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SNIP2 – A TOOL FOR DEVELOPING A STRATEGIC SAFETY IMPROVEMENT PLAN BY MULTIPLE AGENCIES

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ABSTRACT

This paper presents a method of systematic evaluation of road safety needs – the Safety Needs Identification Package (SNIP) and a concept called SNIP2 – an expansion that can match identified safety needs with safety interventions at the regional and city levels. SNIP and SNIP2 can be used by agencies involved in safety planning and management.

This paper presents the SNIP concept and its implementation for safety planning on Indiana roads. SNIP utilizes GIS road and crash databases to help identify road locations that experience safety problems such as night crashes, right-angle crashes at signalized intersections, etc. It can also be applied to user-related safety needs such as drunken driving, motorcycle crashes, speeding, or young driver safety.

SNIP2 involves two new key components: (1) a catalog of safety improvement programs and (2) a safety improvement program builder that identifies the most cost-effective safety improvement programs to address the safety needs identified with SNIP. The novelty of the proposed approach is in developing the safety improvement plan based on specific needs already identified for various locations, thereby providing a realistic approach to safety planning. The known safety effectiveness of the considered safety improvement programs and their unit costs allow planners to control the level of spending.

To make the optimization problem tractable for large regions with multiple alternative safety interventions, an approximate greedy search is applied to the knapsack problem to optimize recurring annualized benefits and costs. This simplified approach fits well the long-term transportation planning where a long-term "static" solution is sough while providing identification of focus areas more realistic than the current practice of developing strategic safety plans.

The paper presents the details of the catalog of safety improvements preliminarily developed for Indiana and formulation of the optimization program for selecting improvement programs. It discusses the implementation issues and the expected benefits from coordinating the development of the strategic safety plans by state agencies.

1 INTRODUCTION

As is common practice for many states in the U.S., the Indiana Department of Transportation (INDOT) develops its Strategic Highway Safety Plan (SHSP) cooperatively with several

other state agencies. The SHSP attempts to apply a comprehensive approach to reducing traffic crash injuries and deaths through coordinated engineering, education, enforcement, and emergency response. Strategies corresponding to Indiana's emphasis areas were initially identified; and INDOT, the Indiana Criminal Justice Institute (ICJI), and the Indiana State Police (ISP) were appointed to lead the efforts in their areas. The plan emphasizes the importance of an integrated approach to traffic safety, data analyses, application of the latest research, and best practices from across the U.S. as a means of generating a sound basis and tools for safety management decisions.

INDOT has a primary role in addressing transportation infrastructure as it relates to traffic safety, mindful of the Highway Safety Improvement Program (HSIP) in its approach to addressing traffic safety performance and, correspondingly, adoption of emphasis areas for analysis and project selection. Population of the safety program with projects by the INDOT Traffic Safety Office is currently in process with system-wide performance screening using the somewhat limited, non-integrated tools available to date. A site-specific countermeasure development and evaluation process (scoring) is being used to determine essential project intent and merit or cost-effectiveness.

The traditional method and associated (computer) applications did not permit the development of a truly systematic, efficient, and optimized traffic safety program. This program should be capable of automating the linkage of crash records to road inventory, to traffic volume assignments, to performance/prediction models, to site-specific analysis (of relative risk and positive countermeasures), all in a geo-spatial format. A unifying approach is needed, as well as a tool for determining the most relevant safety emphasis areas leading to selection of the most cost-effective population of projects with the most favorable effect on statewide traffic safety performance.

In Indiana, crash screening and ranking has been conducted for the last few years as a joint effort of the Indiana Department of Transportation and the Center for Road Safety (CRS) of Purdue University (CRS and INDOT, 2010). The crash assignment methodologies for INDOT crash screening are based on a GIS technique, and the assignment is performed in ArcGIS. Separate tools were developed for network splitting, link and intersection identification, crash database processing, and, finally, for crash assignment. Development of a versatile package of crash screening of INDOT-administered roads in SNIP was completed in 2011 (Tarko et al., 2011). Separate crash rankings based on road location (segment vs. intersection) and ranking of state roads was performed by computing the Confidence Level (that a road needs a safety intervention) and the Crash Cost Index (I), which reflects the difference between the actual and typical crash costs measured with the standard deviation of the difference estimate. The mentioned screening tool allows INDOT to focus on specific safety needs. For example, identifying rural roads with narrow shoulders and excessive numbers of single-vehicle crashes can find roads that may require improving shoulders. SNIP can be used by other Indiana agencies because it can also be applied to user-related safety needs such as drunken driving, motorcycle crashes, speeding, or young driver safety.

This paper presents the SNIP concept and its implementation for Indiana roads. The paper also introduces the concept of SNIP2 for identification of relevant safety improvement programs that match identified safety needs. SNIP2 optimizes the overall safety benefit in the long run while keeping the annual average safety spending at a pre-specified level.

2 SNIP

Safety screening tools have been developed by the Center for Road Safety (CRS) for INDOT in conjunction with past safety research. These tools have been used for a number of different research purposes; and one of important concepts is the integration of various components of safety data management and screening tools. Without preparing and updating a comprehensive database, however, it is not possible to facilitate the necessary operations for safety screening. Therefore, the very first step in the development of SNIP was the integration of the different pieces of datasets, which includes identifying the basic data components and data collection from different sources. Then, the source data were preprocessed, including adjusting the AADT to individual years, preprocessing of the layers, and, finally, developing a master database. This last step included various GIS layers integration, splitting road segments, network integration, updating the segment and intersections datasets, crash assignment, and calculating exposure variables such as demographic and land-use features.

Once the master database was available, a new tool called Safety Needs Identification Package (SNIP) was developed with the following screening tasks in mind:

- Identification of high-crash locations (segments, intersection, ramps, and bridges) in terms of high crash frequency, crash rate, or proportion of a particular crash type.
- Facilitate program-based screening (e.g., shoulder widening, median improvement, etc.)
- Facilitate special programs and projects (e.g., five-percent report, which identifies road elements in Indiana with the highest numbers of severe crashes)

In order to facilitate the versatility of the screening tasks and the data maintenance, four components were included in the screening tool:

1. Data management
2. Standard screening
3. Roads clustering and special studies
4. Results presentation

Figure 1 shows the components of the screening tool and the functional connections between them.

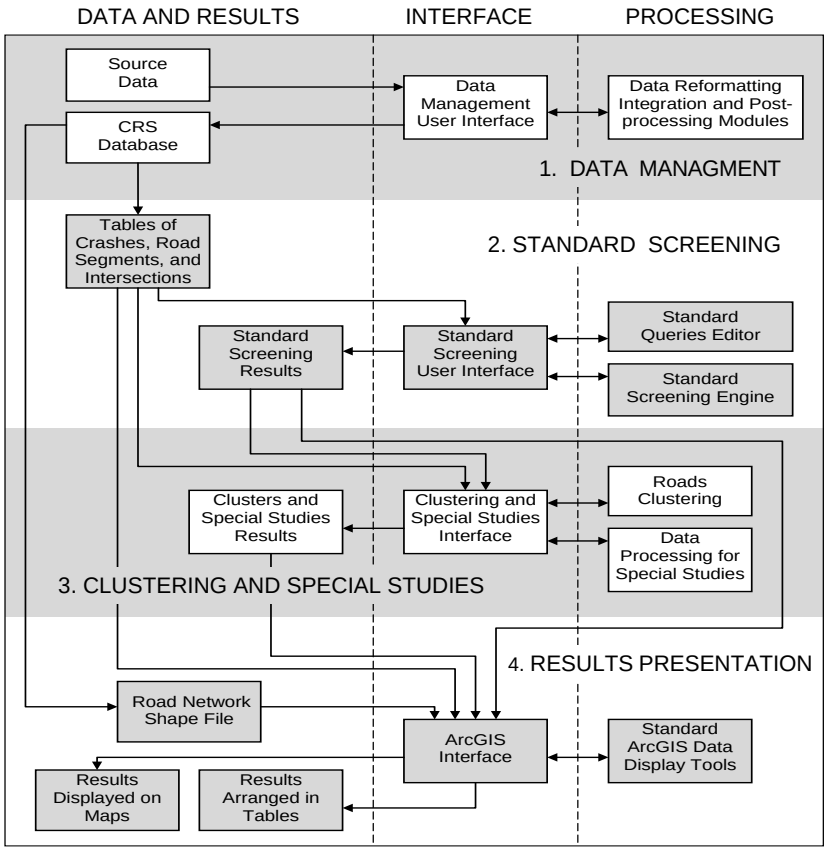

Figure 1 SNIP components

2.1 Data Management

The SNIP Data Management component includes updating the existing data by connecting to sources for new data, reformatting them to meet the standards of the CRS database (called also master database), integrating these data into tables that meet the master database specifications, and replacing the existing data. These newly-formatted and integrated data are then post-processed to make them ready for use by the network safety screening tool. The data maintenance is facilitated by a suite of procedures developed by CRS or available in ArcGIS. The data updating may be performed annually, or when a major change of data at any of the data sources occurs, to incorporate these changes to the screening process.

2.2 Standard Screening Tool

A standard screening tool facilitates building queries for identifying crashes and road elements that meet certain criteria in order to perform a specific screening task. For example, the user may need a list of rural road segments with narrow shoulders with a considerable number of severe single-vehicle crashes to identify locations where widening shoulders might be justified. Two subcomponents of the standard screening interface are used to execute a standard screening task: (1) Query Editor and (2) Screening Engine.

The Query Editor facilitates the application of a set of criteria to the selection of the crashes and road elements (see Figure 2). To help the user build a query, the selection criteria are grouped into four categories: screening scope (entire state, county, city, etc.), type of road

elements (road segments, intersections, ramps, etc.), crash criteria (single-vehicle crashes, incapacitating injury crashes, etc.), and road element criteria (two-lane cross-section, shoulder narrower than two feet, etc.). For example, if the screening task is to rank road segments in a county by fatal crashes, the scope is the *county*, the element is *road segment*, the crash criterion is *fatal crash*, and a road criterion is not specified (all segments).

The Screening Engine is the internal structure of the Standard Screening Tool that executes a certain query based on user-defined criteria. The screening engine receives the query task from the Query Editor (translated automatically into SQL format) and executes the screening task by using the host program's internal engine. It also transforms the raw query into a user-friendly output and computes specific parameters (e.g., mean and variance of population and confidence value).

2.3 SNIP Clustering and Special Studies

Road segments and intersections that exhibit an excessive number of crashes may be concentrated along longer road sections. Clustering these elements can reveal large scale safety issues that otherwise might be overlooked if the screening analysis is focused on individual locations. For example, clustering segments with excessive numbers of rear-end crashes may reveal a spill-over safety effect that originated at a signalized intersection with a capacity shortage or where traffic signals are poorly coordinated. Similarly, clustering smaller geographic units, such as townships, with a particular safety problem (e.g., speeding) can help identify larger areas where police enforcement or campaigning might be beneficial.

Clustering state road segments and intersections along state routes helps identify sections of corridors that may require specific road improvements from a safety standpoint. These clusters might be found useful in scoping such projects.

For a special study, such as the Five Percent Report, the user needs to run three queries (i.e., one for each severity type). The resulting tables include sufficient information to update the average crash costs, develop statistical models of crash frequency per crash severity, and calculate

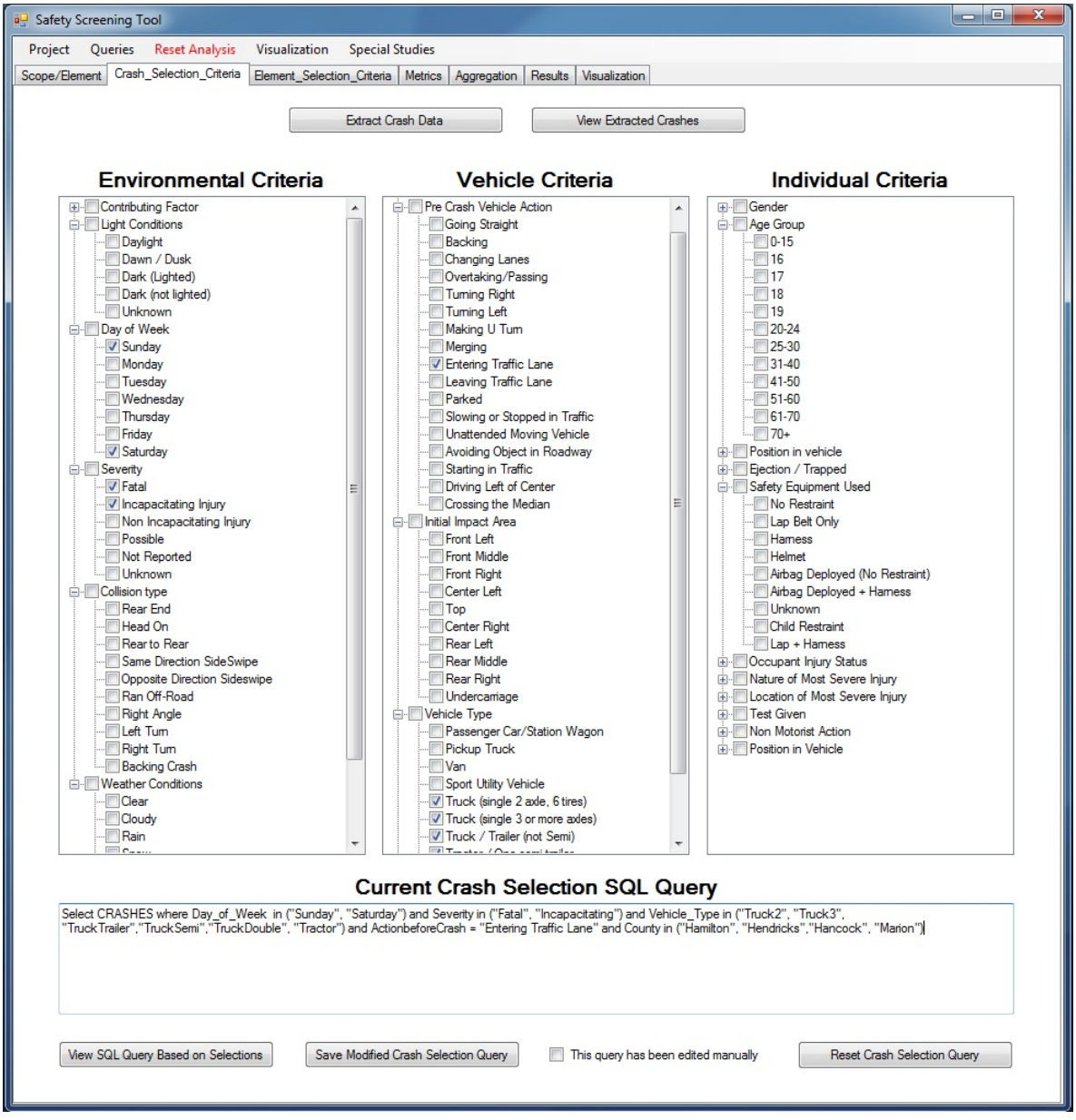

Figure 2 Example SNIP user interface for crash query criteria

safety performance measures (confidence level and I index). These calculations are facilitated with a special study tool: the Five Percent Report.

2.4 SNIP Results Presentation

The standard screening tool presents the results of a query in a tabular format, convenient for clustering and for additional processing that may be performed with the special studies module. SNIP2 can also display the final results on a GIS map to visualize the spatial distribution of the identified roads. Such visualization is beneficial when presenting the results to decision-makers and may help identify other spatial patterns not detectable

otherwise. Since the identified road components are geo-coded with the respective latitude and longitude, they can be visualized with the display features offered by Google Earth and ArcGIS (see Figure 3).

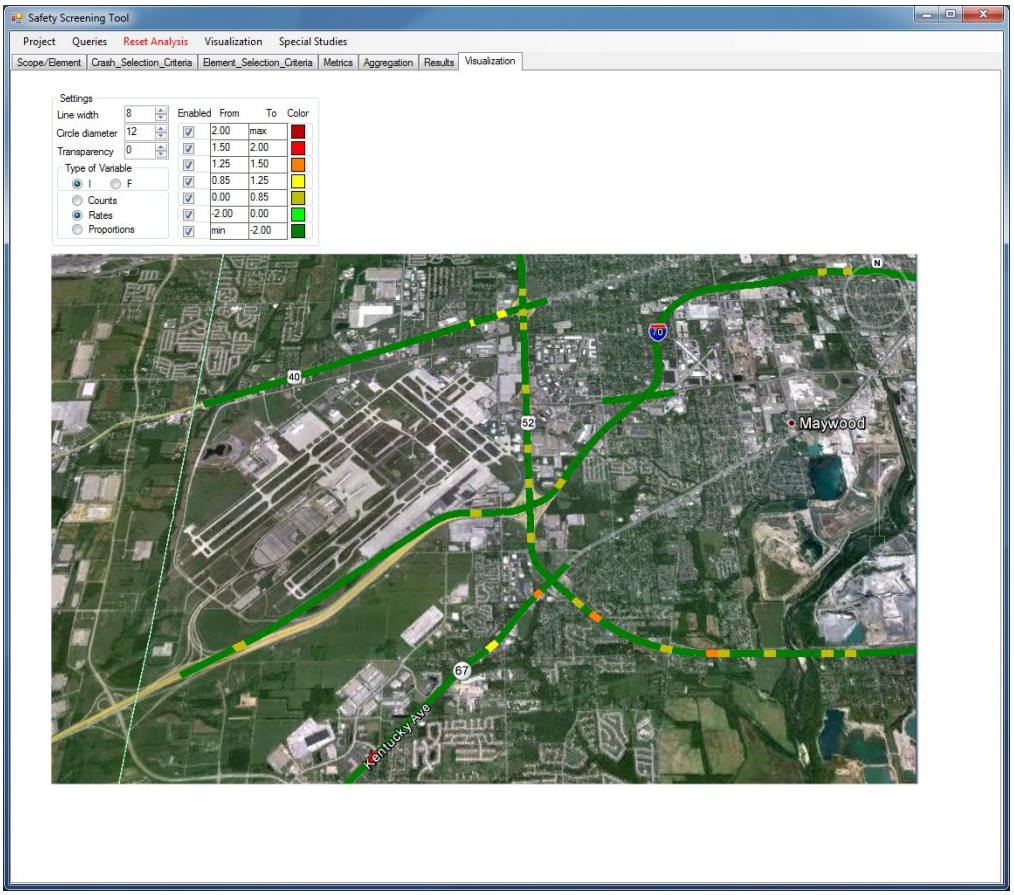

Figure 3 Presentation of an example SNIP results

3 SNIP2

The SNIP2 concept adds two additional components to SNIP: (1) a catalog of safety improvement programs and (2) a safety improvement program builder that identifies the most cost-effective safety improvement programs to address the safety needs identified with SNIP. The novelty of the proposed approach is in developing a safety improvement plan based on specific needs already identified for various locations, thus producing a realistic plan. The known safety effectiveness of the considered safety improvement programs and their unit costs allow controlling the level of spending.

3.1 Catalog of Safety Interventions

The SNIP tool finds road segments and intersections that experience an excessive number of crashes. The user can search for roads with specific characteristics that experience excessive crashes of specific types. This flexibility allows the identification of roads where certain safety interventions are justified by local road and safety conditions. For example, widening

shoulders may be justified on rural roads with narrow shoulders and large numbers of single-vehicle crashes.

Transportation agencies generally select from multiple safety interventions when attempting to improve road safety, and these interventions should be considered in strategic safety planning. Table 1 presents the current safety interventions and programs identified by INDOT representatives for consideration by the agency. The associated Crash Reduction Factors have been determined based on multiple research publications and the Crash Modification Factors Clearinghouse (Highway Safety Research Center, 2012).

Table 1 Road interventions identified by INDOT representatives

Category	Countermeasures	Crash Type	Crash Reduction Factors								Major Sources
			Urban				Rural				
			KA[1]	BC[2]	O[3]	All	KA	BC	O	All	
Access management	Replace TWLTL with raised median	All	21	21	33	23	Not applicable				Mauga/Kaseko 2010
Advanced technology and ITS	Install queue warning changeable signs	Rear end	16	16	-16		16	16	-16		Elvik/Vaa 2004
Alignment	Reduce horizontal curvature by X degree	All	Not applicable				Equations				Tarko/et al 2007
	Flatten crest of curve	All	51			20	51			20	Hovey/Chowdhury 2005
Highway Lighting	Add lighting at intersections	Nighttime				8				8	Donnell/et al 2010
Intersection geometry	Add left-turn lanes to major road approaches at intersections	All	37	37		45	58	58			Harwood/et al 2003
	Add right-turn lanes to major road approaches at intersections	All	9	9		16	9	9		16	Harwood/et al 2003
	Replace direct left-turns with indirect left-turns	All	43	43	20	28	43	43	20	28	Xu 2001
		Rear end				13				13	
		Angle				35				35	
	Convert intersection to roundabout	All	65	65	42		65	65	42		Schoon/Minnen 1994
	Sight distance improvements	All								11	Monsere/et al 2006
Pedestrians	Install pedestrian hybrid beacon at intersection	All	15	15		29	Not applicable				Fitzpatrick/Park 2010
	Construct pedestrians bridge or tunnel	Peds				86	Not applicable				Gan/et al/2005
	Install sidewalk	Peds				74	Not applicable				Gan/et al/2005
Railroad at grade crossings	Install gates at crossings with signs	All				87				87	Park/Saccomanno 2005
	Build a grade-separated crossing	All				100				100	Park/Saccomanno 2005
Roadside	Install guardrail	All	43	17			43	17			Elvik /Vaa 2004
		Run off road	44	47			44	47			Elvik/Vaa 2004
	Install cable median protection interstates	cross-median	92				92				Chandler 2007
Roadway delineation	Add centerline rumble strips	All	Not available					15		14	Persaud/et al, 2003
	Add shoulder rumble strips	Run off road		13		18		13		18	Griffith, 1999
Speed management	Traffic calming and speed limits	All	16	24	10	18				9	Elvik & Vaa, 2004 Park/et al, 2010; Parker, 1997

Shoulder	Widen shoulder width	All	Not available				Equation				Tarko/et al 2007
	Widen outside shoulder width	All	Not available				Equation				Tarko/et al 2007
Roadway signs and traffic control	Install a combination of chevron signs, curve warning signs/advisory speed signs, and sequential flashing beacons	All	24	24	51	34	24	24	51	34	Elvik & Vaa, 2004 Montella, 2009
Intersection traffic control	Retiming signal change intervals to ITE standards	All		12		8		12		8	Retting/et al, 2002
		Rear end		-8		-12		-8		-12	
		Angle		-6		4		-6		4	
		Veh/bicycle Veh/ped		37		39		37		39	
	Increase visibility of signals	All				8				3	Srinivasan/et al, 2008b; Sayed/et al, 2007
	Change from permissive or permissive/protected to protected-only phasing	All				1	Not applicable				Harkey/et al, 2008
		Left turn				99					
	New flasher installation	All				30				30	Srinivasan/et al 2008a
	New signal installation	All				23				23	Bahar/et al 2007 Gan/et al/2005
		Right angle				67				67	
		Rear end				38				38	
Road diet	Re-stripe 4 lane undivided to two lane with bicycle lanes	All				29				29	Tan, 2011

Notes: [1]KA = fatal and incapacitating injury crashes, [2]BC = non-incapacitating and possible injury crashes, [3]O = property-damage-only crashes.

A SNIP2 catalog of safety interventions includes the Crash Reduction Factors, the unit cost of the intervention (per mile, per mile-lane, or per intersection), and the relevant conditions (road and safety conditions that justify the intervention). SNIP2 reads one by one the relevant conditions and performs queries to find road locations where the intervention may be considered. The list of such locations for each safety intervention is saved and used in the next step – optimization of safety interventions in the optimization module.

3.2 Optimization Module

Once the safety needs (represented by the types of crashes, crash circumstances, etc.) and their geographic locations are identified, the next step is to select the best combination of relevant safety interventions that offer the largest safety benefits. This analysis may be done under unlimited or limited resources and at various levels of detail, ranging from large programs and intervention packages which are suitable for long-range Transportation Safety Planning to the level of individual projects identified based on road safety audits.

Optimization of the potential budget by applying interventions to address the safety issues has become an integral part of safety research by a number of authors. Turochy (2001) reported nine different methods of prioritizing transportation interventions (not only safety projects). The prevailing practice at that time was to apply performance measures, some were data-based and some were subjectively evaluated, with subjective weights to rank competing projects. These measures and weights varied considerably across investigated agencies. Pal and Sinha (1998) proposed an integer programming method to optimize safety improvement programs. This method minimizes the number of crashes while accounting for the budget constraints, the major cost components, and the effectiveness of the safety interventions; and it carries over unspent funds and safety impacts into future years. Kar and Datta (2004) proposed a simpler method of one-time budget allocation across a Michigan region (no time dimension.) The objective of the resource allocation was to maximize the average reduction

of crashes under the given budgetary constraint. These two examples of research publications proposed tools for implementation. Another study conducted by the Kentucky Transportation Center (2003) attempted to identify and prioritize high crash locations in need of safety improvement and to develop software to produce a generalized estimation of the benefits and costs based on the crash reduction factors and the present worth of the annual benefits. Two different computer software programs were generated as project outcomes. The first program uses a dynamic program model to select the optimal group of candidate projects given the limited budget; and the second program actually calculates the individual benefit and cost estimation of already selected projects. Lambert et al. (2006) proposed a combinatorial optimization that allows considering multiple quantitative and qualitative objectives. The decision-making process is based on a visualization of the problem to help participants of the planning process compare alternatives. This method may be useful when the number of alternative safety interventions is limited and the interventions have well defined scopes. Mishra and Khasnabis (2012) applied dynamic programming to program safety improvements at signalized intersections. The results indicated a large computational demand for solving the dynamic programming problem. It seems that applying this approach to large non-linear problems is not feasible, at least today.

The use of dynamic programming for time-specific investments presents two issues that are difficult to solve: (1) computational demand that leads to infeasible computational time (weeks or months) and (2) specific input requirements that may not be available in strategic planning. The proposed SNIP2 optimization approach utilizes annualized benefits and costs, thus eliminating the time dimension. The objective of the program, which can be classified as a non-linear knapsack problem, is to maximize the safety benefit under a fixed budget and other constraints:

$$\max_{\{X\}} \sum_{j \in J} \sum_{h \in H} A_{jh} \prod_{i \in I_j} \left(1 - X_{ij} \cdot F_{ijh}\right)$$

subject to

- total annual cost (annualized capital and maintenance costs) cannot exceeds the annual safety budget

$$\sum_{j \in J} \sum_{i \in I_j} X_{ij} \cdot C_{ij} \leq B$$

- mutually exclusive interventions constraint at a road site (for example, building a modern roundabout eliminates installing signals from viable interventions for that intersection)

$$\sum_{m,n \in I_j} X_{mj} \cdot X_{nj} \leq E_{mn}$$

where:
A_{jh}= total cost of crashes of severity h at location j,
B = total budget,
C_{ij} = cost of intervention i at location j,
E_{mn} = 1 if interventions m and n cannot be applied at the same location, = 0 otherwise,
F_{ijh} = crash reduction factor for countermeasure i, crash severity h, and location j,
H = set of considered levels of crash severity,
I_j = set of interventions justifiable at location j,
J = set of considered locations,

X_{ij} = 1 if intervention *i* is applied at location *j*, = 0 otherwise.

This class of optimization problems: non-liner integer, convex, and non-separable knapsack is difficult to solve and has not been well researched (Bretthauer and Shetty, 2002). We consider two alternatives in our approach:

1. Linearization of the problem by forming all possible combinations of relevant improvements for each location and adding a constraint that no more than one combination can be used at a location. The combining of relevant interventions addresses the mutually exclusive interventions constraint. The problem then can be solved using one of the existing algorithms. The computational time is the major concern.
2. Using a heuristic method with greedy search and with the budget constraint relaxed. The current value of an intervention is represented by its benefit-cost ratio at the time of consideration. It should be mentioned that the value of an intervention reduces if other interventions have already been selected for the location (decreased number of crashes). The intervention selection process addresses the mutually exclusive interventions constraint. Two approximate solutions (one with underutilized budget and one with budget exceeded) are obtained. The accuracy of the solution is the major concern.

4 ENVISIONED APPLICATION OF SNIP2

It is expected that an integrated approach to safety management including road and user perspectives, multiple transportation modes, and various safety stakeholders will increase the effectiveness of safety management and will reduce costs. Indiana has made a significant effort in the area of traffic and safety data integration, by establishing a Traffic Records Coordinating Committee (TRCC), composed of major state agencies that include transportation, vehicle records, criminal justice, enforcement, and health organizations, which holds scheduled meetings throughout the year.

The next logical step for Indiana is an inter-agency coordination effort to evaluate safety needs and to define focus areas. The two key players in determining state strategic safety programs (the Indiana Department of Transportation (INDOT) and the Indiana Criminal Justice Institute (ICJI)) currently formulate their programs separately from each other, which leads to overlaps, omissions, and incorrect prediction of effectiveness. Our Center on Road Safety has been working on a comprehensive approach that provides a common ground for the involved agencies and can potentially promote better communication between them.

Development of this comprehensive method of identifying road safety needs and its implementation via SNIP was a necessary first step. Although its implementation focuses on road–related needs, the concept can be applied to any safety problem and is only limited by the data availability. The second step is underway (SNIP2), which supplements the identification of safety needs with identification of relevant improvement programs that meet certain optimization criteria. The limits on improvement programs are imposed by the availability of such programs and their effectiveness. These two efforts have been funded by INDOT. The concept of the tool was presented at the TRCC meetings and it has attracted interest from ICJI.

Further expansion of the SNIP2 method by including a road user-oriented component represented by safety problems involving dangerous behavior and high-risk road users (speeding, drunken driving, texting, other driving distractions, motorcyclists, young drivers, motor-carriers, etc.) and corresponding safety improvement programs (regulations, licensing, education, and

enforcement). These programs are typically the focus areas of criminal justice and enforcement organizations.

A common platform of analyzing infrastructure-related and road user-related safety needs and improvement programs will provide the involved agencies with a means of communicating these needs and solutions, which will allow building consensus based on joint analysis of the solutions and the effects, overlapped geographically and in time. At the same time, the proposed approach does not require modifications of the status quo of the involved organizations, but rather provides an interface or a means for better interactions between them. This new approach might become a model solution for other states.

5 CLOSURE

The SNIP2-generated list of safety interventions that match the identified safety needs are valuable input to strategic safety planning and may also be useful for asset management. SNIP2 is useful in at least two situations:

1. The need to define performance-based safety goals set forth for a certain period (i.e., selecting what the safety emphasis areas should be and which would be the most effective safety interventions relevant to these areas).
2. The implementation of a road improvement program for a certain period. This program would be the result of a project selection process that includes the impacts of congestion and safety as well as the economic effects. In this case, the safety benefits would be generated by the proposed program alone.

The proposed SNIP2 can be viewed as a platform for inter-institutional coordination as the same approach of identification of safety needs and focus areas can be applied by various agencies involved in safety management. Consequently, the combined effects of various improvements applied in the same areas can be better predicted and complementary improvements identified. A more balanced strategic safety improvement plan and more efficient allocation of state safety funds could result from the use of SNIP2.

A considerable amount of research is needed to develop a practical method of solving the optimization problem. It seems that a heuristic approach of greedy search that satisfies the constraints only approximately may be a feasible solution.

DISCLAIMER

The contents of this paper reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Indiana Department of Transportation or the Federal Highway Administration at the time of publication. This report does not constitute a standard, specification, or regulation.

REFERENCES

Bahar, G; Masliah, M; Wolff, R and P. Park (2008). Desktop Reference for Crash Reduction Factors, Report FHWA-SA-08-011, Washington, D.C., 2008

Bretthauer, K.M. and B. Shetty (2002). “The Nonlinear Knapsack Problem – Algorithms and Applications.” European Journal of Operational Research Vol. 138, pp. 459–472.

Chandler, B., "Eliminating Cross-Median Fatalities: Statewide Installation of Median Cable Barrier in Missouri." TR News, No. 248, Washington, D.C., Transportation Research Board of the National Academies, (2007) pp. 29-31.

CRS and INDOT (2010). "2010 Indiana Five Percent Report." Indiana Department of Transportation and Center for Road Safety, Purdue University.

Donnell, E.D., R.J. Porter, and V.N. Shankar (2010). "A Framework for Estimating the Safety Effects of Roadway Lighting at Intersections." TRB 89th Annual Meeting Compendium of Papers CD-ROM. Washington, D.C.

Elvik, R. and Vaa, T. (2004). Handbook of Road Safety Measures. Oxford, United Kingdom, Elsevier.

Highway Safety Research Center (2012). *Crash Modification Factors Clearinghouse*. University of North Carolina, http://www.cmfclearinghouse.org/, last visited on Dec 14, 2012.

Hovey, P. W. and Chowdhury, M. (2005). "Development of Crash Reduction Factors." 14801(0), Ohio Department of Transport.

Fitzpatrick, K. and E.S. Park (2010). Safety Effectiveness of the HAWK Pedestrian Crossing Treatment, FHWA-HRT-10-042, Federal Highway Administration, Washington, DC.

Gan, A., J. Shen, A. Rodriguez (2005). "Update the Florida Crash Reduction Factors and Countermeasures to Improve the Development of District Safety Improvement Projects, pp.39.

Harkey D.L., R. Srinivasan, C. Zegeer, B. Persaud, C. Lyon, K. Eccles, F. Council, H. McGee (2008). NCHRP 617: Accident Modification Factors for Traffic Engineering and ITS Improvements. Transportation Research Board. Washington, D.C.

Harwood, D. W., K. M. Bauer, I. B. Potts, D. J.Torbic, K. R.Richard, E. R. Rabbani, E. Hauer, L. Elefteriadou, and M.S Griffith, (2003). "Safety Effectiveness of Intersection Left- and Right-Turn Lanes." 82nd Transportation Research Board Annual Meeting, Washington, DC.

Kar, K. and T.K. Datta (2004). "Development of a Safety Resource-Allocation Model in Michigan." Transportation Research Record 1865, pp. 64-71.

Kentucky Transportation Center (2003). "Development of Procedures for Identifying High-Crash Locations and Proritizing Safety Improvements." Kentucky Transportation Center, University of Kentucky, Research Report KTC-03-15/SPR250-02-1F.

Lambert, J.H., K.D. Peterson, and N.N. Joshi (2006). "Synthesis of Quantitative and Qualitative Evidence for Accident Analysis in Risk-Based Highway Planning." Accident Analysis and Prevention 38, pp. 925–935.

Mauga, T. and Kaseko, M. (2010). "Modeling and Evaluating the Safety Impacts of Access Management (AM) Features in the Las Vegas Valley." Presented at the 89th Annual Meeting of the Transportation Research Board, Washington, DC.,

Mishra, S. and S. Khasnabis (2012). "Optimization Model for Allocating Resources for Highway Safety Improvement at Urban Intersections." ASCE Journal of Transportation Engineering, Vol. 137, No. 5, 2012, pp. 535-547.

Monsere, C. Bertini, R.L., Breakstone, A. (2006). "Update and Enhancement of Oregon Department of Transportation's Crash Reduction Factors." Oregon Department of Transportation, FHWA-OR-RD-06-11, Salem Oregon.

Montella, A. (2009). "Safety Evaluation of Curve Delineation Improvements: An Empirical Bayes Observational Before-After Study." TRB 88th Annual Meeting Compendium of Papers CD-ROM. Washington, DC.

Pal, R. and K.C. Sinha (1998). "Optimization Approach to Highway Safety Improvement Programming." Transportation Research Record 1640, pp.1-9.

Park, E.S., J. Park, and T.J. Lomax (2010) "A Fully Bayesian Multivariate Approach to Before–After Safety Evaluation." Accident Analysis & Prevention, Vol.42, No. 4, pp. 639 1118-1127.

Parker, M. R. Jr. (1997). "Effects of Raising and Lowering Speed Limits on Selected Roadway Sections." FHWA-RD-92-084, Federal Highway Administration, Washington, DC.

Park, Y.-J. and F.F. Saccomanno (2005). "Collision Frequency Analysis Using Tree-Based Stratification. Transportation Research Record 1908, pp. 121-129.

Persaud, B.N., R.A. Retting, and C. Lyon (2003). "Crash Reduction Following Installation of Centerline Rumble Strips on Rural Two-Lane Roads." Accident Analysis & Prevention, Volume 36, Issue 6, November 2004, Pages 1073–1079

Retting, R.A. and Chapline, J.F. (2002). Changes in Crash Risk Following Re-Timing of Traffic Signal Change Intervals. Accident Analysis and Prevention 34/2: 215-220.

Sayed, T., M. El Esawey, and J. Pump (2007). "Evaluating the Safety Impacts of Improving Signal Visibility at Urban Signalized Intersections." TRB 86th Annual Meeting Compendium of Papers CD-ROM, Vol. TRB#07-135, Washington, DC., (2007)

Schoon, C. and J. van Minnen (1994). "The Safety of Roundabouts in the Netherlands." Traffic Engineering & Control, Vol. 35, No. 3, London, United Kingdom, Hemming Information Services, pp. 142-148.

Srinivasan, R., Carter, D., Persaud, B., Eccles, K., and Lyon, C. (2008a). "Safety Evaluation of Flashing Beacons at Stop Controlled Intersections", Presented at the 87th Annual Meeting of the Transportation Research Board, Washington, D.C.

Srinivasan, R., F. Council, C. Lyon, F. Gross, N. Lefler, and B. Persaud (2008b). "Evaluation of the Safety Effectiveness of Selected Treatments at Urban Signalized Intersections." TRB 87th Annual Meeting Compendium of Papers CD-ROM. Washington, DC.

Srinivasan, R., J. Baek, D. Carter, B. Persaud, C. Lyon, K. Eccles, F. Gross, and N. Lefler (2009). "Safety Evaluation of Improved Curve Delineation." Report No. FHWA-HRT-09-045, Federal Highway Administration, Washington, DC.

Tan C.H. (2011). "Going On A Road Diet: Lane Reduction Can Increase Safety For Pedestrians, Bicyclists, And Motorists While Improving The Quality Of Life In Downtowns Across The Country," Public Roads, U.S. Federal Highway Administration (www.fhwa.dot.gov); at www.fhwa.dot.gov/publications/publicroads/11septoct/05.cfm.

Tarko, A. P., M. A. Iqbal, M. A. Inerowicz, H. Liang, and G. Panicker. Safety Conscious Planning in Indiana: Predicting Safety Benefits in Corridor Studies, Volume 1: Research Report. Publication FHWA/IN/JTRP-2006/21-1. Joint Transportation Research Program, Indiana Department of Transportation and Purdue University, West Lafayette, Indiana, 2007.

Tarko, A.P., S. Azam, M. Romero, J. Thomaz (2011). "Identifying Traffic Safety Needs – A Systematic Approach," Joint Transportation Research Program, Final Draft Report, Purdue University.

Turochy, R.E. (2001). Prioritizing Proposed Transportation Improvements Methods, Evaluation, and Research Needs. Transportation Research Record 1777, pp. 123-128.

Xu, L. (2001). "Right Turns Followed by U-Turns Versus Direct Left Turns: A Comparison of Safety Issues." ITE Journal, Vol. 71, No. 11, Institute of Transportation Engineers, pp. 36-43.