# *Decision Analysis for Toxic by Inhalation Material Routing*


George Mason University OR-680/SYST-798 Dr. Laskey

Railroad Team

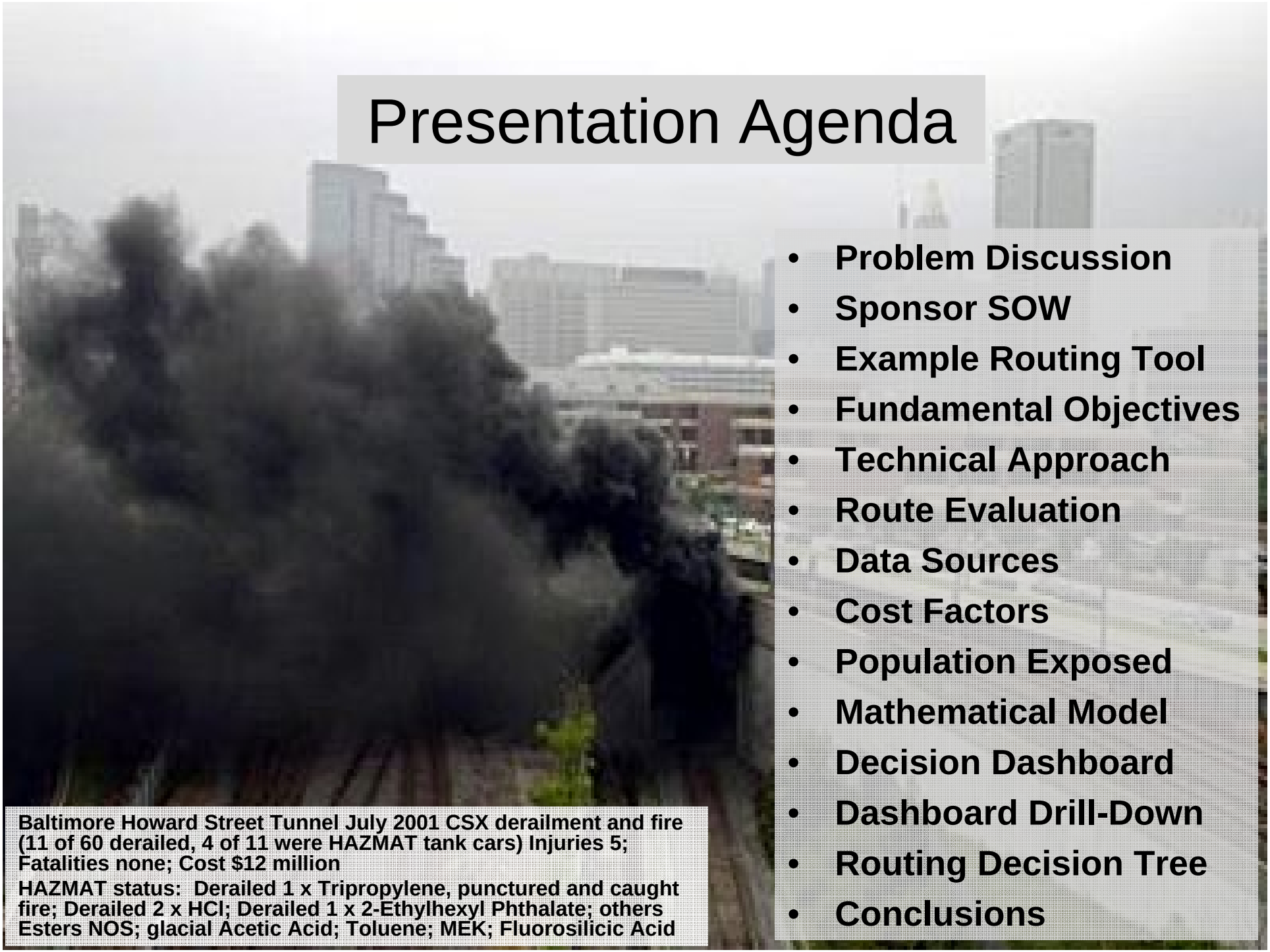
Matthew Albin; Ruben Luna; Danielle Martin
Danielle Obuchon; Andrew Ramsay

Sponsors

Dr. Duminda Wijesekera, George Mason University
Mr. Mark Hartong, Federal Railway Administration
Dr. Rajni Goel, Howard University

# Presentation Agenda

- Problem Discussion
- Sponsor SOW
- Example Routing Tool
- Fundamental Objectives
- Technical Approach
- Route Evaluation
- Data Sources
- Cost Factors
- Population Exposed
- Mathematical Model
- Decision Dashboard
- Dashboard Drill-Down
- Routing Decision Tree
- Conclusions



**Baltimore Howard Street Tunnel July 2001 CSX derailment and fire (11 of 60 derailed, 4 of 11 were HAZMAT tank cars) Injuries 5; Fatalities none; Cost $12 million**

**HAZMAT status: Derailed 1 x Tripropylene, punctured and caught fire; Derailed 2 x HCl; Derailed 1 x 2-Ethylhexyl Phthalate; others Esters NOS; glacial Acetic Acid; Toluene; MEK; Fluorosilicic Acid**

# TIH RR Transport Problem

- TIH materials routinely transported by rail through highly populated areas – potential hazards due to terrorism and accidents

- Uncontrolled release of toxic gases and liquids can create risks with severe consequences
  - Risk is the product of event probability and its consequence
  - $NH_3$ $Cl_2$ $SO_2$ HF $HNO_3$ and $H_2SO_4$ are of most concern

- TIH releases can cause deaths, injuries, and property damage; for example, release of one 90-ton tank car near the center of DC could create a 14 x 4 mile plume immediately dangerous to life or health

# TIH RR Transport Problem (Concluded)

- US/DOT and RR industry implementing risk-based transport planning analyses with alternate routing (mandatory in 18 months)
  - Plan timeframe is in part a function of threat and RR operational factors; possibly days to weeks
  - What is an optimal route at an HSL with estimated attack probabilities?

- Tools are being built to automate risk analyses, but as of yet there are no easy-to-use tools for RR managers providing operationally useful interpretations of complex routing solutions
  - Cost factors pertaining to routes not considered
  - Twenty-seven variables complicates understanding results

- Current prototypes in toolbox
  - Transportation Routing Analysis Geographic Information System (TRAGIS)
  - Rail Routing and Visualization Application (RRVA)

# Problem Statement

- Provide capabilities to enable decision-makers to be better informed about TIH RR route selection while helping to minimize risk. Key aspects are comparisons of alternatives, cost trade-offs, and simplification of results.

- Use an operationally relevant scenario in development of proposed solutions
  - Of the TIH routes possible between Alexandria VA (metropolitan DC area) and Philadelphia, which is the least risk route that is economically viable?

# Sponsor Statement of Work

- Develop decision support algorithm to support risk-based planning for TIH transport
- Incorporate cost penalties for re-routing
- Incorporate security risk (threat) related factors
- Simplify evaluation of TIH transport risk
  - Data requirements, availability, and management
  - Analysis time and reporting
- Provide algorithm implementation options
- Utilize TRAGIS and RRVA for initial route model

# Replacement Slide for Screen Capture of RRVA Client Homepage

Refer to Offline Graphic

# Replacement Slide for Screen Capture Showing Example RRVA Route Outputs

Refer to Offline Graphic

# Replacement Slide for Screen Capture of RRVA Potential Routes

Refer to Offline Graphic

# Operational Concept

***Objective: To minimize TIH trains en-route security risk (intentional attacks)***

***Railroad Traffic Managers***

***Manage Risk (Select Route)***

*Security Plan*
*(Routing Alternatives)*

*Warnings and Threat levels*

***Regulate (Efficiency,Safety)***

***Protect Homeland (Security)***

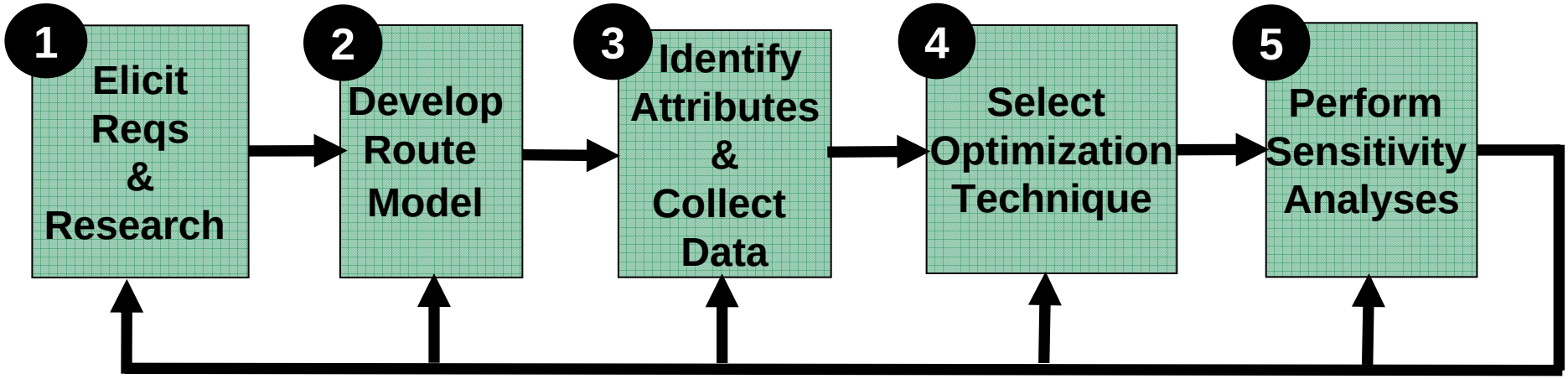
*Safety and security regulations*

*Intelligence assessments and Security*

***Federal Regulators***

***Homeland Security DHS / TSA***

# Technical Approach




**Step 1**

✓ Define project scope, problem statement and deliverables

**Step 2**

✓ Develop problem via decision analysis and risk modeling

**Step 3**

✓ Select relevant data set

**Step 4**

✓ Implement model to define analytic solution

**Step 5**

✓ Conduct successive iterations in decision analysis cycle

✓ Analyze decision model and results

# Route Evaluation

- Cost functions provide a way to evaluate routes based on risk
    - Probability of attack
    - Consequences of attack
    - ***Risk = (Probabilities) X (Consequences)***

- Risk calculations show expected costs per route segment
- Optimal route is selected in terms of optimal *risk costs*
    - Cost to haul TIH
    - Cost of life
    - Cost of injury
    - Cost of remediation
- A train routing decision model:
    - Structures and defines values and objectives for risk algorithm
    - Provides a logical framework for decision elements

# Fundamental Objectives

**Minimize**
**TIH Train En-Route Risk**

**Minimize Probability**

- **Minimize shipments**
  - *Tons TIH / Train*

**Minimize Vulnerability**

- **Maximize Safety**
  - *Track infrastructure (derailment chance)*
  - *Tank survivability*
- **Maximize Security**
  - *TIH car dwell time*

*Include TSA threats*

**Minimize Consequences**

- **Minimize Public Damage**
  - *Loss of life*
  - *Injuries*
- **Minimize Cost**
  - *Transportation*

*Not included in this project*

*Included in this project*




# Data Sources

- Railroad Routing Visualization and Analysis (RRVA) Data
  - Possible routes between origin and destination points
  - Route segments
  - Railroad carriers
  - Length of segments in miles

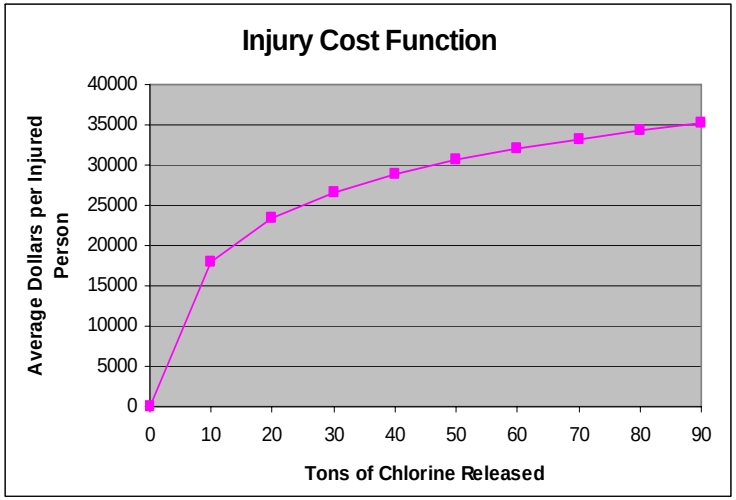
- 2000 US Census Data
  - Determine county/city of each route segment
  - Map average population density for 1 sq mile from the census data to RRVA segments

# Cost Factors Explained

- **Cost per Chlorine Car / Mile:**

| Rail Company | | Commodity | Shipping Cost per Car/Mile |
|---|---|---|---|
| Canadian Pacific Railway | CPR | Chlorine | $21.37 |
| Conrail (handled by CSX and Norfolk Southern) | CN | Chlorine | assume rate of joint carrier on route |
| CSX Transportation, Inc. | CSXT | Chlorine | $17.98 |
| Norfolk Southern Combined R.R. Subs. | NS | Chlorine | $24.77 |

- **Cost per Injury:**




- **Cleanup and Remediation Costs:**

Worst U.S. $Cl_2$ accident in 2005 at Graniteville SC released 60 tons

5,400 residents evacuated two weeks
Initial site clean-up $3.5M to $4M
Further remediation $6.1M
Follow-on damage claims ranged from $110M to $450M
DOJ seeking civil penalties

**Linear function used** $44k per ton

- **Cost of Lives:**
  - The US EPA calculates the value of a human life to $3.7 million per person (2003)

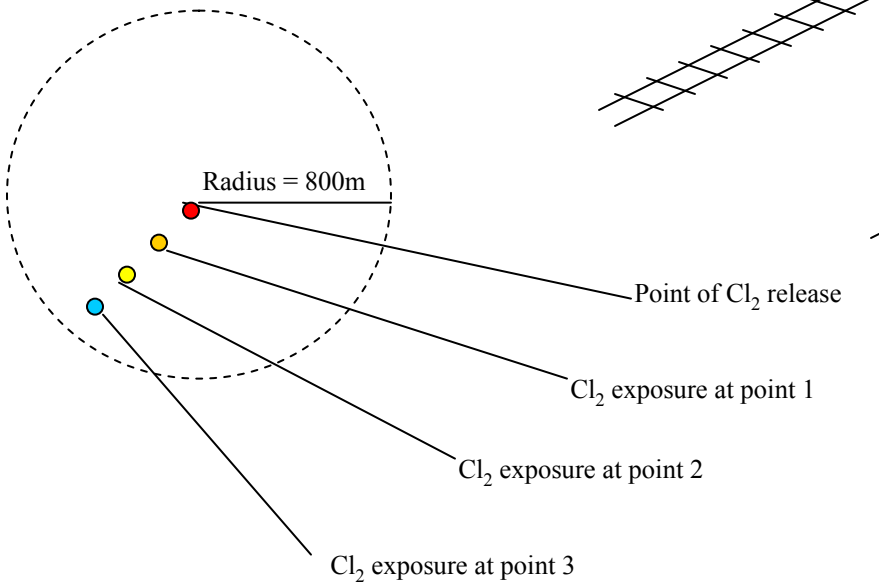
# Population Exposed (Deaths and Injuries)

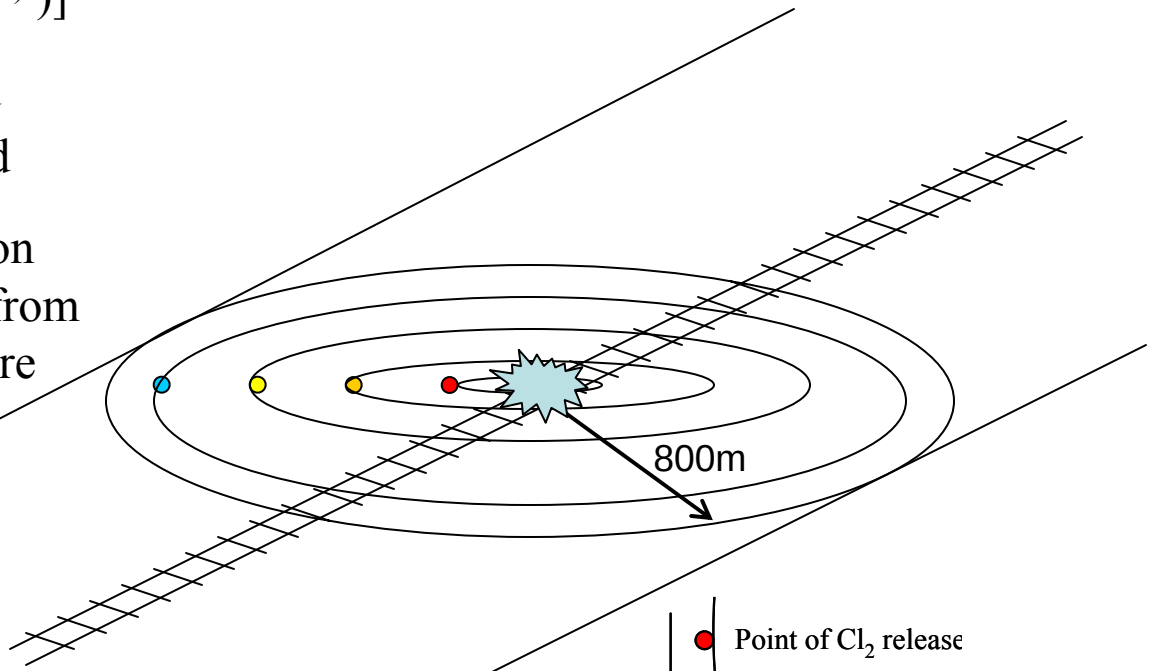
$P(K/R) = [1/(1+e^{-((LDOES - \mu)/\sigma)})]$

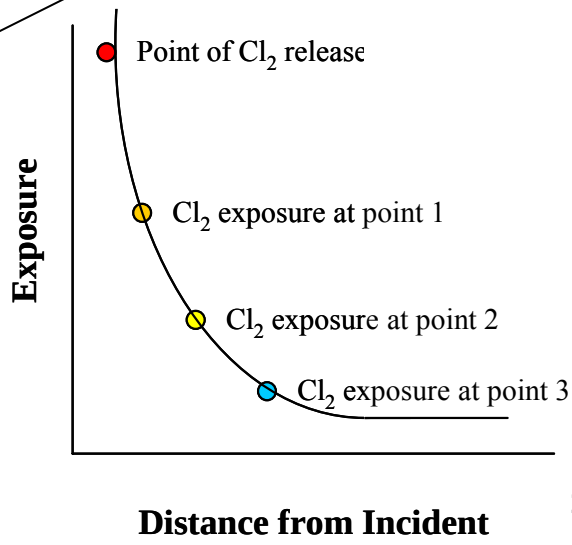
$\#killed = P(K/R) * pop_{exposed}$

$\#injured = pop_{exposed} - \#killed$

Negative exponential function used to show as one moves from the release point, the exposure one receives decreases.



# The Mathematical Model

$$\text{Risk Cost}_{route} = \sum_{\text{all segments}} \Big[ \text{cost}_{\text{car-mile}} * \#\text{cars} * \text{distance} + P(attack) * P(attack\ occurs\ on\ segment \mid attack) * \big[ \#\text{killed} * \text{cost}_{lives}(\#\text{killed}) + \#\text{injured} * \text{cost}_{injury}(\text{volume}_{released}) + \text{volume}_{released} * \text{cost}_{remediation}(\text{volume}_{released}) \big] \Big]$$

- Four variables determine risk cost of route:
  1. Haul cost
  2. #killed
  3. #injured
  4. Remediation

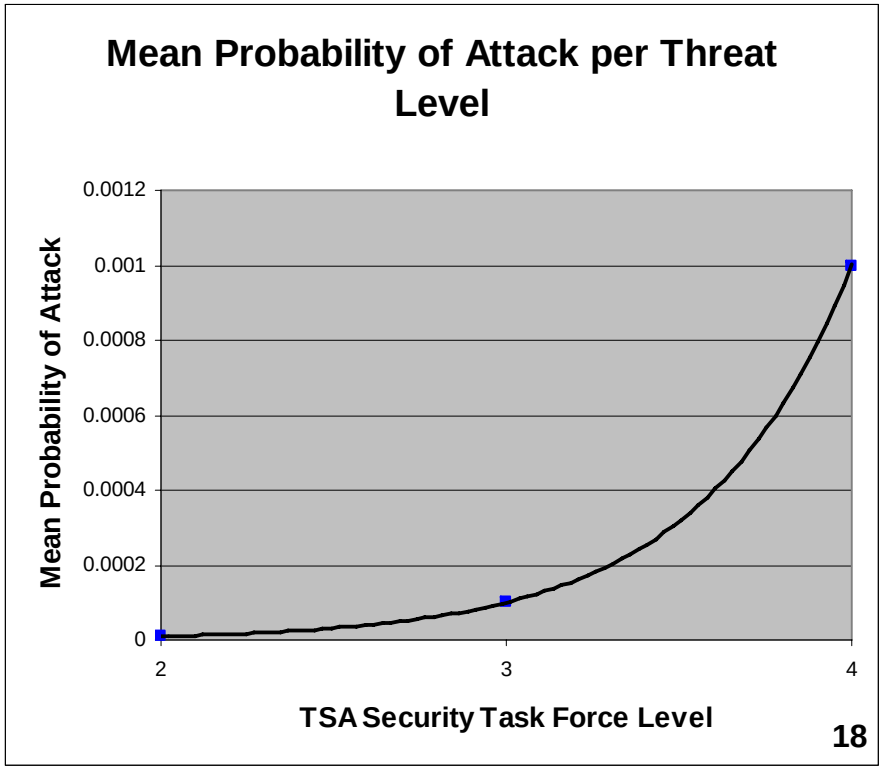
# Probability of Attack (P(attack))

TSA Railroad Security Task Force Provides Four Threat Levels

- Level 4 (Maps to HSL Red)
  - Confirmed threat of attack against RR industry or actual attack in US
  - Implemented up to 72 hours
- Level 3 (Maps to HSL Orange)
  - Credible threat to US or RR industry
  - Reevaluated every 1-2 months
- Level 2 (Maps to HSL Yellow)
  - Reevaluated every several months to years
- Level 1 (Maps to HSL Green)
  - Reevaluated every several months to years

Nominal values selected
Typically a decision-maker/intelligence function

| | TSA Security Task Force Level | | |
|---|---|---|---|
| **P(attack)** | **4** | **3** | **2** |
| **95th %ile** | 0.01 | 0.001 | 0.0001 |
| **mean** | 0.001 | 0.0001 | 0.00001 |
| **5th %ile** | 0.0001 | 0.00001 | 0.000001 |



# Decision-Maker Dashboard

Railroad Security Task Force Level 4 (Red)
Number of Cars: 5

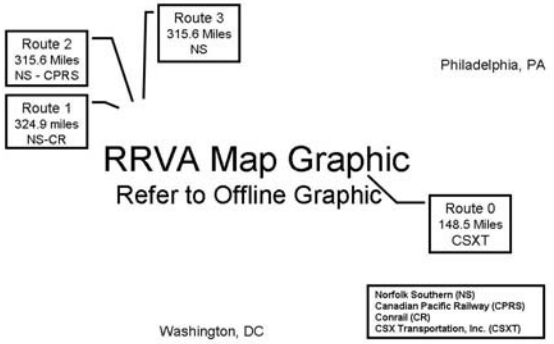
| | Risk Point Estimate | Risk Range | Greatest Contribution to Cost | Avg Fatality if Attack Occurs | Route 3 optimal for cost of life > $228,958; otherwise Route 0 optimal |
|---|---|---|---|---|---|
| Route 3 | $692,497 | ($104,004 - $6,577,422) | Loss of Life | 165 | |
| Route 2 | $770,605 | ($111,792 - $7,358,730) | Loss of Life | 185 | |
| Route 1 | $982,871 | ($134,357 - $9,468,010) | Loss of Life | 238 | |
| Route 0 | $1,100,930 | ($122,157 - $10,888,660) | Loss of Life | 275 | |

Railroad Security Task Force Level 3 (Orange)
Number of Cars: 5

| | Risk Point Estimate | Risk Range | Greatest Contribution to Cost | Avg Fatality if Attack Occurs | Route 3 optimal for cost of life > $2,291,576; otherwise Route 0 optimal |
|---|---|---|---|---|---|
| Route 3 | $104,004 | ($45,155 - $692,497) | Loss of Life | 165 | |
| Route 2 | $111,792 | ($45,911 - $770,605) | Loss of Life | 185 | |
| Route 0 | $122,157 | ($24,280 - $1,100,930) | Loss of Life | 275 | |
| Route 1 | $134,357 | ($49,506 - $982,871) | Loss of Life | 238 | |

Railroad Security Task Force Level 2 (Yellow)
Number of Cars: 5

| | Risk Point Estimate | Risk Range | Greatest Contribution to Cost | Avg Fatality if Attack Occurs | Route 3 optimal for cost of life > $22,915,998; otherwise Route 0 optimal |
|---|---|---|---|---|---|
| Route 0 | $24,280 | ($14,492 - $122,157) | Haul Cost | 275 | |
| Route 3 | $45,155 | ($39,270 - $104,004) | Haul Cost | 165 | |
| Route 2 | $45,911 | ($39,323 - $111,792) | Haul Cost | 185 | |
| Route 1 | $49,506 | ($41,021 - $134,357) | Haul Cost | 238 | |

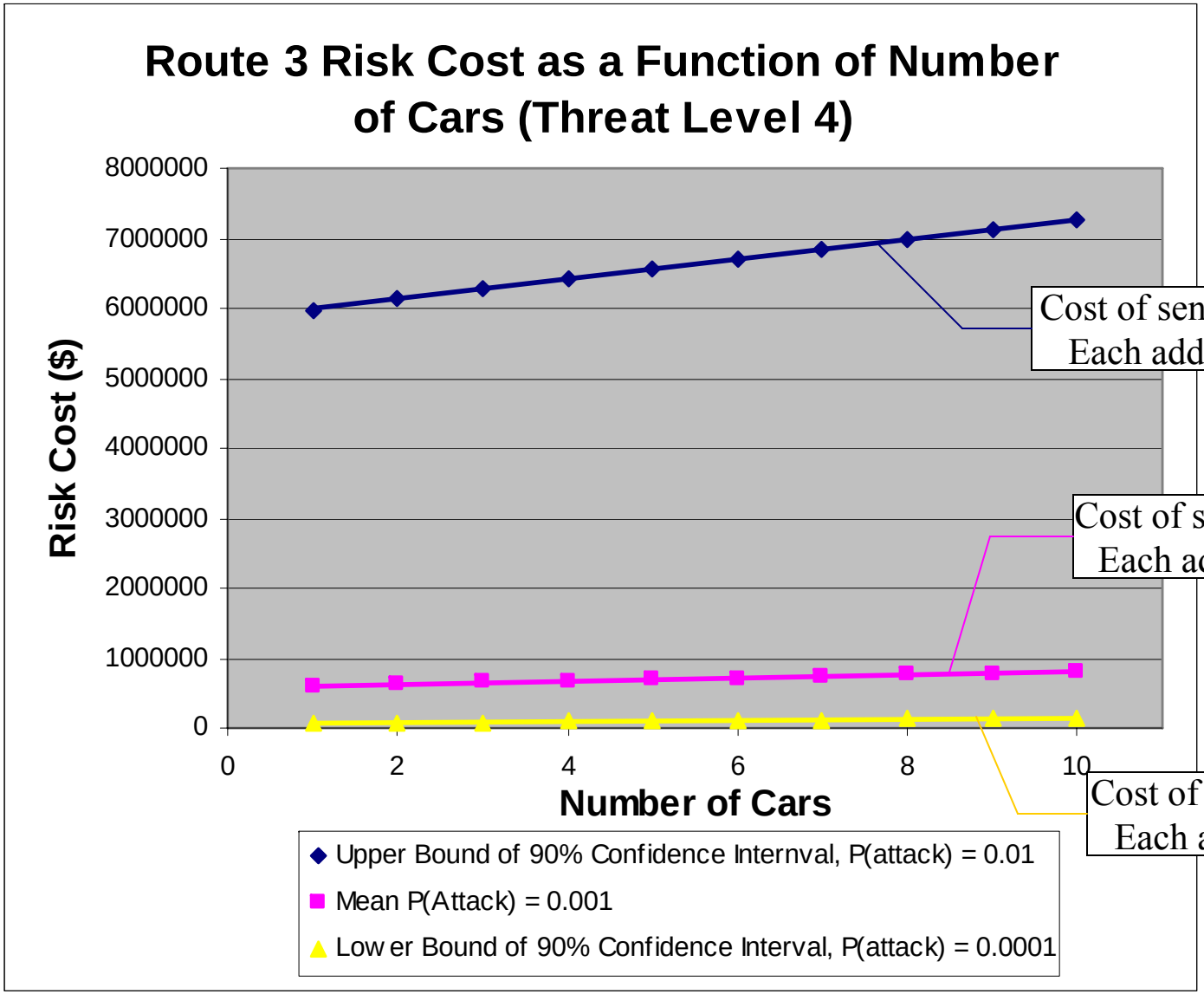



| | Maximum Damage |
|---|---|
| Route 0 | $1,333,696,333 |
| Route 1 | $1,333,723,006 |
| Route 2 | $1,333,721,519 |
| Route 3 | $1,333,721,544 |

Optimal Route

R0 is the baseline route

# Optimum Number of Cars to Ship:
## A Dashboard Drill-Down




Cost of sending 1 car: $5,987,949
Each additional car: $143,463

Cost of sending 1 car: $605,746
Each additional car: $21,297

Cost of sending 1 car: $67,526
Each additional car: $9,081

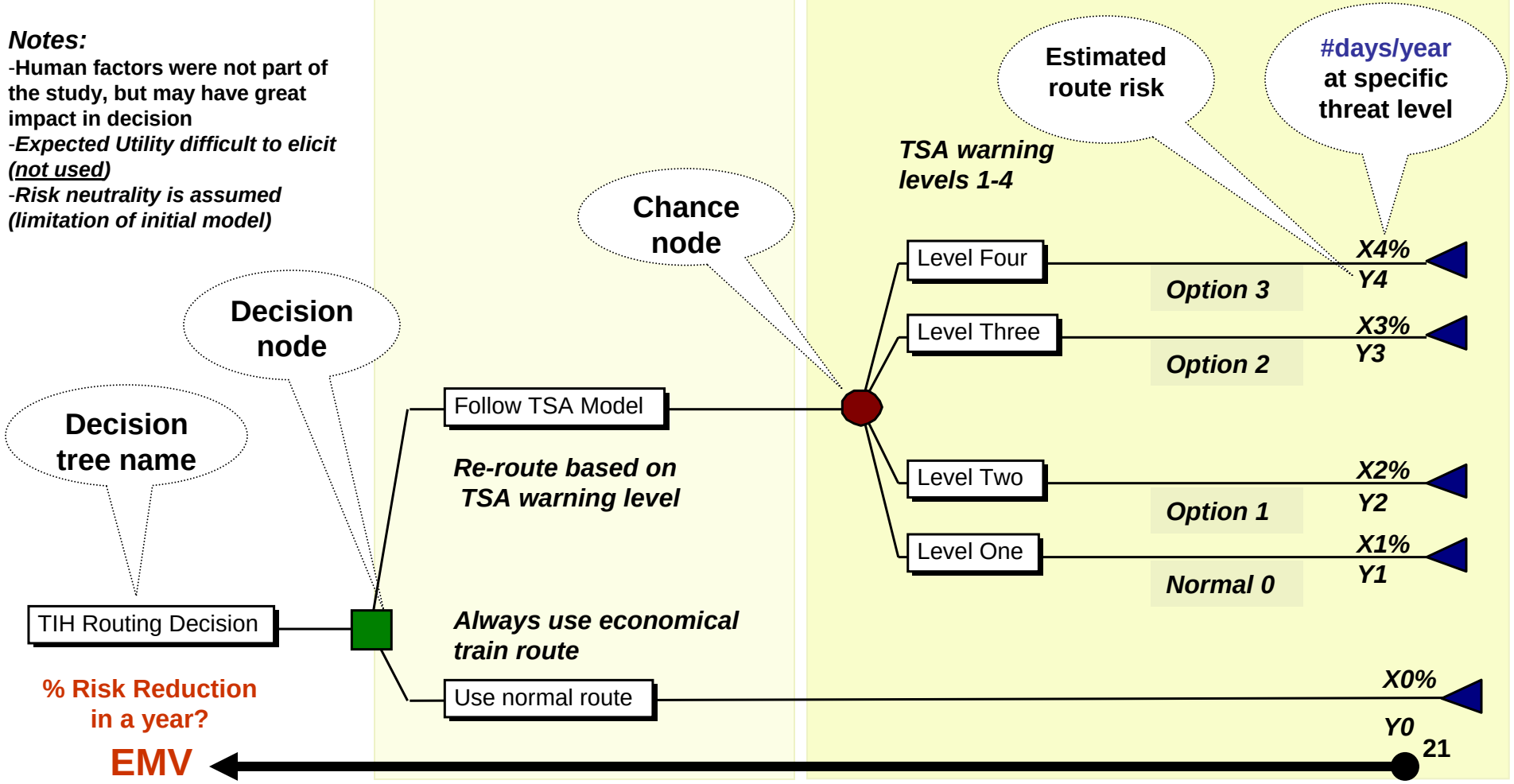
# TIH Train Routing: Decision Tree

-**Expected Monetary Value (EMV)**
- **One year time interval**

***Notes:***
-**Human factors were not part of the study, but may have great impact in decision**
-***Expected Utility difficult to elicit (not used)***
-***Risk neutrality is assumed (limitation of initial model)***

**Decision 1**
**React to threat warnings by re-routing train or do nothing?**

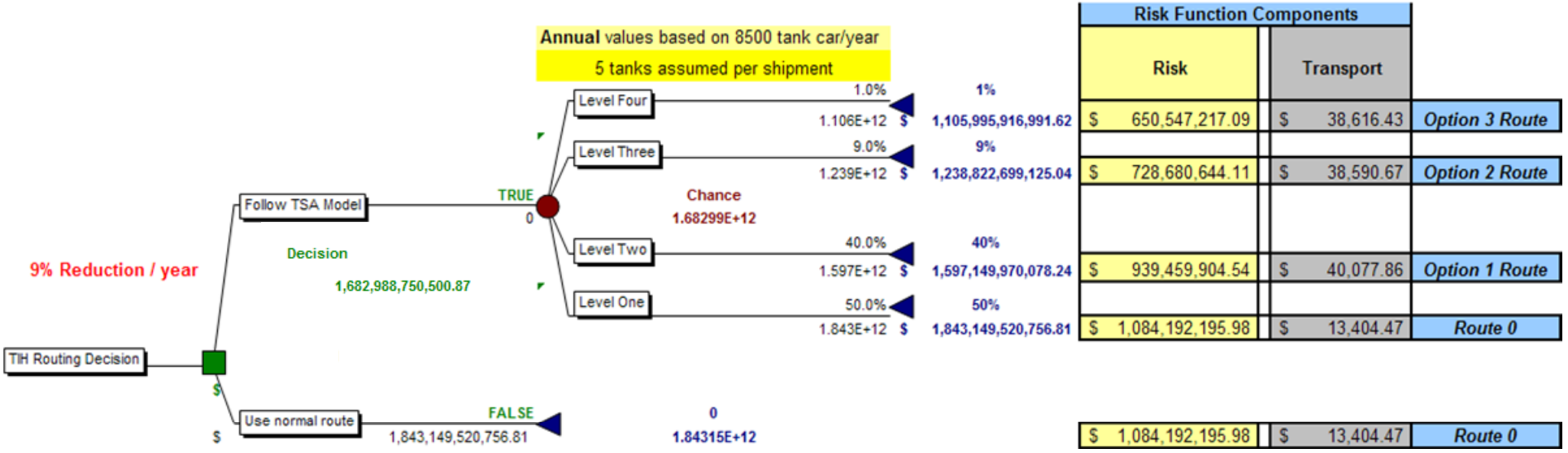
**Decision 2 (Implicit in branch payoff assignments)**
***- As threat increases, select next available train route with longer distance but less exposure to population***



# Decision Tree Framework

**Railroad Security Task Force** (The plan establishes four alert levels and describes progressive series of actions to thwart terrorist threats to railroad personnel and facilities):

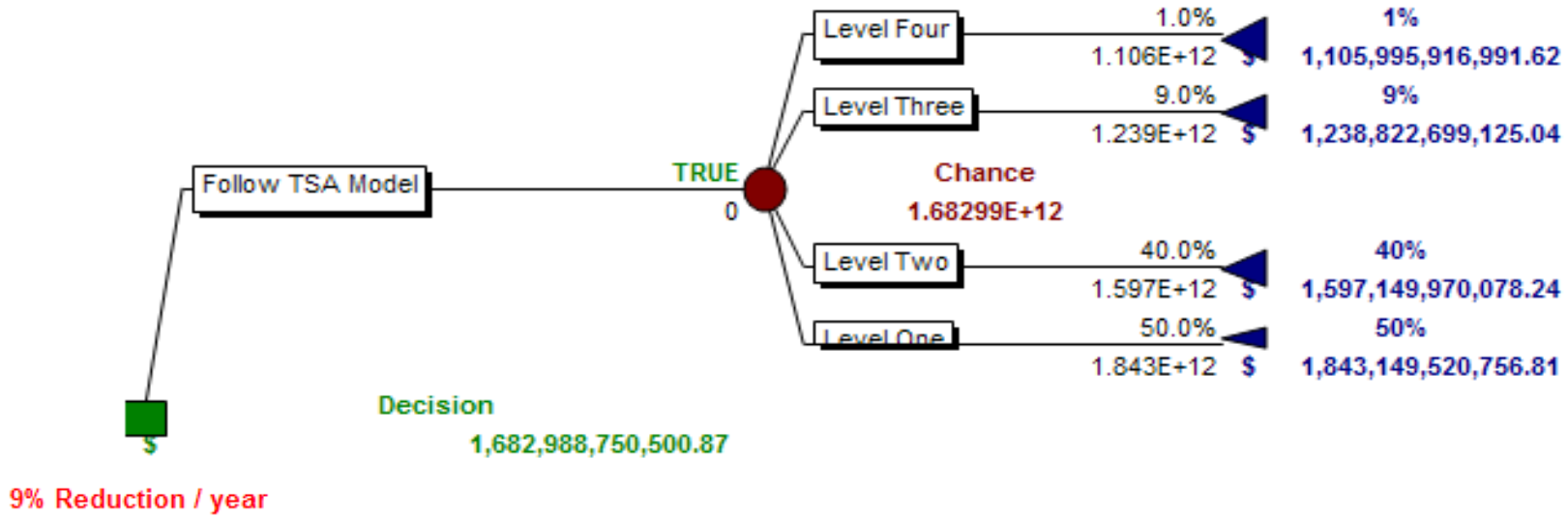
- **Level 4**: A Confirmed Threat of attack against the railroad industry or actual attack in the United States (implemented up to 72hours and reevaluated)
- **Level 3**: A Credible Threat of an attack on the Unites States or the railroad industry
- **Level 2**: Heightened Security Awareness
- **Level 1**: New Normal day-to-day operations




| | Per shipment calculations | | |
|---|---|---|---|
| | Risk | Transport | Distance (miles) |
| *Route 3* | 6.505472E+08 | $38,616.43 | 315.6 |
| *Route 2* | 7.286806E+08 | $38,590.67 | 315.6 |
| *Route 1* | 9.394599E+08 | $40,077.86 | 324.9 |
| *Route 0* | 1.084192E+09 | $13,404.47 | 148.5 |
| | TSA goal: Forced Decreasing Value | Increasing Transporting Cost Concerns | |

# Policy Suggestion

**Results for this case is a 9% security risk reduction (for this specific I&W distribution in a year)**




**Recommendation: Further explore the option of following TSA countermeasure model because this course of action satisfies the RR's objective of reducing TIH train en-route security risk**

# Conclusions

- The results show that a cost-based risk assessment tool can potentially enable decision-makers to be better informed about TIH material transport route selection, while incorporating analysis of costs, alternative routes, and simplification of results.
- Model results show sensitivity of route selection to cost as a risk assessment variable.


Questions?

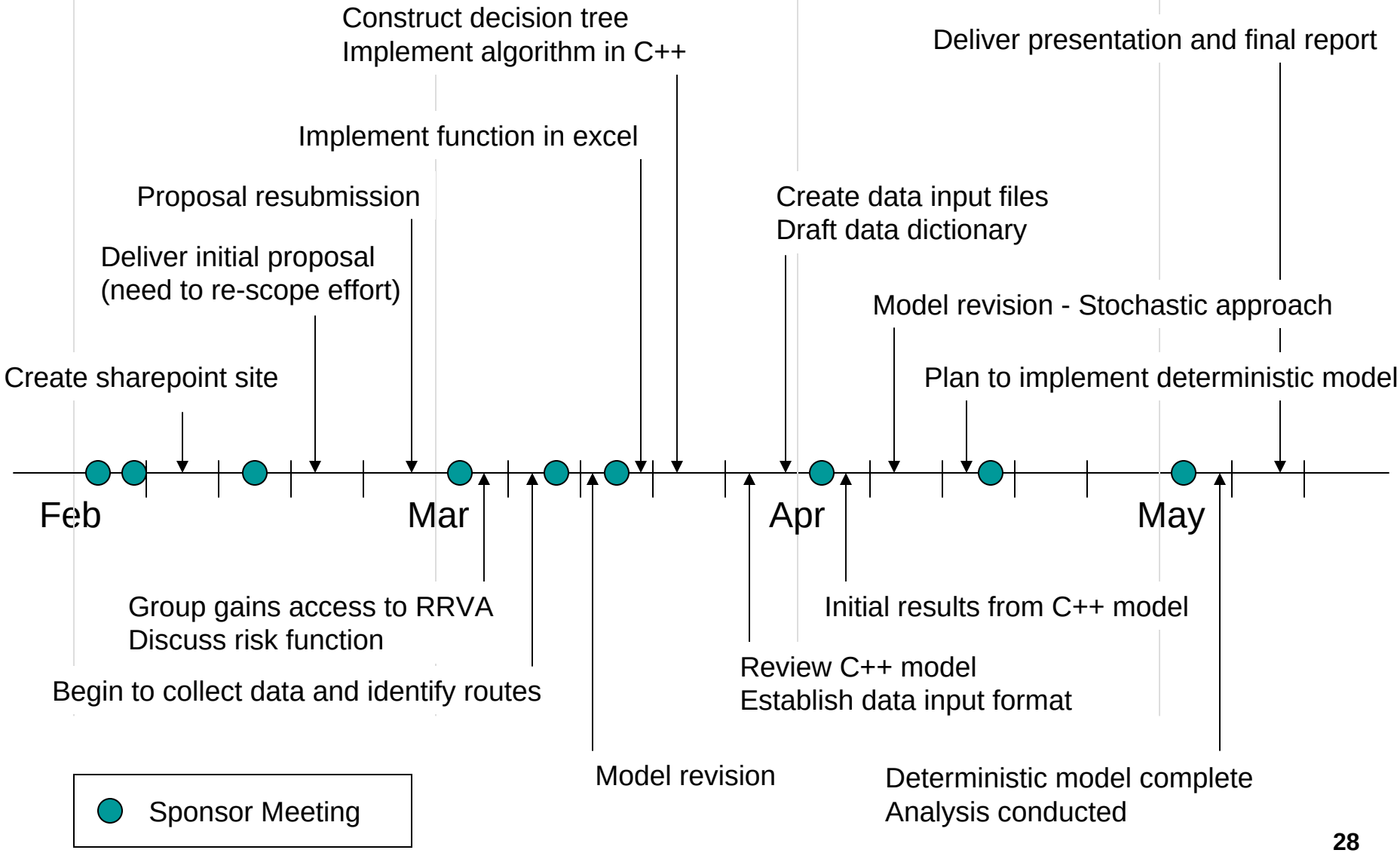
# Backup Vugraphs

# Project Schedule

| Week Complete | TASK | Hours Allocated |
|---|---|---|
| | | |
| all weeks | **Project Management Framework** | 403 |
| | **Initiating** | |
| 1 | Develop Project Scope and Goals | 25 |
| 2 | Define deliverables and expected results | 25 |
| | **Planning** | |
| 3 | Identify constraints & assumptions | 24 |
| 3 | Define Project Components and Stakeholders | 24 |
| 3,4 | Generate Cost/Resource/Tasking | 10 |
| | **Executing** | |
| 3 | Maintain traceability to sponsor requirements | 15 |
| all weeks | Attend internal and sponsor meetings | 35 |
| | **Monitor and Control** | |
| all weeks | Monitor Technical performance | 40 |
| all weeks | Monitor and Control schedule | 40 |
| | **Closure** | |
| 1 | Project Plan and Proposal | 25 |
| 2 | Status Report Deliverable 1 | 15 |
| 3 | Progress Report | 15 |
| 5 | Status Report Deliverable 2 | 10 |
| 7 | Team Progress Review Meeting | 25 |
| 9 | Formal Progress Presentation | 25 |
| 11 | Formal Dry-Run Presentation | 25 |
| 13 | Final Presentation and Final Report due | 25 |

| | | |
|---|---|---|
| Weeks 3-8 | **SE and OR Development** | 176 |
| | **Problem Identification** | |
| 4 | Identify approach | 25 |
| 5 | Identify and classify risks | 30 |
| | **Perform Research** | |
| 3,4,5 | Literature Review | 50 |
| 5 | Obtain railroad data,statistics and routes | 21 |
| | **Develop Product** | |
| 5 | Define Optimization Model parameters | 5 |
| 5 | Identify all assumptions | 4 |
| 5,6 | Identifies variables, weights, constants, and metrics | 5 |
| 6 | Identify scenarios and calculate algorithm | 6 |
| | **Perform Sensitivity Analysis** | |
| 7,8 | Perform analysis for various sets of probabilities | 30 |
| Weeks 8-10 | **Integration and Testing** | 85 |
| | **Integrate** | |
| 8 | Algorithm Integration - RRVA | 25 |
| 9,10 | Compare algorithm output | 15 |
| | **Test and Evaluate** | |
| 9,10 | Test Evaluation parameters | 15 |
| 9,10 | Evaluate weaknesses and strengths of RRVA and optimization algorithm. | 30 |
| Weeks 10-12 | **Operations and Maintenance** | 32 |
| | **Web services** | |
| 10 | Maintain Web-site for Project | 20 |
| | **Manufacture Product for RRVA** | |
| 11 | Manufacture Algorithm for RRVA | 9 |
| 12 | Produce Lessons Learned | 3 |
| | **Totals:** | 696 |

# Timeline


Construct decision tree
Implement algorithm in C++
Deliver presentation and final report
Implement function in excel
Proposal resubmission
Create data input files
Draft data dictionary
Deliver initial proposal
(need to re-scope effort)
Model revision - Stochastic approach
Create sharepoint site
Plan to implement deterministic model
Feb
Mar
Apr
May
Group gains access to RRVA
Discuss risk function
Initial results from C++ model
Begin to collect data and identify routes
Review C++ model
Establish data input format
Model revision
Deterministic model complete
Analysis conducted
Sponsor Meeting

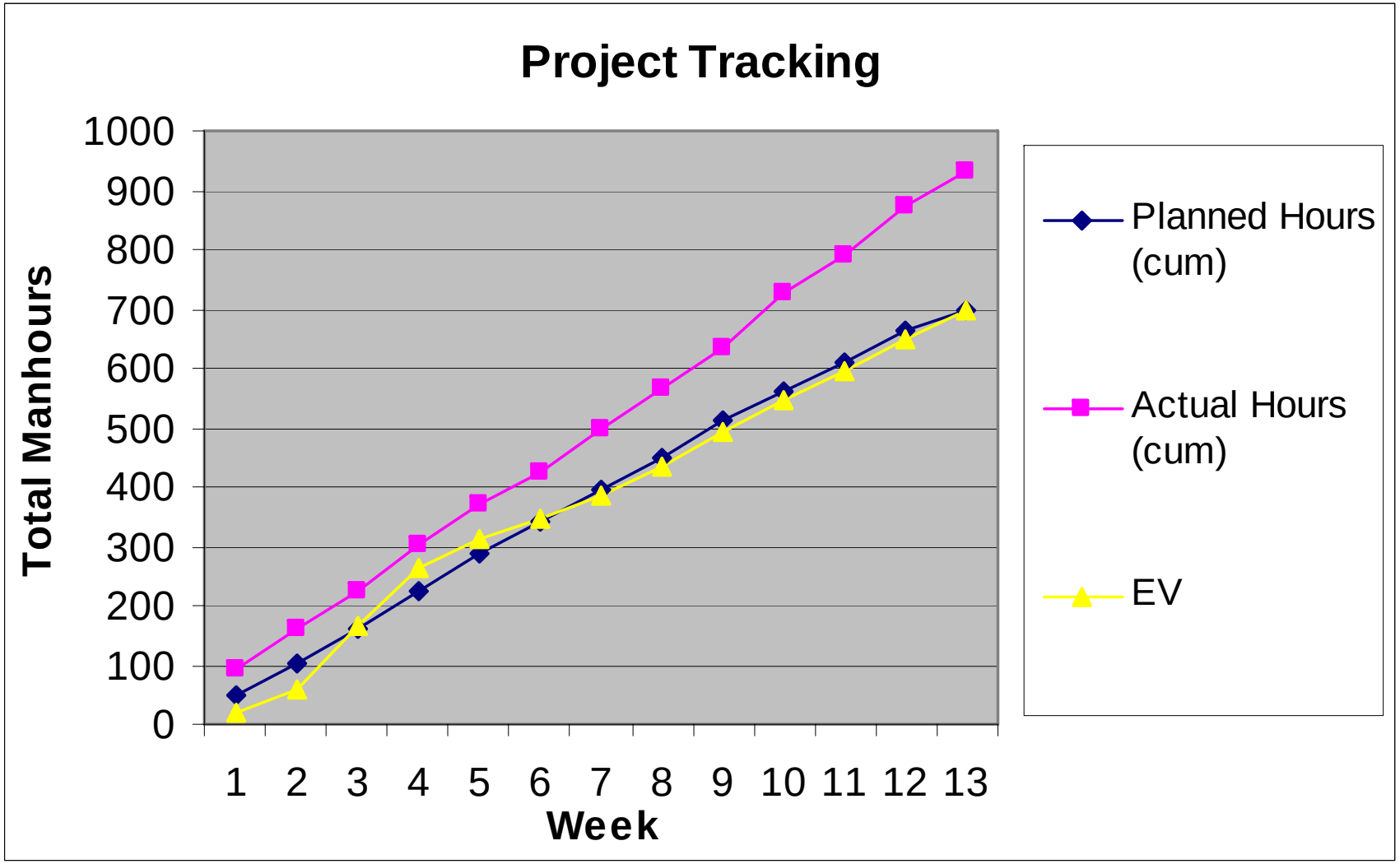
# Project Roles and Responsibilities

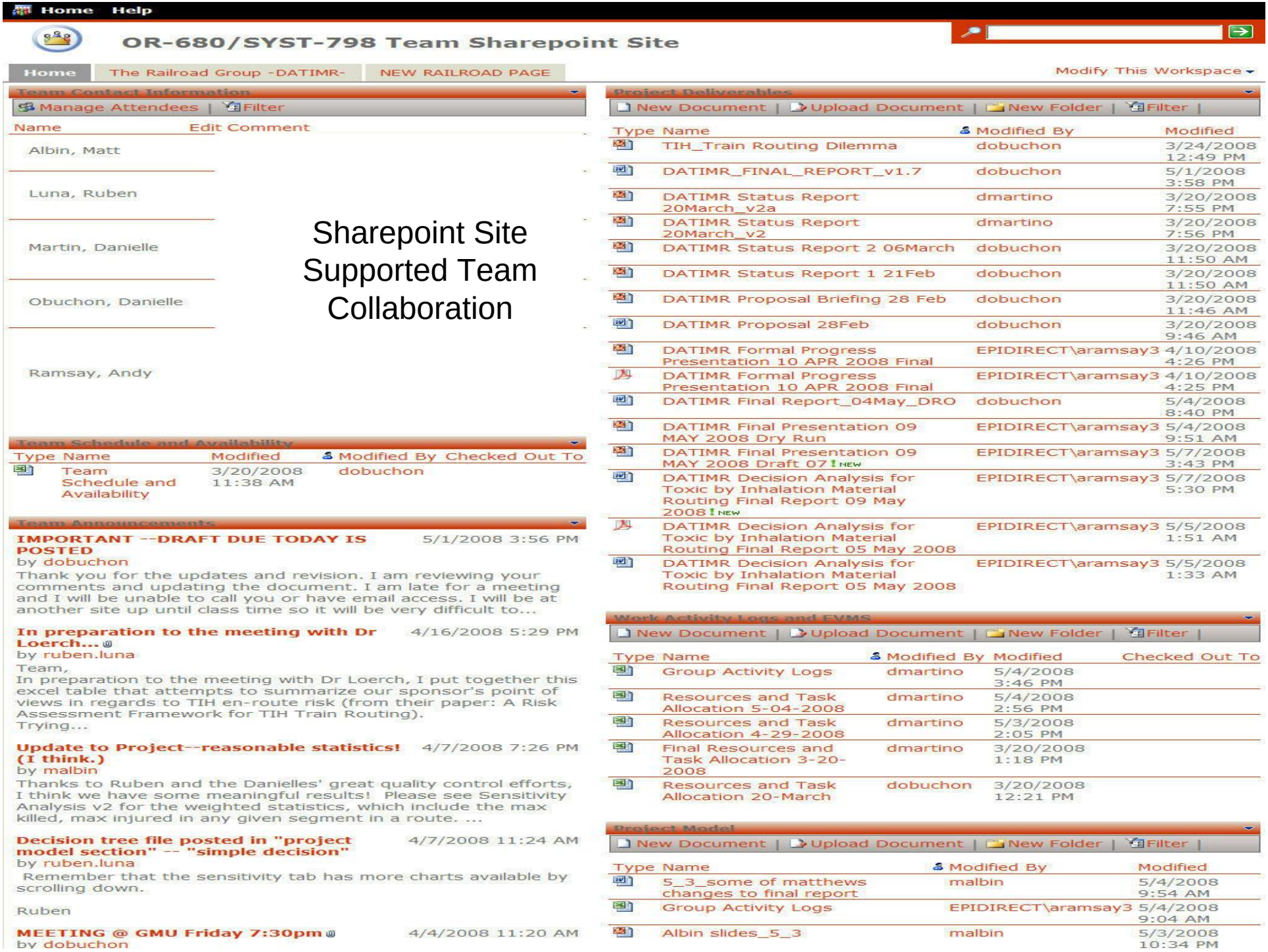
- **Matthew Albin (Operations Research Analyst/Developer)**
  - Developed risk cost mathematical models for route analysis; implemented them in C++, and conducted detailed senstivity analysis
- **Ruben Luna (Senior Systems Engineer/Risk Analyst**
  - Provided technical guidance and analytical products needed to develop the approach and rationale for the mathematical model. Assessed application of decision trees, influence diagrams, and sensitivity analyses to demonstrate alternative approaches to risk analysis.
- **Danielle Martin (Operations Research Analyst/Quality Assurance)**
  - Researched, analyzed, and developed domain data essential to the mathematical model; provided the rationale and logic for data representation in the mathematical model; developed and assessed observations, findings, and conclusions of modeling results.

# Project Roles and Responsibilities (Concluded)

- **Danielle Obuchon (Project Lead/Project Planner/Systems Engineer)**
  - Provided guidance, planning, and project development. Led the team through project delivery, organization, quality assurance, and meeting coordination. Maintained Sharepoint site to support team collaboration. Organize and verified action items and their results, and assisted in development and integration of project deliverables.
- **Andrew Ramsay (Senior/Lead Systems Engineer/Data Analyst)**
  - Provided the team with technical rationale, data input and analysis. Accomplished production and delivery of time-critical deliverables. Acted as the lead expert on the RRVA tool and provided analyses and recommended calculations for the mathematical model. Reviewed and assessed implementation of mathematical model.

# EVM Update


Project Tracking
Total Manhours
1000
900
800
700
600
500
400
300
200
100
0
1 2 3 4 5 6 7 8 9 10 11 12 13
Week
Planned Hours (cum)
Actual Hours (cum)
EV


Home Help
OR-680/SYST-798 Team Sharepoint Site
Home
The Railroad Group -DATIMR-
NEW RAILROAD PAGE
Modify This Workspace
Team Contact Information
Manage Attendees | Filter
Name
Edit Comment
Albin, Matt
Luna, Ruben
Martin, Danielle
Obuchon, Danielle
Ramsay, Andy
Sharepoint Site Supported Team Collaboration
Team Schedule and Availability
Type Name
Modified
Modified By
Checked Out To
Team Schedule and Availability
3/20/2008 11:38 AM
dobuchon
Team Announcements
IMPORTANT --DRAFT DUE TODAY IS POSTED
5/1/2008 3:56 PM
by dobuchon
Thank you for the updates and revision. I am reviewing your comments and updating the document. I am late for a meeting and I will be unable to call you or have email access. I will be at another site up until class time so it will be very difficult to...
In preparation to the meeting with Dr Loerch...
4/16/2008 5:29 PM
by ruben.luna
Team,
In preparation to the meeting with Dr Loerch, I put together this excel table that attempts to summarize our sponsor's point of views in regards to TIH en-route risk (from their paper: A Risk Assessment Framework for TIH Train Routing).
Trying...
Update to Project--reasonable statistics! (I think.)
4/7/2008 7:26 PM
by malbin
Thanks to Ruben and the Danielles' great quality control efforts, I think we have some meaningful results! Please see Sensitivity Analysis v2 for the weighted statistics, which include the max killed, max injured in any given segment in a route. ...
Decision tree file posted in "project model section" -- "simple decision"
4/7/2008 11:24 AM
by ruben.luna
Remember that the sensitivity tab has more charts available by scrolling down.
Ruben
MEETING @ GMU Friday 7:30pm
4/4/2008 11:20 AM
by dobuchon
Project Deliverables
New Document | Upload Document | New Folder | Filter
Type Name
Modified By
Modified
TIH_Train Routing Dilemma
dobuchon
3/24/2008 12:49 PM
DATIMR_FINAL_REPORT_v1.7
dobuchon
5/1/2008 3:58 PM
DATIMR Status Report 20March_v2a
dmartino
3/20/2008 7:55 PM
DATIMR Status Report 20March_v2
dmartino
3/20/2008 7:56 PM
DATIMR Status Report 2 06March
dobuchon
3/20/2008 11:50 AM
DATIMR Status Report 1 21Feb
dobuchon
3/20/2008 11:50 AM
DATIMR Proposal Briefing 28 Feb
dobuchon
3/20/2008 11:46 AM
DATIMR Proposal 28Feb
dobuchon
3/20/2008 9:46 AM
DATIMR Formal Progress Presentation 10 APR 2008 Final
EPIDIRECT\aramsay3
4/10/2008 4:26 PM
DATIMR Formal Progress Presentation 10 APR 2008 Final
EPIDIRECT\aramsay3
4/10/2008 4:25 PM
DATIMR Final Report_04May_DRO
dobuchon
5/4/2008 8:40 PM
DATIMR Final Presentation 09 MAY 2008 Dry Run
EPIDIRECT\aramsay3
5/4/2008 9:51 AM
DATIMR Final Presentation 09 MAY 2008 Draft 07 ! NEW
EPIDIRECT\aramsay3
5/7/2008 3:43 PM
DATIMR Decision Analysis for Toxic by Inhalation Material Routing Final Report 09 May 2008 ! NEW
EPIDIRECT\aramsay3
5/7/2008 5:30 PM
DATIMR Decision Analysis for Toxic by Inhalation Material Routing Final Report 05 May 2008
EPIDIRECT\aramsay3
5/5/2008 1:51 AM
DATIMR Decision Analysis for Toxic by Inhalation Material Routing Final Report 05 May 2008
EPIDIRECT\aramsay3
5/5/2008 1:33 AM
Work Activity Logs and EVMS
New Document | Upload Document | New Folder | Filter
Type Name
Modified By
Modified
Checked Out To
Group Activity Logs
dmartino
5/4/2008 3:46 PM
Resources and Task Allocation 5-04-2008
dmartino
5/4/2008 2:56 PM
Resources and Task Allocation 4-29-2008
dmartino
5/3/2008 2:05 PM
Final Resources and Task Allocation 3-20-2008
dmartino
3/20/2008 1:18 PM
Resources and Task Allocation 20-March
dobuchon
3/20/2008 12:21 PM
Project Model
New Document | Upload Document | New Folder | Filter
Type Name
Modified By
Modified
5_3_some of matthews changes to final report
malbin
5/4/2008 9:54 AM
Group Activity Logs
EPIDIRECT\aramsay3
5/4/2008 9:04 AM
Albin slides_5_3
malbin
5/3/2008 10:34 PM

# Selected Observations

- The proprietary nature of railroad industry operational and financial data limits efforts to develop comprehensive decision analysis capabilities in support of customer operational risk management initiatives (TIH routing problem)
- TIH train en-route problem includes many stakeholders with conflicting objectives
- Risk management is highly influenced by decision-maker's preferences and requires achievement of consensus to a sufficient extent when multiple stakeholders participate in the process.
- Railroads are constrained by rail network physical connectivity (there are limited options for train routes that satisfy regulations and operational constraints for the transport of TIH)

# Selected Recommendations for Future Work

- Explore exposed number of people as a substitute for security risk along the train track (vice monetary cost of loss of life)
- Investigate applicability of expected utility concept to combine exposed population and incidental cost in an additive utility function
- Investigate other O-D pairs that provide more diversity of branches payoff (e.g. Niagara Falls $Cl_2$ plant to Richmond City Wastewater plant)
- Do further work on application of operationally relevant threat factors (what/when/where/how)

# Selected References


- Carter, M., Howard, M., Owens, N., Register, D., Kennedy, J., Pecheux, K., Newton, A., Effects of Catastrophic Events on Transportation System Management and Operations, Department of Transportation, July 2001.
- Hartong, M., Goel, R., Wijesekera, D., A Risk Assessment Framework for TIH Train Routing, Federal Railroad Administration, Howard University, George Mason University, Dec 2007.
- Johnson, P. E., Railroad Routing Visualization and Analysis (RRVA) Tool User's Manual, Oak Ridge National Laboratory, Oak Ridge, TN, May 2006.
- Kawprasert, A. and Barkan C. P.L., Reducing Railroad Hazardous Materials Transportation Risk by Route Rationalization, Railroad Engineering Program, University of Illinois at Urbana-Champaign, January 2008.
- Parentela, E., Risk Modeling For Commercial Goods Transport Final Report California State University, Long Beach, CA, July 2002.
- Pate-Cornell, E., Probabilistic Modeling of Terrorist Threats: A Systems Analysis Approach, Stanford, May 2004.