



## Technical Report

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# MBS modeling of a reach stacker container truck using SimulationX software

## Abstract

A 3D multi-body system (MBS) model of a reach stacker container truck has been modeled in the SimulationX software within the scope of the 'Energy efficient hydraulic systems with energy regeneration' research project at ITH. The objective of the simulation exercise was to find out whether or not MBS modeling is an efficient tool in the process of evaluating the energy efficiency of heavy equipment load handling and propulsion systems; and the conclusion is that it is indeed an efficient tool. It visualizes the load handling and driving motions in a comprehensible way and it has a very user friendly interface. Key parameters and result variables become easy accessible and the energy consumption can be effectively studied for the whole system as well as for subsystems. A simulation run of 50 seconds container handling simulates the load handling and driving motions quite good. The result figures are not validated though since all coefficients of friction, drag and rolling resistance etcetera are estimations only.

In addition, the simulation results show that a validated MBS heavy equipment model could be a very useful tool not only for evaluating energy efficiency but also for a number of additionally design work question formulations. Axle pressure figures could be used for determining the vehicle stability in extreme load positions and/or motions; and power figures could be used for dimensioning hydraulic and propulsion systems out of a vehicle performance specification. Front tire centre height and effective rolling radius might be of interest when studying tractive power and vehicle velocity respectively. MBS simulations are of great value in early design phase as well as a tool for simulation driven design.



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4. SimulationX element type help section: *RS - driving*

## **1 Background**

The ‘Energy efficient hydraulic systems with energy regeneration’ research project is an ITH post-graduate project supervised at Luleå University of Technology. The project is financed by the European Regional Development Fund together with BAE Systems Hägglunds, the County of Örnköldsvik and the County Administration of Västernorrland. The research project will increase the level of competence within the area of energy efficient hydraulics in general and especially potential and kinetic energy regeneration in heavy equipment hydraulic load handling systems. Heavy equipment here refers to motor-driven vehicles specially designed for executing load handling tasks such as wheel loaders, excavators, container trucks, forklift trucks, mobile cranes etc.

The project comprises computer simulations where an existing heavy equipment hydraulic load handling system is compared to alternative hydraulic and electro-hydraulic system solutions in order to map out the most energy efficient solution for different system conditions. Electro-hydraulic systems here refer to hydraulic systems where parts of the hydraulics are replaced with electrical components as for example electrical machines and batteries. Since heavy equipment load handling system and propulsion system are interacting, also the propulsion system will be considered in some measure.

So far a literature study has been done with focus on the product and system solution state of the art concerning energy efficient heavy equipment. Also, a simulation software evaluation has been carried out resulting in the selection of the SimulationX software from ITI GmbH. In addition to hydraulic and mechanic system modeling, 3D multi-body systems (MBS) can be modeled in SimulationX. This is physical models simulating the motions of rigid bodies affected by gravity and other forces. An MBS model could probably be a useful tool in evaluating the energy efficiency of a hydraulic load handling system and/or a propulsion system. In order to evaluate the use of an MBS heavy equipment model, this has now been modeled in SimulationX.

A reach stacker container truck is a very interesting simulation object for this kind of project since there is a great energy saving potential due to a lot of energy losses during lowering heavy containers. Thus, a container reach stacker was chosen to be the object of the SimulationX MBS simulation exercise.

## **2 Objectives**

The objective of the simulation exercise is to find out whether or not SimulationX MBS modeling is an efficient tool in the process of evaluating the energy efficiency of heavy equipment load handling and propulsion systems.

## **3 Materials and methods**

### ***3.1 Simulation software***

The 3D multi-body system model is built in the SimulationX computer software, which is a multi-domain system simulation tool for simulation of physical effects. In addition to the 3D multi-body system library, there are standard libraries for hydraulics, power transmission, electrical drives, thermodynamics, electrics and controls etc. [1]

### 3.2 Simulation object

The simulation object is a commonly occurring reach stacker container truck handling 20 and 40 feet containers with a maximum lift capacity of 45 ton. The simulation model is based on approximately dimensions and estimated technical data for a typical reach stacker.

### 3.3 Model description

The model is divided into two submodels; one load handling submodel and one driving submodel. This way load handling can be simulated separately by the load handling submodel or both load handling and driving can be simulated by connecting the two submodels to each other. It's important that the submodels can be connected when evaluating system solutions where energy is transferred from one subsystem to another. The simulation tool is considered to be efficient if the whole system as well as subsystems can be effectively studied.

The two submodels are built by rigid bodies, joints and forces from the SimulationX 'MBS Mechanics' library and tire elements from the 'Power Transmission MBS' library. They are built as two new SimulationX element types which mean that important coefficients and variables can be made accessible in the 'property window' for a more user friendly approach. Figure 1 and Figure 2 show the load handling and driving element types connected to each other in SimulationX diagram view and 3D view respectively. Energy analysis calculations are embedded in both element types.

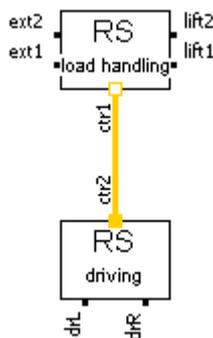


Figure 1. Diagram view of the container reach stacker multi-body system model.

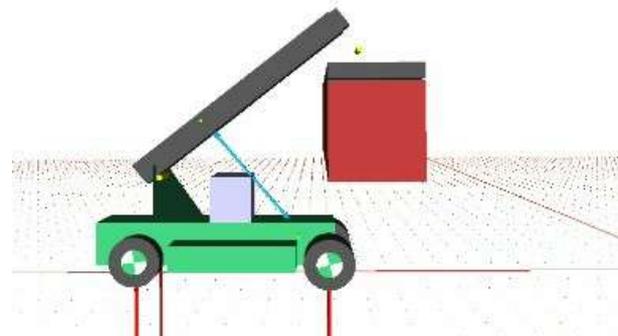


Figure 2. 3D view of the container reach stacker multi-body system model.

#### 3.3.1 Load handling element type

The load handling element type seen in Figure 3 consists of a number of rigid bodies representing chassis, outer boom, inner boom, spreader, container etc; each of them with a defined geometry and mass. In addition it has a lift cylinder force, a boom rotational joint, a boom extension joint and a spreader rotational joint. The boom can be set into lift and extension motion by affecting the lift cylinder force and the boom extension joint by mechanical forces. During simulation, these forces can be determined for example by simply defining a velocity or by connecting a hydraulic cylinder from a hydraulic simulation model. More information about the load handling element type and how the energy analysis is calculated can be found in the element type help section seen in Appendix 3.

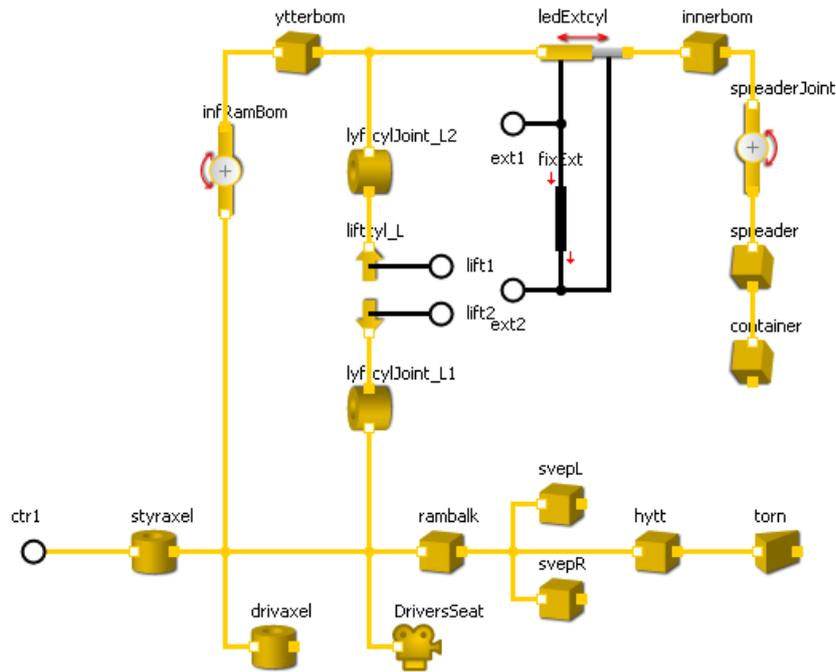


Figure 3. Diagram view of the load handling element type.

### 3.3.2 Driving element type

The driving element type seen in Figure 4 consists of rigid bodies with geometries and mass representing rims and tires. It also includes ‘Tire Plane Contact’ elements simulating the tire motions, a force element representing the drag force and rotational as well as translational joints in order to enable the driving motions of the vehicle. The vehicle is set into motion by affecting the left and right front tires by mechanical torques. During simulation, the torques can be determined for example by simply defining an angular velocity or by connecting a differential gearbox from a drive system simulation model. More information about the driving element type and how the energy analysis is calculated can be found in the element type help section seen in Appendix 4.

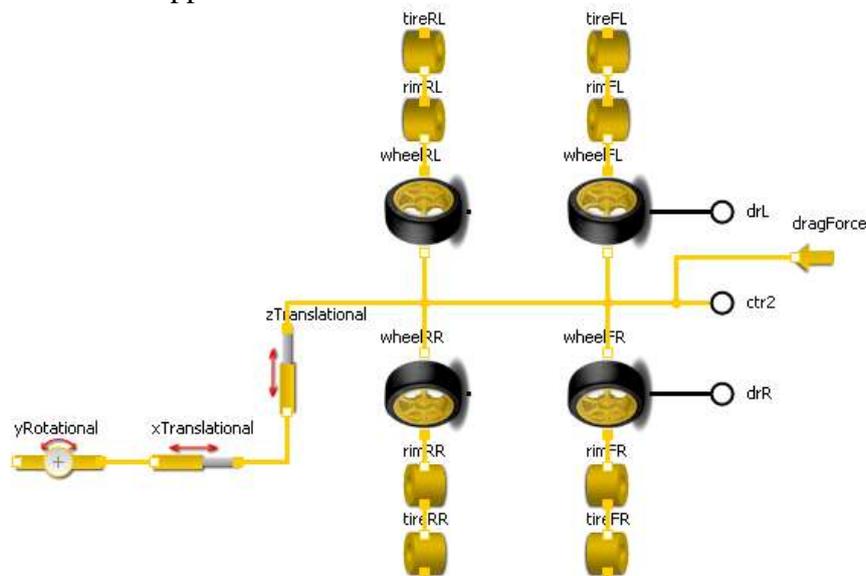


Figure 4. Diagram view of the driving element type.

### 3.4 Simulation run description

In order to evaluate the MBS model a 50 seconds simulation run has been carried out on the reach stacker container truck model. This was simulated by defining velocities for extension cylinder, lift cylinder and driving wheels. The simulation run (see 3D images in Appendix 2) begins by connecting a 30 ton container at 8 meter load height and then driving 20 meter backwards while lowering the container to transport position. The container truck is then driven 50 meter forward where it's unloading the container at 1.5 meter load height. The driving and load handling motions during the simulation run are visualized in Figure 5 and Figure 6. See Appendix 1 for some variable definitions.

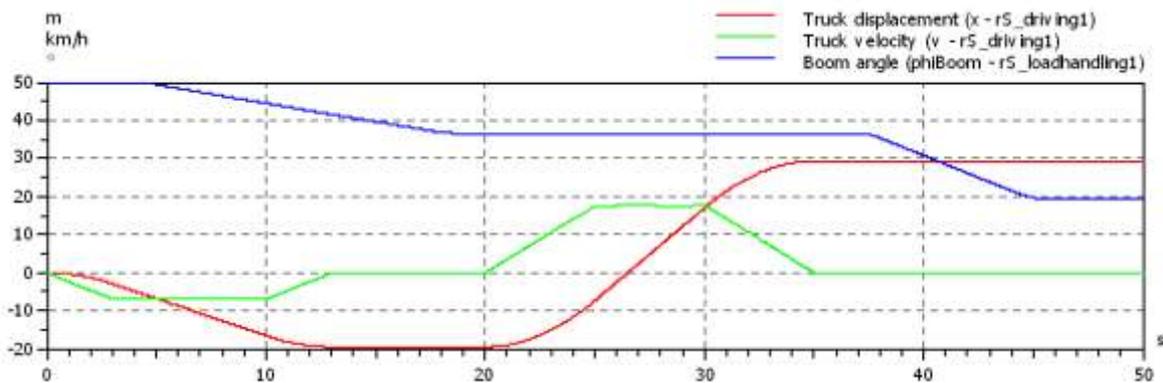


Figure 5. Vehicle displacement, vehicle velocity and boom angle for the simulation run.

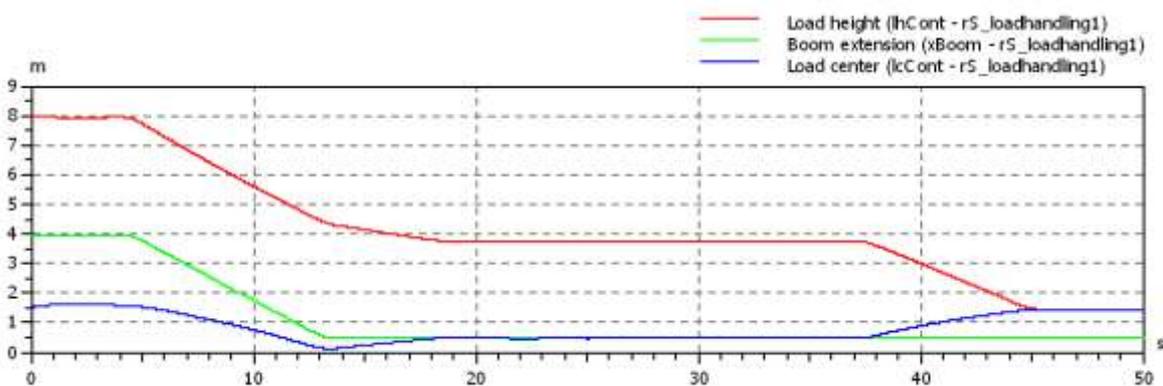


Figure 6. Load height, boom extension and load centre for the simulation run.

## 4 Results

### 4.1 SimulationX as design tool

By building the load handling and driving submodels as element types they can be designed in a very user friendly way. For example, the property window of the load handling element type enables you to change a number of parameters such as container weight, initial load position and friction coefficients (see Figure 7 and Figure 8). In the same way the property window of the driving element type enables you to change parameters such as drag coefficient, rolling resistance coefficient, tire stiffness etcetera (see Figure 9 and Figure 10). Also result variables can be defined and easy accessible via result dialog pages in the element type property window.



Figure 7. The 'Initial values' dialog page of the load handling property window.

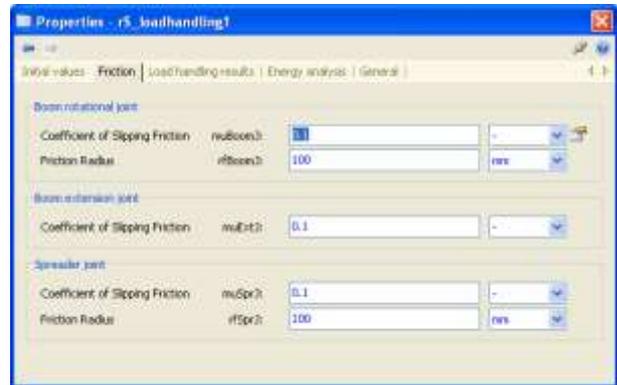


Figure 8. The 'Friction' dialog page of the load handling property window.



Figure 9. The 'Initial values' dialog page of the driving property window.

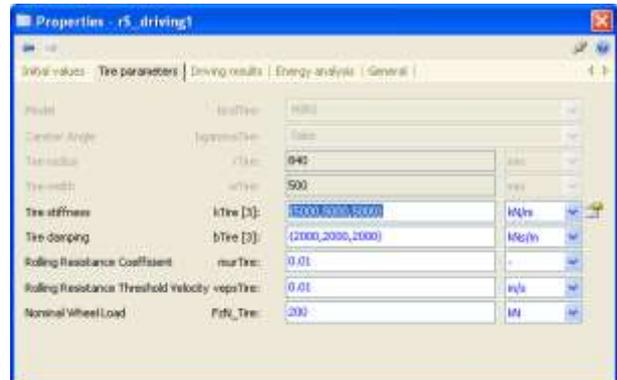


Figure 10. The 'Tire parameters' dialog page of the driving property window.

## 4.2 Simulation run results

Figure 11 shows the driving energy analysis where we can see that the 50 second simulation run takes more than 800 kJ in driving work assuming all brake energy is recovered. The total energy loss including rolling and drag resistance is approximately 700 kJ.

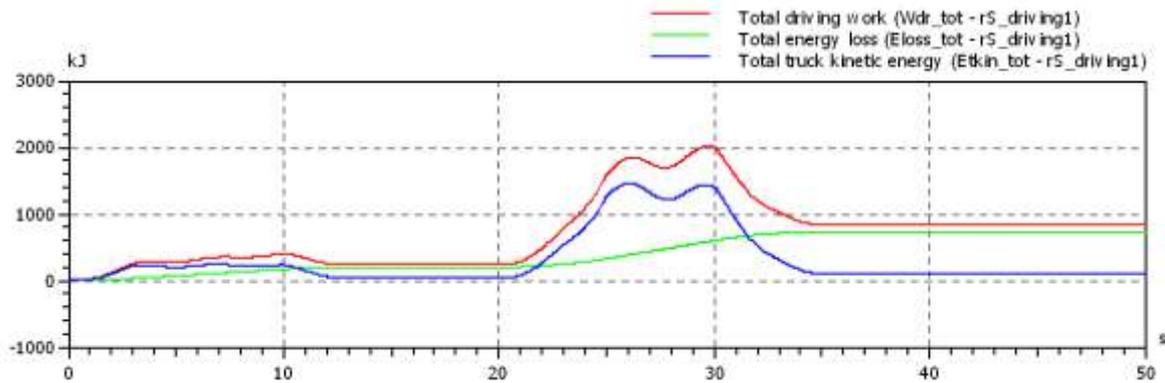


Figure 11. Driving energy analysis with input energy, energy loss and output energy.

Figure 12 shows the load handling energy analysis where we can see that the total cylinder work (extension and lift hydraulic cylinders) amounts to approximately -2600 kJ for the 50 second simulation run (a negative value since the simulation run only includes the lowering of a container). The total energy loss including friction losses of boom rotational, boom extension and spreader rotational friction is approximately 150 kJ. The total cylinder work of -2600 kJ would theoretical, if being recovered, be enough to cover both driving and load handling energy losses.

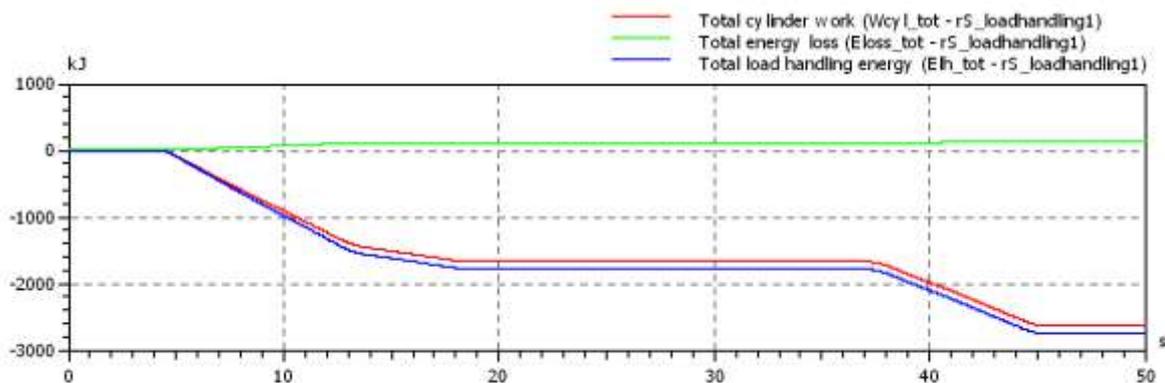


Figure 12. Load handling energy analysis with input energy, energy loss and output energy.

Figure 13 shows the load handling and driving power flow. The total cylinder power is the sum of the lift and extension hydraulic cylinder powers, where a negative value indicates lowering the container and thus a large possibility to recover potential energy. The total driving power is describing vehicle acceleration (positive value) and braking (negative value). This can be very useful for hydraulic and propulsion system dimensioning when you know desired performance.

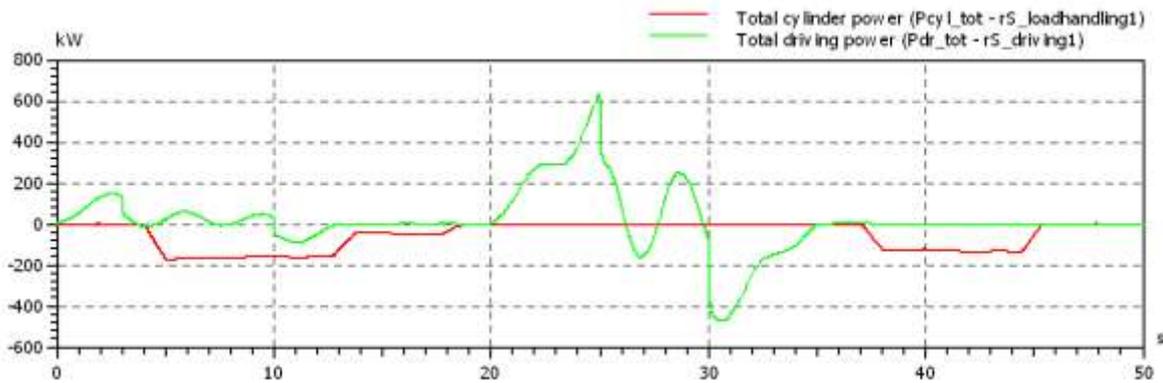


Figure 13. Total cylinder and driving power (negative value enables energy recovering).

The axle pressures seen in Figure 14 can be useful for determining vehicle stability in extreme load positions and/or motions. We can see that the rear axle pressure is only approximately 15 ton when connecting the 30 ton container at 50° boom angle and 4 meter boom extension (see Figure 5 and Figure 6 respectively).

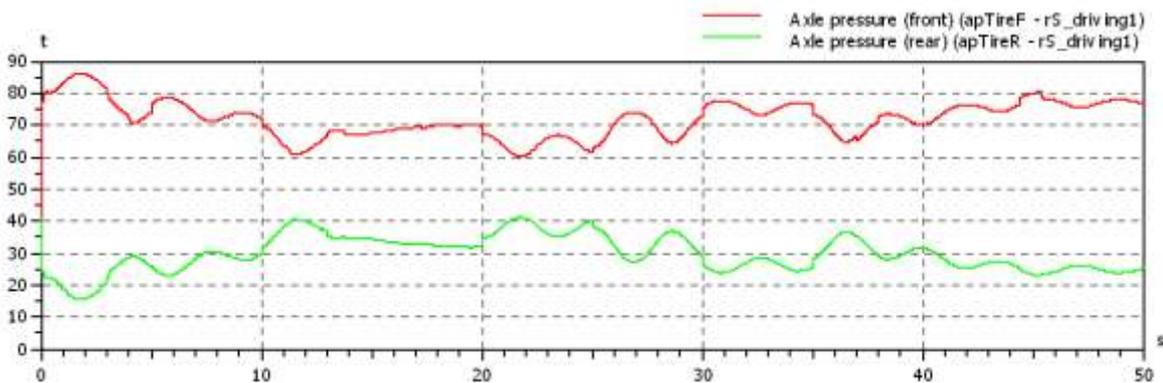


Figure 14. Front and rear axle pressures.

Figure 15 shows the front and rear tire centre height which varies along with axle pressure (see Figure 14). The front tire centre height might be of interest when studying the tractive power of the vehicle in relation to driving torque. The same figure shows the effective rolling radius at front wheel axle which might be of interest when determining the vehicle velocity in relation to the angular velocity of the driving wheels. See variable definitions in Appendix 1.

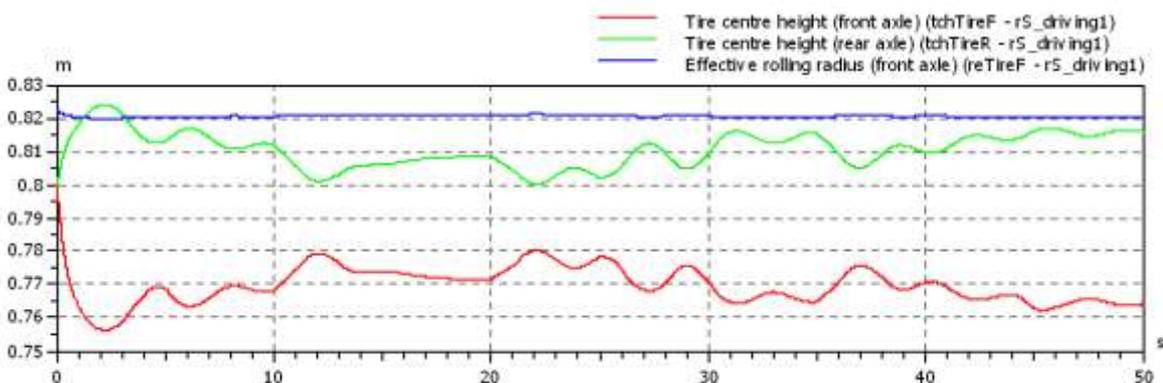


Figure 15. The figure shows the effective rolling radius at front wheel axle and both front and rear tire centre heights which varies along with axle pressure.

## 5 Conclusions

MBS modeling in SimulationX has proven to be an efficient tool in the process of evaluating the energy efficiency of heavy equipment load handling and propulsion systems. It visualizes the load handling and driving motions in a great way and a user friendly interface is obtained by building element types. Key parameters and result variables become easy accessible via the element type property window and the energy consumption can be effectively studied for the whole system as well as for subsystems.

The element type module way of thinking also enables the user to add hydraulic systems as well as power transmission systems for a more comprehensive energy analysis, still with a clean and ‘easy to overview’ structure. The MBS simulation of this report includes load handling and driving motions but steering and suspension could be simulated as well.

The simulation run of this report is simulating the load handling and driving motions of a container reach stacker quite good. However, the model and the corresponding result figures of chapter 4.2 are not validated since friction coefficients, rolling resistance coefficient, drag resistance coefficient etcetera are estimations only. This kind of simulations always needs to be verified with measurements in order to find correct values of these coefficients.

## 6 Discussion

The simulation run result figures of chapter 4.2 show that a validated MBS heavy equipment model can be a very useful tool not only for evaluating energy efficiency but also for a number of additionally design work question formulations, in both new design and design modifications. Axle pressure figures could be used for determining the vehicle stability in extreme load positions and/or motions. Power figures could be used for dimensioning hydraulic and propulsion systems out of a vehicle performance specification. Front tire centre height and effective rolling radius might be of interest when studying tractive power and vehicle velocity respectively. MBS simulations are of great value in early design phase as well as a tool for simulation driven design.

## 7 References

- [1] [www.itisim.com](http://www.itisim.com), ITI GmbH (2011-01-18)



## Definitions

### Axle pressure ( $ap$ )

The axle pressure is defined as the total mass acting on one wheel axle. The sum of the two axle pressures (front and rear) equals the total mass of the vehicle including container weight as long as the container is not standing on the ground.

### Boom angle ( $\phi_{Boom}$ )

The boom angle is defined as the angle between the boom and the horizontal plane of the vehicle (see  $\phi_{Boom}$  in Figure 1).

### Boom extension ( $x_{Boom}$ )

The boom extension is defined as the longitudinal displacement of the inner boom section in relation to the outer boom section (see  $x_{Boom}$  in Figure 1). The value is zero when inner boom section is maximum withdrawn.

### Effective rolling radius ( $re_{Tire}$ )

The effective rolling radius is defined as the tire radius that consists with the vehicle velocity and the angular velocity of the tire. The effective rolling radius varies with tire load.

### Load center ( $lc_{Cont}$ )

The load center is defined as the horizontal distance between tire front edge and the longitudinal centre of the container (see  $lc_{Cont}$  in Figure 1).

### Load height ( $lh_{Cont}$ )

The load height is defined as the vertical distance between the container bottom and ground (see  $lh_{Cont}$  in Figure 1)

### Tire centre height ( $tch$ )

The tire centre height is defined as the vertical distance between the tire centre and the ground (see  $tch$  in Figure 1).

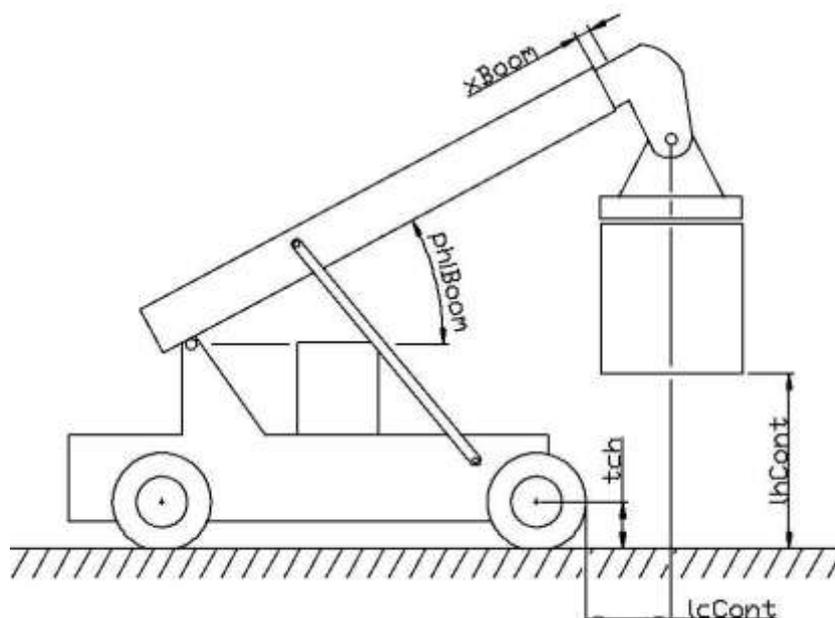


Figure 1. Some geometrical definitions.

### Images of the simulation run

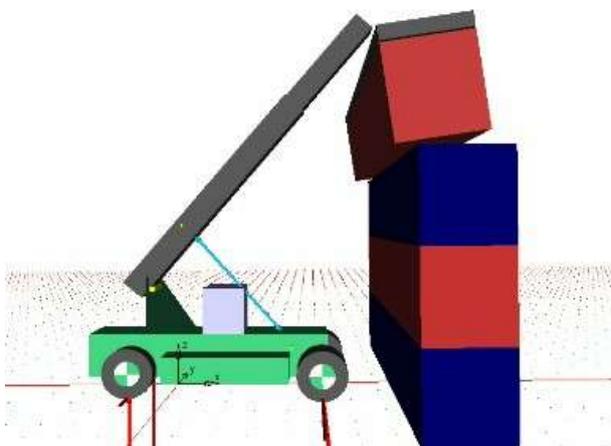


Figure 1. Connecting a 30 ton container at 8 meter load height and then driving backwards.

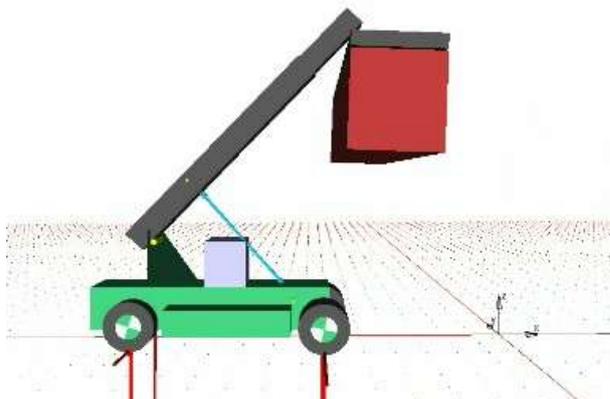


Figure 2. Driving 20 meter backwards while lowering the container.

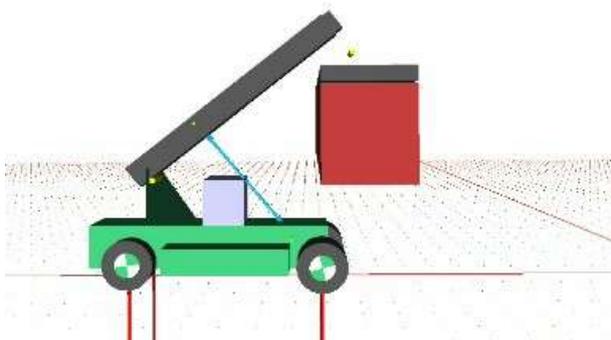


Figure 3. Standing still while lowering the container to transport position.

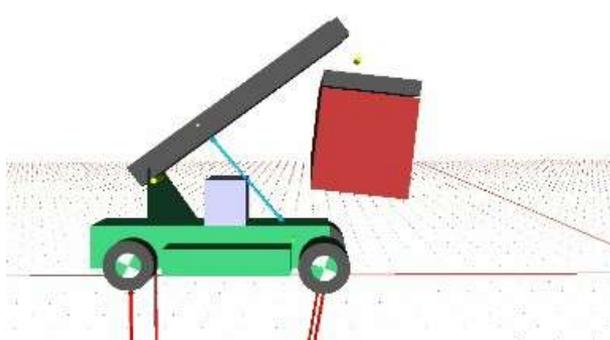


Figure 4. Driving 50 meter forward.

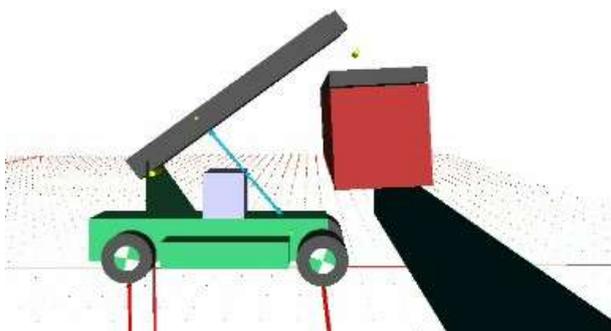


Figure 5. Braking.

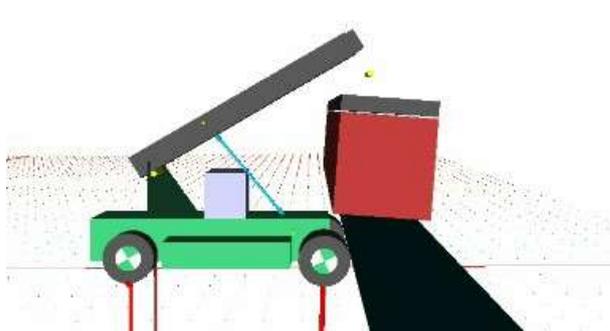


Figure 6. Unloading the container at 1.5 meter load height.

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