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Intervention Model

Technical Documentation

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Overview

The Intervention Model measures the effectiveness of the Federal Motor Carrier Safety Administration's (FMCSA) Roadside Inspection and Traffic Enforcement programs in terms of safety. The majority of roadside inspections and traffic enforcements are conducted by state personnel under the Motor Carrier Safety Assistance Program (MCSAP) grant program.[1] Effectiveness, for the purposes of this analysis, is defined as the estimated reduction in commercial motor vehicle crashes attributable to the existence and implementation of the aforementioned safety programs. The model is a key element of the FMCSA's Safety Program Performance Measures project.

Intervention Data

Raw intervention data serve as the inputs from which all further determinations flow. The data consist of individual records of roadside inspections and traffic enforcements carried out during a given period. The model creates a crashes-avoided figure for each intervention based on the number and type of violations detected.

Roadside Inspections

Roadside inspections are interventions performed by qualified safety inspectors using the North American Standard (NAS) guidelines.[2] The NAS is a vehicle and driver inspection structure established by the FMCSA and the Commercial Vehicle Safety Alliance (CVSA).

Traffic Enforcements

MCSAP traffic enforcements are a subset of traffic enforcements in general.[3] MCSAP traffic enforcements include only those enforcement stops that lead to an on-the-spot roadside inspection. The enforcement agent, if qualified, performs the subse-

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[1] "The MCSAP is a Federal grant program that provides financial assistance to States to reduce the number and severity of accidents … involving commercial motor vehicles (CMVs). … Investing grant monies in appropriate safety programs will increase the likelihood that safety defects, driver deficiencies, and unsafe motor carrier practices will be detected and corrected before they become contributing factors to accidents." http://www.fmcsa.dot.gov/safetyprogs/mcsap.htm.

[2] See http://www.inspector.org/37stepin.htm.

[3] § Sec.350.111 of the Federal Motor Carrier Safety Regulations defines a MCSAP traffic enforcement as follows: "Traffic enforcement means enforcement activities of State or local officials, including stopping CMVs operating on highways, streets, or roads for violations of State or local motor vehicle or traffic laws (e.g., speeding, following too closely, reckless driving, improper lane change). To be eligible for funding through the grant, traffic enforcement must include an appropriate North American Standard Inspection of the CMV or driver or both prior to releasing the driver or CMV for resumption of operations."

quent roadside inspection. Otherwise, a safety inspector is called to the scene to conduct it. Since a traffic infraction precipitates the ensuing roadside inspection, 17[4] moving violations are incorporated into the driver section of the roadside checklist. The model classifies an intervention as a traffic enforcement intervention when at least one traffic enforcement violation is present in the intervention record. The only exception is when one or more drug and alcohol violations (392.4A and 392.5A)[5] are the only traffic enforcement violations present. These interventions are counted as roadside inspection interventions rather than traffic enforcement-initiated interventions.

Intervention Level Impact

As the name implies, the Intervention Model places a great deal of importance on individual interventions. The reason for this is that violation tabulations come from interventions and those tabulations are matched against a Violation Crash Risk Probability Profile (VCRPP), which then serves as a basis for determining the number of crashes avoided for a given intervention. Aggregates developed from the intervention-level crashes avoided numbers eventually form national and state statistics.

Violation Crash Risk Probability Profile

The model assumes that observed deficiencies (OOS and non-OOS violations) can be converted into crash risk probabilities. This assumption is based on the belief that detected defects represent varying degrees of mechanical or judgmental faults and, as a result, some are more likely than others to play contributory roles in causing commercial motor vehicle crashes. These differences can be estimated and ranked into discrete risk categories. Thus, the VCRPP contains all violation codes, each with an assigned risk category and a corresponding crash probability.

Using Cycla's risk categories[6] and the relative weights assigned to the categories, the Volpe Center analysts sought to account for error margins by opting for two probability sets - a Higher Bound set and a Lower Bound set. The outputs computed from the two sets are used to compute a mean with a range of ± 20 percent. Because crash causation data is still forthcoming, users are reminded to employ caution interpreting the Model's results.

The values in Table 1 and Table 2 indicate the Lower Bound and Higher Bound numbers of violations that would have to be discovered to cause the model to credit one of the programs with an avoided crash. Keep in mind, however, the numbers in the tables are not meant to be definitive. They constitute the "best guesses" of industry

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[4] The list of traffic enforcement violations was updated in October 2006; previously there were 21 violations.

[5] Prior to October 2006 the violations 392.4 and 392.5 were also included.

[6] Cycla Corporation, *Risk-Based Evaluation of Commercial Motor Vehicle Roadside Violations: Process and Results*, U.S. Department of Transportation, Federal Highway Administration, Office of Motor Carriers, July 3, 1998.

experts interpreting available data. Volpe Center analysts used these figures to test and calibrate the model. As more reliable crash causation statistics become available, table quantities may have to be revised.[7] These revisions will not affect the overall soundness of the model.

Note that in moving from Risk Category (RC) 1 to RC 2, from RC 2 to RC 3, and so on, each step varies by a factor of ten. This tracks Cycla's variation in designated relative weights between risk categories. Note further that the weight given to traffic enforcement violations is four times that of the roadside inspection counterpart violations. Table 1 and Table 2 illustrate the factor and weighting differences. For example, the tenfold factor variation can be seen when Traffic Enforcement RC1 OOS Violations jump from 30 to 300 when stepping to Traffic Enforcement OOS Violations RC2. Additionally, it takes quadruple the number of Roadside Inspection OOS Violations in RC1 (120) to have the same impact as Traffic Enforcement OOS Violations in RC1 (30), demonstrating the reduced weight given to roadside inspection violations vis-à-vis traffic enforcement violations. Volpe Center analysts used the latest, preliminary data available from ongoing crash causation studies to support this difference. The studies found that driver faults represented by traffic enforcement violations are more likely to lead to motor carrier crashes than are roadside inspection driver or vehicle faults of an equivalent risk category.[8]

Table 1. Lower Bound of Number of Violations to Avoid One Crash

Risk Category	Roadside Inspection		Traffic Enforcement	
	OOS	Non-OOS	OOS	Non-OOS
1	120	240	30	60
2	1,200	2,400	300	600
3	12,000	24,000	3,000	6,000
4	120,000	240,000	30,000	60,000
5	1,200,000	2,400,000	300,000	600,000

Table 3 and Table 4 display the higher bound and lower bound probabilities, respectively. The crash reduction probabilities are the reciprocals of the numbers in Table 1 and Table 2, so it follows that the probabilities also experience a tenfold change between steps. The crash reduction probabilities associated with each violation form the VCRPP.

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[7] The Volpe Center, supported by the FMCSA, is currently assessing the safety risk of violations by assigning weights based on their likelihood to cause, contribute to, or worsen the outcome of a commercial vehicle crash.

[8] Ibid.

Table 2. Higher Bound of Number of Violations to Avoid One Crash

Risk Category	Roadside Inspection		Traffic Enforcement	
	OOS	Non-OOS	OOS	Non-OOS
1	80	160	20	40
2	800	1,600	200	400
3	8,000	1,600	2,000	4,000
4	80,000	16,000	20,000	40,000
5	800,000	160,000	200,000	400,000

Table 3. Lower Bound Crash Reduction Probabilities

Risk Category	Roadside Inspection		Traffic Enforcement	
	OOS	Non-OOS	OOS	Non-OOS
1	8.33×10^{-3}	4.167×10^{-3}	0.033	0.0167
2	8.33×10^{-4}	4.167×10^{-4}	3.3×10^{-3}	1.67×10^{-3}
3	8.33×10^{-5}	4.167×10^{-5}	3.3×10^{-4}	1.67×10^{-4}
4	8.33×10^{-6}	4.167×10^{-6}	3.3×10^{-5}	1.67×10^{-5}
5	8.33×10^{-7}	4.167×10^{-7}	3.3×10^{-6}	1.67×10^{-6}

Table 4. Higher Bound Crash Reduction Probabilities

Risk Category	Roadside Inspection		Traffic Enforcement	
	OOS	Non-OOS	OOS	Non-OOS
1	0.0125	6.25×10^{-3}	0.05	0.025
2	1.25×10^{-3}	6.25×10^{-4}	5.0×10^{-3}	2.5×10^{-3}
3	1.25×10^{-4}	6.25×10^{-5}	5.0×10^{-4}	2.5×10^{-4}
4	1.25×10^{-5}	6.25×10^{-6}	5.0×10^{-5}	2.5×10^{-5}
5	1.25×10^{-6}	6.25×10^{-7}	5.0×10^{-6}	2.5×10^{-6}

Examples

Applied to Recorded Violations. Because each inspection used in the analysis has one or more violations, the model classifies recorded violations according to their VCRPP ratings. Table 5 and Table 6 display the classification process for two example interventions.

Intervention A is a roadside-initiated intervention, since no traffic enforcement violations are present. It contains roadside RC 1 OOS violations and both OOS and non-OOS RC 2 violations. Using the VCRPP, the violations receive their respective probabilities from the Higher Bound and Lower Bound probability sets.

The VCRPP is also applied to Intervention B. Unlike Intervention A, Intervention B is classified as a traffic enforcement-initiated intervention, because it has at least one traffic enforcement violation. Additionally, several roadside inspection violations were identified during the subsequent roadside inspection.

Table 5. Violations for Intervention A

Violation Number	Violation Description	Violation Type	OOS	Risk Category	Lower Risk Probability	Higher Risk Probability
392.5C	Operating a CMV while fatigued	Roadside	Yes	1	8.33×10^{-3}	0.0125
393.9H	Inoperable head lamps	Roadside	Yes	1	8.33×10^{-3}	0.0125
395.3A1	10 hour rule violation	Roadside	Yes	2	8.33×10^{-4}	1.25×10^{-3}
392.14	Failed to use caution for hazardous condition	Roadside	Yes	2	8.33×10^{-4}	1.25×10^{-3}
393.201B	Bolts securing cab broken	Roadside	Yes	2	8.33×10^{-4}	1.25×10^{-3}
393.9T	Inoperable tail lamp	Roadside	No	2	4.167×10^{-4}	6.25×10^{-4}
393.60C	Use of vision reducing matter on windows	Roadside	No	2	4.167×10^{-4}	6.25×10^{-4}
392.9A3	Driver’s view is obstructed	Roadside	No	2	4.167×10^{-4}	6.25×10^{-4}
393.77	Prohibited heaters	Roadside	No	2	4.167×10^{-4}	6.25×10^{-4}

Table 6. Violations for Intervention B

Violation Number	Violation Description	Violation Type	OOS	Risk Category	Lower Risk Probability	Higher Risk Probability
393.48A	Inoperative brakes	Roadside	Yes	1	8.33×10^{-3}	0.0125
393.209D	Inoperative steering system component	Roadside	Yes	1	8.33×10^{-3}	0.0125
393.17B	No deflective side marker	Roadside	No	2	4.167×10^{-4}	6.25×10^{-4}
392.9A	Failure to secure load	Roadside	No	2	4.167×10^{-4}	6.25×10^{-4}
392.5A	Possession/use/under influence of alcohol	Traffic	Yes	1	0.033	0.05
392.2C	Failure to obey traffic control device	Traffic	Yes	2	3.3×10^{-3}	5.0×10^{-3}
392.2P	Improper passing	Traffic	Yes	2	3.3×10^{-3}	5.0×10^{-3}

Occurrences per Risk Category. After the application of the VCRPP, the model aggregates violations occurring in a particular risk category. Table 7 continues with the example interventions from Table 5 and Table 6 by exhibiting the results of the aggregation.

Table 7. Violation Occurrences per Risk Category†

Inspection	Roadside Inspection				Traffic Enforcement			
	RC 1 Viol.		RC 2 Viol.		RC 1 Viol.		RC 2 Viol.	
	OOS	Non-OOS	OOS	Non-OOS	OOS	Non-OOS	OOS	Non-OOS
A	2	0	3	4	0	0	0	0
B	2	0	0	2	1	0	2	0

†. To avoid needless complexity, the examples have been crafted using risk categories 1 and 2, rather than the entire range of risk categories 1 through 5.

Crashes Avoided per Intervention

To generate an intervention's crashes avoided, the number of violation occurrences per risk category is multiplied by the crash probability associated with that risk category. For instance, if four occurrences of roadside inspection OOS violations in RC 1 were noted on an inspection report, then the model would multiply four by the roadside OOS RC 1 probability from the VCRPP. This would be done for all roadside inspection OOS and non-OOS violations, along with all traffic enforcement OOS and non-OOS violations. Summing the products creates an initial crash risk reduction for the inspection's risk category being evaluated.

$$ICRR_{rc} = \sum_{t}\sum_{oos} v_{rc,\,t,\,oos} \cdot P_{rc,\,t,\,oos} \qquad \textbf{[1]}$$

where:

Variable	Description	Values
$ICRR$	Initial Crash Risk Reduction	$0 \ldots \infty$
v	Number of Violations	$0 \ldots \infty$
P	Crash Risk Probability	Table 5, Table 6
rc	Risk Category	1,2,3,4,5
t	Type of Violation	Roadside, Traffic
oos	Out of Service	Yes, No

Next, all violations recorded for a risk category during an intervention, roadside inspection OOS and non-OOS and, if applicable, traffic enforcement OOS and non-OOS, are added together. Multiplying the total by the initial crash risk reduction calculated in Equation [1] produces the final crash risk reduction for a given risk category in a particular intervention. Equation [2] is designed to capture the increased risk arising from the discovery and correction of numerous violations during a single intervention. The logic behind this is that, while each violation carries a certain degree of crash risk in isolation, additional violations occurring in tandem elevate the crash risk beyond the mere combined, additive, risk levels caused by each violation alone. In essence, the final crash risk reduction per risk category equation measures the multiplicative crash risk effect of compound safety defects.

$$CRR_{rc} = \left(\sum_{t} \sum_{oos} v_{t,\,oos} \right) \cdot ICRR_{rc} \qquad [2]$$

where CRR_{rc} is the final calculated crash risk reduction for a given risk category within an intervention. Equation [1] and Equation [2] must be calculated for each of the five risk categories.

When all five risk categories have had their respective crash risk reductions determined, the model calculates the intervention's crashes avoided by adding the five CRR_{rc} numbers as shown in Equation [3]. A cap of 0.75 is placed on the outcome for each intervention, thus ensuring that the model never produces a crashes avoided total greater than one. Volpe Center analysts chose three-quarters of a crash avoided as a cap to maintain a more conservative tendency in the model, given the lack of empirical crash causation data.

$$I_A = \sum_{rc} CRR_{rc} \qquad [3]$$

where I_A is the calculated crashes avoided due to an intervention.

Repeating this process using both Higher Bound and Lower Bound probabilities yields the crashes avoided range for each intervention.

Examples

Intervention A. For Intervention A (see Table 5), a vehicle given a roadside inspection is found to have two out-of-service violations in Risk Category 1, three out-of-service violations in Risk Category 2, and four non-out-of-service violations in Risk Category 2. The calculation of the total crashes avoided of this single inspection, using Higher Bound probabilities, appears below.

Multiplying the crash reduction probability for each risk category by the number of out-of-service violations in that risk category and adding it to the product of the risk reduction probability and the number of non-out-of-service violations gives the initial crash risk reduction as formalized by Equation [1].

Risk Category	Higher Bound Calculation
1	$ICRR_1 = 2 \cdot 0.0125 = 0.025$
2	$ICRR_2 = 3 \cdot 0.00125 + 4 \cdot 0.000625 = 0.00625$

Final crash risk reduction becomes known after multiplying the initial crash risk reduction for each risk category by the number of violations in that risk category. The model supplies total crashes avoided for the intervention by tallying the final crash risk reduction from each risk category as formalized by Equation [2] and Equation [3].

Risk Category	Higher Bound Calculation
1	$CRR_1 = 0.025 \cdot 2 = 0.05$
2	$CRR_2 = 0.00625 \cdot 7 = 0.04375$
Total	$I_A = 0.05 + 0.04375 = 0.09375$

Therefore, Inspection A's range of crashes avoided begins at the Higher Bound result, 0.09375, and would extend to the Lower Bound output.

Intervention B. For Intervention B (see Table 6), a traffic enforcement stop has resulted in both traffic enforcement violations and roadside inspection violations. The intervention involved one traffic enforcement out-of-service violation in Risk Category 1 and two out-of-service violations in Risk Category 2. In addition, the inspection involved two roadside inspection out-of-service violations in Risk Category 1 and two non out-of-service violations in Risk Category 2. Inspection B's computations follow:

Risk Category	Higher Bound Calculation
1	$ICRR_1 = 2 \cdot 0.0125 + 1 \cdot 0.05 = 0.075$
2	$ICRR_2 = 2 \cdot 0.000625 + 2 \cdot 0.005 = 0.01125$

To account for multiple violations, the model makes the following intensification adjustments to calculate the final crash risk reduction for each risk category:

Risk Category	Higher Bound Calculation
1	$CRR_1 = 0.075 \cdot 3 = 0.225$
2	$CRR_2 = 0.01125 \cdot 4 = 0.045$
Total	$I_B = 0.225 + 0.045 = 0.27$

The crashes avoided range for Inspection B starts at 0.27 at the higher bound and extends down to the lower bound.

Program Level Impact

Measuring interventions at the program level is next. It is here, however, that the model follows two divergent paths, one measuring direct effects and the other measuring indirect effects. Direct effects, it should be remembered, are the immediate products of roadside inspections and traffic enforcement stops performed in a given year, while indirect effects are based on behavioral changes caused by program awareness. Figure 1 provides an overview of the Intervention Model.

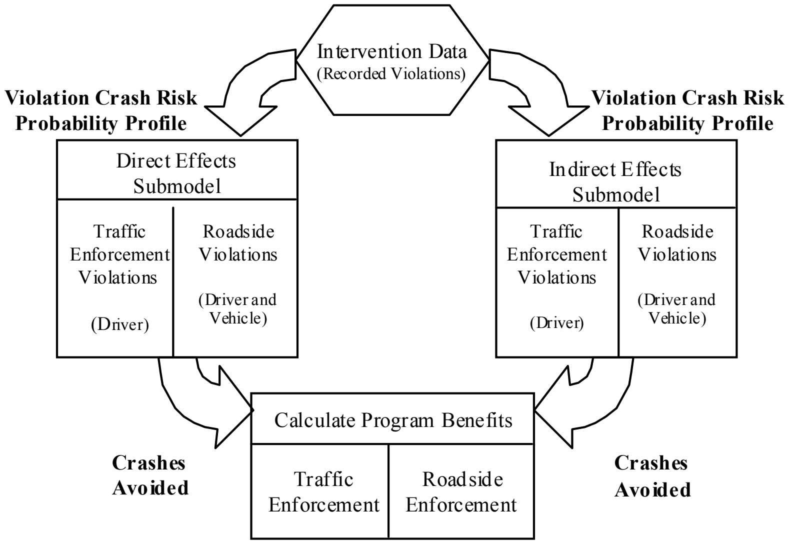

Figure 1. Overview of the Intervention Model

Direct Effect Approach

This section outlines the development of direct-effect crashes-avoided estimates. Figure 2 shows the process used to determine the direct effects of the programs. First, there is a primary crashes avoided computation that calculates crashes avoided for each program. Afterwards, the Traffic Enforcement Program is further analyzed to better understand how each Traffic Enforcement Program activity contributes to the number of crashes avoided. Figure 2 provides an overview of the direct effects approach.

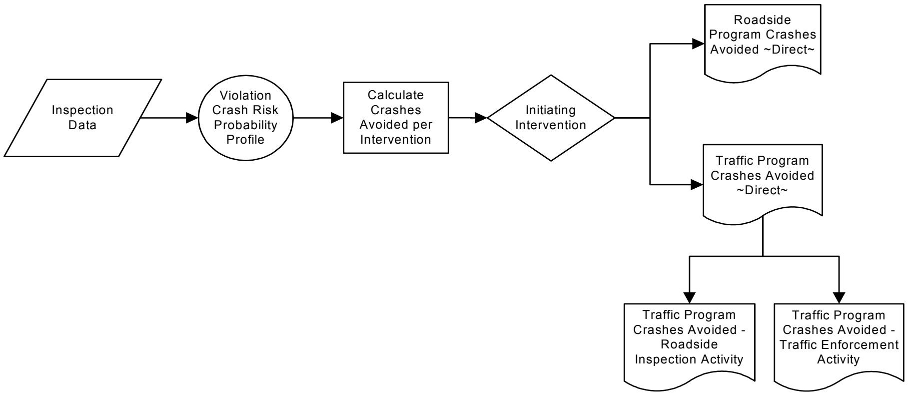

Figure 2. Direct-Effect Approach

Primary Determination. The model initially examines all inspections in a given year in terms of the numbers and types of violations associated with each individual inspection. Based on the VCRPP described above, inspection violations (both OOS and non-OOS) are matched with their respective crash risk reduction probabilities, to produce an estimated range of crashes avoided for that inspection. The model next segregates the complete set of inspections into two groups, depending on whether the initiating intervention was a roadside inspection or a traffic enforcement. Interventions with drug and alcohol violations (392.4A and 392.5A)[9] as the only traffic enforcement violations are counted as roadside inspection interventions. The logic behind this is the only way an officer could have identified drug and alcohol violations is by stopping the vehicle, and if the vehicle was not stopped for a moving violation, then it must have been detained as a part of a roadside inspection. Thus these types of interventions are counted as part of the Roadside Inspection Program, but the drug and alcohol violations are assigned the traffic enforcement crash reduction probabilities. Once all of the inspections have been divided among the two programs, the estimated crashes-avoided ranges are summed across all inspections in each program. Two overall estimates of crashes avoided emerge: one for the Roadside Inspection Program and one for the Traffic Enforcement Program.

$$Total_{Roadside} = \sum_{i=1}^{n} I_{j,\,Roadside} \qquad \textbf{[4]}$$

$$Total_{Traffic} = \sum_{i=1}^{n} I_{j,\,Traffic} \qquad \textbf{[5]}$$

Traffic Enforcement Program. Since the Traffic Enforcement Program is broken out into both traffic enforcement activities and roadside inspection activities, the next

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[9] Prior to October 2006 the violations 392.4 and 392.5 were also included.

step in the model is to understand the contribution each type of activity makes to the number of crashes avoided. In previous years, a roadside inspection allocation was calculated to credit a portion of traffic enforcement crashes avoided back to the Roadside Inspection Program, recognizing the contribution to the traffic enforcement total made by the ensuing roadside inspection, however, this approach has been modified. The current methodology provides a breakdown of the Traffic Enforcement Program and analyzes the contribution of each type of activity separately and in combination within the Traffic Enforcement Program.

To analyze the benefits of each activity type individually, the same calculations are applied as in determining the impact of the Traffic Enforcement Program as a whole, but the data for traffic enforcement activities and roadside inspection activities are treated separately.

To calculate the initial crash risk reduction for a risk category for each type of activity, Equation [1] is modified to look at the roadside inspection violations and traffic enforcement violations that make up the Traffic Enforcement Program independently, where $ICCR_{RI,\,rc}$ represents the initial crash risk reduction for roadside inspection activities within each risk category and $ICRR_{TE,\,rc}$ represents the same for traffic enforcement activities:

$$ICRR_{RI,\,rc} = \sum_{oos} v_{rc,\,oos,\,RI} \cdot P_{rc,\,oos,\,RI} \qquad \textbf{[6]}$$

$$ICRR_{TE,\,rc} = \sum_{oos} v_{rc,\,oos,\,TE} \cdot P_{rc,\,oos,\,TE} \qquad \textbf{[7]}$$

where:

Variable	**Description**	**Values**
$ICRR$	Initial Crash Risk Reduction	$0\ldots\infty$
v	Number of Violations	$0\ldots\infty$
P	Crash Risk Probability	Table 5, Table 6
rc	Risk Category	1,2,3,4,5
oos	Out of Service	Yes, No

To determine the final calculated crash risk reduction per risk category for Traffic Enforcement Program roadside inspection activities and traffic enforcement activities, Equation [2] can be modified as follows:

$$CRR_{RI,\,rc} = \sum_{oos} v_{RI,\,oos} \cdot ICRR_{RI,\,rc} \qquad \textbf{[8]}$$

$$CRR_{TE,\,rc} = \sum_{oos} v_{TE,\,oos} \cdot ICRR_{TE,\,rc} \qquad [9]$$

Where $CRR_{RI,\,rc}$ is the final calculated crash risk reduction for a given risk category gained through roadside inspection activities and $CRR_{TE,\,rc}$ is the final calculated crash risk reduction for a given risk category gained through traffic enforcement activities.

Equation [3] can be modified to determine the number of crashes avoided as a result of roadside inspection activities or traffic enforcement activities within one intervention:

$$I_{A,\,RI} = \sum_{rc} CRR_{RI,\,rc} \qquad [10]$$

$$I_{A,\,TE} = \sum_{rc} CRR_{TE,\,rc} \qquad [11]$$

Finally, the total crashes avoided as a result of the Traffic Enforcement Program activities can be determined by summing up across all interventions:

$$T_{RI} = \sum_{j=1}^{n} I_{j,\,RI} \qquad [12]$$

$$T_{TE} = \sum_{j=1}^{n} I_{j,\,TE} \qquad [13]$$

Where T_{RI} is the total number of crashes avoided through Traffic Enforcement Program roadside inspection activities and where T_{TE} is the total number of crashes avoided through the program's traffic enforcement activities:

$$T_{TE} + T_{RI} + T_C = Total_{Traffic} \qquad [14]$$

$$T_C = Total_{Traffic} - T_{RI} - T_{TE} \qquad [15]$$

Equation [14] and Equation [15] describe the contribution of both traffic enforcement activities and roadside inspection activities to the crashes avoided through the entire Traffic Enforcement Program, where T_C represents the effect of the combined activity of uncovering both roadside inspection and traffic enforcement violations during a traffic enforcement. The model applies a multiplier for each additional violation identified during an intervention, by the same logic, correcting both roadside inspection and traffic enforcement violations during one intervention will increase the chances of preventing a crash when compared to interventions that uncover only roadside inspection violations or only traffic enforcement violations.

Examples

Intervention B . The following example illustrates the Traffic Enforcement Program breakdown methodology through Intervention B. Intervention A will not be used to illustrate this portion of the model, as it represents a roadside intervention with only roadside inspection violations and does not apply in this example.

First, initial crash risk reduction is calculated. This value is calculated separately for roadside inspection activities and traffic enforcement activities, respectively, using Equation [6] and Equation [7]:

Risk Category	Higher Bound Calculation
1	$ICRR_{RI,1} = 2 \cdot 0.0125 = 0.025$
2	$ICRR_{RI,2} = 2 \cdot 0.000625 = 0.00125$

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Risk Category	Higher Bound Calculation
1	$ICRR_{TE,1} = 1 \cdot 0.05 = 0.05$
2	$ICRR_{TE,2} = 2 \cdot 0.005 = 0.01$

Next, Equation [8] and Equation [9] calculate the final crashes avoided for each risk category within roadside inspection activities and traffic enforcement activities, respectively, and Equation [10] and Equation [11] calculate the totals for Intervention B, notated by $I_{B,RI}$: and $I_{B,TE}$.

Risk Category	Higher Bound Calculation
1	$CRR_{RI,1} = 0.025 \cdot 2 = 0.05$
2	$CRR_{RI,2} = 0.00125 \cdot 2 = 0.0025$
Total	$I_{B,RI} = 0.05 + 0.0025 = 0.0525$

Risk Category	Higher Bound Calculation
1	$CRR_{TE,1} = 0.05 \cdot 1 = 0.05$
2	$CRR_{TE,2} = 0.01 \cdot 2 = 0.02$
Total	$I_{B,TE} = 0.05 + 0.02 = 0.07$

Calculating Equation [12] and Equation [13] determines the total number of crashes avoided across all interventions in this example, evaluating roadside inspection activity and traffic enforcement activity independently, such that T_{RI}=0.0525 and T_{TE}=0.07 (note that T_{RI} and T_{TE} are equal to $I_{B,RI}$ and $I_{B,TE}$ since this example only uses one intervention).

As previously calculated on page 8, $Total_{Traffic} = I_B$=0.27 when evaluating the Traffic Enforcement Program as a whole. Note: $Total_{Traffic} = I_B$ because I_A is a roadside intervention and hence has no traffic enforcement activities.

Finally, Equation [15] yields $T_C = 0.27 - 0.0525 - 0.07 = 0.1475$, where T_C expresses the combined effect of uncovering and correcting both roadside inspection and traffic enforcement violations during traffic enforcement interventions.

Indirect-Effect Approach

The fundamental premise of the indirect-effect approach is that once motor carriers have been exposed to roadside inspection and traffic enforcement actions, a change in their behavior will be manifested by a reduction in crashes. This section presents a summary of the methods used in the model to arrive at the programs' indirect effects. Figure 3 provides a view of the processes involved in assessing the indirect effects of the model.

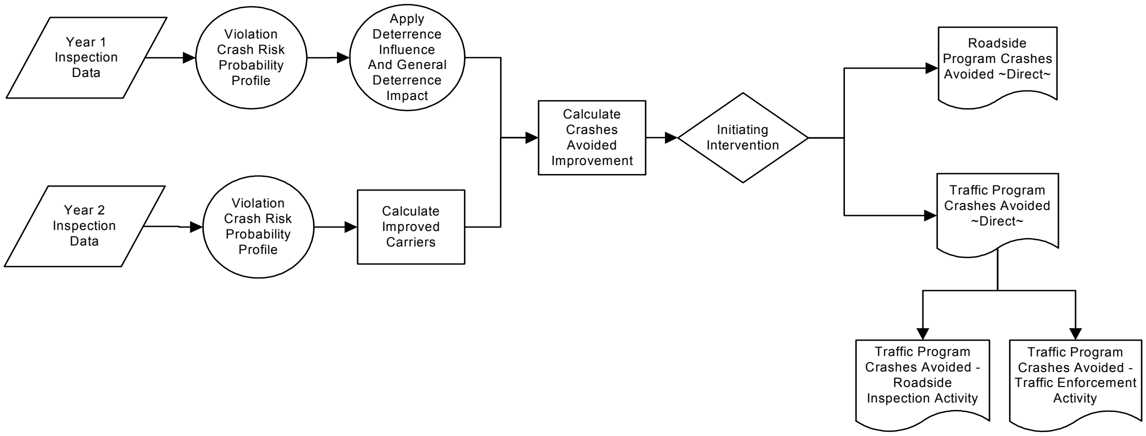

Figure 3. Indirect Effect Approach

Indirect effects require means other than direct measurement to reveal their presence. For that reason, the model uses changes in the number of violations recorded during inspections to identify and evaluate the indirect effects. Specifically, the model's algorithm employs two successive years of inspection data to undertake this process.

To conduct a year-to-year comparison, it is necessary to identify and link the carriers who were inspected with the inspections each received during the two-year span. Only in this way can a cross-year evaluation discern the indirect influence (i.e., behavior modification) that causes a reduction in crashes. In contrast, this inspection-carrier link is not needed in the direct-effect approach.

Modified Approach. The method of computing indirect effects has been modified. For the years 1998 to 2000, the Intervention Model used the methodology described in the September 2002 report "Intervention Model: Roadside Inspection and Traffic Enforcement Effectiveness Assessment."[10] This methodology has been modified so that the results of a program's effectiveness can be computed in the year following the program's execution rather than two years after. This section will discuss the modified approach to computing the indirect effects.

According to the modified approach, for each program, an unweighted average of the indirect benefits' contribution to the total is computed using the results from the previous two years. For example, to calculate the estimated indirect benefits as a percentage of total for 2006, the actual indirect benefits as a percentage of the total benefits for 2005 and 2004 are averaged. See the most recent Intervention Model Executive Summary[11] for more details.

Since the estimated indirect benefits are measured as a percentage of the total benefits, which are also composed of the indirect benefits, it is necessary to manipulate basic equations in order to express the indirect benefits as a function of the direct benefits.

$$IE_{Roadside} = Pct_{Roadside} \cdot TCA_{Roadside} \tag{16}$$

$$DE_{Roadside} = (1 - Pct_{Roadside}) \cdot TCA_{Roadside} \tag{17}$$

Where $Pct_{Roadside}$ is the indirect effect percent of roadside inspection total benefits.

Solving Equation [17] for the Total Crashes Avoided (*TCA*) and substituting that expression into Equation [16] yields the desired result.

$$IE_{Roadside} = Pct_{Roadside} \cdot \frac{DE_{Roadside}}{(1 - Pct_{Roadside})} \tag{18}$$

Similarly for the Traffic Enforcement Program:

$$IE_{Traffic} = Pct_{Traffic} \cdot \frac{DE_{Traffic}}{(1 - Pct_{Traffic})} \tag{19}$$

The indirect effect percentages are not intended to be constants. In fact, they will be continually updated as the second year's worth of data becomes available and the full version of the indirect model can be run. To continue with the example for 2006, once the 2007 data become available the indirect benefits for 2006 will be replaced with the actual benefits instead of the estimated numbers.

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[10] See http://ai.volpe.dot.gov/CarrierResearchResults/PDFs/FMCSA_RI_02_006.pdf.

[11] See http://ai.volpe.dot.gov/ProgramMeasures/PM/PM.asp.

Examples

Continuing with Intervention A and Intervention B yields the following results for the program level indirect benefits.

An example of the indirect effect percentages for both programs is given below in Table 8, for the most recent indirect effect percentages please refer to the most recent Executive Summary[12] document.

Table 8. Indirect Benefits as Percentage of Total

Program	Percentage
$Pct_{Roadside}$	20.00%
$Pct_{Traffic}$	15.00%

Substituting these percentages into Equation [18] and Equation [19] yields the indirect effect benefits for Intervention A ($IE_{Roadside}$)and Intervention B ($IE_{Traffic}$).

$$IE_{Roadside} = 0.2000 \cdot \frac{0.09375}{(1 - 0.2000)} = 0.023438$$

$$IE_{Traffic} = 0.1500 \cdot \frac{0.27}{(1 - 0.1500)} = 0.047647$$

Program Benefits

Crash severity varies. Some crashes may result in no more than minor property damage, while others may result in bodily harm or loss of life. Of the many gradations possible, two classifications of crashes suffice for calculating program benefits, fatal crashes and injury crashes. Any commercial vehicle crash that results in at least one fatality is a fatal crash. A fatal crash may also involve injuries, but the fatality governs the crash's classification. Any motor carrier crash that results in at least one injury requiring transport for immediate medical attention but no fatalities, is an injury crash.

Statistics of fatal and injury crashes supply the basis for creating lives saved and injuries avoided figures. Fatal crashes avoided translate to lives saved and injuries avoided, while injury crashes avoided translate to injuries avoided. Figure 4 shows the process used to calculate program benefits.

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[12] See http://ai.volpe.dot.gov/ProgramMeasures/PM/PM.asp.

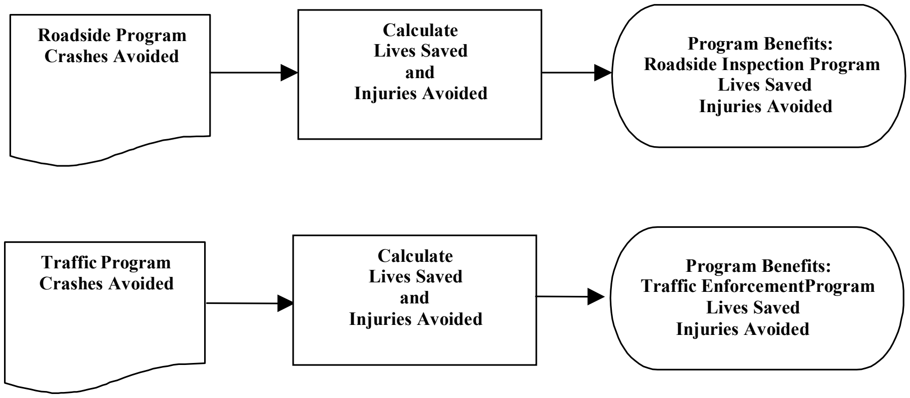

Figure 4. Program Benefits Determination

Obtaining program benefits from estimated crashes-avoided figures requires two prior determinations, the first being a proportional identification of crashes by severity and the second being the average numbers of fatalities and injuries per crash.

State-reported crash data in the Motor Carrier Management Information System (MCMIS) are used to determine the shares of fatal, injury, and tow away[13] crashes. In order to smooth out yearly fluctuations, the Intervention Model uses a two-year average in partitioning the crashes avoided into fatal and injury crashes. The share of fatal, injury, and tow away crashes is also referred to as the probability of a fatal, injury, or tow away crash given a crash.

In the second step in the determination of program benefits, the expected number of fatalities and injuries per crash type are used to compute the lives saved and injuries avoided. State-reported crash data in the MCMIS were used to compute the average number of fatalities in fatal crashes[14]. The number of injuries per crash are found in both fatal and injury crashes, since fatal crashes can also result in injuries. The average number of injuries in fatal and injury crashes in a given year are derived from the state-reported crash data in MCMIS. These values are recomputed each year and used in the program benefits calculations. In order to be consistent with the Compliance Review Effectiveness Model[15] and to smooth yearly fluctuations, a two-year average is used by the Intervention Model to estimate the lives saved and injuries avoided.

The input to the program benefits portion of the model requires the union of crashes avoided attributable to direct effects and indirect effects. The program benefits calculations use the output of Equation [20] and Equation [21]. The calculations entail the

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[13] A tow away crash results in no fatalities or injuries requiring transport for immediate medical attention, but in one or more motor vehicles incurring disabling damage as a result of the crash, requiring the vehicle(s) to be transported away from the scene by a tow truck or other motor vehicle.

[14] The average number of fatalities per fatal crash are compared with the National Highway Traffic Safety Administration's (NHTSA) Fatality Analysis Reporting System (FARS) and found to be similar; thereby MCMIS numbers are used.

[15] For the complete report see http://ai.volpe.dot.gov/ProgramMeasures/PM/PM.asp.

development of estimated totals of crashes by severity as well as the final tally of lives saved and injuries avoided.

$$TCA_{Roadside} = DE_{Roadside} + IE_{Roadside} \quad [20]$$

$$TCA_{Traffic} = DE_{Traffic} + IE_{Traffic} \quad [21]$$

where *TCA* is the Total Crashes Avoided for each of the programs (Roadside Inspection and Traffic Enforcement).

Fatal and Injury Crashes Avoided

The model breaks out program crashes-avoided figures into the numbers of program crashes avoided by severity. The expected number of fatal crashes avoided are computed as follows:

$$FCA_{Roadside} = TCA_{Roadside} \cdot Prob_{Fatal} \quad [22]$$

$$FCA_{Traffic} = Total_{Traffic} \cdot Prob_{Fatal} \quad [23]$$

where *FCA* is the Fatal Crashes Avoided for each of the programs (Roadside Inspection and Traffic Enforcement) and $Prob_{Fatal}$ is the probability of a fatal crash given a crash.

The expected number of injury crashes avoided are computed as follows:

$$ICA_{Roadside} = TCA_{Roadside} \cdot Prob_{Injury} \quad [24]$$

$$ICA_{Traffic} = Total_{Traffic} \cdot Prob_{Injury} \quad [25]$$

where *ICA* is the Injury Crashes Avoided for each of the programs (Roadside Inspection and Traffic Enforcement) and $Prob_{Injury}$ is the probability of a injury crash given a crash.

Lives Saved

To calculate the number of lives saved, the number of fatal crashes avoided is multiplied by the average number of fatalities per fatal crash.

$$LS_{Roadside} = FCA_{Roadside} \cdot Fatals_{FC} \quad [26]$$

$$LS_{Traffic} = FCA_{Traffic} \cdot Fatals_{FC} \quad [27]$$

where *LS* is the Lives Saved for each of the programs and $Fatals_{FC}$ is the average number of fatalities per fatal crash.

Injuries Avoided

To calculate the number of injuries avoided, the number of fatal crashes avoided is multiplied by the average number of injuries per fatal crash, and the number of injury crashes avoided is multiplied by the average number of injuries per injury crash. The two products are then added to obtain the total number of injuries avoided.

$$IA_{Roadside} = FCA_{Roadside} \cdot Injuries_{FC} + ICA_{Roadside} \cdot Injuries_{IC} \qquad [28]$$

$$IA_{Traffic} = FCA_{Traffic} \cdot Injuries_{FC} + ICA_{Traffic} \cdot Injuries_{IC} \qquad [29]$$

where IA is the Injuries Avoided for each of the programs, $Injuries_{FC}$ is the average number of injuries per fatal crash, and $Injuries_{IC}$ is the average number of injuries per injury crash.

Examples

Continuing with the example interventions, the program benefits are estimated using the following two year averages of crash severity proportions and fatalities and injuries given in Tables 9 and 10. For actual crash severity statistics, see the most recent Executive Summary[16] document.

Table 9. Two Year Average of Crash Severity Proportions

Crash Severity	Percentage
Fatal	5%
Injury	45%
Tow Away	50%

Table 10. Two Year Average of Fatalities and Injuries

	Two-Year Average
Fatalities Per Fatal Crash	1.2
Injuries Per Fatal Crash	1.1
Injuries Per Injury Crash	1.5

The first step is to apply Equation [20] and Equation [21] to determine the total crashes avoided for each program.

$$TCA_{Roadside} = DE_{Roadside} + IE_{Roadside} = 0.09375 + 0.02344 = 0.11719$$

$$TCA_{Traffic} = DE_{Traffic} + IE_{Traffic} = 0.27 + 0.04765 = 0.31765$$

Now that the total number of crashes avoided has been computed, these crashes can be partitioned into the expected number of injury and fatality accidents according to Equation [22] through Equation [25].

Fatal Crashes Avoided.

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[16] See http://ai.volpe.dot.gov/ProgramMeasures/PM/PM.asp.

$$FCA_{Roadside} = TCA_{Roadside} \cdot Prob_{Fatal} = 0.11719 \cdot 0.05 = 5.86 \times 10^{-3}$$

$$FCA_{Traffic} = Total_{Traffic} \cdot Prob_{Fatal} = 0.31765 \cdot 0.05 = 1.59 \times 10^{-2}$$

Injury Crashes Avoided.

$$ICA_{Roadside} = TCA_{Roadside} \cdot Prob_{Injury} = 0.11719 \cdot 0.45 = 5.27 \times 10^{-2}$$

$$ICA_{Traffic} = Total_{Traffic} \cdot Prob_{Injury} = 0.31765 \cdot 0.45 = 0.143$$

The second step in the computation of the overall program benefits is to apply Equation [26] through Equation [29] to determine the number of lives saved and the number of injuries avoided.

Lives Saved.

$$LS_{Roadside} = FCA_{Roadside} \cdot Fatals_{FC} = 5.86 \times 10^{-3} \cdot 1.2 = 7.03 \times 10^{-3}$$

$$LS_{Traffic} = FCA_{Traffic} \cdot Fatals_{FC} = 1.59 \times 10^{-2} \cdot 1.2 = 1.91 \times 10^{-2}$$

Injuries Avoided.

$$IA_{Roadside} = 5.86 \times 10^{-3} \cdot 1.1 + 5.27 \times 10^{-2} \cdot 1.5 = 0.08555$$

$$IA_{Traffic} = 1.59 \times 10^{-2} \cdot 1.1 + 0.143 \cdot 1.5 = 0.23188$$

Table 11 summarizes the program benefits from the two example interventions.

Table 11. Example Program Benefits

	Crashes Avoided	Lives Saved	Injuries Avoided
Roadside Inspection	0.11719	0.00703	0.08555
Traffic Enforcement	0.31765	0.0191	0.18122
Intervention Model Total	**0.43484**	**0.02613**	**0.26677**