

# Validation of Real-Time Multi-Body Vehicle Dynamics Models for Use in Product Design and Acquisition

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## ABSTRACT

The United States Research, Development, and Engineering Command's Tank Automotive Research, Development and Engineering Center (U.S. Army RDECOM-TARDEC) laboratories, in accordance with a Science and Technology Objective (STO), are looking for both real-time and non real-time modeling and simulation methods to advance the capabilities and methodologies used in the Army's Modeling and Simulation areas. Advancing technologies require TARDEC to model new components and vehicles that may be significantly different from prior systems. TARDEC's ultimate goal is to develop the capability to model and accurately recreate the behaviors of advance technologies that may present themselves in the Army's Transformation and its Future Combat System (FCS) of vehicles in real-time with the soldier-in-the-loop. This paper discusses TARDEC's effort to accomplish this goal.

## INTRODUCTION

As computing power and technologies advance, the availability of real-time problem solving methods becomes more and more feasible. TARDEC's Science and Technology Objective (STO) is focusing on advancing the technologies that will allow for faster and more complex simulations to be run. Real-time solving capabilities are a key enabler to allow for interaction between human subjects and the created vehicle models. By adding this functionality, hardware-in-the-loop and operator-in-the-loop simulations can be achieved with very accurate, physics-based results. TARDEC's Ride Motion Simulator (RMS) and Crew Station/Turret Motion Base Simulator (CS/TMBS) allow users to interact directly with the model or system and feedback from the user is fed back into the computer model to provide results similar to those that would be experienced in the real world. Linked with graphics, the RMS and CS/TMBS can recreate scenarios an actual vehicle would experience in the field and the user can

respond within the interactive environment and get the model to behave as if it were an actual physical entity. Real-time computations and results are essential to provide this realistic portrayal of the dynamic events experienced as the vehicle model is driven.

Currently, the Dynamic Analysis and Design System (DADS) software package is and has proven to be a reliable and accurate way of modeling and solving the Army's ground combat and tactical vehicles' dynamic behavior and maneuvers. The DADS software package is a commercially available product through LMS International (formerly CADSI). DADS allows multi-body models to be created and solved through the use of a catalog of pre-defined joint and body templates. However, the computation times can prove to be excessive for complex models. The ability to achieve a real-time system simulation capability would allow for almost instantaneous interaction with the model during solving time. The SimCreator software, a real-time multi-body dynamics package, was found to provide easy construction of conventional 4X4 passenger vehicle models, realistic and reliable results, and was capable of interaction with real world simulators. Studies were also conducted in creating a generic 4X4 HMMWV military vehicle. SimCreator is a graphical modeling software package offered by Realtime Technologies, Inc. Models are constructed by connecting components in a block diagram styled approach. TARDEC has initiated efforts to adapt this capability for use in its RMS and CS/TMBS hardware and manned hardware-in-the-loop simulation experiments.

The Marine Corp Medium Tactical Vehicle Replacement (MTVR) was chosen as the case vehicle system to be modeled in the SimCreator methodology because it is a 6X6 and due to the availability of its vehicle design characteristic data and field test results to be used for validation purposes. The MTVR is a six wheeled cargo truck with each wheel having an independent spring suspension configuration. It was previously modeled in DADS software and was recently validated using ride dynamics field test data and considered to be accurate.

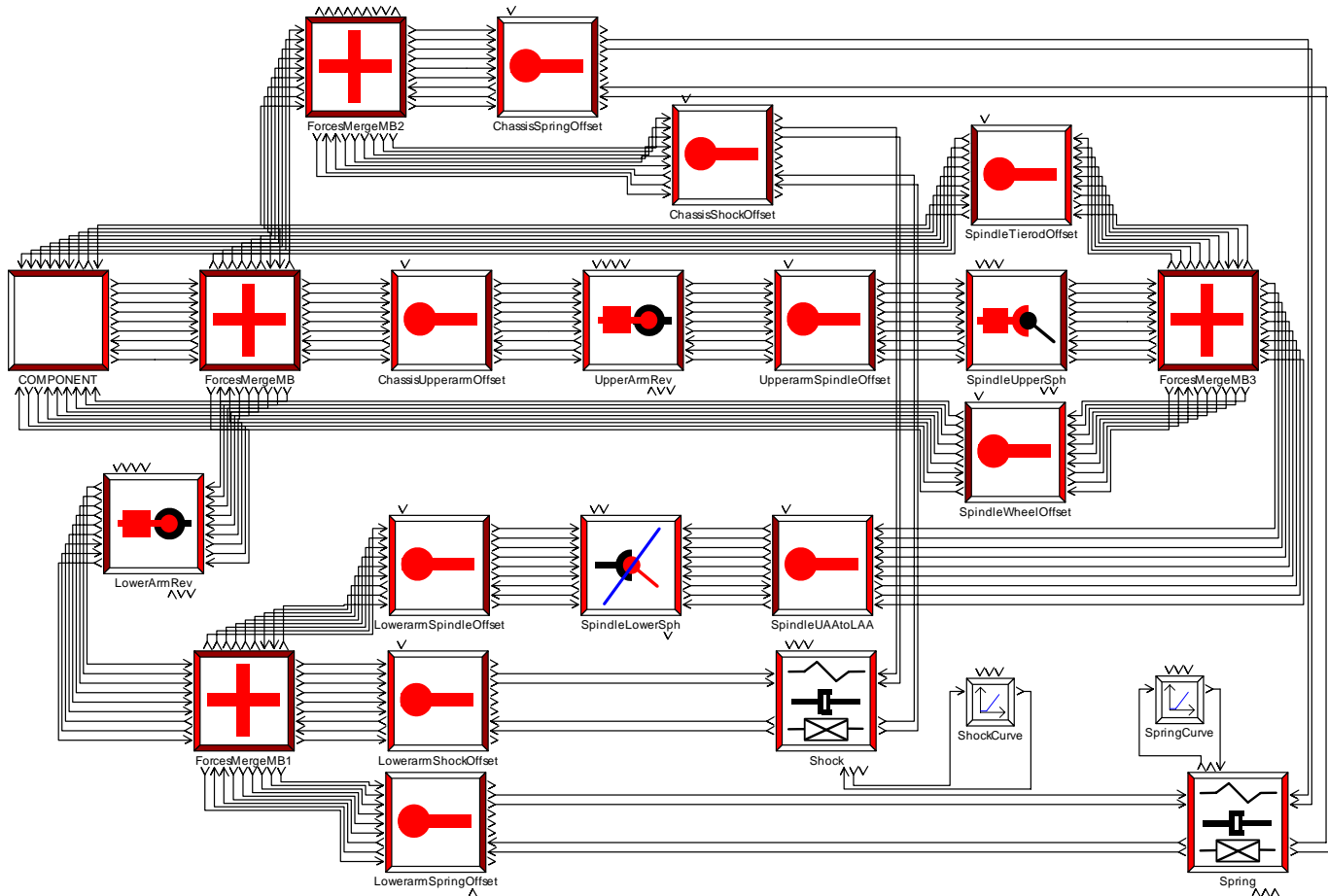
The DADS based MTVR model was recreated in SimCreator, in order to assess SimCreator's ability to accurately predict the MTVR's performance in real-time.



Figure 1: Medium Tactical Vehicle Replacement (MTVR) Truck

Real-time models allow both operator-in-the-loop and hardware-in-the-loop simulations that can assist in the product design and acquisition process. Initial analysis has focused specifically on SimCreator's accuracy in predicting the kinematics and compliance of the MTVR's vehicle corners. The vehicle's suspension was modeled in SimCreator using recursive dynamics models and a cut joint formulation. Initial results were found to agree closely with the DADS model.

Figure 2: SimCreator Double A-Arm Model



## PROCEDURE

A single wheel station of the MTVR was modeled in SimCreator. A similar MTVR model existed in DADS. Each model had the same inputs and level of complexity. Joints, bodies and force elements in DADS were identified and replicated in SimCreator. Romano [1] has previously presented SimCreator's multi-body modeling methodology and validation. DADS uses a Cartesian modeling approach while SimCreator uses a recursive dynamics approach.

During the past year, SimCreator has been extended to support closed kinematic chains by using cut joint techniques. Currently, two cut joints are supported: a spherical joint and a distance constraint. In SimCreator's recursive formulation, each degree of freedom of a joint adds an equation to the augmented mass matrix. Each removed degree of freedom for a cut joint adds an equation to the augmented mass matrix. Therefore a cut spherical joint adds three equations to the augmented mass matrix while a cut distance constraint adds one equation to the augmented mass matrix. The real-time performance of the resulting multi-body model is dependent on a number of factors. In SimCreator the size of the augmented mass matrix is typically the most important since inverting the mass matrix is a time consuming operation. The list of joints and the number of equations they add to the mass matrix is given in Table 1.

Joint Type	# of Equations
Revolute	1
Prismatic	1
Cylindrical	2
Universal	2
Screw	1
Spherical	3
Cut Spherical	3
Distance Constraint	1

**Table 1: List of Joint Types.**

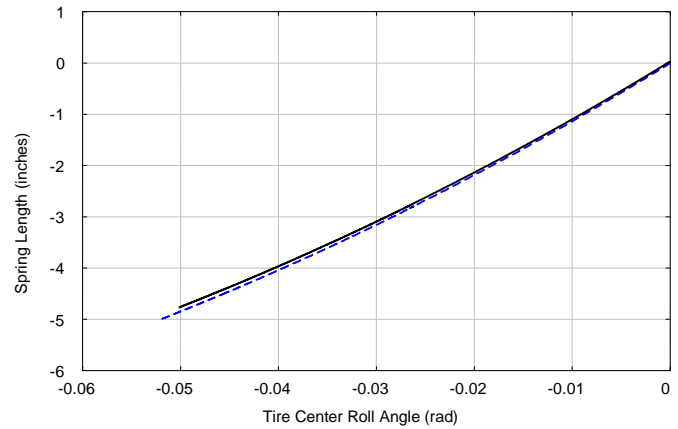
The MTRV uses a double A-Arm suspension. Using the same joints and bodies as DADS the suspension was modeled in SimCreator as shown in Figure 2.

The double A-Arm model uses two revolute joints, one spherical joint, and one cut spherical joint for a total of 8 equations in the mass matrix. Two translational spring damper actuators (TSDA) are used: one for the shock and one for the spring. The resulting suspension includes three masses: the mass of the upper A-Arm, the mass of the lower A-Arm, and the mass of the spindle.

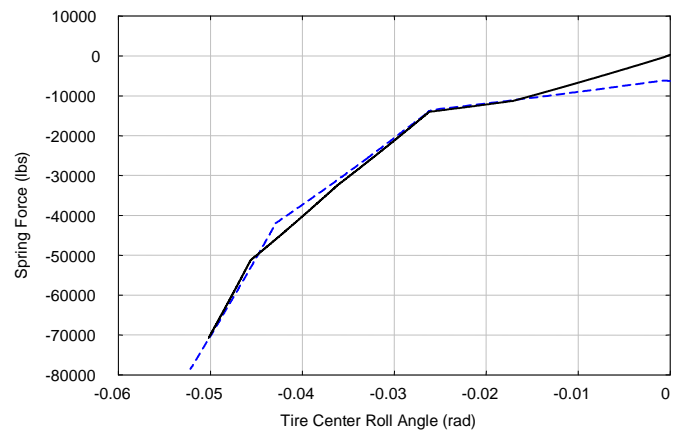
When the double A-Arm is connected to the base body a tie rod is required. The tie rod is modeled using a distance constraint which adds one additional equation to the mass matrix. Finally, in order to model the rotating wheel hub a third revolute joint must be added increasing the number of equations in the mass matrix to 10. This increases the number of masses represented to four and the number of joints represented to six.

## VALIDATION

A simulation was performed on a single wheel station of the third axle of the vehicle in both DADS and SimCreator. In order to exercise the suspension, a vertical force was applied to the wheel spindle. The resulting spindle motion was measured and compared. Figures 3 through 7 show the results. The lateral and vertical motion of the spindle, with respect to the spindle roll angle, show excellent correlation between SimCreator and DADS. However, the tire yaw angle and spring force show minor differences. In reviewing the SimCreator output, all cut joint constraints were maintained with less than a  $10^{-9}$  meter error. Therefore it is believed that any errors were produced by slight differences in the input data. The spring length itself is shown in Figure 3. The calculated spring length correlates very well between SimCreator and DADS. The calculation of spring force from spring length is done using a table lookup. Therefore an error must have been introduced when converting the spring data from DADS to SimCreator. The spring data conversion required changes in units of both force and distance. It also required a conversion of the default length and default force.

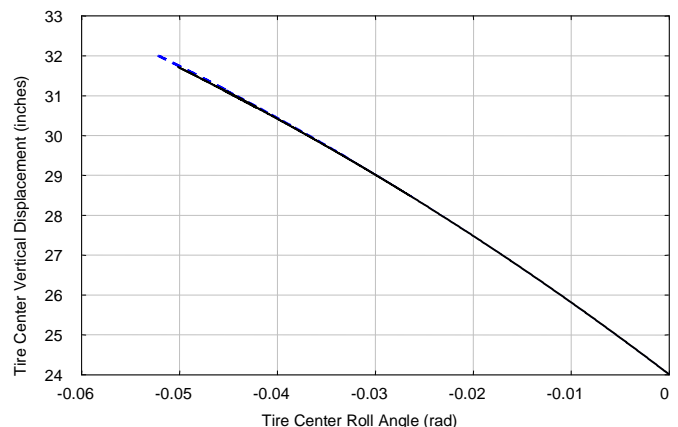


**Figure 3: Spring Length Versus Tire Roll Angle (SimCreator results shown as solid line)**

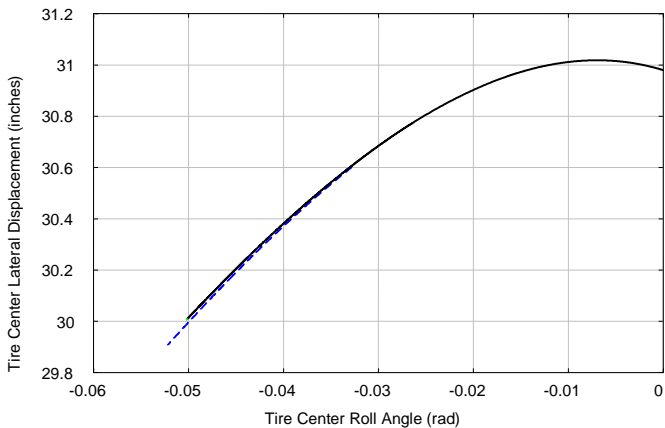


**Figure 4: Spring Force Versus Tire Roll Angle (SimCreator results shown as solid line)**

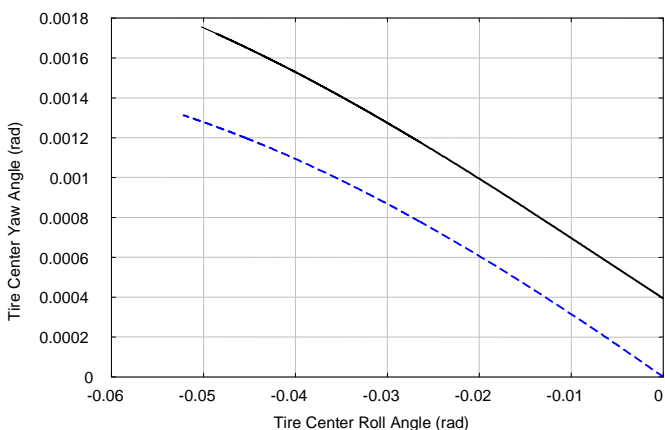
The conversion process was not automated and an error may have been introduced when performing the calculations by hand. In reviewing the yaw calculations, the yaw angle has a bias of 0.0004 radians in the SimCreator model while the trend in the yaw angle is correct. A sensitivity analysis was performed on the tie rod length and found that a variance of 0.15 mm in the tie rod length will account for this difference in yaw angle.



**Figure 5: Tire Vertical Displacement Versus Tire Roll Angle (SimCreator results shown as solid line)**



**Figure 6: Tire Lateral Displacement Versus Tire Roll Angle (SimCreator results shown as solid line)**



**Figure 7: Tire Yaw Angle Versus Tire Roll Angle (SimCreator results shown as solid line)**

Unfortunately some numbers were rounded off at the 0.05 mm level when they were converted from DADS. A succession of rounding errors could account for the

difference in yaw angle. In contrast to the typical changes in yaw angle during driving the 0.0004 radian difference is quite small but should be accounted for.

## REAL-TIME CONSIDERATIONS

Six of the wheel stations were assembled together to form an MTVR vehicle. Revolute joints were added to represent the wheels, and a six-degree of freedom base body was added to capture the entire vehicle motion. In addition a six wheel drive power train, as shown in Figure 8, previously developed by Romano [1,2] was incorporated into the model.

The resulting system had the following complexity:

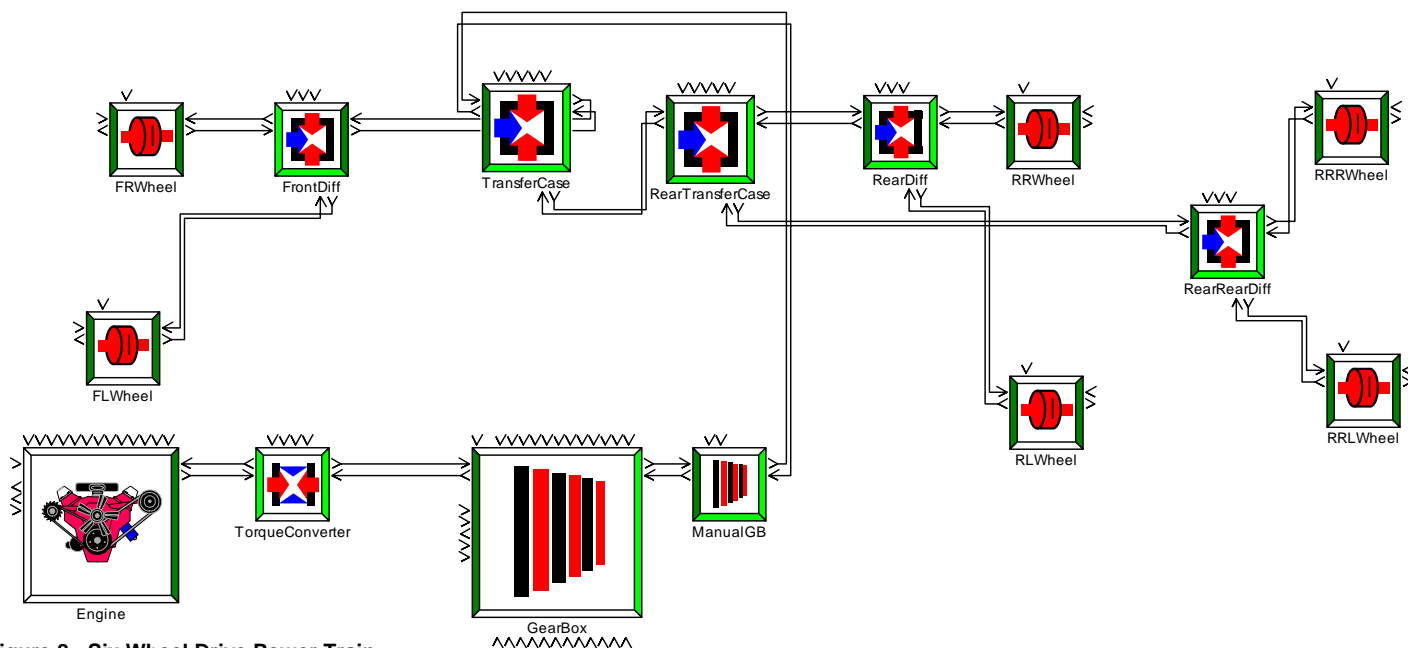
1. 66 equations in the augmented mass matrix
2. 36 equivalent joints
3. 25 equivalent bodies
4. 115 states

Some timings were made of the vehicle to determine if the model was capable of running in real-time. The model was integrated using a 2<sup>nd</sup> order Runge-Kutta method at 500 Hz.

Using a computer with a 600 MHz Pentium III processor, it was found that the model took 110 seconds to perform a 60 second simulation. TARDEC will be using a 2.8 GHz computer system to run the vehicle simulation in real-time so it is expected that the performance will be acceptable.

## CONCLUSION

The SimCreator based MTVR model was found to produce results that are very similar to the DADS model. Where there are slight differences in results it is believed that the accuracy was limited by the model conversion



**Figure 8: Six Wheel Drive Power Train**

process. Developing more automated techniques for importing DADS models into SimCreator should assist in making the results more consistent. Real-time testing of the model showed acceptable performance and it is expected that the model will run in real-time on the target system.

Once the input data have been corrected, the next step in the evaluation process is to compare dynamic results for the two models for a variety of maneuvers.

In order to perform this step, the tire model in SimCreator must be modified to match the tire model used in DADS. Then the tire data used with the DADS model can be converted for use with SimCreator.

Real-time performance of the multi-body model without any reduction in model complexity will allow TARDEC engineers to easily adjust the vehicle design parameters and predict the effects of the adjustments using both hardware in the loop and operator in the loop evaluations.

## **ACKNOWLEDGMENTS**

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## **REFERENCES**

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## **CONTACT**

Richard Romano has been working in driving simulation for twelve years focusing on motion cueing, vehicle dynamics, and human factors research. Dr. Romano was the manager of simulator research and development at the Iowa Driving Simulator and supervised the brake system simulation group at ITT Automotive. He is now president of Realtime Technologies, Inc. He may be contacted at [raromano@ix.netcom.com](mailto:raromano@ix.netcom.com).

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