RELATIONSHIP BETWEEN BOGIE LOCATION AND THE RIDE PERFORMANCE IN A MONORAIL CAR.

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ABSTRACT

A cross sectional study was conducted to analyze a relationship between bogie locations and the ride performance in a monorail car. This study was carried out to determine exposure levels of whole body vibration in a certain location in a monorail car and related to various condition path of the beam. Human Vibration Meter (HVM) 100 Larson Davis and Whole Body Vibration (WBV) sensor as a device were used to measure at 2 positions within 3 locations inside a monorail car and 3 different paths of beams. The measurement of whole body vibration was done on a consumer monorail in operation and service during off peak hour. The data in the form magnitude collected and recorded by HVM 100 was transferred to the computer using Blaze software. The analysis of graph pattern and the difference of magnitude value for each location inside a car was studied to determine the exposure level of vibration. Data was evaluated and the results show high magnitude vibration for all three axes x, y, z which are 6.92 m/s^2, 4.61 m/s^2, and 3.9 m/s^2 respectively. The Vibration Calculator was used to calculate the risk of WBV in the daily vibration exposure that a passenger is subjected to comply health and safety requirements. The finding showed there are relations between bogie location and vibration exposure, which resulted over the allowable exposure limit value 1.15 m/s^2. The individual subjected to frequently vibration exposure would tend to receive higher rate transmission of vibration in the body and will cause health problem. Among the improvements suggested reducing the vibration such as by putting the seat with a cushion, rubber padding on the floor, and installing more hand pole at the center of the car.

ABSTRAK

Satu kajian rentas telah dijalankan untuk menganalisis hubungan diantara lokasi bogi dan keselesaan di dalam monorel. Kajian ini dijalankan untuk menentukan dan mengenalpasti tahap pendedahan getaran seluruh badan terhadap lokasi di dalam monorel dan hubungkait diantara laluan monorel yang berbeza-beza. Getaran Seluruh Badan (HVM) 100 Larson Davis telah digunakan untuk mengukur keseluruhan getaran pada badan manusia dalam 2 posisi dengan 3 lokasi di dalam monorail serta 3 rasuk jalan yang berlainan. Pengukuran getaran seluruh badan telah dijalankan ketika monorel beroperasi iaitu di luar waktu puncak. Data magnitud yang disimpan dan dikumpul dari HVM 100 perlu dipindahkan ke komputer dengan menggunakan perisian Blaze untuk mendapatkan nilainya. Nilai magnitude untuk setiap lokasi di dalam kereta telah dikaji dan dianalisis di dalam graf yang berbeza untuk menyatakan bentuk getaran yang terhasil. Data yang dinilai menunjukkan tahap getaran adalah tinggi untuk ketiga-tiga paksi x, y, dan z, yang mana 6.92 m/s^2, 4.61 m/s^2, dan 3.9 m/s^2 bagi setiap bacaan masing-masing. Kalkulator Getaran juga digunakan untuk mengira nilai dan tahap risiko getaran yang terdedah kepada penumpang dalam seharian bagi mematuhi akta kesihatan dan keselamatan yang ditetapkan. Melalui keputusan yang ditunjukkan, terdapat hubungkait diantara lokasi bogi dan pendedahan getaran, yang mana nilainya melebihi had yang dibenarkan iaitu 1.15 m/s^2. Seseorang yang sering terdedah kepada getaran lebih cenderung untuk menerima transmisi getaran di dalam badan dan mengakibatkan masalah kesihatan. Diantara penambahbaikkan dan cadangan untuk mengurangkan getaran adalah, dengan menggantikan kerusi asal dengan kusyen, pelapik getah di atas lantai, dan memasang tiang untuk genggaman tangan di dalam mnonorel.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Life in a global around of technology, there have many types of transportation. Types of mobile used in some city will portray an image of developing country in that area. Management of transportation is concerned with the overall purchase and control of this movement service by using a firm in achieving its logistic objectives.

Logistics is the process of planning, implementing and controlling the efficient, effective flow and storage of raw materials, in process inventory, finished goods, services, and related information from point of origin to point of consumption (including inbound, outbound, internal, and external movement) for the purpose of conforming to customers' requirements. (Coyle et al., 2006)

Transportation is an important factor in the implementation of various activities in moving both freight and passengers around the world. Times have changed since airplanes, cars, buses and trucks were already offering mobile alternatives at every scale. Given the pressure of competition, the railway had to modernize and improve, especially as regards speed, reduction of cost, better organization and improvement of service offered.

This research is more details about the railway transportation. Some of the characteristics of rail transport can be categories in several advantages. Mostly, person rides one train can be more than one car. Concerning passengers, railways are capable of transporting a large number of people.

Rail transport is characterized by the guided movement of wheels on tracks through the metal to metal contact, which considerably reduces rolling resistance to less than 3 kg per ton carried (Ashgate, 2006).

Railway transportation is lowest environmental pollution. Electric trains cause no pollution. It is good for green technology and protects the global warming to be happening. Another advantageous characteristic of rail transport is one direction compared to road transport, which has two directions. One direction makes the train more safety and less accidents, because it is only moving straight and parallel with the track, while the track cannot be shared by other modes transport. Finally, land occupation for railway is less used than other logistic modes and practically lower compared to road transport. In the comparison between train and airplane, railway used a small area for a station. The station is less space to be distinguished with the airport.

In Malaysia, the railway has some issues about the ride performance or ride comfort. It can express what a comfort level when the train responds to rail conditions as the passengers. The main area of this research is the relationship between bogie location and effect to ride performance in a monorail car as passengers reflection. Analysis the different approaches, whether theoretical or experimental that is used to evaluate ride quality. (Orlova & Boronenko, 2006)

In terms of ride quality, it is tough to define the main course of railway part needs to be controlled or monitoring by reducing the vibration which is effected to the human body. However, the absorber is the most attract to be studied. This appliance was put in the form of bogie or truck (in US term) is a chassis structure for vehicles, which is in various forms for different modes of transport.

Vibration refers to oscillatory motions of solid bodies. A simple vibrating system is represented by a weight suspended on a spring and set into an up and down motion. The vibrating weight is displaced above and below an average position. The direction of the vibration has an effect on how sensitive humans are at specific frequencies. For this and measurement reasons the direction of the vibration should be noted.

Up and down vibration (z-axis) is the most common vibration to which people are exposed. An example of this is the vibration experienced when driving over potholes or when trotting on a horse. There is also *lateral, or sideways vibration* (y-axis), commonly experienced on rail vehicles. Lastly, there is a forward vibration (x-axis), for example in front end loaders and dozers. (McPhee et al., 2009)

The effects on humans of exposure to vibration at best may be discomfort and interference with activities; at worst may be injury or *disease. Vibration is believed* to cause a range of problems.

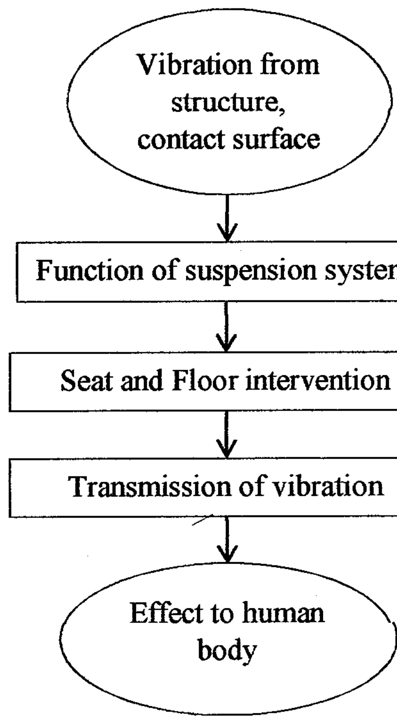

Figure 1: Flow chart transmission of vibration

1.2 Problem Statement

In urban areas like Kuala Lumpur, there are various activities such as employment, commercial, tourism, etc. Therefore, traffic jams often occur at the focus of activity that resulted in a significant private vehicle used. The government has taken steps to provide public transport solutions such as the monorail to facilitate daily activities in order to reduce congestion. Residents and tourists frequent use of public transport in daily business to move from one place to another.

However, through a study conducted by (Das *et al*,, *2003), passengers* are facing some problems such as uncomfortable ride which is caused by vibration. The level of vibration will affect and determined according to the ride performance for passengers. The different vibration level at different locations will produce a different comfort level.

The ride quality of monorail is affected by a variety of factors, including high frequency vibrations, noise, momentum movement as well as the vertical spring action. When the train is braking, and cornering, the body produces a booming resonance, and the occupants normally experience an *uncomfortable ride*. All of this related to power motor, brake and suspension system were installed in bogie frame. According to (Manal El Sayed et al., 2012) it was clear that the metro passengers were exposed to serious magnitudes of WBV. That WBV gained by human body increased when the duration of vibration exposure and the total metro trips experienced by the subject enlarged.

Vibration level was specified in ISO 2631. If the resulting high vibration exceeding permitted limits to the user it would be side effects such as back pain, shoulder pain, emotional instability, and so on. (McPhee et al., 2009)

While the uncomfortable ride is common, there is an insufficient analysis technique that is able for identifying the causes and consequently mitigate the problem.

So far, there was no analysis on the comfort level or vibration level on KL Monorail. This research was conducted on several locations in a monorail car and difference beam path chosen by strong tremors were felt. With the presence of this problem statement, a study will be carried out and some solutions will propose.

1.3 Objective of Study

The objectives of this research are:

i. To establish the relationship between bogie locations and the ride performance inside a monorail car.

ii. To suggest actions for improving ride performance in order to reduce comfort disturbances.

1.4 Scope of Study

This study has focused on several aspects as follows:

i. Interact and communicate with a specific company to link with them and request join to make a research.

ii. Select the suitable two car monorail which has a good condition after service as change new tires, engine oil.

iii. Data acquisition of quality on two car train by measure the magnitude of vibration straight line, corner right, and corner left the situation.

iv. Analyze the value of level vibration and passenger comfortable.

v. The study was based on the vibration magnitude based on ISO 2631 (1997).

1.5 Significance of Research

This research has been useful to identify the risk whole body vibration due to an uncomfortable problem for monorail passengers. From the data obtained through the measurement of vibration, it can be used to suggest the place inside the car which is less exposure to the passenger. The results show, the lower exposure vibration during riding the monorail at the center of location with standing position. While the high exposure was sitting on the sit above the bogie location. It is caused by the operating system as motor, brake and suspension installed in the frame of the bogie. Other than that, this research can help manufacture to improve performance train by minimizes vibration exposure on consumer perception.

CHAPTER 2

LITERATURE REVIEW

2.1 Ride Comfort

Comfort is a state of being relaxed and feeling no pain, a feeling of freedom from worry or disappointment, the act of consoling; giving relief in affliction

Comfort is not only defined by the absence of negative attributes. It is possible to feel a positive experience of comfort to various degrees. Comfort involves evaluation; it is felt to be good and its opposite is felt to be bad The only way to of finding whether a person is comfortable or not is ask the person in question.

Passenger comfort is another important factor in the design of the monorail system. The straddle design provides stability as the vehicle rides along the guide way. Passenger comfort is enhanced by the vehicles' air spring suspension and use of the latest power traction technology to drive rubber-tired wheels.

Rapid KL monorails offer a sure-footed, significantly quieter and more comfortable ride compared to steel wheeled transit vehicles. And also rubber tire system makes running vehicles less noisy. But, in the certain position during accelerating or braking and cornering, the movements of trains will effect to the human body by the momentum of speed applied.

To provide a smooth ride, the straddle-type bogie design features full vertical pneumatic, shock absorber suspension and a progressive stiffness lateral suspension. Its traction system is connected to the axle through constant velocity (CV) joint shafts. (Scomi, 2014)

2.2 Types of Monorail

The monorail is a vehicle that operates on a single concrete or steel beam, hence the word 'mono' which means one. This beam is also known as a guide way. In monorails, the guide ways are always narrower than the train it supports (around 0.6-0.9 meters wide) (Somi, 2014). This is one of the fundamental features of the monorail which gives it a competitive advantage over other rail systems. Most of the monorails are elevated (run above ground) and are electrically powered. They can be classified into several versions:

2.2.1 Monorail (Schwebebahn)

The first generally recognized monorail was the Schwebebahn (swaying railroad) in Wuppertal as shown ib figure 2.1, Germany. It is the only true 'mono-rail' (Kennedy, 2010). A single steel rail is suspended from an elevated structure along which a single rail runs as shown in figure 2.1. In this instance, the vehicle weight is both supported by the rail and guided by it. As Kennedy (2010) statement, the position of the vehicle in respect to the rail is unlike traditional dual-rail systems, but the basic technology by which the vehicle operates is no different from that of a railroad except that the wheels are double-flanged.

Figure 2.1: The Wuppertal Schwebebahn Monorail. (Zweisystem, 2015)

2.2.2 Suspended Monorail (Safege Type)

Modern versions of the Schwebebahn look similar in that the monorail is suspended from above. The suspended version as shown in figure 2.2 has supported the train from the top. The train and the rolling stock (passenger cars) are suspended beneath the wheel carriage; with the wheels riding within the single beam.

Figure 2.2: Japan "Townliner" Suspended Monorail (Kennedy, 2010).

2.2.3 Straddle Beam

The straddle version is the most common type of monorail. Basically, as shown in figure 2.3, the train straddles the single concrete or steel guide way. A rubber-tired carriage contacts the beam on the top and both sides for traction and to stabilize the vehicle.

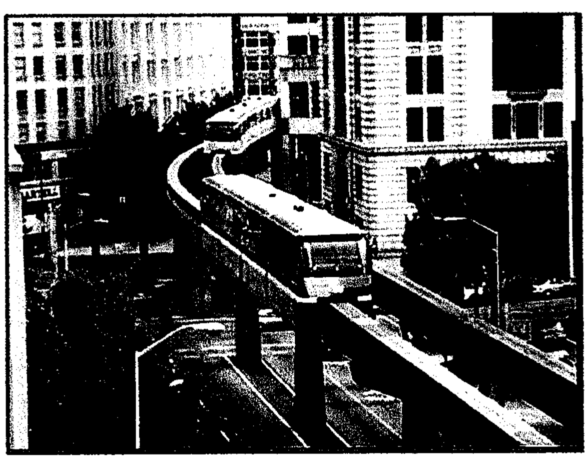

Figure 2.3: Straddle Monorail (Kennedy, 2010).

2.2.4 Cantilevered Monorail

The cantilevered or side-straddle monorail is similar in appearance and operation to the straddle monorail. However, trains going in opposite directions can share a single (but rather large) beam since cantilevered monorails are balanced by wheels on surfaces found on the sides of the beam. While several companies promote such monorails, they have not seen any applications as of yet.

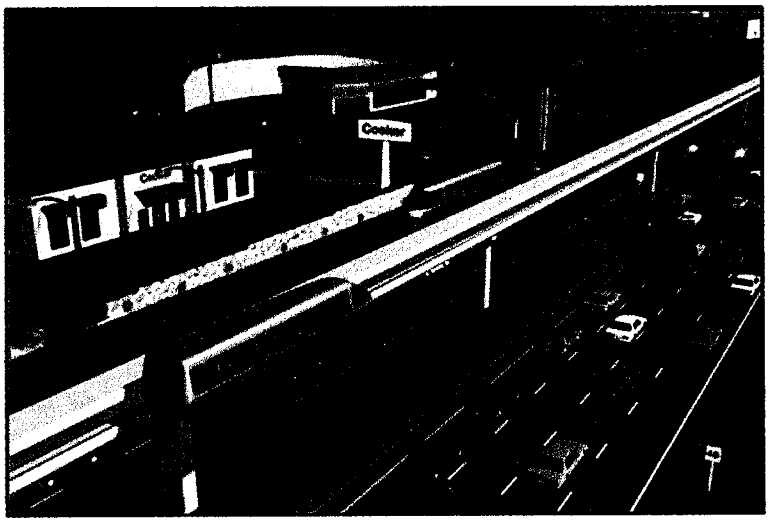

Figure 2.4: Transit cantilevered monorail (Kennedy, 2010).

2.2.5 Maglev (Magnetic Levitation)

Most maglev (short for "magnetic levitation") trains are essentially variations on the straddle monorail. Instead of on-board motors, the interaction of magnets on the vehicle and on the track moves the vehicle forward, while the vehicle itself is slightly levitated by other magnets. While maglev is an interesting technology, its complexity suggests that it is best suited to intercity rather than intra-city installations, placing it beyond the scope of this study. In addition, maglev monorail's dramatically different operating principles compared with other monorail types suggest that it serves little purpose to analyze maglev alongside more established monorails. The advantage of this technology is that maglev trains can reach top speeds exceeding 500km/h (Somi, 2014).

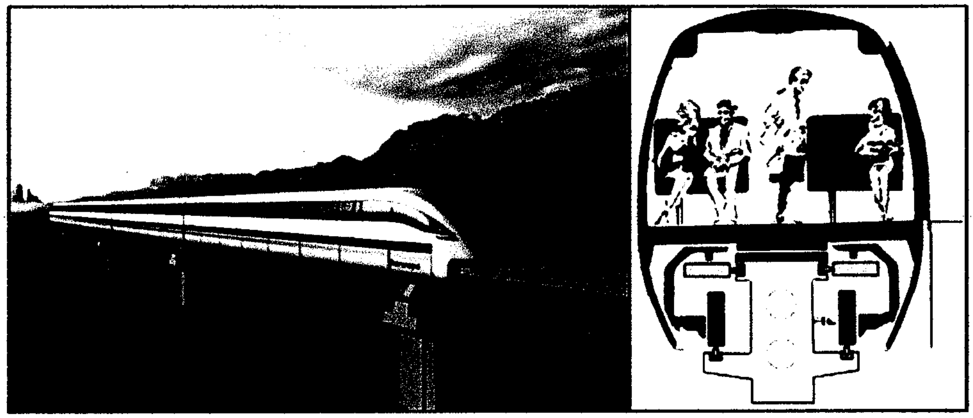

Figure 2.5: -The Maglift system (Left) and the transrapid system (Right), two of several levitating monorail (Kennedy, 2010).

2.3 Bogie

In modern bogies, the bogie frame transmits all the longitudinal, lateral, and vertical forces between the car body and the wheelsets. The frame also carries braking equipment, traction drive, suspension, and dampers. It includes also house tilting devices, lubrication devices for the wheel-rail contact and mechanisms to provide radial positioning of wheelsets in curves. Bogies vehicles are normally heavier than two-axle vehicles. However, the design of railway vehicles with bogies is often simpler than for two-axle vehicles it also provides reliable and maintenance benefits. (Orlova & Boronenko)

A monorail train typically consists of two bogies in one car at the front and rear axles, respectively. Each bogie consists of a set of driving wheels, steering and stabilizing wheels that firmly grasp the track grinder. Each bogie is equipped with two load wheels together with 6 guide wheels, 3 on each side. Since the tires are made from rubber and it was a primary suspension, this study was very interested to measure the transmission of vibration.

The bogie structure as shown in Figure 2.6 and 2.8 is designed to support static and repeated with loads for as long as 30 years (Scomi Engineering, 2014). The bogie was important to ensure the railway vehicle safety. Each car is mounted on a two single axle bogie having the designed for a maximum speed of RSV which is 70km/h. (Prasarana, 2014)

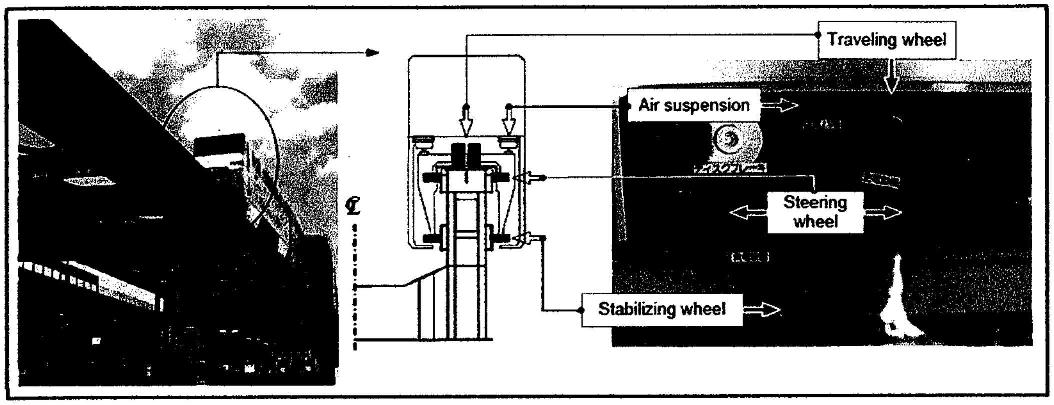

Figure 2.6: Monorail Bogie. (Hun, 2005)

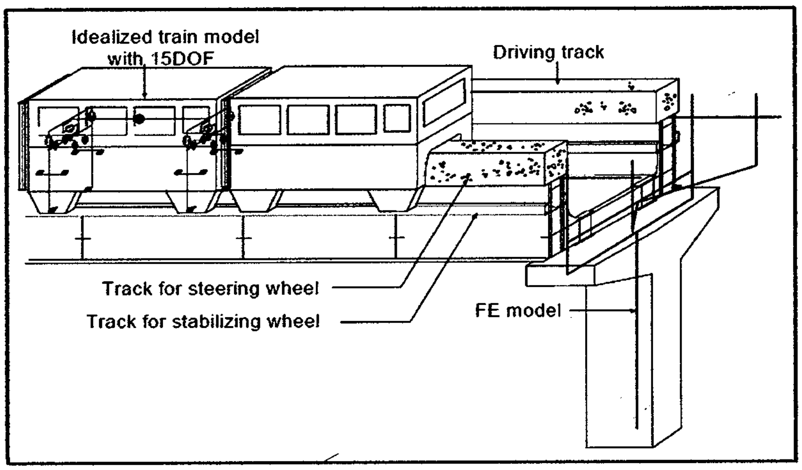

Figure 2.7: Schematic of Monorail Way. (Hun, 2005)

The primary suspension of the vehicle is the load wheel which is a rubber tire filled with nitrogen gas with a pressure of 11.5 bar at tare condition. Secondary suspension utilities (Prasarana, 2014). Secondary suspension utilize the air bag and lavelling system to provide compensation for the vertical forces. Automatic leveling is achieved by the way of a present leveling valve that controls the volume of air into a laterally mounted air bag directly coupled to the lower suspension arm (Shaffei, 2014). This arrangement allows air pressure in the air springs to maintain a constant floor height, independent of passenger loading or vertical forces encountered during running of the vehicle.

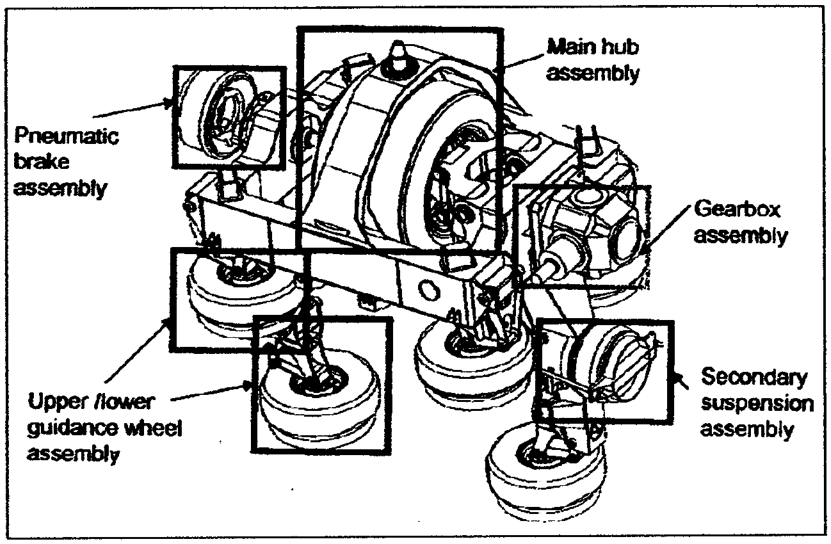

Figure 2.8: Bogie Assembly
(Courtesy of Syarikat Prasarana Malaysia Berhad)

2.4 Vibration

Vibration is determined as oscillatory motion where the motion is not constant but alternately greater and less than some average value. The extent of the oscillation determines the magnitude, while the frequency is determined by the repetition rate of oscillations cycle (Griffin, 1990). The oscillation and repetitive motion of an object is around an equilibrium position. The equilibrium position of an object is when the summation of force is equal to zero (S. S. Rao, 2003).

Vibration theory is concerned with the oscillatory motion of physical systems, the motion may be harmonic, periodic, or general motion in which the amplitude varies with time. Vibrations are encountered in many mechanical and structural applications. The example of vibration applications are mechanisms and machines, buildings, bridges, vehicles, and aircraft. Vibrations are classified into two which free or forced vibration. Free vibration is determined as no external forces that act on the system. Forced vibrations are the external excitations. But, in these both cases of free and forced vibration the system must be capable of producing restoring which tend to maintain the oscillation motion. The level of vibration is depending on the amount of the energy dissipation of dry friction between surface, viscous damping, and structural damping of the material (Shabana, 1996).

According J. S. Rao and Gupta (1999) free vibration called as natural vibration which is the object vibrate under own free natural condition. One of the simplest examples is the classical simple pendulum. When the pendulum is disturbed from the state of rest, the bob of pendulum gains some potential energy. The restoring moment due to the gravity of the bob, would swing the pendulum and the pendulum loses the potential energy in this process while gaining the kinetic energy due to its motion. When the pendulum comes to the mean position again it loses all the potential energy with the bob attaining a maximum velocity at its mean position. Then, the kinetic energy of the bob has gained, is spent on lifting the bulb upward, in the ensuring swing. The energy in the system is constantly changing and the pendulum continues to swing unless the energy is dissipated. While force vibration can be considered as a simple example of an electric bell which when the button is pressed, the clapper starts oscillating under the influence of electromagnetic fluctuating force. But when the fluctuating force is removed, then the clapper comes to rest. So, the bell vibrates only under the influence of impressed force. The type of force vibration can be cited for several examples like turbine and compressor shafting, motor car running on a rough road, and crankshaft of a diesel engine.

Vibration is often complex, contains many frequencies, occurs in several directions and changes over time. The effects of vibration may be manifold. Exposure to whole-body vibration causes a complex distribution of oscillatory motions and forces within the body. There can be large variations between subjects with respect to biological effects. Whole-body vibration may cause sensations (e.g. discomfort or annoyance), influences human performance capability or present a health and safety risk (e.g. pathological damage or physiological change). The presence of oscillatory force with little motion may cause similar effects (ISO, 1997).

2.5 Types of human vibration exposure

Human body vibration can be classified into two types of vibration exposure which is whole body vibration and local vibration. Whole body vibration and local vibration can cause vibration through the body at the same time. Seated persons in vehicle (e.g. bus, car, train, and truck driver) exposed to whole body vibration and also exposed to local vibration of the head (e.g. from a head-rest), the hand (e.g. on a steering wheel), and the feet (e.g. on the floor)(Griffin, 1990).

2.5.1 Whole body vibration

Whole-body vibration (WBV) is vibration transmitted to the whole body by the surface supporting it (i.e. via a seat or floor). It is commonly experienced by drivers, operators and passengers in vehicles and machines when travelling over uneven surfaces.

The transmission of vibration to the body is dependent on body posture. The effects of vibration are complex. Exposure to WBV causes motions and forces within the human body that may:

- Cause discomfort
- Adversely affect performance
- Cause health effect or aggravate pre-existing conditions
- Present a health and safety risk.

Whole body vibration can be described when the environment is undergoing motion and affect the whole portion of the body which is not local to any particular point of contact. It occurs when the body is supported on a vibrating surface. There are three principal possibilities: sitting on a vibrating seat, standing on a vibrating floor, or lying on a vibrating bed (Griffin, 1990). Whole body vibration refers to where the whole body is exposed to vibration through contact on body by the buttocks or feet (Sylvester, 2009). The vibration motion of whole body can be described as a combination of individual motion of six different type of motion which is the translation in three orthogonal direction x, y, and z axes, and rotation around x, y, and z axes (S. S. Rao, 2003).

Farhana (2008) has defined the whole body vibration exposure as the vibration transmitted to the whole body from vibration seat or standing platform and measured at the interface between the machine and the operator (driver seat). When a person is sitting on a rigid seat, the vibration will transmit from the seat to the body (Griffin, 1990). Whole-body vibrations tend to affect the human body which is mainly in vertical vibrations. These vibrations are transmitted to the buttocks and back of the occupant along the vertebral axis via the base and back of the seat (El Falou et al., 2002). For example a case study by Ana Picu (2009) has found that the root means square (r.m.s) of the acceleration value for bus in rage of 0.213–

$1.087 m/s^2$ for the x-axis, $0.325–0.968 m/s^2$ for the y-axis and $0.563–1.894 m/s^2$ for the z-axis is in the range of $0.787-2.782 m/s^2$. This prove that the vertical (z-axis) give the largest vibration.

Another example by (Cann, Salmoni, & Eger, 2004) also found the trucks to have a mean (z-axis) frequency-weighted r.m.s. acceleration of 0.44 m/s^2 ($\pm0.19 m/s^2$) and a range from 0.04 to 1.08 m/s^2. Across different pieces of construction equipment, we found (Cann, Salmoni, Vi, & Eger, 2003) *z*-axis values ranging from a mean of 0.55 m/s^2 ($\pm0.15 m/s^2$) for graders to a mean of 1.61 m/s^2 ($\pm0.30 m/s^2$) for scrapers. We have typically found the *z*-axis to be the dominant axis. The study by Bovenzi et al. (2006) also showed that the vibration frequencies with the highest r.m.s acceleration were 1.25-5Hz (z-axis) for most of the vehicles.

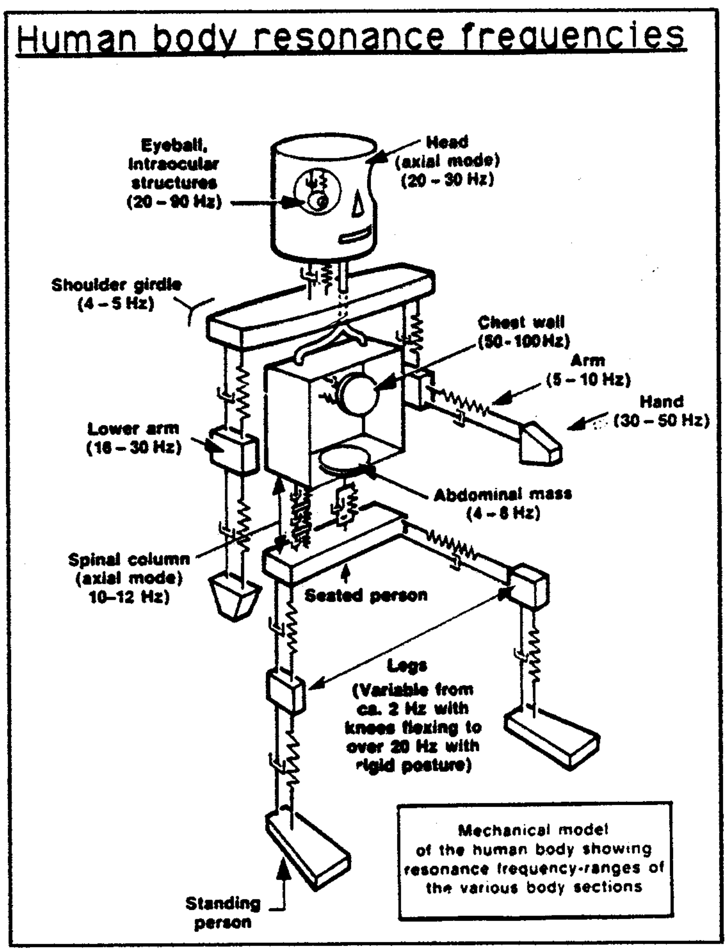

Figure 2.9: The human body standing on a vertically vibrating platform. (Rasmussen, 2009)

2.5.2 Whole body vibration parameters

According to ISO 2631-1, the continuous whole body vibration exposure included:

i. Root mean square average vibration (Aw) calculated at the floor and at the seat pad of the monorail (m/s²).

ii. The weighted root mean square (r.m.s) average weighted vibration (Aw) which is extrapolated to an 8 hour daily value (A(8)), unit are m/s².

The daily exposure to vibration A(8) of a person is ascertained using formula:

$$A(8) = kA_w \left[\frac{T}{T_o}\right]^{\frac{1}{2}}$$ Equation 3.1

Where:

A_w is the vibration magnitude in one of three orthogonal directions, x, y, z at the supporting surface;

T is the duration of exposure to the vibration magnitude

T_o is the reference duration of 8 hours (480 minutes); and

K is a multiplying factor

For horizontal vibration (x and y directions), k=1.4 and A_w is obtained using the W_d frequency weighting. For vertical vibration (z direction), k=1.0 and A_w is obtained using the W_k frequency weighting. Daily exposure to vibration is evaluated separately for x, y, and z directions of vibration.

2.5.3 Whole body vibration on the train

This measurement of whole body vibration in this research was specific on passenger rather than driver since passenger exposure to vibration is limited compared to driver. According literature review, the main sources of harmful WBV in vehicles and machines are:

- Rough road and surface conditions and resistance forces, e.g. mobile plant with scraper blades

- Ehicle activity
- Engine vibration.

Factors that can increase or decrease WBV exposure include:

- Road construction/ maintenance
- Vehicle type/design
- Age/ condition of the vehicle
- Maintenance of vehicle suspension systems
- Seat design, suspension and maintenance
- Cab layout, design and orientation
- Task design and work organization
- Vehicle speed, driver skills and awareness
- Lighting and visibility

The previous study by (Ismail et al., 2010) on whole body vibration exposure to train passenger was found that the daily exposure to vibration A(8) from 3 experiment which experiment A are from Kajang to Seremban (0.3221 m/s^2), experiment B from Seremban to Gemas (0.2884 m/s^2), and last is experiment 3 from Seremban to Tampin (0.3749 m/s^2) is under exposure action value (0.5m/s^2). The result can be categorized as safe exposure to passenger body. The daily exposure action value time only required 7 h 16 min to meet the standardized value of 0.5 m/s^2.The result founded to exceed the standard time of whole body vibration assessment which is 8 h is nearly same.

Another study was done by Birlik (2009) on whole body vibration between Suburban train and Intercity train. The daily exposure for 6 hours on suburban train is 0.3 m/s^2 smaller than intercity train which is 0.52 m/s^2 which more than exposure action limit according ISO 2631-1. The suburban train driver travel duration is usually driven take 1hour 58 minutes. While intercity train driver drive the train at least takes 2 hours and 36 minutes. So the conclusion can be done with this result, the longer exposure time will effect on the daily exposure level of vibration.

Table 2.1: Examples of environment of whole body vibration (Griffin, 1990)

Aerospace systems	**Off-road vehicles**	**Rail transport**	**Road transport**
i. Fixed-wing aircraft ii. Rotary-wing aircraft iii. Spacecraft	i. Tractors ii. Forest machines iii. Tanks iv. Animal rides	i. Trains ii. Monorails iii. Ski iv. Lifts/ cable cars v. Other guided transport	i. Cars ii. Vans iii. Trucks iv. Buses v. Coaches vi. Carriages vii. Motorcycls viii. Pedal cycles
Marine systems	**Building**	**Industrial equipment**	
i. Ships ii. Boats iii. Hovercraft iv. Submarines	i. Houses ii. Officers iii. Workshops iv. Offshore	i. Cranes\fork-lift trucks ii. Equipment control stations	

Table 2.1 shows 7 environment example that cause whole body vibration (Griffin, 1990). One of the environment cause vibration is rail transport which is like train, monorail, cable car and others and the vibration cause by this machine will transmitted to the human body. But there are others cause of vibration on vehicle for example the transportation research by Cann et al. (2004) found that magnitude of vibration was affected significantly by the roughness of the roads travelled.

2.6 Humans vibration standard

There were some standard according to the human vibration parameter. Some of the standards used globally for whole body vibration are tabulated below in table 2.1.

Table 2.2: Major whole body vibration standards (Sylvester, 2009).

ISO 2631-1 (1997) ISO 2631-2 (1989) ISO 2631-4 (2001) ISO 2631-4 (2004)	Mechanical vibration and shock – Evaluation of human exposure to whole body vibration. Part 1: General Requirement evaluation of whole body vibration; Part 2 : Continuous and shock induced vibration in buildings (1 to 80 Hz) Part 4: Guidelines for the evaluation of the effect of vibration and rotational motion on passenger and crew comfort in fixed-guideway transport systems Part 5: Method for evaluation of vibration containing multiple shocks
ISO 8041 (1990)	Human response to vibration – Measuring instrumentation
BS 6841 (1987)	Measurement and evaluation of human exposure to whole body mechanical vibration and repeated shock
SAE J1013 (1992)	Measurement of whole body vibration of the seated operator of off highway work machines
SAE J1384 (1993)	Vibration performance evaluation of operator seats
ANSI S2.72/Part 1-2002 (R 2007)	Vibration National Standard Mechanical vibration and shock -Evaluation of human exposure to whole body vibration -Part 1; General requirements
AS 2670.1-1990	Evaluation of human exposure to whole body vibration - General requirement

2.6.1 ISO 2631-1

The purpose of ISO 2631 is to define methods of quantifying whole body vibration in relation to:

i. Human health and comfort

ii. The probability of vibration perception

The environment that can interfere with the comfort, activities and health such as vehicle (air, land, and water), machinery (agriculture) and industrial activities (such as piling and blasting), exposure people to periodic, random, and transient mechanical vibration.

The standard does not define a precise analysis method and some judgement is therefore required in defining the optimum procedure which will be in accord with its content. The emphasis must be on obtaining reliable weighted value for motion in each axis. It seems unnecessary to incorporate either the time-dependency or the three criteria into the measurement procedure. The time-dependency is not supported by the result of research and does not justify the complexity it introduces. There is little doubt that neither the time-dependency nor the three sets of limits corresponding to the three criteria will survive a revision of the standard (Griffin, 1990).

This part of ISO 2631 does not contain vibration exposure limits. However, evaluation methods have been defined so that they may be used as the basis for limits which may be prepared separately. It contains methods for the evaluation of vibration containing occasional high peak values (having high crest factors).

This part of ISO 2631 defines methods for the measurement of periodic, random and transient whole-body vibration. It indicates the principal factors that combine to determine the degree to which a vibration exposure will be acceptable. Informative annexes indicate current opinion and provide guidance on the possible effects of vibration on health, comfort and perception and motion sickness. The frequency range considered is:

i. 0.5 Hz to 80 Hz for health, comfort and perception, and
ii. 0.1 Hz to 0.5 Hz for motion sickness.

Although the potential effects on human performance are not covered, most of the guidance on whole-body vibration measurement also applies to this area. This part of ISO 2631 also defines the principles of preferred methods of mounting transducers for determining human exposure. It does not apply to the evaluation of extreme-magnitude single shocks such as occur in vehicle accidents.

This part of ISO 2631 is applicable to motions transmitted to the human body as a whole through the supporting surfaces: the feet of a standing person, the buttocks, back and feet of a seated person or the supporting area of a recumbent person. This type of vibration is found in vehicles, in machinery, in buildings and in the vicinity of working machinery.

2.6.2 Exposure action limit and Health guidance caution zone

According Sylvester (2009) various international standard have been developed which govern the way in which human vibration should be measured, as well as provide the indications of the health risk involved. The European Parliament legislation stipulates minimum standard for health and safety of workers exposed to either hand arm or whole body vibration. The EU legislation specifies the daily vibration exposure level which exposure action value (EAV) and exposure limit value (ELV). The prediction of whole body vibration health risk is based on ISO 2631-1 (1997) health guidance caution zone (HGCZ) limits as shown in the table 2.3.

Table 2.3: Exposure action limit values and health guidance caution zone for whole body vibration (Sylvester, 2009).

Exposure / HGCZ	**ISO 2631-1 (1997)**	
	WRMS	**VDV**
EAV/HGCZ lower limit	0.50 m/s^2	9.1 $m/s^{1.75}$
ELV/HGCZ upper limit	1.15 m/s^2	21.0 $m/s^{1.75}$

From the table above, if the exposure level above the EAV, a range of action must be taken to reduce exposure and decrease risks. The greater the exposure level, the greater the risk and the more action employers will need to take to reduce the risk. While if the ELV is exceeded, immediate action must be taken to reduce vibration exposure below the ELV. The vibration exposure is dependent on the magnitude of vibration and duration of exposure, the duration of operation or work time that may cause high level vibration, possibly limited to reduce exposure.

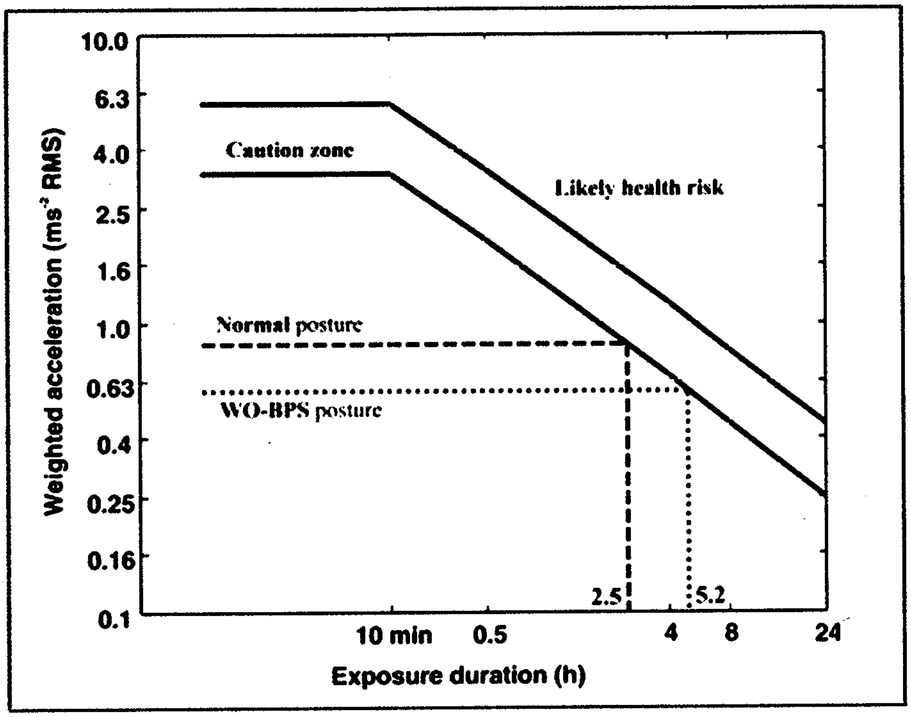

Figure 2.10: Health Guidance Caution Zone (HGCZ) in ISO 2631-1:1997

2.6.3 Root Mean Square (r.m.s)

The vibration evaluation according to this part of ISO 2631 shall always include measurement of the weighted root-mean-square (r.m.s) acceleration. This is expressed in meter per second per squared (m/s^2) for translational vibration and radians per second squared (rad/s^2) for rotational vibration. The weighted r.m.s acceleration shall be calculated in accordance with the equivalent in the frequency domain.

2.7 Health effects.

The longer a worker is exposed to WBV, the greater the risk of health effects and musculoskeletal disorders. The most commonly reported disorders from exposure to WBV is low-back pain.

Epidemiological studies of long-term exposure to WBV have shown evidence of risk to the lumbar spine and the neck and shoulder. Results of epidemiological studies also show a higher prevalence rate of low-back pain, herniated disc and early degeneration of the spine in excessive WBV- exposed workers. Exposure to WBV may also cause or exacerbate other health or safety effects such as:

- Cardiovascular, respiratory, endocrine and metabolic changes
- Digestive problems
- Reproductive organ damage
- Impairment of vision, balance or both
- Interference with activities and discomfort that could lead to accidents.

The deleterious effects of vibration on the human body have been suggested to include low-back pain, spinal degeneration, gastrointestinal tract problems, dysfunction of the autonomic nervous system, degraded circulatory functioning, muscular fatigue, headaches, loss of hearing, eye problems, reduced balance, and nausea (Seidel, 1993). Palmer et al. (2003) was estimated that 95,000 female and 444,000 male have low back pain in United Kingdom because of whole body vibration exposure.

Professional drivers are exposed to whole body vibration (O. O. Okunribido et al., 2006) and it could be a risk to high levels of exposure(Seidel, 2005). High levels of Whole-Body vibration exposure are common to workers who operate heavy machinery, material handling and transport equipment, or whose operator stations are in proximity to heavy rotating, stamping or reciprocating machinery. Physical effects to the worker can include damage to the spinal column, and can manifest as low back pain or back, neck and shoulder disorders.

Some studies point to possible negative reproductive effects in female populations exposed to high levels of Whole Body vibration. Until now, it has been difficult to quantify these exposures accurately and consistently. Vibration must be measured in three directions, or axes, simultaneously and this acceleration information must be integrated into useful values and scientific units of measure. Further, measuring the frequency range of the vibration is critical to assessing the potential for physical damage. For example, the frequencies of interest in determining potential injury from hand tools are as high as 2500 Hz, whereas Whole-Body vibration exposures are most damaging at lower frequencies - in the case of the spinal column, primarily from about 0.2 to 8 Hz (Davis, 2003).

Occupational exposure to whole body vibration and postural stress in a driving environment may contribute to an increased risk for low back pain disorders. In two epidemiological studies of bus drivers and tractor drivers, low back pain disorders were found to be associated with age, back accidents, cumulative whole body vibration dose, and postural overload (Bovenzi et al., 2006; Cutini et al., 2012; Okunribido et al., 2007). During the ride in a train, drivers and passengers are exposed to vibrations from the road surface. But, train driver are exposed to continuous vibration which is time exposure is longer than passengers. Continuous vibrations may cause the feeling of discomfort and it will reduce working ability of the driver, and it may give health effect. From the past investigations in literature review show that occupational drivers are exposed to high intensity vibration. Some of the health problems on occupational driver due to long time exposure to high level vibration are musculoskeletal disorder (Thamsuwan et al., 2012).

2.8 Summary from the Previous Researcher

Table 2.4 shows the comparison of the previous study on whole body vibration between objective, method, and also finding of each study. Based on the previous study, it shows that the relation between back pain and whole body vibration. Most of the study shows that occupational workers as drivers are exposed to whole body vibration, long duration of working time, and also back disorder complaint. These three factors have correlation between each other to identify the relation of this cross sectional factor. Other than that, there was also study of whole body vibration compared with different type of road and also with different type of transport model. So, as the summary for this topic it can be said that there are many factors can affect the exposure of whole body vibration and back pain problem.

REFERENCES

Birlik, G. (2009). Occupational Exposure to Whole Body Vibration-Train Drivers. 47, 5(10).

Bovenzi, M., Rui, F., Negro, C., D'Agostin, F., Angotzi, G., Bianchi, S.Stacchini, N. (2006). An epidemiological study of low back pain in professional drivers. Journal of Sound and Vibration, 298(3), 514-539. doi: http://dx.doi.org/10.1016/j.jsv.2006.06.001.

Bovenzi, M., & Zadini, A. (1992, 17(9), 1048-1059.

Burdorf, A., Riel, M. V., & Brand, T. (1997). Physical Load as Risk Factor for Musculoskeletal Complaints Among Tank terminal Workers. American Industrial Hygiene Asscociation Journal, 58(7).

Coyle, J. C., Bardi, E. J., & Novack, R. A. (2006). *Transportation.* South Western: Thomas.

Cann, A. P., Salmoni, A. W., & Eger, T. (2004). Predictors of whole-body vibration exposure by highway transport truck operators. Ergonomics, 47(13), 1432-1453.

Das, A. M., Ladin, M. A., Ismail, A., & Rahmat, R. O. (2003). Consumers satisfaction of public transport. Engineeroing Science and Technology.

Farhana, L. (2008). The Effect of Whole Body Horizontal Vibration in Position Sense and Dynamic Stability of the Spine. (Degree of Master's of Science), University of Kansas. (1453307).

Funakosh, M., Taoda, K., Tsujimura, H., & Nishiyama, K. (2004). Measurement of Whole Body Vibration in Taxi Drivers. Journal of Occupational Health, 46(2), 119-124.

Funakoshi, M., Tamura, A., Taoda, K., Tsujimura, H., & Nishiyama, K. (2003). Risk factor for low back pain among taxi drivers in Japan. Sangyo Eiseigaku Zasshi, 45, 235-247.

Griffin, M. J. (1990). Handbook of Human Vibration: Elsevier Science.

Handbook of Railway Vehicles Dynamics, Chp.3 The Anatomy of Railway Vehicle Running Gear by Anna Orlova And Yuri Boronenko.

https://railforthevalley.wordpress.com/2009/07/15/schwebebahn-wuppertal-the-108-year-old-gadgetbahnen/

Hun, L. C. (2005). Dynamic response analysis of monorail bridges under moving trains and riding comfort of trains.

Ismail, A. R., Nuawi, M. Z., How, C. W., Kamaruddin, N. F., Nor, M. J. M., & Makhtar, N. K. (2010). Whole Body Vibration Exposure to Train Passenger. American Journal of Applied Scienes, 7(3), 352-359.

ISO. (1997). Mechanical vibration and shock-Evaluation of human exposure to whole-body vibration-Part 1: General requirements. International Standard Organization.

Kennedy, R. R. (2010). Monorail Rapid Transit. *Considering Monorail Rapid Transit for North American Cities* .