# Matlab/Simulink-Based Modeling for Industrial Electric Vehicle

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***Abstract*— The land transport sector has passed through multiple phases of evolution in design, development, manufacturing of vehicles. In particular, the construction site continues to progress towards the autonomous vehicles (also called self-driving), which were one of its big trends and have become a hot topic in the industrial and academic world. By now, with this new technology of autonomous driving, we can ensure the safety by reducing the number of road accident, also the environmental impact and energy consumption is lessened. The modeling and simulation phases had become a mandatory step to design, characterize and simulate vehicle dynamics while reducing the cost of development. As they provide suitable test beds for the design and evaluation, the impetus of this study is to implement a model of a METALLIANCE's industrial Electric Vehicle based on Matlab/Simulink, that will be close to the reality. The model is implemented based on electrical equations associated with the power supply circuit. The model defines for real time the evaluation of various electric parameters in safe vehicle operation for these vehicles. This work will be completed by the design of a full simulator, which reproduces reliably the dynamic behavior of Métalliance construction vehicles.**

***Keywords- Electric system modeling; Vehicle dynamics; Construction Machinery; Traction and Suspension control.***

## I. INTRODUCTION

The automotive and transportation industry are in perpetual evolution towards autonomous and electric vehicle (AEV), also known as automated car. It is seen as the important future technologies that will change the paradigm of mobility and facilities construction industry operations [1]. The Connected Autonomous Vehicle (CAV) is a system concept that can do driving maneuvers and tasks by itself, without human intervention, and communicate with its occupants and with external elements. The realization of this type of vehicle release humans from the driving task, reduce energy consumption, CO2 and pollutant emissions, and environmental impact. In addition, the autonomous car can improve safety by minimizing and preventing as possible the number of road accidents caused by the driver carelessness (most accidents are caused by human errors). But until now, replacing human driver with an autonomous driver is not guaranteed to avoid all problems. As the automated driving can impact positively the road traffic, it can also have a negative impact. Many works can be taken in order to minimize the negative externalities arising from automated driving [2].

The future of autonomous vehicle is in progress to be electric in order to have a complete vehicle which take the advantages of both autonomous vehicle and electric vehicle (EV) such as environmental benefits (C02 emissions and environmental pollution) and energy efficiency [3]. The combination of the EV and AV could facilitate automatically the charging when the Stage of charge is in short supply and prove the best scan and analysis of the environment by its artificial intelligence system to avoid any kind of collision with static or dynamic objects.

The wider application of AEV requires various real time vehicle operating tests under certain driving scenarios in order to determine if requirements are met for design. This process of development justifies the high cost and the long time taken to produce the final product. For that reason, modeling and simulation are becoming an important tool in solving this kind of problem and are considered as the best solution to dimension all components and achieve the best energy control strategy.

Vehicle modeling was invented to facilitate every kind of parameter change and analyze several powertrain configurations in a computer model before building the vehicle prototype. Thus, it can allow the final product to be well built and faster while reducing cost. Also, it is easy to engineers to examine the performance and energy aspects of vehicle powertrain configuration from a computer-based model than swapping motors in a real vehicle prototype.

This research is part of the Simulation of Autonomous Vehicle "SIMVA-2 "project funded by the French « France relaunch » plan. It is a bipartite link between the DRIVE laboratory and the METALLIANCE, company, which is

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intended to develop a simulator for an autonomous vehicle with an application to the confined industrial environment, in which the company's construction machinery operates. The objectives of this research project are to provide solutions for partial or total driving delegation of a construction vehicle in a controlled indoor environment, predict the physical behavior (electrical, thermal, etc.) of the various parts of the vehicle (engine, battery, perception/vision systems, etc.) and Train driver of this new mode of material transport.

Métalliance, a company specialized in the design of mobile machinery required for tunnel construction, designs, industrializes, manufactures, and markets mobile machinery used for the construction and renovation of tunnels. It has recently turned its attention to make its machines totally autonomous. Therefore, both modeling and simulation are obligatory required to design, characterize, and simulate the behavior of its mobile machinery on an industrial construction site, while reducing costs in the development phase. The aim of this study is to implement a METALLIANCE's electric vehicle model based on Matlab/Simulink that will be used to create a complete vehicle model. Create a vehicle model is then followed by simulation, an autonomous vehicle simulator will be built, which constitutes an easily accessible tool that represents artificially the real operation of Métalliance self-driving cars. This simulator allows reproducing in a more reliable way the dynamic behavior of these machines in their real environment with a huge number of scenarios, system configurations and driver characteristics.

This paper is divided into five parts. Section II outlines a brief introduction of electric vehicles and several electrical models existing in the literature. Section III presents the industrial environment of our case study: the characteristics of Métalliance mobile machinery and their ODDs (Operational Design Domain). Section IV constitutes a literature review of all steps followed to describe the dynamic behavior of a system in the form of a model. Whilst, the Section V introduces the vehicle system modeling based on Matlab/ Simulink, the validation on a real profile and the behavioral analysis. The present work ends with conclusion and Outlook.

## II. LITERATURE ON ELECTRIC VEHICLE MODELS

A wide waste of energy and air pollution was resulted using construction machinery and influenced the health of humans and other human beings. Thus, to solve this problem, it is required increasing fuel efficiency and minimizing fuel consumption. The novel technology “Electric vehicle (EV)” allows both reducing air polluting and noisy mobility. The control of the torque and the speed through motor control was achieved by several electronics components such as transistor.

In the literature, several electrical construction vehicle models have been proposed to evaluate the vehicle energy consumption, examine the impact of different factors influencing the energy consumption and enhance the vehicle efficiency [4]. Most of these models was numerical models which are used most of the time in the first stages of the design process. The aim of these stages design of an energy efficient vehicle is to evaluate all parameters affecting the energy requirement based on a sensitivity analysis.

In [5], a Model-based optimization of an electric vehicle has been developed in Simulink environment. It was used to determine an optimization driving strategy aimed at reducing energy consumption while driving (prototype electric car that has been designed for the Shell Eco-marathon). In this case, genetic optimization algorithm was used. The model includes the vehicle, the electric motor, and the motor controller, the simulation was compared to the real measurements and the results has shown the similar optimized model to the real world. In this wise, a full efficiency of electro-mechanical power system is treated. Nevertheless, each change, like way of the route modeling or the driving conditions modeling, applied in on of electro-mechanical power subsystems must be experimentally evaluated. Also, the driver control system is considered in this model which has as inputs the reference vehicle speed or the accelerator activation.

In [6], a model optimization of the powertrain design has been developed. The system was applicated for the development of fuel cell electric vehicles which were vehicles with three wheels use a carbon-fiber monocoque pushed by a hydrogen fuel cell with a DC electric motor. In the model, the vehicle, and its subsystems (fuel cell, uphill climbing, electric motor, tires rolling resistances, aerodynamic drag, etc.) are simulated in AMESim and the dynamic behavior of the vehicle was analyzed. An optimization algorithm was employed to find the optimal driving strategy leading to least fuel consumption. The model was validated by the comparison of simulation results to results obtained on the track during the competition (Shell Eco Marathon competition).

In [7] The paper describes a numerical modeling of the vehicle powertrain; a vehicle takes part in the Shell Eco-marathon competition. The model includes the vehicle motion and the fuel consumption, it was validated using real measurements. An optimization strategy was employed leading to low fuel consumption.

A Multiphysics dynamical model of a fuel cell vehicle-based power train (urban-concept vehicle used for energetic races) has been developed in [8]. The modeling encompassed several vehicle behaviors such as the losses and consumptions of the power in each train devices, mechanical requirement, thermal behavior of fuel cell, etc… A global optimization algorithm has been integrated to the model in order to find out the best driving optimization according to the road constraints. The simulation results are compared and validated with experimental measurements (real results obtained at the Shell Eco-Marathon competition).

In the view of the METALLIANCE’s machines complexity (two or three vehicle module), no previous modeling of industrial electric vehicles has been done before. Also, none previous established results in modeling defined the validation of all inputs/outputs is made of electrical modeling vehicle before.

## III. MODEL DEVELOPMENT STEPS

Models are usually primarily defined in the scientific literature as a simplified representation of a real-world phenomenon. The model is highly close to the real-world

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vehicle system but it is simpler than the system it represents. The purpose of producing model is to enable the analyst to predict the dynamic behavior of any kind of system, to be a close approximation to the real world and incorporate most of its salient features. The steps involved in developing a model, used to design a powerful simulation are [9]:

- **Identify the problem**: Before proceeding with the modeling of a proposed vehicle system, it is necessary to define the inputs, the corresponding outputs, the temporal and spatial constraints, the traffic conditions, the stochastic elements, the study objectives, etc.
- **Formulate the problem:** Select the bounds of the system, the traffic conditions, the environment conditions, the control rules, and the security constraints. The purpose of this step is to define performance measures and quantitative criteria based on different system configurations. At this stage, formulate briefly hypotheses about system performance. Hence, Problems must be formulated as precisely as possible and specific outputs are defined for each problem.
- **Collect and process real system data:** Collect data on system specifications inputs variables. Generally, sensors are installed on the system and permanently record information about its environment, perception and data fusion algorithms are then used to extract useful information.
- **Formulate and develop a model**: Develop network diagram of the system based on the relationships that connect the different outputs to the different inputs.
- **Simulate and validate model:** Once the previous steps are checked and validated, all that remains is the simulation of the model from the real data and ensures that the model achieves the expected results. At this level, it is required to vary different input parameters over their acceptable range and checking the output in order to verify that the simulation model executes as intended by comparing its performance with the performance of the real system.

In the physical sciences, models are defined from mathematical tools (differential equations, recurrent equations, or partial differential equations), physical tools (generally used for vehicle systems) or computer tools (tools derived formalisms of AI (Artificial Intelligence)). In the case of our study, the electrical model was developed with extreme accuracy for every element based on different physical tools (mechanical block, thermal block, power electronic, electrochemical block, electric energy storage.

## IV. INDUSTRIAL ENVIRONMENT AND OPERATIONAL DESIGN DOMAIN SYSTEM

In this paper, electrical modeling was applied to an industrial environment: vehicles developed by the company Métalliance. These latter designs two types of vehicles: the Multi Service Vehicles (MSV) or Train on Wheels vehicles, that meet specific specifications These vehicles are used to transport the concrete elements required for the construction of tunnel. The Train on Wheels vehicle has a leading vehicle and a trailing vehicle each with a driver cabin to facilitate the reversible operation without having to make a U-turn in small space. Both the leading and the trailing vehicles are of self-propelled type and can be used according to the required direction of travel at the same time. However, The Multi-Service Vehicle is a non-articulated vehicle with only one vehicle. Like the train on wheels vehicle the MSV is also designed to facilitate reversible operation. The vehicles currently used by METALLIANCE are available in three variants with respect to the power source used by the vehicles. The vehicles can operate on a diesel engine, a hybrid between diesel and an electrical engine or a completely electrical engine. They, primarily used to supply logistics to and from the Tunnel Boring Machine (TBM), so they have wheels, which allow them to traverse on flat grounds and even on concave surfaces inside the tunnels without the construction of rails inside the tunnel.

To date, METALLIANCE is developing Automated Guided Vehicles (AGV) to assist the driver in driving operation of the vehicle, facilitate logistics and storage operation in indoor and outdoor environment. The figure below depicts the MEATLLAINCE'S Multi Service Vehicle (MSV) design and its dimension.

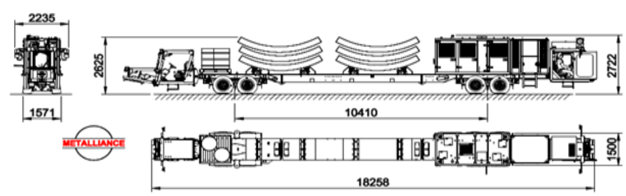


Figure 1. METALLIANCE's Vehicle (MSV).

## V. SIMULATION, RESULTS, AND VALIDATION ON A REAL ROAD PROFILE (RENNES TUNNEL)

Electrical modeling vehicle allows to define the evaluation of all different electric parameters acting on the system at a time t in order to determine the electrical power needed for moving the vehicle forward. It constitutes the system of electrical equations associated with the power supply circuit. The electrical vehicle environment is modeled through the resistive torque applied to the electric motor. Therefore, the proposed electric model receives as input the drive cycle that the vehicle should execute (the given speed and road profile). This reference is given to a pilot model that gives as output a signal representative of torque request.

The followed figure (Figure2) depicts the overall diagram of the electric model vehicle based on the physical description of all forces acting on moving the vehicle [10]. This objective defines the first and second step of model development.

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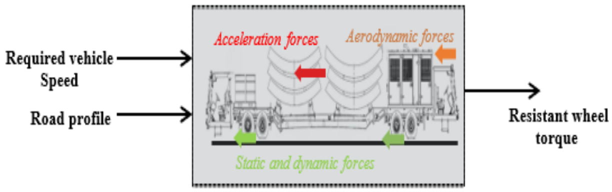


Figure 2- Electrical environment vehicle.

Based on the third model development step, specifications system (road profile and constraint speed vehicle) is recording from Rennes tunnel France and the value of these forces is leaning on the limit conditions that influence the vehicle.

To formulate the model and achieve the fourth model development step, the relationship that connect the different outputs to the different inputs is required. Thus, resistant wheel torque depends on the sum of these forces (rolling friction force, aerodynamic force, acceleration force, and the downhill-slope force) multiplied by the wheel radius. In fact, the rolling friction force is defined by the following equation.

$$F_r = C_r * m * g \quad (1)$$

Where $C_r$ , m and **g** represent respectively the rolling resistance coefficient, vehicle mass (loaded and unloaded vehicle) and gravitational acceleration. The law states that the acceleration force is given by the multiplication of the acceleration a by the mass of the vehicle m.

$$F_{acc} = m * a \quad (2)$$

The force exerted by the air on the vehicle constitutes the aerodynamic force.

$$F_{aero} = 0.5 * S_{vehicle} * C_x * \rho * [V^2] \quad (3)$$

Where ρ represents the air density, $S_{vehicle}$ constitutes the section area of the vehicle, $C_x$ is the aerodynamic coefficient and V is defined as the vehicle speed in m/s. Given that the maximum speed is 18 km/h, the vehicle is moving at low speed so we can neglect the aerodynamic force. Therefore, the resultant force down the slope (downhill-slope force) is given by this equation.

$$F_{slope} = m * g * sin(\alpha) \quad (4)$$

Where **α** is the slope angle. The sum of all these forces multiplied by the wheel radius results the resistant wheel torque, which is given by this equation

$$T_{wheel} = \sum Forces * R_r \quad (5)$$

By the value of the resistant wheel torque and the reduction wheel ration, the motor torque is defined.

$$T_{motor} = T_{wheel} * R_{ratio} \quad (6)$$

The motor speed is defined by from the vehicle speed.

$$S_{motor} = V * \frac{60}{2 * \pi * R_r} \quad (7)$$

And finally, the mechanical power is calculated by this followed equation.

$$P = S_{motor} * T_{motor} \quad (8)$$

All the vehicle parameters used for the simulation are defined in Table I.

TABLE I. REFERENCE VEHICLE DATA

| **Parameter** | **Symbol** | **Value** |
|---|---|---|
| Maximum vehicle speed | $V_{max}$ | *18 km/h* |
| *Wheel radius* | $R_r$ | *599 mm* |
| *Rolling resistance coefficient* | $C_r$ | *0,02* |
| *Unloaded vehicle mass* | $m$ | *15000 Kg* |
| *Laoded vehicle mass* | $m$ | *40000 Kg* |
| *Aerodynamic Coefficient* | $C_x$ | *1* |
| Air Density | ρ | *1.2 kg/m³* |
| *Section area of the vehicle* | $S_{vehicle}$ | *6 m²* |
| *Gravitational acceleration* | $g$ | *0.9419.81 m/s²* |
| *Reduction Wheel ratio* | $R_{ratio}$ | *53* |

Until now, the last step model development is still to validate. An overview of electric vehicle model implemented in Simulink is presented in Figure 3.

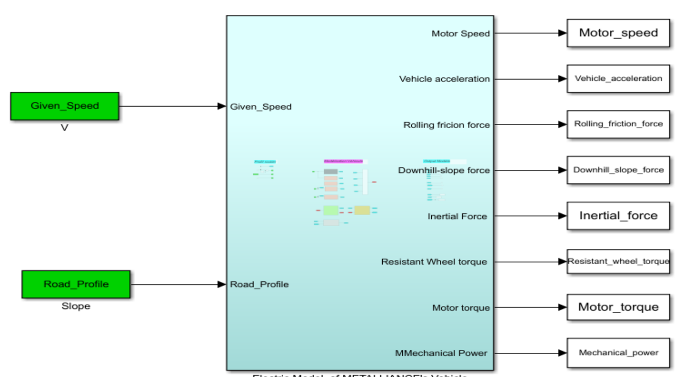


Figure 3- Simulink model of electric METALLINACE' s vehicle.

From a given speed and road profile, the system model estimates all forces applied to the machine, the resistant wheel and motor torque and passes through the relevant motor speed to evaluate the mechanical power needed to move the vehicle forward. The speed profile has a maximum speed of 18 kmph with two phases: the first where the vehicle is loaded and the second where the vehicle is empty. The modeling is applied to a Multi-Service Vehicle (VMS) vehicle.

In order to determine the level of fidelity model to the real world, the model should be compared to real data recorded for each real data of vehicle´s electrical system the driving operation vehicle. Indeed, an actual data has been recorded from driving task of the Métalliance Multi-Service Vehicle (VMS) in Rennes tunnel (France) (data of all electric parameters recording from vehicle operation inside Rennes tunnel during 238 minutes). Therefore, each real data of vehicle's electrical is compared to the corresponding in the simulation model in order to evaluate the performance and the accurate model development as is shown in Figures 4 and 5.

The model input (given speed) is divided into two phases: loaded (from 0 to 107 minutes) and unloaded vehicle (from 122 to 238 minutes). The first plot shows the comparison of the results simulation to their corresponding signals that were recorded during the measurement: vehicle's acceleration from the given speed input, the simulated rotational engine speed, the rolling friction force, and their corresponding signals that were recorded during the measurement. Moreover, the second plot shows the corresponding curves of the acceleration force, resistant wheel torque, motor torque and the mechanical power.

This simulation demonstrates approximately the overlapping curves of each parameter profile. As it shown by the simulation results, the diagrams resulting from the simulation and that of real data are substantially identical. This allows us to conclude that our model is faithfully close to the real world. Even, this work focus is made on the METALLIANCE's industrial vehicles, it could be used for other types of electrical vehicles. Just it must choose the road profile and speed and define the vehicle parameters.

## VI. CONCLUSION

This paper presents the suitable process to implement an electrical model of a Métalliance Multi-Service Vehicle (VMS) in Matlab/Simulink environment, using the model development steps proposed throughout the literature. It falls within the framework of an autonomous vehicle, which can do driving maneuvers and tasks by itself. Therefore, methods and steps for modeling development have been exposed. The third model development step remains to study the operational design domain of the used system: environmental information, vehicle system characteristic and operation.

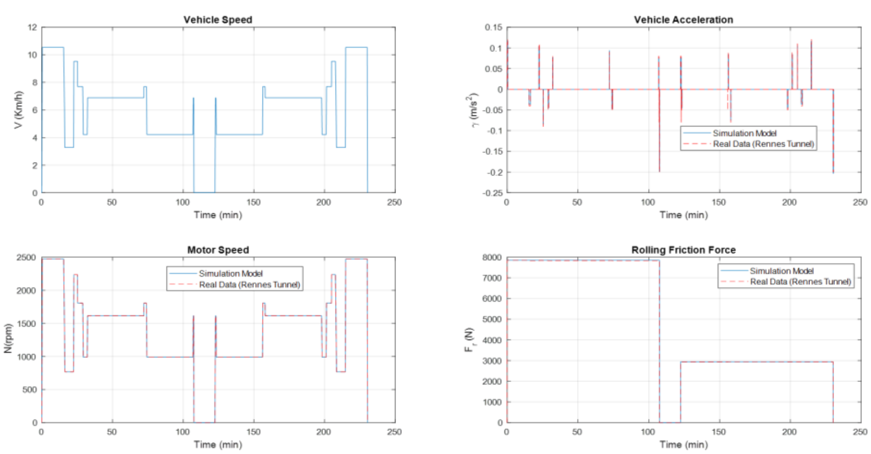


Figure 4-Vehicle speed, simulation results of electric model for vehicle acceleration, motor speed and rolling friction force.

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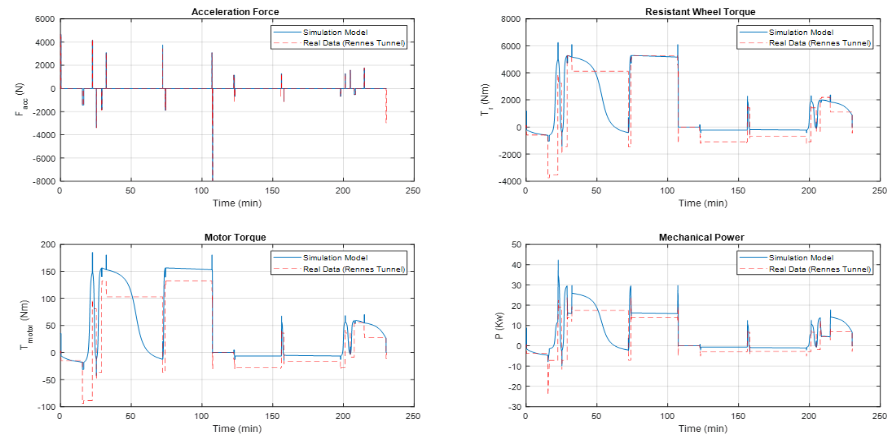


Figure 5-Simulation results of electric model for acceleration force, resistant wheel torque, motor torque and mechanical power.

Hence, an electric model vehicle has been developed based on the electrical equations associated with the power sup-ply circuit. It defines for real time the evaluation of various electric vehicle parameters. It has been validated by real world environment. We conducted its simulation by real data in order to validate its performance and achieve high accuracy in comparison with the actual world. The simulation result showed that the model is highly close to the real world. Some perspectives are considered in order to develop a simulator, which represents a virtual prototype of the real world that could be fast, efficient, and valuable.

The future work will focus on the development of the hydraulic and thermal vehicle model, then combining these models with the present work constitutes the step that achieves a complete Métalliance Multi-Service Vehicle (VMS) model. Thereby, the work will be completed by the design of a full simulator, which reproduces reliably the dynamic behavior of Métalliance construction vehicles.

## ACKNOWLEDGMENTS

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