SIMULATING ROADSIDE SAFETY INSPECTION BENEFITS ENABLED BY ALTERNATIVE V2I PRESCREENING TECHNOLOGIES

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Introduction

Roadside inspection of commercial motor vehicles/trucks (CMV) check for overweight and unsafe vehicles. Inspections cause delays to vehicles which entail economic costs. There is a trade-off between the number and thoroughness of inspections, with attendant delay costs to the driver and vehicles, and the benefits of reductions in overweight damage, improvement in safety, reduction of security threats and efficient collection of taxes. This trade-off is made more efficient when road management can distinguish between vehicles that are more likely to be in violation of weight and safety requirements from those that are less likely. If low risk vehicles could be identified and not delayed, this would save time for those vehicles and make inspection more effective by concentrating on higher risk trucks. Prescreening is the process of evaluating a vehicle prior to its arrival to a fixed or mobile inspection location and deciding whether the vehicle should be called off the highway for inspection. This paper explores how alternative Vehicle to Infrastructure (V2I) prescreening technologies impact vehicle safety and productivity. A simulation model is developed and utilized to estimate the safety impact and to understand the interrelationships between technology choice, inspection capacity and the road safety inspection process.

Prescreening of commercial motor vehicles

Prescreening of CMVs is commonplace for enforcing size and weight regulations, particularly at fixed locations where weigh-in-motion (WIM) technology is utilized to estimate the weight of vehicles as they approach the fixed location and the estimate of the vehicle's weight determines whether the vehicle should be directed into the weigh station for further inspection or allowed to bypass the station. The operations, challenge and benefits of WIM for prescreening has the subject of numerous studies. Kamyab et al (1998), Glassco (1999), Gu et al (2004), Lee and Chow (2007), Sayed et al (2010), Lee and Chow (2011) and Lee et al (2013) are exemplary.

Safe CMVs is an important component of overall traffic safety. Roadside inspection of CMVs has long been recognized as an important accident prevention strategy and important to overall traffic safety. Fixed location CMV safety inspection stations typically coincide with weigh stations. The typical weight and safety inspection process starts from an overhead variable message sign (VMS) that communicates to approaching CMVs to keep in the right lane and whether the inspection scale station is open or not. If the inspection station is open, CMVs will drive through a static weigh scale at a low speed so that the inspectors can obtain an accurate measure of the vehicles' gross weight. During this time, inspectors will visually inspect the passing CMVs and use their experience and intuition to choose some of them for further physical and mechanical inspection. The inspector may also check the CMVs credentials, recent roadside inspection history, safety audit of the motor carrier and other relevant information by manually entering their license plate number or other form of identification. For example, the U.S. Federal Motor Carrier Safety Administration (FMCSA) monitors and ensures compliance with regulations governing both safety and commerce. CMV's operating as for-hire carriers are required to register for both a USDOT Number (safety) and a MC Number (commercial) and display these on their vehicles (FMCSA, 2016). This primary inspection may take less than half a minute and may be conducted without leaving the booth overlooking the vehicles as they pass by. This manual primary inspection process is thus a prescreening activity that determines whether a more in-depth secondary inspection is required.

A VMS or Green (continue to exit)/Red (go to inspection) signal is used to inform truck drivers of the inspector's decision after they have been weighed and pre-screened in this primary inspection. If a vehicle is chosen for secondary inspection, one of three Commercial Vehicle Safety Alliance (CVSA) levels of inspection is performed. The CVSA Level I inspection is the most detailed and time consuming physical inspection which could result in putting a CMV out-of-service (OOS) or the CMV removed from the road permanently. The time spent on the 37 steps of a Level I inspection takes about 40 minutes but can vary widely depending on the number of violations or defects that a truck actually has (Bridgestone, undated). After the inspection, the inspector will take corresponding actions based on the inspection results. Based on the number and types of violations that a CMV might have, this vehicle may be placed OOS or just issued a ticket with the corrective action stated on it.

This traditional primary and secondary inspection process is labor-intensive and combined with the capacity limitations of the inspection station constrain the ability of the inspection station to function by causing the station to close temporarily. The station's entry and exit ramps limit the number of trucks that can enter the station for primary inspection as the trucks may spill onto the highway, increasing safety risk. Within the inspection station, the queue into secondary inspection may be so long, that the station is also closed if an inspection cannot be performed in a reasonable time. Suspension of operations allows CMVs to bypass the scale until the queue is cleared. Alternatively, the secondary inspection can be closed with vehicles which normally would be directed to secondary inspection, allowed to continue with a notation recognizing this evaluation noted in the vehicle record.

The impact of prescreening for road safety has been less studied than for weight enforcement. (Brown et al, 2008; Lee and Chow, 2009; Chow, Lee and Waters, 2010) calculated various benefits of prescreening for road safety. All of these studies recognized that there were technological, institutional and economic barriers to effective implementation of prescreening for road safety. For weight regulation, WIM technology provides a fairly accurate and timely prediction whether a vehicle is likely to exceed the weight limit, for prescreening purposes. A similar physical measurement does not exist for measuring the physical condition of the truck or the driver. This may be changing as Wireless Road Inspection (WRI) technologies are being developed which can inspect critical vehicle conditions (i.e. brakes, tire pressure) and driver capacity (i.e. hours of service) electronically by V2I communications while the vehicle is on the highway (Cherry et al, 2012; Stephens and Petrolino, 2014). The implementation of WRI at this time is not sufficiently mature for deployment at this point (FMSCA, 2014). Instead, prescreening for roadside safety depends on being able to access multiple databases including vehicle registration, driving and safety records record (violations, previous roadside check and audits) and insurance. This information must be consolidated and evaluated to produce a safety risk rating that is used to determine which CMVs are high risk and should be asked to enter the safety inspection facility. This information can also include information about a vehicle that was recently inspected. Vehicles that were evaluated as high risk for a safety violation but allowed to bypass a station would be known at the next inspection station and receive high priority for a full secondary inspection. Conversely, a vehicle recently inspected and given a pass might be given an automatic pass at the next inspection station.

Prescreening process and V2I technologies

V2I technology is used to identify a CMV and transmit that information to the roadside inspection facility. These communication and sensing technologies operate as automatic prescreening filters. They are set up on roadside, get connected to the vehicles passing by, transmit information to processing center or process data by themselves, send out a recommendation regarding whether a deeper check should be undertaken, all of which happen within a second even before the vehicle has to wait in the ramp and enter the inspection station. The basic structure of a road safety prescreening system is the same irrespective of the V2I technology utilized to identify the vehicle.

Dedicated Short Range Communication (DSRC), Automatic License Plate Reader (ALPR), Commercial Mobile Radio Service (CMRS) systems are all technology based communication and identification solutions that enable prescreening. DSRC utilizes a specially allocated spectrum to realize communication between on board transponder and roadside receiver (Hossain et al, 2010; US DOT, 2010). An ALPR system takes a picture of the license plate or other visual identification to identify the vehicle and doesn't require any devices on vehicles. (Chow and Lee, 2009; Chow et al 2010). A CMRS system takes advantage of the smartphone network and uses an app on a cellphone to communicate between the vehicle and the system (Heath et al, 2012)

These three technologies are compared in Table 1. The key performance metric is net participation if implemented. Currently, DRSC and CMRS are voluntary programs while every vehicle has a license plate that can potentially be read by ALPR. Visibility is impacted by license plate visibility, lighting conditions and climate which in turn affect the accuracy of the identification. Hence ALPR cannot have 100% participation. DRSC and CMRS participation is dependent on the economic benefits which are primarily time savings from not having to stop for a primary inspection. There are numerous estimates of penetration and accuracy of these alternative systems but rather than pinpoint exact figures, we simply recognize that these technologies are capable of having participation ranging from 0% (the technology and prescreening is not implemented) to potentially 100%. Our approach is to estimate benefits for different levels of participation, recognizing that these levels would be achieved by using some combination or one of these technologies, with penetration being higher for ALPR than CMRS or DSRC in the current regulatory environment. This condition "current regulatory environment" could change if for example, government required transponder capability to receive and transmit DRSC be installed on all CMVs, resulting in greater potential penetration of DRSC.

A simulation model for assessing the safety benefits of prescreening

Prescreening can have multiple impacts:

- Time savings due to fewer "safe" trucks being delayed at inspection stations for primary inspections.
- Fuel savings due to fewer "safe' trucks being diverted into inspection stations and less idling in the inspection stations.
- Greater safety from fewer unsafe vehicles on the road that were taken off by being put out of service.
- More efficient use of inspection resources.
- Higher fine revenues.

This paper focuses on the additional vehicles put out of service (OOS) as a result of prescreening. Fewer unsafe vehicles lead to fewer accidents. We develop a simulation model of a typical medium size, fixed roadside inspection station in British Columbia to measure how prescreening participation and other factors impact the OOS rate.

An off the shelf discrete-event simulation model, ARENA, was chosen as the simulation engine for this analysis. This flexible, activity-based model facilitated the simulation and understanding of the multiple sub processes in the roadside inspection process. The logic and the sequence of events in the model is described below.

Table 1 Alternative V2I Technologies for Prescreening			
	Technology		
Characteristics	**Dedicated Short Range Communication (DSRC)**	**Advanced License Plate Readers (ALPR)**	**Commercial Mobile Radio Services (CMRS)**
Identification of vehicle	Transponder	License plate and other identifiers that can be read by camera	Application enabled device (e.g. smartphone)
Infrastructure needed	Roadside reader and transmitter	Camera and variable message sign	Uses Cellular network and infrastructure
Communication with vehicle	Through Red or Green light on Transponder	Through Variable Message Sign on roadway	Through application enabled device
Potential penetration	Voluntary	100%	Voluntary
Reliability	Immune to extreme weather conditions, very reliable	Accuracy affected by visibility of license plate and weather conditions	Weather and congestion may influence the network speed and coverage
Accuracy	Very high	High	Very high
Net participation if implemented[1]	8-10%[2]	88%[3]	15-20%[4]
Investment cost – public sector[1]	High	Low	Minimum
Operating cost[1]	Low	Low-Med	Incurred by private sector
[1] Estimate by authors; [2] Actual participation rate for Weigh2Go BC; [3]Chow, Lee and Waters, 2010; [4]Author's estimates from discussions with Intelligent Imaging Systems			

Prescreening to primary inspection

Incoming vehicles are assigned a safety score using a TRIANGULAR distribution (10, 60, 90) with higher scores indicating a low risk and safer vehicle. This distribution was assumed and used as the base distribution. The participating vehicles are asked to come in for a primary inspection if their safety score was <=40. This score was set so that 22.5% of the participating vehicles were brought into the inspection station, the actual percentage of participating vehicles entering primary inspection in the Weigh2Go program for BC inspection stations on November 2015 (BC MOTI, 2015). Ten percent of the remaining participating vehicles are randomly selected for primary inspection. This percentage was used as an assumption in the model. The rest of the vehicles participating in the prescreening, bypass the inspection station. The non-participating vehicles, are always asked to come in for a primary inspection. The sum of the vehicles pulled into the inspection station for primary inspection is the first performance metric of prescreening. Fewer vehicles need to be called into primary inspection as participation in prescreening increases since low risk vehicles are allowed to bypass.

Primary inspection to secondary inspection

All vehicles enter the primary inspection queue where a primary inspector looks at these vehicles one by one. The primary inspection determines whether a vehicle should continue to secondary inspection. The model emulates an inspector's decision on whether the vehicle should be forwarded for secondary inspection using a score of <=36 to filter the vehicles that need a secondary inspection from the bypassing vehicles. The score of 36 was chosen so that 17.5% of the non-participating vehicles are forwarded to secondary inspection, the actual percentage of vehicles that were sent to secondary inspection in BCTA Roadchecks in June 2015 (BCTA Roadchecks, 2015).

The same score of 36 was used to decide whether a participating vehicle needs a secondary inspection. This score was used for the following reason: at the end of primary inspection, the primary inspector has conducted all the inherent steps of primary inspection (visual inspection, running the license plate number against safety databases). It is irrelevant if some of those steps were done during prescreening stage (as is the case for participating vehicles) or were all done during primary inspection stage (as is the case for non-participating vehicles) The inspector has no additional information that help him decide whether the vehicle (participating or non-participating) needs further inspection. The same score condition ensures that the primary inspector has no bias towards participating or non-participating vehicles while deciding whether the vehicle needs secondary inspection or not. The participating vehicles that were pulled in after prescreening due to their higher risk profile are assigned a higher risk distribution (10,38,40) since the low risk vehicles have been removed from this traffic stream. This distribution was chosen since it ensures 80% of the participating vehicles that were evaluated to come in for primary inspection are forwarded to secondary inspection (using score <=36), as estimated by a BC inspection station official.

During prescreening, the participating vehicles have already been checked to ensure conformity with several safety databases. Hence, at the time of primary inspection, the participating vehicles only undergo a visual inspection. In contrast, these databases have to be retrieved by the inspector by manually keying in the vehicle identification for non-participating vehicles. Thus, the primary inspection of a participating vehicle takes shorter time in comparison to a primary inspection of non-participating vehicles, in which the inspector has to do a visual inspection as well as query the license plate of the vehicle to check against several safety databases. The time distribution for participating vehicles was 0.1,0.2,0.5 minutes and for non participating vehicles was 0.15,0.4,1 minutes. This primary inspection produces a second metric, the number of vehicles sent to secondary inspection.

Secondary inspection

The model emulates secondary inspection by utilizing a safety score of 21 to identify those vehicles that should be issued an OOS order. The score of 21 was chosen since it ensures 3.6% of all the non-participating vehicles are issued an OOS order, as determined from BCTA Roadchecks in June 2015 (BCTA Roadchecks, 2015).

The distribution of safety scores for the participating vehicles entering the secondary inspection stage is (10,38,40) while the distribution of scores for non-participating is (10,60,90). The condition of score <=21 is used to evaluate whether the vehicle needs an OOS order or is safe to proceed (the latter can also be done by issuing a ticket at the end of secondary inspection). Participating vehicles evaluated to come for primary inspection have the same probability of getting OOS after secondary inspection as non-participating vehicles**.** The time it takes to conduct a secondary inspection follows the TRIANGULAR distribution of 10,30,60 minutes.

Closures

During the 8 hours (8am to 4pm) the station is fully active with both primary and secondary inspections happening as needed. In these 8 hours, the station gets closed only when primary and secondary queues get filled to the point the relevant inspector deems they are too big to handle. This is reflected in the model by setting primary and secondary queue length limits (10 and 4 respectively). The model does not take into account other reasons for closures, such as hours of operation or staff limitations or special events occurring at station (training). Once the queue limits are reached, the station gets closed temporarily and reopens when all the existing vehicles in the queue have been evaluated. Outside of the 8 hours (before 8am and after 4pm), there are no secondary inspections happening. Thus, the station is temporarily closed only if primary inspection queue reaches its maximum limit.

Simulation Findings

Base case

The ARENA model was used to simulate the penetration of technology from 0% to 100% (incrementing at 5% intervals). The base case assumed the following characteristics of the inspection station and incoming vehicles based on practices observed a medium size weigh/safety inspection stations along the Trans Canada highway from Hope to Vancouver:

- Primary inspection queue capacity was 10 vehicles staffed by 1 inspector.
- Secondary inspection queue capacity of 4 vehicles staffed by1 inspector.
- The inspection station is open for primary inspections 24/7.
- The inspection station only conducts secondary inspections from 8:00 am to 4:00 pm each day.
- The incoming vehicle distribution replicated the hourly volume (average and standard distribution) of a BC weigh/road safety inspection facility in B.C.

Number of primary inspections

The sum of the vehicles pulled into the inspection station for primary inspection as prescreening participation increased from 0 to 100% resulted in the number of primary inspections being reduced from 1664 to 174, a decrease of 89.50%. With increasing penetration, the increase in number of participating vehicles entering the primary inspection is not as rapid as the decrease in non-participating vehicles. This is because an increase in penetration level of technology results in larger number of potentially safe vehicles getting a bypass and therefore, not being asked to come in for primary inspection. This reduces station closures due to congestion in the primary inspection queue.

Number of secondary inspections

Figure 1 illustrates that even with increasing penetration, the number of secondary inspections remain fairly constant. As penetration increases, more participating vehicles enter the primary inspection queue. Compared to non-participating vehicles, the participating vehicles have a higher likelihood of getting forwarded to secondary inspections. Thus, with increasing penetration more vehicles should get forwarded to secondary inspections queues. However, since the numbers of secondary inspectors at an inspection station are limited in this base case to one, the number of secondary inspections that can be completed is limited. As the number of vehicles entering the secondary inspection queue increase beyond the station capacity (secondary queue length of 4), the station gets temporarily closed, resulting in no further secondary inspections until the secondary inspection queue is cleared or station is reopened. Thus, increasing penetration does not increase the number of secondary inspections, due to limited station capacity at the secondary inspection stage.

Secondary inspection and number of out of service orders

The number of OOS orders go up from 2 to 5 per day (an increase of 150%), as shown in Figure 2. Because the vehicles are filtered at prescreening, and only vehicles with higher likelihood of being unsafe are pulled in to the inspection station, the station targets a better set of vehicles (having lower safety levels) as penetration increases. The prescreened vehicles that arrive for secondary inspection have a higher likelihood of being unsafe compared to the rest of the vehicles arriving for secondary inspection. With increasing penetration, more and more number of participating vehicles are evaluated to come in for secondary inspection (shown in Figure 1) and since these vehicles have worse safety levels than other vehicles, the number of OOS orders increase.

Figure 1 Number of secondary inspections at inspection station

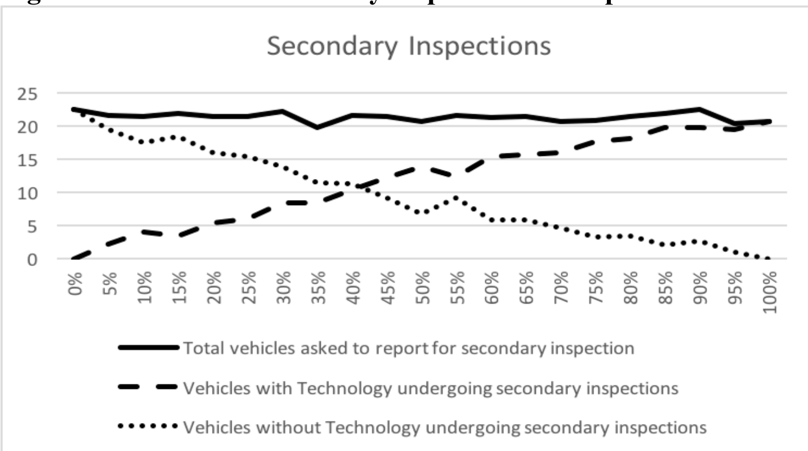
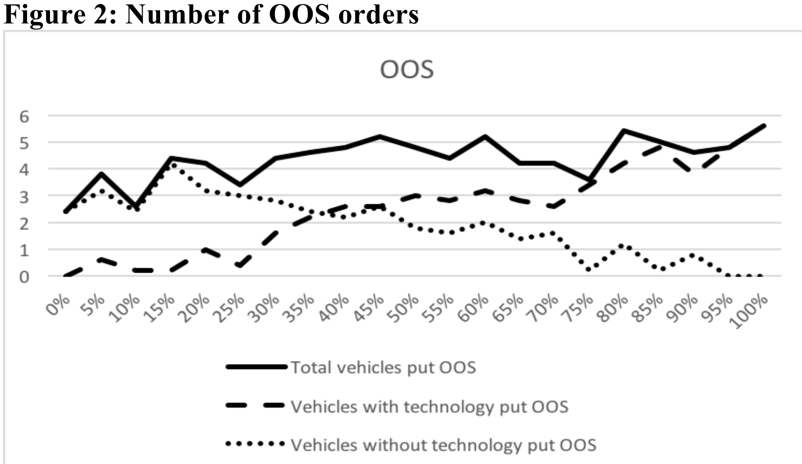


Figure 2: Number of OOS orders

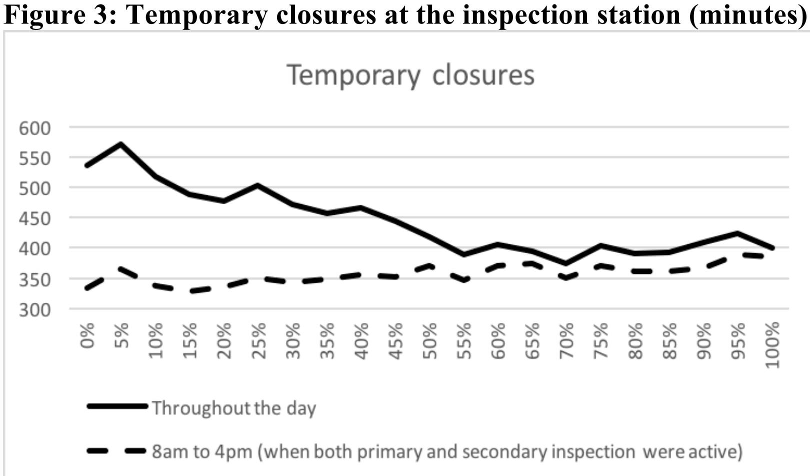


Temporary closures occurring at the station and total vehicles receiving road safety evaluation.
Figure 3 illustrates that the temporary closures occurring at the inspection station throughout the day decrease from 537 minutes to 401 minutes, (a 25.34% decrease), even though the closures within the 8-hour time slot from 8am to 4pm remain fairly constant (or increase slightly from 334 min to 385 min). Moreover, the simulation of prescreening participation increasing from 0 to 100% resulted in the total number of vehicles that were pre-screened or asked to come in for primary inspection increasing from 1664 to 2239, a 34.49% increase. The daily throughput of the station was 2819 vehicles. Therefore, the number of vehicles that bypassed the station without being evaluated (either by the pre-screen or by a primary inspection) due to temporary closures declined from 1145 to 580, a decrease of 49.34%.

From 8am to 4pm, the station capacity is limited by the number of inspectors at the inspection station. The capacity determines how quickly the queues (primary or secondary) are processed during inspection. If the primary inspector is sending vehicles to the secondary inspection queue and the secondary inspector is busy processing the vehicles that came before, the secondary inspection queue begins to grow. This happens quite often since the amount of time secondary inspector takes to inspect vehicles is much more than the time manual inspector takes to make a decision on whether the vehicle needs to be sent to the secondary inspection or not. Once the secondary inspection queue reaches its maximum limit, the station gets closed and does not reopen unless secondary inspections have been performed on all the 4 vehicles in the queue. Figure 1 illustrated that the number of secondary inspection do not change considerably during the 8-hour slot because of limited number of secondary inspectors, which is why the number of minutes for which the station gets closed during the 8 hour slot does not show considerable change.

Between 4:00 pm and 8:00 am, only the primary inspection is active and the only reason for station closure is the primary inspection queue reaching its maximum limit (10 vehicles). The number of vehicles coming in for primary inspection decreases as the prescreening penetration increases. In addition, a larger number of the vehicles coming in for primary inspection are participating vehicles, primary inspections of which take shorter time than other vehicles. Thus, with increasing penetration of technology, the primary inspector is evaluating fewer vehicles and taking lesser time on average per vehicle. This quicker processing of the primary inspection queue results in fewer station closures and more vehicles getting safety evaluations.

Figure 3: Temporary closures at the inspection station (minutes)



Unconstrained secondary capacity case

Figure 1 illustrated that even with increased prescreening, the number of secondary inspections remain fairly constant. This may be due to capacity limitations in secondary inspection. The base case was modified to increase the inspectors in secondary inspection from 1 to 4, effectively increasing the number of vehicles that can be inspected. The secondary inspection queue does not reach its maximum as often as in the Base Case and the station does not close as frequently as in Base Case. As a result, the station can conduct more secondary inspections.

Figure 4 illustrates that the number of secondary inspections increases commensurately in the less constrained secondary inspection case compared to Base Case. At 0% participation in prescreening, the number of secondary inspections rose from 20 in Base Case to 60 in the higher capacity Case. At 100% participation, the number of secondary inspections rises from 21 to 65.

With a greater number of inspectors, fewer closure minutes and more secondary inspections, the number of OOS orders increase from 2 to 10 per day at 0% prescreening participation and from 6 to 11 per day at 100% prescreening participation as illustrated in Figure 5. We observed in the base case where capacity was constrained by only one inspector in secondary inspection (Figure 1), as prescreening participation increased from 0 to 100%, vehicles put OOS increased from 2 to 5 per day. But in the high capacity case, there is no statistically significant increase in OOS over the whole range of participation though there appears to be an increase in OOS that peaks at 50 to 65% prescreening participation. One explanation for this peaking is that demand for secondary inspection from increasing prescreening penetration (Figure 4) has reached the point where secondary capacity has again become the cause of station closure. We are still exploring this relationship which may reflect the interaction of primary inspection efficiency in identifying high risk vehicles more effectively.

Figure 4: Number of secondary inspections, Base Case vs Increased Capacity

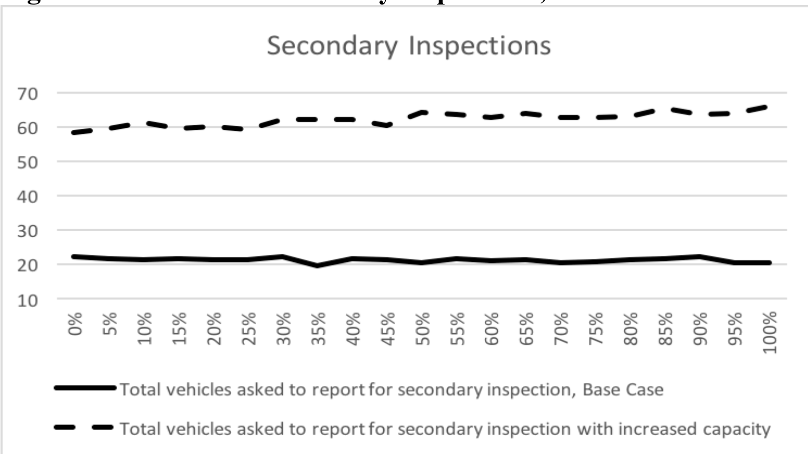
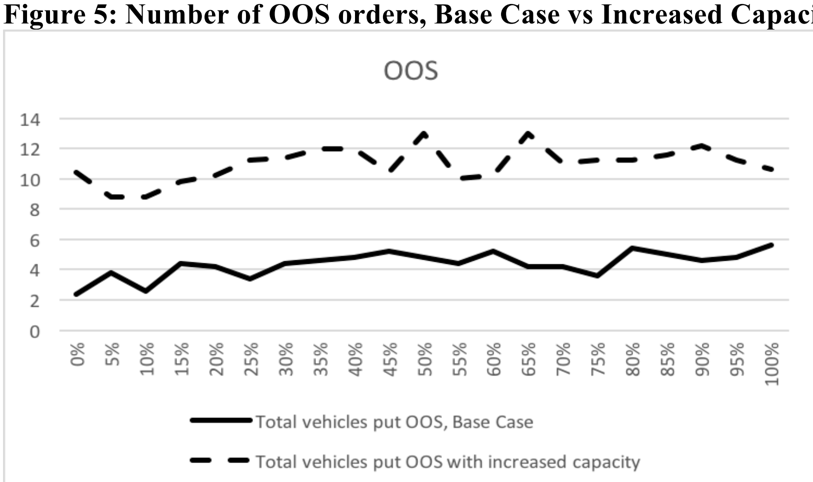


Figure 5: Number of OOS orders, Base Case vs Increased Capacity



Conclusions, Implications and Future Research

We have developed a simulation model to measure the impact on safety and productivity of several decision variables that define prescreening at roadside safety facilities. The results indicate:

- Prescreening significantly increases the number of CMVs that receive some form safety inspection whether it is an electronic prescreen or a primary inspection. At the same time, there is a significant number of CMVs that now bypass the inspection facility completely, producing time savings for these vehicles and reducing fuel usage that would result from slowing speed, stopping and idling in the inspection facility and accelerating upon leaving.
- Prescreening increases the safety risk profile of CMVs entering the inspection station through primary and secondary inspection resulting in a larger number of OOS each day and fewer unsafe vehicles on the highway.

- The safety benefits of a prescreening program may be reduced or negated if the secondary inspection capacity cannot accommodate the increased number of vehicles evaluated in primary inspection and sent to secondary inspection. Secondary inspection capacity decisions should be coordinated with prescreening programs.

The safety impact of increased OOS orders can be extrapolated along with the time and fuel savings benefits for the vehicles allowed to bypass as a result of prescreening supporting full benefit-cost analysis (for example see Chow et al, 2010).

Future research can utilize this simulation model to estimate the impacts on road safety and productivity for different configurations of road inspection facilities such as different capacity and productivity of primary and secondary inspection. Other prospective inquires include:

- Currently, the model simulates inspections from 8:00 am to 4:00 pm, the times in which the secondary inspection activity in the stations that were modeled were open. Such hours of operation are based on the scheduling the inspection station workforce during normal hours in which overtime is not paid. The simulation can be run with secondary inspection opened 24x7 to determine the incremental benefit of 24 hour operation. The model can also be run during the peak hours of truck traffic which was observed to 1:00 pm to 2:00 am. The trade-off between cost and benefit could be evaluated for potential rescheduling of personnel.
- The model simulations utilize an actual truck arrival distribution that may not representative of the hour to hour distribution at other stations. A finite set of representative distributions could be tested for their impact on the findings.
- The WRI initiative has the potential to improve accuracy of prescreening: think of a condition to be put in model, how we would adopt/adjust model to reflect improved ability between high risk and low risk. Look at Cherry paper to see what type of better recognition this could make. This extension is parallel to studies on accuracy of weigh in motion.

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References: Available from authors.