Stories from Industry: Doing System-Level Modeling for the First Time

Engineers across all industries and disciplines are often limited by their lack of modern design tools, but making a change can be difficult. Innovating using traditional processes always comes with a cost, and it's all too easy to focus on the cost of change instead of the opportunities, however substantial.

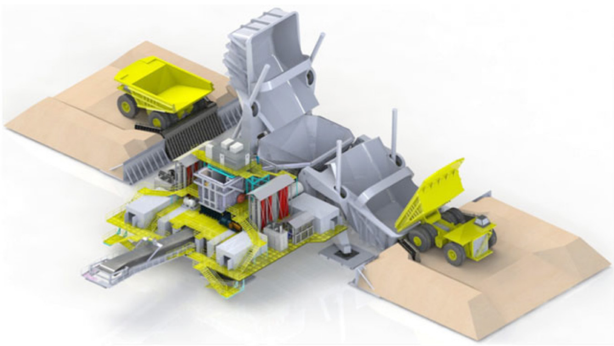
The high demands placed on engineering teams are requiring new technologies and tools that can help turn out higher quality products with fewer costly, late-stage design changes. Many engineers are familiar with some modeling techniques such as CAD or FEA, but they have yet to embrace a system-level modeling approach to analyze the dynamics of their entire design in a fully integrated way. The benefits that system-level modeling offer can be substantial, but they require engineers to make a change to their workflow. And, deciding on new technologies can be difficult when the return on investment is hard to measure.

At Maplesoft, we've worked with many companies who have been in this position. These companies acknowledged the risk involved in a new methodology, but understood the need to adopt new techniques in an evolving industry. This paper highlights the stories of three different companies who were new to system-level models, and shows how they used these models to reduce their development risk and get their product to market faster.

Maplesoft Engineering Solutions Team Helps FLSmidth Develop Revolutionary Mining Equipment

In the mining industry, processing plants are generally constructed on the site of extraction. Mined ore gets transported by super-heavy duty trucks to the plant, where it gets crushed into smaller sizes before being stockpiled, or transported offsite for further processing. Besides the ore, the mine typically has to move four times as much overburden as ore. Big mines typically have to move 700,000 tonne of material per day. As the mine gets larger, the trucks have to travel longer distances to deposit their load, resulting in significant increases in the cost of fuel and vehicle maintenance.

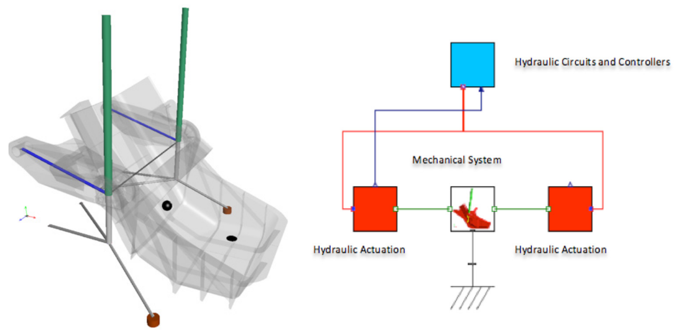
To address this problem, FLSmidth engaged the services of the Maplesoft Engineering Solutions team to develop design and analysis tools that would help them design a Dual Truck Mobile Sizer (DTMS) - an innovative machine that can be relocated throughout a project, as the haul distances increase.



The DTMS increases in-pit crushing efficiency due to its dual-skip configuration. A truck backs into one skip until it reaches a restraining curb in the floor. After dumping its load on the skip floor, it then slowly pulls ahead, lowers its bed, and pulls away. Once the truck clears the end of the skip, the skip can be raised. As the skip is elevated, it pours material from the discharge of the skip and deposits the material into the apron feeder hopper. As material is introduced onto the apron feeder, it conveys the material to the sizer where it is crushed to the appropriate size. After being crushed, the material is deposited onto the discharge conveyor where it is taken to the bench conveyor. This process is performed while another haul truck is depositing material into the twin skip, thereby increasing the number of truck cycles.

- Complex projects involve multiple design groups working on different subsystems which are later integrated together
- System-level modeling provides early identification and correction of integration issues before they become expensive problems
- MapleSim is tightly integrated via API commands to Maple, enabling complex multidomain models to be analyzed and optimized
- Multidomain system-level studies of the DTMS provided early insight into its overall dynamic behaviour, leading to the implementation of significant improvements in its structure and dynamic response
- MapleSim and Maple were invaluable tools for early system design and analysis

To create tools that would help FLSmidth to design this innovative piece of equipment, the Maplesoft team first had to develop a deep understanding of the dynamics of the skip system. They began by using MapleSim, the advanced modeling and simulation platform, to develop a fully parameterized model of the skip. Taking advantage of MapleSim's multidomain modeling capabilities, they were able to create a high-fidelity model that incorporated all the key components of the skip - from its geometric structure and mechanical operation, to the hydraulic circuits and controllers. "The DTMS is a very large and complex machine," says Willem Fourie, Global Product Line Manager - Mobile Sizer Stations, FLSmidth. "The ability to model all aspects of its operation during the design phase using MapleSim gave us confidence that the product we would ultimately build would function correctly the first time. We cannot even begin to put a value on what this means to us."



3D skip model, and corresponding 2D model with hydraulics

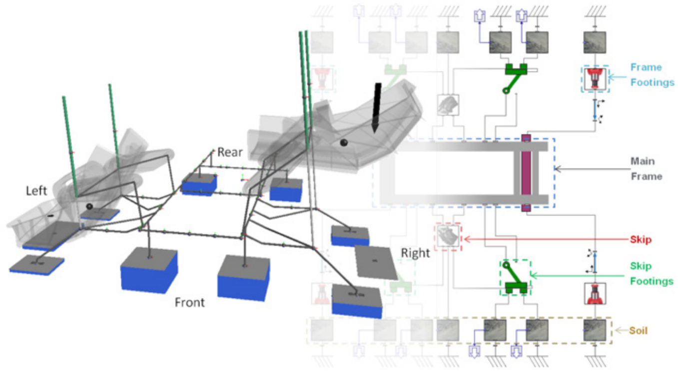
MapleSim's modeling approach not only addresses the basic requirements of dynamic multidomain simulation, but through seamless access to the underlying symbolic equations, enables the user to rapidly create targeted design tools using Maple's high-performance symbolic computation engine.

The creation of the skip model was complemented with the development of multiple design tools to aid in adjusting the model to achieve the desired behavior. One such design tool is the Geometric Design Evaluation tool, which provides the ability to evaluate changes in the dimensions of the skip design and their effect on the dynamics of the system. The tool uses Maple, Maplesoft's symbolic computation tool, to perform a parameter sweep, by simultaneously running simulations using the different parameter values provided. Maple then presents the results overlaid on a single plot window for easy comparison and evaluation. Other tools developed include tools for sizing the hydraulics and components, designing the motion profile, investigating the dynamic loading on the bearings, and estimating the material flow load.

As part of developing and testing the skip model, Maplesoft's technical team also evaluated the design, to identify the sources of vibrations and their effects. They developed an approach to perform stability analysis, which was made possible by the fact that the skip model provided easy access to key geometric features and dynamic properties of the design. The stability analysis approach was demonstrated using a case study in which the location of the feedback sensor was varied. The analysis identified a potential issue very early in the design phase, enabling engineers at FLSmidth to develop a more robust design.

"The stability analysis performed by the Maplesoft team was very insightful," said Fourie. "Knowing about a potential issue early on enabled us to design with it in mind, rather than having to go back and rework our design at a later stage. This contributed to keeping our project on track, and saved us millions of dollars down the line." The stability analysis design approach and all the other analysis tools developed by Maplesoft were delivered to FLSmidth, enabling them to apply them to future projects.

Once the modeling and testing of the skip system was completed, during the following phases of the project, Maplesoft staff went on to develop the chassis model, and finally the full DTMS. Many more design tools were created, providing the ability to evaluate joint flexibility, center of mass variations as the skip was raised and lowered, and even soil modeling to investigate the vertical displacement of the system on different types of soil.



Full DTMS model, including footings and soil interactions

"From start to finish, Maplesoft provided truly knowledgeable and professional service," concludes Fourie. "Their team worked tirelessly to accommodate our schedule, and the power of the Maplesoft toolset is second to none. The level of design detail and the amount of insight we gained have enabled us to revolutionize onsite crushing through the development of the DTMS. We could not have achieved this without the services of the Maplesoft Engineering Solutions team."

Designing an Industrial Pick-and-Place Robot

Industrial automation is on the rise, with machines performing more complicated tasks every day. Designing these complex industrial machines is a challenging process. Engineers need to ensure that the machine they design meets many different performance objectives for productivity, workspace, maneuverability, payload, and so on. At the same time, they also need to develop a design that will minimize both production and maintenance costs, such as using the smallest possible motors and the shortest links for robot arms, and minimizing loading to reduce the wear and tear that leads to expensive repairs and downtime. In light of so many complexities, organizations will over-engineer products, investing in more costly components to reduce unforeseen failures. Others will try to minimize costs, but are more likely to face expensive on-site repairs when unexpected failures occur. System-level modeling offers a third option, providing analysis and deep insight into product performance long before physical prototypes.

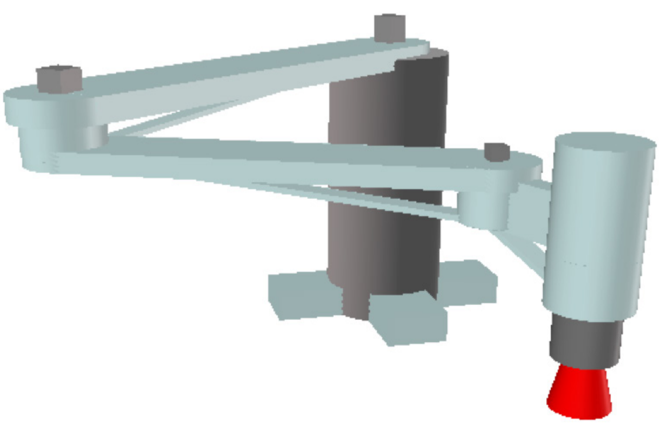
A leading provider of packaging machines approached the Maplesoft Engineering Solutions team looking to understand why they were experiencing reoccurring motor failures in their pick-and-place robots deployed in the field. They turned to Maplesoft to help them answer questions about the design of their product, including many questions that could prove beneficial for all of their future robot designs:

- What is the proper motor sizing for the robot in all operating conditions?
- What lengths should the links be to achieve the desired workspace?
- What effect will different combinations of link lengths have on the design?
- What is the required performance from the motor and gearbox in different use cases?

The Maplesoft Engineering Solutions team applied a parametric system modeling approach to answer these questions. They used MapleSim to develop a high-fidelity parameterized model of the company's pick-and-place robots. Then they used the advanced computation capabilities of Maple to develop analysis tools that examine the operation of the system and its dynamic behavior with different sets of parameter values. These analysis tools, together with the high-fidelity model, provided the company with the insight required to determine how to prevent their motor failures without any new additional hardware. They were able to adjust the robot's motion profile with updated software, eliminating moments when the motors were experiencing damaging levels of torque. What had previously required regular motor replacements was reduced to a simple software update, saving the company substantial amounts of money on their entire line of robots. Further to this, Maplesoft provided them with a toolset they could easily configure for use in the design of similar products.

Model Development using MapleSim

An example of a typical pick-and-place robot is shown below. The robot model is mounted on a reference base, to which three links that form the robot arm are connected. The links are actuated by three servo motors, which provide the rotational motion and control with three degrees of freedom. The end effector consists of a translational component attached to the third link, allowing for the desired pick-and-place action.



Design of a 3-link pick-and-place robot arm in MapleSim

Each of the link structures includes sensor components to provide force and torque information, which can later be used to determine radial force, axial force, and bending moments at each bearing. The model also includes probes embedded at strategic locations within the design to monitor performance characteristics, such as required motor speed and torque, along with joint angle and constraints.

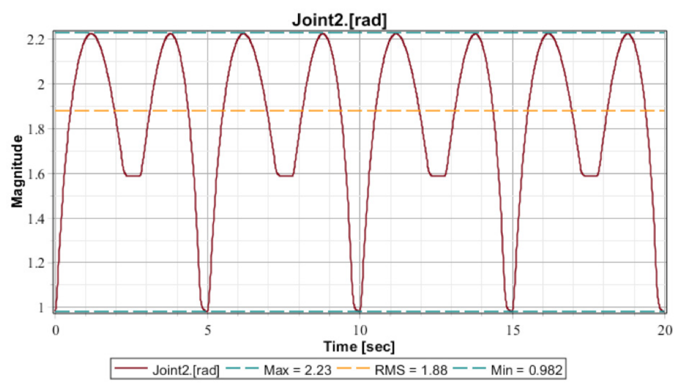
Initial simulations were run in MapleSim to observe the behavior of the system, with the probe information presented in various plots. The model was then loaded into Maple for in-depth analysis.

Design Analysis using Maple

The Maplesoft Engineering Solutions team created a set of analysis tools in Maple to provide the company with deep insight into their design, ensuring that their product is neither over-engineered nor prone to unexpected failure. Taking advantage of the fully parametric MapleSim model and Maple's symbolic computation engine, the tools enable the company to perform simulations across various operating conditions to determine the best combinations of design parameters.

The first design tool developed by Maplesoft enabled the company to perform kinematic analysis. The kinematic analysis allowed them to check the robot's workspace, visualize its motion, and determine any required path offsets. The robot motion is affected by whether the robot's elbow is configured to be on the right side or the left side. One of the features of the kinematic analysis tool was to perform the inverse kinematics calculations, and evaluate for both elbow positions. By observing its behavior in both cases, the company was able to make an informed decision about which side to place the elbow – a decision which was then carried forward and applied to all further analyses.

The next step was to determine whether the robot was operating within the range of allowable motion, and whether any of the joint angles were exceeding the desired limit.

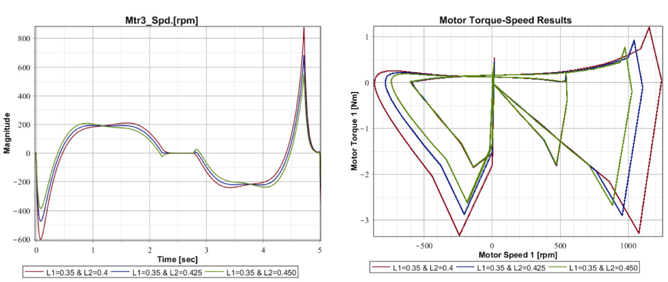


Joint analysis in Maple

For each joint there were multiple variables, including joint angle, angular velocity, and angular acceleration, and these varied based on the desired path of the end effector motion. The results showed that the initial end effector design path resulted in large angular acceleration spikes, indicating that the company needed to make modifications in order to smooth out the motion used to actuate the joints. The adjustment would not only decrease the magnitude of the acceleration spikes, but would also result in reduced joint load, and reduced motor and bearing operating requirements. This insight helped prevent the unnecessary costs of over-engineered motors.

While the company naturally wanted to use the smallest motors possible, they also had to ensure that the motors they selected would still meet the robot's performance goals. The Maplesoft Engineering Solutions team developed an analysis tool to assist the company with motor sizing. The speed, torque, and energy of the motors were determined and plotted, then overlaid on the manufacturer's performance curves for the targeted motors. The motor performance curves were selected from a list of possible motor data imported into Maple. For each of the motors, the company could then compare simulated results with data for different motors from the manufacturer's specifications. Using the analysis tool, the company was able to consider different motor configurations capable of performing within the desired range. A similar approach of overlaying the manufacturer's data on simulated data was taken to explore the gearbox limits and the selection of different gear ratios.

Another analysis tool developed by Maplesoft was a parameter sweep to observe the effects of different link lengths on the operation of the robot. Simulating the model with different link length configurations within a pre-determined permissible range enabled the company to observe the corresponding effects on performance characteristics such as motor speed, torque, load requirements, and workspace variations. Maple automatically makes use of parallel processing, allowing the user's computer to simultaneously run multiple simulations using different parameter values, and then presents the results overlaid in a visualization window for quick and easy comparison.



Example parameter sweep results for varying link lengths

By taking a system-level modeling approach, the company was able to improve their engineering processes, giving them deep insight into their product performance at an early stage of design. The company leveraged this new design process to eliminate a substantial motor replacement program, and continued to make design improvements for future cost savings across their entire robot line.

Summary

The Maplesoft Engineering Solutions team developed a highly configurable solution that helped the company address challenges and unexpected costs they faced when designing industrial pick-and-place robots. Developing a fully parametric system model in MapleSim provided access to all the system parameters required to analyze and optimize the behavior of the system. Maple's symbolic computation engine enabled the development of a wealth of analysis tools that explored the relationships between system parameters, and their effects on the overall performance. This new approach shed light on solutions the company didn't know existed, with overall costs just a small fraction of their previous techniques for robot motor repairs. The parametric models are also being modified and used across various pick-and-place robot designs, reducing potential failures and over-engineered parts early in the design process.

This case study presents just one example of innovation in the industrial automation and packaging machinery sectors. As automated robot requirements become more complex, this company realized the huge role that system-level modeling can play in driving innovation. What started as the desire to fix a simple problem has radically transformed their design process, shortening design cycles and minimizing unnecessary costs every step of the way.

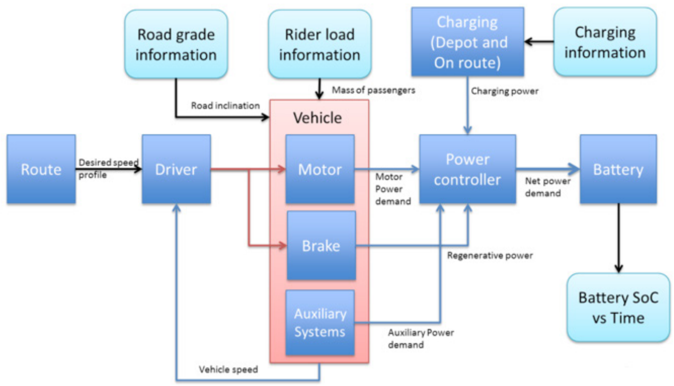
A Modern Electric Bus Fleet: Improving Public Transit with System-Level Modeling

As cities across the world continue to increase in both population and density, public transportation plays a critical role in creating liveable cities by reducing the total number of vehicles operating in urban centers. An effective transit system also has the potential to drastically reduce carbon emissions generated from the transportation of people, resulting in improved urban air quality and sustaining a healthy environment for generations to come.

In order to realize the potential environmental and societal benefits of improved transit, the NRC is determining how to optimize existing transit operations through the implementation of new technologies. Part of their existing research focuses on the analysis of fleet operations using model-driven approaches to transit technology planning. By using physics-based modeling as the core of their analysis methodology, the NRC is able to provide more accurate forecasts of the system-level implications of technology implementations. To improve the flexibility and configurability of their existing modeling tools, the NRC looked to migrate their modeling platform to the modeling and simulations tools developed by Maplesoft.

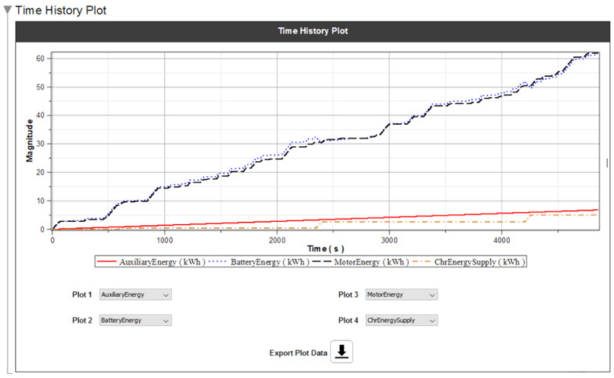
As an initial step towards capability migration, the NRC's modeling team worked with Maplesoft's Engineering Solutions team to create a high-fidelity model of the battery-electric bus dynamics, taking into consideration a wide variety of factors that impact operational decisions. These factors are all necessary to address a range of concerns from transit operators when moving forward with a new type of transit system. For example, transit operators need to know the uptime for an electric bus in comparison to a diesel-powered bus to plan schedules and streamline operations. This requires a detailed understanding of both the charging of bus batteries and determining realistic energy consumption as the bus completes a specific transit route. The operators are also interested in other operating considerations of battery-electric buses such as carbon emission savings, equivalent diesel fuel savings, and the cost of charging the bus during typical usage. The system-level model developed by NRC and Maplesoft helps provide information to address these questions early in the vehicle procurement process.

The battery-electric bus model is composed of a variety of subsystems that are integrated into one unified system for simulation and design exploration. This model was created using MapleSim, Maplesoft's tool for system-level modeling and simulation. The model incorporates interactions from multiple domains of the electric bus system, such as the vehicle body dynamics, electric motor performance, detailed battery models, and passenger loading details as the bus model travels a specific route. This model was created using both the standard MapleSim physics-based components and customized components, which provided the ability to modify the design to the exact bus and transit specifications. With the completed model, the NRC is able to simulate the entire vehicle system, providing system performance information at any point that the engineer wishes to examine.



The model structure includes input from a variety of sources, and captures the dynamics of a range of components in a typical electric bus transit environment.

With the battery-electric bus model fully developed, the NRC and Maplesoft then worked together to create additional tools that would allow for easy import of a variety of transit routes, as well as tools that could be used to quickly gain insight into the performance of different routes and bus configurations. The precision of the produced results from these analyses were far superior to techniques employed elsewhere, which would typically only include performance calculations based on average bus speeds and average energy consumption along a certain distance. MapleSim, the advanced system-level modeling software from Maplesoft, creates system-level models in a symbolic, parameterized environment, so adjustments could be made to easily modify the bus, or specific parameters could be optimized for a required performance characteristic. Tyson McWha, the Program Technical Leader at the NRC leading the fleet optimization team, clarifies how the bus model provided flexibility for their evaluation processes: "The primary advantage of using an advanced simulation platform to evaluate battery-electric bus implementation is that we can now adjust specific vehicle or infrastructure parameters and very quickly understand their effects on the entire system."



A small part of NRC's analysis tools is this overlay plotting window, which allows for a wide variety of simulation results to be compared and automatically exported to programs such as Microsoft Excel.

By using a model-driven approach, the NRC now has the ability to take a given transit route and electric bus, and have their simulation and analysis tools automatically generate the key information required by transit operators and other decision makers. They are able to determine a specific understanding of the vehicle's energy storage requirements for particular bus routes, helping to select the correct mix of technologies to meet the specific demands of the route.

The NRC is continuously refining their battery-electric bus model, increasing its capabilities by feeding in real-world performance data and other environmental variables like weather and traffic. The physics-based modeling platform in MapleSim gave them an intuitive tool that is being used effectively by their transit technology experts. Noting the opportunities to improve upon the bus model, McWha commented on the use of system-level modeling within the fleet optimization team: "Migrating our modeling towards the MapleSim platform has increased our researchers' ability to bring their individual expertise to every facet of the vehicle and infrastructure models. In the end, we have a more user-friendly tool that provides more flexibility and better accuracy."

The NRC is continuing to research the ideal configuration of battery-electric buses in cities across Canada, and they are using modern design approaches to answer questions with greater accuracy than ever before, allowing transit authorities to make informed decisions. By taking a model-based approach to engineering design, the NRC is helping to bring Canadians zero-emission public transportation that caters to the needs of each individual community.

System-Level Models: A Reliable Way to De-Risk and Energize Your Design Process

The process of using system-level models can look different for every company, but the end results are clear: using these models is a reliable way to reduce the risk of late-stage design changes, and speed up the design process with valuable insights at an early stage. Many companies experience hesitation when investing more resources into the study phase of their design, but it is now becoming clear that this is more a product of tradition than it is a product of best practices. By investing even a small amount more into the modeling and simulation phase of a project, the chances of high cost overruns stand to decrease significantly. These stories from industry are showing that, while there is still a cost in adopting a new design tool or process, adopting a model-based design approach is a worthy investment.