Longer Combination Vehicles & Road Trains for Texas?

TxDOT Project 0-6095

August 21, 2009

Objective

- consider the impact that larger, productive trucks would have if permitted on Texas highways
- trucks range from a heavier tridem semi-trailer to a variety of combination trucks, including road trains, i.e. LCVs

TxDOT
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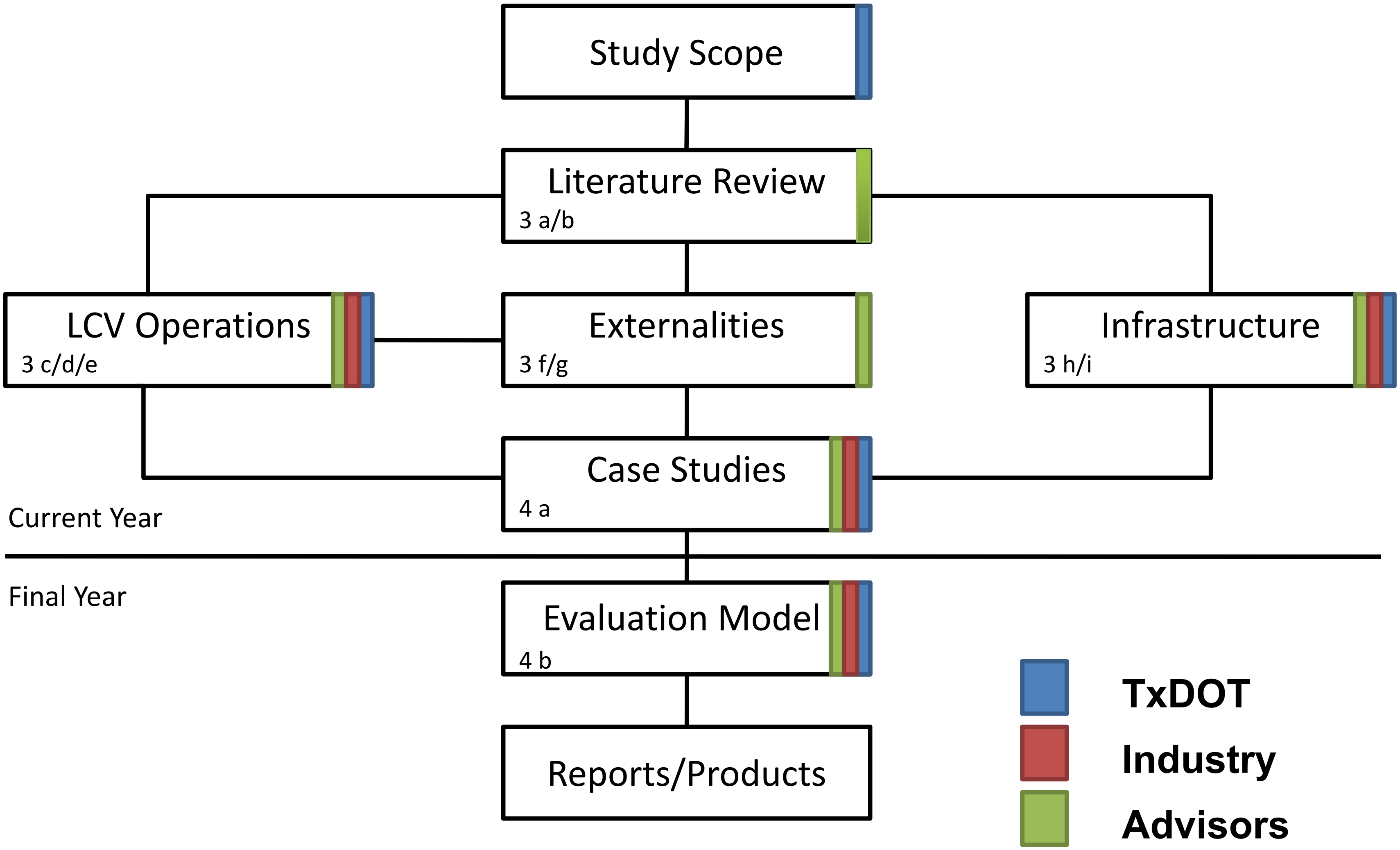
		FY 2009												FY 2010											
Research Activity		Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug
Task 1	LCV Background and Issues	■	■	■	■	■	■																		
Task 2	Representative Vehicle Classes, Demensions, and Specifications	■	■	■																					
Task 3	Highway Infrastructure for Larger Trucks	■	■	■	■	■	■																		
Task 4	First Project Advisory Meeting							■																	
Task 5	Bridge Impacts from LCV Operations	■	■	■	■	■	■	■	■	■	■	■	■												
Task 6	Pavement Consumption and LCV Operations	■	■	■	■	■	■	■	■	■	■	■	■												
Task 7	Larger Truck Operations	■	■	■	■	■	■	■	■	■	■	■	■												
Task 8	Policy Implications of LCV Operations	■		■		■			■	■	■	■	■												
Task 9	Summary of First Year Activities and Second Project Advisory Meeting												■	■											
Task 10	LCV Case Study 1. An Existing Interstate Highway														■	■	■	■	■	■	■	■	■	■	
Task 11	LCV Case Study 2. An Existing State Corridor														■	■	■	■	■	■	■	■	■	■	
Task 12	LCV Case Study 3. Trans-Texas Corridor - TTC-35														■	■	■	■	■	■	■	■	■	■	
Task 13	LCV Case Study 4. Truck Only Toll Road														■	■	■	■	■	■	■	■	■	■	
Task 14	Final Report and Third Project Advisory Meeting																				■	■	■	■	■

Agenda

1. Introductions
2. Overview of Project
3. Project Progress-to-Date
   a. U.S. LCV Operations and Regulations
   b. Harmonization
   c. Operational Characteristics
   d. Safety Issues
   e. Large Truck Operations
   f. Environmental and Energy Issues
   g. Industry Perspectives
   h. Bridge Impacts
   i. Pavement Consumption
   j. Response
4. Next Stage of Research
   a. Case Studies
   b. Evaluation Approach


Study Scope
Literature Review
3 a/b
LCV Operations
3 c/d/e
Externalities
3 f/g
Infrastructure
3 h/i
Case Studies
4 a
Current Year
Final Year
Evaluation Model
4 b
Reports/Products
TxDOT
Industry
Advisors

U.S. Long Combination Vehicle Operations and Regulations

Size and Vehicle Weight Focus

- Historically, changes in motor vehicle size and weight regulations were driven by external factors
- Legal limits changed throughout development of highway system
  - System expansion
  - Improvements to vehicles and roads
  - Economic pressures to reduce costs

Size and Vehicle Weight Focus

- Governments enforce maximum weight limitations
  - Likely pay cost of road improvements and maintenance
- Concerns about incremental increase in truck size and weight limitations without corresponding increase in user fees and infrastructure investment

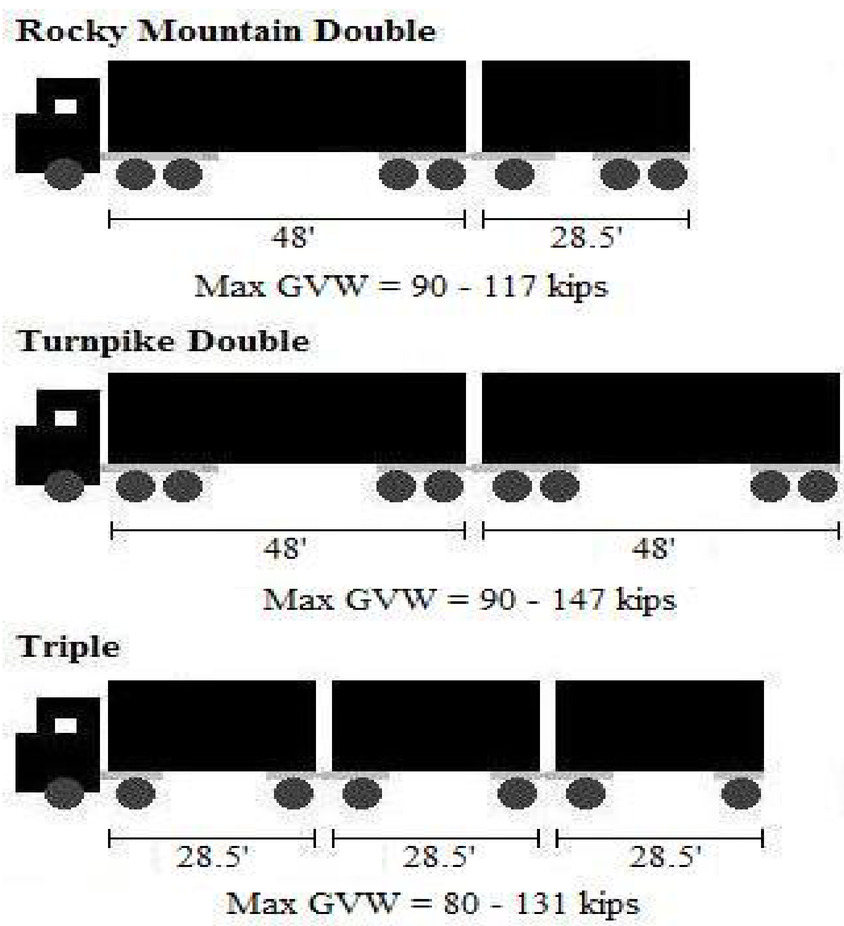
LCV Freeze

- ISTEA (1991) includes most recent revisions in federal truck size and weight limits
- ISTEA thus limits or "freezes" LCV operation on Interstate System to configurations authorized by state officials on or before June 1, 1991
- Allows certain exemptions (grandfather clauses: State must show higher weights would have been allowed before federal limits came into effect)

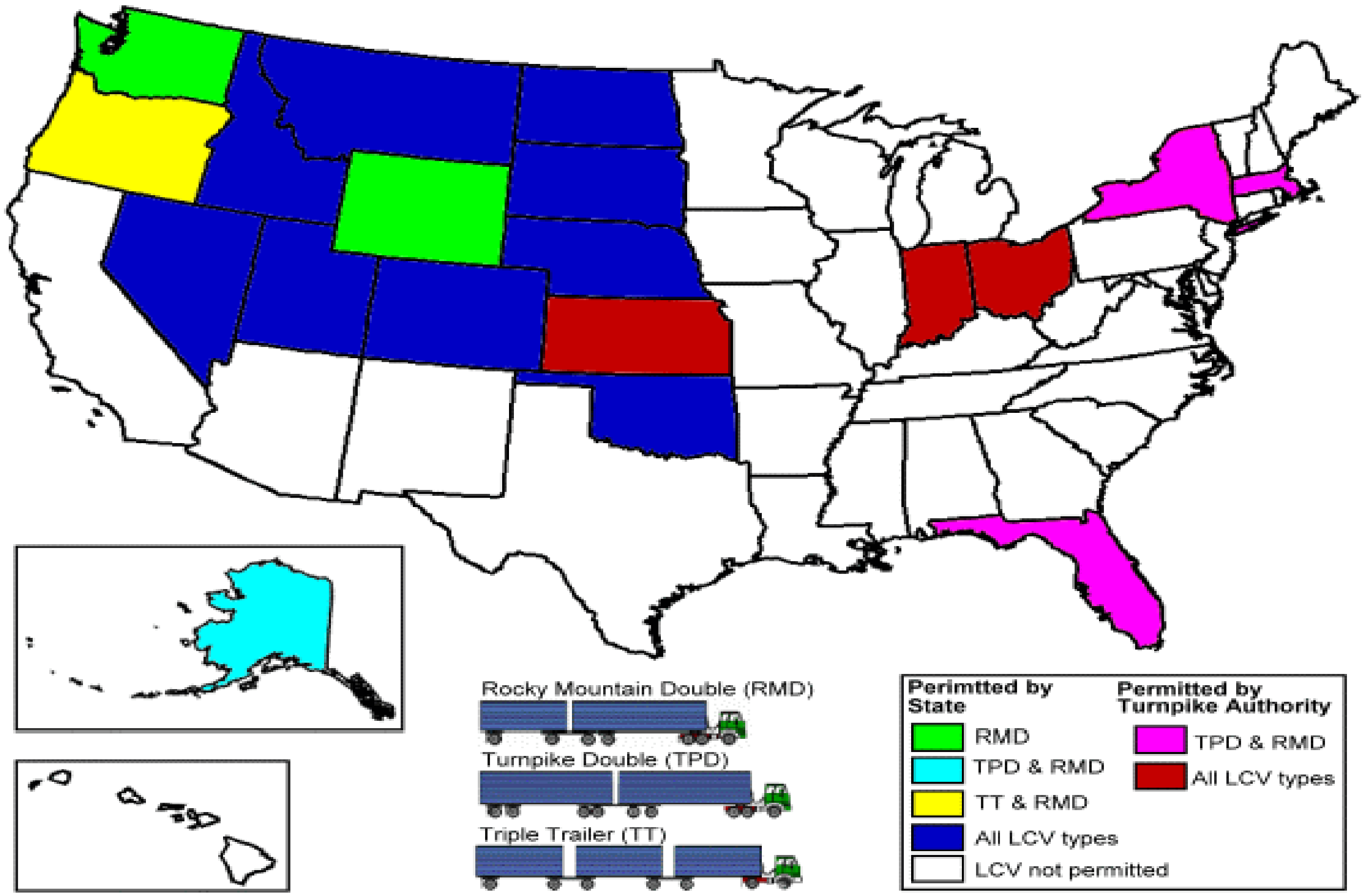
U.S. Regulatory Framework

LCVs may continue to operate only if the LCV type was authorized by State officials (pursuant to State statute or regulation) and in actual lawful operation on a regular or periodic basis on or before June 1, 1991

U.S. LCV Configurations



U.S. LCV Operations



Source: U.S. Department of Energy, 200[illegible]

Major Truck Corridors

- States near Texas currently allowing LCV operations include Oklahoma, Kansas, Nebraska, Colorado, and Missouri
- Important tuck routes traverse Texas to North East, Great Lakes area, and eventually Canada or Mexico
- Texas, Arkansas, Tennessee, and Kentucky do not permit any type of LCV operations

U.S. LCV Operations

- Other U.S. states allow operation according to configuration
  - Oregon
    - 6,000 miles open to RMDs
    - Only 3,500 miles open to Triples

U.S. Regulatory Prohibitions

- Proposals for changes in federal regulation governing vehicle size and weight are always controversial
  - Increased highway construction/ maintenance costs
  - Divert freight from railroads to highways
  - Safety concerns

Harmonization

NAFTA Regional Issues

- Truck size and weight regulations important in region
  - > 2/3 of all merchandise traded between three economies moved by truck

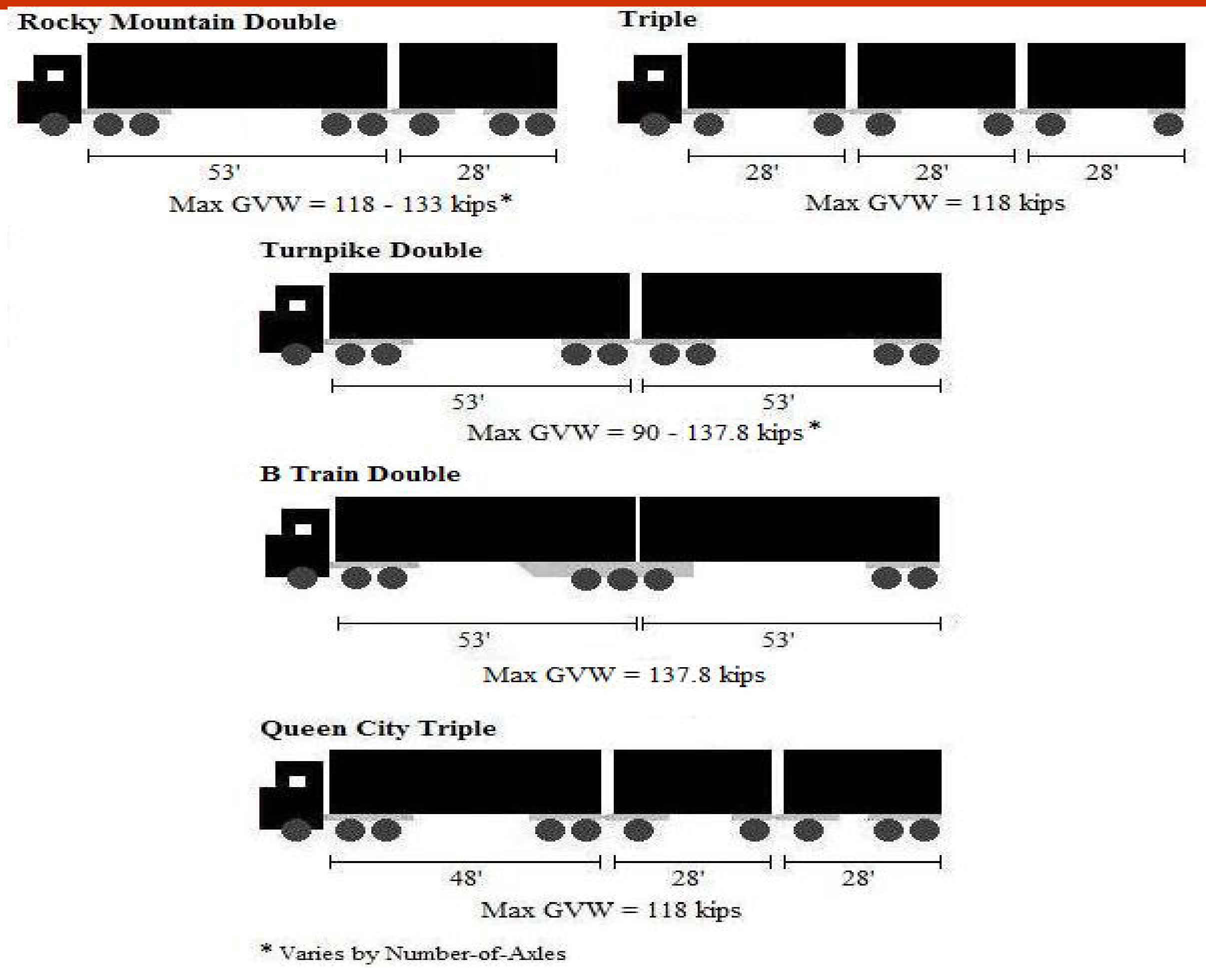
NAFTA Region: Canada

- LCVs usually defined as tractor/trailer combinations using
  - Two/ three semitrailers or
  - Trailers with a total vehicle length exceeding normal limit of 82 feet
- In Canada - 10 provinces and 2 territories have authority to establish weight and dimensions
- LCVs currently operate in AB, SK, MB, QC, and Northwest Territories

NAFTA Region: Canada

- National MOU
  - All provinces allow vehicles complying with national weight and dimension standards
- LCVs not covered by MOU
  - Each province has own regulations
- LCVs operate under special permits
  - Specific safety requirements
  - Other restrictions: only certain routes, at certain times or seasons, and speed restrictions

NAFTA Region: Canada



NAFTA Region: Mexico

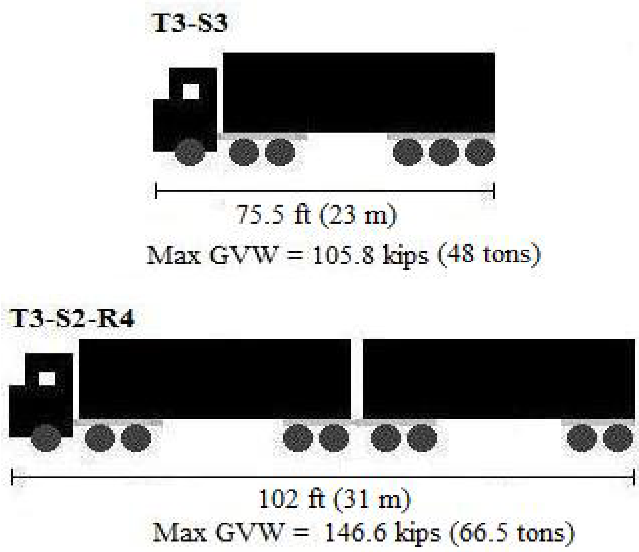
- Federal government set truck size, weight, and dimension limits
  - Apply to federal highways
- 31 state governments
  - Can establish truck size and weight limits on roads under their jurisdiction
  - No state has exercised authority to date

NAFTA Region: Mexico

- In April 2008 - after 14 years of resistance from trucking and industrial organizations - new Mexican Official Norm (NOM-012-SCT-2-2008) enacted
- New NOM encompasses 25 configurations of commercial vehicles
  - Half can be considered LCVs with 6, 7, 8 or 9 axles

NAFTA Region: Mexico

- New NOM presents major changes to LCV usage, operational issues, and extensive restrictions on 9 axle LCVs - commonly known as *fulls* (T3-S2-R4)



Harmonization Challenges

- Lack of political will
  - History of disputes between U.S. and Mexico regarding cross border trucking
- Technical and stakeholder issues
  - Railroad lobby
  - Safety advocacy groups
  - Engineering assumptions about heavy truck impacts on bridges and pavements

Harmonization Challenges

- Jurisdictional complexity
  - U.S. western states want to maintain “grandfather” rights
  - Others wanted the LCV freeze lifted
- Mexican trucks having to adapt to lower weights

Operational Characteristics

Operational Issues

- Roadway geometric design changes may be required to accommodate LCVs
- LCV characteristics (e.g., stability and acceleration speed) may impact traffic operations and safety
- Vehicle weights, dimensions, and connection types may impact basic traffic maneuvers

Effects of Vehicle Features

Vehicle Features		Traffic Congestion	Vehicle Offtracking		Traffic Operations			
			Low Speed	High Speed	Passing	Acceleration (merging and hill climbing)	Lane Changing	Intersection Require-ments
Size	Length	- e	- E	+ e	- E	—	- E	- E
	Width	—	- e	+ e	- e	—	- e	—
	Height	—	—	- e	—	—	—	—
Design	Number of units	—	+ E	- E	—	—	- e	—
	Type of hitching	—	+ e	+ E	—	—	+ E	—
	Number of Axles	—	+ e	+ e	—	—	+ e	—
Loading	Gross vehicle weight	- e	—	- E	- E	- E	- e	- E
	Center of gravity height	—	—	- e	—	—	- e	—
Operation	Speed	+ E	+ E	- E	- E	—	+ e	+ E
	Steering input	—	- E	- E	—	—	- E	—

+/- As parameter increases, the effect is positive or negative.
E = Relatively large effect. e = relatively small effect. -- = no effect.

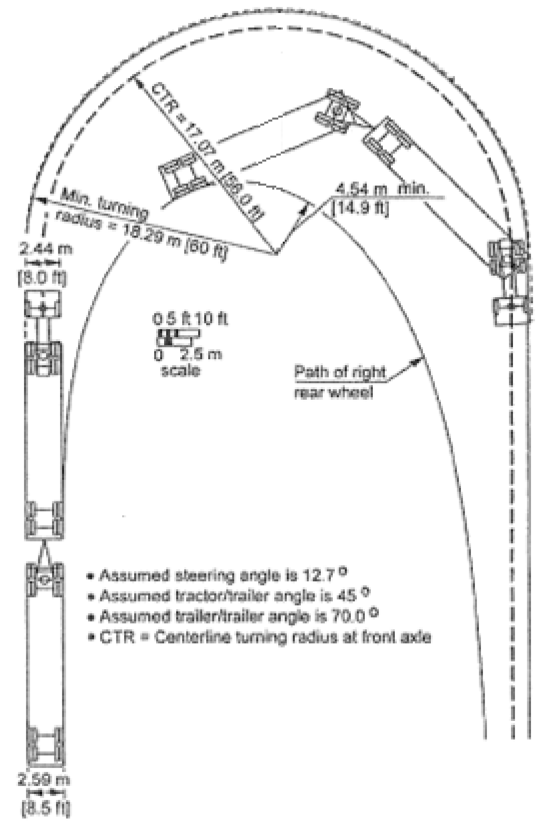
Source: FHWA, 2000

Roadway Geometric Design Impacts

- Lane width
- Turning radius
- Primary vehicle characteristics
  - Wheel base length
  - Number of articulation points

	5 Axle Semi-Trailer	Turnpike Double	Triple Trailer
Minimum Turning Radius (ft)	45	60	45
Center-line Turning Radius (ft)	41	56	41
Minimum Inside Radius (ft)	4.4	19.3	9.9

Source: AASHTO, 2004



Source: AASHTO, 2004

Offtracking

- Low-speed offtracking
- High speed offtracking
- Dynamic high speed offtracking

	Maximum Offtracking (ft)		Maximum Swept Path Width (ft)	
Turn Radius (ft)	100	150	100	150
Vehicle Type				
48 ft Semi-Trailer	10.1	6.9	18.4	15.1
53 ft Semi-Trailer	12.1	8.3	20.3	16.6
STAA Double	6.3	4.2	14.6	12.5
RMD	12.7	8.7	21.0	17.0
TPD – 48 ft	17.1	12.0	25.3	19.2
TPD – 53 ft	17.9	12.6	26.1	20.8

Source: TRB, 2003

Acceleration

- Require more power to accelerate
- Intersections
  - Decreased capacity
  - Increased exposure
- Passing
  - Larger gaps to change lanes
  - Longer passing sight distances (8% on 2-lane)
  - Increased exposure
- Larger speed differentials (accident severity)

Braking and Traction

- Braking performance should not be affected
- Heavier trucks may experience traction problems in slippery conditions
  - Can be mitigated through tandem drive axles, automated traction control

Stability

- Steady state induced rollover
  - Centrifugal force exceeds truck's ability to counteract
  - Static roll stability
  - Primary factors
    - Height of cargo center of gravity
    - Vehicle track width
    - Suspension
    - Tire properties

Stability

- Evasive maneuver induced rollover
  - Truck traveling at high speed must abruptly steer side to side
    - Lateral acceleration amplified at each trailer
  - Rearward amplification and load transfer ratio
  - Primary factors
    - Number of articulation points
    - Length of wheelbase
    - Static roll stability of trailers

Connection Types

- A Dolly
  - Tandem-axle dolly connected to preceding semi-trailer by single drawbar; drawbar connected by “hook” and “eye” can pivot on transverse horizontal axis and on longitudinal axis
- B Train
  - Second trailer connected directly to first at fifth-wheel mount; better dynamic roll stability; higher payload
- C Train
  - Dolly connected by two drawbars; prevents rotation about vertical axis; better dynamic roll stability

Safety Issues

by Avinash Unnikrishnan & Kara Kockelman

LCV Safety Studies

- **Operational** Attributes
  - Studies compare LCV operational needs to roadway designs & speeds.
- **Crash Data** Analysis
  - Comparisons of actual crash rates (per VMT & by outcome) to identify general trends, across vehicle classes.

Operational Attributes
(Harkey et al. 1996)

- **Speed & Acceleration**: Induce speed differentials which may create unsafe conditions.
- Off-tracking & **Encroachment:** 12' lanes allow for high-speed (high-radius) off-tracking.
- Trailer **Sway**: Not expected to pose significant hazard as long as AASHTO lane width guidance met.
- **Rollover** tendencies: Reduced by decreasing number of articulation points & using longer trailers.
- Rearward **Amplification**: A problem for triple-trailer LCVs.

Operational Characteristics (2)
(Knight et al., 2008)

- LCV safety from perspective of maneuverability, field of view, braking & stability.
- **Recommend technology** to improve safety:
  - Mirror configurations & camera technology to identify blind spots;
  - ABS & electronically-controlled braking systems (EBS) to prevent wheel locking;
  - Steered axles & electronic stability controls to reduce stability risks.

Note: Many have concluded that LCVs do ***not*** result in additional maneuverability issues, as compared to other combination vehicles.

Operational Characteristics (3)

Overall Conclusions, across multiple studies:

- Do not recommend LCV use on routes with multiple at-grade intersections, railway crossings or single lanes.
- Recommend LCV usage on motorways & freeways with strict enforcement of speed limits & load distribution rules.

Crash Involvement

- Difficult to identify trends from LCV crashes due to a **lack of data** involving LCVs.
- Longer trucks do not increase accident risk (Vierth et al., 2008), but result in **higher casualty ratios** (Vierth et al., 2008; Zaloshnja et al. 2004).
- Combination-trucks have **significantly lower crash rates**, as compared to passenger vehicles & single-unit trucks (Wang et al., 1999, Woodrooffe, 2001; Montufar et al. 2007, Abdel-Rahim 2006).

Crash Involvement (2)

- **Under difficult driving conditions** multiple unit trucks have a higher likelihood of crash involvement (Forkenbrock et al., 2003).
- Crash rates are lower for multiple trailer trucks (vs. single-trailer trucks) on interstates & urban roads, but **higher on rural roads** (USDOT 2004).

Data Analysis

- Large Truck Crash Causation Study (**LTCCS**) Data, 2001-2003
- 785 crashes with 1+ truck over 10,000 lbs (GVWR)
- Regression analyses using ordered probit & **heteroscedastic ordered probit** models.
- *Y* = 0 to 4 (no injury, no visible injury/only pain reported, non-incapacitating injury, incapacitating injury, & death)

Two Models…

- ***Y*** = maximum injury severity in a crash
- ***Y*** = injury severity (for each involved person)

Outcome	**Max Injury Severity**		**Injury Severity**	
	Count	**%**	**Count**	**%**
No Injury (***Y***=0)	10	**1.3%**	917	**39.3%**
No visible injury (1)	100	12.7	367	15.7
Non-Incapacitating Injury (2)	262	33.4	490	21.0
Incapacitating Injury (3)	262	**33.4**	360	**15.4**
Death (4)	151	**19.2**	202	**8.6**

Maximum Injury Severity

- Likelihood of **death** ***rises***…
  - as the **number of lanes falls** (by 28%),
  - when (largest) involved truck is **not an LCV** (by 46%),
  - when roadway is **not a** rural **freeway** (53%) or not an urban freeway (57%),
  - when driver **unaware of his speeding** (94%),
  - under **non-bright lighting** conditions (151%).

Maximum Injury Severity (2)

- Likelihood of death ***rises***…
  - with **# trailers** on the largest truck,
  - when **drugs** are involved (by 82%),
  - when driver of largest truck is "**emotionally stressed**" (48%),
  - on **undivided two-way** facilities (52%),
  - in presence of **sag or crest** curve (54%), &
  - under **non-bright lighting** conditions (by 151%).

Maximum Injury Severity (3)

- **Greater uncertainty in** crash **outcome** with…
  - Non-bright conditions,
  - Freeway crash locations,
  - More lanes,
  - Higher truck counts,
  - Fewer trailers,
  - Unstressed driver, &
  - No vertical curvature in alignment.

Model 2: Injury Severity
(all involved parties)

- Likelihood of fatal & severe injury reduced significantly with use of **ITS equipment** (32%) & for males (66%), **but increases when** largest truck is an **LCV**.
- Presence of **flow restrictions & wet conditions reduce likelihood of severe injuries** by 52% & 38%, respectively.
- As in the max-severity model, likelihood of death **increases on vertical curves, under inadequate lighting**, with **more involved HDTs, & off freeways**.

Injury Severity (2)

- **Greater uncertainty in** crash **outcome** with…
  - Male drivers,
  - More ITS equipment on board,
  - Largest truck is not an LCV, &
  - Non-freeway crash location.

Conclusions

- LCVs appear to enjoy **significantly lower crash rates, but higher crash costs**.
- **LCVs are less likely to be involved in fatal crashes, but involve more persons** (& more fatal injuries, for severe crashes).
- Can **recommend LCV use on freeways** (with proper speed & other enforcement), but not on roadways with at-grade intersections.

Large Truck Operations

LCV Operator Surveys

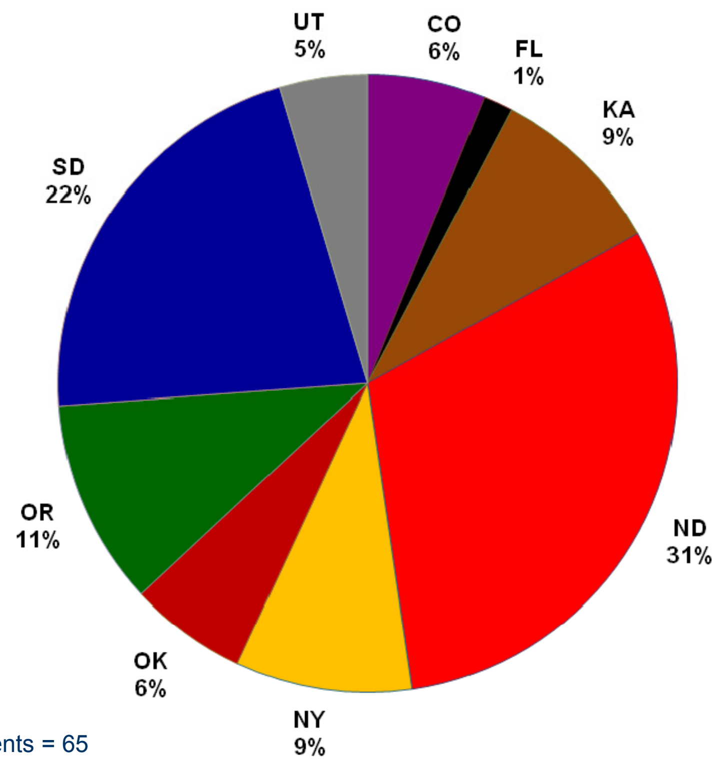
- Objective
  - Insight into LCV use in the U.S. (operator perspective)
- Questions
  - Operations
  - Vehicles
  - Drivers
  - Vehicle Performance/Safety

LCV Operator Surveys

- Conducted telephone surveys
  - Summer 2009
- FMCSA database
  - Separate operators by LCV type
  - Include range of operators
    - Owner operators and larger companies
    - Commodities (harvesters, concrete companies, etc.)
- 65 completed telephone surveys

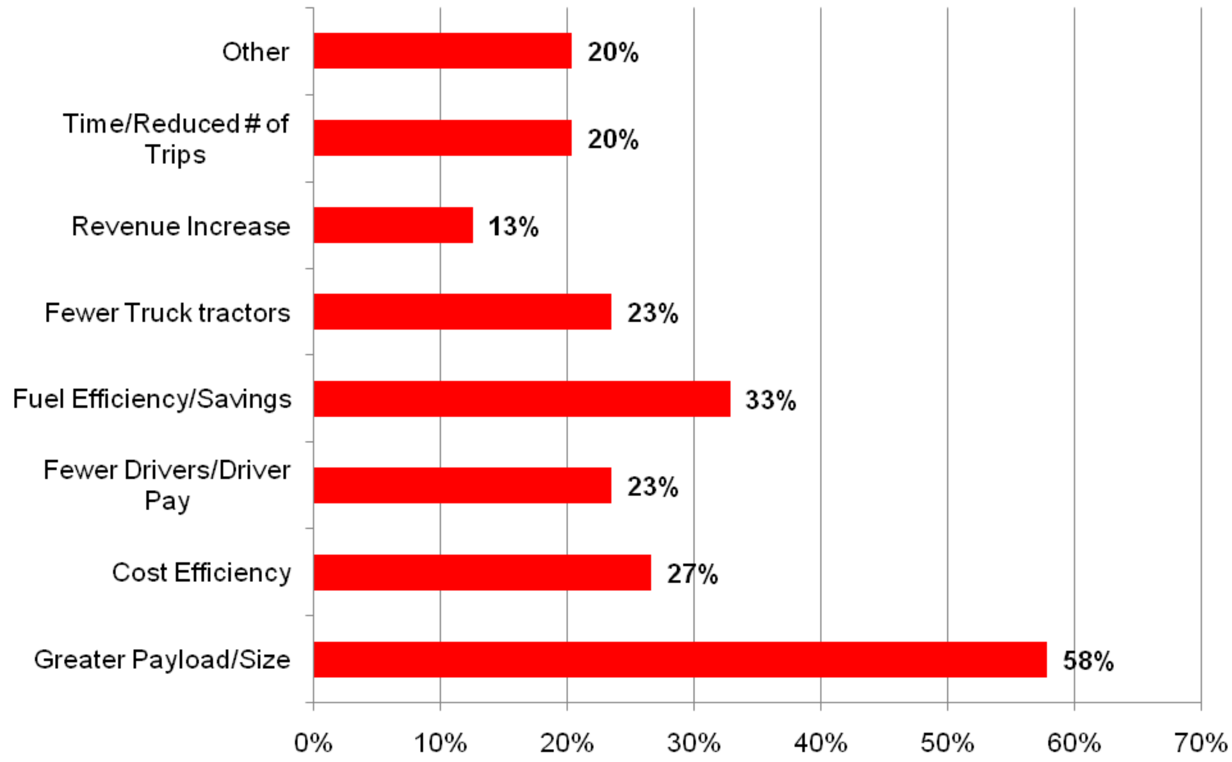
LCV Operator Surveys

- LCV operators in nine states
  - Northeast
  - Northwest
  - Midwest
  - Southeast



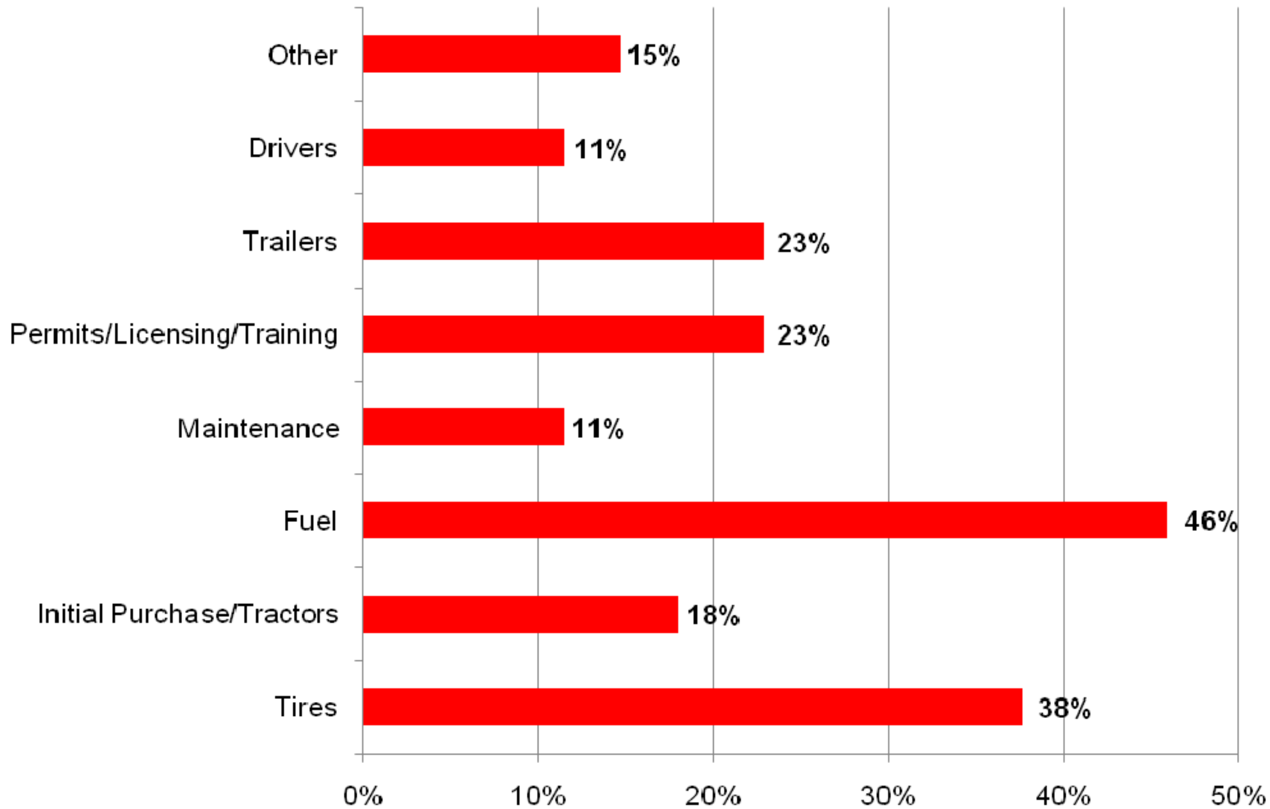
Number of Respondents = 65

Significant Benefits



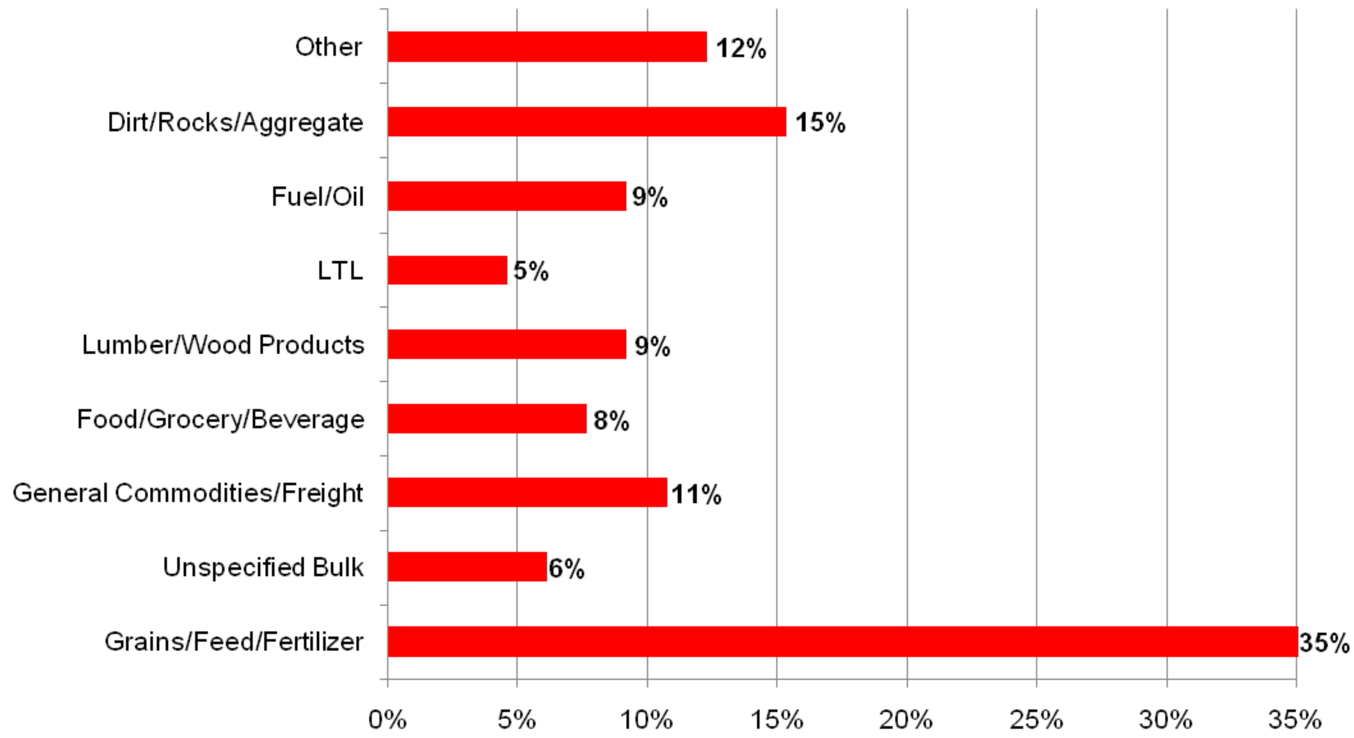
Number of Responses = 139

Major Costs



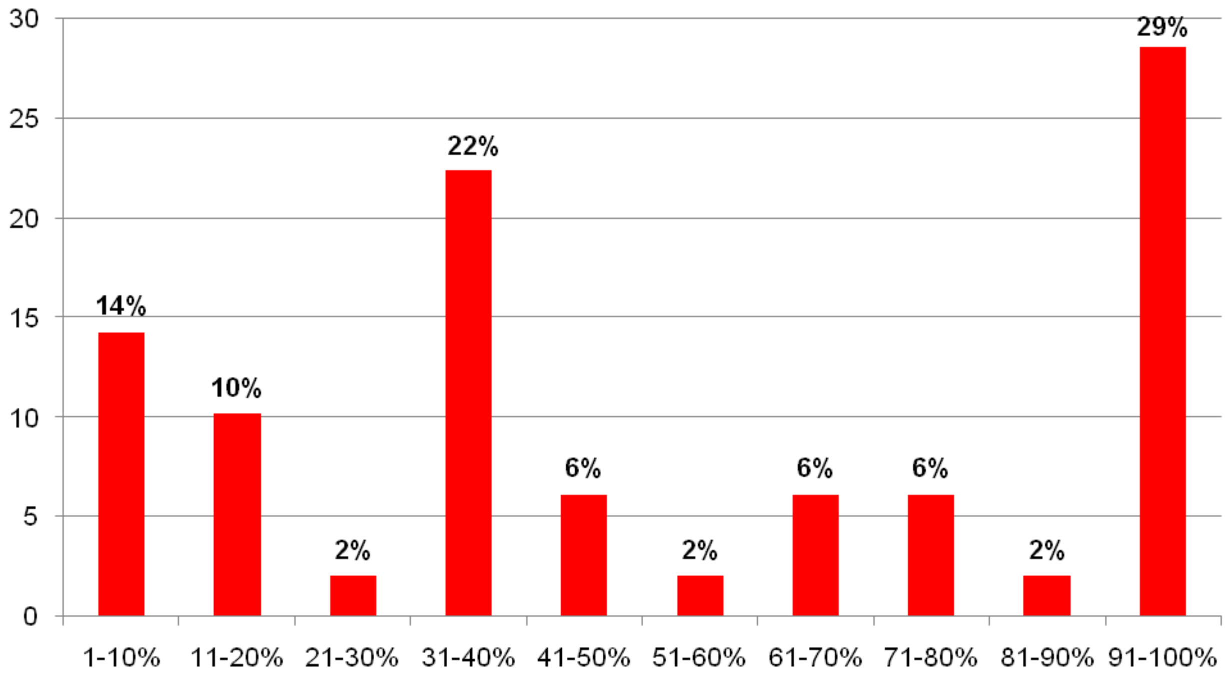
Number of Responses = 113

Major Commodities



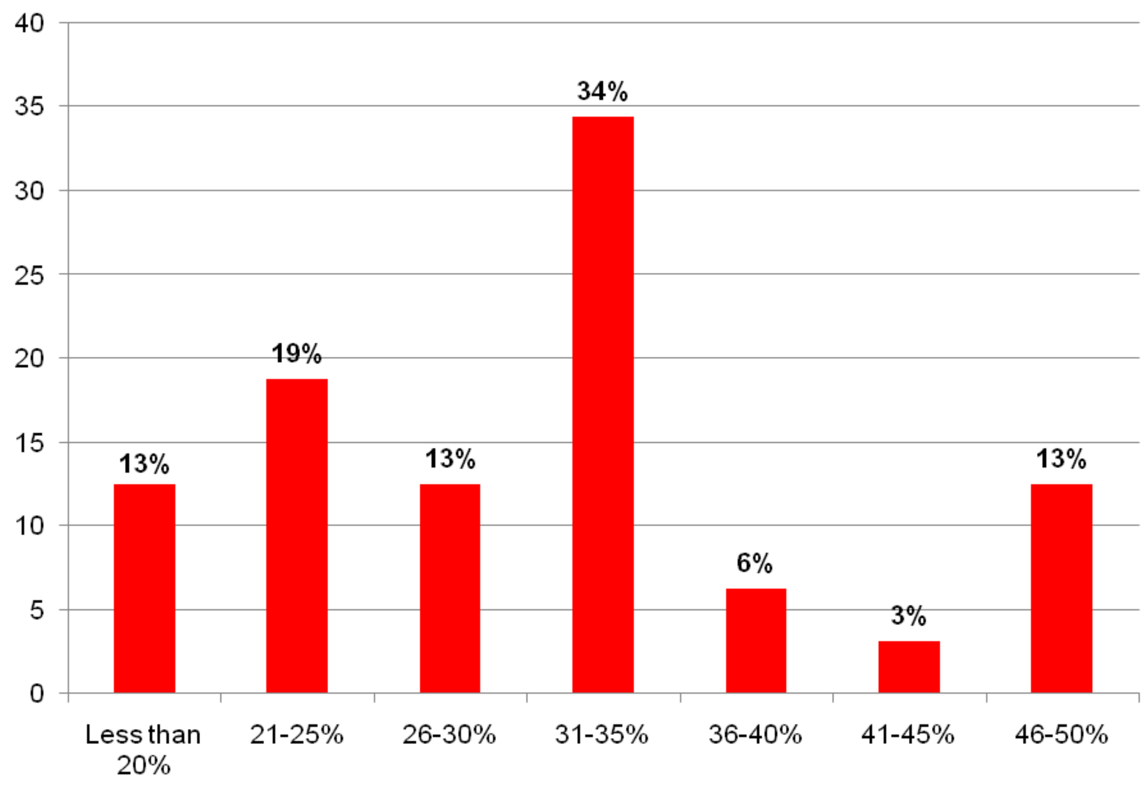
Number of Responses = 72

Percentage of Fleet (LCV)



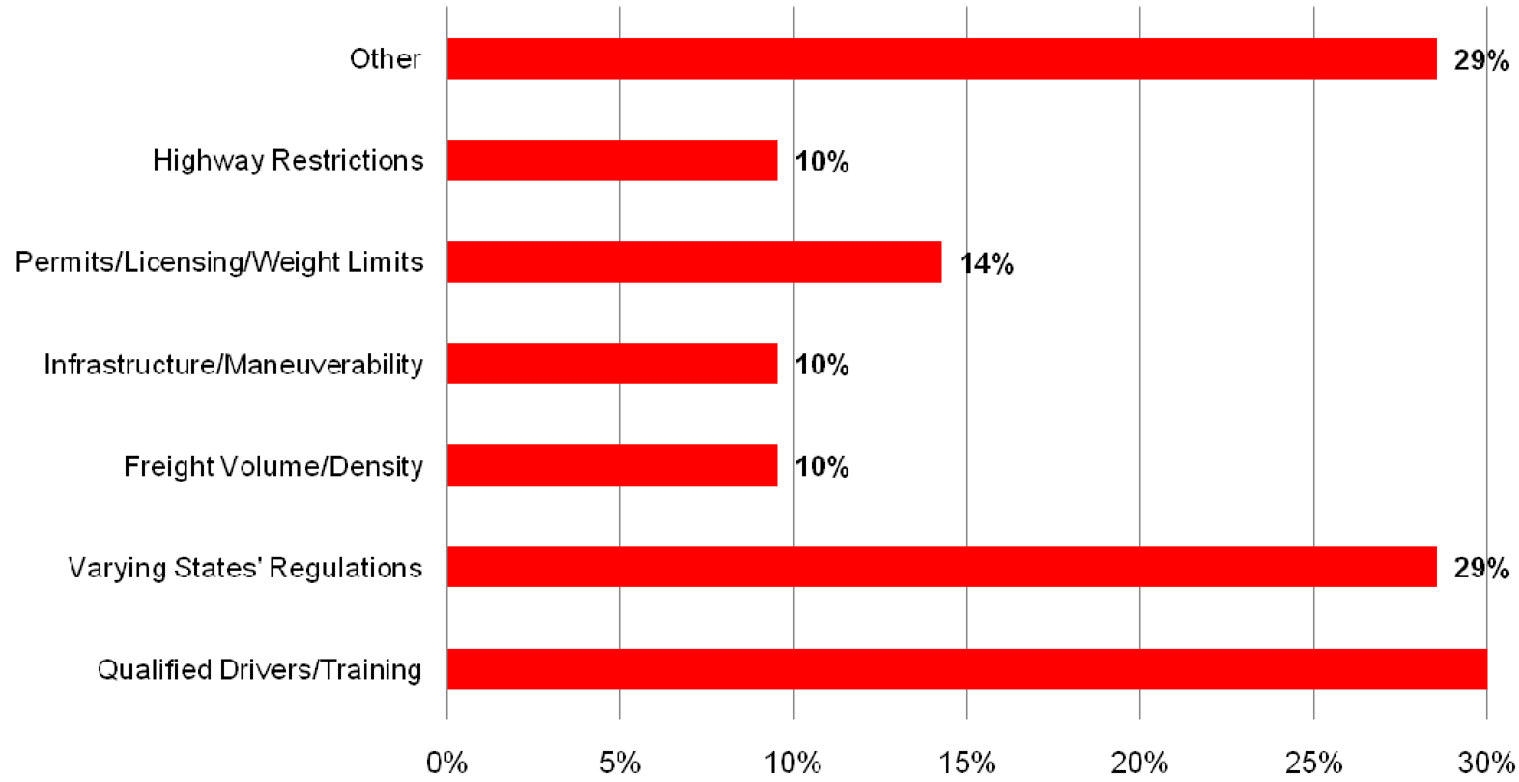
Number of Responses = 49

Percentage Reduction in Truck Loads



Number of Responses = 32

Major Challenges

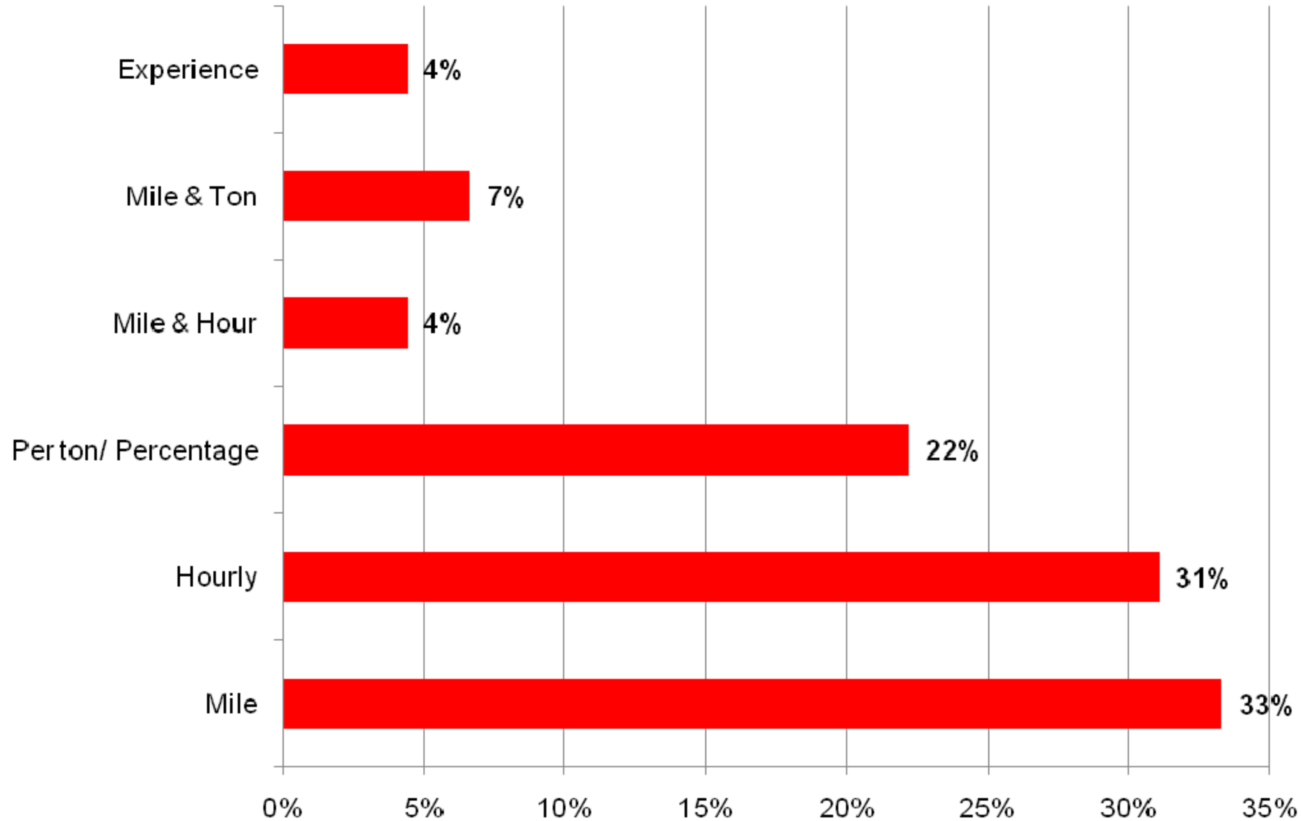


Number of Responses = 82

LCV Driver Training

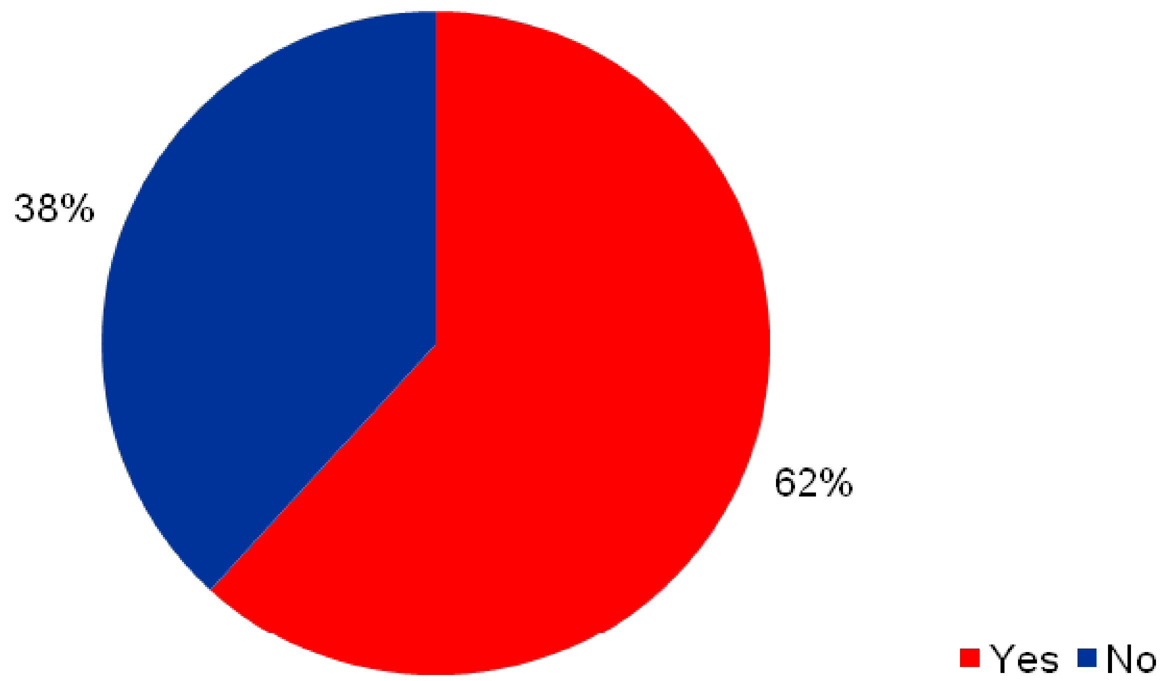
- 58% of respondents provided additional training
  - Written test
  - Driving test with experienced driver
  - Equipment "walk-thru" check
  - Refresher courses
  - Combination of above
- Larger companies had safety instructors/ directors

LCV Driver Compensation



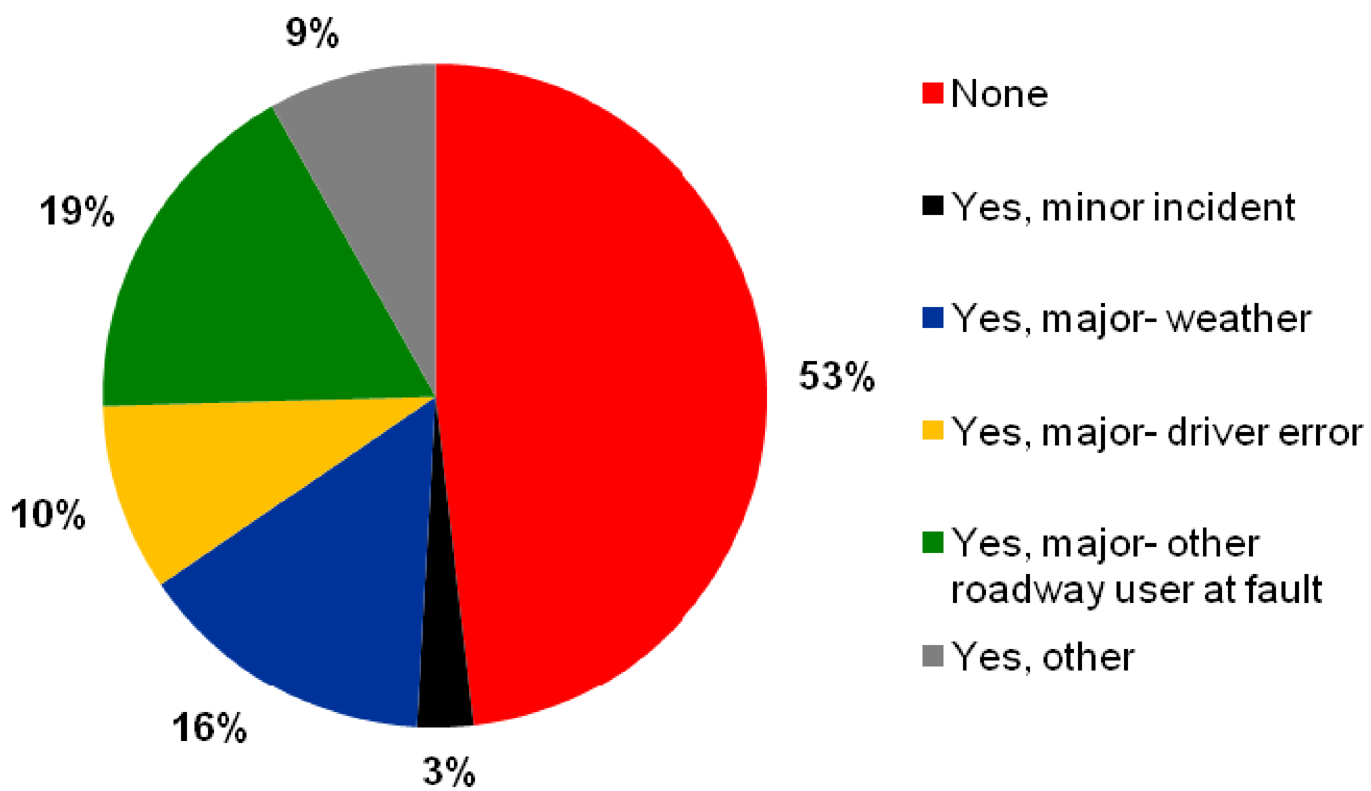
Number of Respondents = 46

LCV Driver Compensation

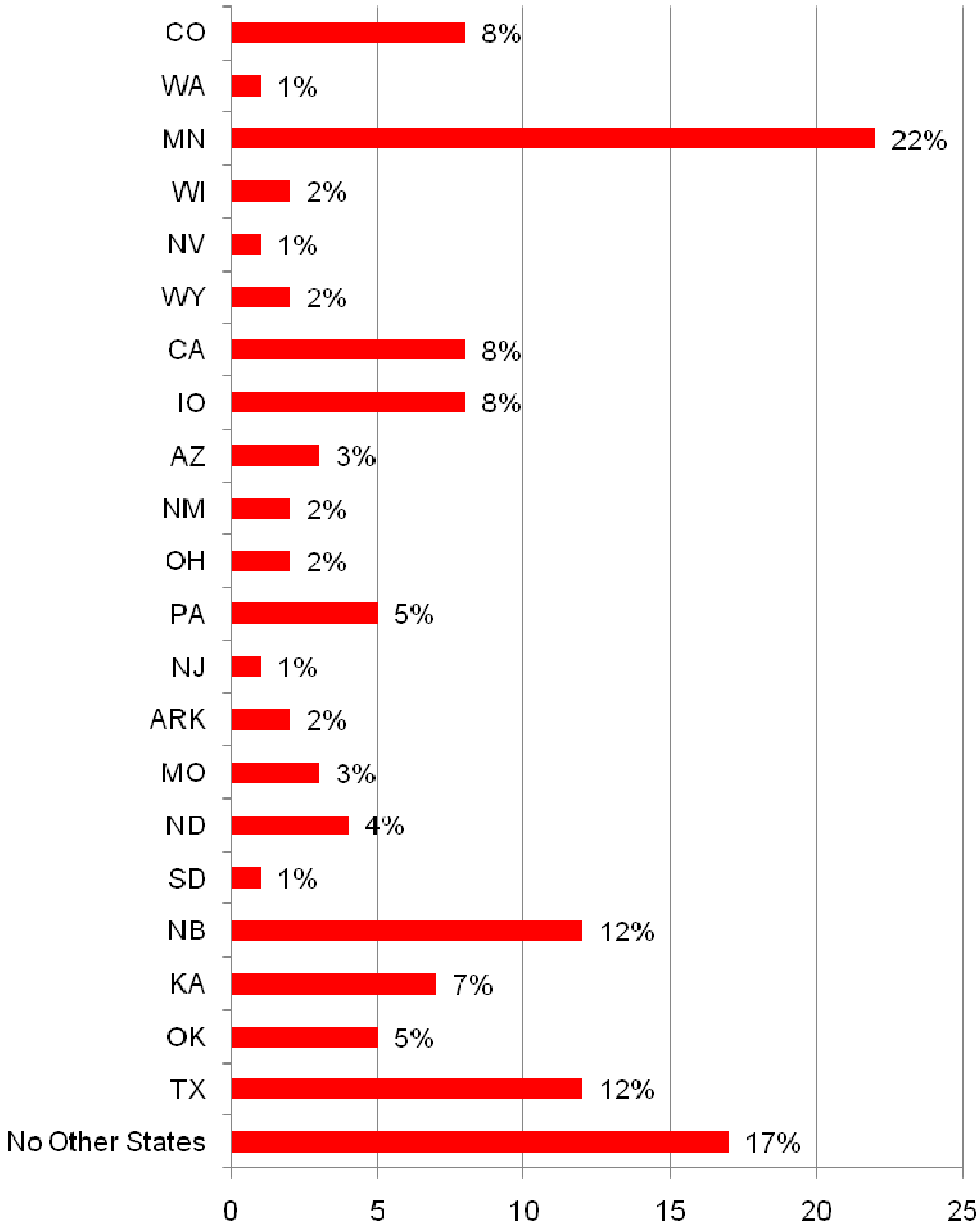


Number of Respondents = 55

Number of Accidents



Number of Respondents = 58



Number of Responses = 128

Preliminary Conclusions

- Major benefit
  - Potential for increased payload, yielding productivity gains, and higher revenues
- Major costs
  - Fuel and tires
  - Initial equipment investment
- Commodities varied by region
  - Tend to be bulk commodities
  - “Weigh out” rather than “cube out”

Preliminary Conclusions

- Major challenges
  - Qualified drivers
  - Varying LCV regulations by state
- Major costs
  - Tires and brakes
  - Fuel (initially)
  - Equipment investment
- Driver training varied
  - Function of company size

Preliminary Conclusions

- Compensation structures varied
  - Per mile
  - Per hour
  - Per ton/%
- 62% of respondents pay LCV drivers more
- ~ 50% of respondents LCVs not involved in accidents
  - Cause of accidents varied
    - Weather, driver error, other road users

Environmental and Energy Issues

Increased Congestion

- Congestion increased substantially from 1982 to 2003
  - While largest cities are most congested, congestion occurs (and has increased) in cities of every size
- Liberalizing limits and authorizing LCVs *could* reduce congestion
  - Fewer truck trips could possibly reduce traffic congestion

Fuel Efficiency

- After driver compensation, fuel costs are typically largest expenditure for heavy-duty vehicle operators
- At first glance
  - LCVs and trucks operating at heavier GVWs have lower fuel economy than regular 5 axle trucks at 60,000 and 80,000 lbs
  - However, LCVs carry heavier loads
  - More fuel efficient when loading capacity of LCV well utilized

ATRI Scenario

- ATRI (2008) compares energy and emissions of RMD with conventional 5 axle truck
- Scenario - 1,000 ton shipment moved 500 miles:

Type of Vehicle	Load (GVW in lbs)	No. of Trips	Fuel Economy (mpg)	Gallons Required for the Delivery	CO2 emissions (tons)	PM emissions (lbs)	NOx emissions (lbs)
5 Axle	80,000	42	5.4	3,889	--	--	--
RMD	120,000	27	4.2	3,215	- 7.5	- 34	- 0.16

Source: ATRI, 2008

Anheuser-Busch Scenario

- Anheuser-Busch evaluated potential benefits of using 97,000 lbs (6 axle) truck instead of 80,000 lbs (5 axle) truck

Route	Trucks per week at 80,000 lbs	Trucks per week at 97,000 lbs	Increase in cargo/ truck (lbs)	Reduction in diesel fuel/ week (gallons)	Reduction inCO2 emissions/ week (lbs)	Reduction on roads and bridges per week (lbs)
Houston to San Antonio (198 miles)	128	96	15,000	807	17,996	1,120,000
Houston to Waco (219 miles)	1,126	845	15,000	7,824	174,475	9,835,000

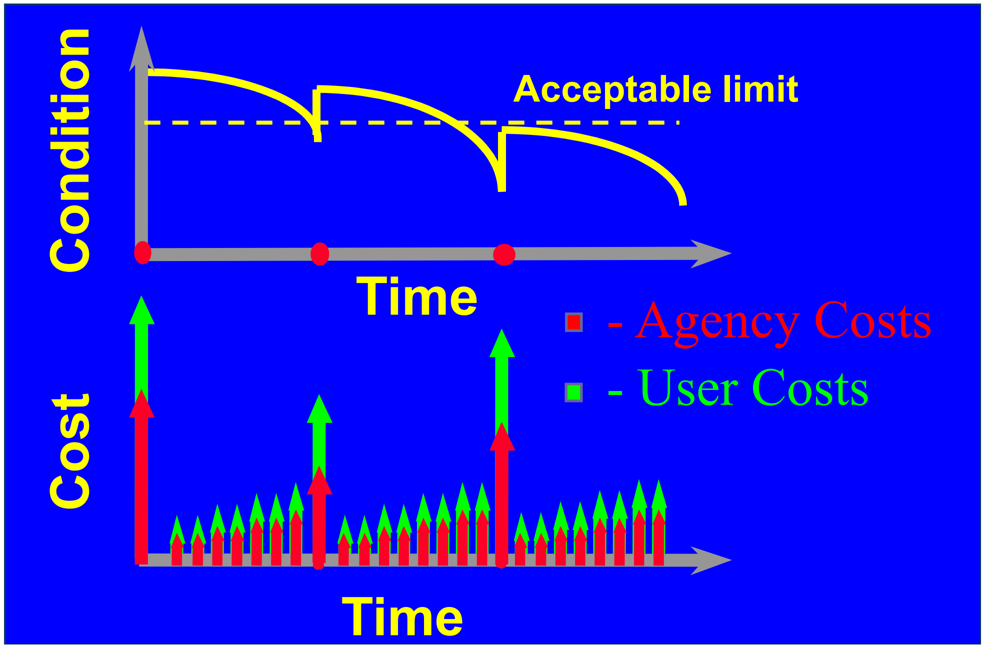
Source: Jacoby, 2008

Industry Perspectives

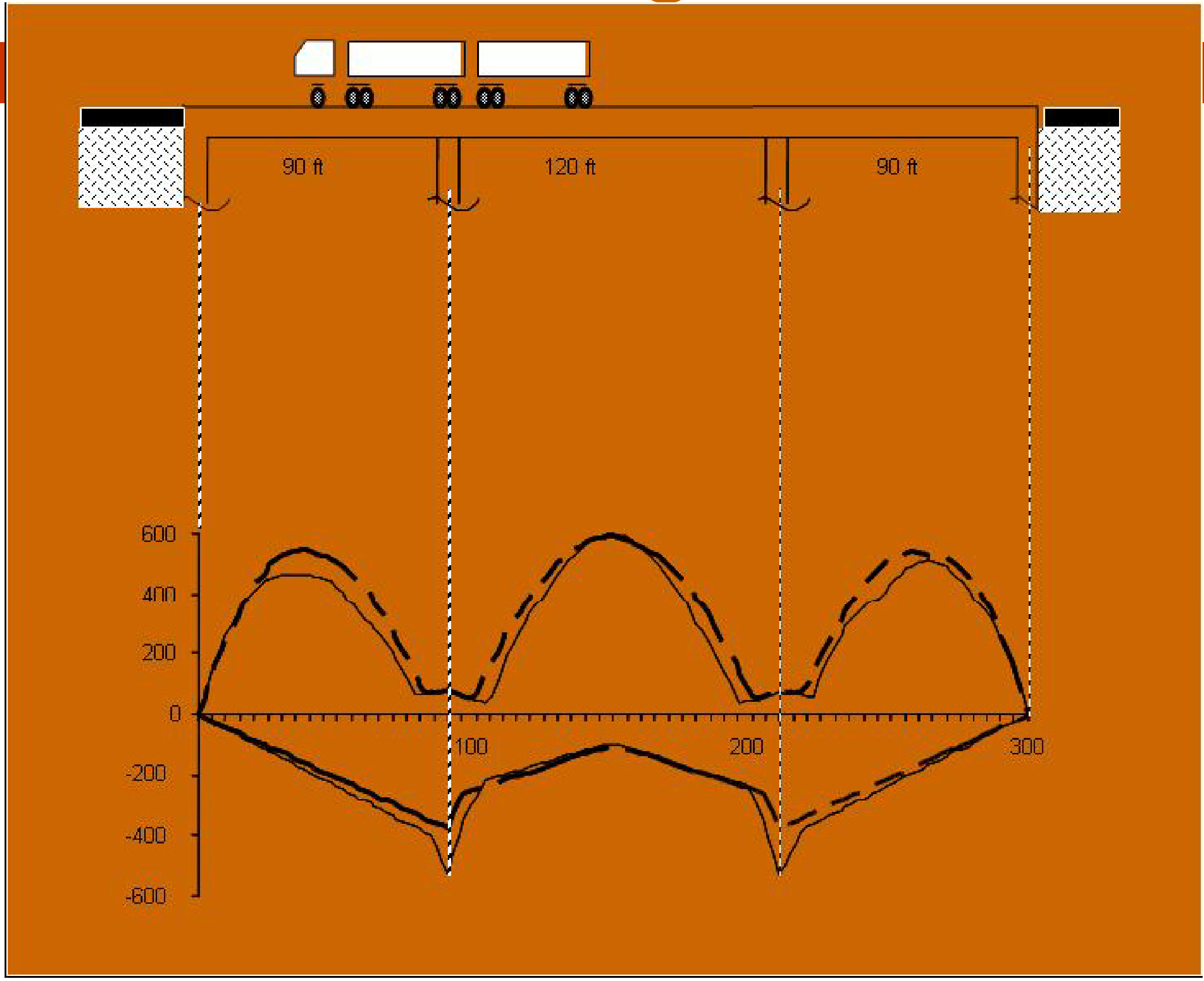
Bridge Impacts

Bridge Cost Allocation

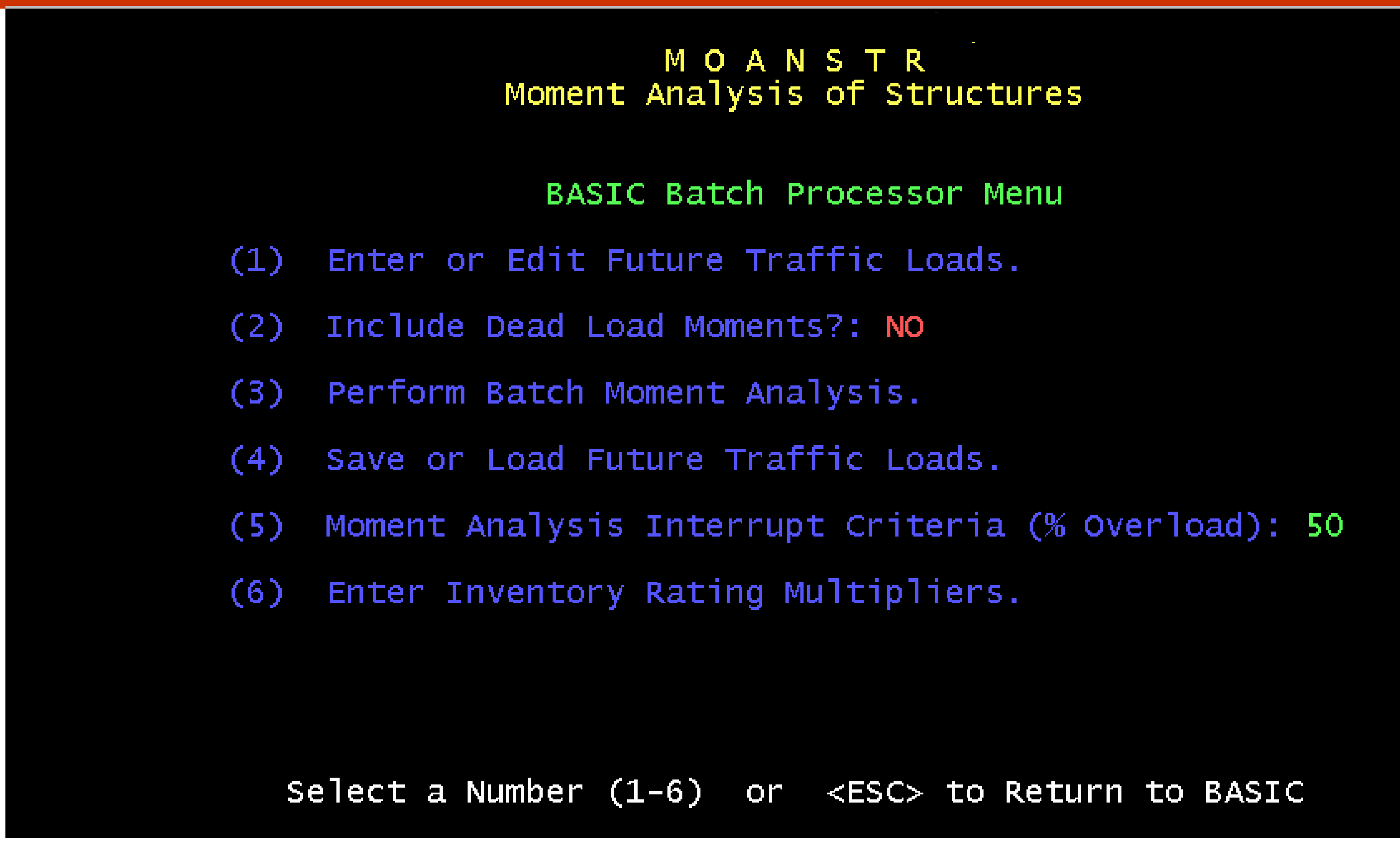
- Bridge Replacement, Maintenance/Rehabilitation and New Construction
  - Load related: Axle loads and configuration and GVW
  - Non-load related: Age and Environment
- Allocators
  - Load-related: Live-load bending moments
  - Non-load related: VMT,PCE
- Costs
  - TxDOT
  - 2030 Study
  - User Costs?
  - Analysis period
- Traffic
  - Forecasts
  - Economic Analysis



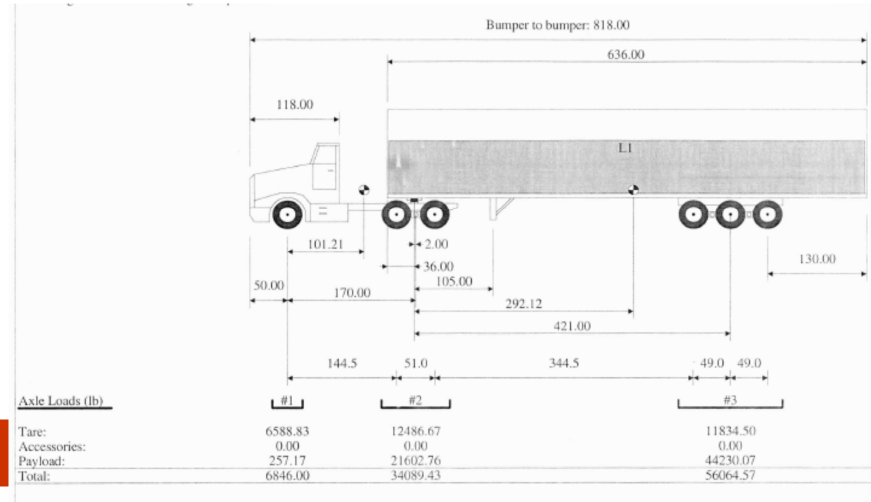
Live-load Bending Moments



Route Moment Analysis



Moment Ratios



Axle	Axle Loads
Steering	6,846
Tractor	34,089
Trailer	56,065
TOTAL	97,000

```
          3            14            35  -6846.00000000000
 -34000.0000000000        -56065.0000000000             1
ID #       M 0+        M 0-   MX.RAT +OR-     M 1+        M 1-   MX.RAT +OR-
36959, 0.312E+07, 0.000E+00,1.000,N/A, 0.505E+07, 0.000E+00,1.617,(+),
36960, 0.312E+07, 0.000E+00,1.000,N/A, 0.505E+07, 0.000E+00,1.617,(+),
36961, 0.312E+07, 0.000E+00,1.000,N/A, 0.505E+07, 0.000E+00,1.617,(+),
36962, 0.312E+07, 0.000E+00,1.000,N/A, 0.505E+07, 0.000E+00,1.617,(+),
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36969, 0.528E+07, 0.000E+00,1.000,N/A, 0.673E+07, 0.000E+00,1.274,(+),
36970, 0.528E+07, 0.000E+00,1.000,N/A, 0.673E+07, 0.000E+00,1.274,(+),
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36974, 0.229E+07, 0.000E+00,1.000,N/A, 0.437E+07, 0.000E+00,1.911,(+),
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36976, 0.240E+07, 0.000E+00,1.000,N/A, 0.420E+07, 0.000E+00,1.752,(+),
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36978, 0.220E+07, 0.000E+00,1.000,N/A, 0.420E+07, 0.000E+00,1.911,(+),
36979, 0.200E+07, 0.000E+00,1.000,N/A, 0.420E+07, 0.000E+00,2.102,(+),
```

Level I analysis

NCHRP
REPORT 495

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Effect of Truck Weight on Bridge Network Costs

$$RF_{AS} = RF_{BC}\,(M_{BC,\ rating\ vehicle}/M_{AS,\ rating\ vehicle})/AF_{rating} \qquad (3.5.1.1)$$

Bridge Fatigue

2003-16

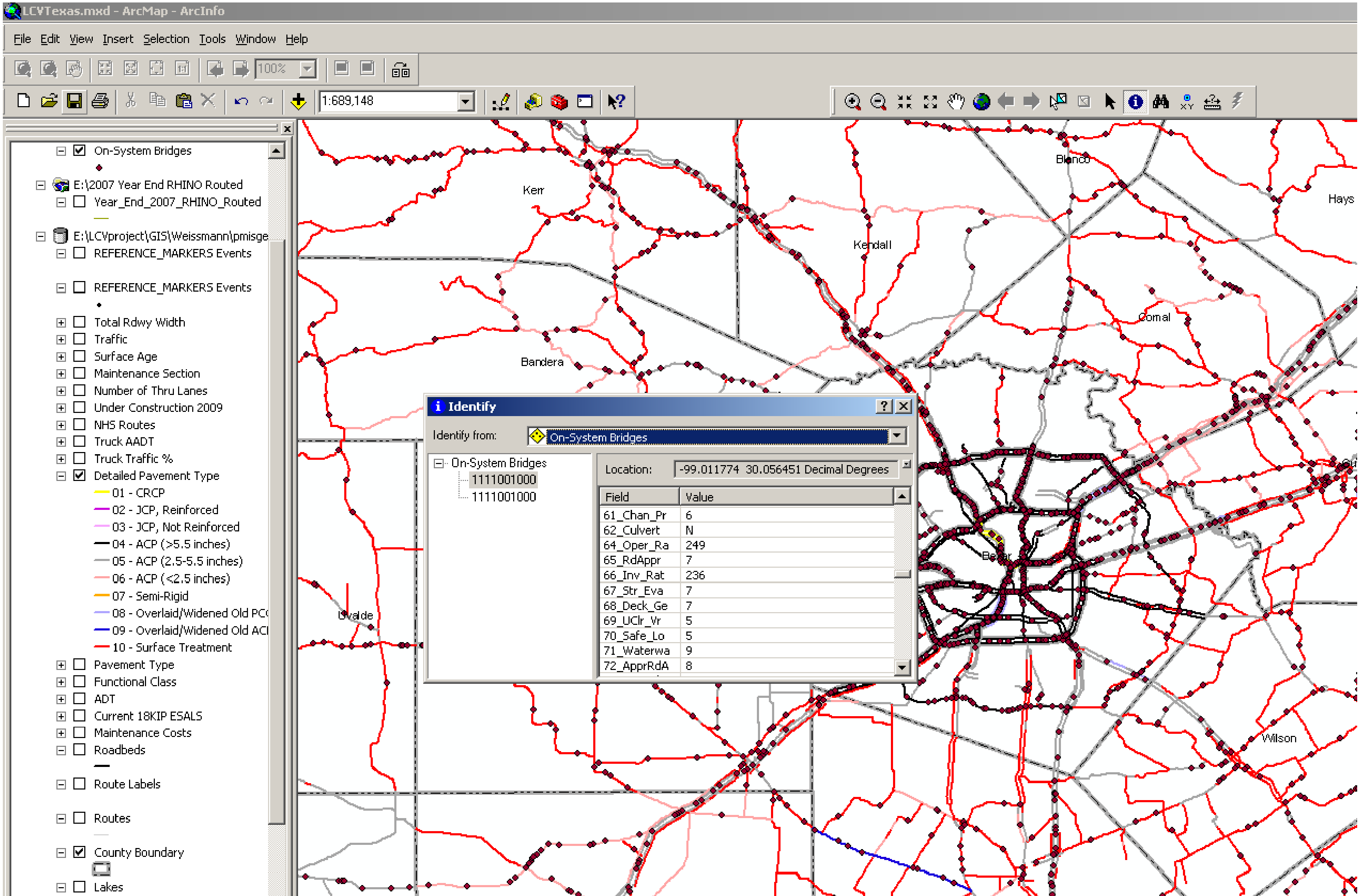
Final Report

Effects of Increasing Truck Weight on Steel and Prestressed Bridges

MINNESOTA DEPARTMENT OF TRANSPORTATION

Research

UTSA



GIS Data Bridges (BRINSAP/NBI)

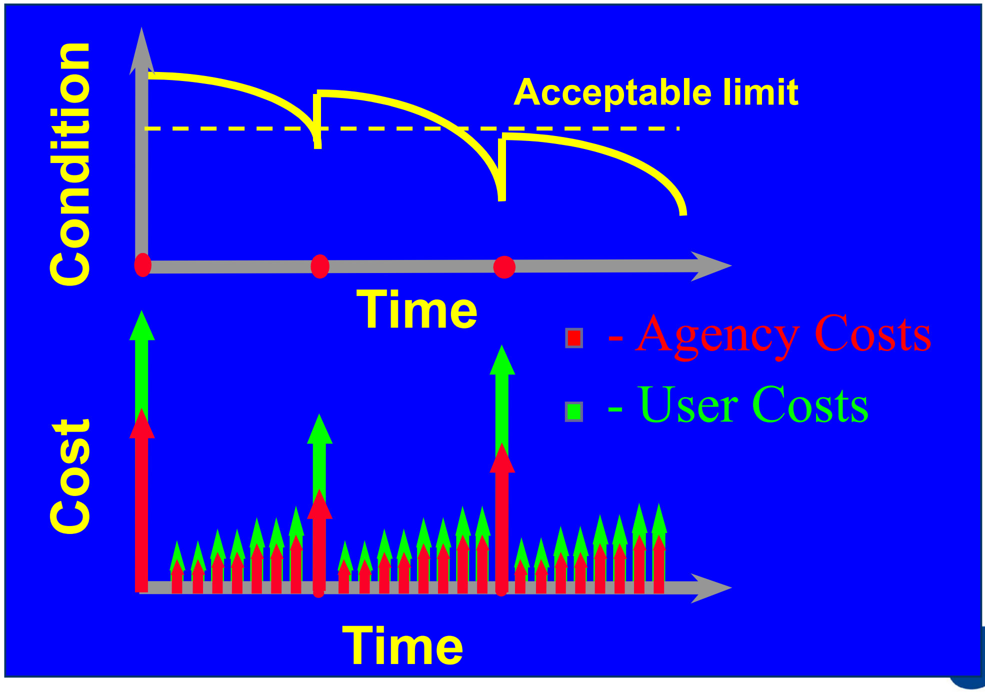
Case Study Framework
Bridge Costs Methodology

- Identify candidate vehicle, route and planning horizon.
- Retrieve bridge data with GIS.
- Forecast traffic based on economic inputs (volumes, classification and axle weights).
- Forecast bridge costs for route over planning horizon for LCV and no LCV and annualize.
- Allocate costs based on Cost Allocation methodologies.

Pavement Consumption

Pavement Cost Allocation

- Pavement Reconstruction, Rehabilitation and Resurfacing (3R) costs
  - Load-related: Axle loads
  - Nonload-related: Pavement age and climate
- Allocators
  - Load related: ESALs
  - Non-load related: VMT
- Costs
  - TxDOT
  - 2030 Study
  - User Costs?
  - Analysis period
- Traffic
  - Forecasts
  - Economic Analysis

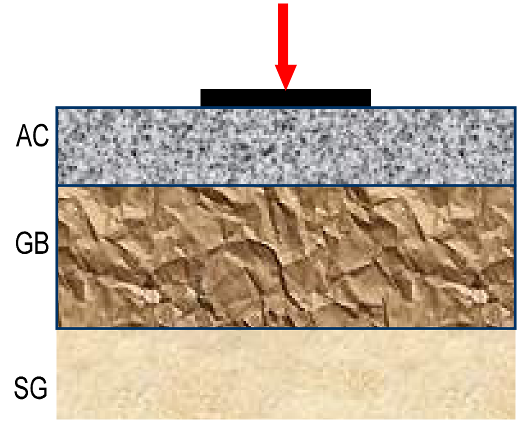


Pavement Load Related ESALs Flexible Empirical

$$\log\left(\frac{W_{tx}}{W_{t18}}\right) = 4.79\log(18+1) - 4.79\log(L_x + L_2) + 4.33\log(L_2) + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}} \quad \text{(Eq. 1)}$$

$$G_t = \log\left(\frac{4.2 - p_t}{4.2 - 1.5}\right) \quad \text{(Eq. 2)}$$

$$\beta_x = 0.40 + \frac{0.081(L_x + L_2)^{3.23}}{(SN+1)^{5.19} L_2^{3.23}} \quad \text{(Eq. 3)}$$



where

W_{tx} = number of applications of given axle
W_{t18} = number of standard axle passes (single 18 kip axle)
L_x = load in kips of axle group
L_2 = axle code (1 for single axle, 2 for tandem axles, 3 for tridem axles, and 4 for quad axles)
β_{18} = value of β_x when L_x = 18 and L_2 = 1
p_t = terminal serviceability
SN = structural number.

Pavement Load Related ESALs
Flexible Mechanistic

- Original ESAL definition:

$$ESAL_x = \frac{\rho_{18}}{\rho_x}$$

ρ_{18} ← axle cycles to terminal PSI from 18 kips

ρ_x ← axle cycles to terminal PSI from *x* kips

- Fatigue life N_f as a fn of tensile strain ε_t:

$$N_f = 0.0795\ \varepsilon_t^{-3.291} E^{-0.854}$$

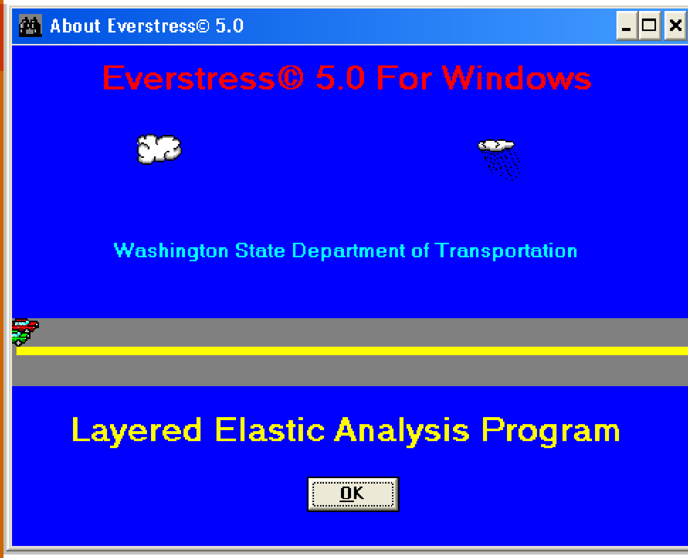
- Rutting life N_r as a fn of compressive strain ε_v:

$$N_r = 1.365\ 10^{-9}\ \varepsilon_v^{-4.477}$$

(Asphalt Institute Expressions)

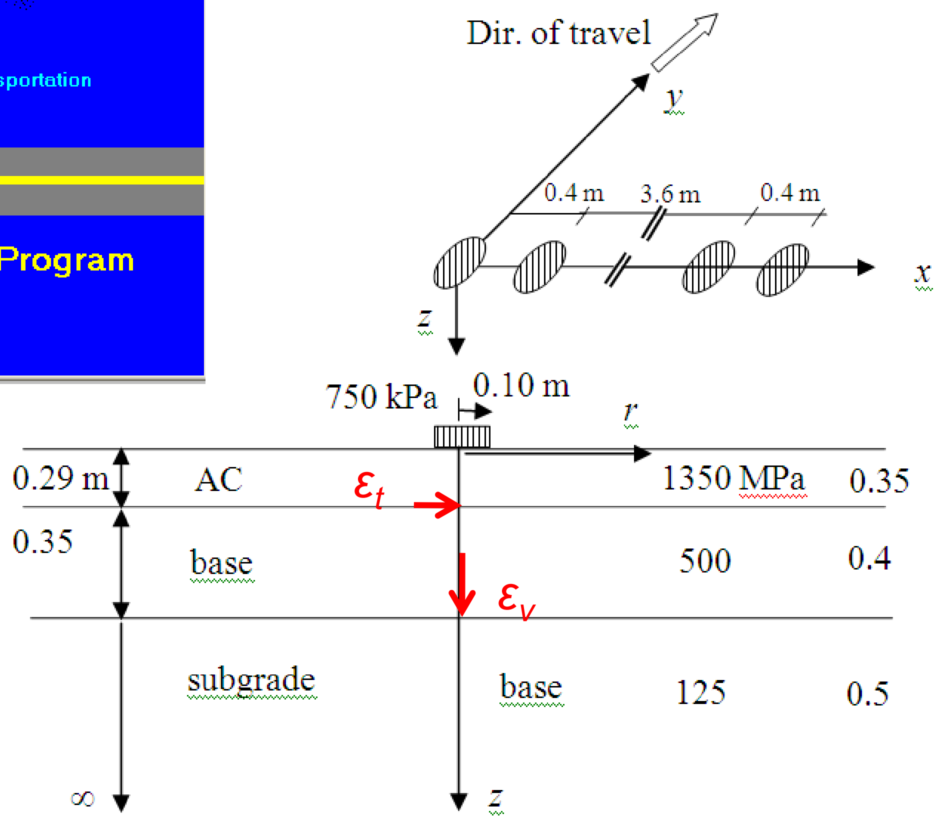
- Strains are computed with layered elastic analysis (e.g., *Everstress*).

Pavement Load Related ESALs Flexible Mechanistic



$$ESAL_x = \frac{\rho_{18}}{\rho_x} = \left(\frac{\varepsilon_{t\,x}}{\varepsilon_{t\,18}}\right)^{3.291}$$

$$ESAL_x = \frac{\rho_{18}}{\rho_x} = \left(\frac{\varepsilon_{v\,x}}{\varepsilon_{v\,18}}\right)^{4.477}$$



Pavement Load Related ESALs
Rigid Empirical

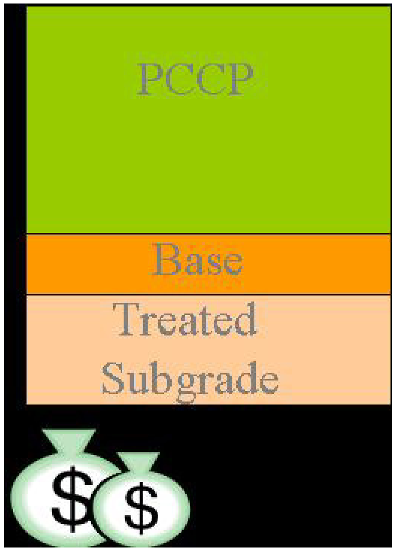
$$\log\left(\frac{W_{tx}}{W_{t18}}\right) = 4.62\log(18+1) - 4.62\log(L_x + L_2) + 3.28\log(L_2) + \frac{G_t}{\beta_x} - \frac{G_t}{\beta_{18}}$$

$$G_t = \log\left(\frac{4.5 - p_t}{4.5 - 1.5}\right)$$

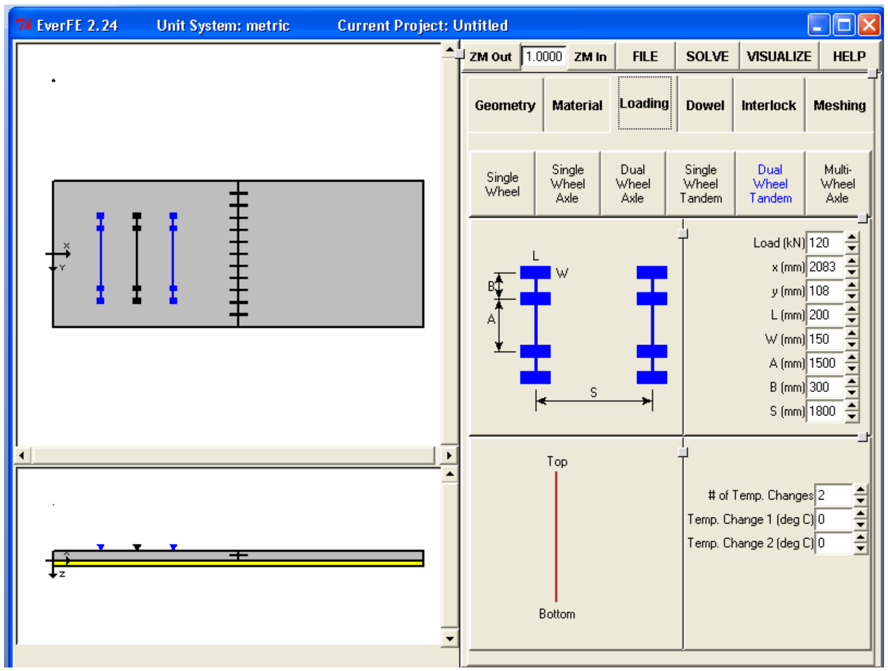
$$\beta_x = 1.00 + \frac{3.63(L_x + L_2)^{5.20}}{(D+1)^{8.46} L_2^{\ 3.52}}$$

where

W_{tx} = number of applications of given axle
W_{t18} = number of standard axle passes (single 18 kip axle)
L_x = load in kips of axle group
L_2 = axle code (1 for single axle, 2 for tandem axles, 3 for tridem axles, and 4 for quad axles)
β_{18} = value of β_x when L_x = 18 and L_2 = 1
p_t = terminal serviceability
D = slab thickness in inches.



Pavement Load Related ESALs
Rigid Mechanistic



$$ESAL_x = \frac{\rho_{18}}{\rho_x} = \frac{10^{2.0\left(\frac{MR}{\sigma_{18}}\right)^{1.22}+0.4371}}{10^{2.0\left(\frac{MR}{\sigma_x}\right)^{1.22}+0.4371}} = 10^{2.0\left[\left(\frac{MR}{\sigma_{18}}\right)^{1.22}-\left(\frac{MR}{\sigma_{1x}}\right)^{1.22}\right]}$$

Where *MR* is the Modulus of Rupture of the PC, (ASTM C 78)

Pavement Costs

District	Route	Lane-miles	Treatment	Trtmt Cost	Summary
Paris	IH 30	140.0	Nothing	$0	$0
Paris	IH 30	40.0	PM	$20,000	$8,000,000
Paris	IH 30	20.0	Light Rb	$80,000	$16,000,000
Paris	IH 30	20.0	Medium Rb	$200,000	$4,000,000
Paris	IH 30	20.0	Heavy Rb	$400,000	$8,000,000
		240.0	**Total Need = $36,000,000**		

Costs Attributable to Non-Load Factors

Table V-8. 2000 Proportion of Federal 3R Pavement Costs Attributable to Non-Load Factors

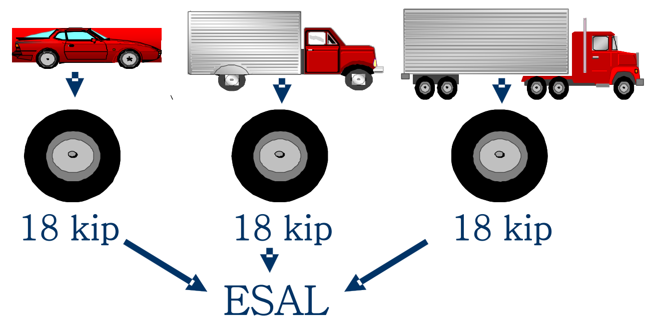
Functional Highway Class		Flexible Pavements (percent)	Rigid Pavements (percent)
Rural	Interstate	11.0	9.3
	Other Principal Arterials	12.1	15.7
	Minor Arterials	12.2	13.7
	Major Collectors	14.7	14.5
	Minor Collectors	14.7	14.5
	Local	14.7	14.5
Urban	Interstate	10.1	7.9
	Other Freeways/ Expressways	10.6	11.0
	Major Arterials	11.5	12.8
	Minor Arterials	12.7	16.3
	Collectors	13.9	20.5
	Local	13.9	20.5

Pavement Costs Traffic

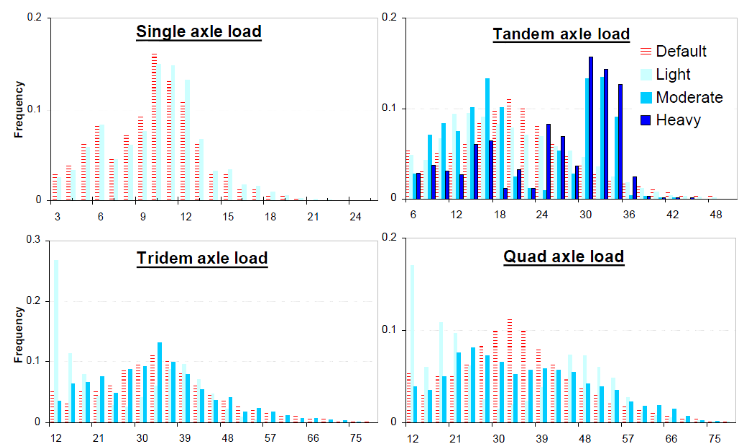
Traffic

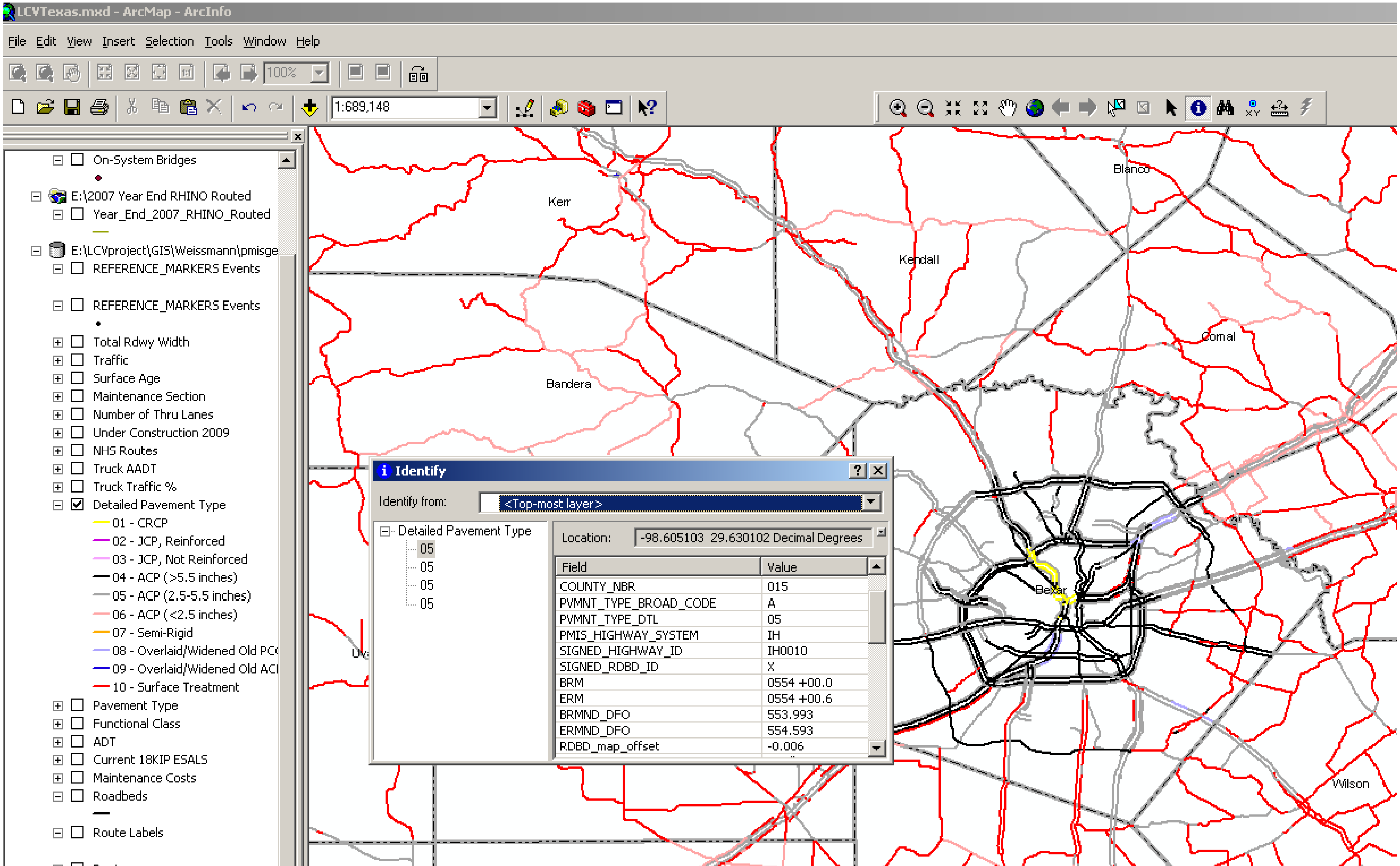
VMT

ESAL



Load Spectra





GIS Data (PMIS, Research Data, LTPP)

Case Study Framework
Pavement Costs Methodology

- Identify candidate vehicle, route and planning horizon.
- Retrieve pavement data with GIS.
- Forecast traffic based on economic inputs (volumes, classification and axle weights).
- Forecast pavement costs for route over planning horizon for LCV and no LCV and annualize.
- Allocate costs based on Cost Allocation methodologies.

Response

Next Stage of Research

Case Studies

LCV Case Study 1

- Existing Interstate Regional Corridor
  - NAFTA
  - Segment
  - LCV Types

LCV Case Study 2

- Existing State Corridor (IH and State)
  - IH-45/IH-37/SH 281
  - Segment
  - LCV Types

LCV Case Study 3

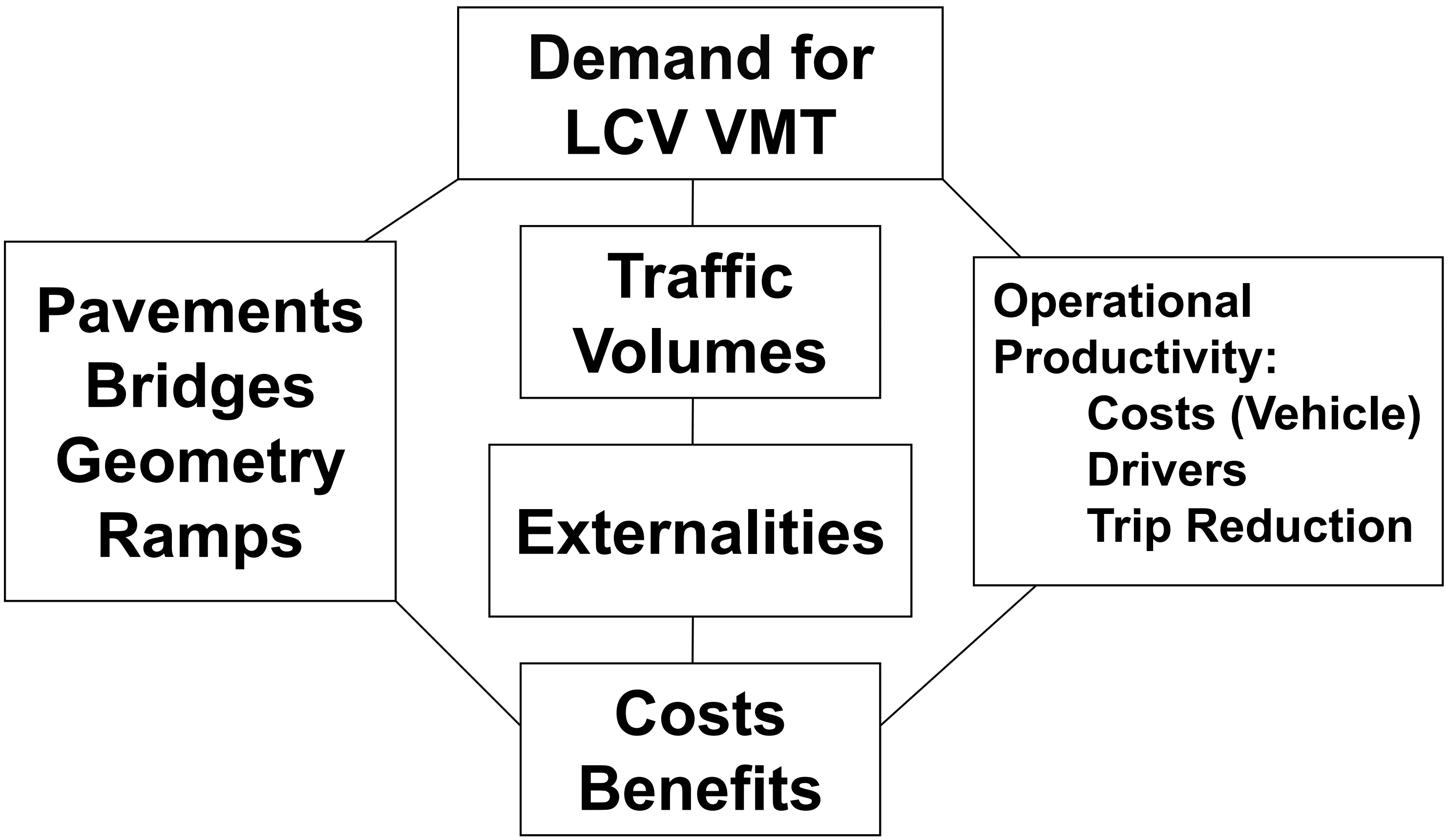
- Toll Road (all vehicles)
  - TTC
  - NAFTA (San Antonio)
  - LCV Types

LCV Case Study 4

- Truck-only Toll Road
  - Laredo-Corpus Christi
  - ICF Study
  - LCV Types

Evaluation Approach

Draft Evaluation Model



Evaluation Model

- Demand – loads and trips will vary between the case studies operational benefits.
- Vehicle Operating Costs – current vehicle types/LCV selected model(s)
- Infrastructure Costs – focus on bridges and pavement use factors for geometry and ramps
- Social Costs – emissions, noise for current vehicle types/LCV selected model(s)
- Economic Analysis

Schedule

Original Schedule

Work Completed

R/M *Revised Schedule/Modification*

Revision Date:

Note: A Tech Memo will be submitted to the PD & RTI at the end of each non-deliverable task

	Research Activity	Estimated % of Total Project Budget	FY 2009												FY 2010												FY 2011											
			Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug
Task 1	LCV Background and Issues	4%																																				
Task 2	Representative Vehicle Classes, Dimensions, and Specifications	2%																																				
Task 3	Highway Infrastructure for Larger Trucks	4%																																				
Task 4	First Project Advisory Meeting	2%																																				
Task 5	Bridge Impacts from LCV Operations	10%																																				
Task 6	Pavement Consumption and LCV Operations	12%																																				
Task 7	Larger Truck Operations	10%																																				
Task 8	Policy Implications of LCV Operations	10%																																				
Task 9	Summary of First Year Activities and Second Project Advisory Meeting	3%																																				
Task 10	LCV Case Study 1. An Existing Interstate Highway	10%																																				
Task 11	LCV Case Study 2. An Existing State Corridor	10%																																				
Task 12	LCV Case Study 3. Trans-Texas Corridor - TTC-35	10%																																				
Task 13	LCV Case Study 4. Truck Only Toll Road	10%																																				
Task 14	Final Report and Third Project Advisory Meeting	3%																																				
Total (should = 100%)		100%																																				

THANK YOU!