	0.002050		3.000	0.015071
13.500	0.500	0.121312		3.900	0.008472
14.000	0.200	0.030125		4.800	0.003732
	0.650	0.028459		6.500	0.003347
	1.100	0.006694	31.5	1.2	0.121312
	1.500	0.007535	32.0	0.500	0.028705
	1.950	0.001682		1.400	0.133180
	2.400	0.000841		2.400	0.006876
	3.200	0.001682		3.400	0.006726
18.000	0.300	0.072209		4.300	0.001682
	0.800	0.010223		4.600	0.040437
	0.900	0.396700		5.300	0.002555
	1.350	0.012018		6.300	0.005853
	2.400	0.002555		8.200	0.000841
	2.600	0.040437		10.000	0.000841
	3.000	0.000841			

APPENDIX 2

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APPENDIX 3

SAMPLE VIOLATION RECORDS AND CODING INSTRUCTIONS

This appendix contains a brief outline of the summons data coding format used by the ISHC to compile the violations tape for 1967. A page of sample violation records is included as Table 3-1. Each record represents 80 columns of data from an IBM card, divided as follows:

Item 1 Columns 1-5, Date summons was issued - day, month, and year.

Item 2 Columns 6-7, Code number of officer issuing summons.

Item 3 Columns 8-12, The last five digits of the summons number.

Item 4 Columns 13-32, Name of the owner of the vehicle in violation.

Item 5 Columns 32-34, Number of the county in which the violation was acted upon.

Item 6 Columns 35-44, Address of the owner of the vehicle.

Item 7 Column 45, Code number of the violating vehicle type.

Item 8 Columns 46-47, Code number of the scale at which violation was apprehended.

Item 9 Columns 48-49, Code number of county of origin for Iowa registered vehicles, or of state of origin for out of state registrations.

Item 10 Columns 50-54, License number of the violating vehicle.

Item 11 Columns 55-56, Code number of type of violation.

Item 12 Columns 57-66, Amount of fines assessed and fines paid.

Item 13 Columns 67-70, Amount of costs paid.

Item 14 Columns 71-77, License class required, and amount paid for license change.

Item 15 Columns 78-80, Type of completion and date of completion.

The computer program, Violation Tape Analysis, documented in Appendix 6, analyzed the data on the violation tape to produce information on the numbers and fractions of violations that were:

1. in state and out of state;

2. overweight and not overweight;

3. apprehended during the day versus apprehended during the night; and

4. the fraction of violators that received more than one summons.

It is recommended that an owner code be added to the record of each violator, so that a file of multiple violators can be maintained by the computer.

TABLE 3-1

SAMPLE VIOLATION RECORDS

```
087672747195AMER BUS           09LINCOLN    1C82000C762C01200012000400     173
207676649919AMER BUS LINES     78LINCOLN    12040BC435820100001000040O     173
077677346588AMER CHIEF VAN LINES75MEMPHIS   3114JT00348201000010000400     173
112666622221AMER COLEMAN       78LITTLETON  3060NTE7669201CC00100005C0     161
J4-676150357AMER COLLOID       78SCOTT BLF  3200NOTEMP300130013000400      174
03-666636716AMER CYANAMID      78JACKSON    3062LP73823CC10CC010000500     164
273678440558AMER CYANAMIC CO   75ALTON      21184012362003700037000400     472
03-6773552CCAMER CYANOMIC      11LCHRV      4  1K13872910300003000050O     174
18067C651541AMER EQUIP         77SX C       322YYA613550057520575204OO     174
034677343579AMER FARM LINE     11OKLA C     3183N0122782010000100C0400     172
056676247494AMER FARM LINES    78CKLA C     3063N02328820100001000050O     172
300673353505AMER FOOD          27K C        3  2M09756820100001000O4CC     174
235677148176AMER FOODS         17ST PAUL    2122K2476720008400084004O0     172
222673142414AMER FUEL & SUP    77MILWAUKEE  2094Q5E81C8201000010000400     171
130673353487AMER HOMES         77D M        323YYA0225301373C137300500     174
066671347438AMER HOMES INC     06C M        305YYA82892005780057800400     172
311672739846AMER LBR           C9MPLS       2082K2771682010000010000400    171
158668230C70AMER LSNG          94D M        3  77003488401C00010000400     163
J9-67535472CAMER MILLING       78RALSTON    321YYA26903001100011000400     174
254666225222AMER MVG & STG     65COL        2101&PE1158201000010000400     162
C23676442905AMER OIL           78CASPER     3064RT1411820100C010000500     171
179678451134AMER RED BALL TRS  75INDPLS     2112J3632C8301000010000400     173
031676624152AMER ROAD EQUIP    78OMAHA      20626162869100400004000500     171
317676649969AMER SHUFFLE BOARDS 78UNION C   3202RP978292014000140004O0     173
J3-671556C95AMER SYNTHETIC     16LOUISV     32810813785009251092510400     174
172678240870AMER T & T         08K C        2172M2354481C10000100004C0     171
C6-678253639AMER TEL & TEG     08K C        2172M69503870050000500050005007C0174
248666133137AMER TENT & CAN    65LA FOLL    3104K044PX5007179071790400     163
158666437991AMER TENT & CANVAS 78LAFOLLETTE3204J433PX8201CCC01C0C0400      164
153665825166AMER TK REN        78FT WORTH   3064K17893820100001000040O     161
236668630408AMER TRF & STG     17MLTN       212        8301C00010000400    162
198678156823AMER TRS           75CHI        3111L3691L8201C00010000400     174
093676641675AMER TRS LINES     78CHI        3201K676778201000010000400     171
076667728231AMER UNIFORM       75BENTON     3114JX02C282C05CC005000400     162
158671551010AMER VALVE         16INDPLS     2281L1327F8201000010000400     173
06267C6B5810AMERICAN OIL       77SCARSB     222790066786                   871
060666632950AMERICAN VAN LINES 78FT WAYNE   3061L9335L99C1000010000500     164
&8-673153817AMES & BASS        77MARCUS     323YYA46825002988029880400     174
017661827640AMES R D           22MC GREGOR 2  220C3CC86C0500000500040O     471
31167C641105AMF W TOOL INC     77C M        3  YYA00732016660166600500     171
195678246943AMMONS B R         85ROGERS     2140LC19768200500005000400     172
166665830040AMR TK LEASE       78FAIRF      30600M83648201000010000500     162
230671154373AMSDEN C D         06VINTON     2  0602941500368203882         174
266672447773AMUNELSON H        45CRESCO     2  960133510005000050004000501500373
048665832563AMWAY CORP         78ADA        3062J27621830150CC15000500     163
086672247094ANAMOSA CONC PROD  16ANAMOSA    4135300399100050000500040082007501720
08-665837399ANASTASI F         78HARLAN     20683017292000750007500500     164
118675449C77ANCHOR LSNG        97OMAHA      22620097C53C0230C023000400     173
264676642967ANCHOR MTR FRT     78WARREN     3202J324CN8201000010000400     172
225665628941ANCO MFG SUP       78TULSA      2063N4577782C1000010000500     162
301672739840ANDERSEN E H       38CDR FALLS 2  380187220027000270004O0     171
159671452339ANDERSON & MANDLE  16MILAN      3291KOP1343003885038850400     173
310678352716ANDERSON BROS      75AKRON      211750307986005000050004O0     174
236667825978ANDERSON C         71SUTHERLAND2  71002242001540015400400     363
039667730366ANDERSON C B       75WAGNER     311407115Y8101000010000400     163
091668218810ANDERSON C L       08GOWRIE     217940304610C05000050004000709500161
284666626297ANDERSON C TKG     78AMARILLO   3064K38214820100001000050O     162
128668335702ANDERSON CHEM      75LITCHF     3112KC763382010000100004O0     164
PAGE  6
```

APPENDIX 4

SAMPLING INSTRUCTIONS FOR OPERATIONAL RECORD SAMPLE

T.W.O. Cost/Effectiveness Data Collection

Sampling Instructions

1. Purpose of Sample: To compare the cost/effectiveness of current fixed scale and roving patrol T.W.O. work parties.

2. Frame or File to be Sampled: Calendar year 1967 file of Form 771 "Scale Station Record - Daily Report."

3. Information to be Recorded from Records: As on enclosed sample information sheets. There should be one sheet filled out for each party's 8-hour period of operation. (There may be several Form 771's covering one such period for busy parties.) Most of the information will come from the Form 771's, but it may be necessary to obtain some corresponding data from accounting or other records.

4. Size of the Sample: Approximately 5 percent (1 out of 19 operating periods for every party).

5. Method of Sampling: Systematic sample of every 19th work period with a new random starting point for each work party.

6. Details of Sampling Procedure:

   A. The records for each party are bound together in a few volumes. The procedure below is repeated for each work party.

   B. Pick a random starting point for the work party from the attached table of random numbers. (Cross off each random number as it is used and do not use any number more than once.)

   C. Count down to the starting point in the first volume for the work party. For example, the first random point is 03; therefore, the first party's starting point is 03, i.e., the first work period (not Form 771) to be sampled is the 3rd.

D. Record all data on the starting point work record (1 or more Form 771's) onto a sample data sheet.

E. Count down 19 more work periods and copy the data on that record. Count down 19 more, copy and so on until all records for the work party have been counted, e.g., the first party will be represented by the 3rd, 22nd, 41st, etc., records, yielding approximately a 5 percent sample for the calendar year 1967.

F. Repeat procedures B through F for all other work parties.

G. If the data on a record are unusable for any reason, simply reject the record, count down 19 more and continue. Keep two tallies on the number of such rejections, one for fixed sites and one for roving patrols.

H. As of now the only known reason for a large number of rejections would be due to unclosed cases which should not be included in the sample. If some other major reason for rejections appears, or if the rejection rate exceeds 10 percent, please advise MRI.

7. Also, if for any reason, you do not consider 1967 sufficiently representative of current methods of operation, please advise MRI.

TABLE OF RANDOM STARTING POINTS

03	17	13	12	09	03	04	05	17	05
19	15	04	18	12	11	17	19	18	11
05	10	11	16	06	15	10	16	01	12
02	14	07	08	01	08	18	02	09	10
09	02	06	07	14	02	13	06	08	16

NOTES: 1. Use in any order.
2. Cross off as used.
3. Do not use any number more than once.
4. Use as many as needed, extras are supplied.

Work Party No. 19 Scale No. ______

T.W.O. SAMPLE OF DAILY OPERATIONS REPORTS

1. Mode of Operation: A. Fixed Station (B.) Roving Patrol (Circle A or B)

2. A. Date 5-1-68

B. Hours of Operation 7AM to 3 PM

C. Inactive Periods: a. Lunch ______ to ______

b. Administrative ______ to ______

c. Other ______ to ______

3. A. Number of Personnel on Duty: a. Capt. ____ b. Sgt. 1 c. Officer 1

B. Number of Man-Hours Charged: a. Capt. ____ b. Sgt. 8 c. Officer 8

4. A. Number of Summons Issued 1 Later opp.

B. Fines Paid ______

C. Court Costs Paid ______

D. Registration Increases Paid to Iowa ______

5. Out-of-Pocket Expenses:

A. Mileage at 4-1/2¢ per mile 136

B. Subsistence 3.80

C. Public Scale Payment ______

D. Other ______

Comments (weather, etc.)

clear
road dry
Traffic subnormal

Sample Information Sheet, Operational Record Sample

APPENDIX 5

OPERATIONAL EXPERIMENT SAMPLE DATA SHEET

Background

Current weight scale traffic count records do not include recording traffic flow rate by time of the date, but only record total traffic by truck type for the entire day of operation.

The attached form was used to gather information on the rate of traffic flow so that an evaluation could be made of the daily manpower scheduling practices now used. The data were also used to analyze the possible "decay" in truck traffic following the opening of a scale. The data were processed by the computer program documented in Appendix 11. The results of the analysis are discussed in Section IIIB4 of the Report.

WEIGHT SCALE TRUCK TRAFFIC COUNT

Scale Location 10 Mile South of Tylon Scale Number 16 - 246 North Hour Period 8AM - 4PM Date 3-5-68

	8 0-15 min		16-30 min		31-45 min		9AM 46-60 min		19-10 2 hour		10-11 3 hour		11-12 4 hour		12-1 5 hour		1-2 6 hour		2-3 7 hour		3-4 8 hour		TOTAL	TOTAL
TRUCK TYPE	Count	Viol	Count	Viol	Count	Viol	Count	Viol	Count	Viol	Count	Viol	Count	Viol	Count	Viol	Count	Viol	Count	Viol	Count	Viol	Count	Viol
TRK	-	-	1	-	5	-	-	-	7	-	2	-	3	-	[illegible]	-	2	-	5	-	7	-	46	-
TK	2	-	2	-	3	-	2	-	6	-	7	-	6	-	7	1	4	1	3	-	2	-	44	2
TK 2	-	-	-	-	1	-	-	-	4	-	4	-	1	-	3	-	4	-	2	-	-	-	19	-
TT - ST	-	-	-	-	-	-	2	-	-	-	2	-	-	-	1	-	4	-	1	-	4	-	14	-
TT - ST 2	3	-	3	-	3	-	3	-	10	2	8	1	[illegible]	1	3	-	3	-	5	-	-	-	46	4
TT2 - ST2	4	-	10	-	6	-	6	-	17	3	20	1	28	1	25	1	33	-	15	-	6	1	170	7
TT2 - ST3	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-	1	-
TK - Pup	-	-	1	-	-	-	-	-	2	-	1	-	1	-	-	-	-	-	1	-	1	-	7	-
Double Bottoms	-	-	-	-	1	-	1	-	4	-	4	-	-	-	2	-	1	-	-	-	B	-	16	-
All Others	-	-	-	-	-	-	-	-	-	-	-	-	1	-	-	-	2	-	1	-	-	-	4	-
All Busses	1	-	-	-	-		-	-	1	-	-	-	-	-	-	-	-	-	-	-	2	-	4	-
																							371	13

TRK - Pickups, Campers, etc.

TK - 2 Axle Truck

TK2 - 3 Axle Truck

TT-ST - 2 Axle tractor 1 Axle Trailer

TT-ST2 - 2 Axle Tractor 2 Axle Trailer

TT2-ST2 - 3 Axle Tractor 2 Axle Trailer

TT2-ST3 - 3 Axle Tractor 3 Axle Trailer

TK - Pup - Tk and any Pup Trailer

APPENDIX 6

COMPUTER PROGRAM DOCUMENTATION: VIOLATION TAPE ANALYSIS

The program IOWA TAPE is written in COBOL and 360 Basic Assembly Language and is presented here. The program computes the numbers and fractions of violations that are: (1) in state and out of state; (2) overweight and not overweight; (3) apprehended during the day versus apprehended during the night, and (4) the fraction of violators that received more than one summons. Input to this program is the T.W.O. violation tape.

```
000010 IDENTIFICATION DIVISION.
000020 PROGRAM-ID. 'IOWATAPE'.
000040 ENVIRONMENT DIVISION.
000050 CONFIGURATION SECTION.
000060 SOURCE-COMPUTER.    IBM-360 F30.
000070 OBJECT-COMPUTER.    IBM-360 F30.
000080 INPUT-OUTPUT SECTION.
000090 FILE-CONTROL.
000100     SELECT INPUT-TAPE ASSIGN TO 'SYS001' UTILITY 2400 UNITS.
000110     SELECT PRINTER ASSIGN TO 'SYS002' UNIT-RECORD 1403 UNIT.
001010 DATA DIVISION.
001020 FILE SECTION.
001030 FD  INPUT-TAPE
001040                     RECORDING MODE IS F
001050                     BLOCK CONTAINS 20 RECORDS
001060                     RECORD CONTAINS 80 CHARACTERS
001070                     LABEL RECORDS ARE OMITTED
001080                     DATA RECORD IS INPUT-X.
002010 01  INPUT-X.
002020     03  DATE                      PICTURE X(5).
002030     03  DATE-X REDEFINES DATE.
002040         05  DAY                   PICTURE X.
002050         05  FILLER                PICTURE X(4).
002060     03  FILLER                    PICTURE X(40).
002070     03  VEHICLE                   PICTURE X(9).
002080     03  VEHICLE-X REDEFINES VEHICLE.
002090         05  FILLER                PICTURE X(2).
002100         05  STATE                 PICTURE XX.
002110         05  FILLER                PICTURE X(5).
```

PAGE 1

```
002120      03  VIOLATION                       PICTURE XX.
002130      03  FILLER                          PICTURE X(5).
002140      03  FINE                            PICTURE X(5).
002150      03  FILLER                          PICTURE X(6).
002160      03  COST                            PICTURE X(5).
002170      03  FILLER                          PICTURE X(3).
003010 FD  PRINTER
003020              RECORDING MODE IS F
003030              RECORD CONTAINS 133 CHARACTERS
003040              LABEL RECORDS ARE OMITTED
003050              DATA RECORD IS LINE.
003060 01  LINE.
003070      03  FILLER  PICTURE X.
003080      03  L       PICTURE X(132).
004010 WORKING-STORAGE SECTION.
004020 77  NIGHT-REV   PICTURE S9(13)V99   COMPUTATIONAL-3.
004030 77  DAY-REV     PICTURE S9(13)V99   COMPUTATIONAL-3       .
004040 77  BOTH        PICTURE S9(7)       COMPUTATIONAL-3 .
004050 77  WEIGHT      PICTURE S9(7)       COMPUTATIONAL-3    .
004060 77  OTHER       PICTURE S9(7)       COMPUTATIONAL-3      .
004070 77  NVIOL       PICTURE S9(7)       COMPUTATIONAL-3     .
004080 77  INSTATE     PICTURE S9(7)       COMPUTATIONAL-3      .
004090 77  OUTSTATE    PICTURE S9(7)       COMPUTATIONAL-3      .
004100 77  NIGHT-NO    PICTURE S9(7)       COMPUTATIONAL-3    .
004110 77  DAY-NO      PICTURE S9(7)       COMPUTATIONAL-3      .
004120 77  TOTAL-VIOL  PICTURE S9(7)       COMPUTATIONAL-3      .
004130 77  S1          PICTURE X.
004140 77  S2          PICTURE X.
004150 77  S3          PICTURE X.
```

PAGE 2

```
005010 01  RECORD-IDENTIFICATION.
005020     03 OLD-RECORD.
005030         05  FILLER  PICTURE X(14) VALUE 'XXXXXXXXXXXXXX'.
005040     03 NEW-RECORD.
005050         05 DATE-NEW PICTURE X(5).
005060         05 VEHICLE-NEW PICTURE X(9).
005070 01  DISTX-2 COMPUTATIONAL-3.
005080     03  DISTX PICTURE S9(7) OCCURS 100 TIMES.
006020 01  LINKAGE-DATA    .
006030     03 REVENUE-OUT       PICTURE S9(5)V99 COMPUTATIONAL-3.
006040     03 FINE-IN           PICTURE X(5).
006050     03 COST-IN           PICTURE X(5).
007010 01  DETAIL  .
007020     03 DESX-01                          PICTURE X(50).
007030     03 FILLER                           PICTURE X(5).
007040     03 DESX-02                          PICTURE Z(9)9.
007050     03 DESX-03 REDEFINES DESX-02        PICTURE Z(7).99.
007060     03 DESX-04 REDEFINES DESX-03        PICTURE Z(3)9.9(5).
007080 01  LINEX.
007090     03  FILLER  PICTURE X(5) .
007100     03  I       PICTURE ZZ9.
007110     03  FILLER  PICTURE X(5).
007120     03  J       PICTURE Z(7)9.
008010 PROCEDURE DIVISION.
008020     OPEN INPUT INPUT-TAPE, OUTPUT PRINTER.
008070     MOVE ALL ' ' TO LINE.
008030     MOVE 'X' TO S1.
008040     MOVE 'X' TO S2.
008060     MOVE 'X' TO S3.
```

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```
008050     MOVE ZERO TO NVIOL.
008080     MOVE ZERO TO BOTH.
008090     MOVE ZERO TO WEIGHT.
008100     MOVE ZERO TO OTHER.
008110     MOVE ZERO TO INSTATE.
008120     MOVE ZERO TO OUTSTATE.
008130     MOVE ZERO TO NIGHT-REV.
008140     MOVE ZERO TO DAY-REV.
008150     MOVE ZERO TO NIGHT-NO.
008160     MOVE ZERO TO DAY-NO.
008170     MOVE ZERO TO TOTAL-VIOL.
           PERFORM ZAP VARYING NVIOL FROM 1 BY 1 UNTIL NVIOL > 100.
           MOVE ZERO TO NVIOL.
           GO TO LOOP.
       ZAP.
           MOVE ZERO TO DISTX (NVIOL).
009010 LOOP.
           READ INPUT-TAPE AT END PERFORM BREAK-VIOLATION GO TO STOP.
009030     MOVE DATE TO DATE-NEW.
009040     MOVE VEHICLE TO VEHICLE-NEW.
009050     IF NEW-RECORD NOT = OLD-RECORD PERFORM BREAK-VIOLATION.
009060     ADD 1 TO NVIOL.
009070     IF STATE  )  '01'
009080                     MOVE 'O' TO S3
009090           ELSE      MOVE 'I' TO S3.
009100     IF VIOLATION = '20' OR VIOLATION = '30' OR VIOLATION = '40'
009110                           OR VIOLATION = '50'
009120                     ADD 1 TO WEIGHT
009130                     MOVE 'Y' TO S1
```

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               ELSE     ADD 1 TO OTHER
                        MOVE 'Y' TO S2.
       MOVE FINE TO FINE-IN.
       MOVE COST TO COST-IN.
       ENTER LINKAGE.
       CALL 'TOTALREV' USING LINKAGE-DATA.
       ENTER COBOL.
       IF DAY ) '0' ADD REVENUE-OUT TO NIGHT-REV ADD 1 TO NIGHT-NO
               ELSE ADD REVENUE-OUT TO DAY-REV ADD 1 TO DAY-NO.
       ADD 1 TO TOTAL-VIOL.
       GO TO LOOP.
 BREAK-VIOLATION.
       IF S3 = 'I' ADD 1 TO INSTATE.
       IF S3 = 'O' ADD 1 TO OUTSTATE.
       MOVE 'X' TO S3.
       IF S1 = 'Y' AND S2 = 'Y' ADD 1 TO BOTH.
       MOVE 'X' TO S1.
       MOVE 'X' TO S2.
       IF NVIOL > 100 MOVE 100 TO NVIOL.
       IF NVIOL > ZERO ADD 1 TO DISTX (NVIOL).
       MOVE ZERO TO NVIOL.
       MOVE NEW-RECORD TO OLD-RECORD.
 STOP.
       MOVE ALL ' ' TO DETAIL.
       MOVE 'TOTAL NUMBER OF VIOLATIONS' TO DESX-01.
       MOVE TOTAL-VIOL TO DESX-02.
       MOVE DETAIL TO L.
       WRITE LINE AFTER 0.
       MOVE 'NUMBER OF INSTATE VIOLATORS' TO DESX-01.
```

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```
012080    MOVE INSTATE TO DESX-02.
012090    MOVE DETAIL TO L.
012100    WRITE LINE AFTER 2.
012110    MOVE 'FRACTION OF INSTATE VIOLATORS' TO DESX-01.
012120    ADD INSTATE, OUTSTATE GIVING NVIOL.
012130    DIVIDE NVIOL INTO INSTATE GIVING DESX-04.
012140    MOVE DETAIL TO L.
012150    WRITE LINE AFTER 1.
012160    MOVE 'NUMBER OF OUT STATE VIOLATORS' TO DESX-01.
012170    MOVE OUTSTATE TO DESX-02.
012180    MOVE DETAIL TO L.
012190    WRITE LINE AFTER 1.
013010    DIVIDE NVIOL INTO OUTSTATE GIVING DESX-04.
013020    MOVE 'FRACTION OF OUT STATE VIOLATORS' TO DESX-01.
013030    MOVE DETAIL TO L.
013040    WRITE LINE AFTER 1.
013050    MOVE 'TOTAL NUMBER OF VIOLATORS' TO DESX-01.
013060    MOVE NVIOL TO DESX-02.
013070    MOVE DETAIL TO L.
013080    WRITE LINE AFTER 1.
013090    MOVE 'TOTAL NUMBER OF VIOLATIONS' TO DESX-01.
013100    MOVE TOTAL-VIOL TO DESX-02.
013110    MOVE DETAIL TO L.
013120    WRITE LINE AFTER 3.
013130    MOVE 'TOTAL NUMBER OVERWEIGHT VIOLATIONS'TO DESX-01.
013140    MOVE WEIGHT TO DESX-02.
013150    MOVE DETAIL TO L.
013160    WRITE LINE AFTER 1.
013170    MOVE 'TOTAL NUMBER NON-OVERWEIGHT VIOLATIONS' TO DESX-01.
```

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```
013180    MOVE OTHER TO DESX-02.
013190    MOVE DETAIL TO L.
013200    WRITE LINE AFTER 1.
014010    MOVE 'NUMBER OF VIOLATORS COMMITTING BOTH' TO DESX-01.
014020    MOVE BOTH TO DESX-02.
014030    MOVE DETAIL TO L.
014040    WRITE LINE AFTER 1
014050    SUBTRACT BOTH FROM NVIOL GIVING DESX-02.
          MOVE 'NUMBER OF VIOLATORS COMMITTING ONE TYPE' TO DESX-01.
014070    MOVE DETAIL TO L.
014080    WRITE LINE AFTER 1.
014090    MOVE 'NUMBER OF DAY VIOLATIONS' TO DESX-01.
014100    MOVE DAY-NO TO DESX-02.
014110    MOVE DETAIL TO L.
014120    WRITE LINE AFTER 3.
014130    MOVE 'NUMBER OF NIGHT VIOLATIONS' TO DESX-01.
014140    MOVE NIGHT-NO TO DESX-02.
014150    MOVE DETAIL TO L.
014160    WRITE LINE AFTER 1.
014170    MOVE 'AVERAGE DAY REVENUE ' TO DESX-01.
014180    DIVIDE DAY-NO INTO DAY-REV GIVING DESX-03
014190    MOVE DETAIL TO L.
014200    WRITE LINE AFTER 1.
015010    MOVE 'AVERAGE NIGHT REVENGE' TO DESX-01.
015020    DIVIDE NIGHT-NO INTO NIGHT-REV GIVING DESX-03.
          MOVE DETAIL TO L.
          WRITE LINE AFTER 1.
015030    MOVE 'NO OF TICKETS, NO. OF OCCURANCES' TO L.
015040    WRITE LINE AFTER 0.
```

```
015050      PERFORM DUMP VARYING NVIOL FROM 1 BY 1 UNTIL NVIOL > 100.
015060      CLOSE INPUT-TAPE, PRINTER.
015070      STOP RUN.
015090 DUMP.
015100      MOVE ALL ' ' TO LINEX.
015110      MOVE NVIOL TO I.
015120      MOVE DISTX (NVIOL) TO J.
015130      MOVE LINEX TO L.
015140      WRITE LINE AFTER 1.


// EXEC ASSEMBLY
TOTALREV START 0
         USING *,15
         STM   14,12,12(13)    SAVE GENERAL REGISTERS
         L     2,0(1)          LOAD ADDRESS OF LINKAGE DATA
         MVC   FININ(5),4(2)   BRING IN THE AMOUNT OF THE FINE
         MVC   FINOT(5),9(2)   BRING IN THE AMOUNT OF LICENSE INCREACE
         MVC   BYTE(1),FININ   MOVE 1ST BYTE INTO WORK AREA
         NI    BYTE,X'F0'      AND OUT THE ZONE
         CLI   BYTE,X'D0'      11 OVER PUNCH = FINE PAID BY JAIL
         BE    ZEROFINE
         CLI   BYTE,X'60'      11 PUNCH ONLY = FINE PAID BY JAIL
         BE    ZEROFINE
         CLI   BYTE,X'F0'      CHECK FOR NUMBER = FINE PAID
         BE    FINEPAID
         CLI   BYTE,X'40'      CHECK FOR BLANK = FINE PAID,
         BNE   ZEROFINE             ELSE FINE DISMISSED
FINEPAID CLC   FININ(5),=C'     '
```

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```
         BE    ZEROFINE        IF THE FIELD = BLANK, NO FINE
         MVC   BYTE(1),FININ+4
         NI    BYTE,X'F0'      RECOVER ZONE OF LAST DIGIT
         CLI   BYTE,X'F0'      F ZONE = 0 ) FINE ) 999.99
         BE    FINEZERO
         CLI   BYTE,X'40'      BLANK = F ZONE
         BE    FINEZERO
         CLI   BYTE,X'D0'      11 PUNCH = 1000.00 ) FINE ) 1999.99
         BE    FINE1000
         CLI   BYTE,X'60'
         BE    FINE1000
         CLI   BYTE,X'C0'      12 PUNCH = 2000.00 ) FINE ) 2999.99
         BE    FINE2000
         CLI   BYTE,X'50'
         BE    FINE2000
         CLI   BYTE,X'E0'      0  PUNCH = 3000.00 ) FINE ) 3999.99
         BE    FINE3000
         CLI   BYTE,X'61'
         BE    FINE3000
ZEROFINE ZAP   TOTAL,=P'0'     ZERO THE TOTAL
         B     CHCKCOST
FINEZERO ZAP   TOTAL,=P'0'
         B     ADDFINE
FINE1000 ZAP   TOTAL,=P'100000'
         B     ADDFINE
FINE2000 ZAP   TOTAL,=P'200000'
         B     ADDFINE
FINE3000 ZAP   TOTAL,=P'300000'
ADDFINE  MVZ   FININ(5),=X'C0C0C0C0C0'  SET ALL ZONES TO C
```

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```
         LA    3,5
         LA    4,FININ+4          CHECK FOR NUMERIC FIELD,
FINELOOP CLI   0(4),X'C0'               IF NOT NUMERIC, SET FINE = ZERO
         BL    ZEROFINE
         CLI   0(4),X'C9'
         BH    ZEROFINE
         BCTR  4,0
         BCT   3,FINELOOP
         PACK  WORK,FININ
         AP    TOTAL,WORK
CHCKCOST CLC   FINOT,=C'
         BE    RETURN
         MVC   BYTE(1),FINOT+4
         NI    BYTE,X'F0'
         CLI   BYTE,X'F0'
         BE    COSTZERO
         CLI   BYTE,X'40'
         BE    COSTZERO
         CLI   BYTE,X'D0'
         BE    COST1000
         CLI   BYTE,X'60'
         BE    COST1000
         CLI   BYTE,X'C0'
         BE    COST2000
         CLI   BYTE,X'50'
         BE    COST2000
         B     RETURN
COSTZERO ZAP   AREA,=P'0'
         B     ADDCOST
```

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```
COST1000 ZAP    AREA,=P'100000'
         B      ADDCOST
COST2000 ZAP    AREA,=P'200000'
ADDCOST  MVZ    FINOT(5),=X'C0C0C0C0C0'
         LA     3,5
         LA     4,FINOT+4
COSTLOOP CLI    0(4),X'C0'
         BL     RETURN
         CLI    0(4),X'C9'
         BH     RETURN
         BCTR   4,0
         BCT    3,COSTLOOP
         PACK   WORK,FINOT
         AP     TOTAL,WORK
         AP     TOTAL,AREA
RETURN   MVC    0(4,2),TOTAL
         LM     14,12,12(13)
         BR     14
         SPACE
FININ    DS     CL5
FINOT    DS     CL5
BYTE     DS     CL1
TOTAL    DS     CL4
WORK     DS     CL4
AREA     DS     CL4
         END
```

END OF DATA

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APPENDIX 7

COMPUTER PROGRAM DOCUMENTATION: FRACTION VIOLATING VS. TIME ANALYSES

This program, written in FORTRAN IV, provides a distribution of truck traffic, summonses issued, and fraction of traffic in violation with respect to time of day and as a decay function from the time a station is opened. The output is normalized to truck traffic per operation hour, summonses issued per operations hour, and fraction of truck traffic in violation per operations hour. Input to this program is a tape with data that come from Weight Scale Traffic Count. An example of a data sheet is shown in Appendix 5.

```
C JOB TITLE TRAFFIC DECAY AND TIME OF DAY MODEL
C
C
C THIS PROGRAM PROVIDES DATA FOR ANALYZING TRAFFIC, SUMMONSES ISSUED,
C AND FRACTION OF TRAFFIC IN VIOLATION. THE DATA IS PRESENTED WITH RESPECT
C TO TIME OF DAY AND AS A DECAY FUNCTION FROM TIME A STATION IS OPENED.
C THE OUTPUT IS NORMALIZED TO TRAFFIC PER OPERATING HOUR, SUMMONSES ISSUED
C PER OPERATING HOUR, AND FRACTION OF TRAFFIC IN VIOLATION PER OPERATING HOUR
C
C INPUT TO THIS PROGRAM IS A TAPE OF WEIGHT SCALE TRAFFIC COUNT
C
C     INPUT-DATA
C     SC = SCALE NUMBER                                       COL  1- 8
C     IHOUR = MILITARY TIME OF OPENING                        COL  9-10
C     IDUR  = HOURS STATION IS OPEN NOT GREATER THAN 8       COL 11-12
C     IPARTY= NUMBER OF CREW PARTY OPERATING SCALE           COL 13-14
C     DATE  = DATE OF OBSERVATION                             COL 15-18
C     ICHECK = LAST DATA CARD
C
C     A(I,J) = TRAFFIC COUNT I TRUCK TYPE J TIME CELL
C     B(I,J) = SUMMONSES ISSUED I TRUCK TYPE J TIME CELL
C VARIABLE DEFINITIONS
C ASUM(J) = TOTAL TRAFFIC J TIME CELL
C BSUM(J) = TOTAL SUMMONSES ISSUED J TIME CELL
C
C TIME OF DAY MODEL
C ITIME = MILITARY TIME OF DAY
C TRAF1(ITIME) = TOTAL TRAFFIC FOR ITIME
C VLT1(ITIME)  = TOTAL SUMMONSES ISSUED FOR ITIME
PAGE  1
```

```
C ISAMP(ITIME) = TOTAL OPERATING HOURS ITIME
C
C DECAY MODEL
C TRAF2(J) = TOTAL TRAFFIC J HOUR FROM OPENING
C VLT2      = TOTAL SUMMONSES ISSUED FOR J HOUR FROM OPENING
C ISAMP2(J) = TOTAL OPERATING HOURS FOR J HOUR FROM OPENING
C
C
      DIMENSION TRAF1(24), TRAF2(11), VLT1(24), VLT2(11), ISAMP(24),
     1ASUM(11), BSUM(11), A(11,11), B(11,11)
      DIMENSION SC(2)
      DIMENSION ISAMP2(11)
C
      DO 10 J = 1,24
      ISTOP = 0
      TRAF1(J) = 0.0
      ISAMP(J) = 0
   10 VLT1(J) = 0.0
      DO 15 J = 1,11
      TRAF2(J) = 0.
      ISAMP2(J) = 0
   15 VLT2(J) = 0.0
   20 READ(12) SC,IHOUR,IDUR,IPARTY,DATE,ICHECK
      IF (ICHECK) 25,25,500
   25 READ(12) ((A(I,J),B(I,J),J=1,11),I=1,11)
      TRFFC = 0.
      VLTNS = 0.
      IX = IDUR + 3
      IF (11-IX) 70,80,80
```

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```
   70 IX=11
      WRITE(3,770) SC
   80 CONTINUE
C CALCULATE TRAFFIC, SUMMONSES ISSUED,AND OPERATING HOURS FOR DECAY-MODEL
      DO 30  J = 1,IX
      ASUM(J) = 0.0
      BSUM(J) = 0.
      ISAMP2(J) = ISAMP2(J) + 1
      DO 30 I = 1,11
      ASUM(J) = ASUM(J) + A(I,J)
      BSUM(J) = BSUM(J) + B(I,J)
      TRFFC = TRFFC + A(I,J)
      VLTNS = VLTNS + B(I,J)
      TRAF2(J) = TRAF2(J) + A(I,J)
   30 VLT2(J) = VLT2(J) + B(I,J)
      ITIME = IHOUR + 1
C CALCULATE TRAFFIC, SUMMONSES ISSUED, AND OPERATING HOURS FOR TIME-OF-DAY-MODEL
      ISAMP(ITIME) = ISAMP(ITIME) + 1
      DO 40 J = 1,4
      TRAF1(ITIME) = TRAF1(ITIME) + ASUM(J)
   40 VLT1(ITIME) = VLT1(ITIME) + BSUM(J)
      DO 50 J=5,IX
      ITIME = ITIME + 1
      IF(24-ITIME) 41,42,42
 41   ITIME=1
   42 TRAF1(ITIME) = TRAF1(ITIME) + ASUM(J)
      VLT1(ITIME) = VLT1(ITIME) + BSUM(J)
   50 ISAMP(ITIME) = ISAMP(ITIME) + 1
C WRITE EXCEPTION STATEMENT IF MORE THAN 5 SUMMONSES ARE ISSUED
PAGE  3
```

```
C WITHIN ANY DATA CELL
      TRADG = VLTNS/TRFFC
      WRITE (3,750) SC,IHOUR,IDUR,IPARTY, DATE, TRADG
      DO 60 J=1,11
      DO 60 I=1,11
      IF (B(I,J)-5) 60,60,66
   66 WRITE(3,761) ((A(I,J),B(I,J),K=1,11))
   60 CONTINUE
      ISTOP = ISTOP + 1
      IF(ISTOP - 183)20,500,500
C PERFORM SUMMARY CALCULATIONS AND WRITE ROUTINE FOR TIME-OF-DAY-MODEL
  500 WRITE(3,730)
      DO 510 I=1,24
      IF (VLT1(I)) 502,503,502
  502 VIOL = VLT1(I)/TRAF1(I)
      GO TO 505
  503 VIOL = 0.
  505 TRAFN1 = TRAF1(I)/ISAMP(I)
      VIOLN1 = VLT1(I)/ISAMP(I)
  510 WRITE(3,735) I, TRAFN1,VIOLN1, VIOL,ISAMP(I)
  520 WRITE(3,740)
C PERFORM SUMMARY CALCULATICNS AND WRITE ROUTINE FOR DECAY-MODEL
      DO 530 I=1,11
      IF (VLT2(I)) 522,523,522
  522 VIOL2 = VLT2(I)/TRAF2(I)
      GO TO 525
  523 VIOL2 = 0.
  525 TRAFN2 = TRAF2(I)/ISAMP2(I)
      VIOLN2 = VLT2(I)/ISAMP2(I)
PAGE   4
```

```
 530 WRITE(3,745) I, TRAFN2,VIOLN2,VIOL2
     CALL EXIT
 700 FORMAT(22F3.0)
701  FORMAT(2A4,3I2,A4,I1)
 730 FORMAT(1H1,T31,'NORMALIZED TIME OF DAY MODEL '///,1H ,T10,'TIME',
    1T22,'TRAFFIC',T43,'VIOLATIONS',T58,'% VIOLATIONS',T83,'SAMPLE'/)
 735 FORMAT(1H ,T11,I2,T22,F10.2,T40,F10.3,T60,F8.4,T80,I5)
 740 FORMAT(1H1,T35,'NORMALIZED DECAY MODEL'///,1H ,T10,'TIME',T20,'TRA
    1FFIC',T43,'VIOLATIONS',T58,'% VIOLATIONS'/)
 745 FORMAT(1H ,T11,I2,T22,F10.2,T40,F10.3,T60,F8.4)
 750 FORMAT(1H0,2A4,3I5,A4,F10.4/)
 761 FORMAT(1H ,22F5.0)
 770 FORMAT(1H ,'DURATION ERROR ',2A4/)
     END
END OF DATA
```

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NORMALIZED TIME OF DAY MODEL

TIME	TRAFFIC	VIOLATIONS	% VIOLATIONS	SAMPLE
1	25.24	0.471	0.0186	34
2	18.91	0.625	0.0331	32
3	18.78	0.889	0.0473	27
4	18.50	0.464	0.0251	28
5	20.23	0.767	0.0379	30
6	25.08	0.632	0.0252	38
7	30.62	0.851	0.0278	47
8	36.91	0.631	0.0171	65
9	42.53	0.714	0.0168	77
10	42.85	1.024	0.0239	85
11	42.85	0.929	0.0217	98
12	38.64	0.790	0.0204	100
13	39.07	0.721	0.0185	104
14	38.66	0.680	0.0176	97
15	39.65	0.710	0.0179	100
16	39.46	0.869	0.0220	84
17	42.32	0.631	0.0149	65
18	36.92	0.600	0.0163	60
19	35.13	0.538	0.0153	52
20	29.43	0.792	0.0269	53
21	30.15	0.348	0.0115	46
22	28.16	0.419	0.0149	43
23	26.26	0.677	0.0258	31
24	23.69	0.538	0.0227	26

NORMALIZED DECAY MODEL

TIME	TRAFFIC	VIOLATIONS	% VIOLATIONS
1	10.78	0.208	0.0193
2	9.37	0.197	0.0210
3	9.96	0.180	0.0181
4	10.67	0.191	0.0179
5	36.49	0.858	0.0235
6	35.76	0.841	0.0235
7	34.30	0.639	0.0186
8	35.28	0.774	0.0219
9	35.25	0.811	0.0230
10	35.06	0.494	0.0141
11	29.80	0.488	0.0164

APPENDIX 8

COMPUTER PROGRAM DOCUMENTATION: COST/BENEFIT ANALYSES

The program, Cost/Benefit Analysis, written in FORTRAN IV is presented here. The program determines the net contribution (benefit less cost), the fraction of trips in violation, and the probability of apprehension for a range of enforcement levels. The program uses as input a card deck that describes the initial operating characteristics of the system. These include: (1) traffic level; (2) initial probability of apprehension; (3) operating cost data; (4) allocation of manpower to fixed site operation, roving patrol, and other activity; and (5) fraction of violators that are overweight, fraction of violators under-registered, and their associated damage costs.1/

1/ The program in its present form applies only when the apprehension effectiveness is manpower limited as discussed in the Apprehension Submodel, Section III-A-4, of this report.

```
C     THIS PROGRAM IS A COST - BENEFIT MODEL FOR THE IOWA TRAFFIC WEIGHT
C     OPERATIONS STUDY. THE PURPOSE OF THIS MODEL IS TO DETERMINE
C     THE NET CONTRIBUTION (REVENUE LESS COST) AND LEVEL OF COMPLIANCE
C     TO THE LAW FOR A RANGE OF STAFF SIZE.
C     TRAFFC - ANNUAL TRUCK TRIPS
C     NACT - NUMBER OF ACTIVITIES (FIXED, ROVING, OTHER)
C     VCOST - VARIABLE OPERATIONS COST PER
C      VCOST - VARIABLE OPERATIONS COST PER MAN
C     VIOLN - INITIAL PROBABILITY OF APPREHENSION
C     STAFFP(I) - ALLOCATION OF MANPOWER TO EACH ACTIVITY
C     FINE(I) - AVERAGE REVENUE PER SUMMONS FOR EACH ACTIVITY
C     STAFFI(I) - INITIAL MANPOWER FOR ITH ACTIVITY
C     PAPPI(I) - INITIAL PROBABILITY OF APPREHENSION FOR ITH ACTIVITY
C     VIOL(I) - FRACTION TRUCK TRAFFIC IN VIOLATION AS FUNCTION OF PAPP(I).
C     VIOLF(J) - FRACTION OF VIOLATORS WITH JTH TYPE VIOLATION
C     DAMAGE(J) - LOSS OR REVENUE PER VIOLATOR WITH JTH TYPE VIOLATION
C     VIOL(I)-FRACTION TRUCK TRAFFIC IN VIOLATION AS FUNCTION OF PAPP(I)
C     PAPPO - INITIAL PROBABILITY APPREHENSION
C     NSITES - NUMBER OF SITES
      DIMENSION STAFFP(10) , FINE(10), XLNGTH(10), XMILES(10),ICREW(10),
     X  APPR(10), FVIOL(10), VIOLFY(10), DAMAGE(10),
     X STAFFI(10), PAPPI(10),ISTAFF(10),FIXEDC(10)
      DIMENSION VIOL(50)
      DIMENSION STAFFS(10), PAPP(10)
      INTEGER STAFFN
      PAPP(2) = 0.
      FINE(2) = 0.
      STAFFP(2) = 0.
      READ(1,704) IPASS
PAGE  1
```

```
      DO 2020 ITIMES = 1,IPASS
   10 READ(1,700) TRAFFC, PAPPO, NSITES, NACT, VCOST,VIOLN
   20 READ(1,701) (STAFFP(I), FINE(I), STAFFI(I), PAPPI(I), I =1,NACT)
   22 READ(1,705) (VIOLFY(I), DAMAGE(I), I = 1,2)
   24 READ(1,706) (ISTAFF(K), FIXEDC(K), K = 1, 5)
      OTHER = 1.0 - STAFFP(1) - STAFFP(2)
      VIOL(1) = 1.00
      DETK =-ALOG((VIOLN - 0.02)/0.98)/PAPPO
      DO 2020 IYEAR = 1, 1
      KYEAR = IYEAR - 1
      WRITE(3,802) TRAFFC,VIOLN,PAPPO,STAFFP(1),STAFFP(2), OTHER
      WRITE(3,800)
C     INCREASE LEVEL OF ENFORCEMENT STAFFN
      DO 2000 STAFFN = 15,400,5
      PAPPT = 0.0
      SBENFT= 0.0
      BENFT1 = 0.
      BENFT2 = 0.
      DEPK = 0.
      IF (STAFFN - 205) 901,900,901
  900 WRITE(3,802) TRAFFC,VIOLN,PAPPO,STAFFP(1),STAFFP(2), OTHER
      WRITE(3,800)
  901 CONTINUE
C     COMPUTE PROBABILITY OF APPREHENDING A VIOLATOR PAPP(I) FOR I ACTIVITY
      DO 1210 I = 1, NACT
      PAPPZ = PAPPI(I)
      APPK(I) = -(ALOG(1.0 - PAPPZ))/STAFFI(I)
      STAFFS(I) = STAFFP(I) * FLOAT(STAFFN)
 1210 PAPP(I) = 1.0 - EXP(-APPK(I) * STAFFS(I))
```

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```
C
C     COMPUTE FRACTION OF TRAFFIC IN VIOLATION AS FUNCTION OF PAPP(I).
      DO 1310 I = 1, NACT
 1310 PAPPT = PAPPT + PAPP(I)
      VIOLN = 0.02 + 0.98 * EXP(-DETK * PAPPT)
C
C     COMPUTE TOTAL OPERATING COST AS FUNCTION OF STAFF LEVEL.
C     FIXED COST BFIXED DETERMINED FROM TABLE LOOK UP.
C     VARIABLE COST VCOST IS VARCOST * STAFF LEVEL
      DO 1420 K = 1, 5
      IF (STAFFN -ISTAFF(K)) 1410,1410,1420
 1410 SFIXED = FIXEDC(K)
      GO TO 1430
 1420 CONTINUE
 1430 COST = VCOST * FLOAT(STAFFN) + SFIXED + DEPR
C
C     COMPUTE TOTAL SYSTEM BENEFITS
C
C     BENFT1  REVENUE FROM FINES FOR I ACTIVITY.
C     BENFT2  REVENUE FROM INCREASED REGISTRATION AND PREVENTED ROAD DAMAGE
      DO 1610 I = 1, NACT
 1610 BENFT1 = BENFT1 + TRAFFC * VIOLN * PAPP(I) * FINE(I)
      DO 1620 J = 1,2
 1620 BENFT2 = BENFT2 + TRAFFC*DAMAGE(J)*(VIOL(1) - VIOLN)*VIOLFY(J)
      SBENFT = BENFT1 + BENFT2
C     COMPUTE PROFIT
      PROFIT = SBENFT - COST
C
      SBENFT = SBENFT/1000.
```
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```
      COST   = COST/1000.
      PROFIT = PROFIT/1000.
      FIXED = TRAFFC * VIOLN * PAPP(1) * FINE(1)/1000.
      ROVING = TRAFFC * VIOLN * PAPP(2) * FINE(2)/1000.
      DMAGE = TRAFFC * DAMAGE(1) * (VIOL(1) - VIOLN) * VIOLFY(1)/1000.
      RGTRE = TRAFFC * DAMAGE(2) * (VIOL(1) - VIOLN) * VIOLFY(2)/1000.
      WRITE(3,801) STAFFN, PROFIT,RGTRE, FIXED, ROVING, DMAGE,SBENFT,
     X COST, PAPPT, VIOLN
 2000 CONTINUE
 2020 CONTINUE
      CALL EXIT
  700 FORMAT(E10.0,F10.0,I10,I10,E10.0,F6.3)
  701 FORMAT(4F10.0)
  702 FORMAT(11F7.0)
  704 FORMAT(I2)
  705 FORMAT(4F10.0)
  706 FORMAT(5(I8,F8.0))
  800 FORMAT(1H ,'STAFF',T17,'NET',T29,'REVENUE',T46,'REVENUE',T60,
     X'REVENUE',T76,'REVENUE',T96,'TOTAL',T109,'OPERATING',T122,
     X'P        V'/,1H ,T15,'REVENUE',T27,'REGISTRATION',T44,
     X'FIXED SITES',T58,'ROVING PATROL',T74,'DAMAGE PREVEN.',T95,
     X'REVENUE',T111,'COST'//)
  801 FORMAT (1H ,I4,T15,F7.0,T29,F7.0,T45,F7.0,T60,F7.0,T75,F7.0,T95,
     X F7.0,T111,F7.0,T120,F5.4,T129,F5.4)
  802 FORMAT(1H1,T50,'SYSTEM INPUT DATA'/,1H ,T30,'TRAFFIC ',F10.0,
     XT50,'FRACTION VIOLATING ',F5.3,T77,'PROBABILITY OF APPREHENSION',
     X F5.3/,1H ,T30,'ALLOCATION OF MANPOWER: FIXED ',F5.3,', ROVING '
     X,F5.3, ', OTHER 'F5.3//)
      END
```

APPENDIX 9

COMPUTER PROGRAM DOCUMENTATION: UNCOMPENSATED ROAD MAINTENANCE USE PER VIOLATING VEHICLE

Two programs, written in FORTRAN, are presented here, FLEXM, and RIGDM. Both programs calculate average uncompensated maintenance use per violating vehicle. The equations used are presented in Appendix 1, Tab I. The computation results are given in average equivalent reference axles per violating vehicle. FLEXM is used for flexible pavements, RIGDM is used for rigid pavements.

Both of these programs (and the programs for life use in the next appendix) use as part of input the axle characteristics of violating vehicles. The programs accept any number of these characteristics up to and including 100. Each card in the axle deck contains

NAXE, LØK, LØVER, AXLES

Format I1, 9X, 3F10.0

Where NAXE = 1 for single axle, = 2 for tandem set

LØK = Legal axle load (Kips)

LØVER = Amount axle load is over legal value (Kips)

AXLES = Average number of axles with these characteristics per violating vehicle

Input for FLEXM

The axle defining deck as described above followed by a card with 3 in position 1.

Output from FLEXM

The contribution from each axle in the deck is printed separately. This output appears in six columns.

Column No.	Value Printed
1	Axle type, 1 = single, 2 = tandem set
2	Axle legal weight (Kips)
3	Amount over legal weight (Kips)
4	Number of reference axles equivalent to legal weight
5	(Number of reference axles equivalent to actual weight) - (number equivalent to legal weight)
6	Contribution to average uncompensated maintenance per violating vehicle in reference axles

Column 6 is summed and printed as the average uncompensated maintenance per violating vehicle in the units reference axles.

The program listing follows:

```
C       FLEXM PROGRAM, MRI PROJECT 3158-P
        REAL LOK,LOVER
        CTAN=.5**2.947
        SUMUN=0.0
        WRITE(3,101)
  101 FORMAT('1','UNCOMPENSATED MAINTENANCE, FLEXIBLE PAVEMENT' ,/)
  201 READ(1,102)NAXE,LOK,LOVER,AXLES
  102 FORMAT(I1,9X,3F10.0)
        GO TO (1,2,3),NAXE
    3 WRITE(3,103) SUMUN
  103 FORMAT(1H0,44HAVE UNCOMPENSATED REF AXLES PER WT VIOL VEH=,E12.5)
        CALL EXIT
    1 C=1.0
        AXE=1.0
        GO TO 4
    2 C=CTAN
        AXE=2.0
    4 ROK=C*((LOK+AXE)/19.0)**3.136
        ROVER=C*((LOK+LOVER+AXE)/19.0)**3.136
        RUN=ROVER-ROK
        RAXUN=RUN*AXLES
        SUMUN=SUMUN+RAXUN
        WRITE(3,104)NAXE,LOK,LOVER,ROK,RUN,RAXUN
  104 FORMAT(1H ,I1,5X,2F12.3,3(5X,E12.5))
        GO TO 201
        END
```

PAGE 1

Input for RIGDM

NTYPE (format I1) (1 for unreinforced pcc, 2 for reinforced)

Axle deck (as defined previously)

Card with 3 in position 1.

Output from RIGDM

The contribution from each axle in the deck is printed separately. This output appears in six columns.

Column No.	Value Printed
1	Type of axle (1 = single, 2 = tandem set)
2	Legal weight for axle (Kips)
3	Amount over legal weight (Kips)
4	For single axle: the equivalent number of reference axles for legal weight For tandem sets: (equivalent reference axles). $D_2^{1.49}$ where D_2 is the as yet unspecified pavement thickness
5	For single axles: (reference axles for actual weight) - (axles for legal weight) For tandem sets: (reference axles for actual weight) - (axles for legal weight) $D_2^{1.49}$
6	(Column 5 value)·(Number of axles of this type, legal weight and overweight per violating vehicle)

The entries in Column 6 are summed separately for single and tandem axles.

The output is

$$\text{Avg. uncompensated ref. axles per violating vehicle} = \text{SUM1} + (\text{SUM2})/D_2^{1.49} .$$

A table of values is printed for slabs from 4 in. to 12 in. The program listing follows:

```
C     RIGDM PROGRAM, MRI PROJECT 3158-P
      REAL LOK,LOVER
      READ(1,101)NTYPE
  101 FORMAT(I1,9X,3F10.0)
      SUM1=0.0
      SUM2=0.0
      GO TO (1,2),NTYPE
    1 WRITE(3,102)
  102 FORMAT('1','UNCOMPENSATED MAINTENANCE, UNREINFORCED RIGID PAVE.')
      COEF1=1./18.0**2.62
      COEF2=1.23058E-02*COEF1
      XPON1=2.62
      XPON2=4.38
      XPON3=1.49
      GO TO 3
    2 WRITE(3,103)
  103 FORMAT('1','UNCOMPENSATED MAINTENANCE, REINFORCED RIGID PAVE.')
      XPON1=2.30
      XPON2=3.13
      XPON3=0.39
      COEF1=1./18.0**XPON1
      COEF2=3.80214E-02*COEF1
    3 READ(1,101)NAXE,LOK,LOVER,AXLES
      GO TO(201,202,203),NAXE
  203 WRITE(3,104)SUM1,SUM2,XPON3
  104 FORMAT(1H0, 45HAVE. UNCOMPENSATED REF AXLES PER WT VIOL VEH=,E12.
     15, 5HPLUS ,E12.5,34HDIVIDED BY D2 RAISED TO THE POWER ,F6.3)
      WRITE(3,105)
  105 FORMAT('0','SLAB THICK      UNCOMP REF AXLES/WT VIOL VEH.')
PAGE   1
```

```
      DO 204 I=4,12
      D2=I
      SUMUN=SUM1+SUM2/D2**XPON3
  204 WRITE(3,106)D2,SUMUN
  106 FORMAT(1H ,3X,F4.1,15X,E12.5)
      CALL EXIT
  201 ROK=COEF1*LOK**XPON1
      ROVER=COEF1*(LOK+LOVER)**XPON1
      RUN=ROVER-ROK
      RAXUN=RUN*AXLES
      SUM1=SUM1+RAXUN
  210 WRITE(3,107)NAXE,LOK,LOVER,ROK,RUN,RAXUN
  107 FORMAT(' ',I1,5X,2F12.3,3(5X,E12.5))
      GO TO 3
  202 ROK=COEF2*LOK**XPON2
      ROVER=COEF2*(LOK+LOVER)**XPON2
      RUN=ROVER-ROK
      RAXUN=RUN*AXLES
      SUM2=SUM2+RAXUN
      GO TO 210
      END
```

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APPENDIX 10

COMPUTER PROGRAM DOCUMENTATION: UNCOMPENSATED PAVEMENT LIFE USE PER VIOLATING VEHICLE

The two programs, FLEXL and RIGDL, written in FORTRAN, are presented here. Both programs calculate average uncompensated pavement life use per violating vehicle. They also calculate useful life and apply it as a basis for calculating average uncompensated life fractions and uncompensated maintenance fractions. FLEXL is used for flexible pavement calculations; RIGDL is used for rigid pavements.

Both programs use as part of input a deck describing the violating axles of violating vehicles. The programs accept any number of these axle descriptor cards up to and including 100. Each card in the deck contains

NAXE, LØK, LØVER, AXLES

Format I1, 9X, 3F10.0

Where NAXE = 1 for single axle, = 2 for tandem set

LØK = Legal axle load (Kips)

LØVER = Amount over legal axle load (Kips)

AXLES = Average number of axles with these characteristics per violating vehicle

Input for FLEXL

The first version of this program performs the calculations for a sequence of pavements with structural numbers separated by uniform increments. The second version calculates for structural numbers which are separately listed in input. The second version simply requires additional input as indicated in the input list below:

SNLO, SNHI, SNINC, RFACT

Format 4 F10.0

FMUN

Format F10.0

(Axle descriptor deck as defined)

Card with 3 in position 1.

SN (Second version only)

Format F10.0

ICON (Second version only)

Format I1

Where SNLO = Minimum structural number of calculation in first version

SNHI = Largest structural number of calculation in first version

SNINC = Increment for advancing structural number in first version

RFACT = Regional factor (used in both versions)

FMUN = Reference axles equivalent to average uncompensated maintenance use per violating vehicle (from program FLEXM)

SN = Structural number for calculation in second version

ICON = A control number, = 1 causes program to return to read another SN value, = 2 causes program exit (second version).

Output from FLEXL

All the output applicable to one value of structural number is printed in sequence. The output is

Structural number

Pavement life in reference axle applications

β_r and ρ_r values in the life calculation

The contribution of each axle in descriptor deck

Average uncompensated life use per violating vehicle (in units of reference axle applications)

Average uncompensated life fraction per violating vehicle

Average uncompensated fraction of maintenance life used per violating vehicle

The contribution of each axle in the description deck is listed in six columns with the following meanings.

Column No.	Value Printed
1	1 = single axle, 2 = tandem set
2	Axle legal weight (Kips)
3	Amount over legal weight (Kips)
4	Reference axles equivalent to legal weight
5	(Reference axles equivalent to actual weight) - (reference axles equivalent to legal weight)
6	Contribution to average uncompensated life use per violating vehicle

The regional factor was omitted in output. It would be a desirable addition to the program.

The program listings follow:

```
C     FLEXL PROGRAM, MRI PROJECT 3158-P, ORIGINAL VERSION
      REAL LOK(100),LOVER(100)
      DIMENSION NAXE(100),AXLES(100)
      BETA(ODE1,ODE2)=0.4+CD*((ODE1+ODE2)/ODE2)**3.23
      RHOCUT(OAD1,OAD2)=OAD2**4.33/(OAD1+OAD2)**4.79
      READ(1,101)SNLO,SNHI,SNINC,RFACT
  101 FORMAT(4F10.0)
      READ(1,101)FMUN
      DO 200 I=1,100
      READ(1,102)NAXE(I),LOK(I),LOVER(I),AXLES(I)
      N=NAXE(I)
      GO TO (200,200,202),N
  102 FORMAT(I1,9X,3F10.0)
  202 NDATA=I-1
      GO TO 203
CDATA READ IN COMPLETE, NDATA SET EQUAL TO NO. OF ITEMS
  200 CONTINUE
CBEGIN OUTER LOOP WITH SN VALUE FOR EACH PASS
  203 SN=SNLO
    1 SUM=0.0
      WRITE(3,103)SN
  103 FORMAT(1H1,45HLIFE USEAGE FLEXIBLE PAVEMENT, STRUCTUAL NO.=,F7.2)
      CD=0.081/(SN+1.0)**5.19
      OAD1=18.0
      OAD2=1.0
      BETAR=BETA(OAD1,OAD2)
      RHOCR=RHOCUT(OAD1,OAD2)
      RHOR=10.0**5.93*(SN+1.0)**9.36*RHOCR
      BETINV=1.0/BETAR
PAGE  1
```

```
      WTR=0.62963**BETINV*RHOR/REACT
      WRITE(3,104)WTR,BETAR,RHOR
  104 FORMAT(1H0,22HTOTAL LIFE REF.AXLES= ,E12.5,6HBETAR=,E12.5,5HRHOR=,
     2E12.5,/)
CNOW ENTER INNER LOOP WITH ONE AXLE DATA SET PER PASS
      DO 400 J=1,NDATA
      AXE=NAXE(J)
      OADOK=LOK(J)
      OADACT=OADOK+LOVER(J)
      WRATOK=0.62963**(BETINV-1.0/BETA(OADOK,AXE))*RHOCR/RHOCUT(OADOK,AX
     2E)
      WRATOV=0.62963**(BETINV-1.0/BETA(OADACT,AXE))*RHOCR/RHOCUT(OADACT,
     2AXE)
      RUN=WRATOV-WRATOK
      RAXUN=RUN*AXLES(J)
      SUM=SUM+RAXUN
      WRITE(3,105)NAXE(J),OADOK,LOVER(J),WRATOK,RUN,RAXUN
  105 FORMAT(' ',I1,5X,2F12.3,3(5X,E12.5))
  400 CONTINUE
      WRITE(3,106)SUM
  106 FORMAT(1H0,47HAVE. UNCOMPENSATED LIFE USE PER WT. VIOL VEH.= ,E12.
     25,16HREFERENCE AXLES.)
      SUM=SUM/WTR
      WRITE(3,107)SUM
  107 FORMAT(1H0,52HAVE. UNCOMPENSATED LIFE FRACTION PER WT. VIOL VEH.=
     2,F12.5)
      SUM=FMUN/WTR
      WRITE(3,108)SUM
  108 FORMAT(1H0,63HAVE. UNCOMPENSATED FRACTION OF MAINT. LIFE PER WT. V
```

```
     1IOL. VEH.= ,F12.5)
CINCREMENT STRUCTURAL NO. AND TEST FOR CONTINUE OF OUTER LOOP.
      SN=SN+SNINC
      IF (SNHI-SN) 500,1,1
  500 CALL EXIT
      END
```

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```
C      FLEXL PROGRAM, MRI PROJECT 3158-P
       REAL LOK(100),LOVER(100)
       DIMENSION NAXE(100),AXLES(100)
       BETA(ODE1,ODE2)=0.4+CD*((ODE1+ODE2)/ODE2)**3.23
       RHOCUT(OAD1,OAD2)=OAD2**4.33/(OAD1+OAD2)**4.79
       READ(1,101)SNLO,SNHI,SNINC,RFACT
  101  FORMAT(4F10.0)
       READ(1,101)FMON
       DO 200 I=1,100
       READ(1,102)NAXE(I),LOK(I),LOVER(I),AXLES(I)
       N=NAXE(I)
       GO TO (200,200,202),N
  102  FORMAT(I1,9X,3F10.0)
  202  NDATA=I-1
       GO TO 1
CDATA READ IN COMPLETE, NDATA SET EQUAL TO NO. OF ITEMS
  200  CONTINUE
CBEGIN OUTER LOOP WITH SN VALUE FOR EACH PASS
    1  SUM=0.0
       READ(1,101)SN
       WRITE(3,103)SN
  103  FORMAT(1H1,45HLIFE USEAGE FLEXIBLE PAVEMENT, STRUCTUAL NO.=,F7.2)
       CD=0.081/(SN+1.0)**5.19
       OAD1=18.0
       OAD2=1.0
       BETAR=BETA(OAD1,OAD2)
       RHOCR=RHOCUT(OAD1,OAD2)
       RHOR=10.0**5.93*(SN+1.0)**9.36*RHOCR
       BETINV=1.0/BETAR
```

```
      WTR=0.62963**BETINV*RHOR/RFACT
      WRITE(3,104)WTR,BETAR,RHOR
  104 FORMAT(1H0,22HTOTAL LIFE REF.AXLES= ,E12.5,6HBETAR=,E12.5,5HRHOR=,
     2E12.5,/)
CNOW ENTER INNER LOOP WITH ONE AXLE DATA SET PER PASS
      DO 400 J=1,NDATA
      AXE=NAXE(J)
      OADOK=LOK(J)
      OADACT=OADOK+LOVER(J)
      WRATOK=0.62963**(BETINV-1.0/BETA(OADOK,AXE))*RHOCR/RHOCUT(OADOK,AX
     2E)
      WRATOV=0.62963**(BETINV-1.0/BETA(OADACT,AXE))*RHOCR/RHOCUT(OADACT,
     2AXE)
      RUN=WRATOV-WRATOK
      RAXUN=RUN*AXLES(J)
      SUM=SUM+RAXUN
      WRITE(3,105)NAXE(J),OADOK,LOVER(J),WRATOK,RUN,RAXUN
  105 FORMAT(' ',I1,5X,2F12.3,3(5X,E12.5))
  400 CONTINUE
      WRITE(3,106)SUM
  106 FORMAT(1H0,47HAVE. UNCOMPENSATED LIFE USE PER WT. VIOL VEH.= ,E12.
     25,16HREFERENCE AXLES.)
      SUM=SUM/WTR
      WRITE(3,107)SUM
  107 FORMAT(1H0,52HAVE. UNCOMPENSATED LIFE FRACTION PER WT. VIOL VEH.=
     2,E12.5)
      SUM=FMUN/WTR
      WRITE(3,108)SUM
  108 FORMAT(1H0,63HAVE. UNCOMPENSATED FRACTION OF MAINT. LIFE PER WT. V
```
PAGE 2

```
     1IOL. VEH.= ,E12.5)
CREAD CONTROL NO. FOR NEXT SN OR EXIT
      READ(1,102)ICON
      GO TO (1,500),ICON
  500 CALL EXIT
      END
```

Input for RIGDL

Axle descriptor deck (not over 100)

3 in position 1

EP, SOILKP, SCP

Format E10.3, 2F10.0

D2, RMUN, CON

Format F10.0, 8X, E12.5, F10.0

Where EP = Modulus of elasticity for concrete (psi)

SOILKP = Soil support value (psi/in)

SCP = Concrete rupture modulus (psi)

D2 = Slab thickness (in.)

RMUN = Number of reference axles equivalent to average uncompensated maintenance use per violating vehicle (from program RIGDM)

CON = A control number, = 0. on all cards containing D2 and RMUN to be calculated, = 1.0 on otherwise blank card to call program exit.

Output from RIGDL

All output for a slab thickness is printed consecutively. The output items are

Thickness

Modulus of elasticity (fails to print because of format error)*

Modulus of rupture for concrete

* A simple correction is required. The program is reported here with the error since it is desirable to provide documentation on programs used, not on revised programs.

Soil support value

Total pavement life in reference axle applications

The β_r and ρ_r used in life calculation

RMATL, the factor compensating for current material properties over AASHO test properties

The individual contributions of violation axles

The average uncompensated life use per violating vehicle (in equivalent reference axles)

The average uncompensated life fraction per violating vehicle

The average uncompensated fraction of maintenance life per violating vehicle, and the RMUN value on which it is based

The list of individual axle contributions appears in six columns which have the same meanings as in the FLEXL output.

The program listing follows:

```
C     RIGDL PROGRAM, MRI PROJECT 3158-P
      REAL LOK(100),LOVER(100)
      DIMENSION NAXE(100),AXLES(100)
      BETA(OAD1,OAD2)=1.0+CD*(OAD1+OAD2)**5.20/OAD2**3.52
      RHOCUT(OAD1,OAD2)=OAD2**3.28/(OAD1+OAD2)**4.62
      DO 200 I=1,100
      READ(1,102)NAXE(I),LOK(I),LOVER(I),AXLES(I)
  102 FORMAT(I1,9X,3F10.0)
      N=NAXE(I)
      GO TO (200,200,202),N
  202 NDATA=I-1
      GO TO 203
CAXLE WT DATA READ IN, NDATA EQUAL NO. OF DATA ITEMS
  200 CONTINUE
  203 READ(1,103)EP,SOILKP,SCP
  103 FORMAT( E10.3,2F10.0)
      DUM1=EP/SOILKP
      DUM2=(DUM1/7.0E+04)**0.25
      DUM1=DUM1/11.52
CNOW ENTER OUTER LOOP WHERE EACH PASS USES A VALUE OF PAVEMENT THICKNESS
  600 READ(1,104)D2,RMUN,CON
  104 FORMAT(F10.0,8X,E12.5,F10.0)
      IF (CON)300,300,500
  300 SUM=0.0
      WRITE(3,105)D2,EP,SCP,SOILKP
  105 FORMAT(1H1,35HLIFE USEAGE, RIGID PAVE. THICKNESS=,F7.2,3HE= ,F12.5
     2/7HSSUBC= ,F8.2/7HSOILK= ,F8.2)
      RMATL=(.607638E04*D2*D2*D2)**0.25-10.0
      RMATL=RMATL/((DUM1*D2*D2*D2)**0.25-10.0)
PAGE  1
```

```
      RMATL=(RMATL*DUM2*SCP/690.)**3.42
      CD=3.63/(D2+1.0)**8.46
      OAD1=18.
      OAD2=1.
      RHOCR=RHOCUT(OAD1,OAD2)
      RHOR=10.0**5.85*(D2+1.0)**7.35*RHOCUT(OAD1,OAD2)
      BETAR=BETA(OAD1,OAD2)
      BETINV=1.0/BETAR
      WTR=.666667**BETINV*RHOR*RMATL
      WRITE(3,106)WTR,BETAR,RHOR,RMATL
  106 FORMAT(1H0,12HTOTAL LIFE= ,E12.5,11H REF. AXLES,/,7HBETAR= ,E12.5,
     28H   RHOR= ,E12.5,9H   RMATL= ,E12.5,/)
CNOW ENTER INNER LOOP WITH ONE AXLE DATA SET PER PASS.
      DO 400 J=1,NDATA
      AXE=NAXE(J)
      OADOK=LOK(J)
      OADACT=OADOK+LOVER(J)
      WRATOK=.666667**(BETINV-1.0/BETA(OADOK,AXE))*RHOCR/RHOCUT(OADOK,AX
     2E)
      WRATOV=.666667**(BETINV-1.0/BETA(OADACT,AXE))*RHOCR/RHOCUT (OADACT
     2,AXE)
      RUN=WRATOV-WRATOK
      RAXUN=RUN*AXLES(J)
      SUM=SUM+RAXUN
      WRITE(3,107)NAXE(J),OADOK,LOVER(J),WRATOK,RUN,RAXUN
  107 FORMAT(' ',I1,5X,2F12.3,3(5X,E12.5))
  400 CONTINUE
      WRITE(3,108)SUM
  108 FORMAT(1H0,47HAVE. UNCOMPENSATED LIFE USE PER WT. VIOL VEH.= ,E12.
PAGE  2
```

```
  25,18H  REFERENCE AXLES.)
      SUM=SUM/WTR
      WRITE(3,109)SUM
109 FORMAT(1H0,53HAVE. UNCOMPENSATED LIFE FRACTION PER WT. VIOL. VEH.=
  2 ,E12.5)
      SUM=RMUN/WTR
      WRITE(3,110)SUM,RMUN
110 FORMAT(1H0,53HAVE. UNCOMPENSATED FRACTION OF MAINT. LIFE PER WT. V
  2IOL. VEH.= ,E12.5,17H  BASED ON RMUN= ,E12.5)
      GO TO 600
500 CALL EXIT
      END
```

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APPENDIX 11

IOWA PUBLIC SCALES AVAILABLE FOR USE BY T.W.O. OFFICERS

Background

Recommendations concerning possible construction of new scales should take into account the fact that there are public scales available for use by T.W.O. officers.

MRI requested that a survey be made of public scales with a capacity of 40,000 lb. and over to determine their number and geographic distribution.

The attached information indicates that there are over 1,500 public scales compared to the Highway Commission's 31 and that some are available in every county.

T.W.O. officers currently use some of these scales routinely. Increased reliance on them is certainly feasible, but not without cost. The average charge to Iowa for use of a public scale is approximately $1-$2.

The effective volume handling capacity of public scales is less than state scales because officers generally have to escort each vehicle to the public scale location.

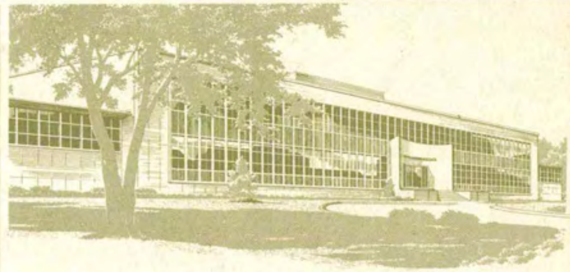
One major possible use for public scales would be for night time roving patrols as discussed in the Results Section of the report.

NUMBER OF SCALES IN EACH COUNTY
40,000 POUNDS AND OVER

Adair, Adams - No scales listed in these two counties, but we know there are scales in these counties.

Allamakee - 4
Appanoose - 9
Audubon - 7
Benton - 22
Black Hawk - 33
Boone - 15
Bremer - 11
Buchanan - 20
Buena Vista - 23
Butler - 1
Calhoun - 21
Carroll - 23
Cass - 2
Cedar - 20
Cerro Gordo - 44
Cherokee - 18
Chickasaw - 18
Clarke - 2
Clay - 22
Clayton - 10
Clinton - 25
Crawford - 13
Dallas - 12
Davis - 6
Decatur - 8
Delaware - 10
Des Moines - 14
Dickinson - 12
Dubuque - 25
Emmet - 16
Fayette - 22
Floyd - 11
Franklin - 8
Fremont - 5
Greene - 18
Grundy -3
Guthrie - 1
Hamilton - 10
Hancock - 21
Hardin - 19
Harrison - 27
Henry - 20
Howard - 11
Humboldt - 22
Ida - 8
Iowa - 7
Jackson - 11
Jasper - 18
Jefferson - 8
Johnson - 19
Jones - 8
Keokuk - 8
Kossuth - 24
Lee - 19
Linn - 42
Louisa - 8
Lucas - 7
Lyon - 16
Madison - 10
Mahaska - 2
Marion - 3
Marshall - 23
Mills - 9
Mitchell - 13
Monona - 9
Monroe - 2
Montgomery - 12
Muscatine - 24
O'Brien - 20
Osceola - 14
Page - 15
Palo Alto - 15
Plymouth - 14
Pocahontas - 13
Polk - 48
Pottawattamie - 22
Poweshiek - 22
Ringgold - 2
Sac - 24
Scott - 36
Shelby - 17
Sioux - 20
Story - 31
Tama - 30
Taylor - 3
Union - 9
Van Buren - 11
Wapello - 13
Warren - 12
Washington - 21
Wayne - 8
Webster - 35
Winnebago - 11
Winneshiek - 7
Woodbury - 29
Worth - 9
Wright - 20

TOTAL 1,505



MIDWEST RESEARCH INSTITUTE/425 VOLKER BOULEVARD/KANSAS CITY, MISSOURI 64110