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Improving the Dynamic Performance of Multitrailer Vehicles: A Study of Innovative Dollies

Volume II

Appendices

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16. Abstract
This study of the dynamic performance of multitrailer articulated vehicles has led to the development of guidelines for the design of innovative dollies that will improve the roll stability and trailing fidelity of doubles combinations. The major effort of this project involved identification, analysis, and further development of innovative dolly and trailer hitching hardware showing potential for the reduction of rearward amplification and prevention of rollover of the second trailer. Specifically, the project (1) reviewed the current state-of-the-art in innovative coupling mechanisms, (2) performed a parametric sensitivity study, based on computer simulation techniques, on combination vehicles using existing and proposed coupling mechanisms, and incorporating various combinations of 96- and 102-in-width hardware, (3) developed a new type of dolly believed to provide superior safety performance, (4) conducted full-scale tests of combination vehicles using various dollies, including a prototype of the new dolly, and (5) examined the potential safety and economic impacts of the use of innovative dolly hardware.

This volume is the second in a series. The others in the series are:

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RD-86/162	I	Final Technical Report

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TABLE OF CONTENTS

VOLUME I: FINAL TECHNICAL REPORT

VOLUME II: APPENDICES

LIST OF TABLES

VOLUME II: APPENDICES

LIST OF FIGURES

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Appendix A

Example Listings of Simulated Vehicle Parameters For the Yaw/Roll Simulation

Table 42. Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the A-dolly.

```
*********************************
*DIRECTIONAL RESPONSE SIMULATION*
*********************************

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (A-TRAIN, FULL/FULL)

# OF SPRUNG MASSES        =  4

TOTAL # OF AXLES          =  5

GROSS VEHICLE WEIGHT      =   80000.00  LB.

FORWARD VELOCITY          =      55.00  M.P.H

PEAK FRICTIONAL COEFFICIENT   = 1.00
```

		DISTANCE AHEAD OF SPRUNG MASS C.G. (INCHES)	HEIGHT BELOW SPRUNG MASS C.G. (INCHES)	ROLL STIFFNESS (IN.LB/DEG)	TYPE OF CONSTRAINT
ARTICULATION PT # 1	ON UNIT # 1	-87.27	-4.00	999999.88	1
	ON UNIT # 2	138.40	33.30		
ARTICULATION PT # 2	ON UNIT # 2	-159.63	37.30	0.0	1
	ON UNIT # 3	80.00	0.0		
ARTICULATION PT # 3	ON UNIT # 3	0.0	-4.00	999999.88	1
	ON UNIT # 4	136.20	32.70		

```
TYPE OF CONSTRAINT :  01  CONVENTIONAL 5TH WHEEL
                      02  INVERTED 5TH WHEEL
                      03  PINTLE HOOK
                      04  KING PIN(RIGID IN ROLL & PITCH)
```

Table 42 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the A-dolly.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (A-TRAIN, FULL/FULL)

UNIT # 1
****

OF AXLES ON THIS UNIT = 2

WEIGHT OF SPRUNG MASS = 9700.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 15000.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 75000.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 75000.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 44.00 INCHES

	AXLE # 1	AXLE # 2	AXLE #		
	*********	*********	*********	*********	*********
LOAD ON EACH AXLE (LB.)	10000.00	17500.00			
AXLE WEIGHT (LB.)	1200.00	2300.00			
AXLE ROLL M.I (LB.IN.SEC**2)	3719.00	4458.00			
X DIST FROM SP MASS CG (IN)	24.00	-96.00			
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50	19.50			
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	23.00	29.00			
HALF SPRING SPACING (IN)	16.00	19.00			
HALF TRACK - INNER TIRES (IN)	40.00	29.50			
DUAL TIRE SPACING (IN)	0.0	13.00			
STIFFNESS OF EACH TIRE (LB/IN)	4500.00	4500.00			
ROLL STEER COEFFICIENT	0.0	0.0			
AUX ROLL STIFFNESS (IN.LB/DEG)	1500.00	8000.00			
SPRING COULOMB FRICTION - PER SPRING (LB)	300.00	1000.00			
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0	0.0			
SPRING TABLE #	1	2			
CORNERING FORCE TABLE #	1	1			
ALIGNING TORQUE TABLE #	1	1			

Table 42 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the A-dolly.

```
FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (A-TRAIN, FULL/FULL)

                                   UNIT #  2
                                   *********
# OF AXLES ON THIS UNIT =  1

WEIGHT OF SPRUNG MASS =   30300.00  LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS =  101204.00  LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS =  475638.00  LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS =  469434.00  LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND =      81.30  INCHES
```

	AXLE # 3	AXLE #			
LOAD ON EACH AXLE (LB.)	17500.00				
AXLE WEIGHT (LB.)	1500.00				
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00				
X DIST FROM SP MASS CG (IN)	-123.70				
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50				
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00				
HALF SPRING SPACING (IN)	19.00				
HALF TRACK - INNER TIRES (IN)	29.50				
DUAL TIRE SPACING (IN)	13.00				
STIFFNESS OF EACH TIRE (LB/IN)	4500.00				
ROLL STEER COEFFICIENT	0.0				
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00				
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00				
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0				
SPRING TABLE #	3				
CORNERING FORCE TABLE #	1				
ALIGNING TORQUE TABLE #	1				

Table 42 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the A-dolly.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (A-TRAIN, FULL/FULL)

UNIT # 3
****

OF AXLES ON THIS UNIT = 1

WEIGHT OF SPRUNG MASS = 1000.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 1900.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 2560.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 2560.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 44.00 INCHES

	AXLE # 4	AXLE #			
	*********	*********	*********	*********	*********
LOAD ON EACH AXLE (LB.)	17500.00				
AXLE WEIGHT (LB.)	1500.00				
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00				
X DIST FROM SP MASS CG (IN)	0.0				
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50				
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00				
HALF SPRING SPACING (IN)	19.00				
HALF TRACK - INNER TIRES (IN)	29.50				
DUAL TIRE SPACING (IN)	13.00				
STIFFNESS OF EACH TIRE (LB/IN)	4500.00				
ROLL STEER COEFFICIENT	0.0				
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00				
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00				
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0				
SPRING TABLE #	3				
CORNERING FORCE TABLE #	1				
ALIGNING TORQUE TABLE #	1				

Table 42 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the A-dolly.

```
FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (A-TRAIN, FULL/FULL)

                                 UNIT # 4
                                 *********
# OF AXLES ON THIS UNIT = 1

WEIGHT OF SPRUNG MASS =   31000.00  LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS =  108375.00  LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS =  497375.00  LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS =  490000.00  LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND =      80.70  INCHES
```

	AXLE # 5	AXLE #			
	*********	*********	*********	*********	*********
LOAD ON EACH AXLE (LB.)	17500.00				
AXLE WEIGHT (LB.)	1500.00				
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00				
X DIST FROM SP MASS CG (IN)	-127.80				
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50				
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00				
HALF SPRING SPACING (IN)	19.00				
HALF TRACK - INNER TIRES (IN)	29.50				
DUAL TIRE SPACING (IN)	13.00				
STIFFNESS OF EACH TIRE (LB/IN)	4500.00				
ROLL STEER COEFFICIENT	0.0				
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00				
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00				
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0				
SPRING TABLE #	3				
CORNERING FORCE TABLE #	1				
ALIGNING TORQUE TABLE #	1				

Table 42 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the A-dolly.

SPRING TABLE # 1
****** *******

FORCE LB	DEFLECTION INCHES
-20000.00	-20.00
0.0	0.0
8645.00	7.20
25000.00	7.50

SPRING TABLE # 2
****** *******

FORCE LB	DEFLECTION INCHES
-29800.00	-11.00
0.0	-1.00
0.0	0.0
4650.00	1.00
7650.00	1.50
11650.00	2.00
16300.00	2.50
21600.00	3.00
59500.00	4.00

SPRING TABLE # 3
****** *******

FORCE LB	DEFLECTION INCHES
-40500.00	-11.00
0.0	-1.50
0.0	0.0
2812.00	0.50
7188.00	1.00
12175.00	1.50
17913.00	2.00
24063.00	2.50
56000.00	3.00

Table 42 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the A-dolly.

CORNERING FORCE TABLE # 1
********* ***** *********

LATERAL FORCE VS. SLIP ANGLE

0.0	1.00	2.00	4.00	6.00	12.00
3000.00	540.00	990.00	1710.00	2130.00	2490.00
6000.00	840.00	1500.00	2760.00	3480.00	4140.00
9000.00	990.00	1710.00	3420.00	4680.00	6210.00

ALIGNING TORQUE TABLE # 1
******** ****** *********

ALIGNING TORQUE VS. SLIP ANGLE

0.0	1.00	3.00	4.00	5.00	7.00	10.00
3000.00	660.00	1104.00	1200.00	1440.00	1500.00	1200.00
6000.00	1560.00	3132.00	3600.00	4248.00	4476.00	3984.00
9000.00	2400.00	5424.00	6396.00	7500.00	7800.00	6780.00

Table 43. Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Asymmetric Trapezoidal Dolly in the Forward IC Condition.

```
*********************************
*DIRECTIONAL RESPONSE SIMULATION*
*********************************

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (4-BAR FORWARD, FULL/FULL)

# OF SPRUNG MASSES      =  4

TOTAL # OF AXLES        =  5

GROSS VEHICLE WEIGHT    =   80000.00  LB.

FORWARD VELOCITY        =      55.00  M.P.H

PEAK FRICTIONAL COEFFICIENT   =  1.00
```

		DISTANCE AHEAD OF SPRUNG MASS C.G. (INCHES)	HEIGHT BELOW SPRUNG MASS C.G. (INCHES)	ROLL STIFFNESS (IN.LB/DEG)	TYPE OF CONSTRAINT
ARTICULATION PT # 1	ON UNIT # 1	-87.27	-4.00	999999.88	1
	ON UNIT # 2	138.40	33.30		
ARTICULATION PT # 2	ON UNIT # 2	-41.00	37.30	0.0	1
	ON UNIT # 3	198.50	0.0		
ARTICULATION PT # 3	ON UNIT # 3	0.0	-4.00	999999.88	1
	ON UNIT # 4	136.20	32.70		

```
TYPE OF CONSTRAINT :  01  CONVENTIONAL 5TH WHEEL
                      02  INVERTED 5TH WHEEL
                      03  PINTLE HOOK
                      04  KING PIN(RIGID IN ROLL & PITCH)
```

Table 43 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Asymmetric Trapezoidal Dolly in the Forward IC Condition.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (4-BAR FORWARD, FULL/FULL)

UNIT # 1
****

OF AXLES ON THIS UNIT = 2

WEIGHT OF SPRUNG MASS = 9700.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 15000.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 75000.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 75000.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 44.00 INCHES

	AXLE # 1	AXLE # 2
LOAD ON EACH AXLE (LB.)	10000.00	17500.00
AXLE WEIGHT (LB.)	1200.00	2300.00
AXLE ROLL M.I (LB.IN.SEC**2)	3719.00	4458.00
X DIST FROM SP MASS CG (IN)	24.00	-96.00
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	23.00	29.00
HALF SPRING SPACING (IN)	16.00	19.00
HALF TRACK - INNER TIRES (IN)	40.00	29.50
DUAL TIRE SPACING (IN)	0.0	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00	4500.00
ROLL STEER COEFFICIENT	0.0	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	1500.00	8000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	300.00	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0	0.0
SPRING TABLE #	1	2
CORNERING FORCE TABLE #	1	1
ALIGNING TORQUE TABLE #	1	1

Table 43 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Asymmetric Trapezoidal Dolly in the Forward IC Condition.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (4-BAR FORWARD, FULL/FULL)

UNIT # 2
****

OF AXLES ON THIS UNIT = 1

WEIGHT OF SPRUNG MASS = 30300.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 101204.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 475638.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 469434.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 81.30 INCHES

	AXLE # 3
LOAD ON EACH AXLE (LB.)	17500.00
AXLE WEIGHT (LB.)	1500.00
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00
X DIST FROM SP MASS CG (IN)	-123.70
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00
HALF SPRING SPACING (IN)	19.00
HALF TRACK - INNER TIRES (IN)	29.50
DUAL TIRE SPACING (IN)	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00
ROLL STEER COEFFICIENT	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0
SPRING TABLE #	3
CORNERING FORCE TABLE #	1
ALIGNING TORQUE TABLE #	1

Table 43 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Asymmetric Trapezoidal Dolly in the Forward IC Condition.

```
FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (4-BAR FORWARD, FULL/FULL)

                        UNIT # 3
                        *********
# OF AXLES ON THIS UNIT =  1

WEIGHT OF SPRUNG MASS =    1000.00  LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS =    1900.00  LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS =    2560.00  LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS =    2560.00  LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND =     44.00  INCHES
```

	AXLE # 4
LOAD ON EACH AXLE (LB.)	17500.00
AXLE WEIGHT (LB.)	1500.00
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00
X DIST FROM SP MASS CG (IN)	0.0
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00
HALF SPRING SPACING (IN)	19.00
HALF TRACK - INNER TIRES (IN)	29.50
DUAL TIRE SPACING (IN)	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00
ROLL STEER COEFFICIENT	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0
SPRING TABLE #	3
CORNERING FORCE TABLE #	1
ALIGNING TORQUE TABLE #	1

Table 43 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Asymmetric Trapezoidal Dolly in the Forward IC Condition.

```
FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (4-BAR FORWARD, FULL/FULL)

                                 UNIT # 4
                                 ********
# OF AXLES ON THIS UNIT =  1

WEIGHT OF SPRUNG MASS =   31000.00  LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS =  108375.00  LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS =  497375.00  LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS =  490000.00  LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND =      80.70  INCHES

                     AXLE # 5
                     ********

 LOAD ON EACH AXLE (LB.)         17500.00

 AXLE WEIGHT (LB.)                1500.00

 AXLE ROLL M.I (LB.IN.SEC**2)     4100.00

 X DIST FROM SP MASS CG (IN)      -127.80

 HEIGHT OF AXLE C.G. ABOVE          19.50
            GROUND (INCHES)

 HEIGHT OF ROLL CENTER ABOVE        29.00
            GROUND (INCHES)

 HALF SPRING SPACING (IN)           19.00

 HALF TRACK - INNER TIRES (IN)      29.50

 DUAL TIRE SPACING (IN)             13.00

STIFFNESS OF EACH TIRE (LB/IN)    4500.00

 ROLL STEER COEFFICIENT              0.0

AUX ROLL STIFFNESS (IN.LB/DEG)   10000.00

 SPRING COULOMB FRICTION -        1000.00
            PER SPRING (LB)

VISCOUS DAMPING PER SPRING           0.0
              (LB.SEC/IN)

SPRING TABLE #                       3

  CORNERING FORCE TABLE #            1

  ALIGNING TORQUE TABLE #            1
```

Table 43 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Asymmetric Trapezoidal Dolly in the Forward IC Condition.

SPRING TABLE # 1
****** *******

FORCE LB	DEFLECTION INCHES
-20000.00	-20.00
0.0	0.0
8645.00	7.20
25000.00	7.50

SPRING TABLE # 2
****** *******

FORCE LB	DEFLECTION INCHES
-29800.00	-11.00
0.0	-1.00
0.0	0.0
4650.00	1.00
7650.00	1.50
11650.00	2.00
16300.00	2.50
21600.00	3.00
59500.00	4.00

SPRING TABLE # 3
****** *******

FORCE LB	DEFLECTION INCHES
-40500.00	-11.00
0.0	-1.50
0.0	0.0
2812.00	0.50
7188.00	1.00
12175.00	1.50
17913.00	2.00
24063.00	2.50
56000.00	3.00

Table 43 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Asymmetric Trapezoidal Dolly in the Forward IC Condition.

CORNERING FORCE TABLE # 1
********* ***** *********

LATERAL FORCE VS. SLIP ANGLL

0.0	1.00	2.00	4.00	6.00	12.00
3000.00	540.00	990.00	1710.00	2130.00	2490.00
6000.00	840.00	1500.00	2760.00	3480.00	4140.00
9000.00	990.00	1710.00	3420.00	4680.00	6210.00

ALIGNING TORQUE TABLE # 1
******** ****** *********

ALIGNING TORQUE VS. SLIP ANGLE

0.0	1.00	3.00	4.00	5.00	7.00	10.00
3000.00	660.00	1104.00	1200.00	1440.00	1500.00	1200.00
6000.00	1560.00	3132.00	3600.00	4248.00	4476.00	3984.00
9000.00	2400.00	5424.00	6396.00	7500.00	7800.00	6780.00

Table 44. Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Linked-Articulation Dolly with 0.44 System Gain.

```
*********************************
*DIRECTIONAL RESPONSE SIMULATION*
*********************************


FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (LINKED ARTIC GAIN .44 FULL/FULL)

# OF SPRUNG MASSES       =  4

TOTAL # OF AXLES         =  5

GROSS VEHICLE WEIGHT     =   80000.00  LB.

FORWARD VELOCITY         =      55.00  M.P.H


PEAK FRICTIONAL COEFFICIENT   = 1.00


                                        DISTANCE AHEAD    HEIGHT BELOW   ROLL STIFFNESS    TYPE OF
                                        OF SPRUNG MASS    SPRUNG MASS    (IN.LB/DEG)       CONSTRAINT
                                        C.G. (INCHES)    C.G. (INCHES)

                 ON UNIT # 1                 -87.27           -4.00       999999.88           1
ARTICULATION PT # 1
                 ON UNIT # 2                 138.40           33.30

                 ON UNIT # 2                -159.63           37.30          0.0              1
ARTICULATION PT # 2
                 ON UNIT # 3                  80.00            0.0

                 ON UNIT # 3                   0.0            -4.00       999999.88           1
ARTICULATION PT # 3
                 ON UNIT # 4                 136.20           32.70

LINKED ARTICULATION:  GAIN:          0.44      STIFFNESS:  10000000.00 (IN-LB/DEG GAMMA2)

TYPE OF CONSTRAINT :  01  CONVENTIONAL 5TH WHEEL
                      02  INVERTED 5TH WHEEL
                      03  PINTLE HOOK
                      04  KING PIN(RIGID IN ROLL & PITCH)
```

Table 44 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Linked-Articulation Dolly with 0.44 System Gain.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (LINKED ARTIC GAIN .44 FULL/FULL)

UNIT # 1
****

OF AXLES ON THIS UNIT = 2

WEIGHT OF SPRUNG MASS = 9700.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 15000.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 75000.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 75000.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 44.00 INCHES

	AXLE # 1	AXLE # 2
LOAD ON EACH AXLE (LB.)	10000.00	17500.00
AXLE WEIGHT (LB.)	1200.00	2300.00
AXLE ROLL M.I (LB.IN.SEC**2)	3719.00	4458.00
X DIST FROM SP MASS CG (IN)	24.00	-96.00
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	23.00	29.00
HALF SPRING SPACING (IN)	16.00	19.00
HALF TRACK - INNER TIRES (IN)	40.00	29.50
DUAL TIRE SPACING (IN)	0.0	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00	4500.00
ROLL STEER COEFFICIENT	0.0	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	1500.00	8000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	300.00	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0	0.0
SPRING TABLE #	1	2
CORNERING FORCE TABLE #	1	1
ALIGNING TORQUE TABLE #	1	1

Table 44 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Linked-Articulation Dolly with 0.44 System Gain.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (LINKED ARTIC GAIN .44 FULL/FULL)

UNIT # 2
****

OF AXLES ON THIS UNIT = 1

WEIGHT OF SPRUNG MASS = 30300.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 101204.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 475638.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 469434.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 81.30 INCHES

	AXLE # 3
LOAD ON EACH AXLE (LB.)	17500.00
AXLE WEIGHT (LB.)	1500.00
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00
X DIST FROM SP MASS CG (IN)	-123.70
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00
HALF SPRING SPACING (IN)	19.00
HALF TRACK - INNER TIRES (IN)	29.50
DUAL TIRE SPACING (IN)	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00
ROLL STEER COEFFICIENT	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0
SPRING TABLE #	3
CORNERING FORCE TABLE #	1
ALIGNING TORQUE TABLE #	1

Table 44 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Linked-Articulation Dolly with 0.44 System Gain.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (LINKED ARTIC GAIN .44 FULL/FULL)

UNIT # 3
****

OF AXLES ON THIS UNIT = 1

WEIGHT OF SPRUNG MASS = 1000.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 1900.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 2560.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 2560.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 44.00 INCHES

	AXLE # 4
LOAD ON EACH AXLE (LB.)	17500.00
AXLE WEIGHT (LB.)	1500.00
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00
X DIST FROM SP MASS CG (IN)	0.0
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00
HALF SPRING SPACING (IN)	19.00
HALF TRACK - INNER TIRES (IN)	29.50
DUAL TIRE SPACING (IN)	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00
ROLL STEER COEFFICIENT	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0
SPRING TABLE #	3
CORNERING FORCE TABLE #	1
ALIGNING TORQUE TABLE #	1

Table 44 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Linked-Articulation Dolly with 0.44 System Gain.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (LINKED ARTIC GAIN .44 FULL/FULL)

UNIT # 4
****

OF AXLES ON THIS UNIT = 1

WEIGHT OF SPRUNG MASS = 31000.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 108375.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 497375.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 490000.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 80.70 INCHES

	AXLE # 5
LOAD ON EACH AXLE (LB.)	17500.00
AXLE WEIGHT (LB.)	1500.00
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00
X DIST FROM SP MASS CG (IN)	-127.80
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00
HALF SPRING SPACING (IN)	19.00
HALF TRACK - INNER TIRES (IN)	29.50
DUAL TIRE SPACING (IN)	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00
ROLL STEER COEFFICIENT	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0
SPRING TABLE #	3
CORNERING FORCE TABLE #	1
ALIGNING TORQUE TABLE #	1

Table 44 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Linked-Articulation Dolly with 0.44 System Gain.

SPRING TABLE # 1
****** *******

FORCE LB	DEFLECTION INCHES
-20000.00	-20.00
0.0	0.0
8645.00	7.20
25000.00	7.50

SPRING TABLE # 2
****** *******

FORCE LB	DEFLECTION INCHES
-29800.00	-11.00
0.0	-1.00
0.0	0.0
4650.00	1.00
7650.00	1.50
11650.00	2.00
16300.00	2.50
21600.00	3.00
59500.00	4.00

SPRING TABLE # 3
****** *******

FORCE LB	DEFLECTION INCHES
-40500.00	-11.00
0.0	-1.50
0.0	0.0
2812.00	0.50
7188.00	1.00
12175.00	1.50
17913.00	2.00
24063.00	2.50
56000.00	3.00

Table 44 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Linked-Articulation Dolly with 0.44 System Gain.

CORNERING FORCE TABLE # 1
******** ***** ********

LATERAL FORCE VS. SLIP ANGLL

0.0	1.00	2.00	4.00	6.00	12.00
3000.00	540.00	990.00	1710.00	2130.00	2490.00
6000.00	840.00	1500.00	2760.00	3480.00	4140.00
9000.00	990.00	1710.00	3420.00	4680.00	6210.00

ALIGNING TORQUE TABLE # 1
******** ****** ********

ALIGNING TORQUE VS. SLIP ANGLE

0.0	1.00	3.00	4.00	5.00	7.00	10.00
3000.00	660.00	1104.00	1200.00	1440.00	1500.00	1200.00
6000.00	1560.00	3132.00	3600.00	4248.00	4476.00	3984.00
9000.00	2400.00	5424.00	6396.00	7500.00	7800.00	6780.00

Table 45. Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Self-Steering B-Dolly with Full Resistance Steering.

```
********************************
*DIRECTIONAL RESPONSE SIMULATION*
********************************

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (SA1 FULL/FULL)

# OF SPRUNG MASSES        =  4

TOTAL # OF AXLES          =  5

GROSS VEHICLE WEIGHT      =   80000.00  LB.

FORWARD VELOCITY          =      55.00  M.P.H

PEAK FRICTIONAL COEFFICIENT   = 1.00
```

		DISTANCE AHEAD OF SPRUNG MASS C.G. (INCHES)	HEIGHT BELOW SPRUNG MASS C.G. (INCHES)	ROLL STIFFNESS (IN.LB/DEG)	TYPE OF CONSTRAINT
ARTICULATION PT # 1	ON UNIT # 1	-87.27	-4..00	999999.88	1
	ON UNIT # 2	138.40	33.30		
ARTICULATION PT # 2	ON UNIT # 2	-159.63	37.30	59999.99	1
	ON UNIT # 3	80.00	0.0		
ARTICULATION PT # 3	ON UNIT # 3	0.0	-4.00	999999.88	1
	ON UNIT # 4	136.20	32.70		

```
LINKED ARTICULATION:  GAIN:        0.00     STIFFNESS:  10000000.00 (IN-LB/DEG GAMMA2)

TYPE OF CONSTRAINT :  01  CONVENTIONAL 5TH WHEEL
                      02  INVERTED 5TH WHEEL
                      03  PINTLE HOOK
                      04  KING PIN(RIGID IN ROLL & PITCH)
```

Table 45 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Self-Steering B-Dolly with Full Resistance Steering.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (SA1 FULL/FULL)

UNIT # 1
****

OF AXLES ON THIS UNIT = 2

WEIGHT OF SPRUNG MASS = 9700.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 15000.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 75000.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 75000.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 44.00 INCHES

	AXLE # 1	AXLE # 2
LOAD ON EACH AXLE (LB.)	10000.00	17500.00
AXLE WEIGHT (LB.)	1200.00	2300.00
AXLE ROLL M.I (LB.IN.SEC**2)	3719.00	4458.00
X DIST FROM SP MASS CG (IN)	24.00	-96.00
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	23.00	29.00
HALF SPRING SPACING (IN)	16.00	19.00
HALF TRACK - INNER TIRES (IN)	40.00	29.50
DUAL TIRE SPACING (IN)	0.0	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00	4500.00
ROLL STEER COEFFICIENT	0.0	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	1500.00	8000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	300.00	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0	0.0
SPRING TABLE #	1	2
CORNERING FORCE TABLE #	1	1
ALIGNING TORQUE TABLE #	1	1

Table 45 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Self-Steering B-Dolly with Full Resistance Steering.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (SA1 FULL/FULL)

UNIT # 2
****

OF AXLES ON THIS UNIT = 1

WEIGHT OF SPRUNG MASS = 30300.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 101204.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 475638.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 469434.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 81.30 INCHES

	AXLE # 3
LOAD ON EACH AXLE (LB.)	17500.00
AXLE WEIGHT (LB.)	1500.00
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00
X DIST FROM SP MASS CG (IN)	-123.70
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00
HALF SPRING SPACING (IN)	19.00
HALF TRACK - INNER TIRES (IN)	29.50
DUAL TIRE SPACING (IN)	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00
ROLL STEER COEFFICIENT	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0
SPRING TABLE #	3
CORNERING FORCE TABLE #	1
ALIGNING TORQUE TABLE #	1

Table 45 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Self-Steering B-Dolly with Full Resistance Steering.

```
FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (SA1 FULL/FULL)

                               UNIT #  3
                               *********
# OF AXLES ON THIS UNIT =  1

WEIGHT OF SPRUNG MASS =     1000.00  LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS =     1900.00  LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS =     2560.00  LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS =     2560.00  LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND =      44.00  INCHES
```

	AXLE # 4
LOAD ON EACH AXLE (LB.)	17500.00
AXLE WEIGHT (LB.)	1500.00
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00
X DIST FROM SP MASS CG (IN)	0.0
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00
HALF SPRING SPACING (IN)	19.00
HALF TRACK - INNER TIRES (IN)	29.50
DUAL TIRE SPACING (IN)	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00
ROLL STEER COEFFICIENT	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0
SPRING TABLE #	3
CORNERING FORCE TABLE #	1
ALIGNING TORQUE TABLE #	1

Table 45 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Self-Steering B-Dolly with Full Resistance Steering.

```
AXLE   4 IS SELF STEERING

PRIMARY STIFFNESS, IN-LB/DEG:1000000.00
COULOMB FRICTION,IN-LB:  30000.00
MECHANICAL TRAIL, INCHES:       5.00

STEERING TORQUE AND DISPLACEMENT BOUNDRIES

     TORQUE,IN-LB         ANGLE,DEG

      -26000.00            -20.000
       -6250.00             -0.250
        6250.00              0.250
       26000.00             20.000
```

Table 45 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Self-Steering B-Dolly with Full Resistance Steering.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (SA1 FULL/FULL)

UNIT # 4
****

OF AXLES ON THIS UNIT = 1

WEIGHT OF SPRUNG MASS = 31000.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 108375.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 497375.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 490000.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 80.70 INCHES

	AXLE # 5
LOAD ON EACH AXLE (LB.)	17500.00
AXLE WEIGHT (LB.)	1500.00
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00
X DIST FROM SP MASS CG (IN)	-127.80
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00
HALF SPRING SPACING (IN)	19.00
HALF TRACK - INNER TIRES (IN)	29.50
DUAL TIRE SPACING (IN)	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00
ROLL STEER COEFFICIENT	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0
SPRING TABLE #	3
CORNERING FORCE TABLE #	1
ALIGNING TORQUE TABLE #	1

Table 45 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Self-Steering B-Dolly with Full Resistance Steering.

SPRING TABLE # 1
****** *******

FORCE LB	DEFLECTION INCHES
-20000.00	-20.00
0.0	0.0
8645.00	7.20
25000.00	7.50

SPRING TABLE # 2
****** *******

FORCE LB	DEFLECTION INCHES
-29800.00	-11.00
0.0	-1.00
0.0	0.0
4650.00	1.00
7650.00	1.50
11650.00	2.00
16300.00	2.50
21600.00	3.00
59500.00	4.00

SPRING TABLE # 3
****** *******

FORCE LB	DEFLECTION INCHES
-40500.00	-11.00
0.0	-1.50
0.0	0.0
2812.00	0.50
7188.00	1.00
12175.00	1.50
17913.00	2.00
24063.00	2.50
56000.00	3.00

Table 45 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Self-Steering B-Dolly with Full Resistance Steering.

CORNERING FORCE TABLE # 1
********* ***** *********

LATERAL FORCE VS. SLIP ANGLL

0.0	1.00	2.00	4.00	6.00	12.00
3000.00	540.00	990.00	1710.00	2130.00	2490.00
6000.00	840.00	1500.00	2760.00	3480.00	4140.00
9000.00	990.00	1710.00	3420.00	4680.00	6210.00

ALIGNING TORQUE TABLE # 1
******** ****** *********

ALIGNING TORQUE VS. SLIP ANGLE

0.0	1.00	3.00	4.00	5.00	7.00	10.00
3000.00	660.00	1104.00	1200.00	1440.00	1500.00	1200.00
6000.00	1560.00	3132.00	3600.00	4248.00	4476.00	3984.00
9000.00	2400.00	5424.00	6396.00	7500.00	7800.00	6780.00

Table 46. Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Controlled-Steering B-Dolly with 0.30 Steering Gain.

```
********************************
*DIRECTIONAL RESPONSE SIMULATION*
********************************

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (PRO.30 FULL/FULL)

# OF SPRUNG MASSES        =  4

TOTAL # OF AXLES          =  5

GROSS VEHICLE WEIGHT      =   80000.00  LB.

FORWARD VELOCITY          =      55.00  M.P.H

PEAK FRICTIONAL COEFFICIENT   = 1.00
```

		DISTANCE AHEAD OF SPRUNG MASS C.G. (INCHES)	HEIGHT BELOW SPRUNG MASS C.G. (INCHES)	ROLL STIFFNESS (IN.LB/DEG)	TYPE OF CONSTRAINT
ARTICULATION PT # 1	ON UNIT # 1	-87.27	-4.00	999999.88	1
	ON UNIT # 2	138.40	33.30		
ARTICULATION PT # 2	ON UNIT # 2	-159.63	37.30	59999.99	1
	ON UNIT # 3	80.00	0.0		
ARTICULATION PT # 3	ON UNIT # 3	0.0	-4.00	999999.88	1
	ON UNIT # 4	136.20	32.70		

```
LINKED ARTICULATION:  GAIN:        0.00    STIFFNESS:  10000000.00 (IN-LB/DEG GAMMA2)

TYPE OF CONSTRAINT :  01  CONVENTIONAL 5TH WHEEL
                      02  INVERTED 5TH WHEEL
                      03  PINTLE HOOK
                      04  KING PIN(RIGID IN ROLL & PITCH)
```

Table 46 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Controlled-Steering B-Dolly with 0.30 Steering Gain.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (PRO.30 FULL/FULL)

FORCED STEER RATIOS

	FRT WHEEL	ARTC # 1	ARTC # 2	ARTC # 3
	*********	*********	*********	*********
AXLE # 2	0.0	0.0	0.0	0.0
AXLE # 3	0.0	0.0	0.0	0.0
AXLE # 4	0.0	0.0	0.0	-0.30
AXLE # 5	0.0	0.0	0.0	0.0

Table 46 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Controlled-Steering B-Dolly with 0.30 Steering Gain.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (PRO.30 FULL/FULL)

UNIT # 1
****

OF AXLES ON THIS UNIT = 2

WEIGHT OF SPRUNG MASS = 9700.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 15000.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 75000.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 75000.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 44.00 INCHES

	AXLE # 1	AXLE # 2
LOAD ON EACH AXLE (LB.)	10000.00	17500.00
AXLE WEIGHT (LB.)	1200.00	2300.00
AXLE ROLL M.I (LB.IN.SEC**2)	3719.00	4458.00
X DIST FROM SP MASS CG (IN)	24.00	-96.00
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	23.00	29.00
HALF SPRING SPACING (IN)	16.00	19.00
HALF TRACK - INNER TIRES (IN)	40.00	29.50
DUAL TIRE SPACING (IN)	0.0	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00	4500.00
ROLL STEER COEFFICIENT	0.0	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	1500.00	8000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	300.00	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0	0.0
SPRING TABLE #	1	2
CORNERING FORCE TABLE #	1	1
ALIGNING TORQUE TABLE #	1	1

Table 46 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Controlled-Steering B-Dolly with 0.30 Steering Gain.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (PRO.30 FULL/FULL)

UNIT # 2
****

OF AXLES ON THIS UNIT = 1

WEIGHT OF SPRUNG MASS = 30300.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 101204.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 475638.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 469434.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 81.30 INCHES

	AXLE # 3
LOAD ON EACH AXLE (LB.)	17500.00
AXLE WEIGHT (LB.)	1500.00
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00
X DIST FROM SP MASS CG (IN)	-123.70
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00
HALF SPRING SPACING (IN)	19.00
HALF TRACK - INNER TIRES (IN)	29.50
DUAL TIRE SPACING (IN)	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00
ROLL STEER COEFFICIENT	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0
SPRING TABLE #	3
CORNERING FORCE TABLE #	1
ALIGNING TORQUE TABLE #	1

Table 46 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Controlled-Steering B-Dolly with 0.30 Steering Gain.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (PRO.30 FULL/FULL)

UNIT # 3
****

OF AXLES ON THIS UNIT = 1

WEIGHT OF SPRUNG MASS = 1000.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 1900.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 2560.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 2560.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 44.00 INCHES

	AXLE # 4
LOAD ON EACH AXLE (LB.)	17500.00
AXLE WEIGHT (LB.)	1500.00
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00
X DIST FROM SP MASS CG (IN)	0.0
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00
HALF SPRING SPACING (IN)	19.00
HALF TRACK - INNER TIRES (IN)	29.50
DUAL TIRE SPACING (IN)	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00
ROLL STEER COEFFICIENT	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0
SPRING TABLE #	3
CORNERING FORCE TABLE #	1
ALIGNING TORQUE TABLE #	1

Table 46 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Controlled-Steering B-Dolly with 0.30 Steering Gain.

FHWA FIVE-AXLE DOUBLE / 27-FT TRAILERS (PRO.30 FULL/FULL)

UNIT # 4
****

OF AXLES ON THIS UNIT = 1

WEIGHT OF SPRUNG MASS = 31000.00 LB.

ROLL MOMENT OF INERTIA OF SPRUNG MASS = 108375.00 LB.IN.SEC**2

PITCH MOMENT OF INERTIA OF SPRUNG MASS = 497375.00 LB.IN.SEC**2

YAW MOMENT OF INERTIA OF SPRUNG MASS = 490000.00 LB.IN.SEC**2

HEIGHT OF SPRUNG MASS CG ABOVE GROUND = 80.70 INCHES

	AXLE # 5
LOAD ON EACH AXLE (LB.)	17500.00
AXLE WEIGHT (LB.)	1500.00
AXLE ROLL M.I (LB.IN.SEC**2)	4100.00
X DIST FROM SP MASS CG (IN)	-127.80
HEIGHT OF AXLE C.G. ABOVE GROUND (INCHES)	19.50
HEIGHT OF ROLL CENTER ABOVE GROUND (INCHES)	29.00
HALF SPRING SPACING (IN)	19.00
HALF TRACK - INNER TIRES (IN)	29.50
DUAL TIRE SPACING (IN)	13.00
STIFFNESS OF EACH TIRE (LB/IN)	4500.00
ROLL STEER COEFFICIENT	0.0
AUX ROLL STIFFNESS (IN.LB/DEG)	10000.00
SPRING COULOMB FRICTION - PER SPRING (LB)	1000.00
VISCOUS DAMPING PER SPRING (LB.SEC/IN)	0.0
SPRING TABLE #	3
CORNERING FORCE TABLE #	1
ALIGNING TORQUE TABLE #	1

Table 46 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Controlled-Steering B-Dolly with 0.30 Steering Gain.

SPRING TABLE # 1
****** *******

FORCE LB	DEFLECTION INCHES
-20000.00	-20.00
0.0	0.0
8645.00	7.20
25000.00	7.50

SPRING TABLE # 2
****** *******

FORCE LB	DEFLECTION INCHES
-29800.00	-11.00
0.0	-1.00
0.0	0.0
4650.00	1.00
7650.00	1.50
11650.00	2.00
16300.00	2.50
21600.00	3.00
59500.00	4.00

SPRING TABLE # 3
****** *******

FORCE LB	DEFLECTION INCHES
-40500.00	-11.00
0.0	-1.50
0.0	0.0
2812.00	0.50
7188.00	1.00
12175.00	1.50
17913.00	2.00
24063.00	2.50
56000.00	3.00

Table 46 (continued). Yaw/Roll Simulation Data Echo for the Fully Loaded Double Equipped with the Controlled-Steering B-Dolly with 0.30 Steering Gain.

CORNERING FORCE TABLE # 1
********* ***** *********

LATERAL FORCE VS. SLIP ANGLL

0.0	1.00	2.00	4.00	6.00	12.00
3000.00	540.00	990.00	1710.00	2130.00	2490.00
6000.00	840.00	1500.00	2760.00	3480.00	4140.00
9000.00	990.00	1710.00	3420.00	4680.00	6210.00

ALIGNING TORQUE TABLE # 1
******** ****** *********

ALIGNING TORQUE VS. SLIP ANGLE

0.0	1.00	3.00	4.00	5.00	7.00	10.00
3000.00	660.00	1104.00	1200.00	1440.00	1500.00	1200.00
6000.00	1560.00	3132.00	3600.00	4248.00	4476.00	3984.00
9000.00	2400.00	5424.00	6396.00	7500.00	7800.00	6780.00

Appendix B

Listings of Equations and Variables Used in the Financial Model

This appendix contains a listing of the rules (equations) and variables used to compute the results given in the tables of incremental costs and/or benefits in Section 5.2. The input variables to the model are displayed in Table 47, with the reference values of the variables shown on the right. Where the value of the input variable is calculated from other input variables, the equation is shown. A key to the input variables appears in Table 48, with a short explanation of each variable name. Table 49 displays a list which indicates the change in cost/benefit values between A and B dollies that are being computed in each row of the model. These equations are shown in Table 50 through Table 53. Different sets of equations were used for calculating the cost/benefit values in different years due to the periodic nature of some of the variables associated with the use of the B-dolly as opposed to the use of the A-dolly. For example, A-dollies require a major overhaul every four years, whereas B-dollies require one every two years. The relationships between these input variables and the resulting cost/benefit values were discussed in the The Financial Model section. Table 50 displays the equations used for computing values for Year 0 (the first year of the project). Table 51 displays the equations used in Years 1, 5, and 9. The equations in Table 52 were used in computing the cost/benefit values for Years 2, 4, 6, and 8. Table 53 displays the equations used for the Years 3 and 7.

The financial model was implemented using the Microsoft spreadsheet program "Excel" on an Apple Macintosh computer.

Table 47. Variables Used in the Operational Impacts Study.

Variables	Reference Case Values
PER GROSS	0.6
GROSSED OUT	TRUE
DOLLY WEIGHT	1000
MILES PER YEAR	100000
COST LB MILE	0.0000894
B ADDED	6
DOLLIES OWNED	15
B PERCENT	=B_ADDED/DOLLIES_OWNED
MILES PER TIRE	100000
PER TIRE WEAR	0.15
PER COST OVERHAUL	0.2
PREV MAINTENANCE	500
BACKUP	TRUE
BREAK UPS	1
ACC SAVE PER MILE	0.008
INTEREST RATE	0.1
SCHEDULING BASE	0
SCHEDULING CURVE BASE	1000
TRAINING BASE	1000
SCHEDULING CURVE	=(SCHEDULING_CURVE_BASE*(1-2*ABS(0.5-B_PERCENT)))/EXP(-1)
TRAINING CURVE	=TRAINING_BASE/EXP(-1)
LOCALS	TRUE
LOCAL DROPS	500
ALLOW OVER WEIGHT	FALSE
OVER WEIGHT	0
YEAR	1
TIRE MILES LEFT	=IF(MILES_PER_YEAR+0>=MILES_PER_TIRE,MILES_PER_YEAR-MILES_PER_TIRE,MILES_PER_YEAR+0)

Table 48. Key to the Variables Used in the Operational Impacts Study.

Variables	Explanation
PER GROSS	Percentage of trips made at GVW
GROSSED OUT	True or False : Are vehicles with B-dollies operating at GVW?
DOLLY WEIGHT	Additional weight of B-dolly over A-dolly
MILES PER YEAR	Miles traveled per year by vehicle
COST LB MILE	Price charged by trucking company to haul freight (price per lb per mile)
B ADDED	Number of B-dollies added to the fleet
DOLLIES OWNED	Total number of A and B dollies owned
B PERCENT	Percentage of B-dollies in the fleet
MILES PER TIRE	Number of miles a set of tires will run before replacement
PER TIRE WEAR	Percent increase in tire wear by B-dollies over A-dollies
PER COST OVERHAUL	Percent increase in the cost of a major overhaul for B-dollies over A-dollies
PREV MAINTENANCE	Increase in the cost of preventive maintenance for B-dollies over A-dollies
BACKUP	True or False : Will the vehicles with B-dollies be backed up?
BREAK UPS	Number of times the unit is backed up per day
ACC SAVE PER MILE	Accident saving per dolly per mile traveled
INTEREST RATE	Discount Rate after taxes
SCHEDULING BASE	One time cost of updating computer programs used in scheduling
SCHEDULING CURVE BASE	Variable used in calculating scheduling learning curve
TRAINING BASE	Variable used in calculating training learning curve
SCHEDULING CURVE	Equation to determine coefficient for scheduling Learning Curve
TRAINING CURVE	Equation to determine coefficient for training Learning Curve
LOCALS	True or False : Are vehicles with B-dollies allowed on secondary roads to make deliveries?
LOCAL DROPS	Number of local deliveries made per year
ALLOW OVER WEIGHT	True or False : Are vehicles with B-dollies allowed a higher GVW to account for the additional weight of the dolly?
OVER WEIGHT	Amount of additional weight vehicles with B-dollies are allowed to carry
YEAR	Variable that indicates the year of the project - one entry for each year
TIRE MILES LEFT	Variable that indicates the number of miles left until replacement on the current sets of tires - one entry for each year

Table 49. Economic Issues Considered in the Operational Impacts Study.

Δ costs/benefits between A and B dollies
Initial cost of dollies Converting existing equipment Major overhauls Tire wear Preventive maintenance Scheduling Training Ability to back up Less weight hauled Fewer accidents Ability to operate on secondary roads Allow higher GVW
Total
Net Present Value
Cost increase to cover loss /100lb / mile
Change in operating cost / dolly / mile

Table 50. Equations Used for the Year Zero in the Operational Impacts Study.

Year 0
=-B ADDED*3000 =-500*B_ADDED+IF(BACKUP,INT(BREAK_UPS*B_ADDED/60)*15000,0) =0 =-INT((B ADDED*MILES PER YEAR)/MILES_PER_TIRE)*900*PER_TIRE_WEAR =-PREV MAINTENANCE*B ADDED =IF(AND((DOLLIES OWNED>30),(B ADDED>0)),-SCHEDULING CURVE*EXP(-YEAR)-SCHEDULING_BASE,-SCHEDULING_CURVE*EXP(-YEAR)) =IF(B ADDED>0,-TRAINING CURVE*B ADDED*EXP(-YEAR),0) =IF(BACKUP,B ADDED*BREAK UPS*7*260,0) =IF(AND(NOT(ALLOW OVER WEIGHT),GROSSED OUT),-COST_LB_MILE*B_ADDED*DOLLY_WEIGHT*MILES_PER_YEAR*PER_GROSS,0) =MILES PER YEAR*B ADDED*ACC SAVE PER MILE =IF(LOCALS,30*LOCAL DROPS*B ADDED,0) =IF(AND(GROSSED OUT,ALLOW OVER WEIGHT),(OVER WEIGHT-DOLLY WEIGHT)*COST LB MILE*MILES PER YEAR*B ADDED*PER GROSS,0)
=SUM(D3:D14)
=NPV(INTEREST RATE,E15:N15)+D15
=IF((NET PRESENT VALUE<0),(-NET PRESENT VALUE/(10*B ADDED*(PER GROSS*50000+(1-PER GROSS)*25000)*MILES PER YEAR))*100,0)
=-(NET PRESENT VALUE-D3-(500*B ADDED)-(IF(AND((DOLLIES OWNED>30),(B ADDED>0)),SCHEDULING BASE,0)))/(10*B ADDED*MILES PER YEAR)

Table 51. Equations Used for Years One, Five and Nine in the Operational Impacts Study.

Year 1
=0
=IF(BACKUP,INT(BREAK_UPS*B_ADDED/60)*15000,0)
=-PER_COST_OVERHAUL*7225*B_ADDED
=-INT((B_ADDED*MILES_PER_YEAR+TIRE_MILES_LEFT)/MILES_PER_TIRE)*900*PER_TIRE_WEAR
=-PREV_MAINTENANCE*B_ADDED
=-SCHEDULING_CURVE*EXP(-YEAR)
=IF(B_ADDED>0,-TRAINING_CURVE*B_ADDED*EXP(-YEAR),0)
=IF(BACKUP,B_ADDED*BREAK_UPS*7*260,0)
=IF(AND(NOT(ALLOW_OVER_WEIGHT),GROSSED_OUT),-COST_LB_MILE*B_ADDED*DOLLY_WEIGHT*MILES_PER_YEAR*PER_GROSS,0)
=MILES_PER_YEAR*B_ADDED*ACC_SAVE_PER_MILE
=IF(LOCALS,30*LOCAL_DROPS*B_ADDED,0)
=IF(AND(GROSSED_OUT,ALLOW_OVER_WEIGHT),(OVER_WEIGHT-DOLLY_WEIGHT)*COST_LB_MILE*MILES_PER_YEAR*B_ADDED*PER_GROSS,0)
=SUM(E3:E14)

Table 52. Equations Used for Years Two, Four, Six and Eight in the Operational Impacts Study.

Year 2
=0
=IF(BACKUP,INT(BREAK_UPS*B_ADDED/60)*15000,0)
=0
=-INT((B_ADDED*MILES_PER_YEAR+TIRE_MILES_LEFT)/MILES_PER_TIRE)*900*PER_TIRE_WEAR
=-PREV_MAINTENANCE*B_ADDED
=-SCHEDULING_CURVE*EXP(-YEAR)
=IF(B_ADDED>0,-TRAINING_CURVE*B_ADDED*EXP(-YEAR),0)
=IF(BACKUP,B_ADDED*BREAK_UPS*7*260,0)
=IF(AND(NOT(ALLOW_OVER_WEIGHT),GROSSED_OUT),-COST_LB_MILE*B_ADDED*DOLLY_WEIGHT*MILES_PER_YEAR*PER_GROSS,0)
=MILES_PER_YEAR*B_ADDED*ACC_SAVE_PER_MILE
=IF(LOCALS,30*LOCAL_DROPS*B_ADDED,0)
=IF(AND(GROSSED_OUT,ALLOW_OVER_WEIGHT),(OVER_WEIGHT-DOLLY_WEIGHT)*COST_LB_MILE*MILES_PER_YEAR*B_ADDED*PER_GROSS,0)
=SUM(F3:F14)

Table 53. Equations Used for Years Three and Seven in the Operational Impacts Study.

Year 3
=0
=IF(BACKUP,INT(BREAK_UPS*B_ADDED/60)*15000,0)
=-(PER_COST_OVERHAUL*7225-PER_COST_OVERHAUL*3800)*B_ADDED
=-INT((B_ADDED*MILES_PER_YEAR+TIRE_MILES_LEFT)/MILES_PER_TIRE)*900*PER_TIRE_WEAR
=-PREV_MAINTENANCE*B_ADDED
=-SCHEDULING_CURVE*EXP(-YEAR)
=IF(B_ADDED>0,-TRAINING_CURVE*B_ADDED*EXP(-YEAR),0)
=IF(BACKUP,B_ADDED*BREAK_UPS*7*260,0)
=IF(AND(NOT(ALLOW_OVER_WEIGHT),GROSSED_OUT),-COST_LB_MILE*B_ADDED*DOLLY_WEIGHT*MILES_PER_YEAR*PER_GROSS,0)
=MILES_PER_YEAR*B_ADDED*ACC_SAVE_PER_MILE
=IF(LOCALS,30*LOCAL_DROPS*B_ADDED,0)
=IF(AND(GROSSED_OUT,ALLOW_OVER_WEIGHT),(OVER_WEIGHT-DOLLY_WEIGHT)*COST_LB_MILE*MILES_PER_YEAR*B_ADDED*PER_GROSS,0)
=SUM(G3:G14)