**GLOBAL APPROACHES TO SETTING SPEED LIMITS**

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## ABSTRACT

Static maximum speed limits are set to inform motorists of appropriate driving speeds under favourable conditions, and are almost always enacted with an overarching goal of increasing safety while retaining reasonable mobility. The first speed limits actually predate the automobile, and as such they have a long and varied history in protecting the traveling public. Today, the speed limit is by far the most popular tool used by engineers and traffic engineering professionals to manage travel speeds. Besides being a popular Canadian road safety tool, speed limits are almost universally employed by all motorized countries. Despite the long and wide-spread use of speed limits as a road safety tool, there are numerous speed limit setting methodologies, and there is no consensus in the traffic engineering community on a single speed limit setting methodology. While there are literally countless guidelines/methods for setting speed limits, these methods can be roughly categorized into four general approaches. The purpose of this paper is to outline the four general approaches to setting speed limits that are available to the transportation engineering community, and to discuss the strengths and weaknesses of each. The four approaches to setting speed limits are the **engineering approach** (including the traditional use of the 85$^{th}$ percentile speed, and the road risk methodology), the **expert system approach** (including VLIMITS, USLIMITS), **optimization** (using speed limits to minimize the total societal costs), and the **safe system approach** (linking road types and crash types to travel speeds).



## INTRODUCTION

Setting maximum speed limits is a common technique used by almost all road authorities that has a long and storied history. In fact, legislated maximum speed limits actually precede the automobile by about 200 years when Newport, Rhode Island prohibited the “galloping” of horses on major thoroughfares, and Boston, Massachusetts limited horse-drawn carriages to “foot pace” on Sundays. The world’s first speed limit for mechanically-propelled vehicles was enacted in 1861 in the United Kingdom. At that time, automobiles were propelled by steam power, and were deemed “light locomotives”. The Locomotive Act of 1861 limited the speed to 10 mph (16 km/h) on public highways, and 5 mph (8 km/h) through any City, Town, or Village. (1). The Act was amended four years later to set lower speed limits of 4 mph (6 km/h) outside of towns and 2 mph (3 km/h) within them. These new operating speeds also required three operators for each vehicle – two travelling in the vehicle and one walking ahead and carrying a red flag to warn pedestrians and equestrians. (2)

Today the world’s highest maximum speed limits include 140 km/h speed limits on Polish freeways, and 150 km/h on the autostrade in Italy. The highest permitted speed limit in Canada is 110 km/h. The only roads in highly motorized areas that do not have maximum (numerical) speed limits are sections of the autobahn in Germany, and some roads on the Isle of Man.

Static speed limits inform motorists of the maximum appropriate operating speeds *under favorable conditions*. Speed limits come in two varieties: statutory speed limits and individual speed zoned regulations (usually established on the basis of site-specific studies).

**Statutory Speed Limits**

Statutory limits are colloquially known as "blanket" or "default" speed limits and are established under the principle that a single preset speed limit is applicable (and safe) for all roads in a certain category or classification. Statutory speed limits are always in effect, even when the road authority does not post them. Statutory speed limits in any jurisdiction are either "absolute limits" or "prima facie" limits – the difference being whether a person can contend a charge of driving over the speed limit. With an absolute speed limit, it is unlawful to drive above the limit for any reason; with a prima facie speed limit, drivers operating above the speed limit may argue that their speed was safe for the prevailing conditions, that their actions were reasonable, and that they are not guilty of a speed limit violation. Statutory speed limits are an important part of an overall speed management program, but they are not the subject of this paper.

Statutory speed limits are a rather broad brushed approach to setting speed limits, and use only basic criteria for such an important decision. For example, the Newfoundland and Labrador Highway Traffic Act (3) prescribes the following Statutory speed limits for roads:

> *Except where a higher or lower speed limit is prescribed by this Act or the regulations or by a traffic sign prescribed by the Minister of Works, Services and Transportation or by regulations made by a council, a driver shall not drive a vehicle at a speed greater than*
>
> *(a) 100 km/h on paved portions of the Trans-Canada Highway;*
> *(b) 80 km/h on paved highways other than the Trans-Canada Highway;*
> *(c) 60 km/h on gravel highways; or*
> *(d) 50 km/h*
> *(i) through settlements,*
> *(ii) when passing a school building or the grounds of school buildings between 8 a.m. and 5 p.m. on days when school is in session, or*
> *(iii) when passing a church, theatre or other place of public assembly or its grounds while people are entering or leaving it.*

The above statutory speed limits take into consideration road surface type, pedestrian activity (schools, churches, and places of assembly), and whether the facility is a part of the Trans-Canada Highway. It should be evident that there are situations where specific road, traffic or land uses conditions suggest that a safe and prudent speed is different (higher or lower) from the statutory limit. In these situations, the road authority also is permitted to establish a reasonable and prudent speed resulting in what is commonly called a "speed zone". The maximum speed limit in a speed zone must still be established by legislation, and is selected based on an engineering or similar type of study.

## APPROACHES TO SETTING SPEED LIMITS

The objective of a speed limit is to provide safety while retaining reasonable mobility. The only exception to the safety objective is a few instances where speed limits were altered as a means of fuel conservation. This latter and less prevalent objective was used in the United States in the 1970s, and more recently in Spain in early 2011 (4). The Spanish dalliance with lower speed limits for fuel conservation lasted only four months.

Although it is universally accepted that speed limits are first and foremost a tool for safety, the methodologies and techniques used for setting static maximum speed limits are wide and varied. The differences are generally related to the different interpretations concerning the complex interaction between road infrastructure (including the context), speed, and crash risk.

Having stated the above, the global approaches to setting maximum speed limits can neatly be organized into four groups: engineering approaches, expert systems, optimization methods, and safe systems approaches. Each of these groups is outlined in the following sections.

**Engineering Approach**

Engineering approaches to setting speed limits are so-called because road infrastructure and traffic conditions heavily factor into the decision criteria. Most engineering approaches are a two-step process where:

1. An initial reference speed is set by considering the 85$^{th}$ percentile speed, the design speed, and/or other criterion, and
2. The reference speed is adjusted according to traffic and infrastructure conditions to establish a recommended speed limit.

Engineering approaches to setting speed limits seem to be the most widely-used, have apparently been around the longest, and as a result have the most variants. Nonetheless, there are similarities in the underlying mechanics of each variant which allows categorizing the myriad of engineering approaches to setting speed limits into two groups: operating speed methods, and road risk methods.

*Operating Speed Methods*

Operating speed methods to setting speed limits follow the two-step engineering approach described above, using the 85$^{th}$ percentile speed – the speed at which 85 percent of free-flowing traffic is traveling at or below – as the initial reference speed. The factors that are considered when adjusting the speed for site-specific conditions vary from agency to agency, but include such things as horizontal and vertical alignment, type and density of accesses, pedestrian activity, and cross-section design.

Setting a speed limit in accordance with the 85$^{th}$ percentile speed is premised on safety research that concluded traveling at or around one standard deviation above the mean operating speed (approximately the 85$^{th}$ percentile speed) yields the lowest crash risk for drivers. Therefore, a speed limit coincident with the 85$^{th}$ percentile speed encourages motorists to travel at the safest speed. The operating speed method based on the 85$^{th}$ percentile speed is also attractive because it reflects the collective judgment of motorists as to a reasonable limit for roadway. Assuming that the majority of motorists are acting reasonably, this aligns with the legislative objective that laws (i.e., speed limits) should not make people acting reasonably into law-breakers. The use of the 85$^{th}$ percentile speed as the primary criterion for selecting a suitable speed limit also satisfies the legal concept that a law cannot be effectively enforced without the consent and voluntary compliance of the public majority. Finally, the operating speed method is advantageous in that the speed limit will provide residents, businesses, and pedestrians with a realistic representation of actual vehicular speeds on the street.

While the operating speed method for setting speed limits is prevalent, there are relatively few road authorities that have quantitative criteria for completing step 2 of the speed limit setting process – adjusting the 85th percentile speed. For example, how much should a speed limit be adjusted if the street has a painted median, or no sidewalks?

Criticisms of the operating speed method of setting speed limits are mainly levelled at the core assumption that the 85th percentile speed is a sound basis on which to base a speed limit. To begin with, there is an inherent assumption that the vast majority of motorists can self-select a safe operating speed because each individual is aware of the collision risk factors present, is adept at assessing these factors, and can reflexively select the safest operating speed. Even if this assumption is valid, the research has clearly shown that motorists are typically poor at accounting for the externalities of their driving. In other words, while the selected speed is appropriate for motor vehicle travel, the impact of that operating speed on others (i.e., pedestrians, residents, etc.) are generally underestimated (or not considered) and may create an inequity in the safety of different road users, and unacceptable quality of life impacts for residents and businesses.

A further criticism against the operating speed method of selecting a speed limit is that this practice creates an upward drift or creep in average operating speeds over time. An example of this drift is shown in Figure 1. In this example, an in-service facility has a posted speed limit of 60 km/h, and it is due to be reconstructed. The road authority selects a design speed of 70 km/h (10 km/h over the posted speed limit), and reconstructs the road accordingly. The operating speeds subsequently increase in response to the improved road design, and under an operating speed method the speed limit is increased to 70 km/h. Repeating this process results in a slow, long term increase in operating speed called the *speed limit spiral*.

Perhaps the greatest criticism of the operating speed method of setting speed limits is the erroneous assumption concerning the relationship between operating speed and crash risk. The traditional U-shaped curve (see Figure 2) that has influenced so much of the decision-making on speed limits is based on older research that has some methodological shortcomings, and does not stand up under careful scrutiny. In particular, the U-shaped relationship between speed and crash risk is questionable because of:

- Errors in the measurement of speed during the initial research (5, 6); and
- The strong correlation between mean speed and speed variance makes it difficult to separate the effects of mean speed and speed variance on crash risk (7).

The true relationship between speed and crash risk is a direct correlation – increases in speed, increases crash risk. This relationship is based on statistically sound and methodologically robust analysis to determine causation and not just correlation (8, 9). Figure 3 shows the crash modification factors for fatal, injury, and property damage only crashes as the operating speed increases from 50 km/h.

*Road Risk Methods*

Also an engineering approach to setting speed limits, the road risk method considers the risks associated with the physical design of the road, the setting, and the expected traffic conditions generally without factoring in the operating speed of the facility. This method also follows the two-step engineering process but ordinarily uses the functional classification of the road (which also tends to direct the design of the road) to establish the initial reference speed, and adjusts it based on the relative risk introduced by various road and roadside design features.

In 2009 the Transportation Association of Canada issued the "Canadian guidelines for establishing posted speed limits" (10) in an attempt to develop current and comprehensive Canada-wide guidelines that provide a systematic, consistent, and repeatable process for establishing posted speed limits. The TAC guidelines for setting speed limits use a road risk methodology.

Under the road risk method the initial reference speed, and hence the ultimate speed limit, is derived from the function of the road and the level of roadside development. This approach is appealing because individual roads have specific objectives concerning mobility, access, and accommodation of different road users, and these objectives are neatly reflected in the functional classification and the roadside development (or setting). So there is a direct connection between selecting a speed limit and the overall functional objectives of the road.

Because the road risk methods are not considerate of operating speeds, there can be instances where the majority of operating speeds on a road exceed the speed limit. These situations are untenable since effective laws require largely voluntary compliance (as previously discussed). In these situations, road risk methodologies require engineering techniques be used to lower vehicle speeds.

At the end of the day, engineering approaches (both operating speed and road risk methods) to setting speed limits are intuitively appealing and have been accepted in many jurisdictions globally. The troubling thing about this is that the engineering approach purports to enhance safety, but there have not been any conclusive studies that support the assertion. We simply don't know if a speed limit set according to an engineering approach is safer than any other speed limit.

**Expert System Approach**

Expert systems attempt to replicate the expert's thought process in solving complex problems. They offer a method of problem solving that is structured and repeatable, and well-suited to a problem such as selecting appropriate speed limits. Typically, an expert system contains a knowledge base containing accumulated knowledge and experience (knowledge base), and a set of rules for applying the knowledge to each particular situation (the inference procedure). Expert systems are generally computer-based.

Speed limits set by expert systems and engineering methods are methodologically similar, with the engineering approach often consisting of a limited study, and the expert system approach using a more involved and structured set of decision and judgment rules.

The original expert system for setting speed limits (VLIMITS where the "V" is for VicRoads the road authority in the State of Victoria, Australia) was developed by the Australian Road Research Board, based on site studies at over 60 locations. The field data were reviewed by a panel of experts who used this information to come up with decision rules for appropriate speed limits for different types of roads and traffic conditions. This information was coded into a computer program which prompted users to respond to a series of questions, which the system used to recommend a speed limit. It is important to note that the Australian expert system logic is hard coded, and the system does not learn with previous experience, as some expert systems do.

The most recent attempt at an expert system approach to setting speed limits is USLIMITS2 – the second American iteration of an expert system. (11) FHWA has developed a knowledge-based expert system for recommending speed limits in speed zones that are considered to be credible and enforceable. The system is based on results from research, responses from practitioners to hypothetical case studies, input from experts, and lessons learned from the first generation expert system.

USLIMITS2 calculates a speed limit using an operating speed methodology as discussed earlier in this paper. The recommended speed limit is heavily influenced by the 85th percentile speed, but also considers:

- The crash and injury rate as compared to the critical and average crash rates;
- Interchange spacing and AADT (on freeways);
- The roadside hazard rating (for road sections in undeveloped areas); and
- Pedestrian/bicycle activity, presence/usage of on-street parking, number of traffic signals, and the number of driveways and unsignalized access points (for road sections in developed areas).

The expert system does not recommend speed limits higher than the 5 mph (8 km/h) increment closest to the 85th percentile speed; it also does not recommend speed limits lower than the 5 mph (8 km/h) increment closest to the 50th percentile speed. The system also provides warnings if the 85th percentile speed is unusually low or high for a particular road type.

Again, there is a missing link between the outcomes from the expert system and speed. It is simply not known whether the speed limits recommended by the expert system result in a lower crash risk.

**Optimization**

Optimal speed limits are set by assessing the total societal impacts of operating speeds, and setting the speed limit to minimize those impacts. The optimum speed limit is the speed limit that yields the minimum total cost of travel when considering vehicle operation costs, crash costs, travel time/delay costs, and other social costs. This method of setting speed limits is congruent with and considerate of overall transportation objectives, considers non-motorized road users in a meaningful way, and is thus appealing from a context sensitive solutions perspective.

Setting optimal speed limit starts with identifying the various costs that are contingent on operating speed, and obtaining cost models for each of the underlying factors. Typical costs include those from crashes, person/vehicle delay, fuel consumption, and vehicle emissions. The costs models are used to determine the cost for each factor under the range of feasible speed limits. These results are than assembled into a total cost for each speed limit expressed as a cost per unit length of travel. The optimal speed limit is the speed limit with the minimum total cost to society.

A schematic for an optimization approach to setting speed limits is shown in Figure 4.

Optimal speed limits have been explored for use on shared-use roadways in New Jersey. (12) This method of setting speed limits seems particularly useful in situations where pedestrians, cyclists, and motorized traffic share the road and motorists may not be fully aware of the externalities of speed on other road users – in particular the harm borne by pedestrians and cyclists when struck by a motor vehicle moving at a rapid speed.

Determining socially optimal speed limits is more complicated than calculating speed limits that have been optimized for the individual driver. Moreover, setting speed limits using optimization techniques is rarely used because of the difficulty of quantifying key variables.

As with any multifaceted system, optimization is dependent on value judgements of the analyst and the quality of the data available. For example, the societal cost of noise caused by motor vehicle operation is a value judgement that is generally established through stated preference surveys of different groups (e.g., motorists, local residents, etc.). Additionally, optimization models require significant data – both as an input for each road, and in order to develop or calibrate the various prediction models that are the heart of the system.

In general the road user perspective and the taxpayer perspective result in the highest speed limits, the residential perspective in the lowest. In some cases, in particular for freeways, the variation in the total costs of travel is found to be very small for speeds in the range of 70 to 110 km/h, almost making the choice of an optimal speed limit in this range an individual agency preference.

In addition to the above-noted issues with the optimization approach to setting speed limits, it is possible that the optimized speed limits may not appear rationale or realistic to motorized road users, as they may not be congruent with the design of the road. This would likely result in an inordinate percentage of drivers exceeding the speed limit, and an untenable burden on enforcement personnel.

The concept of setting optimal speed limits has been studied by some jurisdictions, but to the authors knowledge has not been adopted by any road authority.

**Safe Systems**

The safe systems approach (also known as an injury minimization approach) to setting speed limits is based solely on a road safety platform, and advocates that it is unethical to legally permit operating speeds that create situations where fatalities are a likely outcome of a crash simply to reduce delay/fuel consumption, or achieve other societal objectives. The safe systems approach uses basic physics, and knowledge gained from vehicle crash tests and crash reconstructions to develop speed limits that minimize the likelihood of a fatal or serious injury crash.

The human body was never designed to travel faster than it could be propelled under its own power (i.e., foot speed). So from the start the tolerance of the human body to absorb impacts/energy, and typical highway speeds are mismatched. This mismatch has been somewhat mitigated by crumple zones, air bags, collapsible steering wheels and the other pro-safety features of motorized vehicles. However, these mitigating measures are insufficient to eliminate the incongruity and the tolerance of the human body remains a critical factor in determining the outcome of any crash.

The safe systems approach to setting speed limits, caps legal speeds to those that are unlikely to cause severe harm or injury to all road users. In this regard, a safe systems approach is directly aligned with Vision Zero type programs and makes the goal of no deaths from motor vehicle crashes achievable.

The key to the safe systems approach to speed limits is to manage crash energy so that no user is exposed to impact forces capable of causing death or serious injury. This is accomplished by considering the types of collisions that are likely to occur on a facility, and the maximum speed that will reasonably ensure survivability. The types of crashes probable for any situation are based on the road design (intersection type, alignment, etc.), traffic volume and types of road users permitted, and collective crash statistics. For example, it is reasonable to expect right-angle crashes on an urban collector road, but not on a freeway where access is controlled. The maximum speed at which a crash configuration is reasonably survivable is derived from vehicle crash testing, and crash reconstructions.

Under the current Canadian road system and fleet, speed limits in a safe system would be similar to the speeds shown in Table 1.

A safe system strategy does not imply that crashes are caused solely (or even mainly) by speed and recognizes that any given crash event is likely to be the result of an interplay of many factors. Accordingly, a safe system approach requires all aspects of the transport system to work together for the safest possible outcomes, with speed representing but one component, albeit a critical one.

The injury minimization approach to speed limit setting results in lower speed limits than those traditionally used in most Canadian jurisdictions (which are generally set by engineering and expert system methods). Thus, should a road authority want to implement an injury minimization approach to speed limits, it will be problematic at first. The road authority cannot simply lower the speed limit and expect immediate or substantial compliance. Drivers are unlikely to fully respond except in the face of almost constant enforcement.

Speed limits need to be credible – they must generally reflect driver expectancies respecting travel speed. So while a obtaining safe travel speeds is the prime objective of the injury minimization approach (as well as the major challenge), it needs to be recognized that many jurisdictions need to understand they are starting from a point where expectancies result in operating speeds that are higher than the target speeds.

In order to achieve safe speeds and make the associated speed limits credible for the driving population, road authorities will need to:

- Make the road and its environment more "self-explaining" through traffic control devices, publicity and education campaigns, and reconstruction where required; and
- Build a case over time for a new paradigm as to what is regarded and legislated as a safe speed limit for the street network.

## DISCUSSION

Speed limits are a cornerstone of a speed management program, and are the most often used tool in the engineering toolbox. The long history of speed limits has shown that managing speed by legislating maximum speeds has almost always been for the sake of improved safety. Several methods and techniques for setting speed limits have been developed while being mindful of the safety objective.

The available methods (engineering, expert system, optimization, and safe systems), as might be expected, have certain appeal, strengths, and weaknesses. Engineering approaches and expert systems are intuitively appealing, optimization techniques provide consideration of overall system goals, and the safe system approach provides a clear line-of-sight between speed and injury. Having stated that, it is noted that despite the prime objective of safety, following the speed limit recommendations of any of these methods has not been proven to reduce crash risk.

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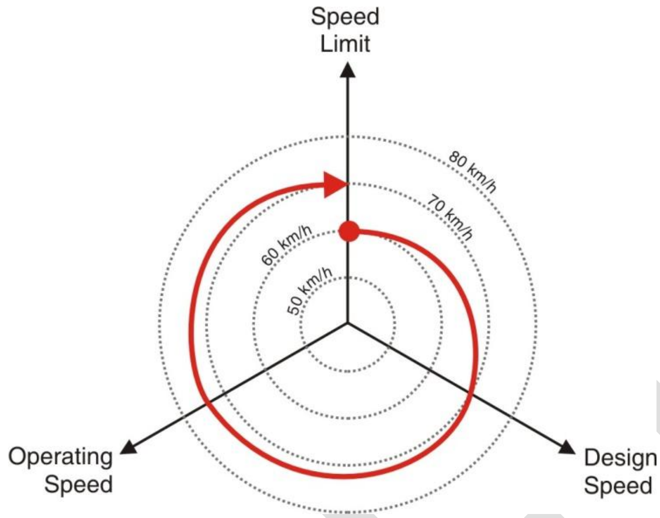


FIGURE 1: Speed Limit Spiral

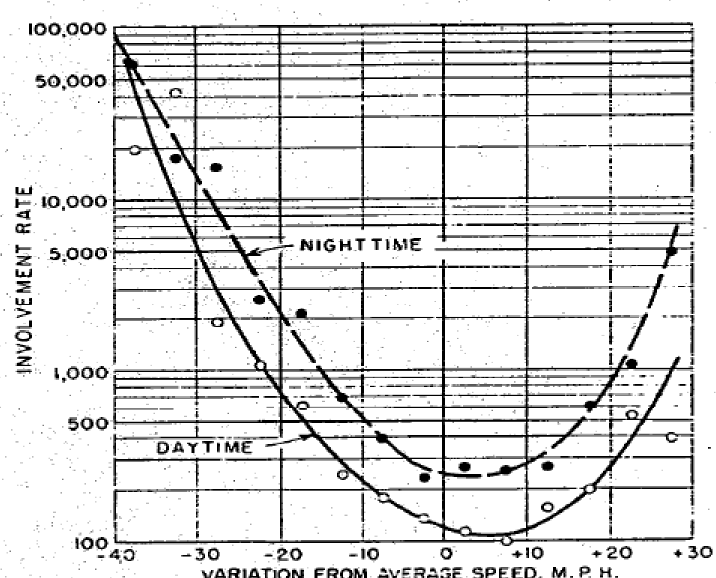


FIGURE 2: Solomon Curve Relating Speed to Crash Risk
(Source: Solomon D (1964) "Accidents on Main Rural Highways Related to Speed, Driver and Vehicle", US Department of Commerce & Bureau of Public Roads, Washington DC.)

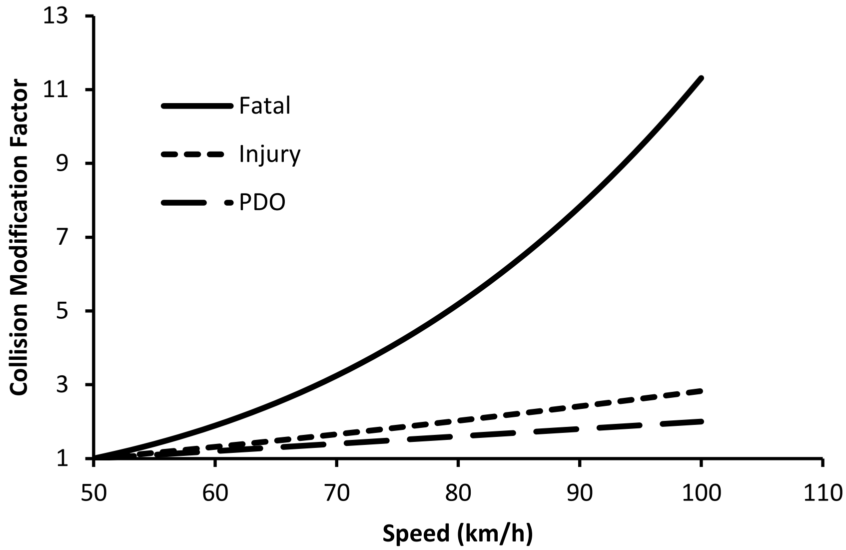


FIGURE 3: Relationship of Speed to Crash Risk

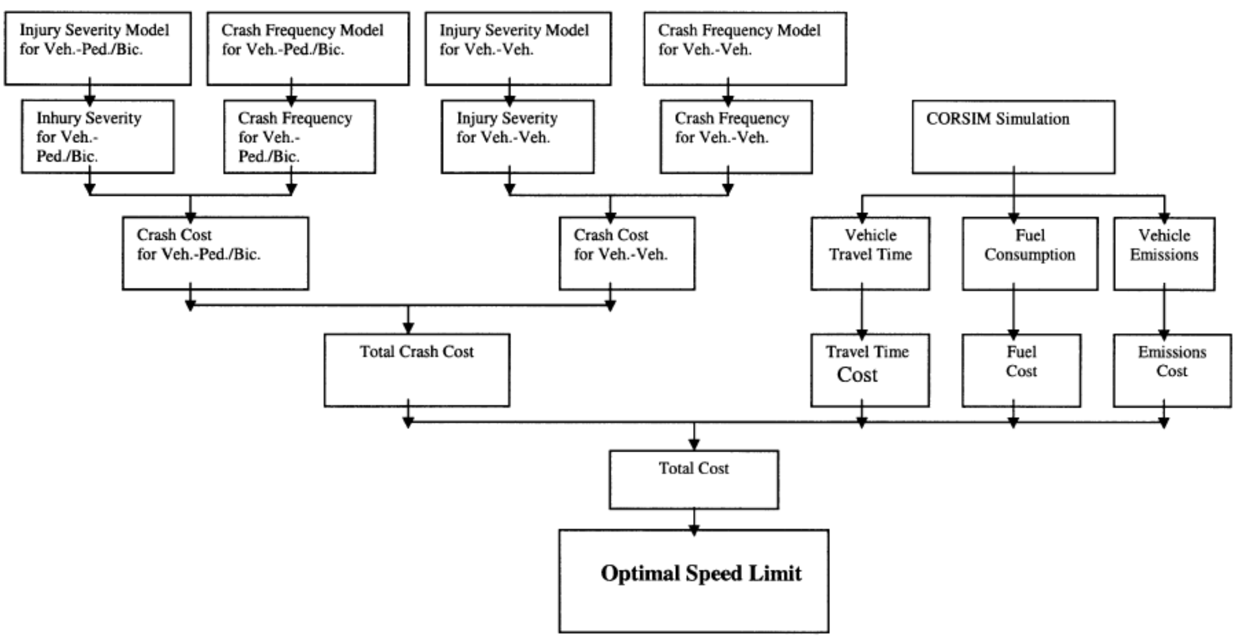


FIGURE 4: Process for Setting Optimal Speed Limits (Source 12)

Table 1: Recommended Speed Limits Under a Safe System

| Road type | Speed Limit (km/h) |
|---|---|
| **Roads with a mix of motorized and unprotected road users (i.e., pedestrians and cyclists)** | 30 |
| **Roads with uncontrolled access where side impact crashes can result** | 50 |
| **Undivided roads where head-on crashes can result** | 70 |
| **Controlled access facilities with a physical median separation, where at-grade access and non-motorized road users are prohibited** | >100 |