Ph.D. Dissertation Proposal Presentation
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Feasibility Study of Implementation of Maglev Regenerative Braking System (RBS) to MTA-NYCT
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Research Objective

1. The basic research objective of this project is to show the world that RBS can bring enormous saving and various advantages which is not utilized by most of the transportation systems of the world at this point.

2. The primary research is concentrated on technical feasibility in terms of energy saving. The main objective is to determine net energy saving using Maglev RBS to MTA-NYCT. The cost factor is not considered in this primary research.

3. Calculation of efficiency of proposed MTA-NYCT Maglev with RBS: (Dr H. Choi Dissertation work) South Korean Urban Maglev system (without RBS) LCC is converted into energy cost. Through MTA-NYCT system characteristics, South Korean Urban Maglev system energy cost is converted to MTA-NYCT energy cost without RBS. Since Energy cost is known from this research of Proposed MTA-NYCT Maglev system with RBS. Hence efficiency of proposed MTA-NYCT Maglev RBS can be calculated.
Publications & Presentations

1. AREMA Conference 2011 Presentation; Topic: Increasing Diverging Speed over Turnout without Changing basic infrastructure of track system

2. Publication in RT & S Magazine- Oct 2011; Topic: Increasing Diverging Speed over Turnout without Changing basic infrastructure of track system


   [(Lecture on Advancement in Railroad Engineering, Part 1 and 2 ( Four Hour each- two lectures)]

5. Marzzo Engineering –Presentation in NY-October 2/23- 2013
   [(Lecture on Advancement in Railroad Engineering, Part 3 and 4 ( Four Hour each- two lectures)]

   [(Lecture on Structural Evaluation of High Rise Suspension Bridges- Highway and Railroad, Part 1 and 2 ( Four Hour each- two lectures)]
Motivation

The following points motivated to do feasibility study of implementation of Maglev RBS to MTA-NYCT.

There are obvious advantages of using Maglev technology compared to other modes of transportation including rail systems.

1. No fossil fuel requirement, powered by electricity.
2. Environmental friendly compared to other transport modes
3. More energy efficient compared to other transport modes
4. More economical compared to other transport modes

These advantages of a Maglev system over other transport modes in economic and environmental fields making it definite alternative for future transportation needs.
Motivation

The following points motivated to do feasibility study of implementation of Maglev RBS to MTA-NYCT (Contd.)

- A regenerative brake is an improvement over conventional braking system. In conventional braking system, the kinetic energy is lost in heat and sound and is not reused. In RBS, the majority of kinetic energy is conserved as electrical, chemical and or other useful forms of energy which can be reused.

- The Maglev with RBS is already operative in countries like China (Shanghai Transrapid), South Korea (UTM-02) and Japan (Linimo).

- The various advantages of Maglev with RBS will shift its operation from a technical research stage to a commercial operation stage throughout the world in near future.
Problem Statement

MTA-NYCT is going through following problems:
1. Less Efficient Energy consumption
2. Unsatisfactory Economic Condition
3. Aging infrastructure.

The above mentioned Problem Statements is considered in feasibility study of implementation of Maglev regenerative braking system to MTA-NYCT. No such research done in the past to take care of these problems. Through this feasibility study, it can be shown that it is beneficial to implement Maglev regenerative braking system to MTA-NYCT.
Basic Principles/Theorems of Maglev technology

1. Earnshaw’s theorem
2. Faraday’s law of electromagnetic induction
3. Lenz’s law
4. Maxwell’s law
5. Maxwell-Faraday’s law
Earnshaw’s theorem

• Earnshaw theorem explains the concept of Magnetic levitation.
• Earnshaw’s theorem applies to condition of static stability and affects the static levitation of magnetic systems. It does not apply to dynamic systems.
• According to this theorem, it is impossible to attain a static equilibrium in a system in which only inverse square law electrostatic or magnetostatic forces are acting.
• The maximum magnetic pressure $P$ between two magnetized objects of magnetization $M_1$ and $M_2$ at zero gap between them is given by

$$P = \frac{(M_1 + M_2)}{2\mu_0}$$

...............(i)
Faraday’s Law of Electro Magnetic Induction

• Faraday’s law of electromagnetic induction is a basic law of electromagnetism.
• It predicts how a magnetic field will interact with an electric circuit to produce an electromotive force (EMF).
• It is a fundamental principal of transformers, inductors, electric motors and the generators.

\[ \Phi_B = \int \int_{\Sigma(t)} B(r, t) \cdot dA, \]

Where symbols having their usual meanings.
Lenz’s Law

According to Lenz law, an induced electromotive force (EMF) always gives rise to a current whose magnetic field opposes the original change in magnetic flux.

\[ \mathcal{E} = -N \frac{d\Phi_B}{dt} \]

Where symbols having their usual meanings.
Maxwell’s Equations

- Maxwell’s equations are a set of partial differential equations that together with Lorentz force law forms the foundation of classical electrodynamics and electric circuits.

- The following are a set of four equations that describe the relation between the electricity and magnetism.

\[
\begin{align*}
\nabla \cdot \mathbf{E} &= \frac{\rho}{\varepsilon_0} \\
\nabla \cdot \mathbf{B} &= 0 \\
\nabla \times \mathbf{E} &= -\frac{\partial \mathbf{B}}{\partial t} \\
\nabla \times \mathbf{B} &= \mu_0 \mathbf{J} + \mu_0 \varepsilon_0 \frac{\partial \mathbf{E}}{\partial t}
\end{align*}
\]

Where symbols having their usual meanings.

Source: http://www.irregularwebcomic.net/1420.html
The Maxwell-Faraday Equation

- The Maxwell-Faraday equation is a generalization of Faraday’s law that states that a time varying magnetic field is always accompanied by a spatially-varying, non-conservative electric field, and vice-versa.

\[ \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t} \]

Where \( \nabla \times \) is the Curl operator

And other symbols having their usual meanings.
MTA-NYCT Subway System

1. Current Subway Map
2. Summary of Current NYC subway system (2 slides)
Summary of Current MTA-NYCT Subway System

- 656 one-way miles of reverse track
- 846 miles welding yards
- 6292 subway cars on roster
- 1.62 billion riders/year (5.3 million/day on weekdays)
- $2.25 single ride fare
- ~ 4 billion $/year fare revenue
- Fares cover 67% of operating cost; ~ $ 2 B/year subsides
- 500 MW peak power demand; 200MW averages ( 8Billion kwH/year)
Summary of Current MTA-NYCT Subway System

- ~ 80,000 for older subway cars (empty): ~ 70,000 for newer cars
- 22-yr average service lifetime for subway cars
- 44 seated, 202 standing passenger capacity per car
- $ 2M per car capital cost
- 8 to 11 cars is typical subway train
- A division and E & L lines are beyond capacity
- 24 train routes in systems
- 1.1 kwH per average trip
- 95 dB average noise level in cars: 100+ dB on platforms
Literature Review Topics

- Brief description of Maglev technology with RBS
- Magnetic braking
- Regenerative braking system (RBS)
- Regenerative braking characteristics of linear induction motor for Maglev
- Feasibility study of on-car RBS for electric rail
Brief Description of Maglev Technology with RBS

• Present Stages of Maglev With/Without RBS

• Electro-magnetic Suspension (EMS) System, its application in Germany

• Electro-dynamic Suspension (EDS) System, its application in Japan

• Comparative analysis of EMS & EDS System and & their compatibility to regenerative braking system (RBS)
Present Stages of Maglev With/Without RBS

- Commercial Operation Case Study

<table>
<thead>
<tr>
<th>Linimo in Japan</th>
<th>Shanghai Transrapid</th>
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<tbody>
<tr>
<td>(EMS with RBS System)</td>
<td>(EMS with RBS System)</td>
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Present Stages of Maglev With/Without RBS

- Current Maglev Research Centers in Global

| Emsland Test Facility in Germany (EMS System) | Yamanashi Test Track Japanese Railway (JR), Japan (EDS System) |
Electro-Magnetic Suspension System

The levitating force comes from an attractive pull between a laminated iron rail in a guideway and a conventional electromagnet in the vehicle.
Electro-Magnetic Suspension System

- In Electro-magnetic suspension (EMS) system, The EMS is levitating the object stably by the changing the magnetic field controlled by a complex servomechanism. The first generation EMS Maglev system is already operative in many countries like Japan (Linimo), China (Shanghai Transrapid) and South Korea (UTM-02).
Electro-Magnetic Suspension System

5 Linimo is a first commercial application of high speed surface transport (HSST) system (Tobu-Kyuryo-Line). The Linimo train uses conventional electromagnets and attractive-type "Electro-Magnetic Suspension" (EMS) and runs at a maximum speed of 100km/hr in Japan.

25 The Shanghai Maglev Train or Shanghai Transrapid is a magnetic levitation train, or maglev line that operates in Shanghai, China.

26 UTM-02 is a light rail type Maglev vehicle used in South Korea.
Electro Dynamic Suspension System

MAGLEV Train Platform

Magnetic Tracks

Repulsive Force
Electro Dynamic Suspension System

- Produces a magnetic field through coils of superconducting magnets.
- Super conducting magnets produce a field of the same polarity as that induced in guideway coil.
- Repulsive forces are generated by eddy currents induced in a guideway by passage of a superconducting magnet.
- Resulting magnetic repulsion levitates the vehicle.
- The Governing Principle’s are Faraday’s law and Lenz’s Law.

\[
\Phi_B = \int \int_{\Sigma(t)} B(r, t) \cdot dA, \quad \mathcal{E} = -N \frac{d\Phi_B}{dt}
\]
Comparative analysis of EMS & EDS System

Electro Magnetic and Dynamic Suspension Systems advantages and disadvantages are as follows:
Electro-Magnetic Suspension System

Advantages
- Commercial Operation History
- The lower magnetic field strength
- No secondary propulsion system

Disadvantages
- Complex servomechanism to control the gap (1cm)
- Weak guideway material
- Expensive Initial Capital Cost
Electro Dynamic Suspension System

Advantages

• Above 10cm gap is allowed
• This system has the highest speed record
• Cheaper O&M cost

Disadvantages

• Strong magnet field
• Secondary Propulsion System
Comparative analysis of EMS & EDS systems and their compatibility to RBS

- EMS systems have commercial operation history in many countries of the world particularly China (Shanghai Transrapid), Korea (UTM-02), & Japan (Linimo).

- These countries has implemented RBS in their Maglev EMS system.

- Since EDS system is not commercialized as yet, hence RBS system is not implemented in it.
Magnetic Braking

A. Magnetic braking of a rectangular sheet moving linearly through the magnet

B. Image method based on Maxwell’s equations (The Principle of Mirror Images)

C. Force on magnet moving over conducting plane & Calculation of forces

D. Practical use-Eddy Current brakes

Magnetic Braking (Basic Formula)

- The concept of magnetic braking can be explained using Faraday's law of electromagnetic induction and Lorentz forces.
- Lorentz force:
  \[ F = q (v \times B) \]

Here, \( v \) is the velocity vector of the charge \( q \), and \( B \) is the magnetic field vector. The direction of Force vector \( F \) is perpendicular to the direction of the Velocity Vector and Magnetic field vector. Also,

\[ F = IL \times B \]
Magnetic Braking (Basic Formulae)

\[ F_D = \left( \frac{-w}{v} \right) F_L \]

\[ W = \frac{2}{c \mu \sigma \mu_0} \]

\[ F_L = \left( \frac{3 \mu_0 p^2}{32 \pi z_0^4} \right) \left[ 1 - \frac{w}{\sqrt{v^2 + w^2}} \right] \]

\[ F_D = \left( \frac{-w}{v} \right) \left( \frac{3 \mu_0 p^2}{32 \pi z_0^4} \right) \left[ 1 - \frac{w}{\sqrt{v^2 + w^2}} \right] \]
Significance of Important Terms (Magnetic Braking)

1. **FD** = Drag Force (SI Unit Newton)
   This results from magnetic braking of the vehicle. This force can be used for transformation from kinetic energy to electric energy.

2. **FL** = Lift Force (SI Unit Newton)
   This is the levitation force for the maglev vehicle.

3. **B** = Magnetic field (SI Unit is Tesla - Weber/ Square Meter)
   This depends upon what type of magnet we are using. The magnetic field characteristics of dipole magnet and quadrupole magnets are quite different.

4. **p** = dipole moment (unit is debye) [A debye is defined as statcoulomb second]

5. **σ** = conductivity of conductor, (conductivity definition. ... Its units are Siemens per meter [S/m] in SI and millimhos per centimeter) (opposite to resistivity)

6. **μ** = permeability of conductor. (Unit is H m⁻¹) (magnetic property)

7. **μ₀** is $4\pi \times 10^{-7}$ H m⁻¹, the magnetic constant (permeability of free space).

8. **v** - Velocity of magnetic dipole , (SI Unit Meter/ Sec or FPS Unit Ft/Sec)

9. **w** - Velocity of mirror images (SI Unit Meter/ Sec or FPS Unit Ft/Sec)

10. **q** = Charge on a particle (SI unit is Coulomb)
Regenerative Braking System

1. A regenerative brake is an improvement over conventional braking system.

2. In conventional braking system, the kinetic energy is lost in heat, sound etc and none of energy is used.

3. In regenerative brake system, a portion of kinetic energy is conserved as electrical, chemical and or other useful forms of energy which can be used.
Regenerative Braking System

• Regenerative braking occurs when the load torque has reversed its direction but the operation direction remains the same. When the load drives the motor, synchronous speed can be exceeded and mechanical power converted into electrical allowing regeneration.

• A regenerative braking system uses a back-to-back converter, which allows bidirectional power flow. The electricity generated by the deceleration of linear motors can be used by the auxiliary systems of the vehicle or returned to the grid, eliminating the use of resistive load to dissipate energy.

Regenerative Braking System

• A regenerative brake is an energy recovery mechanism which retards a vehicle or object down by converting its kinetic energy into another form of energy which can be either used immediately or stored until needed.

• This concept is different than the conventional braking systems, where excessive kinetic energy is wasted in form in heat, sound through friction in the brake linings.

• The most common form of regenerative brake involves using an electric motor as an electric generator.

• In electric railways system, the generated electricity through regenerative braking system is reused, whereas in battery electric and hybrid electric vehicles, the energy is stored in batteries etc.

Regenerative Braking System

In regenerative braking systems, the electric motor that propels an electric or hybrid vehicle also does most of the braking.

When the brakes are applied, instead of employing a conventional friction-based braking process, the system signals the electric motor to run in reverse mode, creating resistance to slow the vehicle.

An electric motor running backwards also acts as an electric energy generator or dynamo that converts the kinetic energy of motion into electrical energy that can be stored for reuse, improving efficiency.

http://www.energymanagertoday.com/maxwell-american-maglev-team-up-for-trimet-braking-project-091256/
Concept of LIM (Linear Induction Motor) and its application

- A brief description of the linear induction motor is mentioned in the following slides. The characteristics and behavior of the LIM during operation are analyzed.

- The relationship between various parameters like braking force, attractive force, phase current, voltage to frequency ratio etc are mentioned and plotted against each other.
Regenerative Braking System

Reference: Southern, Network Rail and Bombardier (2013) Making regenerative braking a reality on the third rail network

Motor is used as a generator, braking the axle, and converting the train’s Kinetic Energy to Electrical Energy. The generated power is smoothed and conditioned by the train control system. The smoothed and conditioned power is returned to the outside world.
A linear induction motor (LIM) is an AC asynchronous linear motor that works by the same general principles as other induction motors but is very typically designed to directly produce motion in a straight line. Its practical uses include magnetic levitation, linear propulsion, and:

- LIMs are often used where contactless force is required,
- Low maintenance is desirable,
- The duty cycle is low.

Reference: http://en.wikipedia.org/wiki/Linear_induction_motor#cite_ref-force_8-1
Concept of LIM (Linear Induction Motor) and its application

The linear induction motor (LIM) allows the displacement of a load in a longitudinal direction without gears, pulleys, or other mechanical mean.

The main parts of a LIM are defined as:

• Primary: it contains the phase windings and receives the energy supply.

• Secondary: made by laminated iron and short-circuited conducting bars, similar to a squirrel cage rotor.
Linear Induction Motor (LIM); Equivalent Circuit

\[ T_2 = \frac{L_m + L_2}{R_2} \]

\[ T_v = \frac{D}{v} \]

\[ Q = \frac{T_v}{T_2} = \frac{DR_2}{v(L_m + L_2)} \]

\begin{tabular}{|l|l|}
  \hline
  \textit{D} = & primary length \\
  \hline
  \textit{v} = & motor speed \\
  \hline
  \textit{R}_2 = & secondary resistance \\
  \hline
  \textit{L}_2 = & magnetizing inductance \\
  \hline
  \textit{L}_m = & secondary magnetizing \\
  \hline
\end{tabular}

Reference: Roberto André Henrique de Oliveira, Richard Magdalena Stephan (unknown year) Energy Regeneration in a Magnetically Levitated Vehicle for Urban Transportation; Federal University of Rio de Janeiro
Linear Induction Motor (LIM); Equivalent Circuit

- The LIM develops a force ($F_X$) in longitudinal direction responsible for the movement. The electromagnetic traction power developed by the motor is given by the equivalent circuit and is $P_m$

$$P_m = \frac{3I_2^2R_2\omega_1}{\omega_2}$$

Reference: Roberto André Henrique de Oliveira, Richard Magdalena Stephan (unknown) Energy Regeneration in a Magnetically Levitated Vehicle for Urban Transportation; Federal University of Rio de Janeiro
Regenerative Braking Characteristics of Linear induction Motor (LIM) for Maglev

This is one of the papers in which regenerative braking characteristics of linear induction motor (LIM) for Maglev system is mentioned.

In the case of LIM of maglev train, efficiency of maglev train falls because regenerative braking is performed until 20km/h and then plug braking is performed until 5km/h about shortage of braking.

In one of the analysis graph X, regenerative braking force, normal force, voltage, current is plotted against various ranges of speed (110 km/h to 20km/h) and frequency of operation.

Regenerative Braking Characteristics of Linear induction Motor (LIM) for Maglev

In another analysis graph Y, trolley power and trolley current is plotted against various ranges of speed (110 km/h to 20 km/h) and frequency of operation. It is to be noted that reduction of attractive force can affect the magnetic levitation load during regenerative braking.

The braking performances are analyzed using the finite element method in this paper. The finite element method is used to calculate the various parameters like braking force, attractive force, phase current, voltage to frequency patterns and its magnetic fields of braking linear induction motor.

Characteristic Curves of LIM

Reference: http://en.wikipedia.org/wiki/Linear_induction_motor#cite_ref-force_8-1
Characteristic Curves of LIM

Figure X

Braking force
Current
Normal force
Voltage

Characteristics Curves of LIM

In the preceding slides, a brief description of the linear induction motor is mentioned. The characteristics and behavior of the LIM during operation are analyzed. The relationship between various parameters like braking force, attractive force, phase current, voltage to frequency ratio etc. are mentioned and plotted against each other.

The raw RBS data (if available) can be transformed to proposed MTA-NYCT Maglev RBS using its various characteristics. These information can be used for technical feasibility analysis of proposed MTA-NYCT Maglev RBS system. (Details will follow in subsequent slides).

Feasibility Study of On-Car Regenerative Braking System (RBS) for Electric Rail Applications

1. Dayton T Brown (DTB),
2. ElectroMotive Designs (EMD)
3. KLD Labs (KLD)

researched the feasibility of on-car regenerative braking energy storage for the New York City MTA subway system.
Feasibility Study of On-Car Regenerative Braking System (RBS) for Electric Rail Applications

This study involved the characterization of three energy storage devices and the simulation of their use in a subway car as storage for regenerative braking energy.

1. A high power Lithium Ion cell,
2. An Electric Double Layer Capacitor (EDLC or ultracapacitor) and
3. A Nickel Capacitor (NiCap).
Feasibility Study of On-Car Regenerative Braking System (RBS) for Electric Rail Applications

- MTA-NYCT purchased 2500 Rail cars with RBS capabilities since 1999.
- AC propulsion (AC trains)

According to this paper, a single car decelerating from 50MPH will produce 2.4kWH. A 10-car train will produce approximately 24kWh

Feasibility Study of On-Car Regenerative Braking System (RBS) for Electric Rail Applications

This study determined that the implementation of an on-board ESS comprised of EDLC ultracapacitors (or Lithium Ion batteries) could increase the recoverable regenerative energy to approximately 75% of the full amount available. The simulation results indicate that purely from the perspective of energy density, the Lithium Ion cell is clearly superior.

Additional benefits of an on-car ESS solution include:

- Storage and use of regenerative energy enroute. Performance not limited to stations. Results in increased savings.

- Utilization of regenerative energy for partial acceleration/deceleration events. Results in increased savings.
Hypothesis

• Collecting the technical information, experts opinion and survey from EMS Maglev system with RBS from Linimo Japan, EMS Maglev system with RBS from UTM-02 South Korea, EMS Maglev system with RBS from China or equivalent system.

• Through subjective probability, above collected technical information, experts opinion and survey can be transformed to MTA-NYCT using its various characteristics. These information can be used for technical feasibility analysis of proposed MTA-NYCT Maglev RBS system.
Research Methodology

- Analysis of MTA-NYCT Maglev RBS, Concept of Energy/Power Management
- Methods to analyze energy/power management of MTA-NYCT Maglev RBS with respect to Figure Z and further analysis
- Concept of stochastic queuing theory in proposed MTA-NYCT Maglev RBS
- Concept of Monte Carlo Simulation in proposed MTA-NYCT Maglev RBS
- Data for Proposed MTA-NYCT Maglev RBS
Analysis of MTA-NYCT Maglev RBS Concept of Energy/Power Management (Figure- A)

Acceleration Zone = O-A-C.

Constant Speed Zone = A-B-D-C

Deceleration Zone = B-D-E
Analysis of MTA-NYCT Maglev RBS Concept of Energy/Power Management

• $X =$ AC Power required from grid by an accelerating maglev vehicle
• $A =$ Acceleration of a Maglev Vehicle a given point of time.
• $M =$ No of units of Maglev vehicles accelerating at a given point of time.
• $Y =$ AC Power delivered back to grid by an decelerating maglev vehicle
• $D =$ Deceleration of a Maglev Vehicle a given point of time.
• $N =$ No of units of Maglev vehicles decelerating at a given point of time.
• $Z =$ AC Power loss in System

The following are functions for above conditions
• Function $F1( M, A, \ldots) =$ Power Requirement Function $= X$
• Function $F1( N, D, \ldots) =$ Power Generation Function $= Y$
• Net power requirement Function $= [\text{Power Requirement Function} - \text{Power Generation Function}] + \text{Power Loss in System}$ $= ( X - Y + Z )$

Note: MTA-NYCT Third rail 600V DC Supply is converted to AC supply through alternators and or suitable conversion devices.
Analysis of MTA-NYCT Maglev RBS
Concept of Energy/Power Management (Figure-Z)
Analysis of MTA-NYCT Maglev RBS
Concept of Energy/Power Management
(Figure-Z)

1. Deterministic approach
2. Stochastic approach
Methods to analyze energy/power management of MTA-NYCT Maglev RBS wrt Figure-Z and further analysis

Experimental Method:
This method includes a Maglev test train with regenerative braking feature on a test track. The Maglev train is accelerated / decelerated on a test track and corresponding energy/power consumed/generated (in terms of measurable parameters) is recorded to draw the Figure-Z. Using this developed Figure-Z, further analysis of MTA-NYCT Maglev RBS can be done.
Methods to analyze energy/power management of MTA-NYCT Maglev RBS wrt Figure-Z and further analysis

Analytical Method using raw RBS data of Japan and or South Korea and or China EMS Maglev system with RBS.

• This method is the basis of analytical thesis. This is based on the use of RBS raw data expected from Japan and or South Korea and or China EMS Maglev system with RBS.

• It is proposed to get the data for defined Figures X, Y from Authors of paper. After analyzing the Figures X and Y with above mentioned data, Proposed MTA-NYCT Maglev regenerative system data can be calculated using suitable conversion factors. Using these data, A Sketch Z is plotted using acceleration/deceleration & corresponding energy consumed/generated data.

Methods to analyze energy/power management of MTA-NYCT Maglev RBS wrt Figure- Z and further analysis

Analytical Method using raw RBS data of Japan and or South Korea and or China EMS Maglev system with RBS. (Contd.)

- Similar steps will be followed after getting RBS raw data from Japan (example-Linimo, EMS Maglev system with RBS), China (EMS Maglev system with RBS) in development of the proposed analysis of MTA-NYCT Maglev RBS.

- Collecting the technical information, experts opinion and survey from EMS Maglev system with RBS from Linimo Japan, EMS Maglev system with RBS from UTM-02 South Korea, EMS Maglev system with RBS from China or equivalent system.

- Through subjective probability, above collected technical information, experts opinion and survey can be transformed to MTA-NYCT using its various characteristics. These information can be used for technical feasibility analysis of proposed MTA-NYCT Maglev RBS.
Methods to analyze energy/power management of MTA-NYCT Maglev RBS wrt Figure-Z and further analysis

Analytical Method: Energy/Power equations developed using basic laws of Magnetic levitation (no raw RBS data is available)

The basic laws of Magnetic levitation are

- Earnshaw’s theorem
- Faraday’s law of electro-magnetic induction
- Lenz’s law
- Maxwell’s law
- Maxwell-Faraday’s law as mentioned previously.

Using the developed Energy and Power equations, a Figure-Z can be plotted using acceleration or deceleration data on the horizontal axis and corresponding energy/power consumed or generated data on the vertical axis. Using this Figure-Z, further analysis of MTA-NYCT Maglev RBS can be done.
Concept of Queuing theory in proposed MTA-NYCT Maglev RBS

- It is the mathematical study of waiting lines & is useful to define modern information technologies require innovations that are based on modeling, analyzing, designing to deals as well as the procedure of traffic control of daily life of human.

- It studies queuing systems by formulating mathematical models of their operation and then using these models to derive measures of performance.

- This analysis provides fundamental information for successfully designing queuing systems. Stochastic Processes are systems of events in which the times between events are random variables.

Source: QUEUEING THEORY APPROACH WITH QUEUEING MODEL: A STUDY, by Ajay Kumar Sharma1, Dr. Rajiv Kumar2 ,Dr. Girish Kumar Sharma3
Concept of Queuing theory in proposed MTA-NYCT Maglev RBS

- Queuing theory can be used in expressing the traffic management of proposed maglev system in MTA-NYCT.

- Queuing theory will be based on various planning, policies and assumptions of MTA-NYCT system.

- This will include following factors like gap between consecutive Maglev train services, reliability of Maglev operated train services, expected passenger load for peak hours or for non peak hours, power requirement of Maglev system per day during peak hours as well as during non peak hours.

- In this proposed feasibility analysis, mass transit is a system, riders are the customers, MTA-NYCT is the server.
Concept of Queuing theory in proposed MTA-NYCT Maglev RBS

- When the ratio of \( (\mu/\lambda) \) approaches one, actual system becomes unstable and it is assumed that both input process follow poisson distribution. Here \( \mu \) and \( \lambda \) are mean service rate for the overall system and mean arrival rate (number of calling units per unit of time) respectively.

- Normally two types of queuing models are used. In the first type of queuing model, it is assumed that infinite unit population is served, whereas as in the second type of queuing model, it is assumed that finite unit population is served.
Concept of Queuing theory in proposed MTA-NYCT Maglev RBS

- These two above mentioned queuing models are based on the assumptions that the arrival rates and service rates are stochastic variables that follow specific probability distributions.
- The proposed model will have characteristics of Stochastic modeling.
- The Probability of certain no. of units $n$ in the Queue is given by

$$P(X_t = n) = \frac{e^{-\lambda t} \lambda^n}{n!} \quad n = 0, 1, 2, 3$$

Where $X_t =$ number of occurrences in time interval $t$, $n =$ number of arrivals, $t =$ size of the time interval, $\lambda =$ mean arrival rate (number of calling units per unit of time)
Monte Carlo Simulation

• The treatment of simulation will be limited to numerical simulations. A static simulation represents a system at any particular point in time. This type of simulation is often referred to as a Monte Carlo simulation.

• Palisade’s @Risk software package will be used for simulation of proposed data of MTA-NYCT system.

• @RISK uses the technique of Monte Carlo simulation for risk analysis.

• With this technique, uncertain input values in spreadsheet are specified as probability distributions.
Monte Carlo Simulation

• Monte Carlo simulation is a computerized mathematical technique that allows people to account for risk in quantitative analysis and decision making.
• Monte Carlo simulation furnishes the decision-maker with a range of possible outcomes and the probabilities they will occur for any choice of action.
• Monte Carlo Methods provide approximate solution to a variety of mathematical problems by performing statistical sampling experiments.
Monte Carlo Simulation

• The Monte Carlo Simulation through palisade @Risk software will be used as analytical method for analysis of proposed MTA-NYCT Maglev RBS data.
Proposed MTA-NYCT Maglev  RBS

<table>
<thead>
<tr>
<th>Propulsion System</th>
<th>LIM (Linear Induction Motor)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levitation System</td>
<td>EMS (Electromagnetic Suspension)</td>
</tr>
<tr>
<td></td>
<td>System</td>
</tr>
<tr>
<td>Brake System</td>
<td>RBS (Regenerative Braking System)</td>
</tr>
</tbody>
</table>
Data for proposed MTA-NYCT Maglev regenerative braking system (RBS)

- At present, EMS system is more commercialized compared to EDS system.

- There are only three countries (Japan, China and South Korea) in the world where Maglev regenerative braking system is operative as sub-system of Maglev EMS system.

- The efforts have been made to contact the concerned officials of
  a. Japan (example- Linimo-Maglev EMS type with RBS),
  b. South Korea (example -UTM 02- Maglev EMS type with RBS)
  c. China (Maglev EMS type with RBS)
to obtain the RBS raw data which will be used in development of the proposed MTA-NYCT Maglev RBS.
Data for proposed MTA-NYCT Maglev regenerative braking system (RBS)

- The efforts have been made to contact the concerned officials of 1Dayton T Brown, Inc., and Keith Cummings who did 1feasibility study of on-car regenerative braking system (RBS) for electric rail, applications to get RBS raw data. This is requirement for the optional research objective.

- No response received so far inspite of repetitive reminders from
  a. Japanese, Chinese and South Korean Maglev officials regarding supply of RBS raw data.
  b. 1Dayton T Brown, Inc., and Keith Cummings regarding supply of RBS raw data.
Alternate Option if?

- Options in case no raw RBS data is received from above three countries (Japan, China and South Korea) where Maglev RBS is operative as sub-system of Maglev EMS system.

- There may be various laboratories in USA and abroad where experiments are done on EMS/EDS system with RBS. Efforts will be made to collect data from these institutions.

- Through subjective probability, above collected technical information, experts opinion and survey can be transformed to MTA-NYCT using its various characteristics. These information can be used for technical feasibility analysis of proposed MTA-NYCT Maglev RBS.
Research Expectation

1. Show the world that RBS can bring enormous saving and various advantages which is not utilized by most of the transportation systems of the world at this point.

2. The various advantages of Maglev system with RBS shows that Maglev should be implemented in MTA-NYCT system along with RBS.

3. Proposed MTA-NYCT Maglev RBS should be more energy efficient as well as economical to the current MTA-NYCT system and on-car RBS for electric rail.

4. Joint effort by railroad companies in implementation of Maglev system with RBS.

5. Availability of Raw RBS data for success of this analytical thesis.
Optional Research Objectives

1. Economical feasibility study of implementation of Maglev regenerative braking system to MTA-NYCT.

2. Comparison of proposed MTA-NYCT Maglev regenerative braking system (RBS) with MTA-NYCT on-car regenerative braking system (RBS) for electric rail.
## Dissertation Schedule

<table>
<thead>
<tr>
<th>Period</th>
<th>2007</th>
<th>2007-2010</th>
<th>2011-2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Milestone</td>
<td>Admitted to PhD Program</td>
<td>Course work &amp; Qualifying Exam</td>
<td>Multiple Preliminary Proposals</td>
</tr>
<tr>
<td>Period</td>
<td>2014</td>
<td>2014/2015</td>
<td>2015/16</td>
</tr>
</tbody>
</table>
Thank You

Questions?