Measuring the Impact of Intermodal Rail Movements in State Transportation Planning

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As state transportation planners seek to build or support sustainable transportation systems in an era of economic challenges, they find few publicly available rail analysis models for stakeholders to examine the environmental impacts, socio-economic effects and costs associated in investing in rail infrastructure. This paper, taken from a University Transportation Center Program (UTCP Region 6) funded study presents stakeholders with the building blocks necessary to develop an integrated rail analysis model. It also reviews the current state of rail modeling, current rail models and presents a preliminary intermodal rail costing model .

INTRODUCTION

Analyzing rail operational benefits and costs is an inherently complex process. Forkenbrock (2001) and Bereskin (2009), suggest several factors which may contribute to this complexity and which include technological innovations, economies of scale, scope and density, joint production among rail companies-, and lack of data on specific expenditures pertaining to individual freight movements. Furthermore, the high capital costs required to construct and maintain rail service obscures the ability of outside analysts to determine how much it actually costs the railroad to transport any given shipment. Nevertheless, an understanding and ability to simulate rail operations is essential for transportation stakeholders to examine the environmental impacts, socio-economic effects and costs associated with investing in rail infrastructure.

Methods to determine rail costs have always been central to rail operations and since de-regulation several academicians and_–government organizations have developed models to examine various components of rail operations. In the area of rail costing, noted authors like Bereskin (2001, 2007, 2009), Forkenbrock (2001), Caves et al. (1980,1981), Ivaldi and McCullough (2001), and Spady et al.(1976,1979) reported on the railroad industry's achievement of productivity gains over time and through mergers, the non-linearity of rail costs (Bereskin, 2001), and the existence of economies of scope in the railroad industry[1] and produce different outputs at different cost levels (Bereskin, 2009). In addition, findings have shown that increases in rail traffic have the potential to result in diseconomies (Bereskin, 2009) as a result of traffic delays. Government agencies such as the Surface Transportation Board (STB) are more limited in the types of tools they can use in determining impacts of rail service change or whether rates are in line with variable cost. For two decades, the Surface Transportation Board (STB) has used the Uniform Rail Costing System (URCS) model. URCS is the STB's railroad general purpose costing system that is used to estimate variable and total unit costs for Class I U.S. railroads. While the model has significant limitations, it is still the official tool used by the STB. The URCS model can be used for costing specific traffic with less concern for economic

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[1] Especially the ability of railroads to use similar infrastructure and equipment for different operational purposes,

characteristics (Bereskin, 2001). URCS uses system average units based on costs relationships and system data for Class I railroads. The data are updated annually by the STB however the basic structure of the models remains as it was when it was developed decades ago and does not reflect modern railroad operations. For example, there is no clear way to delineate double stack intermodal as this technology was not widespread at the time of the model's development. For several reasons, the cost estimation method used by URCS is now not entirely accurate. Recently the STB announced its intention to begin the process of replacing the URCS model due to its well known limitations.

In the area of railway engineering, DeSalvo (1969), Hay (1982) and Avallone et al. (2006) have published work on rail operations which can assist researchers in simulating line haul movements. Others have investigated railroad system performance, technological innovations, terminal operations, and preventive maintenance schemes. However the need for a publicly available rail analysis modeling framework that can be used by stakeholders in policy making still remains. Such a framework would assist stakeholders in determining the environmental impacts, socio-economic effects and costs associated with investing in rail infrastructure. This paper seeks to introduce the building blocks of such a framework, and also present a preliminary intermodal rail costing model developed as part this UTCP study. The framework as show in Figure 1 is composed of three main components external parameters, asset management, and operating parameters.

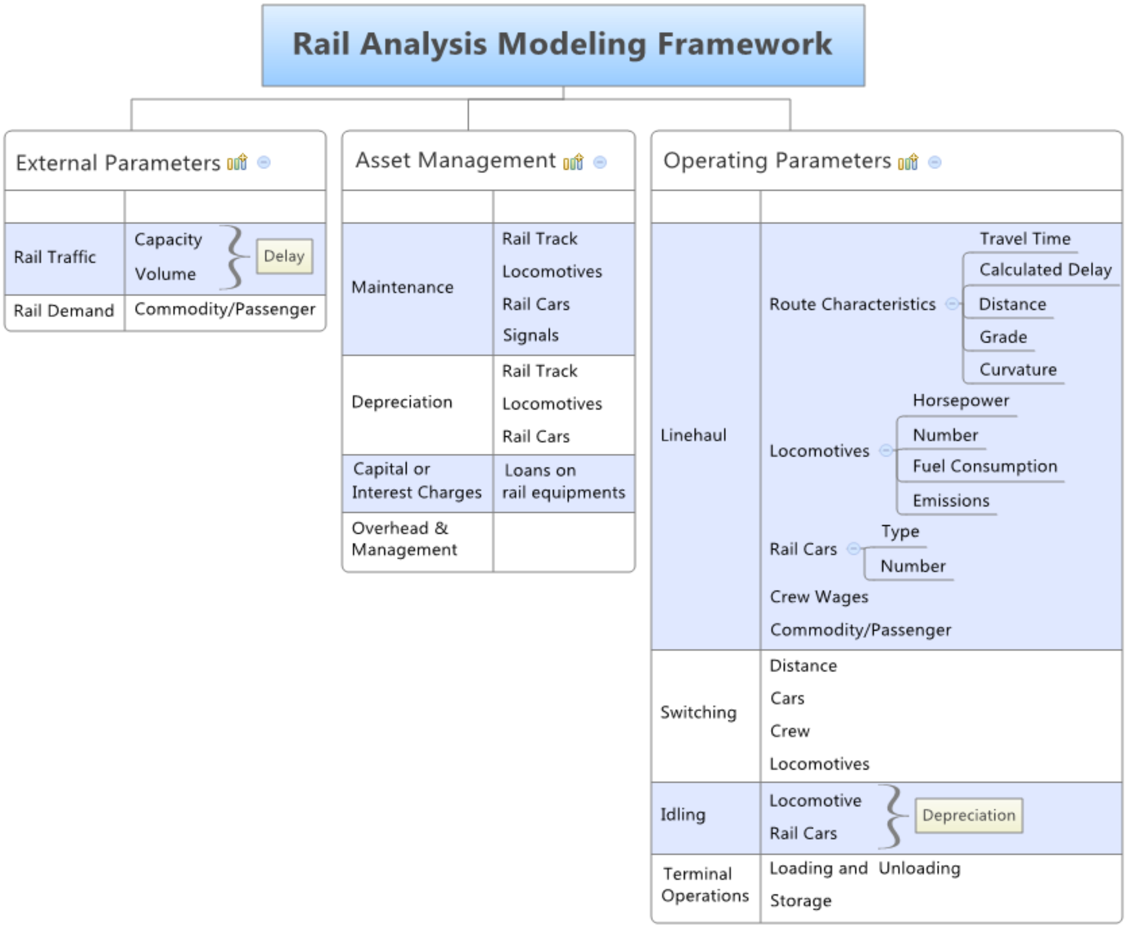

Figure 1: Rail Analysis Modeling Framework

METHODOLOGY

External Parameters

External parameters include the influence of rail traffic and rail demand on individual rail movements. As noted by Hay (1982), railroads incur continuing capital and maintenance costs regardless of whether equipments are used or not. These fixed or continuing costs are referred to as overhead costs. Overhead costs and direct costs are distributed over the volume of traffic handled. The greater the rail traffic, the lower the share of fixed cost borne by a single unit of traffic. This concept is illustrated in Figure 2: Illustration of Unit Cost versus Traffic VolumeFigure 2 by Hay (1982).

Unit cost decreases from point A to B as traffic volume increases. As volumes keep increasing from B to C, unit cost begins to increase again as congestion, delays and maintenance costs build up. When additional capacity is provided at point D, unit cost begins to reduce again to point E (Hay, 1982). The graph also illustrates incremental costs as any increase traffic x (e.g. x+1) results in decrease in unit cost y (i.e. y-y').

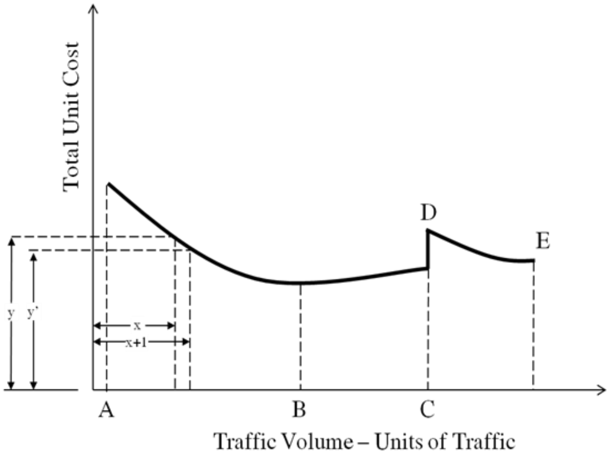

Figure 2: Illustration of Unit Cost versus Traffic Volume
Source: Hay, 1982

The external parameters block assists stakeholders in measuring the impact of rail capacity and corresponding delays when volumes increase. It can also be used in projecting how demand can affect the entire rail network. This is important as demand drives the volume of traffic on the network at any given time. The external parameter block serves as an input for the operating parameters block, thereby assisting stakeholders in determining how demand and volume influence individual rail movements.

Asset Management

Rail asset management involves the management of all railroad equipments and personnel. Items include equipment maintenance, asset depreciation, capital or interest charges, and overhead and personnel management. Equipment maintenance includes taking stock of the number of specific equipments and the cost associated with maintaining the equipment. Asset depreciation accounts for the reducing value of owned equipment. Capital or interest charges are cost accrued from the purchase of new equipments and the upgrading or development of rail infrastructure such as tracks and signals. Overhead and personnel management is comprised of the salaries and benefits meted out to employees of the railroad. Asset management may also include equipment leasing and rental where applicable. The asset management block also provides data to be used in the operating parameters block when simulating the cost associated with individual rail movements.

Operating Parameters

Operating parameters involve the simulation of a single train through a pre-specified set of inputs such as route characteristics, type of locomotive, type of rail cars, commodities transported, emission rates, crew wages, and loading and unloading operations. Some inputs of the operating parameters block such as travel time and maintenance costs are calculated from the two other building blocks. The external parameters block determines the calculated delay of rail operations based on capacity and demand, and items such as the cost associated with equipment depreciation and track maintenance is calculated from the asset management block.

With all of these building blocks working together, stakeholders have the capability of modeling various scenarios of rail operations and determining the environmental impacts, socio-economic effects and costs associated with investing in rail infrastructure.

INTERMODAL RAIL MODEL

As part of this study, a preliminary intermodal rail model (IRM) which forms part of the line haul section of the operating parameters block was developed. The core equations governing the line haul model were adapted from work by DeSalvo (1969), Hay (1982) and Avallone et al. (2006). The model enables stakeholders to measure operational differences between TOFC and double stacked intermodal service, emissions produced during line haul operations, operational differences when using multiple locomotives or car types, influence of delay, and other route specific characteristics such as grade changes and road curvature.

Cargo Weight, Number of Containers, and Rail Car Configuration

There are numerous types of rail cars and each has its own tare weight, cargo capacity, and load limit. IRM allows users to select between ten different types of rail cars and container types. When simulating an intermodal TOFC service and given a certain number of cars, N_c, the total weight of cargo will be

$$W_c = \sum_{i=1}^{N_C} w_{c_i} \qquad (1)$$

For an intermodal double stacked service, given a certain number of containers, X, the total number of cars will be

$$N_x = \frac{X}{2} \qquad (2)$$

And the total cargo weight will be

$$W_s = \sum_{i=1}^{N_x} w_{s_i} \tag{3}$$

Locomotive(s)

The total number of locomotives is dependent on the horsepower of each locomotive and the desired horsepower per trailing ton ratio (HPTT). HPTT is determined by railroads, and varies by route and service type. It dictates the desired maximum speed of the train which in turn influences travel time and fuel consumption. The typical ratios used by Class I railroads varies between 2.5 to 3.5 HPTT for intermodal and less than 2.5 for coal and other heavier cargo. IRM enables the user to specify the desired ratio and calculates the total HP required. The total number of locomotives (N_L) is then calculated based on the required HP divided by the specified horsepower of each locomotive (HP_{L_i}).

$$N_L = \frac{HP_{required}}{HP_{L_i}} \tag{4}$$

Given the weight of a single locomotive as w_{l_i}, the total weight of all the locomotives is equal to the sum

$$W_L = \sum_{i=1}^{N_L} w_{l_i} \tag{5}$$

The total weight of the train, W, can be calculated for a non-containerized movement or a TOFC service as

$$W = W_c + W_L \tag{6}$$

For a double stacked service, W is calculated as

$$W = W_s + W_L \tag{7}$$

For a mix of single and double stacked containers[2], W is calculated as

$$W = W_c + W_s + W_L \tag{8}$$

Train in Motion

According to Hay (1982), train movement and speed are opposed by various forces (resistances) which must be overcome by the propulsive force (tractive effort) of the locomotive. These forces contribute to the operation of the rail and the overall operating costs (Hay, 1982). Internal resistance of the locomotive, resistances varying directly at the axle loading (journal friction, rolling resistance, and track resistance), flange resistance, air resistance, and track modulus resistance are always present during train movement. An expression for these resistances was

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[2] The model gives users the ability to combine single and double stacked containers and other different car types

developed empirically and known as the train resistance. Wind resistance, external axle loading resistance, curve resistance, grade resistance, acceleration resistance and inertia (starting) resistance are only present intermittently but are also estimated through empirical relationships (Hay, 1982). IRM currently calculates train speed as a function of tractive effort, train resistance, curve resistance and grade resistance.

Tractive Effort

Tractive effort is the force required to pull a train. It is determined by the equation

$$\mathrm{F_T} = (\mathrm{hp_e} - \mathrm{hp_a}) \times 375 \times \mathrm{e/V} \tag{9}$$

where

$F_T = tractive\ effort\ in\ pounds$
$hp_e = engine\ shaft\ horsepower$
$hp_a = horsepower\ to\ auxiliaries$
$V = speed\ in\ miles\ per\ hour$
$e = efficiency\ which\ varies\ between\ 0.70\ (AC)\ and\ 0.8 - 0.85\ (DC)\ locomotives$

The most common interpretation (DeSalvo, 1969; Hay, 1982) for the above equation is shown below by taking efficiency (e) as 0.82 (e can however be modified by the user in IRM)

$$F_T = \frac{308hp}{V} \tag{10}$$

hp is the manufacturer's rated horsepower, and F_T and V are as before (Hay, 1982). IRM allows the user to input any desired efficiency as it varies greatly for each kind of locomotive.

Train Resistance

Train resistance is modeled using the Basic Davis Equation, the Modified Davis Equation and the Adjusted Davis Equation. The Basic Davis Equation is known to result in resistances higher than the Modified and Adjusted versions but still relevant for calculating drag and flange friction resistance for locomotives.

Using the Basic Davis Equation, the train resistance for one locomotive is

$$R_{l_i} = 1.3w_l + 29a_l + bw_lV + cZV^2 \tag{11}$$

where

$R_{l_i} = train\ resistance\ of\ a\ single\ locomotive$
$w_l = weight\ of\ a\ single\ locomotive$
$a_l = number\ of\ axles - locomotives$
$V = train\ speed$
$Z = locomotive\ cross - sectional\ area\ (120\ sq. ft)$
$b = coefficient\ of\ flange\ friction\ (0.03 for\ locomotives)$
$c = drag\ coefficient\ of\ air\ (0.0025\ for\ locomotives)$

The total train resistance for all locomotives is the sum of all locomotive resistances

$$R_L = \sum_{i=1}^{N_L} R_{l_i}$$

$$R_L = 1.3W_L + 29A_L + bW_LV + cN_LZV^2 \tag{12}$$

where

$R_L =$ total train resistance of all locomotives
$W_L =$ total weight of all locomotives
$A_L =$ total number of axles of all locomotives
$N_L =$ number of locomotives

Substituting the values of b, c and Z, the resistance function for all the locomotives is

$$R_L = 1.3W_L + 29A_L + 0.03W_LV + 0.3N_LV^2 \tag{13}$$

Current improvements[3] in railroad operations resulted in the need to adjust the Basic Davis equation especially for rail cars (Hay, 1982). The modified Davis Equation is similar to AAR's equations and is appropriate for relatively high weights of 70 tons or more (RailSIM website, 2007). The modified Davis Equation for a single locomotive car is

$$R_{c_i} = 0.6w_c + 20a_c + 0.01Vw_c + KV^2 \tag{14}$$

where

$R_{c_i} =$ resistance of a single freight car
$w_c =$ gross weight of a single freight car
$a_c =$ number of axles of a single freight car
$V =$ speeed in miles per hour
$K =$ air resistance (drag) coefficient with values of 0.07 for conventional equipment, 0.0935 for containers, and 0.1600 for trailers on flatcars.

The total train resistance for all rail cars is

$$R_C = \sum_{i=1}^{N_C} R_{c_i} = 0.6W_C + 20A_C + 0.01VW_C + N_CKV^2 \tag{15}$$

where

$R_C =$ total train resistance of all freight cars

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[3] Current improvements include improvement on car trucks, improved wheels, roller bearings, heavier loading per car, improved journal lubricants and lubricators, stiffer subgrades, and stiffer rails (Hay, 1985)

$\mathrm{W_C} = total\ weight\ of\ all\ cars$
$\mathrm{A_C} = total\ number\ of\ axles\ of\ all\ cars$
$N_L = number\ of\ cars$

The adjusted Davis equation is appropriate for intermodal trains, particularly those with double-stack containers or mixtures of different intermodal car types namely TOFC, single stack COFC, and double stack COFC (RailSIM website, 2007).

$$R_{adj} = K_{adj}\,(0.6W_c + 20A_C + 0.01VW_c + KN_CV^2) \qquad (16)$$

where
$R_{adj} = adjusted\ unit\ train\ resistance$
$R_D = conventional\ Davis\ resistance$
$K_{adj} = an\ adjustment\ factor\ to\ modernize\ the\ Davis\ equation$

Total train resistance is therefore equal to

$$\mathrm{F}_u = \mathrm{R_L} + \mathrm{R_C}$$

$$F_U = 1.3W_L + 29A_L + 0.03W_LV + 0.3N_LV^2 + K_{adj}\,(0.6W_C + 20A_C + 0.01VW_c + KN_CV^2) \qquad (17)$$

IRM automatically varies the K and $\mathrm{K_{adj}}$ values based on the equipment selected by the user. Other modifications of the Davis equation have been developed for more specific applications all of which apply to the cars trailing locomotives. These equations though not currently included into IRM, were developed by Tuthill and the Canadian National Railway (Avallone et al., 2006).

Grade Resistance

Grade resistance is taken as 20 lbs/ton per percent of grade. It is derived from a relationship between the angle of ascent (or descent) and gravitational forces acting on the train (Avallone et al., 2006). The number 20 is a result of the conversion from tons to pounds. Grade resistance, train weight, and percentage grade can therefore be expressed as

$$\mathrm{F_g} = 20\mathrm{Wg} \qquad (18)$$

where
$\mathrm{F_g}$ = grade resistance, in pounds
W = total weight of train (locomotive and cars), in tons
g = percentage gradient of terrain

Curve Resistance

According to Avallone et al. (2006) the behavior of rail vehicles in curve negotiation is the subject of several ongoing AAR studies. Recent studies indicate that flange and/or gage face lubrication can significantly reduce train resistance on tangent tracks (Avallone et al., 2006). However, for general estimates of dry (unlubricated) rail with conventional trucks, the following expression is used

$$F_c = 0.8Wc \tag{19}$$

where

$W = gross\ weight\ of\ train\ in\ tons$
$c = degree\ of\ curvature$

Train Cruising Speed

Train cruising speed can be found using the equation of motion

$$F_T - F_u - F_g - F_c = 0 \tag{20}$$

Substituting into the above equation with the earlier defined F_T, F_u, F_g and F_c the equation of motion can be rewritten in the form

$$308hp - \left[1.3W_L + 0.6K_{adj}\,W_C + (20g + 0.8c)W + 29A_L + 20K_{adj}\,A_C\right]V - \left[0.03W_L + 0.01K_{adj}\right]V^2 - \left[0.3N_L + K_{adj}\,KN_C\right]V^3 \tag{21}$$

Solving Equation 21 iteratively, results in the determination of the train's cruising speed, *V*. On the other hand if the train's maximum speed is specified, IRM varies the horsepower per trailing ton (hptt) ratio in order to calculate the required horsepower needed to power the train at the specified maximum speed.

Fuel Consumption and Cost

Fuel consumption is calculated as a function of thermal efficiency, HP, and travel time. Thermal efficiency (η) is defined as the ratio of work performed to energy consumed, and varies between 25 – 30 percent for a rail diesel engine (DeSalvo, 1969). To relate work and energy, the energy content of a gallon of fuel is assumed to be 138,700 Btu[4], and work defined as the product of horsepower and time is converted to Btu via the formulae 2544 Btu = 1 hp-hr.

$$Work = 1hp - hr = 2545\ Btu \tag{22}$$

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[4] 138,700 Btu/gallon is the value reported by the Bureau of Transportation Statistics. Btu content of diesel however can vary between 129,500 Btu/gallon and 141,700. DeSalvo used 139,900 Btu/gal. in his analysis.

$$Energy = 138{,}700\ Btu/gal \tag{23}$$

$$\eta = \frac{Work}{Energy} = \frac{2545\ gal}{138{,}700\ hp{-}hr} \tag{24}$$

Given a diesel engine with horsepower, HP, let n be equivalent to gallons of fuel consumed per hour.

$$\eta = \frac{2545\ HP}{138{,}700\ \ n} = 0.0183HP/n \tag{25}$$

The above equation can then be solved as

$$n = 0.0183HP/\eta \tag{26}$$

n is the gallons of fuel consumed per hour by a diesel locomotive with horsepower HP (DeSalvo, 1969). The model allows the user to specify the efficiency of the diesel engine as this varies with the type of locomotive. Current technological innovations have also increased locomotive fuel efficiency so the model allows users to correctly specify efficiencies greater than 30%. Future enhancements of the model will seek to include innovations that have increased fuel efficiency.

To calculate the cost of fuel, the user specifies a price (p) for a gallon of diesel fuel, and the fuel cost per hour (C_{f_h}) can be calculated as

$$C_{f_h} = p * n \tag{27}$$

The total fuel cost per trip may be found by multiplying trip time (in hours) by fuel cost per hour. Trip time (*T*) is calculated by dividing the distance travelled (*D*) by the train cruising speed (*V*).

$$T = \frac{D}{V} \tag{28}$$

Therefore, given trip time (T) the fuel cost for a trip can be calculated as

$$C_F = p * n * T \tag{29}$$

$$C_F = p * \frac{0.0183HP}{\eta} * T \tag{30}$$

Locomotive Emissions

According to the EPA, there are several sets of locomotive emission standards. Each set is dependent on the date a locomotive was first manufactured. The first set of standards, Tier 0, applies to majority of locomotives manufactured before 2001 and the last set of standards, Tier 4, are the most stringent standards for locomotives to be manufactured from 2015 and later (EPA, 2009). IRM's default emission standard is Tier 0 because majority of the locomotives currently in use by railroads fall under this category. However, the user can choose between any of the five standards when running the model. It should be noted that the emission rates provided by the EPA are approximations based on simplified assumptions as a single locomotive emission rate varies throughout its life as the engine ages and as ambient conditions change (EPA, 2009).

EPA emissions were estimated for two different types of operation: a low power cycle representing operation in a switch yard, and a higher power cycle representative of general line-haul operation (EPA, 2009). Line-haul emission rates are used in IRM and future modifications of the model will include switch yard operations. The EPA also provides conversion factors which relate fuel consumption (gal/hr) to usable power (bhp) of the locomotive engine. The difference is conversion factors can be traced to the locomotive age and duty cycle which tend to predict different emission rates for older locomotives and locomotives used for switching operations. Volatile organic compounds (VOC) are assumed to be equal to 1.053 times the HC emissions (EPA, 2009). Based on this assumption, it was possible to include VOC estimates in the model. Pollutants not included in the emission tables and the model include sulfur dioxide (SO_2) and carbon dioxide (CO_2) which are largely independent of engine parameters and primarily dependent on fuel properties (EPA, 2009).

Crew Labor Cost

The model currently assumes a fixed daily labor rate. Previous authors have used formulas to calculate crew wages based on distance travelled. This approach though appropriate may not necessarily be accurate as different railroads have different rates and formulas when determining crew wages. An adjustable fixed daily rate is therefore used so user can input actual known crew wages. The number of crew members is then multiplied by the specified daily rate to determine crew labor cost. Future enhancements of IRM will seek to integrate crew labor wages with estimates provided by the asset management block. This would provide stakeholders with more accurate estimates of crew wages on line haul estimates as well as its influence on the overall operations of the railroad.

Maintenance Cost

Track maintenance cost is determined by multiplying a known per mile system average rate (${c_m}_T$) by the number of cars and locomotives in operation since track maintenance cost can be associated with the amount of traffic on a particular road. Car maintenance cost is specified by the user on a per-mile (${c_m}_c$) basis, and multiplied by the number of cars in operation. Locomotive maintenance cost is also specified by the user on a per mile value (${c_m}_l$) basis, and multiplied by the number of locomotives in operation.

$$ {C_M}_T = (N_C + N_L) * {c_m}_T \tag{31} $$

$$ {C_M}_C = N_C * {c_m}_c \tag{32} $$

$$ {C_M}_L = N_L * {c_m}_l \tag{33} $$

Total maintenance cost is calculated as

$$C_M = C_{M_T} + C_{M_C} + C_{M_L} \tag{34}$$

where

$C_{M_T} = Total\ track\ maintenance\ cost$

$C_{M_C} = Total\ car\ maintenance\ cost$

$C_{M_L} = Total\ locomotive\ maintenance\ cost$

Current estimates used in IRM are based on rail expert recommendations and may not be necessarily accurate for each individual railroad. However, with the integration of the asset management block, stakeholders would be able to develop more accurate maintenance figures based on the railroads anticipated maintenance expenditures. These can be calculated as a function of locomotive miles and car miles moved annually, as well as the cost associated with maintaining the rail tracks. Higgins (1998), Johansson and Nilsson (2004), Ferreira and Murray (1997), and Dekker (1996) all provide recommendations on the modeling and scheduling of maintenance scheme of rail tracks which can be used in predicting track maintenance costs.

Capital and Investment Cost

Capital and investment cost are the most difficult to model. Railway capital costs include large investments in the construction of rail tracks, structures, rail yards, signals, and car and locomotive purchases. Without sufficient and reliable data, modeling investment cost associated with rail tracks, structures, rail yards and signals is almost impossible. IRM therefore only accounts for investment costs associated with locomotive and car purchase. These are known as the locomotive ownership cost and the car ownership cost. Using the straight-line depreciation equation, depreciation charge per hour is determined and multiplied by the total trip time.

$$Hourly\ Depreciation = \frac{Cost\ of\ Asset - Scrap\ Value}{Life\ Span\ (years) \times 8760 \frac{hrs}{years}} \times Trip\ Time\ (hrs) \times N \tag{35}$$

where

N = number of locomotives when calculating hourly depreciation of locomotives

N = number of cars when calculating hourly depreciation of cars

Model Limitations

IRM is limited to line haul movement operation and therefore does not account for terminal operations which include arrival operations, inspection operations, classification operations, assembly and disassembly operations, and the labor involved in the above operations. Terminal operations are a substantial part of railroad operations and the cost involved in running terminal operations cannot be ignored in railroad cost analysis. However, for purposes of this research, we assume that terminal operations and costs are the same for all origins and destinations, and the primary concern is to determine how cargo weight, number of cars, type of loading (TOFC or double stack), rail track, car and locomotive maintenance, distance, travel time, delays, and capital investments influence line haul movement operation cost. Also of significant interest is how varying fuel costs influence the rail industry. Loading and unloading operational costs are included to account for economies of scale in line haul operation.

Capital investments such as road construction, right-of-way acquisition, grading, signal and interlock installation, stations and office buildings, and all other infrastructural investment cost are not included. These costs do have a significant influence in the overall rail operation costs but are ignored because of lack of sufficient supporting data and variability amongst the various rail companies. Other expenses ignored include equipment rentals, purchased services, and other indirect expenses (AECOM, 2007).

Other operational limitations include assumption of trains being operated at full throttle even though this is not necessarily the case because of acceleration and deceleration. Acceleration and deceleration calculations can be omitted because of relative insignificance in comparison to the entire trip. However, research work has been done over the years to calculate the time lost during acceleration and deceleration (DeSalvo, 1969).

Concerning fuel consumption, the model assumes the train is running at full throttle. Example, for a SD70MAC, 4000hp locomotive running full throttle, the maximum gallons per hour consumed is 191.0 (Krug, 2006). When idling, locomotives consume 3-7 gallons of fuel each hour (Hotstart), a small figure in comparison with running at full throttle.

Finally, there is insufficient data from the rail companies to enable modelers to adequately estimate capital, maintenance and administrative cost associated with each trip, thereby making the determination of actual prices almost impossible. Railroads are reluctant in sharing such data due to the competitive nature of the business. Depending on the commodity type, railroad monopoly, and the route being used, railroad companies have additional charges such as switch charges, hazmat, and other charges not currently captured in the model. In addition, railroads install and maintain traffic signals, construct sidings, develop double tracks and spend on other capital investments which cannot be captured by this model. Based on all these limitations, IRM is not a complete rail analysis model and would need to be integrated with the other blocks of the rail analysis modeling framework.

FINDINGS

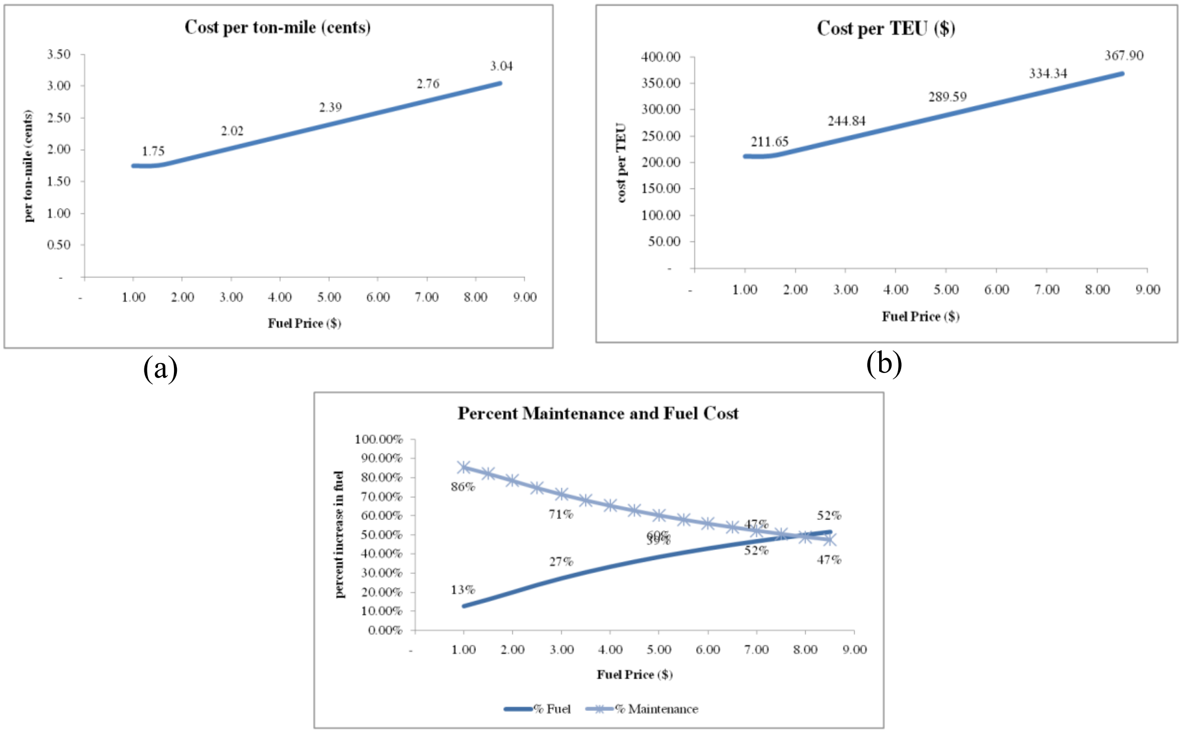
Using IRM, various scenarios were simulated to determine their influence on rail costing and the environment. These include changing price of fuel, varying trip distance, comparison of TOFC movements to double stack movement, and relationship between train speeds, fuel consumption and emissions.

Changing Price of Fuel:

The inputs below were used and fuel price was varied from $1.00 a gallon to $8.50 a gallon at 50 cents increments.

Number of containers: 200
Fuel Price: Varied
Max Speed: 60mph
Utilization ratio: 100%
Distance: 1000 miles
Locomotive HP: 4,000 HP
Loading and Unloading Cost per container: $0.00

As shown in Figure 3 (a) and (b), the relationship between costs and fuel price is a linear one with costs increasing with increasing fuel price. Figure 3 (c) demonstrates how the percentage of fuel in relation to other costs also increases with increasing prices. The rate of change for costs however is dependent on all the other fixed cost components like maintenance costs and crew wages.



(a)

(b)

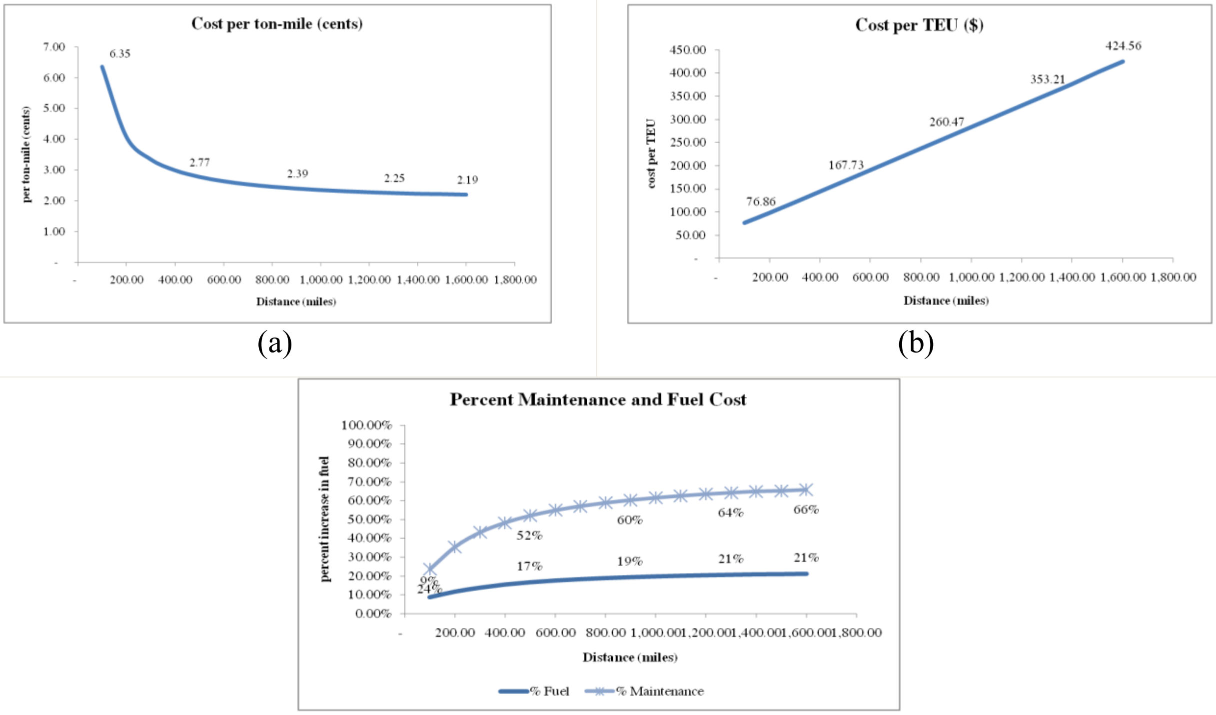
(c)

Figure 3: Effect of increasing fuel price on variable cost

Varying Trip Length

Trip length was varied from 100 to 1,600 miles at 100 mile increments. This analysis was performed to determine the influence of trip length on rail line-haul costs. A loading and unloading cost of $50.00 a container was included in the analysis to demonstrate economies of scale. Fuel price is kept constant at $2.50 per gallon.

Because of the loading and unloading cost input, the economies of scale attributed to railway distances is shown in Figure 4 (a) and (b). After 500 miles, line haul costs begin to stabilize and this is the reason why rail is said to be more efficient for long distances compared to trucking. Fuel cost and maintenance cost also increase with increasing distance. Figure 4 (c) shows that the percentage of fuel and maintenance cost in comparison with other costs increases with increasing distance. Other components not shown here like required HP, train weight and number of locomotives remain constant.



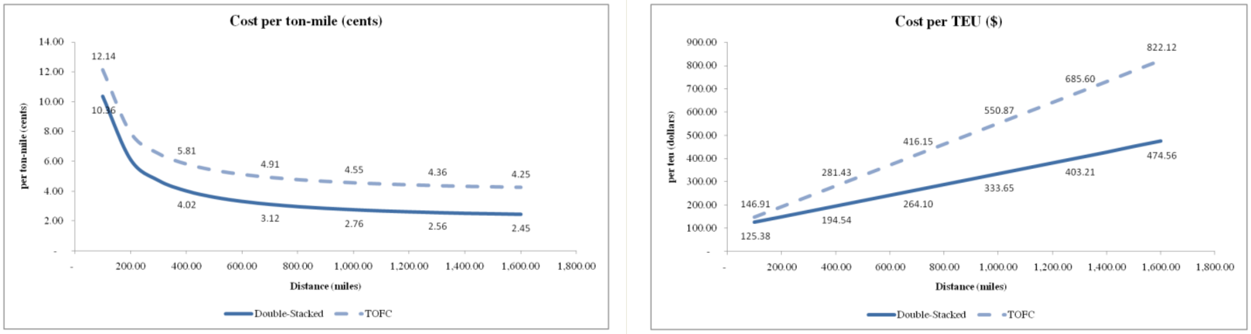
(a) (b)

(c)

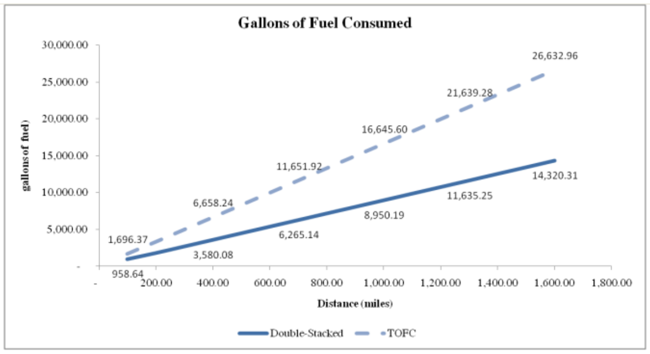
Figure 4: Effect of increasing distance on variable cost

Comparison of TOFC to Double Stack Movements

Using similar scenarios as above, comparisons of TOFC and double-stacked movements were made by comparing the cost and fuel consumption for increasing distances. The results are as expected where double stack has been known to be more efficient than TOFCs. Measuring fuel consumption enables modelers to be able to estimate emissions produced as a result of the cargo configuration. This is a useful tool for stakeholders to decide on whether it is worth investing in rail infrastructure expansion and to measure the resulting outcome when such an investment is not made.



(a) (b)

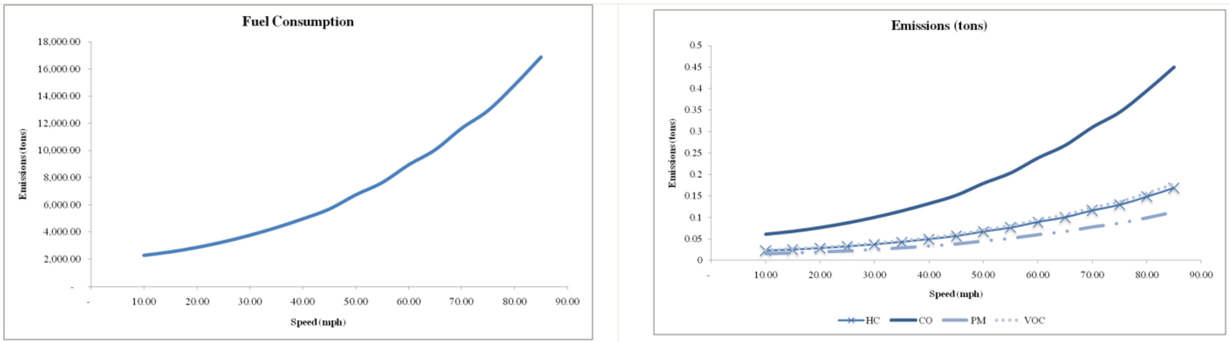


(c)

Figure 5: Comparing costs and fuel consumption differences between TOFC and Double Stacked containers.

Relationship between Train Speeds, Fuel Consumption And Emissions

Another area of interest to stakeholders is the relationship between train speeds, fuel consumption and emissions emitted. The results below show how fuel consumption increases with increasing train speeds. Emissions are currently calculated based on the gallons of fuel consumed and this relationship can be clearly observed for HC, CO, PM and VOC emissions in Figure 6.



(a) (b)

Figure 6: Comparing costs and fuel consumption differences between TOFC and Double Stacked containers.

CONCLUSION

This study seeks to provide stakeholders with a means to examine the environmental impacts, socio-economic effects and costs of rail before making an investment. The rail analysis model framework is composed is of three main components external parameters, operating parameters and asset management. With these three components working together, analyses can be performed with a tool such as the intermodal rail model to evaluate the effects of different intermodal schemes and the associated costs. Initial findings also showed how IRM was used in modeling scenarios such as the impact of changing price of fuel, the economies of scale associated with trip distance, the comparison of TOFC movements to double stack movements, and the relationship between train speeds, fuel consumption and emissions.

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