

Maglev Trains
A Look into Economic Concessions

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Abstract

The primary purpose of this report is to provide an efficient solution for the current transportation problem that exists in the north east corridor. Traffic between New York and Washington D.C. is a major issue with congestion frequently leading to hours of delays. Air travel is currently a solution, but not an effective one. The amount of time spent at the airport (security, boarding/disembarking, flight checks, etc.) and en route to the airport, easily overrides any potential time saved in the air.



The current train system is not a great alternative either. Amtrak provides interstate train service in the region, but is fairly time consuming. The regular Amtrak trains take up to three and half hours to get to New York from Washington D.C. Amtrak does have a High Speed Rail train service, called the Acela; however, even the Acela takes two hours and forty five minutes to travel the distance. Another problem with the Acela is the cost. The Acela is much more expensive than regular Amtrak regional trains. This report tests the feasibility of implementing a Maglev transportation system between New York and Washington D.C.

Table of Contents

Problem Statement	4
Proposed Solution	5
Maglev trains	5
Speed:	5
Low Maintenance Cost:	5
Less travel time/ minimal hassle:	5
Safety:	6
All weather conditions:	6
Description of Maglev system	7
Project Goal	9
Requirements	11
High Level Requirements	11
Low Level Requirements	12
Traceability	13
Structure Diagram	14
Requirement Diagram	15
Use Case Diagram	16
Textual Scenarios	17
Textual Scenario 1: Driving Train	17
Textual Scenario 2: Tracking the Train	22
Textual Scenario 3: Train Preparation	25
Textual Scenario 4: Inspect Components	28
Parametric Diagram	31
Trade-off Analysis	32
Summary	36
System-Component Testing	37
(Validation/Verification)	37

Credits	38
References	39

Chapter 1

Problem Statement

Traffic congestion has been a major speed bump in creating a fast and flexible method of travel for commuters. The current highway systems allow commuters to travel long distances in a short amount of time, but since an automotive vehicle is easily accessible, more and more are arriving on the streets, thereby exceeding the recommended capacity for fast highway transportation. Let's take the highway system in the Northeast corridor for example. We will consider the distance from Washington D.C. to New York to be of medium distance. Travel time from the district to New York is already a tiresome drive in an automobile, but with traffic congestion it can delay that travel time by two to three hours. Combine this fact with the ever rising gas prices, and driving becomes a major problem for most commuters. If time is not a issue, money becomes an issue for many of the other drivers.

Usually people look to public transportation as a solution for their problems, but this is not the case here in the USA. This is mainly due to the fact that the public transportation system is not well conceived and developed. Air travel is a major hassle. The amount of time spent at the airports and en route to the airport, easily compensates for the amount of time saved in the air. The current train system is not a great alternative either. The Amtrak provides interstate train service in the region, but is fairly time consuming. The regular Amtrak trains take up to three and half hours to get to New York from Washington DC. Amtrak does have a High Speed Rail train service, called the Acela, but even that takes two hours and forty five minutes to travel that distance, and is a lot more expensive than the regular Amtrak regional trains.

Chapter 2

Proposed Solution

Maglev trains

There are several contributing factors that support the implementation of a Maglev transportation system over a conventional train system for the connection of Washington D.C. and New York.

Speed:

The feature of Maglev trains that gets the most attention is the speed at which they travel. Maglev trains can obtain a maximum speed of about 360 miles per hour. In comparison, the Acela can only obtain a top speed of a 150 miles per hour. However since the trains do not always travel at their maximum speeds, the number that makes the biggest difference is the average speed these trains travel at and the Acela only has a average velocity of 70 miles per hour. This is very fairly low number for a train that is considered High Speed Rail. In contrast, maglev trains average at least a 150 miles per hour, which is more than double the Acela's average speed.

Low Maintenance Cost:

Another positive feature of maglev trains is that the cost of maintaining and running Maglev trains is much less compared to conventional trains. A large reason is that since Maglev trains are levitating over the guideways, wear and tear damage due to the wheels of conventional trains rubbing on the tracks does not apply to Maglev trains. Conventional train tracks have to be worked on frequently to maintain their standards and this requires a lot of resources to accomplish. Especially once you consider that these tracks are across state lines, the amount of money required to work on them is very high this is never an issue for maglev guideways, so maintenance cost is relatively much lower. The Maglev train is never in contact with the rail during acceleration or deceleration because of the force between the train magnets and the rails. This eliminates friction, so the train is moving on a frictionless plane, with electricity generated power and aerodynamic drag being the limiting factors in the speed of the train. Also, since the train is not in contact with the rail, the actual rail will not degrade due to that friction. So the cost for maintaining the rail is very little, since frequent repairs and checkups are not required.

Less travel time/ minimal hassle:

With Maglev trains being introduced, travel time between Washington DC and New York will significantly decrease. With their average speed being at least twice as much as Acela's, commuting time would be decreased by half. In comparison to airplanes, Maglev trains are actually slower, but they still save time due to the minimal hassle it takes to travel in them. With air travel, people still have to take into consideration the time they have to spend at the airports for security, boarding and luggage checking. All this will not be needed for traveling in Maglev trains and so the commute time will still be less.

Safety:

Maglev trains are designed so they can never derail. They contain systems to always make sure the train is always kept balanced on top of the tracks and never shift off of it. Maglev trains system is also designed to never have accidents with other vehicles. The guideways are kept secured so no foreign vehicles such as cars or trucks can cross them. The system also protects trains from each other. Maglev trains travelling in opposite directions are always on different guideways, so there is never a possibility of head on collisions. And during operation, current is only provided to the part of the track where the trains are located at that specific time. This way they can check to make sure that trains never get too close to each other to have a rear end collision.

So far, there has never been a reported collision accident of a commercial maglev train. Overall there has been only one accident, but this took place during testing in Germany. Since then they have taken more precautions to make sure this never occurs. It should be noted that it is easier to track the current commercial trains as they all only travel short distance. It will be much harder to do so in a long distance scenario, but if implemented correct the safety system should still be feasible for our route

Environmentally friendly:

Maglev trains are extremely environmentally friendly as they have zero carbon emissions, since they run on electricity. Maglev trains also reduce noise pollution compared to regular trains.

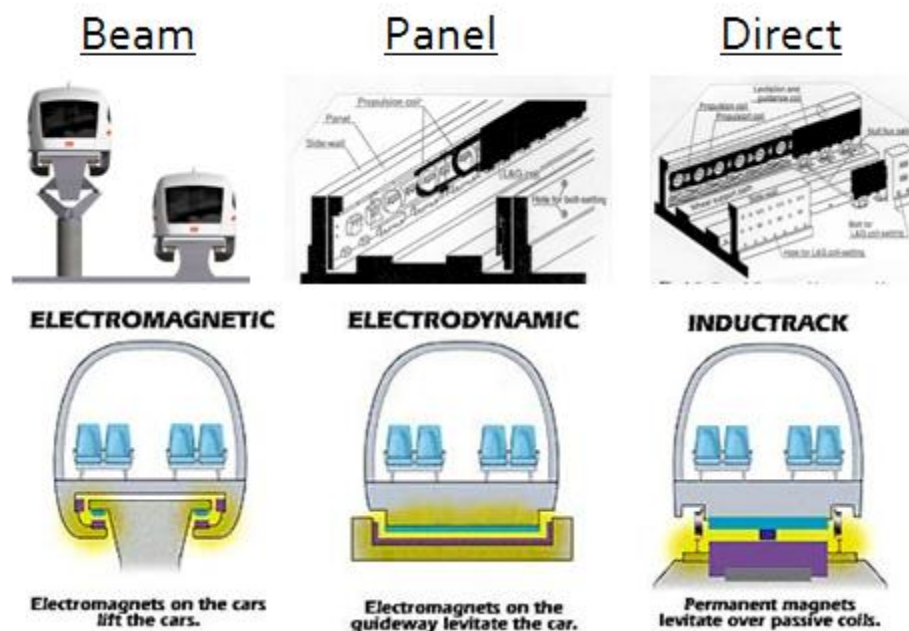
All weather conditions:

Another positive of implementing Maglev trains is that they operate punctually in all weather conditions. Airplanes are constantly delayed for long hours or cancelled during severe storms, and it is nearly impossible to drive in such weather conditions and not get stuck in severe traffic. Trains are not as bad usually but they still get delayed during bad weather such as heavy snow fall. With Maglev trains, since there is no contact with the tracks, they are operational during any weather condition and will never be delayed.

Chapter 3

Description of Maglev system

Maglev, or magnetic levitation, is a transportation system that uses magnets in order to lift and propel the train along a guideway. There are multiple different variations of the Maglev system based on the propulsion system, levitation system, and type of magnets. Propulsion systems include the linear induction motor and linear synchronous motor. Levitation systems include electromagnetic suspension (EMS), electrodynamic suspension (EDS), permanent and superconducting magnet electrodynamic suspension (PM and SC EDS). The different magnets used for the Maglev are permanent magnets, electromagnets, and superconducting magnets. Also, for each levitation system there is a corresponding guideway. For EMS beam type guideways are used and for EDS systems direct-type and panel guideways are used.

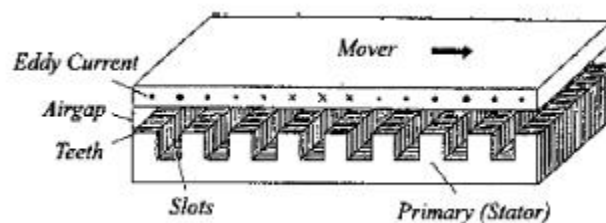


The first type of levitation system is the electromagnetic suspension. This particular type involves wrapping the train car around a T-shaped rail. Electromagnets on the track use alternating current to attract the train above the guideway. The guideway electromagnets' attraction pulls the train 10mm above the track. The small air gap allows for decent levitation at low speeds, but at high speeds the air gap must be heavily monitored, so this system requires many sensors and control systems to maintain the required air gap. The EMS systems also have the capability of stabilizing the train about the guideway, but that is not ideal for high speeds.

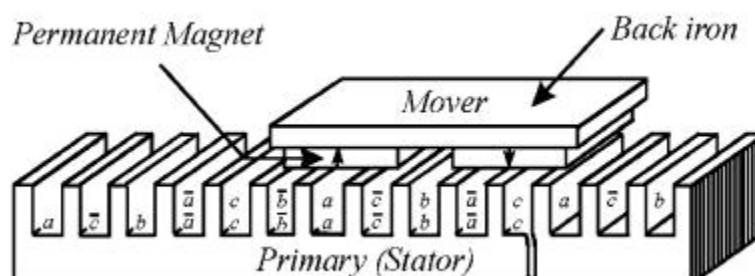
Some examples of EMS systems include the Chinese Shanghai Maglev Train and the Maglev trains made by the German company Transrapid.

The second type of levitation system is the electrodynamic suspension. Unlike the EMS, the EDS places the train car in a U-shaped guideway, so that it sits inside the rail. This system is capable of using permanent magnets, electromagnets, and superconducting magnets. These different magnets are placed on the guideway to repel the train above the track. The air gap produced by the magnets is significantly larger than the air gap produced by the EMS system; with an air gap of 100mm. EDS systems also are beneficial because extra control systems are not required because the levitation is controlled by permanent magnets. Even if the system uses electromagnets or superconducting magnets, the EDS system still exhibits a higher stability than an EMS system. The only issue surrounding EDS systems is that they are not able to levitate under static conditions (no movement), so Maglevs with an EDS system require rubber wheels for low speed travel. Some examples of an EDS system include Inductrack (they use permanent magnets) and the Japanese Maglev train JR-Maglev MLX01 (they use superconducting magnets).

The two types of propulsion systems LIM and LSM are similar, since they are linear motors, but they each have their advantages and disadvantages. LIM (linear induction motors) use the concept of induced EMF coming from the guideway that produces an eddy current in the undercarriage of the train to produce a force (Lorentz force) that pushes the train down the guideway. Two different types of LIM systems include the short primary type and long primary type. The long primary type is more expensive to construct, but can achieve higher speeds than the short primary type. Some Maglev's that use LIM include the Japanese HSST or Korean UTM.



The LSM (linear synchronous motor) is different from the LIM because there is a magnetic source within itself. Using LSM the Maglev speed can be controlled by the controller's frequency of the current. There are currently two types of LMS that are used in today's Maglevs, the electromagnets with iron-core and the superconducting magnets with air-core. This LSM is popular with Maglev trains because they have a higher efficiency and power factor than the LIM systems. These systems are found in the Shanghai Maglev Train and many other Maglev systems.



Chapter 4

Project Goal

Our ultimate goal is to make the Maglev train system as cost and energy effective as possible for the Northeast corridor. We will analyze specific components of the system, learning about what each component does, and how it affects the entire system both energy-wise and economically.

There are many components of a Maglev system. Strictly speaking, our project observes only the components that will affect the effectiveness of the entire system, which also accounts for the economic costs. Therefore, the system can be broken down into four major components; propulsion, levitation, station stops, and guideway type.

The propulsion and levitation systems have a direct impact on the costs. The EDS type with superconducting electromagnets requires an additional cooling source, which vastly increases energy consumption, thereby costing more. The additional coolant system will also require more maintenance, which will increase the overall cost.

The station stops will affect the speed of the train, because depending on the distances, the train will not be able to reach maximum speeds. Increasing the number of stops increases the overall travel time, but increases the amount of money generated by the Maglev system (due to an increase in the number of passengers that could potentially be serviced). We decided to fix the number of stops to be 6. This proved to be a good number because this is more stops compared to the Acela, but the overall travel time is still shorter than the Acela.

In further selecting components for analysis, we find that it is best to consider just the propulsion and levitation components. These two systems can be matched up differently with each other. For example, the EDS levitation can have an LMS or LIM propulsion system, and the same can be said for the EMS system. The guideway is constrained to a set type of levitation system. As we mentioned earlier, the T-shape rail is specifically designed for the EMS, and the U-shape rail is designed for the EDS. Therefore, it is best to view the propulsion and levitation systems as the major factors in our analysis.

Chapter 5

Requirements

High Level Requirements

This chart describes the general requirements of the Maglev system. This chart describes the general goals that this Maglev must achieve such as levitation, acceleration and deceleration etc.

#	High Level Requirement Description
1	Train must levitate
2	Train must accelerate and decelerate
3	Must be able to stop
4	Train must stay on the track/guideway
5	Train must hold passengers
6	Guideway must be sturdy enough to hold train
7	Permanent/Electro-magnets must keep train propelled above the track

Low Level Requirements

Here are the low level requirements which describe rudimentary functions with individual components within the system and how they operate.

#	Low Level Requirement Description
1	Top speed must be higher than 150 mph
2	Train must have at least 5 cars
3	Capacity of the train car must be at least 125 passengers
4	Train must make 6 stops
5	Have track and <u>guideway</u> be located at least 100 m from buildings
6	Must travel from DC to New York in under an hour
7	Must operate in all weather conditions
8	Must have emergency procedure for problems with train/track/or overall system
9	Each train car can weight no more than 50 tons
10	Guideway must be at least 225 miles long (362km) to get from DC to New York

Chapter 6

Traceability

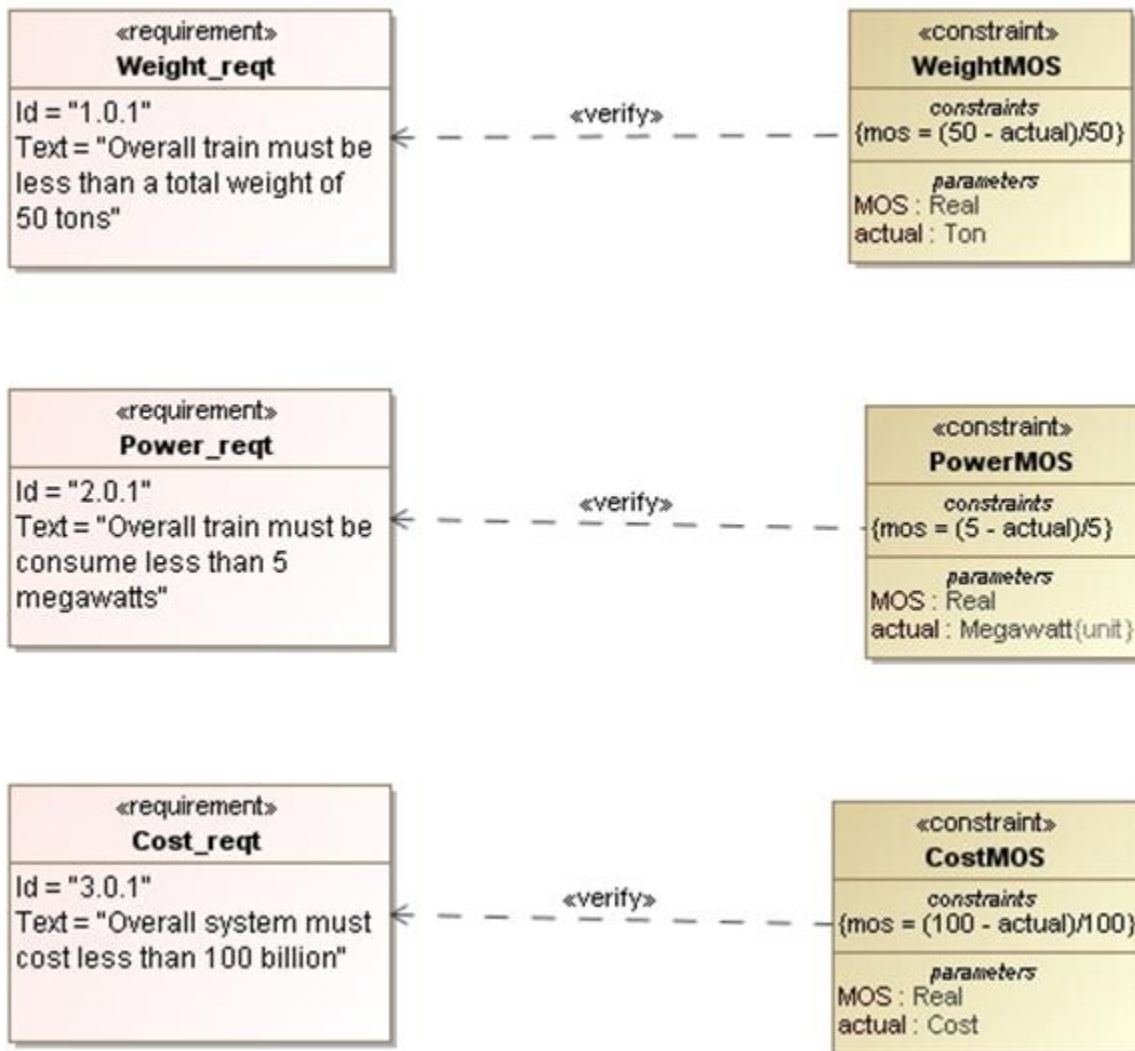
Use Case	High Level Requirements	Low Level Requirement	Description	Components
Drive Train	1, 2, 4	1,4,6,7	Train must drive at a top speed above 150 mph, operate in all weather conditions, and finish the trip from DC to New York in less than 2 hours.	Levitation system (EMS, EDS), Propulsion system (LIM, LSM)
Track Train Location	3	5	Must have a GPS unit and camera system that is able to track the train's location at all times.	Sensor System (GPS, Camera network)
Train Preparation	6	9	Guideway must be sturdy and free of faults. The train must also be properly aligned with the track.	Guideway type (panel, direct-attaching, beam)
Ride Train	5	2,3	Train must have a capacity of at least 125 per a train car.	N/A
Inspect Maglev Components	7	8, 10	Must be an inspection and emergency procedure for fixing the train.	N/A

Chapter 7

Structure Diagram

The diagram below illustrates the general structure of the Maglev system. We have divided the system into two components, physical and control component. Physical components focus on the hardware, while the control components focus on the software portion. Underneath each part, we have several specifications or parameters which each part must meet before going into production

The figure below illustrates the systems main requirements for implementing the Maglev train. We have three requirements regarding weight, power, and cost. Each one has a check, a calculation of the margin of safety between the target value and actual value divided by the target value. This ensures that each parameter is within the specific requirement.



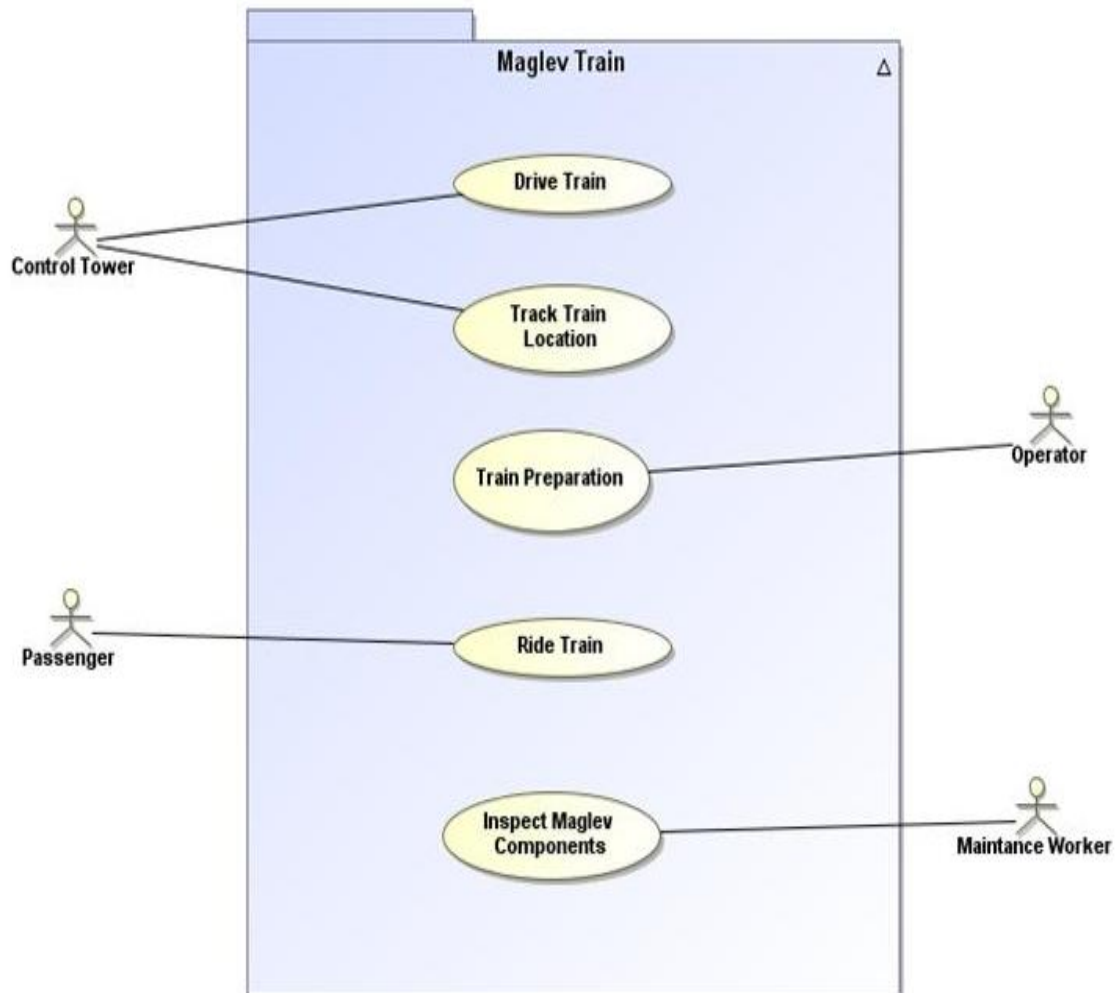
Chapter 9

Use Case Diagram

The figure below illustrates the interaction between the actors and each of the use case for the Maglev train. We have four actors present in this system. They are:

- Control Tower: who drives the train, and tracks the train's location
- Operator: who prepares the train for operation

- Passenger: who rides the train
- Maintenance Worker: who inspects and repairs any problem on the train



Chapter 10

Textual Scenarios

Textual Scenario 1: Driving Train

Description:

Controlling the acceleration and deceleration of the train

Primary Actor:

Control Tower

Pre-conditions:

Device to control electromagnetic polarity to push-pull train to speed up/slow down

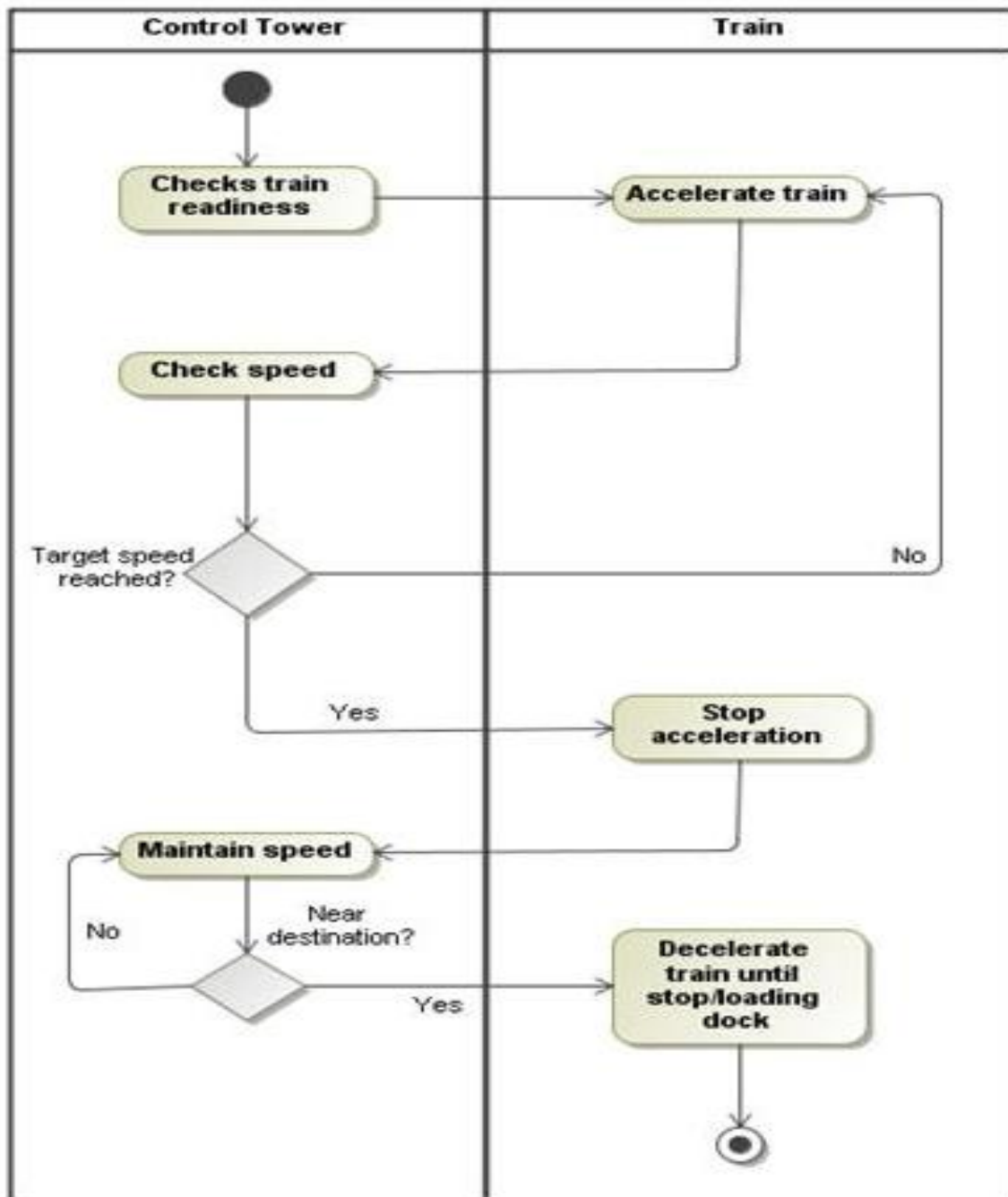
Flow of events:

- a. Control Tower accelerates train through some action
- b. Check to see if target speed has been achieved
- c. If targeted speed is not reached, continue accelerating
- d. Decelerate train when approaching next station
- e. Come to complete stop at the destination

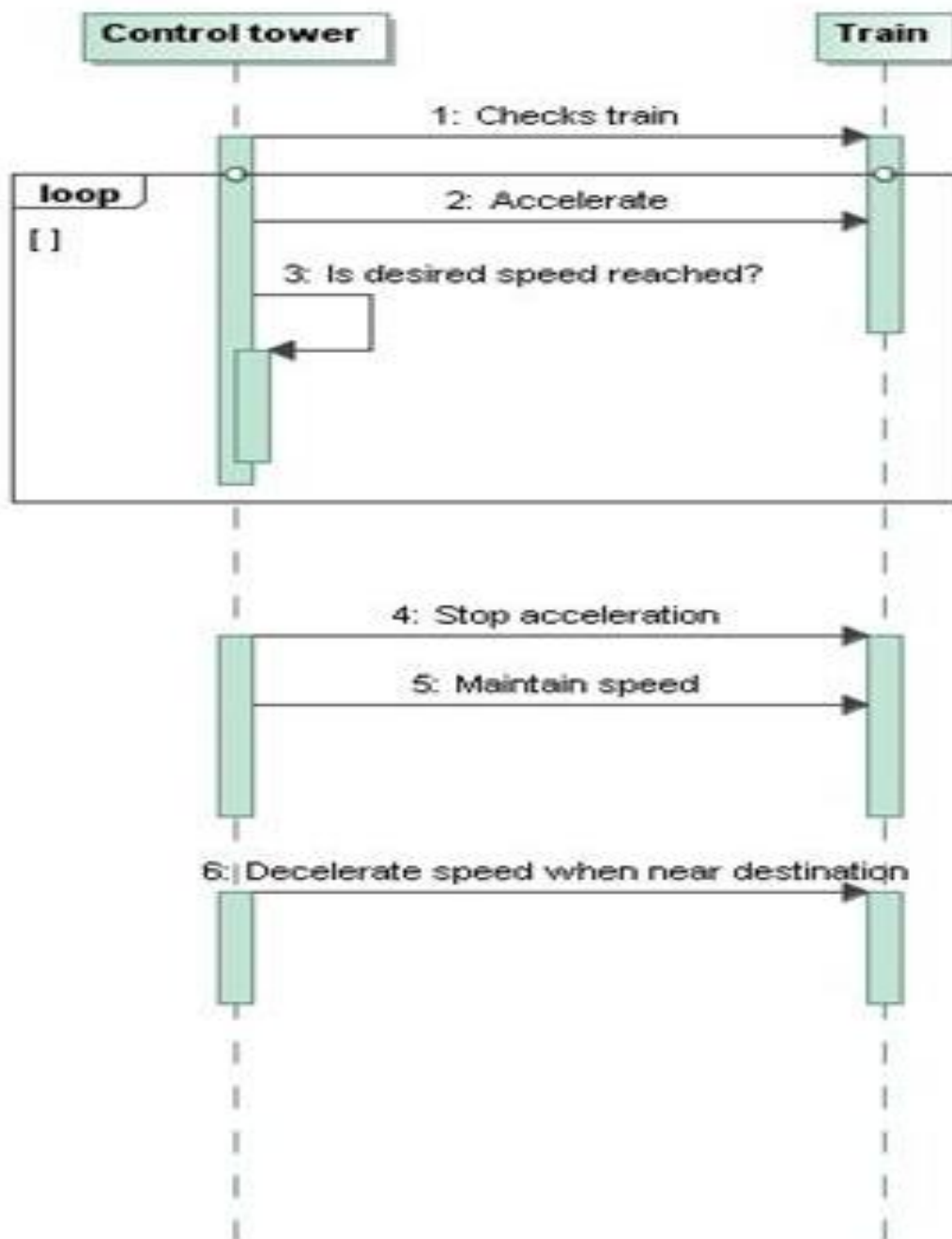
Post-Conditions:

Train will come to complete halt within an inch of desired location

Activity Diagram



Sequence Diagram



Textual Scenario 2: Tracking the Train

Description:

Keeping track of train arrival/departure times for all trains

Primary Actor:

Control Tower

Pre-conditions:

GPS to track train location and speed

Flow of events:

- a. Control tower connects to satellite
- b. Satellite bridges connection from control tower to train GPS
- c. Control tower uses signal to track location of trains at all times

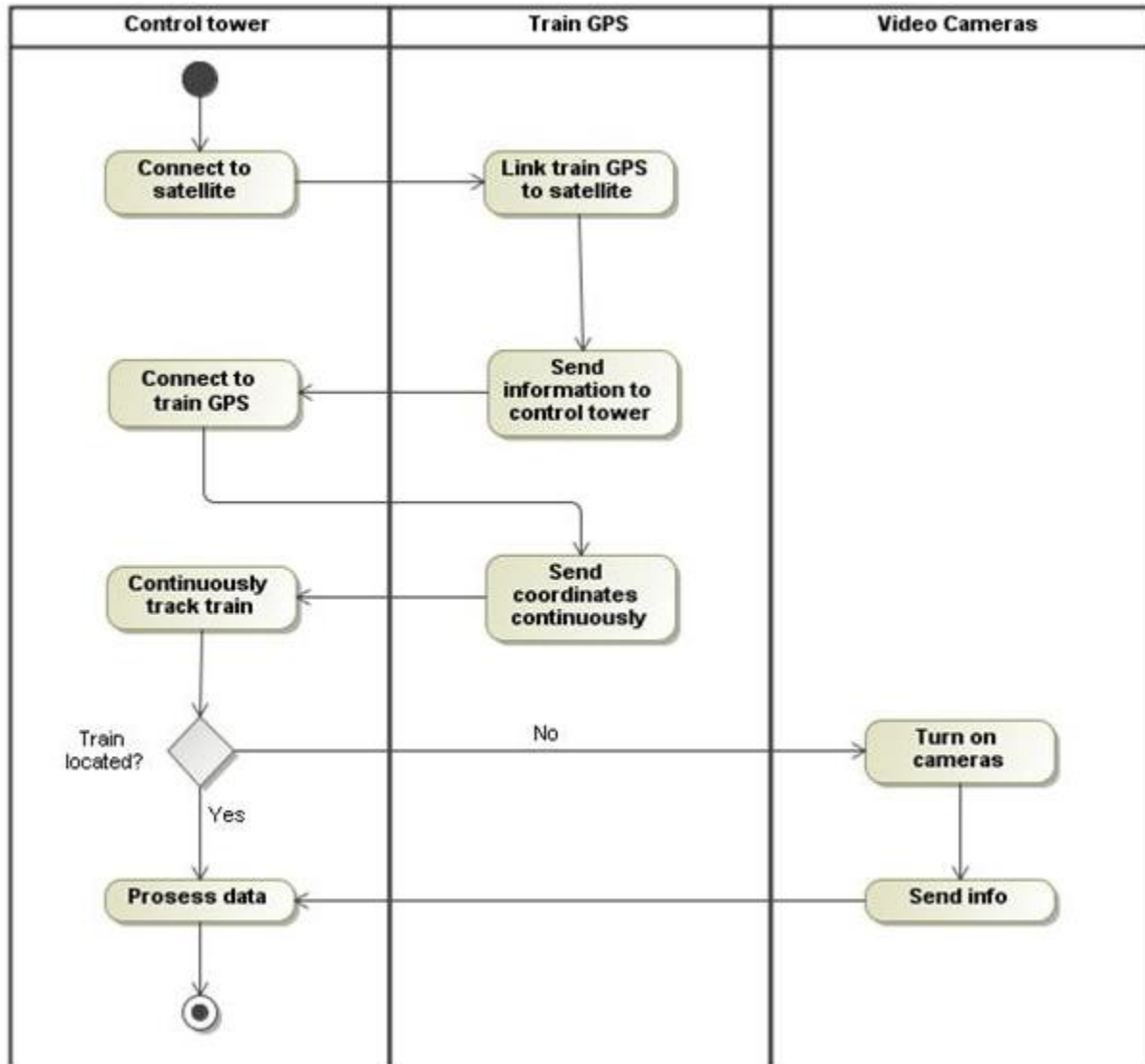
Alternate flow of events:

- a. Satellite does not receive signal from train GPS
- b. If no signal is returned back to control tower, video surveillance is used to track the trains
- c. Video data sent back to control tower until reconnection with satellite is achieved again

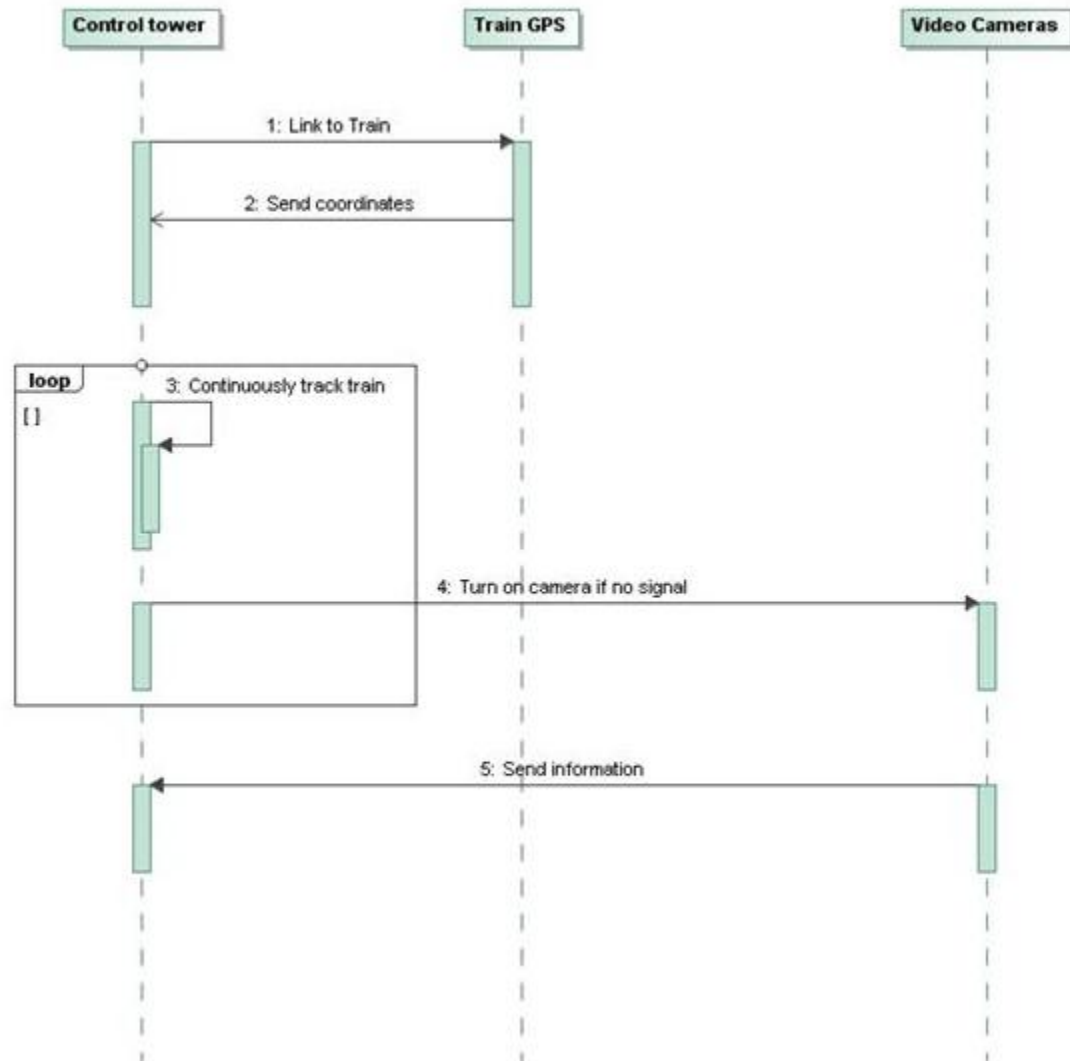
Post-Conditions:

Train location will be known at all times in case of emergency

Activity Diagram



Sequence Diagram



Textual Scenario 3: Train Preparation

Description:

Runs a series of checks on the train and reporting them before starting the ride

Primary Actor:

Operator

Pre-conditions:

Arrives 90 minutes early to have enough time to run through all the checks

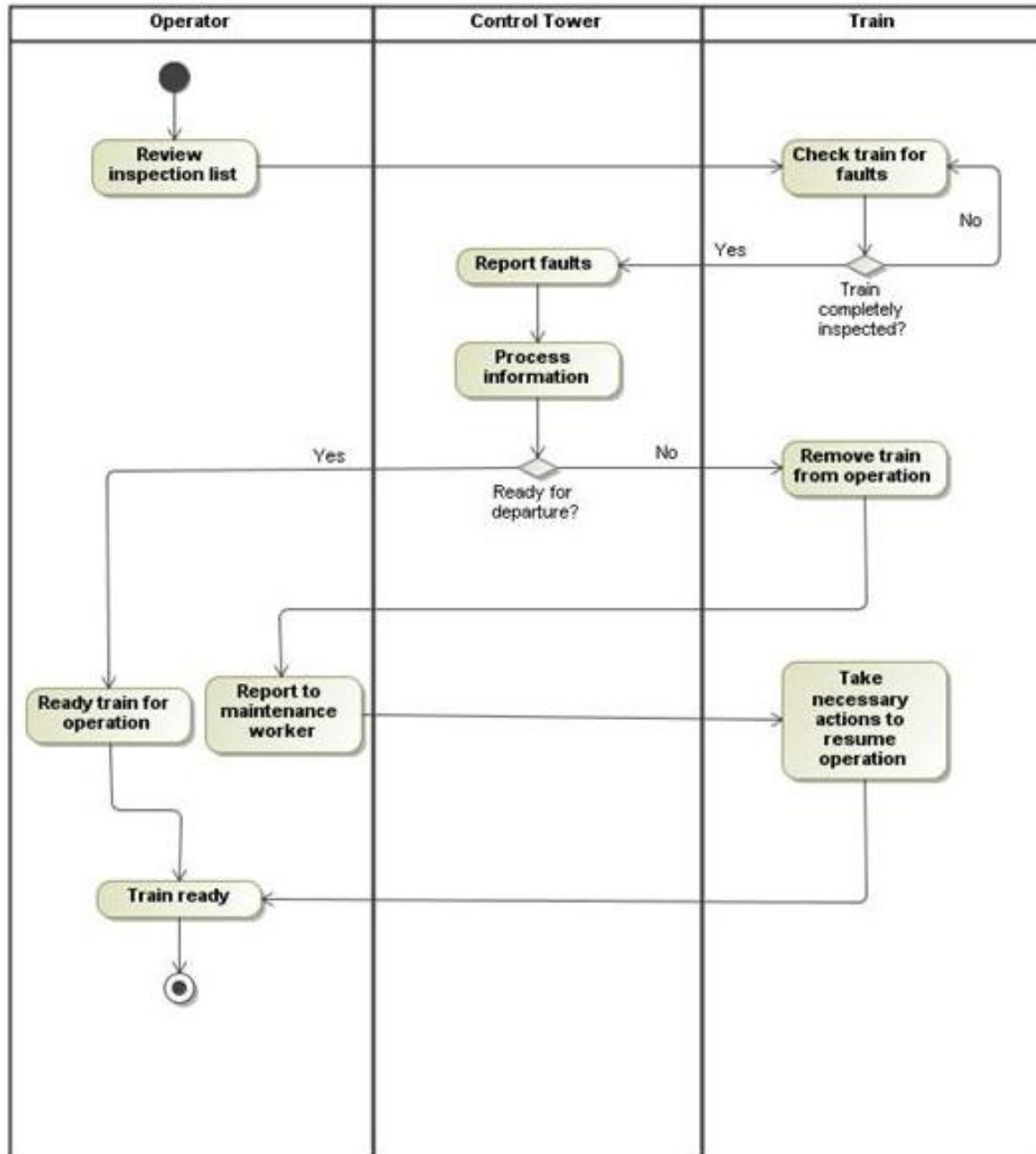
Flow of events:

- a. Operator runs through a series of checks to look for possible faults
- b. Reports back to control tower to relay the information
- c. If no faults are found, train will be ready to depart
- d. If faults are found, train will be pulled from operation, and operator will send a report to the control tower so that maintenance can be performed immediately

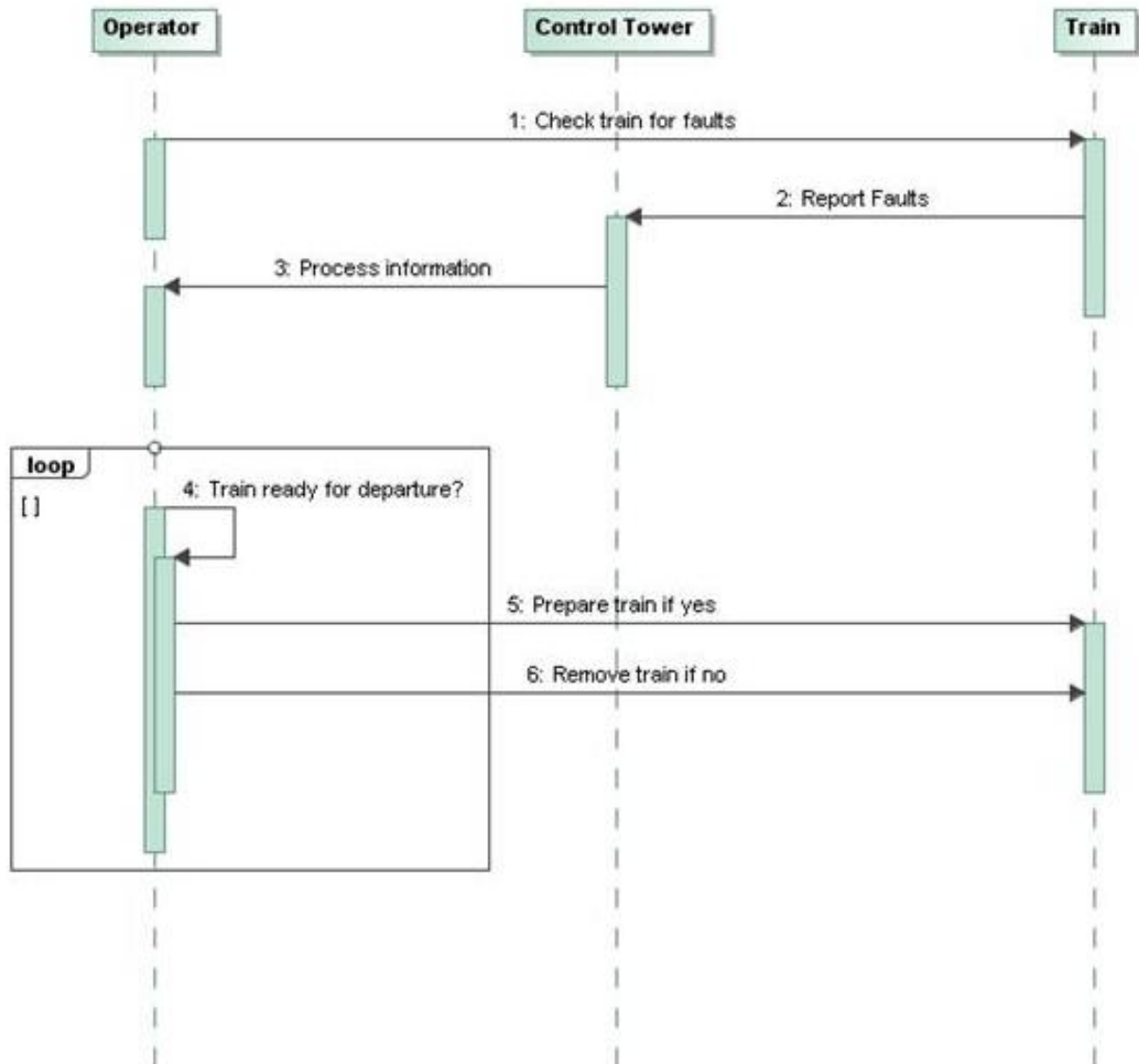
Post-Conditions:

Train preparation information is relayed back to control tower and train is ready to depart

Activity Diagram



Sequence Diagram



Textual Scenario 4: Inspect Components

Description:

Daily/nightly inspections to make sure propulsion and levitation systems are running smoothly

Primary Actor:

Maintenance Worker

Pre-conditions:

Review list of daily reports to check for any maintenance issues on the train and track

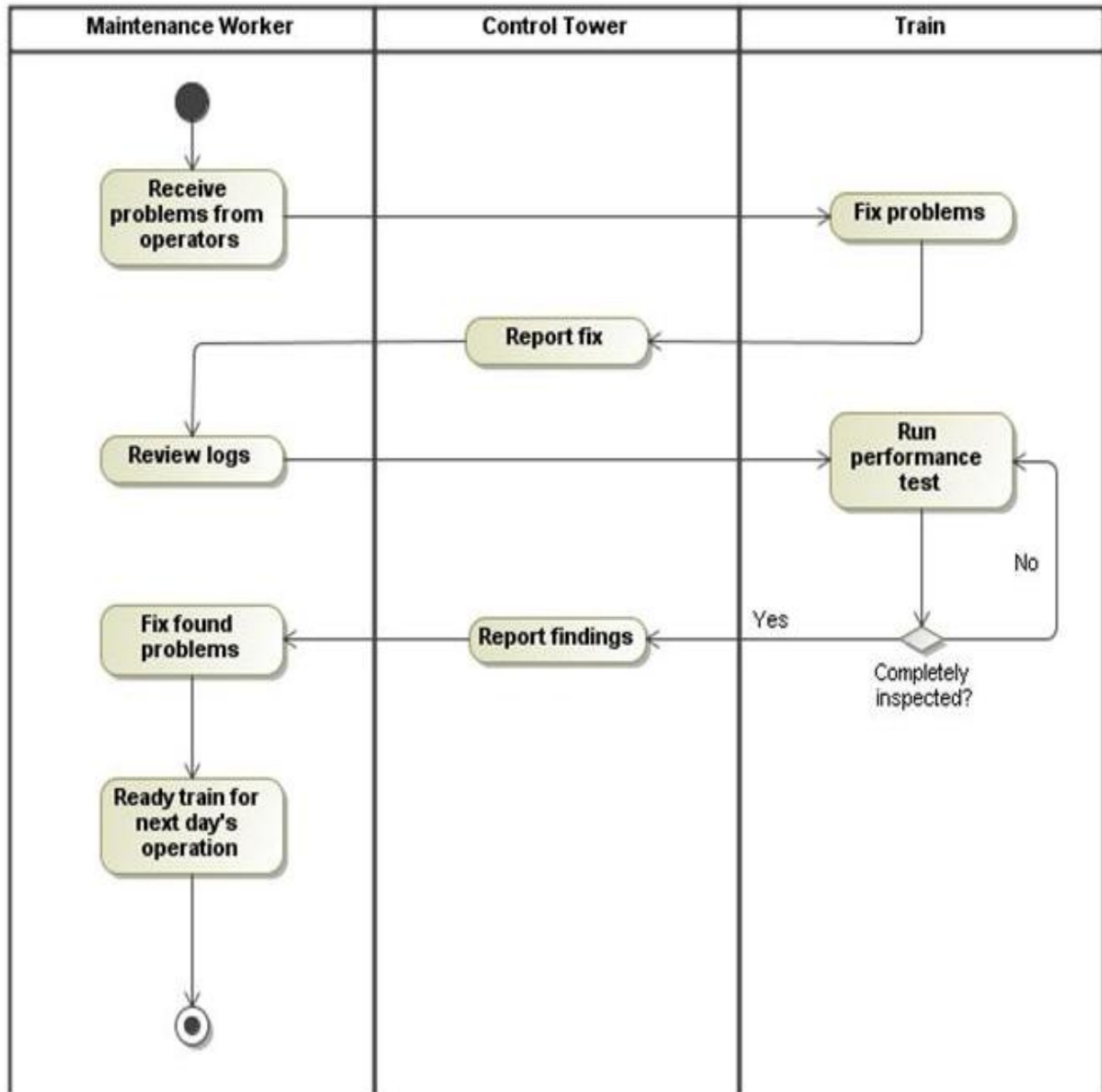
Flow of events:

- a. Worker receives and reviews daily reports from all train operators
- b. If there are problems with the train, the worker will fix the faults
- c. Worker will report the fixes back to the control tower
- d. Train will run performance checks to review operation after fix
- e. Train will report checks back to control tower to see if any more faults need to be fixed

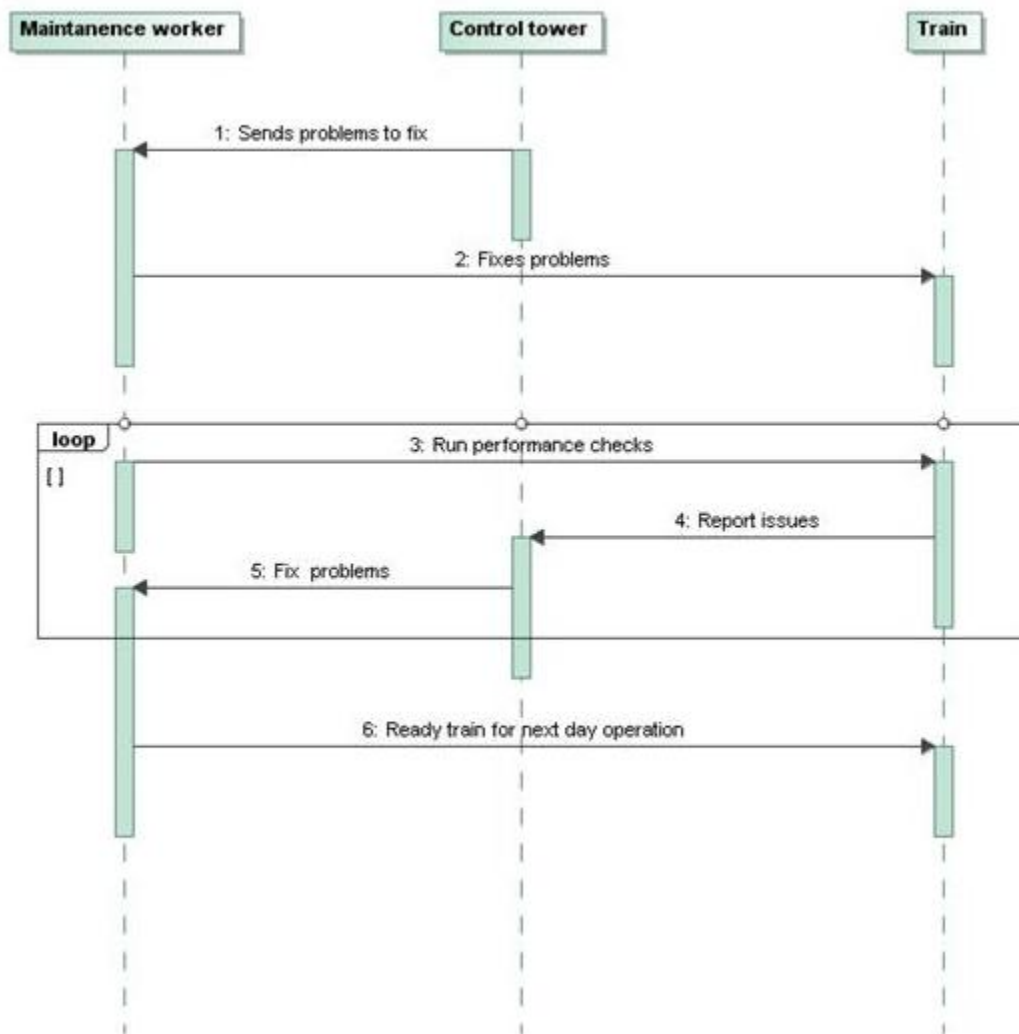
Post-Conditions:

Train and track will be fully ready for operation

Activity Diagram



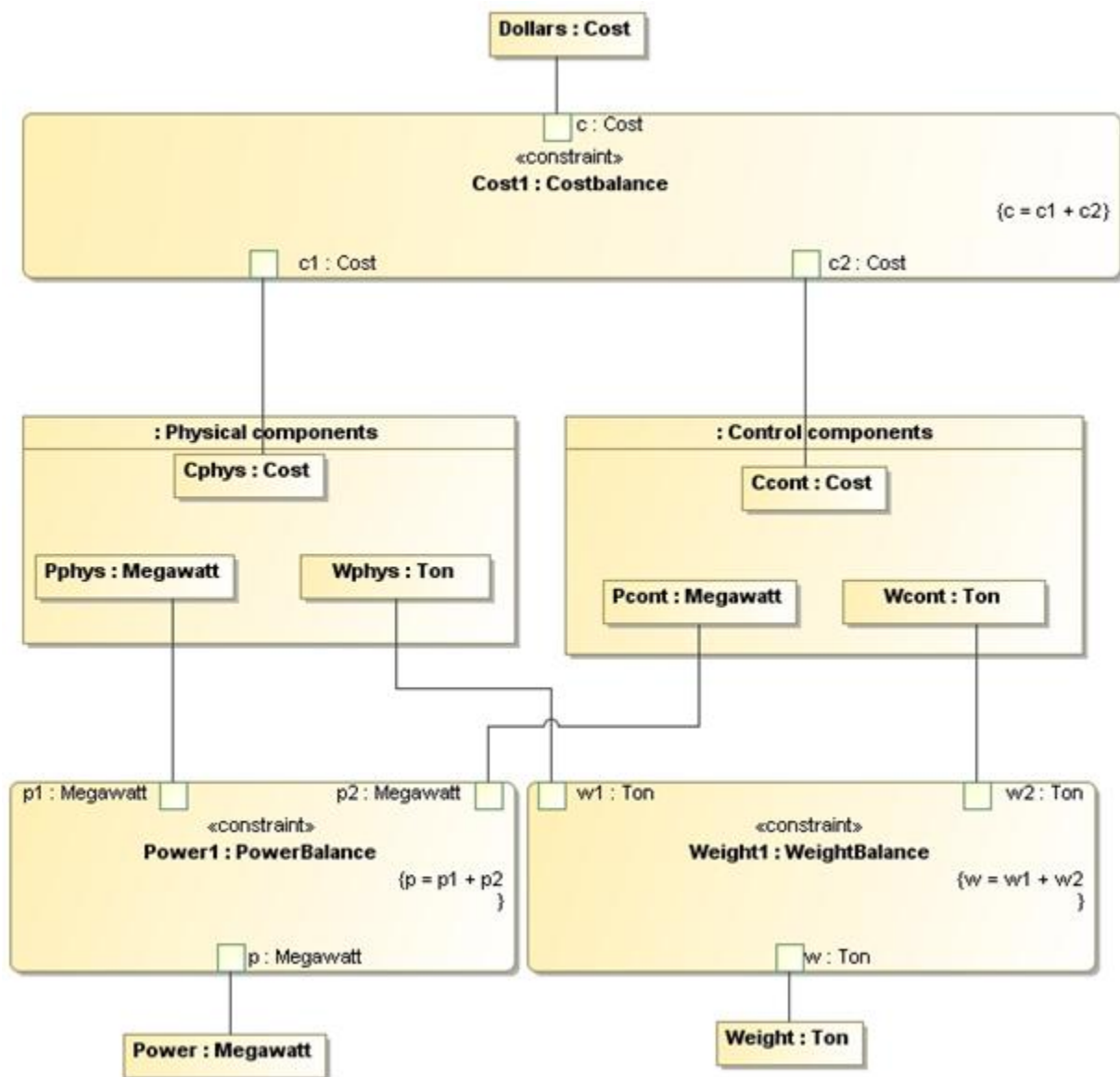
Sequence Diagram



Chapter 11

Parametric Diagram

The figure below illustrates the parametric diagram which shows a mathematical relationship among the each of the requirement. We have below the three constraints based on the requirement diagram: cost, power, and weight. Thus we can see that both the physical and control components have the three requirements. Each constraint can be found by adding up their respective physical and control parameters.



Chapter 12

Trade-off Analysis

The trade-off analysis focuses on three system aspects: cost, speed, and reliability. These performance metrics were chosen because they are the basic characteristics of a train system.

Cost of train systems are always compared to one another and used as a measure of whether or not a transportation project is feasible. The cost metric takes into consideration all of

the components in the Maglev system and its construction, but not the cost of purchasing land for the guideways or building station along the track. The measure for cost in the trade-off analysis is in billion dollars scale.

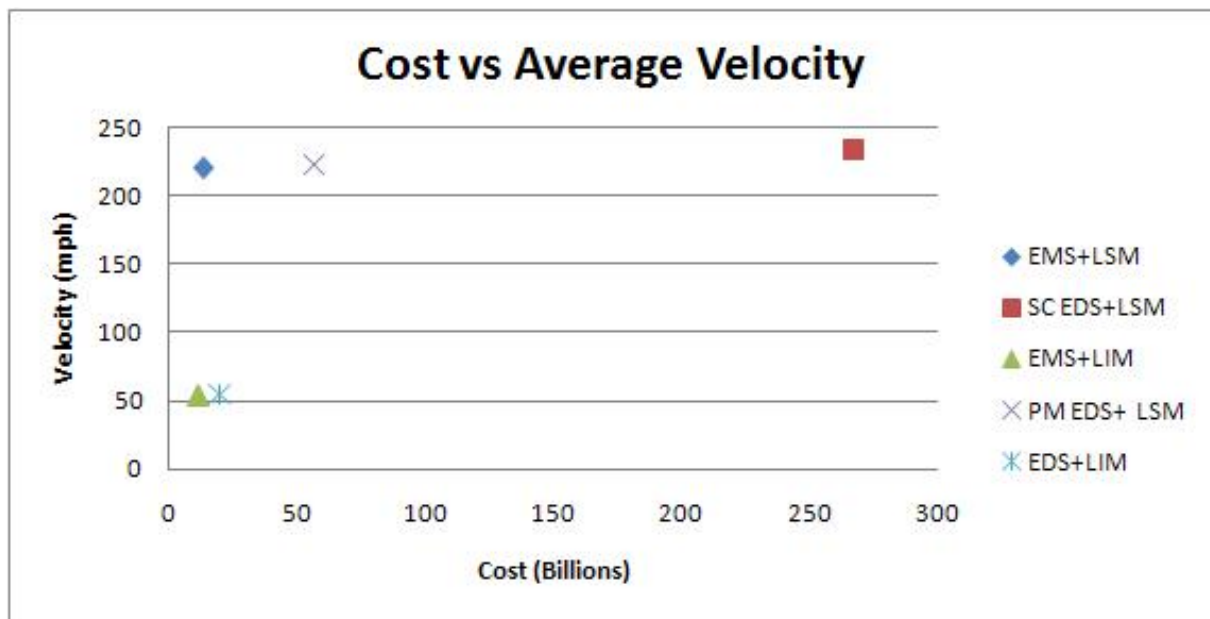
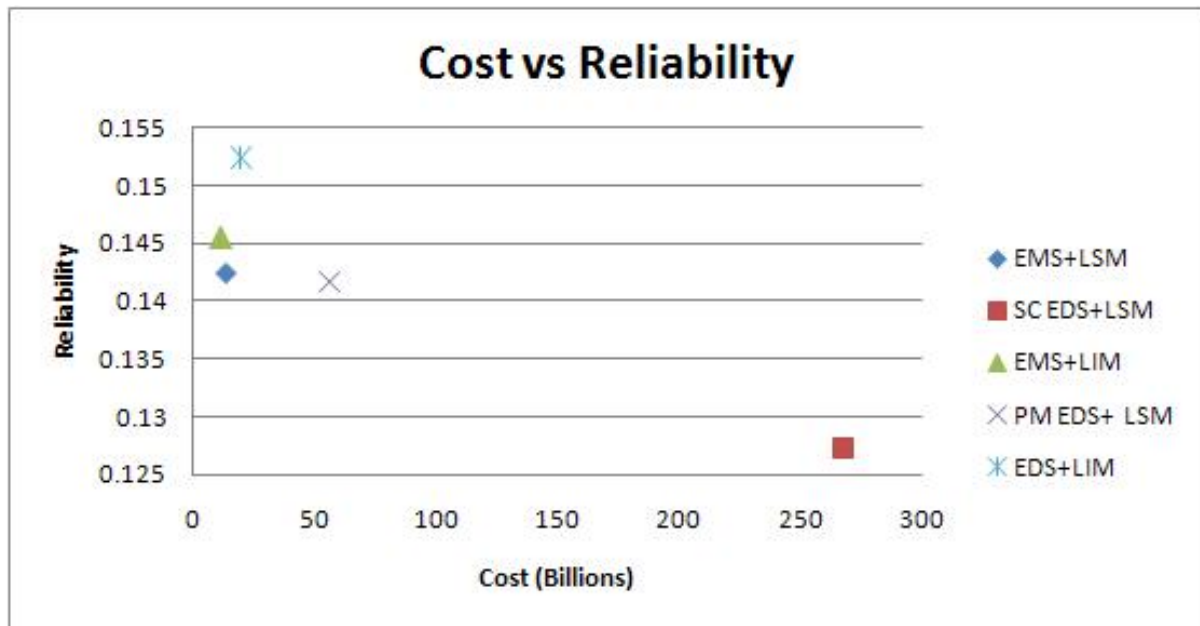
Speed is the most common standard used to compare transportation systems and is directly related to the time needed to travel. For the Maglev, speed is an extremely appealing attribute since it can travel over a hundred miles per hour faster than the current high speed rail in the Northeast Corridor. The measure for speed is in miles per hour.

Lastly, reliability is the most crucial parameter because knowledge of a transportation system's safety is the determining factor whether or not the system is viable. Passenger safety requires transportation reliability, which is paramount to all other system aspects. But testing and measuring how reliable a transportation system can become highly complex. For this project an analysis of the maintenance cost and operational cost are used to determine the reliability.

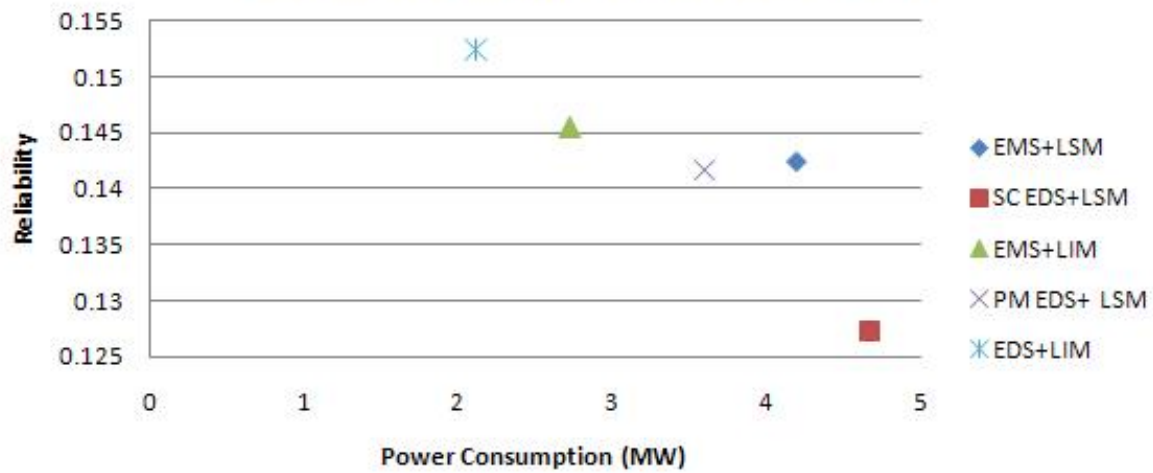
The design variable analyzed for this projects are the different type of levitation systems (EMS and EDS) and different propulsion systems (LIM and LSM). By choosing a system instead of a physical component the cost and other performance metrics were more easily accessible.

Performance Metrics	Average Velocity (mph)	Reliability		Cost (\$ billion)
		Maintenance Cost (\$ per track mile)	Operational Cost (\$ per hour)	
EMS/LIM (Linimo)	54.11	248,600	42	11.18
EMS/LSM (Transrapid)	220.8023	400,000	180	13.5
EDS/LIM (AMT)	54.45	155,000	48	19.57
PM EDS/LSM (Inductrack)	223.996	212,000	54	56.25
SCM EDS/LSM (JR-Maglev)	233.3	121,000	30	267.03

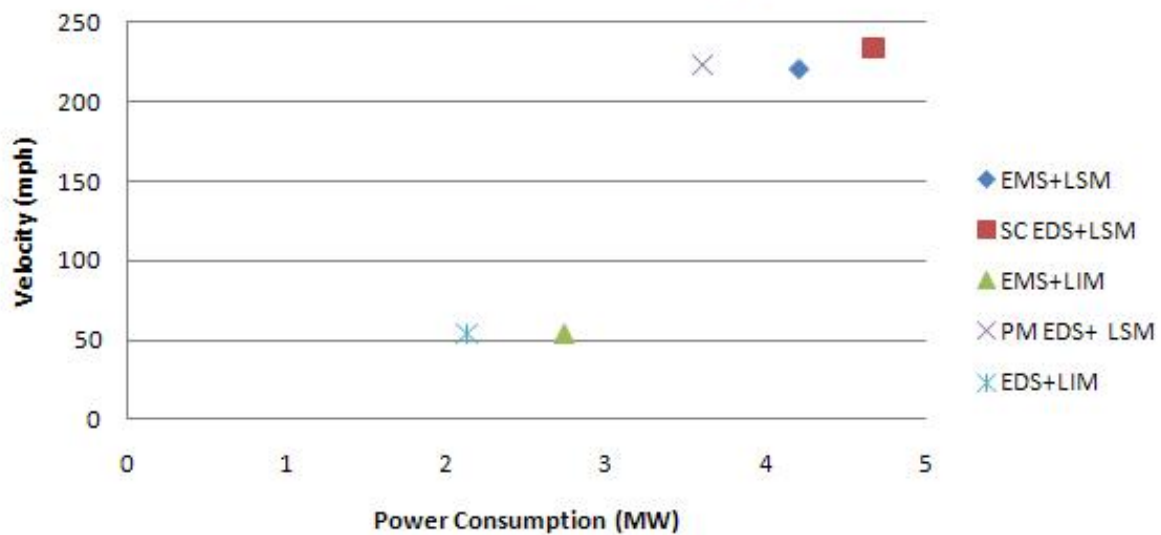
To calculate reliability the maintenance and operational cost were multiplied. Then the product is put on a log scale and inverted. So the a higher reliability means it is a safer system, whereas a lower reliability means the system is less safe.



Power Consumption vs Reliability



Power Consumption vs Average Velocity



Chapter 13

Summary

Trade off Curve	Points of Interest
Cost vs Reliability	EDS+LIM, PM EDS+LSM
Power Consumption vs Reliability	EDS+LIM, PM EDS+LSM
Cost vs Average Velocity	EMS+LSM, PM EDS+LSM
Power Consumption vs Average Velocity	EMS+LSM, PM EDS+LSM
Overall	PM EDS+LSM, EMS+LSM

From this analysis we can infer that the best choices for a Maglev system is the PM EDS+LSM (such as the Inductrack) or EMS+LMS (such as the Transrapid).

Chapter 14

System-Component Testing

(Validation/Verification)

For validation of the system requirements testing, analysis, and demonstration are used. The following table shows how validation would be implemented.

Validation			
System Requirement	Testing	Analysis	Demonstration
Maglev speed	Simulate in Matlab with required	-	-
Operation in all weather conditions	-	-	Build a model that shows
Maglev weight requirement	-	Get weight of each component	-
Emergency Procedure	-	-	Show how emergency procedure would be implemented
Power Requirement	-	Measure the average power Maglev trains use	-

Verification of the requirements such as cost and reliability can be checked parametric diagrams, and solvers like Mathematica and Matlab, to compute the how the cost and reliability are effected by change in conditions.

Chapter 15

Credits

- Binyam Abeye: Trade Off analysis, Requirements, and Research
- Harsh Mishra: Parametric Diagram, Textual Scenarios, Research
- Alan Tang: Structure, Activity & Parametric Diagrams, Research
- Stephen Wong: Use Cases, Requirements, Research
- Khai Van: Textual Scenarios, Activity Diagram, Research

Chapter 16

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