Guidelines for Designing Heavy Vehicle Monitoring Stations to Benefit Road Users

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ABSTRACT

This paper presents rational guidelines for designing a Heavy Vehicle Monitoring Station (HVMS) and for developing a national system of such stations. It explains how the stations' locations, functions, configurations, and operational procedures can be selected to reduce inconvenience to both the road users and the roading authorities. The functions of a specific HVMS may include weighing, measuring vehicle dimensions, determining vehicles' road-worthiness, and verifying operating authority. Weigh-in-Motion (WIM) technology, already widely used for data collection(1) is a major element in improving the efficiency of weight enforcement and monitoring systems. Finally, the economic benefits gained from a well-designed HVMS system are discussed. Not only is the damage to the highway and bridge structures reduced, but delay time is minimized and fair competition is enhanced, to the benefit of road users.

1. INTRODUCTION

As the road transport industry strives to increase productivity and lower costs in the highly competitive environment in which it operates, a natural tendency is to operate vehicles of increasing size and weight. The benefits gained from increasing the allowable weights and dimensions of heavy trucks should always be viewed in conjunction with the incurred additional cost of pavement and bridge damage in the highway network. New Zealand's roading authorities are striving to protect their investment in their infrastructure, while simultaneously promoting the economic viability of truck transportation. Because the deterioration of the nation's pavement and bridge structures can be directly related to deficiencies in an enforcement program, a more comprehensive and effective weight enforcement program is being implemented.

However, the effectiveness of the enforcement program is also dependant upon its acceptance by the trucking industry. Dramatic changes in regulations may have a negative impact on a trucking firm's viability, if some existing vehicles do not comply with new regulations. But they cannot be suddenly and arbitrarily forbidden to

Then, the present conditions are analysed to yield projections of the peak hourly truck traffic volume by direction and the expected distribution of vehicle characteristics for the chosen design period, which should be 15 to 20 years. If new weight and dimension regulations are implemented during the development of the HVMS, then the shift in weight distribution patterns for heavy trucks must be considered during the analysis of projected distributions and design volumes(3,4).

5. DESIGNING AND PLANNING THE TRUCK INSPECTION STATION

The design of a particular HVMS must satisfy both enforcement requirements and the financial restraints imposed by the budget. The main variables involved in the design of a Heavy Vehicle Monitoring Station's layout are the functions assigned to and the heavy truck volumes incurred at the HVMS site.

Roadside information signs should be used to indicate what types of vehicles are requested to report when the HVMS is open. Normally, only about two-thirds of the commercial vehicles might have to be weighed; the remainder could bypass the weighing if they are empty or lightly loaded. The HVMS truck-handling capacity must include those that fail their initial weighing and inspection, and must be re-weighed or re-inspected.

5.1 CONFIGURATION OF THE ENFORCEMENT SCALES. The main function at most Heavy Vehicle Monitoring Stations is weighing vehicles for the purpose of enforcing weight regulations. The configuration, motion dampening characteristics, and method of operating the weighing scales all influence the capability of the HVMS to handle the truck volumes incurred at the site. Most importantly, the configuration and dimensions of the scales must be capable of handling the peak hourly truck volume at an optimal level of service.

In order to achieve the required truck-handling capacity, a very high percentage (ie. approaching 100%) of the truck volume must be processed by weighing all of the axle groups of a truck simultaneously, if the vehicle must be stopped for static weighing, or by using Weigh-in-Motion scales. At slow 'roll-over' speeds of 5 km/h or less, the error in measuring loads with WIM scales is less than +/- 0.5%.

5.2 WEIGH-IN-MOTION SORTER SCALES. A major consideration for improving the traffic handling capability of a HVMS is the incorporation of Weigh-In-Motion (WIM) scales for sorting vehicles; these sorter scales can be located either on the highway or in the lane(s) approaching the enforcement scale. The vehicles are sorted according to the measured weights, and directed to the appropriate lane. WIM sorter scales placed in the travelled lanes ahead of the primary or enforcement scales reduces the number of trucks to be weighed by the primary scales by as much as 80%. This provides a dramatic improvement in the traffic handling capacity of the facility. The sorter scales may also permit the size of the enforcement scale to be reduced. WIM sorter scales are a major component of many overseas Heavy Vehicle Monitoring Stations already(1).

The accuracy of the WIM equipment depends on its design, vehicular factors, characteristics of the roadway, and environmental factors(1,5). Typical accuracies expected of WIM scales at different speeds are shown in Table 1. The maximum approach roughness must be specified. Generally, speeds in the range of 15 to 60 km/h are satisfactory.

Table 1. Typical Accuracies Expected of WIM Scales

Weight Considered:	Speed (km/h)	Mean (%)	One Standard Deviation (%)
Single Axle	20	0.5	3
Single Axle	60	1.0	5
Tandem Axles	20	0.5	2
Tandem Axles	60	1.0	4
Gross Vehicle	20	0.5	1.5
Gross Vehicle	60	1.0	3

Because the headway between arriving trucks is a crucial factor in the efficiency of the sorter scale, the HVMS entrance must be designed so that trucks flow continually and evenly across the sorter scale. Queuing of trucks before the sorter scale and back onto the highway exit ramp cannot occur; queuing can occur only ahead of the enforcement scale.

Queues that develop ahead of the primary weigh scale are a function of the average service rate for truck inspection. Delay times are minimized by prescribing the maximum allowable time that any one truck should be in the queue, and by selecting a HVMS layout that does not permit queue lengths to exceed the theoretical maximum.

The length of a queue is also governed by the level of tolerance of overweight vehicles. For example, any axle load or gross vehicle weight which equals 105% of the legal regulations might be permitted to proceed at certain times, such as during peak traffic flows.

It is desirable to use WIMs whose microprocessors automatically analyse the measured weights, consider axle spacings if necessary, and determine if the truck's load violates the regulations. Then, the trucks are directed by means of overhead or roadside signals to either the enforcement scales or the bypass lane. The distance between the sorter scale and the overhead signalisation must be sufficient to allow enough time for the WIM equipment to process the signal and display instructions, and give the driver time to safely respond to those instructions. The computer cannot begin processing the data until 1 second elapses after the last axle of a truck has passed over. As an example, a tractor-trailer combination 20 m long and travelling 16.7 m/s or 60 km/h would require a distance of at least 40 m between the WIM scale and the signal board to meet the above conditions.

If a HVMS does not have WIM sorters in the station, but does have WIM scales in the travelled lanes of the highway for data acquisition purposes, then the latter can be used also as sorters, if they are located a short distance ahead of the HVMS. Only a slight modification of the WIM scale software and roadside signalisation is needed to allow the WIM to perform both functions. Vehicle weights measured in this manner, under smooth approach conditions at highway speeds, are within 5% of the actual weight(5). If WIMs cannot be placed in all travelled lanes, then signing is used to direct truck drivers to the lane containing a WIM.

5.3 <u>AUTOMATED DATA-ACQUISITION AND PROCESSING.</u> Actual axle spacings, weights, and other data must be calculated in real time, and compared with allowable limits specified for the truck's configuration. Then, the information and indications of infractions are displayed immediately, preferably on video monitors. The regulations should be presented in a form (see Figure 1) that makes comparisons easy and quick to do. If the vehicle contains special features, such as using other than normal tyres, or if the regulations are altered at a later date, then it must be possible for that information to be entered into and accounted for by the system.

A variety of axle sensors are available that can measure axle spacings, both between axle groups and individual axles. Axle sensors installed at critical locations in the bypass and weigh/inspection lanes help to determine if drivers are correctly following instructions. The axle-monitoring system should be able to automatically diagnose incorrect movements, and notify the HVMS operator of such movements by means of an audible alarm or video screen display. In response, the HVMS operator should then be able to re-direct the driver with new instructions.

VEHICLE CONFIGURATION	o———o o		———o o		GVW
SPACINGS (m)	4.11	1.22	6.53	1.41	
ALLOWABLE LOAD (kg)	5400	14500		15000	34900
ACTUAL LOAD (kg)	4370	*16040*		13820	34230

* - overloaded

Figure 1 - Video Display of Weight and Dimension Data(6)

Signing must be clearly visible and contain simple, easy-to-follow instructions, to aid the flow of traffic and reduce potential misunderstandings. Internationally-recognizable symbols should be used instead of words alone.

The data acquisition and monitoring system should be capable of determining and recording the numbers of vehicles passing through, and of calculating the relative frequency of vehicles that violate the regulations. The information on violators and all vehicles going through the HVMS should be stored in a database. Any data, such as records, orders and fines, should be easily retrievable and printed by the computer on request.

Sensors that automatically detect the height of vehicles are readily available and possess a high degree of accuracy. Also, systems for detecting vehicle width are commercially available. If vehicle identification codes or devices are attached to the exteriors of vehicles, then those vehicles can be readily identified, by sensors located beside the highway exit ramp, as the vehicle passes over the WIM sorter scale.

5.4 <u>WEIGH HOUSE.</u> A building may be needed for housing sensitive monitoring equipment and facilities for personnel and visitors. The Weigh House may accommodate the administrative functions of the station, such as providing informational services, issuing special permits, checking the operating authority and levying fines on regulatory infractions.

The degree of visibility of the vehicles on the scales and of those bypassing the weighing should be enhanced either by an enlarged viewing area and elevated observer position, or the introduction of remote video monitoring. The camera could be mounted in a position that permits clear viewing of multiple lanes and the far side of vehicles. The station operator remains inside where more functions can be handled by one person.

5.5 VEHICLE STORAGE. Storage is provided between the sorter scale and the platform weigh scales to allow room for temporarily stopped vehicles, because queuing is expected to develop in front of the scales.

If sufficient funds and land are available, and the truck traffic volumes warrant it, then a parking area may be provided after the enforcement scales, for vehicles that must stop for either a thorough inspection or an adjustment of their load. This area is entered and exited via the 'racetrack'(7). The size and configuration of the racetrack and parking area should be designed to accommodate the numbers and types of heavy vehicles expected. A critical factor is the turning characteristics of larger, multi-unit vehicles. The design of the approaches, exits and storage areas of the racetrack should consider future developments in heavy vehicle configurations and technology.

The movements of trucks leaving a weigh/inspection area must be carefully planned and strictly controlled. They should be able to proceed to the racetrack or the exit with minimal interference from other traffic. The approach to the racetrack must be clearly indicated and visible to vehicle drivers. The racetrack itself must be designed to handle a number of different vehicle configurations. The parking and storage area of the racetrack must provide for further inspection and load adjustments, including unloading of goods. Special storage areas may have to be provided for hazardous materials or illegal goods.

The trucks returning to the weigh/inspection lanes from the racetrack will have to merge with the newly arrived vehicles if no provision is made for separated lanes. The planning of these movements is a crucial element in maintaining the capacity and efficiency of the station.

6. CONFIGURATION OF STATIONS.

As suggested earlier, the HVMS configuration is very dependent on the heavy vehicle traffic volumes to be handled at the particular site.

6.1 EXAMPLE OF A CONCEPTUAL LAYOUT OF A HVMS. Figure 2 illustrates a typical HVMS layout, consisting of a Weigh House, a single lane for weighing and inspecting, and minimal storage space for vehicles. A WIM scale in the approach lane sorts the incoming vehicles, directing them to either the weigh/inspection lane or the bypass lane. Signing at the start of the turnoff ramp instructs drivers to maintain the necessary headway between vehicles, which is approximately 30 m.

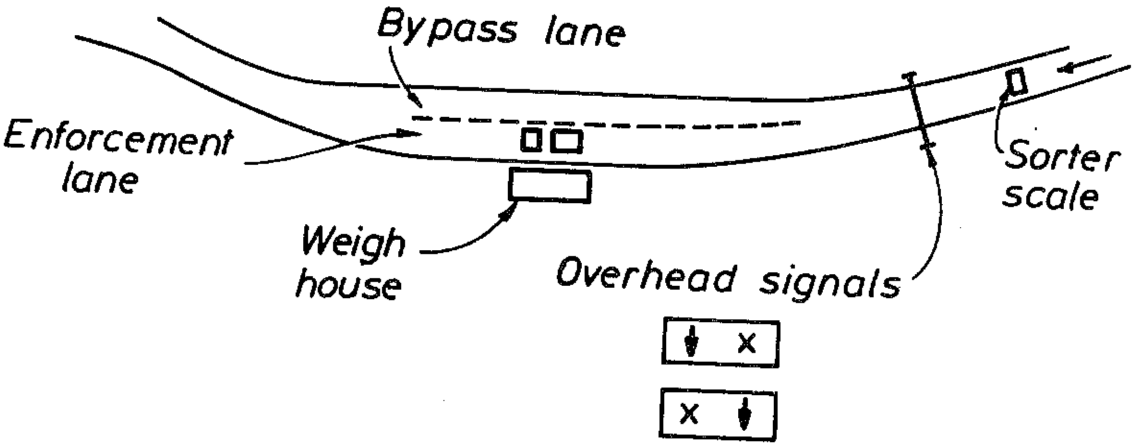

Figure 2. Conceptual of Layout of an HVMS - Initial Phase

A bypass lane permits vehicles that do not have to be weighed to pass by the station's observation booth, allowing the HVMS personnel to make a visual inspection of the vehicle. The bypass lane's speed limit is chosen to permit a proper visual inspection and to aid the station's truck traffic volume capacity.

Provision for future expansion, such as for a racetrack and extra parking spaces, should be considered in the initial design. The configuration for an expanded station, like the one shown in Figure 3, provides drivers and station personnel with safe and easy access between the weigh house and the station's other areas.

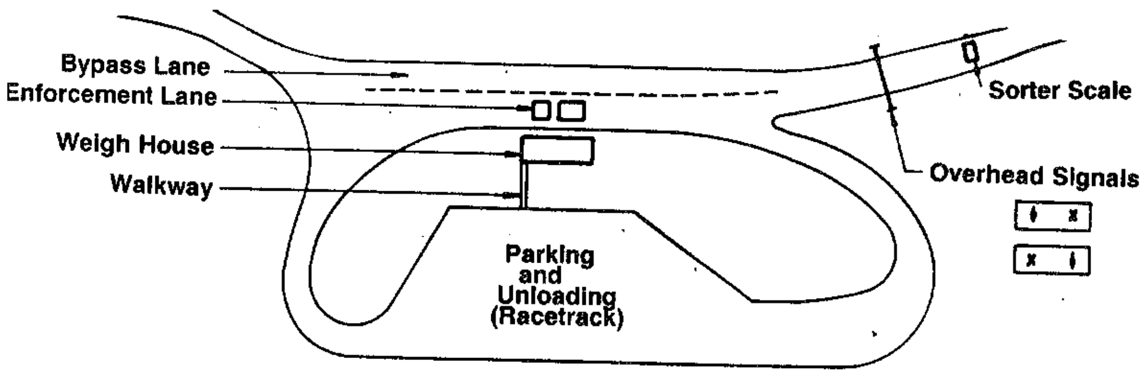

Figure 3. Proposed HVMS Layout for Increased Truck Numbers

6.2 HIGH TRAFFIC VOLUMES. Generally, the maximum volumes that can be handled by a single enforcement scale is 90 vehicles/hour/direction. If the truck traffic volumes are expected to exceed that limit, then the HVMS should include additional, parallel weigh/inspection lanes and a series of scales positioned to weigh multiple axle vehicles with one stop.

7. OPERATING STRATEGIES

Operating strategies should be devised to suit to the functions and characteristics of each Heavy Vehicle Monitoring Station. Some options for operating strategies are presented.

7.1 TIMES OF OPERATION. Ideally, the HVMS should be operated continuously, 24 hours a day, year round(2). However, if continuous operation is not feasible, then random opening times should be implemented. For obvious reasons, random opening times cannot have a discernible pattern. Also, if a WIM scale is installed in the travelled lanes of the highway, then weights can be monitored without the drivers knowledge. This data would be used for determining the relationship between commercial vehicle characteristics and the operating schedule of the station. Studies have shown that, even where only about 1% of the vehicles weighed by enforcement scales are overweight, up to 30% of the trucks passing over WIMs located in the travelled lanes were overweight(1). However, because the dynamic characteristics of WIMs under high truck speeds yield statistics that possess relatively large variations, the data must be carefully analysed so that a statistical bias towards overweight trucks is minimized or removed.

7.2 HANDLING QUEUING UNDER PEAK CONDITIONS. At locations experiencing high traffic volumes, weighing/inspecting only representative samples of heavy vehicles reduces queuing. However, a definite selection sequence should not be obvious because drivers may position themselves in large convoys to avoid inspection(2). Therefore, a random selection of trucks for inspection is more effective because it does not lend itself to such manipulation.

Another alternative for handling temporary peaking in truck traffic volume is to increase the level of tolerance of the allowable weight limit (e.g. from 100% to 105% of the legal limit). The sorting system can be altered to temporarily allow vehicles that would normally be considered overweight to bypass the enforcement weigh scales and inspection. Information of this procedure must be kept confidential because drivers might take advantage of this procedure by travelling in convoys of overweight vehicles.

When unforeseen excessive volumes arise, the enforcement personnel can be given the option of allowing empty or lighter trucks to bypass the sorter scale, on their honour.

The drivers of these trucks should be instructed to slow down, and travel past an observation booth close enough to allow visual inspection by enforcement officials.

7.3 HANDLING VEHICLE INSPECTION. The degree of examination to which the commodities, documentation, vehicles and operators are subjected affects the time required to complete the inspection cycle for each vehicle. This cycle time determines the processing capacity of the HVMS. The procedure for processing vehicles that are overweight or violate other regulations must be devised to minimize delay times and should be clearly defined beforehand.

8. ECONOMIC CONSIDERATIONS

The economic analysis should consider at least the following items:

1. initial construction,

2. operation and maintenance costs,

3. vehicle delay, and,

4. damage to the highway and bridge infrastructure.

The latter two items are discussed here because they are relevant to the theme of this paper.

8.1 REDUCED DELAY. Delay costs are substantially reduced if vehicles are stopped for inspections only when it is considered absolutely necessary. For example, assume the delay cost to a trucking unit is assigned a value of $100/hour, which accounts for the driver's time, fuel burnt during idling, lost revenues due to late deliveries, overhead and miscellaneous expenses. If each truck movement involves just one unnecessary delay of one minute duration, the accumulated yearly expense could easily add up to over a $1,000 per year. The cost of stopping thousands of truck movements for extended periods of time every year quickly accumulates to large values.

Proper selection of the weighing equipment and their configuration ensures that the interruption of vehicular movements is kept to a minimum. Ideally, the HVMS planner should balance the incremental costs of providing faster vehicle processing with the benefits resulting from reduced delay.

8.2 HIGHWAY AND BRIDGE STRUCTURAL DAMAGE. Highway usage costs due to the continuous need for maintenance caused by heavy loads on the pavement and bridge structures are quite substantial. However, recent Australian studies have indicated that the costs of weight limit increases are modest compared to the substantial benefits; a potential return of between 300% and 600% on invested funds is suggested(8). On the other hand, if overweight loadings are allowed to accumulate to significant levels, then the financial gains will be offset by dramatic reductions in the serviceability (and, eventually, the life) of the highway and bridge structures. Because road user charges are indirectly related to the structural damage caused by the user's vehicle, road users benefit from the prevention of unnecessary structural damage.

9. CONCLUSIONS

This paper has introduced a rational approach to the monitoring of heavy vehicle traffic, and the enforcement of a jurisdiction's truck safety, weight, and dimensions regulations. Both the road transport industry and the roading authorities can benefit from Heavy Vehicle Monitoring Stations that are designed to suit the conditions found at specific sites and are properly located on the road network.

A well-developed and comprehensive weight enforcement system including Heavy Vehicle Monitoring Stations:

1. reduces delay costs for road users,

2. enhances fair competition among road transport firms,

3. may encourage increases in statutory weight and dimension limits because authorities mould be more certain that there would be positive compliance,

4. might prevent increases, and may even decrease, regulatory fees levied against all trucking concerns because a reduction in overweight vehicles yields a reduction in structural damage to the pavements and bridges, and,

5. gathers data on vehicle classification distributions, and axle and gross vehicle loads, that can be analysed, to provide a more equitable assessment of road user costs.

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