Environmental and Energy Concerns for Life Cycle Analysis of Transportation Systems

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Acknowledgement

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“National Center for Intermodal Transportation For Economic Competitiveness”
And
“U.S. Department of Transportation / RITA”
Objectives and Scope

• Address environmental sustainability dimensions of multimodal infrastructure assets
• Enhance commuter passenger mobility by providing rail service and reducing road traffic congestion along the Mississippi Gulf Coast
• Investigate harnessing energy from vibrations due to trains moving on the rail corridor.

Based on two projects funded by the National Center for Intermodal Transportation for Economic Competitiveness (NCITEC) and U.S. Department of Transportation RITA
http://www.olemiss.edu/projects/cait/ncitec/
Case Study 1: Mobility on Mississippi Gulf Coast & Commuter Rail Revival

- The Mississippi DOT’s indicate that most of Interstate-10 corridor has average speeds (in both directions) at or below 55 mph (88 kmph).
- The high commercial traffic volume increases congestion on highways, safety risks to other auto commuter traffic, and vehicular emissions.
- Significant traffic volume from within Mississippi Coastal counties on I-10 and US-90.
- 1997 Fatal accident and 2005 Hurricane Katrina caused indefinite interruption of Amtrak Sunset passenger rail service on the Gulf Coast.
Solutions

Passenger Rail reduces number of cars on roads plus less driving per car.

Intermodal integration increases rail share, frees lane space and reduces:

- Congestion on roads and incidents
- Crashes and Stress on commuters
- Congestion related wastage of fuel
- Harmful air pollutants (NOx and Ozone)
- CO$_2$ and GHG emissions
Environmental Degradation and Public Health Impacts of Transportation Modes

Modal comparison of passenger transport emissions

Credit: European Environment Agency/Allianz, SE

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Solution: Revitalization of Passenger Rail Service

- Before and after rail service studies
  - Traffic volume demand and through traffic on Gulf Coast highways
  - In-county commuter trips and auto traffic volume
  - Ridership estimation for rail service
  - Revenue & economic development impacts (concessions at rail stations, jobs created due to revived rail service and integration with other local transport modes such as transit or privately owned short-haul shuttle transport services).
Spatial Map of Average AADT of Major Highways and Vehicle Trips in Each County
Mississippi Gulf Coast Counties, 2012

Total I-10 & US-90 Daily Traffic Volume: 46,247
West of Mississippi

Total I-10 & US-90 Daily Traffic Volume: 49,690
East of Mississippi

Source:
Existing Transportation Infrastructure on Mississippi Gulf Coast Map

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Rail Alternatives for Mississippi Gulf Coast

- **Commuter rail** – Yes; on existing rail lines
- **Tram/Street Car** – No; occupies lanes on highways
- **BRT** – Not suitable; occupies lanes on highways
- **LRT** – Not suitable; occupies lanes on highways
- **Elevated Monorail** – No; high capital costs
Revitalization of Passenger Rail Service

• Comprehensive VE and life cycle assessment (LCA)
  o Capital improvement cost; shared use of rail tracks
  o Annual operational and maintenance costs
  o Annual revenues (fare, advertisement, sales tax for city/county, city and state gaming tax)
  o Other quantifiable benefits
    (safety of casino patrons, reduced congestion, less pollution and associated public health costs, reduction in carbon emissions; more patrons/visitors)

• Economic impact analysis also considers fuel savings by car owners and additional external benefits of jobs created/saved, employer participation, transit connectivity.
Proposed Commuter Rail Lines:
Casino Train E-W and Beach Train N-S
Value Engineering and Life Cycle Benefit-cost Analysis of Gulf Coast Rail Lines

NCITEC 2013-33: Mississippi Gulf Coast Rail Restoration Study (5% Annual Discount Rate Assumed)

<table>
<thead>
<tr>
<th>Rail Alternative</th>
<th>Commuter Rail E-W</th>
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<tr>
<td>CL Length; Track</td>
<td>200 km; CSX rail track</td>
<td>110 km; KCS rail track</td>
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<td>Rail Infrastructure</td>
<td>6 train stocks; 10 stations</td>
<td>4 train stocks; 3 stations</td>
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<tr>
<td>Initial Infrastructure Cost</td>
<td>$335.2 Million</td>
<td>$226.9 Million</td>
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<td>Riders per Day</td>
<td>20,000</td>
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<tr>
<th>Present Worth Cost-Benefit Analysis</th>
<th>Cost</th>
<th>Benefit</th>
<th>Cost</th>
<th>Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-Year Present Worth Analysis, $ Million</td>
<td>344</td>
<td>344</td>
<td>230</td>
<td>247.1</td>
</tr>
<tr>
<td>5-Year Present Worth Analysis, $ Million</td>
<td>375</td>
<td>1,489</td>
<td>247</td>
<td>1,030</td>
</tr>
<tr>
<td>10-Year Present Worth Analysis, $ Million</td>
<td>407</td>
<td>2,656</td>
<td>263</td>
<td>2,110</td>
</tr>
<tr>
<td>20-Year Present Worth Analysis, $ Million</td>
<td>450</td>
<td>4,287</td>
<td>286</td>
<td>2,907</td>
</tr>
<tr>
<td>50-Year Present Worth Analysis, $ Million</td>
<td>504</td>
<td>6,279</td>
<td>313</td>
<td>5,049</td>
</tr>
</tbody>
</table>

Breakeven Year
(considering all revenue sources, fuel saving, and economic benefits)
Year 1

Benefit/Cost Ratio
1.0
1.1

Breakeven Year
Within 6 years
Within 8 years

Environmental and Energy Concerns for Life Cycle Analysis of Transportation Systems
## Value Engineering and Life Cycle Benefit-cost Analysis of Gulf Coast Rail Lines

### NCITEC 2013-33: Mississippi Gulf Coast Rail Restoration Study (5% Annual Discount Rate Assumed)

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<td>20,000</td>
<td>10,000</td>
</tr>
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<td>Breakeven Year (considering only direct revenues)</td>
<td>Within 6 years</td>
<td>Within 7 years</td>
</tr>
</tbody>
</table>

| CO₂ Emission reduction (due to less cars on highways): | 2,397 Tons per Year | 1,253 Tons per Year |
| Added Sales Tax Revenue Assumed: | Annual 5% | Annual 2.5% |

| Annual 10% Added Casino Patrons & Visitors/Tourists: | 1.48 Million | (boost to state economy) |
| Total Jobs created from commuter rails: | 500 | (added economic benefits) |

Data sources: U.S. Census Bureau, American Community Survey 2012; National Transit Database; Mississippi DOT

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Value Engineering & Life Cycle Analysis Results

Present Worth Direct Benefit/Cost Ratio (50 years)

- E-W Commuter Rail
- N-S Commuter Rail
- Monorail
- Bus Rapid Transit

Breakeven Year:  Commuter Rail (6-8 Years)  BRT (50 Years)  Monorail (>>>50 Years)  
(Direct Revenues)

Monorail needs heavy government subsidy to operate if only direct revenues are considered in the benefit cost analysis.
# Highlights of Gulf Coast Commuter Rail Revival

<table>
<thead>
<tr>
<th>“Casino Train” in E-W corridor of the existing CSX rail from New Orleans to Mobile</th>
<th>“Beach Train” in N-S corridor of the existing KCS rail from Hattiesburg to Gulfport</th>
</tr>
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<td><strong>Sustainable mobility for up to 34,000 vehicle users</strong></td>
<td><strong>Service for coastal residents to employers in north</strong></td>
</tr>
<tr>
<td><strong>Reduction in traffic congestion on I-10 &amp; US-90</strong></td>
<td><strong>Reduction in emissions and public health hazards</strong></td>
</tr>
<tr>
<td><strong>Safe travel alternatives for casino patrons from within the coastal counties, New Orleans, and Mobile</strong></td>
<td><strong>Safe mass evacuation of coastal communities in case of a coastal hurricane disaster</strong></td>
</tr>
<tr>
<td><strong>Increase of 1.48 million casino patrons &amp; revenue each year</strong></td>
<td><strong>Total 500 new jobs and boost to regional economy</strong></td>
</tr>
</tbody>
</table>

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“Casino Train” **Call to Action** “Beach Train”

ITS Technology Implementation And Energy Harvesting For Commuter Rail Lines

- Real-time Video Surveillance – on Rail Tracks, Trains, Stations
- Traveler’s Information System & Messages
- Wi-Fi Availability – Cost included in “fare”
- Coastal Evacuation – MEMA/MDOT

- Energy Harvesting from Train-Rail Vibrations using Nano-coated PZT Sensors

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Case Study 2: Nano-Coated PZT System

Composition

• Lead Zirconium Titanate (PZT) is one of the Most Promising Piezoelectric Material for Energy Harvesting

• Nano-Coating Enhancement of PZT Composite

• Nano-Coating Film Constituents:
  ➢ Zinc Oxide Nanoparticles
  ➢ Ferrofluid containing Ferrous Nanoparticles
  ➢ Epoxy Resin
Nano-coated PZT Composite Showing Different Layers [Top & front View] with Dimensions

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Methodology

• Percentage Composition of Nano Coating Mixture: 60 Percent Ferrofluid and 40 Percent ZnO
• Nano Coating Mixture is Applied onto PZT Composite
• Nano-coated PZT is Cured under Ambient Conditions for 36 Hours inside Desiccator
• Three PZT Composites are Placed on Rectangular Stainless Steel Cantilever Plate
• Vibrational Energy is Harvested from Non-coated and Nano-coated PZT Composite Systems in Frequency Range of 20 Hz to 1000 Hz
Multi Non-coated PZT Composite System

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Multi Nano-coated PZT Composite System
Experimental Set-up in The Laboratory
### Table 1. Rectangular Steel Plate Cantilever Energy Harvesting Data For Non-coated and Nano-coated PZT

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Frequency (Hz)</th>
<th>Resistance (Megaohm)</th>
<th>Multi Non-coated PZT Composite Cantilever System</th>
<th>Multi Nano-coated PZT Composite Cantilever System</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Voltage (volt)</td>
<td>Power (microwatt)</td>
</tr>
<tr>
<td>1</td>
<td>20</td>
<td>1</td>
<td>2.125</td>
<td>4.516</td>
</tr>
<tr>
<td>2</td>
<td>40</td>
<td>1</td>
<td>2.893</td>
<td>8.369</td>
</tr>
<tr>
<td>3</td>
<td>60</td>
<td>1</td>
<td>6.624</td>
<td>43.877</td>
</tr>
<tr>
<td>4</td>
<td>80</td>
<td>1</td>
<td><strong>19.890</strong></td>
<td><strong>395.612</strong></td>
</tr>
<tr>
<td>5</td>
<td>100</td>
<td>1</td>
<td>6.058</td>
<td>36.699</td>
</tr>
<tr>
<td>6</td>
<td>150</td>
<td>1</td>
<td>2.281</td>
<td>5.203</td>
</tr>
<tr>
<td>7</td>
<td>200</td>
<td>1</td>
<td>2.725</td>
<td>7.426</td>
</tr>
<tr>
<td>8</td>
<td>250</td>
<td>1</td>
<td>0.640</td>
<td>0.410</td>
</tr>
<tr>
<td>9</td>
<td>300</td>
<td>1</td>
<td>2.683</td>
<td>7.198</td>
</tr>
<tr>
<td>10</td>
<td>350</td>
<td>1</td>
<td>5.179</td>
<td>26.822</td>
</tr>
<tr>
<td>11</td>
<td>400</td>
<td>1</td>
<td><strong>18.080</strong></td>
<td><strong>326.886</strong></td>
</tr>
<tr>
<td>12</td>
<td>600</td>
<td>1</td>
<td>0.664</td>
<td>0.441</td>
</tr>
<tr>
<td>13</td>
<td>800</td>
<td>1</td>
<td>0.858</td>
<td>0.736</td>
</tr>
<tr>
<td>14</td>
<td>1000</td>
<td>1</td>
<td>0.662</td>
<td>0.438</td>
</tr>
</tbody>
</table>

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Comparison of Harvested Energy from Multi Non-coated and Nano-coated PZT System on a Rectangular Cantilever Plate

Energy Harvested Profiles as a Function of Frequency for Non-coated and Nano-coated PZT Systems
Table 2. Comparison of Power Density Result with Other Researchers

<table>
<thead>
<tr>
<th>Reference</th>
<th>Device Type</th>
<th>Frequency (Hz)</th>
<th>Overall Size (mm)</th>
<th>Power Density (μW/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roundy (2004)</td>
<td>Resonant-Cantilever Beam</td>
<td>120</td>
<td>30x3.6x7.7</td>
<td>450.9</td>
</tr>
<tr>
<td>Sodano (2002)</td>
<td>Resonant –Cantilever</td>
<td>50</td>
<td>80x40x1.0</td>
<td>625</td>
</tr>
<tr>
<td>Zheng (2008)</td>
<td>Resonant- Cantilever Beam</td>
<td>150</td>
<td>42x22x0.85</td>
<td>41.4</td>
</tr>
<tr>
<td>Glynne-Jones (2001)</td>
<td>Resonant- Cantilever Beam</td>
<td>80</td>
<td>23x20x0.1</td>
<td>65.2</td>
</tr>
<tr>
<td>Marinkovich (2009)</td>
<td>Resonant- Tethered Mass</td>
<td>160-400</td>
<td>4x4x0.5</td>
<td>125</td>
</tr>
<tr>
<td>UM Researchers (current study)</td>
<td>Frequency-Cantilever</td>
<td>20-1000</td>
<td>12x10x1.83</td>
<td>2807</td>
</tr>
</tbody>
</table>
Life Cycle Assessment of Enhanced Piezoelectric Sensors

- Piezoelectric Sensors are Low-cost Technology used on Roads for over 20 Years to Count and Classify Traffic (ILDOT 2004; Qi et al. 2013)

- Installed under Road Surface, the Life Cycle Costs of Piezoelectric Sensors include: Installation cost of $9,000 beneath the Pavement Surface and Annual Operation and Maintenance Cost of $5,000

- Based on the UM Research Study, Cost of Nano-Coated Piezoelectric Assembly is Less that $5 per unit

- Implementation Costs will be lower for Rail Track Applications because of Its ease to Install and Maintain in middle of the Track

- Implementation Costs will also be offset by Reduced Use of Grid Electricity Consumption to Power Rail Stations, Light and Signal Fixtures, and Other ITS Infrastructure
Conclusions

• Piezoelectric Energy Harvesting Study Showed Almost 100% Improvement in Nano-coated PZT System as Compared to Non-coated PZT System

• Nano-coated PZT System Showed Almost 400% Improvement in Energy Harvesting Capability as Compared to Other Researchers

• Great Opportunity to Harvest Energy throughout the Life of Infrastructure from Transportation-induced vibrations
White Paper Report available from CAIT-NCITEC web site or by contacting Dr. W. Uddin.

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