USING THE OTTO TRUCK-SIMULATION SOFTWARE TO MANAGE HAUL OPERATIONS

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Abstract

FERIC's OTTO 2000 truck-performance simulation program is described. The basic theory behind the simulation technique is explained and the general power equation that underlies all calculations is presented. Modeling of the driver is based on six parameters: straight-line driving speed, speed around curves, acceleration and braking techniques, gearshift technique, and gear shifting time. Modeling the road is based on the distance, slope, curve radius, surface type, and speed limit for each road segment. The logic and flow of the simulation technique is based on iterative steps of 0.1 seconds and is centered around the limits imposed by the driver, the road parameters, and the vehicle's mechanical limits. The structures of the program's user interface and of the various modules are briefly explained. The drive-train component modules include engines, transmissions, axles, and tires. Vehicle modules are used to define a wide range of tractor and trailer configurations, and vehicles are assembled with their components in a separate module. Road modules include a road editor and tools to join and divide roads, as well as modules for importing and averaging GPS profiles. In the final section, three possible uses of OTTO are outlined: the cost of choosing a larger engine, the costs and benefits of resurfacing a road, and the economics of changing to a different vehicle configuration.

1.0 INTRODUCTION

Transportation costs have become one of the major components of the total cost of goods, especially in the forest products sector. Because of the forest industry's near-total dependence on contract hauling for the transportation of raw forest products, there is a need for tools that can help operations managers predict the cost and operational parameters of trucking. This can help them set rates that are reasonable and fair, thus maintaining a balance between controlling their trucking costs and providing their haul contractors with reasonable revenues. As well, managers and their contractors must be able to specify vehicles and driving techniques that are optimized to their specific operations.

FERIC's OTTO 2000 truck-performance simulation program was designed to help forestry operations and truck fleet managers make these important decisions. OTTO 2000 is based on an original MS DOS–based program (OTTO v 2.0) that had been developed with the assistance of the Transportation Development Center of Transport Canada. There have been more than 100 installations of OTTO v 2.0 in the 8 years since its inception, and users have found numerous ways to profit from its power. FERIC has kept close contact with many of the software's users and has used the program for many research and consulting projects for its members, and has thus been able to determine the program's strengths and weaknesses. In response to the identified problems, many improvements have been introduced into a new version of the software (OTTO 2000), which is now based on the Windows 95/98 platform, with a totally redesigned user interface and many new features.

This paper explains the basic concepts behind the program and its design, and presents some practical examples of its use.

2.0 CONCEPT OF SIMULATION

2.1 Basic Theory

The road performance of heavy vehicles is a factor of three main elements that are subject to a certain measure of control: the vehicle's characteristics, the road conditions, the trucker's driving techniques, and environmental conditions. Correlating these elements is a complex process that has prompted numerous studies. FERIC has used the knowledge generated by these studies as well as its own studies over the years to develop the model and to quantify the parameters on which OTTO is based.

The development of the model centered on the two following principles:

- Encompass the specific conditions of the forest transport sector;
- Integrate driving techniques into the program

Performance modeling for haul operations is based on mathematical descriptions and the development of equations for the three factors that control performance: the vehicle, the road, and the driving technique. These are represented by the general power equation:

[Eq. 1] tractive power = power of inertia + resistive power

Tractive power depends upon the driving technique and the vehicle's capabilities, and is affected by the drive-train efficiency. Engine partial load curves are used to calculate net fuel consumption at each instant. These curves are derived from full-load curves through an original model developed by FERIC.

The *power of inertia* is calculated from variations in speed, the gross vehicle weight, and the power-train inertia.

Resistive power relates to losses to slopes, cornering, air resistance, and rolling resistance.

- Losses due to slope are calculated using the conventional approach based on gross vehicle weight and slope angle.
- The formulas and parameters for resistance due to cornering were developed and validated by FERIC through tests conducted as part of joint research with Transport Canada.
- The formula for determining losses due to air resistance is taken from the literature; the coefficient values are specific to logging vehicles and were determined by previous FERIC testing.
- Rolling resistance was determined based on FERIC's tests on numerous roads.

2.2 Modeling of Driving Technique

Modeling of the driving technique accounts for the decisions and actions of the driver Given the scarcity of literature on this subject, we had to establish descriptive parameters for this model, then develop specific equations and define intervals for the parameter values. The following parameters were chosen based on an analysis of test results for more than 60 drivers:

- The *straight-line speed* is the driver's customary cruising speed on a given type of road, with regard to vehicle and load configurations.
- The *cornering speed* is the maximum speed attained by the driver as a function of the sharpness of the turn, the road type and conditions, and the vehicle and load configurations.
- The *gearshift technique* determines the minimum and maximum limits within which the driver runs the engine. One or more gears may be skipped where conditions warrant.
- The *gear shifting time* depends upon whether the driver is upshifting or downshifting and varies with slope.
- The *acceleration rate* describes the driver's aggressiveness in handling the conditions encountered. It determines the desired power level.

- The *braking technique* depends upon current vehicle speed and target speed, which is determined by the constraints within the driver's field of vision and by the upcoming road characteristics.

The possible settings for these parameters are slow, medium and fast, except for the gear shifting time, which has no medium speed, and the shifting technique, which can be set either as "progressive" or "top RPM", depending on the actual technique. The program comes with five predefined driver styles, but users can create their own drivers if so desired.

2.3 Road modeling

One of the strong points of OTTO is that it uses actual road profiles to simulate vehicle performance. With the advent of inexpensive, reliable, and accurate GPS, road profile data can be acquired quickly and efficiently. FERIC has developed a GPS averaging technique that increases the accuracy of GPS profiles in the vertical direction and efficiently eliminates erroneous points. This method is described more fully in a later section.

In addition to the vertical and horizontal profiles, road modeling accounts for the road's surface type, the season, and the legal and safe speed limits. The following 10 categories of road types are available:

Winter	Summer
Frozen asphalt	Asphalt
Frozen gravel	Worn asphalt
Packed snow	Crushed rock
Wet snow	Selected gravel
	Rough gravel or earth road
	Muddy or soft road

2.4 Simulation Logic

The program resolves the general power equation by iteration using the descriptive parameters that represent the selected vehicle configuration and the road survey data. Calculations are made at 0.1-second intervals to optimize calculation times and the quality of the results. Figure 1 provides a simplified flow chart of the program's logic.

The first step in the process is to calculate the current road and engine speed and the distance traveled based on the acceleration level and speed that had been determined in the previous 0.1 seconds. At the beginning of the simulation, a separate module simulates the

starting period until the vehicle attains an engine speed that is within the working range of the engine.

The next step is to determine the amount of power that the driver intends to use. This calculation is based on the specified driving technique, the slope and radius of the road, and the vehicle speed. Once this power level is established, the level of acceleration is calculated. To simplify the iterative process, it is always assumed that the truck will accelerate in the next 0.1 seconds. A future speed can then be calculated. In the following step, this future speed is validated to determine whether the acceleration level is maintained or whether to decelerate (by braking or using negative power) or maintain the current speed. If the decision is to decelerate or maintain speed, the power and fuel consumption are recalculated.

The decision whether to accelerate, decelerate, or maintain speed is based on the driver's braking technique, the road profile, and the mechanical limits of the truck. The braking technique determines how far ahead a stop or a section with a change in speed limit must be for the driver to begin decelerating. The driving technique also determines the speed at which the driver will cruise given the road's geometry and the speed limit for each particular section.

Once the appropriate future speed has been determined, the engine speed that corresponds with this speed and the current transmission gear are checked to determine whether it's necessary to shift gears. If so, the power is set to zero during the gearshift, fuel consumption is calculated at the engine's idle speed, and the duration of shifting is based on the driver's gear shifting time.

The calculations are then complete for this 0.1-second iteration, and the process continues for the next 0.1-second interval, and so on until the vehicle reaches the end of the simulated road.

3.0   PROGRAM DESIGN

OTTO 2000 comprises four basic groups of modules: the component databases, vehicle design and assembly, road editing and tools, and simulations. These modules can be accessed either through the menu or through a shortcut bar.

3.1 Component databases

The component databases contain the information that defines each drive-train component needed to propel a truck: engines, transmissions, rear axles, and tires. The driver module is also grouped with this set of components. Many of the most popular components used in Class 8 trucks are already included in the databases. However, users can easily add new components to the database.

All components are classified in terms of the manufacturer and model name, and include information specific to that component. The specifications that define each component and those that are necessary for the simulation are as follows:

- **Engines** are defined in terms of their rated power, maximum torque, and rated rpm. Power and brake-specific fuel consumption at full throttle (at 100-rpm intervals in the engine's rpm operating range) are also required. A procedure developed by FERIC determines the fuel consumption at partial engine powers based on the full-power curve.
- **Transmissions** are defined in terms of the maximum torque rating, the number of gears, and the ratio of each gear. The program will warn users of selection errors, such as choosing a transmission with a lower torque rating than the engine's maximum torque output.
- **Axles** are defined in terms of the axle's weight rating, the gross combination weight rating, and the reduction ratio. The program warns users of selection errors, such as when the gross combination weight or axle weights of an assembled vehicle are higher than an axle's ratings.
- **Tires** are defined in terms of their size, type of ply, and number of revolutions per mile.

3.2 Vehicle Design and Assembly

The vehicle design and assembly modules let users create their own trucks and trailers, and assemble them into vehicles. Tractors and trailers are defined by their dimensions (height, width, length, and axle spacing) and tare weights. Four types of trucks can be chosen: tractors or straight trucks, both with three or four axles (tandem or tridem drive, respectively). Trailers include pole-trailers; logging trailers; logging, van, and flatbed semi-trailers and B-trains; and dollies and jeep dollies.

In assembling a vehicle, users choose the drive-train components that made up their truck, the tractor and trailer units, the driver and payload types, and the weight that the vehicle would carry. When setting the payload, the province in which the truck would operate can be selected so that the software can display the legally allowed gross vehicle weight for that particular configuration.

3.3 Road Editing and Tools

The road editor is the main road module. OTTO defines a road in terms of the following properties:

- The road's overall length.
- The speed limit for each section of the road, or for the road as a whole.
- The type of surface for each section of the road, or for the road as a whole.

OTTO lets users change the surface type and speed limit for all or part of the road in a few simple steps without having to modify each individual point on the road. For more detailed changes, OTTO displays an editable table of data for each point along the road, in order of increasing distance from the start of the road. For each section of road in this table, the user can change the slope, curve radius, speed limit, and road surface type. The road editor also offers a map view and a profile (distance vs. elevation) view of roads that have points with co-ordinates. The map view can be enlarged to fill the screen and offers a tool that shows the straight line and road distances between any two points the user selects.

OTTO offers many useful tools to manage road data. Roads can be copied (in whole or in part), inverted to change the starting point, or joined together end to end. There is also an module for importing GPS profiles and converting them into the road data required by OTTO, and modules for importing the road files used with the previous version of OTTO and files that contain road data expressed in text format.

The last tool permits GPS averaging. GPS surveys of roads contain inherent inaccuracies for a variety of reasons related to the technology itself and the forest environment. For this reason, surveyors commonly survey a road at least twice (outbound and returning) so they can combine the data and produce a better overall estimate of the road's true position. OTTO's GPS averaging function combines two or more GPS data files into a single road file and produces a more accurate overall map of the road.

3.4 Simulations

Three modules make up the simulation set: the simulation editor, a Quick Run module that lets users start an existing simulation without having to use the editor, and a Report module that gives access to saved reports generated by previous simulations.

With the simulation editor, users can create new simulations or edit existing ones. A simulation can include any combination of roads and vehicles, and each selected vehicle will be simulated on each of the selected roads. A simulation can be run in either direction (outbound or inbound) or for a full cycle (both directions). For each vehicle, empty travel or travel fully loaded can be selected for each direction. For each road, simulations can be run for the entire length of the road or from any starting point to any endpoint along the road.

When the simulation is running, a display window indicates which vehicle, road, and travel direction are currently being simulated. The progress of the vehicle, its fuel consumption, the present road and engine speeds, and the elapsed travel time are also displayed. As soon as the simulation is complete, users can display the results, which are provided in two formats: global and detailed. The global results summarize total elapsed time, average travel speed, and fuel consumption for each combination of vehicle, road, and direction of travel. The detailed results give the state of the vehicle at every point defined in the road file. The detailed results can also be exported for analysis by Microsoft Excel 97 Both forms of OTTO reports can be saved for later viewing with the Report module.

4.0 EXAMPLES OF PROGRAM APPLICATION

This last section presents three examples of how OTTO 2000 can be used. We used the same road in all three examples, one that is fairly typical of the hauling distances found in current forestry operations. The details of the road can be found in Table 1 The actual road is in the Gaspé region of Quebec. The base vehicle used for the simulations was a tractor paired with a four-axle semi-trailer, a combination that is commonly used in log hauls in Quebec. The specifications for the vehicle can be found in Table 2. We used a driver with an aggressive driving style because this style is better suited to the hilly terrain found in the Gaspé.

The three examples focus on switching to a more powerful engine, determining the effects of deterioration of the road surface on the primary road, and switching to a B-train combination. The results of all simulated configurations can be found in Table 3 Please note that a full cycle was simulated, with an empty outbound trip and a loaded return trip.

4.1 Drive-train Specification

Many truckers equip their trucks with increasingly big engines. But what effect does this have on the performance of the truck? Is the time saved with the bigger engine worth the various costs? In this example, we replaced the engine in the base model with a Caterpillar 3406E 550 HP engine. As the results show (Table 3), we only saved 2 minutes over the entire trip by using the bigger engine, but fuel consumption increased by 4.5%. With two shifts per day, a truck in this type of operation would perform a minimum of 15 trips per week over a 40-week period, for a total of 600 trips per year The extra 7 L of fuel consumed per trip by the larger engine, at $0.65/L, would cost about $2730.

4.2 Road Improvement Decisions

Roads with crushed rock surfaces degrade over time, and the road must usually be resurfaced with new crushed material after 5 to 10 years, depending on the traffic level. This simulation assumes that the surface of the primary forest road in our example degraded to the point at which it was equivalent to a good gravel surface, as on the secondary road. Can a forest operations manager justify the cost of resurfacing 69 km of road at a cost of $12 000/km, for a total cost of $828 000?

If we let the surface of the 69 km of primary road degrade to selected gravel, without changing the speed limit, the results are dramatic. Fuel consumption increases by 17.6% (27 L per trip) compared with the original road (i.e. newly surfaced), and the trip time increases by almost 17 minutes (the base truck is simulated in both cases). Our truck carries a payload of 37.5 tonnes per trip. A large forest haul operation can haul between 100 000 and 1 million tonnes/year on its primary haul road, with typical values of around 400 000 tonnes. To simplify our calculations, we will assume an annual haul of 375 000 tonnes on

our primary road. These conditions would require 10 000 trips per year to supply the mill. If the vehicles consume an additional 27 L per trip, this represents an annual increase in fuel consumption of 270 000 L, for a total cost increase of $175 000. Over a 5-year lifespan for a crushed rock surface, this represents a total cost of $875 000. It's obvious that fuel savings alone can justify the investment. On top of this, we can add reductions in wear and tear on the vehicles as a result of travelling on smoother surfaces, plus reduced road maintenance costs due to reductions in grading and increased safety. The decision to maintain the road becomes a quite clear

4.3 Choice of Truck Type

In our final example, we will determine whether it is economically justifiable to switch from a semi-trailer to a B-train configuration. In Quebec, B-trains have a legal GCW of 62.5 tonnes, which amounts to 7 tonnes more than is permitted for a four-axle semi-trailer Typical B-trains used to haul wood have tare weights of about 21 tonnes, so we would be hauling an additional 4 tonnes of payload on each trip (41.5 t for the B-train vs. 37.5 t for the semi-trailer).

Our simulation shows that the B-train would consume 11.2% more fuel per trip (17.3 L) without any significant reduction in overall travel speed. If we calculate the fuel consumed per tonne transported, the semi-trailer is more energy-efficient, consuming 4.09 L/tonne versus 4.12 L/tonne for the B-train. However, we also performed an economic analysis using a spreadsheet developed by FERIC to calculate the operating cost of logging trucks, the B-train is more cost-effective. This spreadsheet takes into account factors such as maintenance, depreciation, and labor costs in addition to fuel costs. The costs per tonne hauled calculated by the spreadsheet amount to $11.05 for the B-train, versus $11.57 for the four-axle semi-trailer. Based on total operating costs, the switch to a B-train would provide a slight economic advantage.

5.0 CONCLUSIONS

OTTO 2000 is simple to use, and is based on solid scientific and technical information. It lets permits managers do the following:

- Gauge the costs and benefits of proposed modifications to a transportation system;
- Specify a vehicle tailored to their specific operations;
- Manage the logistics of their operation by providing estimated cycle times and average speeds for their haul vehicles;
- Establish the relation between road cost and trucking cost.

In the future, FERIC plans to broaden the usefulness of OTTO by integrating it with the Geographical Information Systems (GIS) being used by many companies. This can help them with road design by matching simulation results to their road network database. We will also integrate OTTO with the other software that FERIC has produced or that is

currently under development (e.g., Interface and a Road Management System). Interface is FERIC's cost-analysis software for forest operations, and integrating it with OTTO will let managers quickly estimate the total cost of various options. The Road Management Software, currently under development, will help FERIC members to manage and plan their road assets. Its integration with OTTO will help operations managers think of trucking and road construction and maintenance as a combined system rather than as independent entities.

There is little doubt that in its present format and with the planned integrations, OTTO will be increasingly popular and useful among our members, and its installed base should continue to grow.
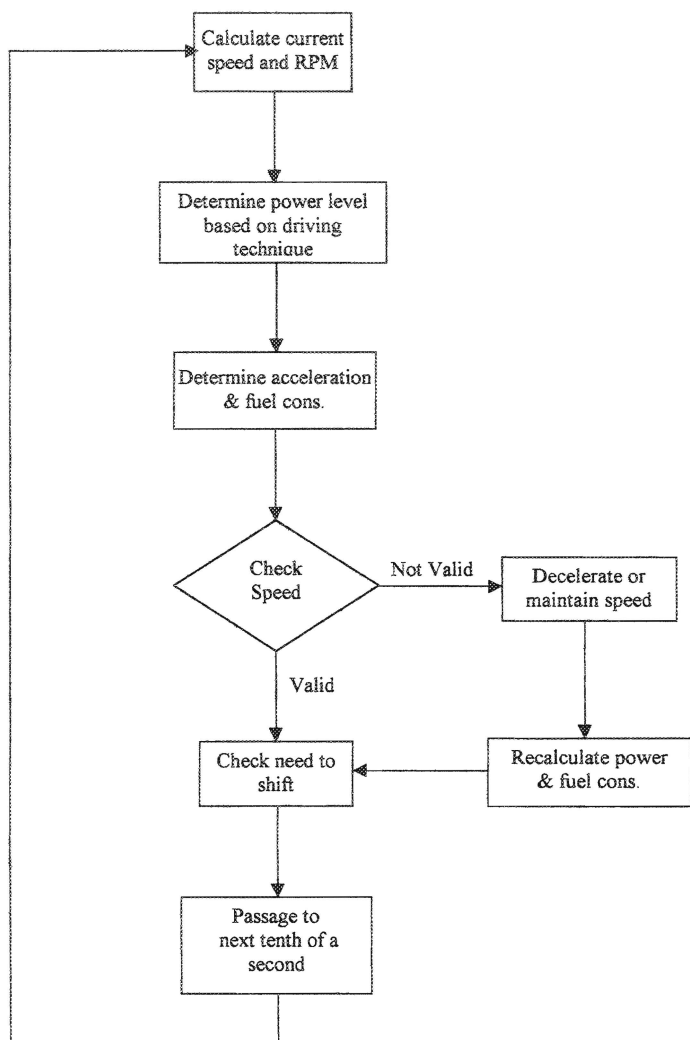
Figure 1. Flowchart of simulation logic

403

Table 1. Details of the road used for the three simulations

Section	Length (km)	Surface	Speed limit (km/h)
Provincial highway	51	New asphalt	90
Primary forest road	69	Crushed rock	70
Secondary forest road	25	Select gravel	60
Tertiary forest road	6	Rough gravel or earth	40
Total	151	—	—

Table 2. Specifications of the base vehicle used in the three simulations

Engine	Caterpillar 3406E 455 hp, 1650 ft-lb max. torque
Transmission	Fuller RTLO 18-speed rated torque of 1850 ft-lb
Rear axle	Meritor RT 52000/215000 with a 4.89 reduction ratio
Drive tires	Michelin XDE A/T 11R22.5
Weights	Tare: 18.0 t; Gross Combination Weight: 55.5 t

Table 3. Simulation results

Configuration	Trip time (h:m:s)	Average speed (km/h)	Fuel consumed (L)	Fuel consumption (L/100 km)
Base	4:27:28	67.9	153.5	50.7
550-hp engine	4:25:09	68.5	160.5	53.0
Rougher road	4:44:01	63.9	180.5	59.6
B-train	4:30:13	67.2	170.8	56.4