Presented at the 4th DLSU Innovation and Technology Fair 2016
De La Salle University, Manila, Philippines
November 24 & 25, 2016

Design of a Light Rail Vehicle Simulator for Manila LRT Line 1

Homer S. Co, Dustin Aaron S. Dee, Miguel Benjamin G. Guico, Brian Leemark C. Po, Gino B. Quinio
Manufacturing Engineering and Management Department, De La Salle University
2401 Taft Avenue, Malate, Manila, Philippines
Corresponding Author: leemarkpo@yahoo.com, miguel.benjamin.guico@gmail.com

Abstract: Efficiency in public transportation is certainly a key in reducing carbon emissions from road vehicles' and decongesting major cities. Although trains may be fully automated, some cases require a human driver especially in tracks where a lot of variables come into play like in the Philippines with our open rails where debris or unforeseen circumstances often occur. The use of train simulators is becoming a standard in the training and development of the train operation industry. Currently, the Light Rail Transit Authority (LRTA) does not have a simulator for use in the training of their future train operators, and in keeping the skills of current operators sharp. Because market available Light Rail Vehicle (LRV) simulators are expensive (>$100,000), while video game simulators do not measure driver performance, the aim of this study is to locally develop a Light Rail Vehicle simulator that measures driver performance for possible use in training LRV operators at low cost. The simulator has since been tested by drivers of the LRT Line 1 for whom it has been tailor fit. Aside from a few technical adjustments, the machine has been received well and its use as a classroom teaching tool or an applicant screening tool will be explored further.

Key Words: public; transportation; rail; train; simulator;

1. INTRODUCTION

In other countries, simulators are increasingly being used in the training of operators [1] [2]. Many companies create and manufacture simulators, in varying degrees of realism, ranging from arcade-like train games, to full cockpit imitations with audio-visual and motion feedback.

In the Philippines, no simulators are yet used to train operators [3]. When training train operators, the Light Rail Transit Authority (LRTA) uses actual trains that run the same route during regular operations [3]. Operator training is currently handled by the Human Resources of the LRT [3]. Acquiring a simulator may be beneficial for the training of train operators.

In a city like Manila where traffic is ever-present, railways can decisively contribute to the alleviation of exploding traffic problems by their large carrying capacities [4]. An effective rail system could decongest the dismal traffic situation as well as help reduce carbon emissions from road vehicles. However, these trains will require operators, who will require training. Familiarizing a driver with a new route, a different signaling system, and other factors, would involve either using a full cab simulator or driving an actual tram along the route out of operational hours [1]. Railways can also have high costs due to obsolete operating methods and staff over-crowding [4]. Development strategies for railways often include reducing costs which may come from the application of new technology [4].

The use of simulators could mean increasing the safety of our railways as well as lowering the costs of training and operating the LRT. However, the simulator must be customized to the line the operator is travelling in.

Since simulators need to be tuned to a specific line, the group arbitrarily chose to simulate Line 1 of the Manila LRT. Due to the myriad of events that could happen while driving a train, the complexity of simulating each one of these, and the limited time and budget constraints of the researchers, it was decided to focus on the normal train driving experience – the ferrying of passengers from station to station, daytime, sunny, with no extraordinary circumstances.

The group had the assistance of the Light Rail Transit Authority of Metro Manila and the Light Rail Manila Corporation (currently in-charge of training and operations since September 2015) to come up with criteria by which drivers will be evaluated and to cross-check the scope of normal train driving operations.

Since the simulator focuses on normal train driving operations, the controls included are only those identified that are in use in the ferrying of passengers from station to station. The machine will give audiovisual output to the user, but will not simulate the motion of the train.

2. METHODOLOGY

2.1 CONSOLE PANEL

Fig. 1 Open right door

Fig. 2 Close right door

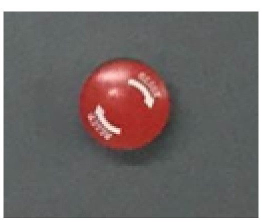


Fig. 3 Emergency Break

The console panel contains the buttons for the doors, emergency brakes, and the horn. Since the LRT line 1 only uses the right side doors, the left side doors buttons are only placed for aesthetic purposes and for possible future expansion of the project to include other circumstances.

Fig. 4 Console and Rate Controller

The metal casing houses all the necessary hardware and circuitry needed to physically interact with the simulator. It is 80 centimeters long, 25 centimeters wide, and 30 centimeters high. The front, however, is slanted at an angle of 67.3 degrees starting a centimeter above the foot of the case. The group was able to look around the driver's cabin of the LRT's 3rd generation train and take the necessary measurements. However, the width, height, and slanted angle of the console board has been adjusted for it to be easier to open up the machine and perform any maintenance requirements on the hardware.

The two rectangular gaps were made with the consideration that these could be filled depending on the need of the user of the simulator. These are to be filled with plates that will either cover or contain a part such as speedometer or LED and may be installed into the machine itself. For the moment, they house the two LEDs of the simulator as the rest are filled with blank plates.

2.2 RATE CONTROLLER

Fig. 5 Rate Controller

The rate controller is an input device that controls the acceleration of the train [3], it also incorporates a safety feature called the Deadman's Handle. The Deadman's Handle is an input safety feature device that is integrated in the Automatic Train Protection system or ATP, which stops the train in the event of an incapacitated driver. Due to lack of schematics, the team reverse-engineered the dead-man's handle function of the rate controller. The electronic components consist of a pushbutton, which also serves as a mechanical spring for the handle, and a potentiometer to change an electric signal to indicate the position of the handle.

2.3 MICROCONTROLLER

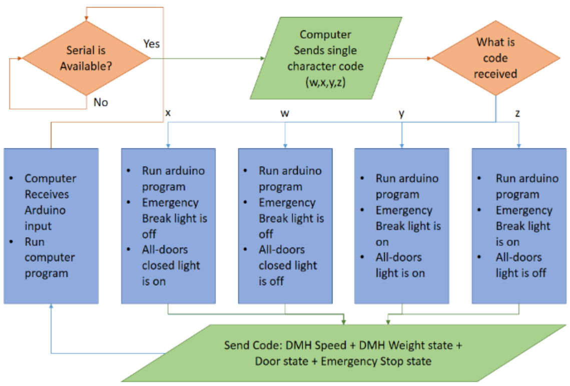


Fig. 6 Arduino Flow Chart

Due to familiarity and ease of use, Arduino was used as a microcontroller to handle communications and lower-level control logic in the simulator. The circuitry has been designed to send either high or low inputs (no pulse or change electrical signals, with high being 5V and low being close to 0V). Arduino receives all the inputs from the buttons and the rate controller and sends a single line of string to the computer for processing. The inputs it receives from the different controls are by way of detecting the presence of HIGH or LOW signal; except for the rate controller wherein it receives an analog input and translates it into numbers. The computer will respond after afterwards by sending a single character back to Arduino which notifies Arduino which states have been changed within the program. With this type of communication, Arduino and the program are able to respond to each other's inputs and changed states.

2.4 SOFTWARE MODEL

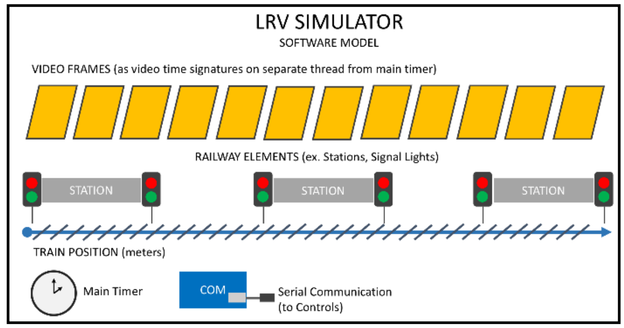


Fig. 7 Software Model

The railway track is divided into finite segments (in meters) upon which the various elements of the railway are placed. As the train moves along the track as commanded by the user and calculated by the physics engine, the software shows the corresponding video frame whose time signature matches the corresponding train position. The software uses the train's position to detect whether it's in a station or not and to operate the signal lights. The train's velocity, position, and controls determine any violations.

2.5 PHYSICS

Since the train is travelling along a single path defined by the rails, it would be suitable to model the train system using linear motion physics. As such, the position of the train is defined by:

$$x_f = x_i + v_f t_f + \frac{1}{2} a t_f^2 \qquad \text{(Eq. 1)}$$

Where:

x = position on the rail

v = velocity

t = time (given by the program)

a = acceleration

The subscript *i* means *initial*, and the subscript *f* means *current*. Current velocity is computed as:

$$v_f = v_i + at_f \quad \text{(Eq. 2)}$$

The position and the velocity are the result of the input of the controls. The input comes in the form of acceleration. All trains along line 1 are driven by electric motors - some DC, some AC. The computation for acceleration is an approximation of a Power-Speed Curve of a DC electric motor. The actual Power-Speed curve of the train's motors was not available for use. The justification for using the Power-Speed Curve as a basis for computing acceleration is shown below:

Rearranging Newton's 2nd Law of Motion

$$a = \frac{F}{m} \quad \text{(Eq. 3)}$$

Relating *Force* (tangential) and *Torque* via a *Radius*:

$$F = \frac{T}{r_{wheel}} \quad \text{(Eq. 4)}$$

Connecting *Acceleration* (tangential) and *Torque* by substituting (4) into (3):

$$a = \frac{T}{r_{wheel}m} \quad \text{(Eq. 5)}$$

The *Output Power* is given as:

$$P_{out} = T \cdot rpm \quad \text{(Eq. 6)}$$

Where *rpm* is rotational speed.

Placing (6) into (5), we get:

$$a = \frac{P_{out}}{r_{wheel}m \cdot rpm} \quad \text{(Eq. 7)}$$

From this we can conclude that:

$$a \propto P_{out} \quad \text{(Eq. 8)}$$

And that acceleration follows the power speed curve.

The group approximated the curve using the top half of a circle because the actual Power-Speed curve of the train's motors was not available for use, the variety of motor curves, and simplicity. We then approximate this curve in acceleration's terms using the equation of a circle of the form:

$$(x-h)^2 + (y-k)^2 = r^2 \quad \text{(Eq. 9)}$$

Substituting in values:

$$[v_{now} - (v_{min} + r)]^2 + (a-7)^2 = r^2 \quad \text{(Eq. 10)}$$

Where V_{now} stands for the current velocity of the train, V_{min} for the nearest rate controller increment less than V_{now}, and the radius of the circle, r defined by:

$$r = \frac{v_{max} - v_{min}}{2} \quad \text{(Eq. 11)}$$

Where V_{max} is the target speed determined by the operator via the rate controller.

Re-arranging (10) for acceleration, we get:

$$a = 7 + \sqrt{r^2 - [v_{now} - (v_{min} + r)]^2} \quad \text{(Eq. 12)}$$

The value for a is then used in equations (2) and (1) to find out the next position of the train in the program model. These equations do not account for friction or slippage on the tracks and represents net acceleration of the various forces acting on the train.

2.6 USER ACCOUNTS AND REPORT GENERATION

The program allows for the creation of user profiles - trainee profiles and administrator (admin) profiles. Trainee profiles can run simulations, receive a report of their performance, and view reports of their past performances. Administrators can view trainee profiles and reports of their past performances, but cannot run simulations. The report generated at the end of the simulation was based on parameters from the training manuals of the LRTA and agreed upon with management.

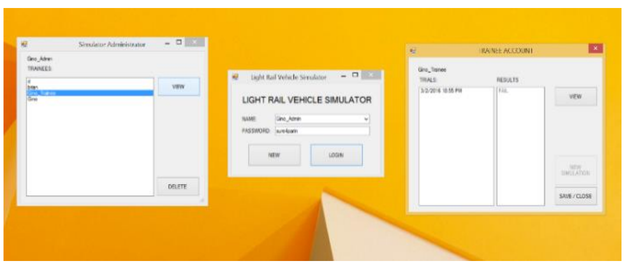


Fig. 8 Login and User Accounts

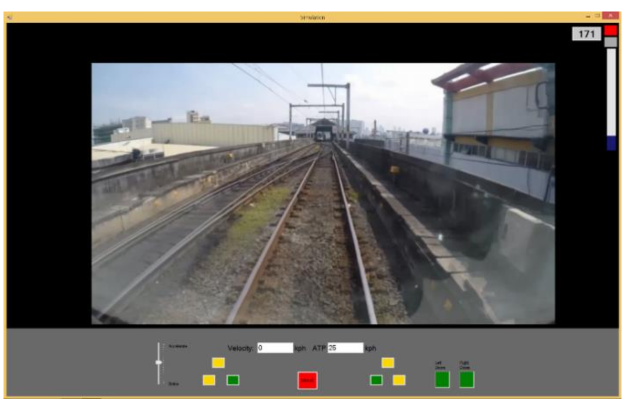


Fig. 9 Simulator View

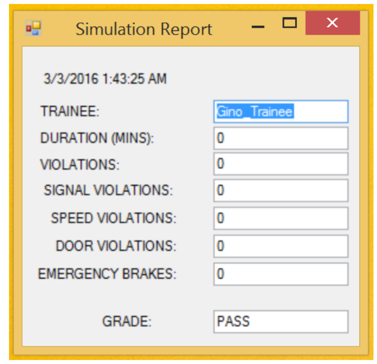


Fig. 10 Simulation Report

2.7 AUDIOVISUAL EDITING

The video used in this thesis came from raw train driving footage given by the LRMC. The file requires processing before use in the simulator program. The following sub-sections discuss how the video was processed using Adobe Premiere Pro video editing software, as well as the equations used in adjusting the lengths of the videos. Below is a flowchart of the process of video editing, followed by the sub-sections explaining them.

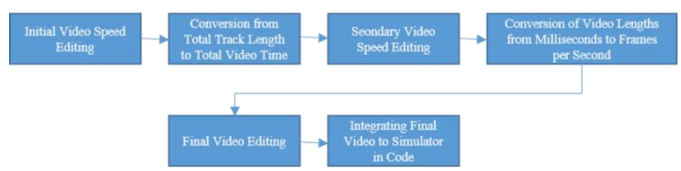


Fig. 11 Video Editing Process

The raw video footage taken from the LRMC was of varying speeds. The train was shot in its normal operation, from full stop, acceleration, coasting, deceleration, and full stop again upon entering the next station. Thus, the video had to be edited in such a way that the visual representation of the fastest speed of the footage was taken to be the base speed, and all other visual representations of different train speeds were sped up to the base speed. The output for step 1 of editing was a video of the train at 60 KPH.

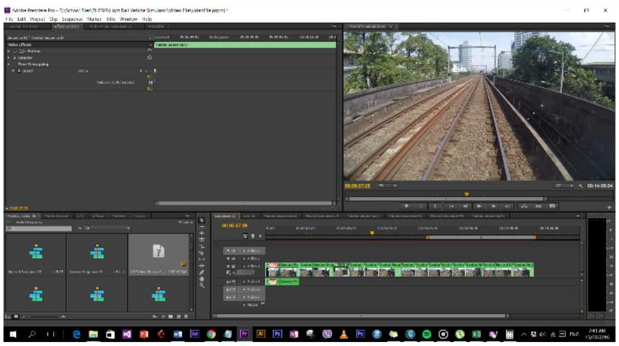


Fig. 12 Adobe Photoshop Panel

Before editing the video into the file to be used by the program, its length λ_{vid} must be made proportional to the track lengthλ_{track}. The equivalent video length in seconds for a given track length in meters could be computed using a simple conversion equation, assuming the video has a speed of 60 KPH:

$$\lambda_{vid} = \lambda_{track} * \frac{1\,\cancel{km}}{1000\cancel{m}} * \frac{1\,\cancel{hr}}{\cancel{60\,km}} * \frac{\cancel{60\,min}}{1\,\cancel{hr}} * \frac{60\,sec}{1\,\cancel{min}}$$

Which clears out to:

$$\lambda_{vid} = \lambda_{track} * 0.06 \qquad \text{(Eq. 13)}$$

Where:

λ_{vid} = total video length

λ_{track} = total track length

Aside from making the total video length λ_{vid} proportional to the total track length λ_{track}, the video lengths in between stations ($\lambda_{vidStation1}$ …. $\lambda_{vidStation18}$) should also be proportional to the track lengths in between stations ($\lambda_{trackStation1}$ …. $\lambda_{trackStation18}$). This can be done by applying Equation 3.13 to all the lengths in between stations.

To make the video smoother, the initial footage was slowed down by five times the original speed. This ensures smooth transitions whenever the operator slows down the simulator. Translating this mathematically, this would mean that the new Station Lengths ($\lambda_{vidStation1Long}$ …. $\lambda_{vidStation18Long}$) would be increased five times the original Station Lengths ($\lambda_{vidStation1}$ …. $\lambda_{vidStation18}$)

For the purpose of final video editing, the decimals of the station lengths ($\lambda_{vidStation1Long}$ …. $\lambda_{vidStation18Long}$) were converted from milliseconds (M:SS.00) into frames per second (M:SS.FPS). Instead of having decimals which range from values of 0-100, the values were converted into frames per second which have values from 0-30.

$$1\,sec = 1000\,ms = 30\,frames$$

Next page is the table detailing the final video length for final editing:

Table 1: Computed Video Lengths

Tag #	Position (m)	Current Station	Video Length (secs) (λvidStation1 .... λvidStation18)	Increased Video Length M:SS.00 (λvidStation1Long .... λvidStation18Long)
S0104	129			
S0110	315	Baclaran	11.2	55.8
S0206	904	EDSA	35.3	176.7
S0306	1912	Libertad	60.5	302.4
S0404	2644	Gil Puyat	43.9	219.6
S0506	3704	Vito Cruz	63.6	318
S0606	4530	Quirino	49.6	247.8
S0704	5324	Pedro Gil	47.6	238.2
S0904	6077	UN Ave.	45.2	225.9
S1008	7292	Central	72.9	364.5
S1106	8018	Carriedo	43.6	217.8
S1204	8702	Doroteo Jose	41.0	205.2
S1304	9350	Bambang	38.9	194.4
S1404	9968	Tayuman	37.1	185.4
S1504	10639	Blumentritt	40.3	201.3
S1706	11565	Abad Santos	55.6	277.8
S1804	12225	R. Papa	39.6	198
S1906	13179	5th Avenue	57.2	286.2
S2106	14264	Monumento	65.1	325.5
		End of Line		Total: 4240.15

In order to accurately match the position calculated using the equations in section 3.6 with the position of the train in the video, the current position coordinate x_f must be converted into the current video position coordinate x_{vf}. We use the following ratio and proportion equation in computing for the current video time given the position computed earlier in the position equations:

$$x_{vid} = (x_f - 129) * \frac{\lambda_{vid}}{\lambda_{track}} \quad \text{(Eq. 14)}$$

Where:
X_{vid} = current position of video
X_f = current position in track
λ_{vid} = total video length
λ_{track} = total track length

The offset of 129 is due to the position X_f starting at 129 in code, but the video position X_{vid} starts at 0.The audio output of the simulator comes from two .mp3 files which were recorded through an iPhone. The first file of the two is a moving LRV sound named moving.mp3, while the second file is a stationary LRV sound named idle.mp3. The following chart represents the flow of the method, and how the mp3 files are called in the program:

Fig. 13 Simulator Testing by Students

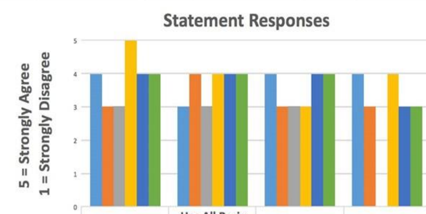
3. RESULTS AND DISCUSSION

In order to attain the General Objective of "possible use in training LRV operators" and test the effectiveness of the machine, the group had a test driving session with the Light Rail Manila Corporation, who as of September 2015, took over management and operations (including training) of LRT Line 1 from the Light Rail Transit Authority. The test session was done in order to recognize specific problem areas and retrieve specific recommendations on how the machine can be improved in terms of its usability. After driving the machine, the participants answered a survey. They were asked to rate the simulator from 1-5 with 1 being "Strongly Disagree" and 5 being "Strongly Agree" and remark on the following statements:

1. It was easy for me to use the LRV Simulator
2. The simulator contains all the basic functions needed to drive the train
3. The train driving experience is well simulated
4. I did not encounter any problems with the simulator.

In order to obtain a better understanding of the drivers' response to the use of the simulator, the group took a look at the qualitative responses of the drivers through a box after each question wherein they could state their remarks.

From the scores in Fig. 11, one can see that the response to the simulator was generally positive with a few reservations. With regards to the realism of the simulator, written comments tell us that the simulator is able to properly simulate real train driving with some recommendations. The most common recommendation for improvement refers to the use of the Rate Controller where most feedback cited that it could be improved by added notches wherein a driver could physically feel the feedback as to the degree of acceleration and braking of the train (see Recommendations).



	Easy to Drive	Has All Basic Functions	Well Simulated	No Problems
Froilan M. Uy - 15yrs XP	4	3	4	4
Edwin A. De Rojas - 13yrs XP	3	4	3	3
Janssen L. Yambao - 13yrs XP	3	3	3	
Boyet Lucas - 5yrs XP	5	4	3	4
Alexander A. Maglonzo - 3yrs XP	4	4	4	3
Jake Janeo - 1yrs XP	4	4	4	3

Fig. 14 Simulator Survey Scores

4. CONCLUSION

The simulator is limited only to regular train driving operations, however it was designed with further improvements and additions in mind. The group hopes that the simulator will be a starting point for the use of simulators in training railway operators, and other fields of transportation for cost-effective training while reducing risks to people and infrastructure, as well as contributing to the development of rail transportation for the reduction of carbon emissions.

After presenting the thesis to the Light Rail Manila Corporation, the simulator has received an official acknowledgement for meeting agreed-upon objectives and testing by their train drivers. After several meetings, they have shown great interest in the simulator and are interested in developing it further.

Fig. 15 Simulator Testing by Train Drivers

Based on feedback by the train drivers, professors and other technology available, the following are points for improvement:

1. The rate controller must have notches/tangible increments that can be felt by the driver.
2. Improvements to the accuracy of the braking and coasting
3. Accuracy of positioning of signal lights distance to the signal light in the video.
4. A great improvement which would be a large task in itself would be the addition of different train driving scenarios and emergency cases.
5. Another great improvement yet also a large task would be providing a physical feedback during acceleration, braking and jerking.
6. More instruments can be moved away from the digital display and unto the console (dashboard) such as the speedometer and ATP. The console can also be modelled better to more accurately reflect the real console panel.
7. The current thesis was designed with the program needing separate installation on the computer dedicated to run the simulator, while the console would function much like a video game controller. Small computers like the Raspberry Pi or the integration of a full CPU with the console can make the thesis independent of a separate computer. Although the value of this improvement should be judged against how the final users intend to use the simulator.
8. Virtual Reality is also a possible improvement and would require full 3D modelling of the driver's cabin and the track itself.

5. ACKOWLEDGEMENTS

The group would like to acknowledge the contribution of Dr. Gregg Garcia for helping facilitate discussions with the LRTA. We would also like to acknowledge Mr. Jerome Erik Enriquez of the LRTA and Mr. Alex Maglonzo of the LRMC for their generous help in providing useful data and feedback with regards to the machine.

6. REFERENCES

[1] Anonymous, (2010, July 15) Using Simulators to Train Tram Drivers. [Online]. Available: http://www.ergonomics.org.uk/transport/using-simulators-to-train-tram-drivers/.

[2] Sallee R. (2006, March 20) Simulator shows operator that it's not easy to keep light rail on track, [Online]. Available: http://www.chron.com/news/houston-texas/article/Simulator-shows-operator-that-it-s-not-easy-to-1882026.php

[3] LRTA – interviews, visits and documents

[4] V.A. Profilidis, Railway Engineering, Second Edition, Hampshire, England, Ashgate Publishing Limited, 2000, pp. 2, 14, 15, 24.

[5] H. Co, D. Dee, M. Guico, B. Po, G. Quinio, Light Rail Vehicle Simulator, Undergraduate Thesis, De La Salle University, Manila, Philippines, 2016