Design of an Analysis Model for Automatic Subway

Date: 19/02/2016

Developed by:

Dongcai CAI

PreranaSHAMSUNDAR PUNJABI

Table of Contents

Executive Summary

Automatic train operation (ATO) is an operational safety enhancement device used to help automate operations of trains. Mainly, it is used on automated guide way transits and rapid transit systems which are easier to ensure safety of humans.

In this assignment we will develop a simple system design for ATO for GoA 4 – train system with system engineering approach.

Where GoA 4 - is unattended train operation (UTO) where starting and stopping, operation of doors and handling of emergencies are fully automated without any on-train staff.

Trains are capable of operating automatically at all times, including door closing, obstacle detection and emergency situations. On-board staff may be provided for other purposes, e.g. customer service, but are not required for safe operation.

Assumptions

- Our subway will be used on an existing line (stations, rails, signaling) with same configuration as [Toulouse Metro - VAL system.]
- Platforms have been equipped with automatic doors for wagons and a set of cameras that observe doors
- There is central supervision that can dialog with trains through radio in order to regulate traffic

Purpose, Missions and Objectives:

The automatic subway system is a public transportation system used in metropolitan city. It is mainly used underground powered by electricity, passing usually across where there is higher population density to transport people from one station to another. The **purpose** of the subway system is to carry more people safely and easily with high speed. And the **mission** of the subway system is to transport people from a certain station to another station safely.

The **objective** is stop at every station in its schedule and to open the doors and let passengers in and out. After a fixed duration of time the train makes an announcement, closes the door and starts to approach its next station. The train should run smoothly so that the passengers will not feel any uncomfortable.

Our mission is to design this system.

We follow the system engineering processes below to finish the design:

1. Mission and Context
2. Requirement Definition
3. Logical Architecture
4. Physical Architecture
5. Verification and Validation

1 System Context

The system context of the subway is designed in this section.

The following concepts and their relationships and attributes (properties) are added to respective entities

- Railway Network
- Station
- Platform
- Railroad
- Signal light

1.1 Subway Context

The environment and sub units that composes of the train context.

1. Platform – the train stops at
2. Rail Track – the train runs on
3. Light Signal – That indicates that a train can enter the station
4. Train Vehicle – The train itself
5. Electric Network – necessary for the train to run on tracks and for the regular operation of the train, opening of doors, lights, audio announcements, the AC etc
6. Platform doors – to let passengers in and out

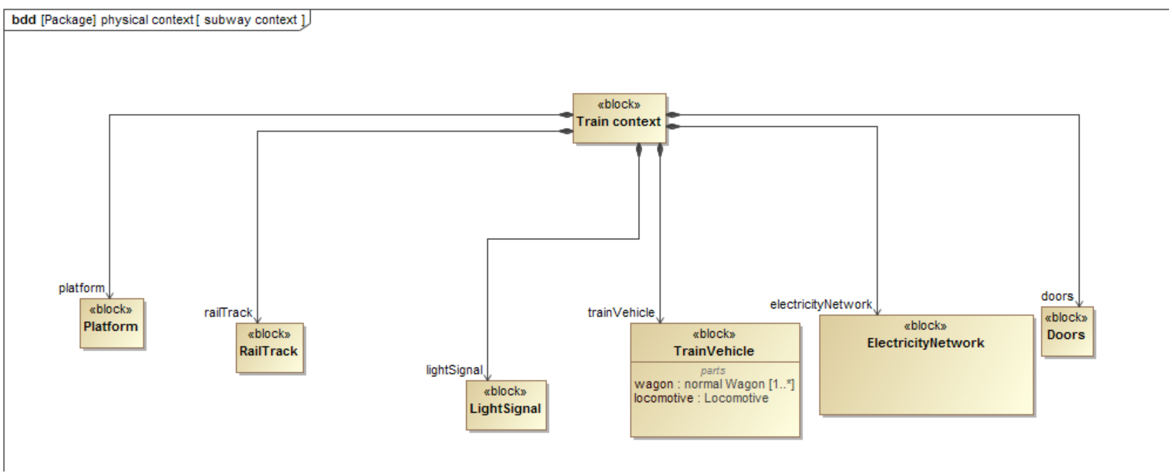


FIGURE 1: BLOCK DIAGRAM REPERSENTING SUBWAY CONTEXT

1.2 Train Context

In this part we defined what are the units connecting the components in the subway context.

Note the platform is and external entity and it not directly connected with the train.

The main units that necessary / constitute to the correct operation of the train are

1. Sensors on the train door - to open and close
2. Track circuit – that require the Electricity Network - For the train to run between the station
3. Camera – of the train that indicates if it ok to arrive at the station or not.
4. Wheels – that run on the train Tracks

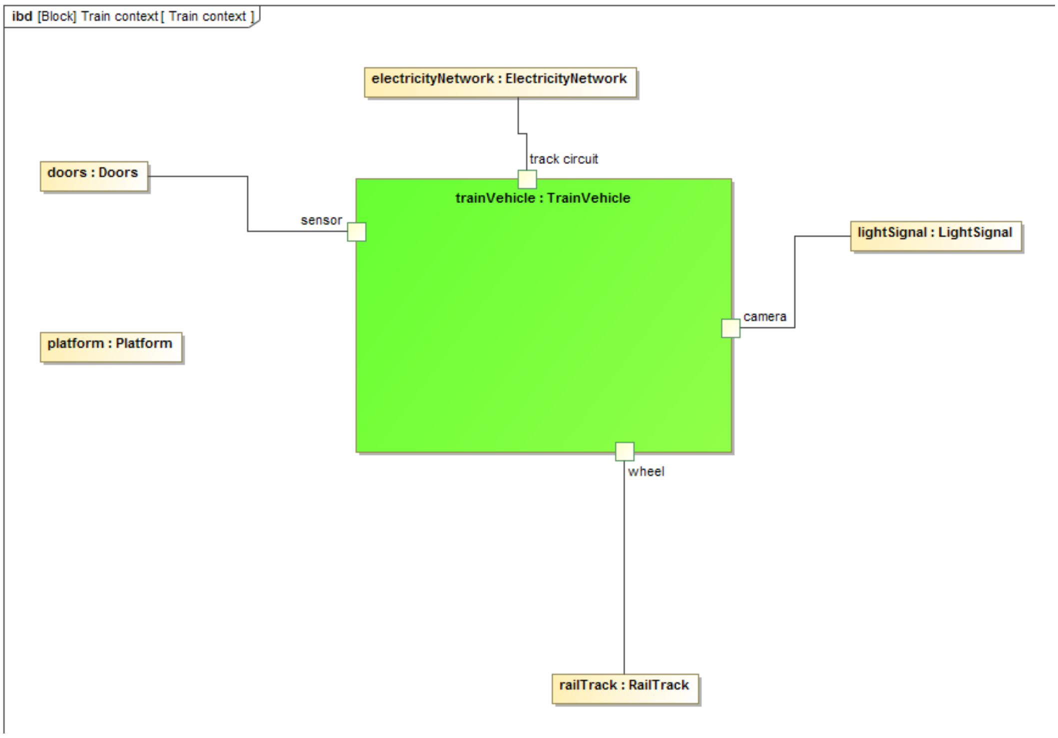


FIGURE 2: BLOCK DIAGRAM REPERSENTING TRAIN CONTEXT

2 Requirements Definition

2.1 Actors and Use Case definition

We identify the different actors and use cases required to design our system

Actors	Use Cases
Passengers	Follow the line with a schedule
Control Center	
Time	
Workers & Time	Maintenance
Supervisor	Communication

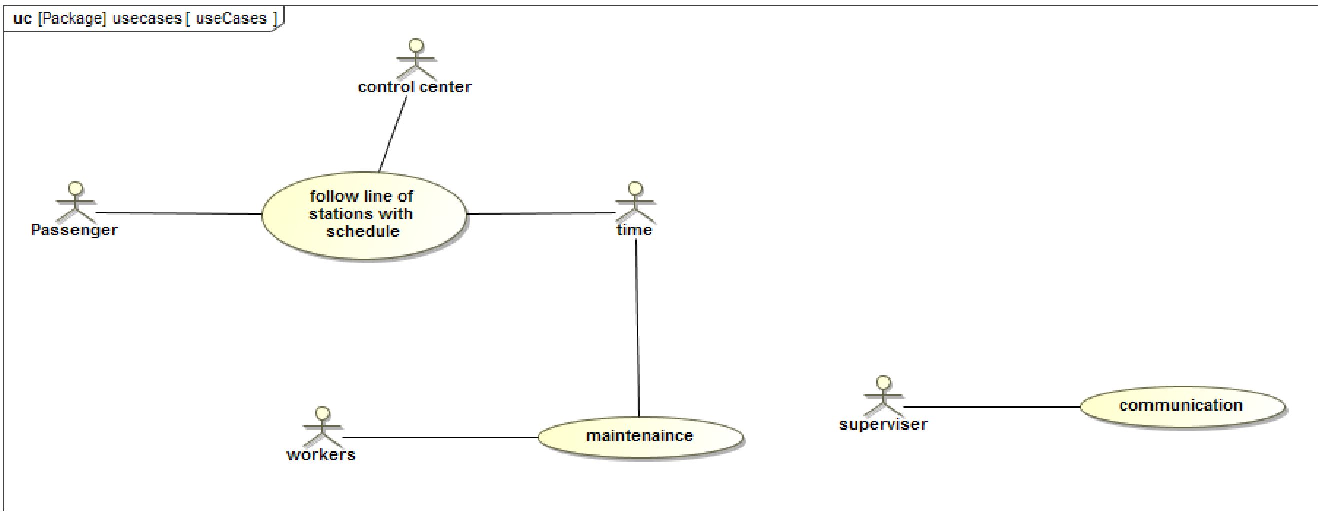


FIGURE 3: SYSTEM USE CASE DEPICTION

2.2 System Requirements

For designing an automatic subway system, we start with listing basic system requirements that would help us with our design.

Requirement ID	Requirement Description
STR-REQ-0010	The train shall start its schedule in the morning
STR-REQ-0020	The train shall follow a fixed, pre-designed schedule that lists the path the train must follow
STR-REQ-0030	The train shall stop at every station in its schedule for 2 minutes
STR-REQ-0040	The train shall open its door after it arrives at a station
STR-REQ-0050	The train shall close its door after 2 minutes of wait at a station
STR-REQ-0060	The train shall start only when all its doors are secured
STR-REQ-0070	The train shall play an audio recording to warn the passengers with respect to closing of doors
STR-REQ-0080	If the doors do not close due to an obstacle at the door, then the shall keep the doors open for additional 0.15 seconds
STR-REQ-0090	Five trails shall be made by the train to close the doors successfully
STR-REQ-0100	The Maintenance department shall be notified in case of failure to close the doors
STR-REQ-0110	The train shall be notified in case another train in delayed at the station that it has to arrive at
STR-REQ-0120	The train shall arrive at a station only when the platform is clear (no other train waits at the platform)
STR-REQ-0130	The train shall stop when its schedule is completed

3 Logical Architecture

3.1 System Modes

An Automatic subway system is defined and the corresponding system modes are as illustrated below.

1. The train shall start in the morning and shall continue to follow the schedule until night (i.e. until the last station in schedule is arrived at).
2. The train shall stop at each station and open the doors to facilitate passenger's entry and exit.
3. The doors shall be closed before the train starts again

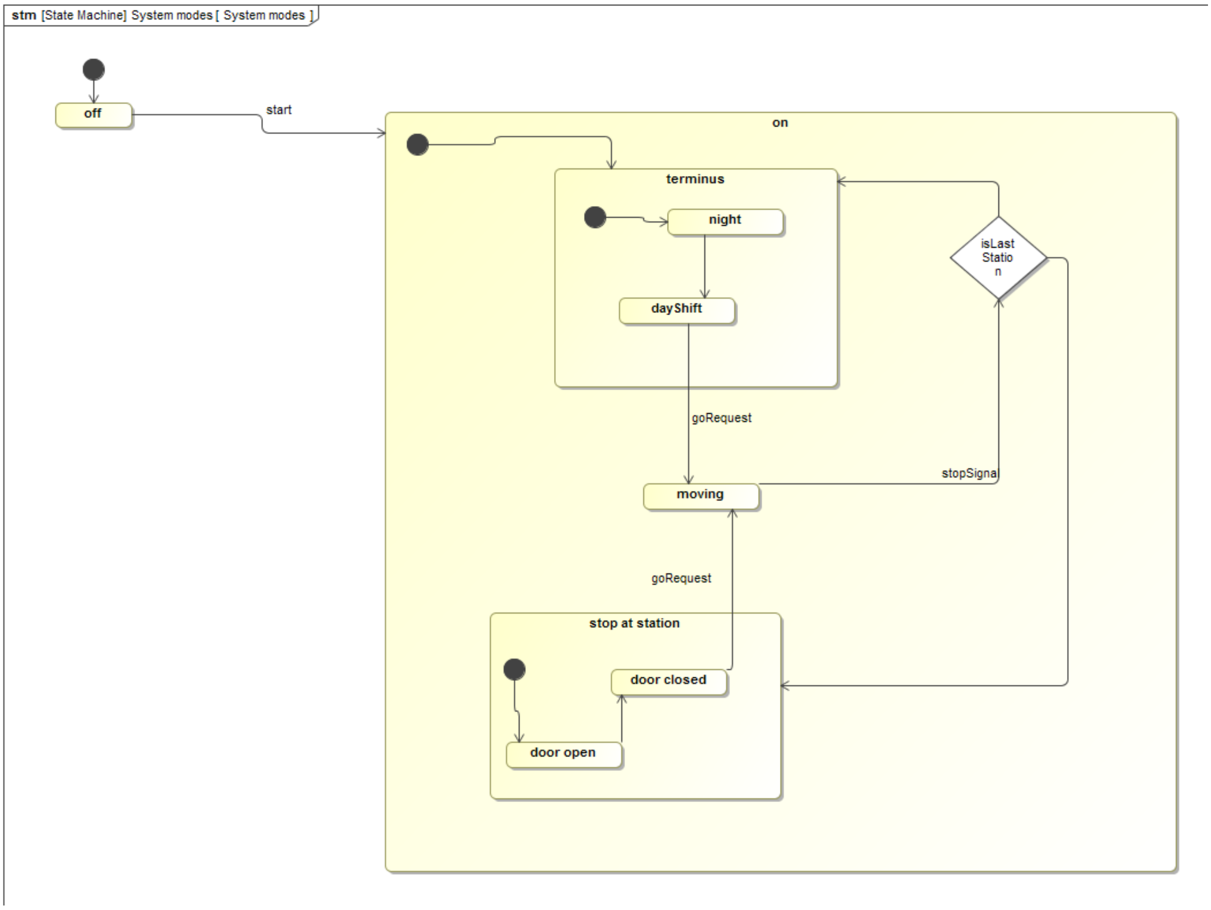


FIGURE 4: SYSTEM MODES

The sequence of the day shift mode is shown below:

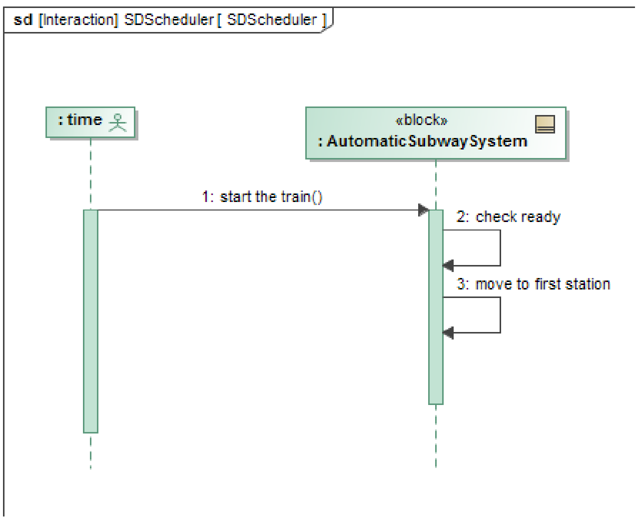


FIGURE 5: SQUENCE DIAGRAM REPERSENTING-THE START OF THE DAYSHIFT

3.2 Function Activities

The door operation of the train when it arrives at a station is indicated using an activity diagram

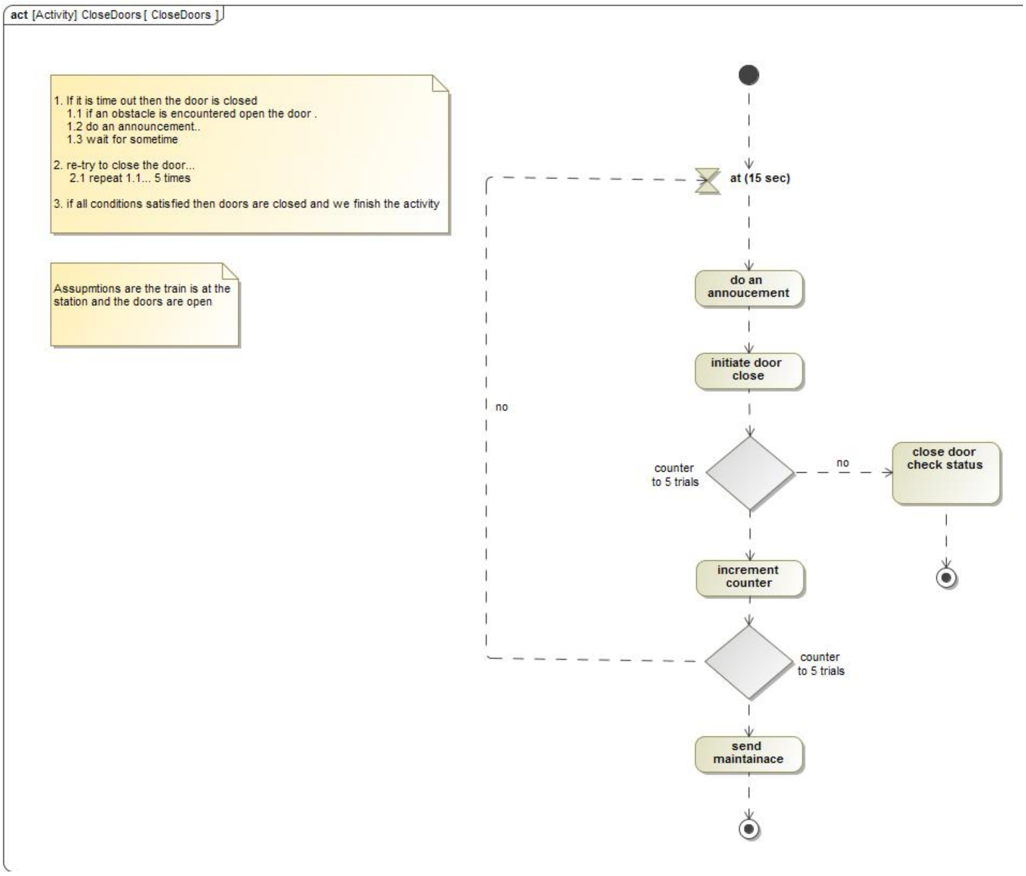


FIGURE 6: ACTIVITY DIAGRAM REPERSENTING-DOOR OPERATION/MISSION

3.3 Sequence Diagrams

If there is a fault, the system could be having sequences as Figure 7.

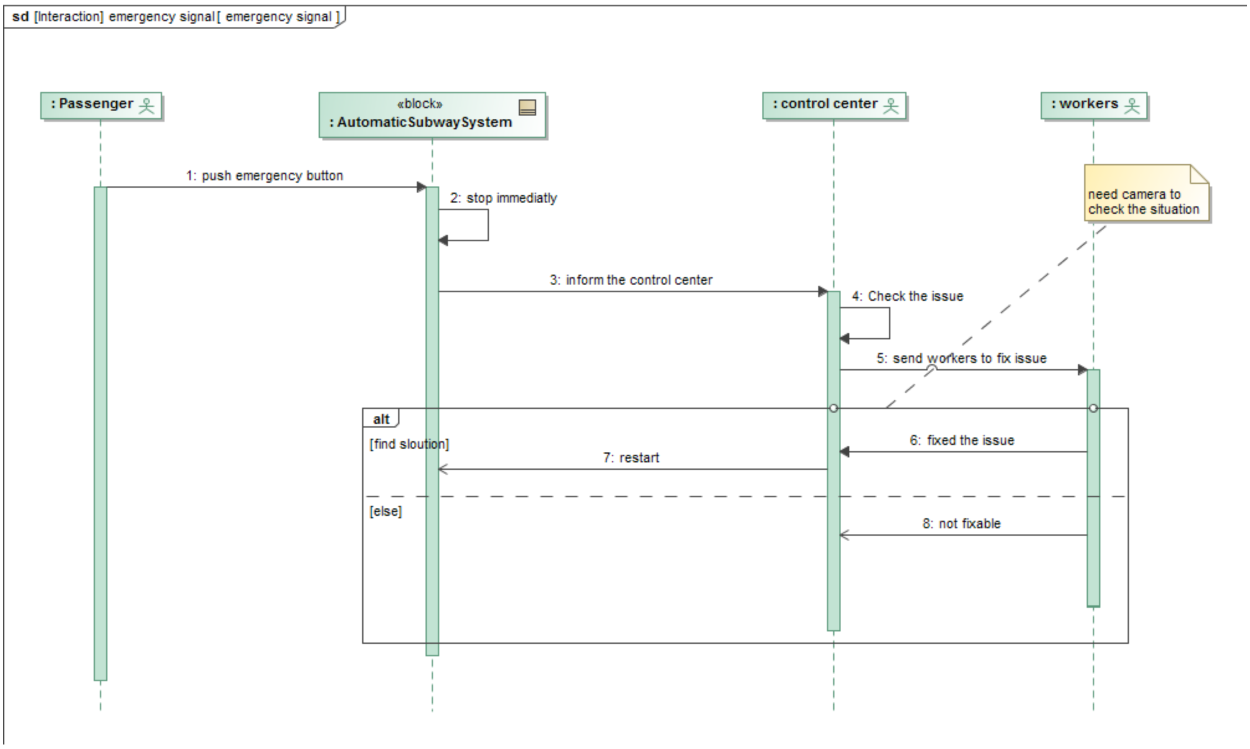


FIGURE 7: SQUENCE DIAGRAM REPERSENTING-EVENT FLOW DURING A FAULT ENCOUNTERED

3.4 Train Vehicle

Defines the basic design of the train.

1. A train basically constitutes of the locomotive and the Wagons.
2. Each has a Mass and Friction due to movement
3. The locomotive constitutes to the acceleration / deceleration of the train
4. There exists a force between the two physical bodies

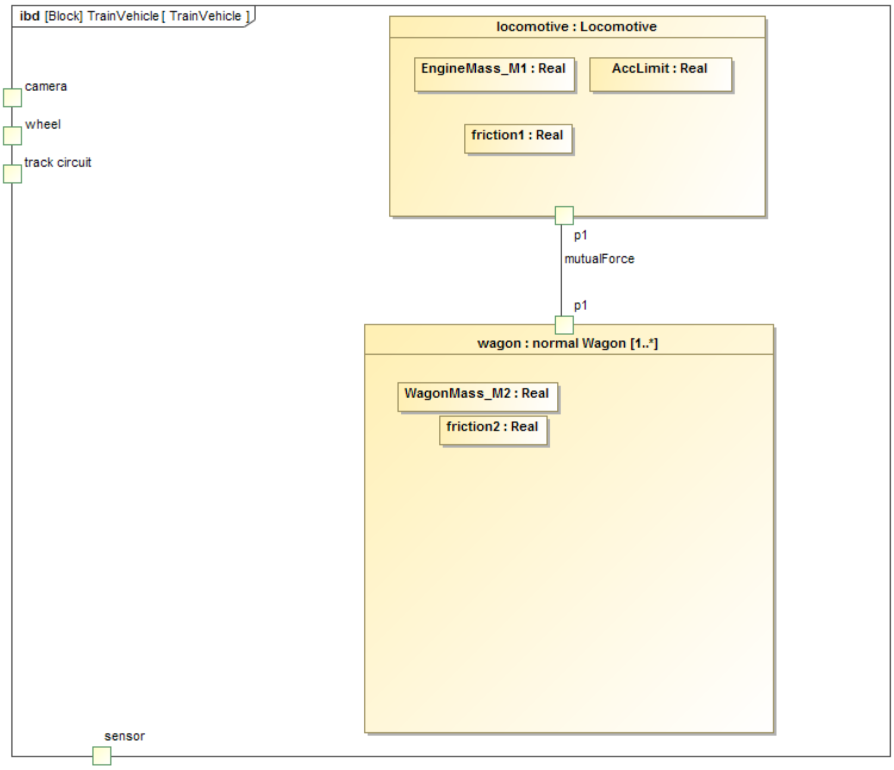


FIGURE 8: INTERNAL BLOCK DIAGRAM REPERSENTING TRAIN VEHICLE

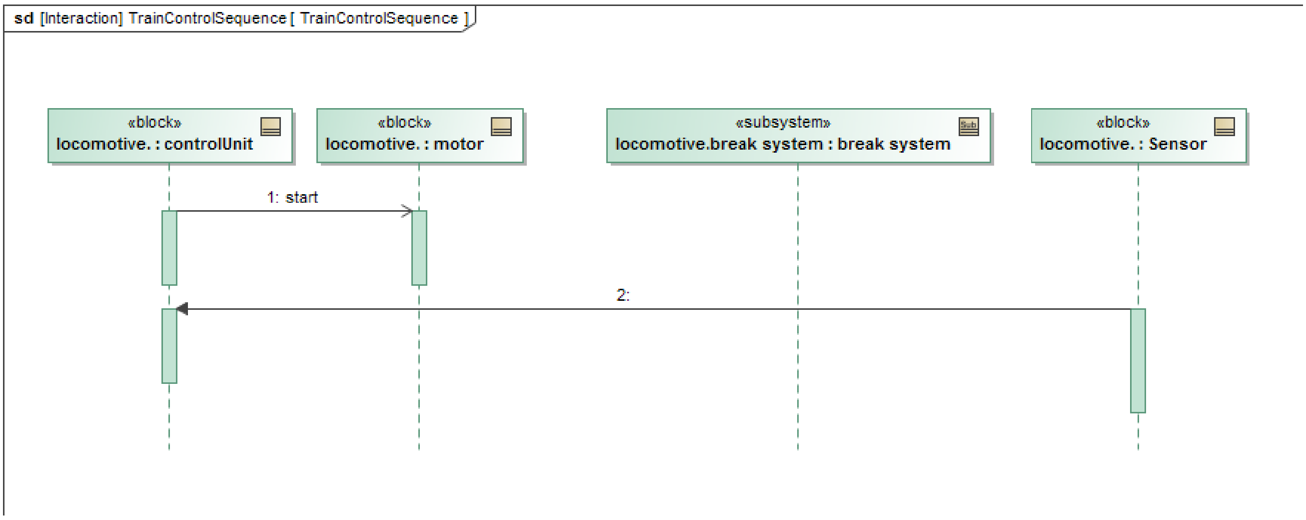


FIGURE 9: SEQUENCE DIAGRAM REPERSENTING OPERRATION BEWTEEN THE LOCOMOTIVE AND WAGON

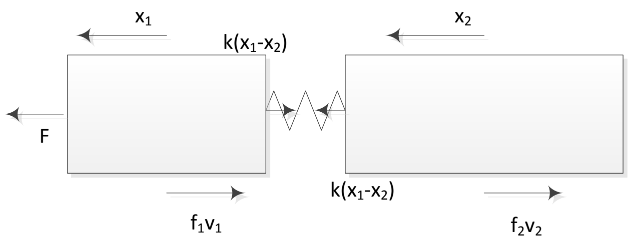
4 Control Trade-off

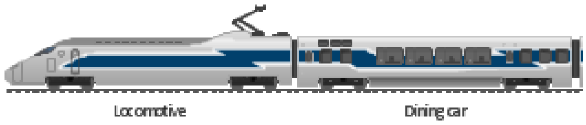
To relate the design with practical quantities that can constitute to some important requirements of this system like

1. Speed / Acceleration
2. Mass
3. Friction etc

Matlab is used to design these quantities. This is to enable performance trade-off from behavioral studies.

Hence a Matlab Model representing the 2 mass (locomotive and Wagon) and the force and friction between each is modeled using Matlab.





The parameters of the model are as follows:

```
M1 = 5 tons;
M2 = 10 tons;
K = 1000 N/m;
f1 = 98 N/(m/s);
f2 = 196 N/(m/s);
g = 9.8 N/kg;
F = 400 N;
Tau = 0.5s;
```

`Tao` is the time constant of the motor in the locomotive. `F` is the output force of the motor.
The differential equations of the system are as blow:

$$F - k(x_1 - x_2) - f_1\dot{x}_1 = m_1\ddot{x}_1$$
$$k(x_1 - x_2) - f_2\dot{x}_2 = m_2\ddot{x}_2$$

Taking Laplace transform of above equations:

$$F(s) - k\big(X_1(s) - X_2(s)\big) - f_1X_1(s)s = m_1X_1(s)s^2$$

$$k\big(X_1(s) - X_2(s)\big) - f_2X_2(s)s = m_2X_2(s)s^2$$

From the 2 equation above the open loop system representing the acceleration, velocity and position of the system achieved as shown below:

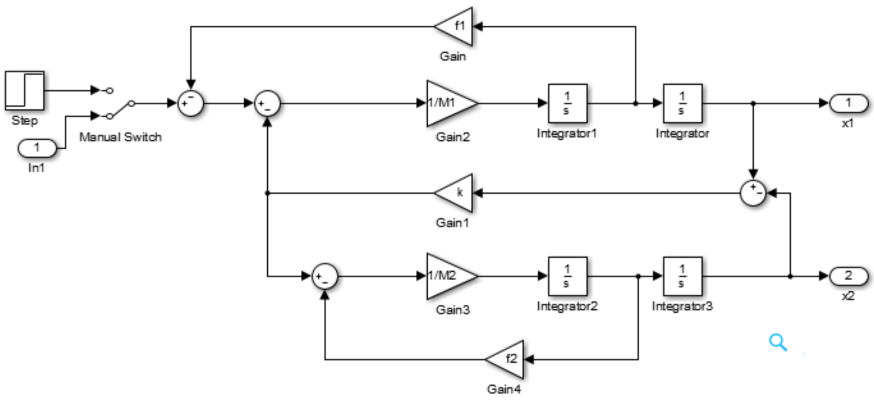


FIGURE 10: OPEN LOOP MODEL

Now, to control the system and to have a steady acceleration a closed loop system is designed.

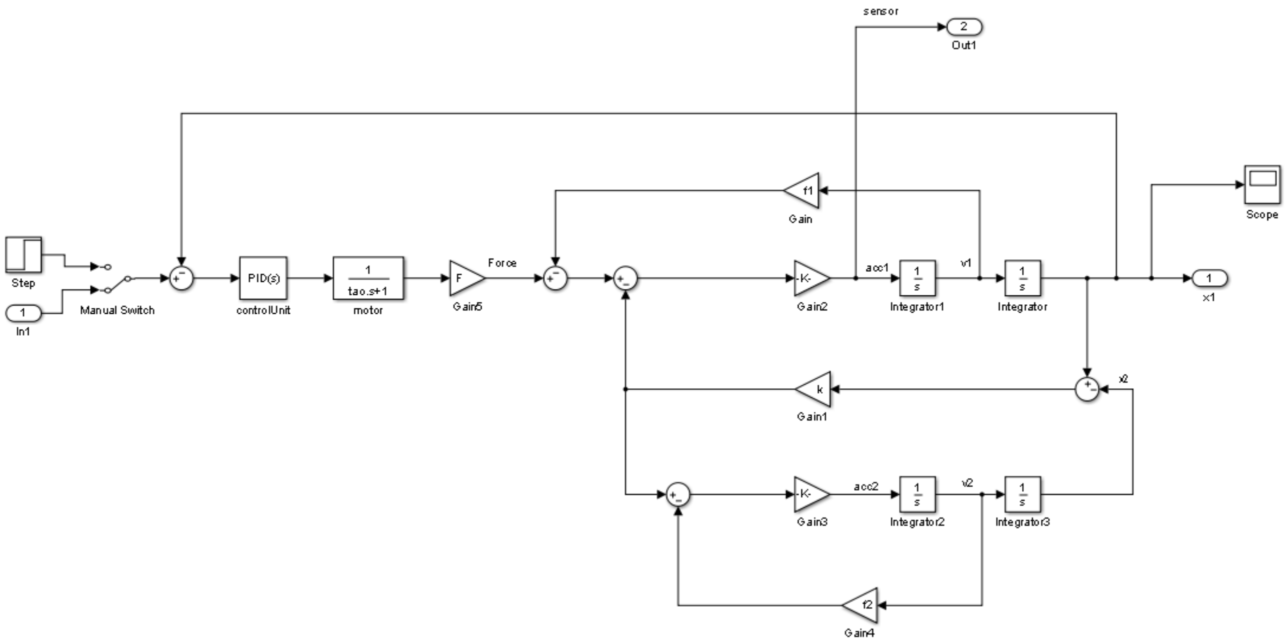


FIGURE 11: CLOSED LOOP MODEL WITHOUT A SATURATION LIMIT

A PID Controller is integrated to control the motor using the actual position as feedback.

Our close loop simulation result is as below.

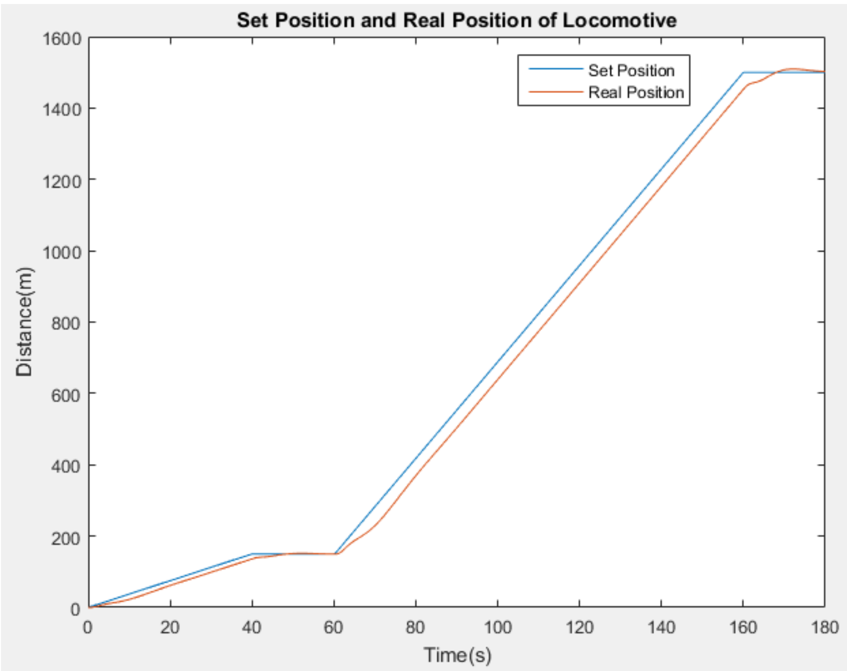


FIGURE 12: CLOSED LOOP SIMULATION WITHOUT A SATURATION LIMIT

As shown in this figure, the first station is 150m far away from the starting terminal. The train will reach there in 40secs, and it will stay there for 20 secs. As the PID parameters were elaborately tuned, the real position is quite close to the set position.
However, if we check the acceleration of the locomotive, it will reach ±7m/s^2, this high acceleration will make the passengers uncomfortable.

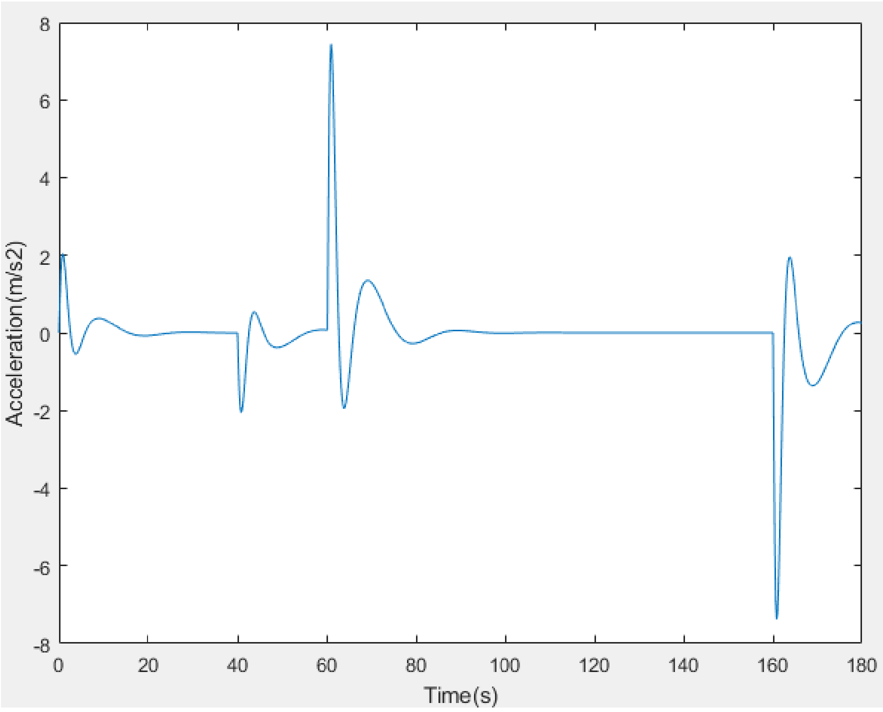


FIGURE 13: ACCELERATION OF LOCOMOTIVE – WITHOUT A SATURATION LIMIT

To avoid very high acceleration, saturation is added in the model: A bound of +/- 3 is set such that it prevents the train's acceleration from going further

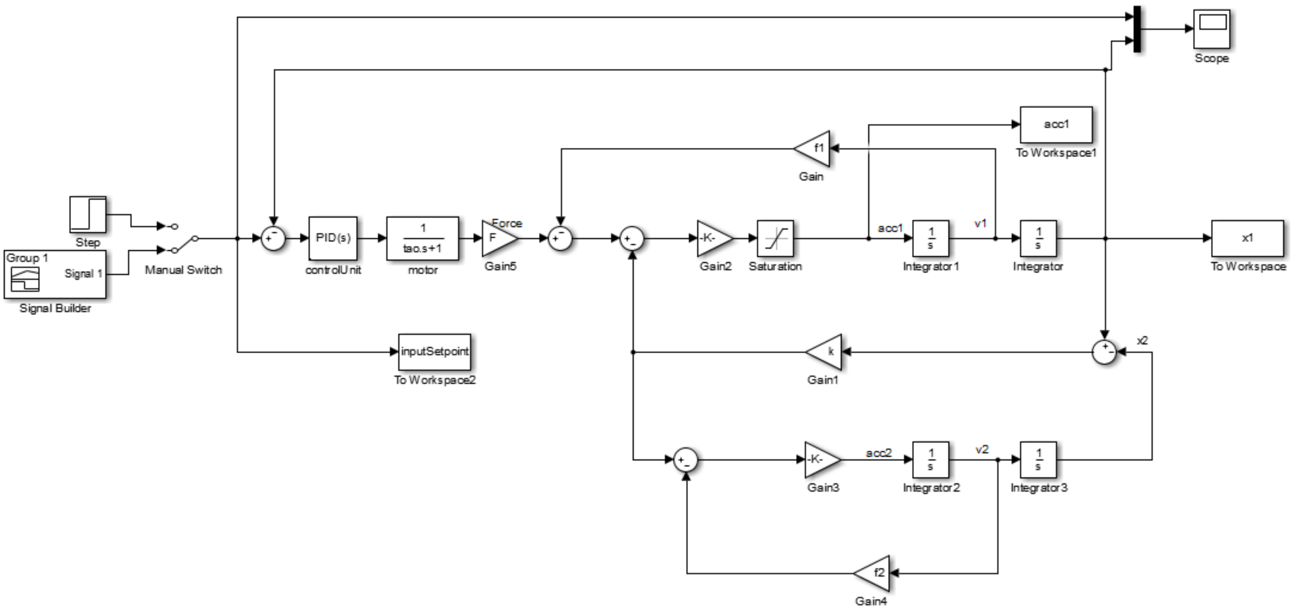


FIGURE 14: CLOSED LOOP MODEL WITH A SATURATION LIMIT

After adding saturation, the simulation result is as below:

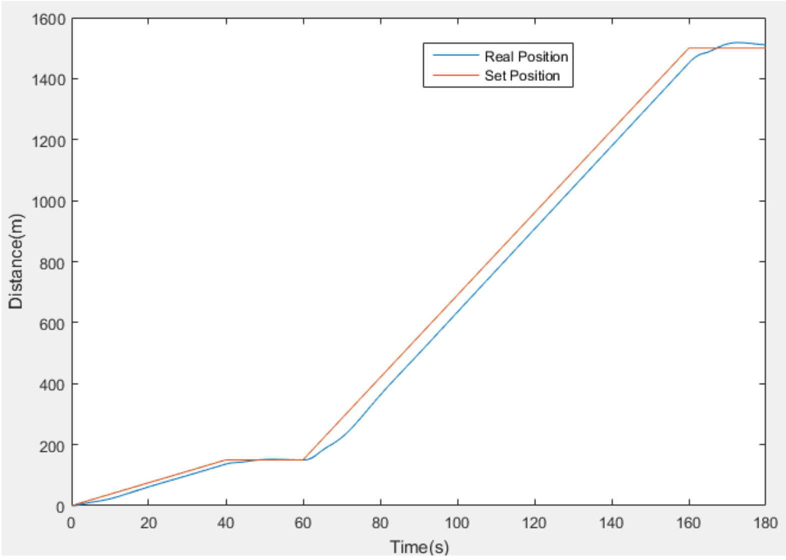


FIGURE 15: CLOSED LOOP SIMULATION WITH A SATURATION LIMIT

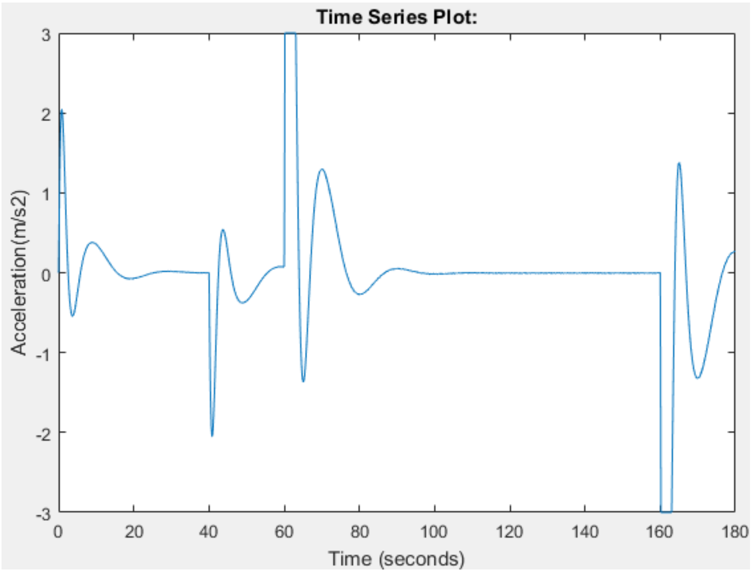


FIGURE 16: ACCELERATION OF LOCOMOTIVE WITH A SATURATION LIMIT

From the above results we can deduce that with the saturation the system works very well and the acceleration is within the bounds.

The values obtained from Matlab for the friction and acceleration are now mentioned as constraints in the physical architecture. This is necessary as to indicate clearly that these are the optimum values that the system has to be modeled for operating correctly.

5 Physical Architecture

For The physical Architecture the Train Vehicle is sub divided into parts such as

1. The Locomotive – is constituted with following entities
   a. Sensors
   b. Breaks
   c. Camera
   d. Control Unit

    e. Motor
2. The Wagon
    a. Doors
    b. Wheels
    c. Brakes
3. The system required for correct operation of the Vehicle
    a. Braking system - Locomotive
    b. Door System - Wagon
    c. Air-condition - Wagon
    d. Light System – Wagon

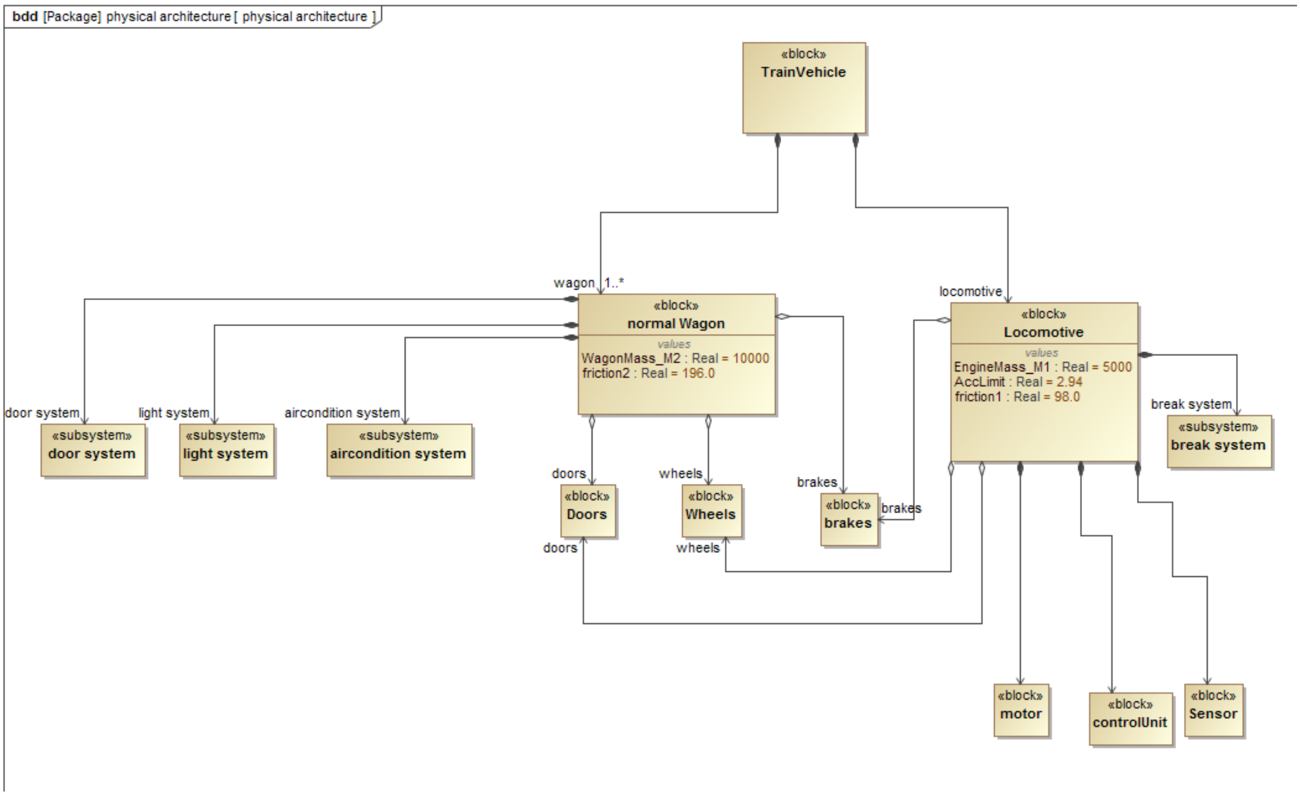


FIGURE 17: PHYSICAL ARCHITECTURE WITH REALISTIC VALUES OPTAINED FROM MATLAB

The control unit mainly monitors and controls the motor and the breaking system -

1. The status information is received from the doors and if the doors are secured the control unit sends a start command to the motor.
2. If a station is reached then the doors are opened.
3. The control unit receives the data from all the sensors:-
    - If the acceleration values sent by the speed sensor is too high the control unit sends command to reduce the torque on the motor hence reducing the speed
    - If the train is approaching a station, the acceleration of the train is reduced by send control commands to both the breaking system and the motor.

By executing the following operation the acceleration of the train can be control at a steady rate.

The control of the locomotive and the door could be shown as Figure 18:

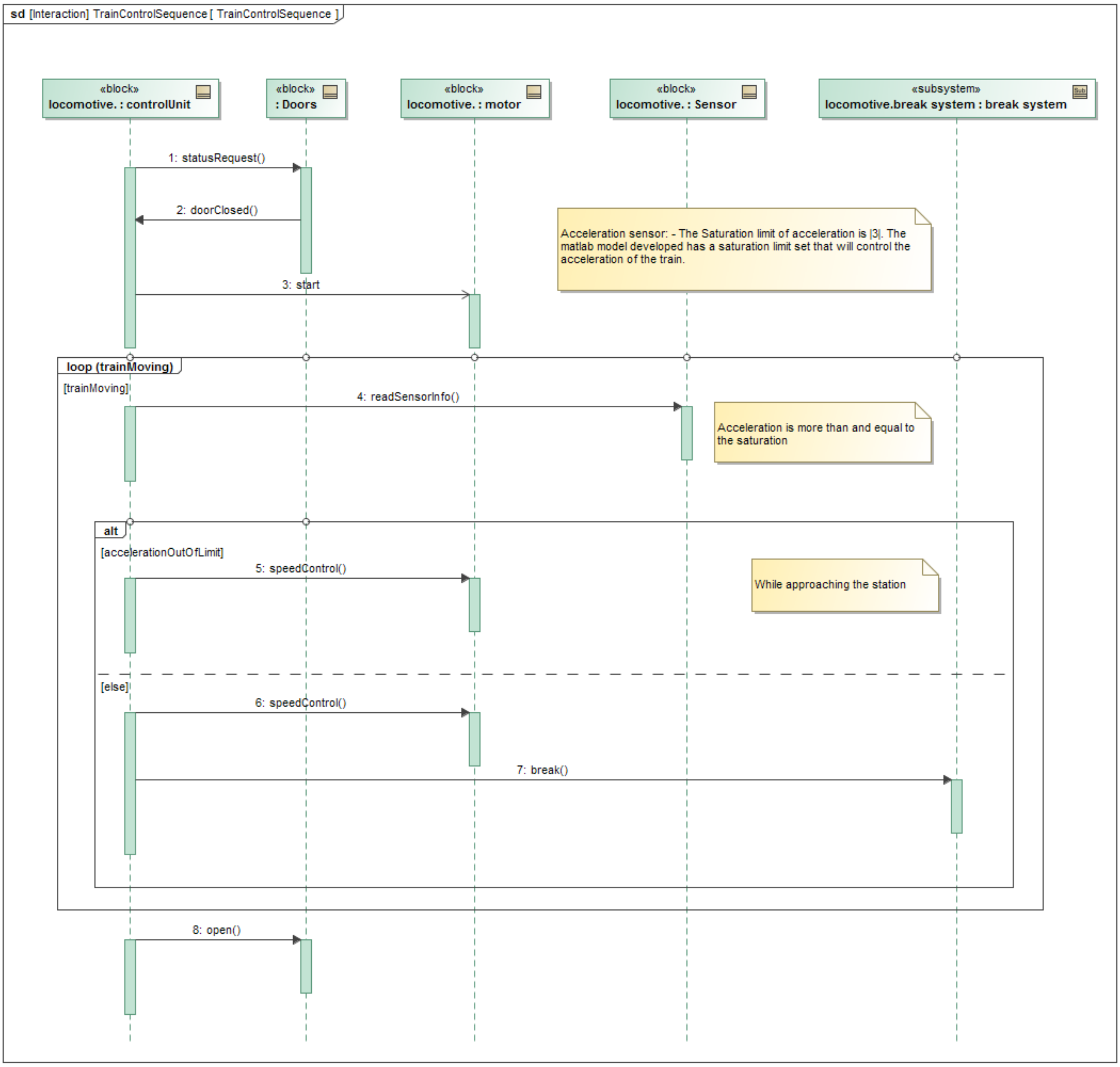


FIGURE 18: SQUENCE DIAGRAM REPERSENTING-TRAIN TRANSPORTATION CONTROL

6 Conclusion

This project exposure helped us to understand for a step by step approach is applied to develop a design model. Right from defining the purpose -> mission -> context -> use cases -> detailed requirements → designing the individual components, defining the sequence of operation for each action -> clearly defining the physical constraints. This step is very important as in real scenario many different teams are included in developing a system and most times the communication between the team might not be very efficient.

Analysis the system design constraint with tools like matlab to refine the system performance is very necessary. As these constraint can be added to the design models, which become the input for many other teams and their development. The final step is to verify and validate if the system is performing as per the expectations.

This project is a good opportunity to apply the advices and the lessons taught. This session gave us a unique exposure to realize a dynamic model and provided us with an insight on system engineering methodology. And we have a very good experience in using SysML.