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# Profit Based Simulation Model for The Rail Transportation Industry

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**PROFIT BASED SIMULATION MODEL FOR**

**THE RAIL TRANSPORTATION INDUSTRY**

by

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ABSTRACT

PROFIT BASED SIMULATION MODEL FOR THE RAIL TRANSPORTATION INDUSTRY

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Schedules often conflict in the rail transportation industry. Operations managers assign resources and make scheduling decisions with no visibility of the revenue, cost, and profitability characteristics of the route they are manipulating. Transit speed decisions focus on ensuring trains safely reach their destination on time with little regard given to the actual service needs of the customer. Although all customers want on-time deliveries, few actually pay a premium to garner this level of preferential treatment. Operating in this type of environment results in decisions that severely erode profits.

In this dissertation, a simulation model referred to as the Rail Profit Model (RPM) is developed to test three transit strategies that reveal how transit speed decisions impact supply chain and rail service provider profits and to lay the groundwork to challenge the cultural premise that the rail industry must behave like the trucking industry in order to thrive. In fact, the Rail Profit Model demonstrates that most trains should maintain the most economical speed to maximize profits. The model also identifies specific scenarios where increasing speed to arrive on time is the most profitable solution, contributing to the ability to leverage revenue management techniques to ensure customers pay the adequate premium that on-time delivery requires. Equipped with the Rail Profit Model, operations managers can now examine transit speed decisions and de-conflict

competing resources to form recommended solutions that preserve maximum profits for the rail service provider and supply chain.

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Lastly, and certainly not least, I thank my Lord and savior Jesus Christ without whom I am nothing.

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# CHAPTER 1

# INTRODUCTION

## 1.1 BACKGROUND

The rail transportation industry encompasses passenger and freight transportation with annual revenues of $71 billion (AAR, 2015). Rail transport represents 15% of the entire transport sector, making it the third largest sector (by revenues) behind truck and air (IBIS World, 2008). Rail transportation's competitive advantage stems from its ability to transport large volumes of goods over long distances at a cheaper per unit cost. For example, with one gallon of fuel, one ton of cargo can be shipped an average distance of 479 miles by rail (AAR, 2014); whereas trucks average 106 miles for the same gallon of fuel (Rodrigue, 2008).

The rail industry is highly concentrated with 70% of revenues captured by the four top corporations (Union Pacific, Burlington Northern Santa Fe, CSX, and Norfolk Southern). Market entry is impeded by high capital costs (infrastructure, locomotives, rail cars, etc.) with the need to have rail lines near suppliers and customers. Rail remains one of the most capital intensive of economic activities with 18% of revenue dedicated to capital expenditures, whereas manufacturing incurs only 4% (Rodrigue, 2008). Coal, industrial and agricultural goods, and chemicals make up 60% of the rail market, with coal representing 40% of the tonnage, 21% of the carloads and 20% of the revenue (Hansen, 2016).

In 1980, the Staggers Rail Act was passed, deregulating portions of the industry by introducing free market pricing and confidential contracts with customers. Other portions of the industry remain moderately regulated with Surface Transportation Board (STB) oversight and compliance with the Resource Conservation Recovery Act, Clean Air Act, and Comprehensive

Environmental Response Compensation and Liability Act of 1980. The results of deregulation have been mixed; the rates that shippers pay have declined by an average of 40% (Vinje et al., 2006) although consolidation and mergers have reduced the number of Class I rail transporters to only seven, down from 39 in 1980 and 71 in 1970 (Rodrigue, 2008). Recent rate increases have focused attention on complaints from shippers who claim to be captive to the high rates charged by rail freight service providers.

A captive shipper is one who lacks alternatives and is compelled to use a single (or very few) service provider(s). Normal competition usually involves multiple modes of transport, such as a second rail provider, truck, or barge, with as few as 15% of all rail service being judged as captive by the STB (Frittelli et al., 2007). Approximately 66% of all captive revenues consist of chemical and coal traffic (Pittman, 2010). Since coal transport is already under such "captive" scrutiny, rail service providers need to better justify rates and develop more robust means of price discrimination across their entire customer base. The Rail Profit Model (RPM) serves as one of those robust means, enabling the rail industry to move towards a more market-based pricing system that would enhance railroad viability without harming those with fewer transport options (Bitzan, et al., 2014).

Overall, the industry remains solvent primarily due to increased productivity and increased efficiencies. One such efficiency arose from terminating unprofitable routes. Technology advancements also increased operating efficiency of locomotives and reduced the number of laborers required to operate the rail lines. In fact, U.S. railroads moved 50% more ton-miles with 61% fewer employees, using 38% fewer track miles, 23% fewer cars, and 28% fewer locomotives (Spychalski et al., (2004)). Technology has also improved safety, reducing the rates of accidents by 79% and employee injuries by 83%, making the rail transportation industry one of the safest (Bureau of Labor Statistics, 2014), better than the manufacturing, trucking and airline industries.

The largest cost drivers in the rail industry are wages (30%), purchases (20%), utilities (20%), and depreciation (9%), leaving 10.2% as profit (IBIS World, 2008). Recent years have seen a tremendous increase in fuel costs. For example, for Class I railroads, fuel costs rose $4.1 billion between 2004 & 2007 alone (STB, 2009). To offset these costs, rail operators instituted fuel surcharges. As fuel prices continue to rise so does the competitive advantage rail transportation has over the trucking industry, especially as the distance shipped increases.

### 1.2 INDUSTRY CULTURE

The rail industry routinely operates under a paradigm that they must operate like their primary competitor – the trucking industry. Going as far back as Eastman (1932), who stated, "the prime problem for railroad managers is to determine to what extent these apparent enemies, and particularly the motor truck, can be used as auxiliaries and allies to supplement and improve strictly railroad service" has the challenge been examined. Many of the same challenges remain today. Continued literature references to "increasing service levels" of rail transport serves to reinforce the irrational phenomena.

The rail industry invests significant capital in new technologies to reduce operating costs. Despite these significant outlays, operational decisions are routinely made considering the outcome with little consideration given to the impact the decision has on profit. For example, if rail operators have the option to safely increase transit speed and reach the destination on time, with few exceptions, the rail service provider will do so. The trucking industry has infinitely more flexibility in routing and assigning loads to drivers and can more easily adjust schedules to accommodate the changing needs of customers. In fact, a major trucking freight company advertises “on time, every time” as their motto. The rail industry is much more constrained, both in routes and resources (locomotives, rail cars, and crews). Despite these obvious structural differences, and in an attempt to operate more like trucks, the rail industry has assumed a mandate to increase service levels, namely on-time delivery, in an attempt to improve customer perception and competitive position within the transportation industry. Increasing speed to arrive on time depletes profit and in some cases increases cost to the point where the rail service provider actually loses money by providing the service. The RPM demonstrates how speed decisions must take into account more than just arrival time and quantifies the overall effects speed decisions have on profitability.

Bucklew (2011) points out significant differences between rail and motor carriers. For example, rail carriers have a higher fixed cost and lower variable costs. The rail industry builds its own infrastructure and needs consistently high freight density to be profitable. As such, rail carriers prefer intermodal containers over long-haul routes, predominantly above 700 miles. Although each railroad operates in a different geography, most cannot compete with trucks for service distance below 600 miles in terms of price and total transit time. Beyond that point rail and trucks can compete but primarily complement each other, and both are needed for movement of goods. In the short-haul finished goods market, trucks will likely remain as the exclusive mode.

Sheib (2002) emphasizes that "improved service and low rates will attract more traffic to the railroads in the future." The conundrum is that rail service providers are assuming this service mandate is an industry standard without overtly passing the costs of providing such service levels to downstream customers whom supposedly demand these enhanced levels of service. Tornquist et al. (2004) state that railway transports are often considered a weak link in the supply chain due to substandard reliability and punctuality, citing 15 studies and surveys of freight transport buyers. A recurring theme arises: cost, reliability (on-time service), transit time, flexibility and environment prove important. From a practical perspective, the first two, cost and reliability, should be highly correlated; the higher the cost, the greater the reliability, yet the rail industry attempts to treat customers equally. Service levels (reliability) should be a primary discriminating factor in the pricing decision, especially the customer segment that falls under just-in-time (JIT). For example, a customer who demands lowest cost should garner little priority over other consists (a set of vehicles that form a complete train). Further, whenever consists compete for the same constrained resource, the consist that has paid the highest premiums would garner the higher priority, leaving the remaining consist(s) to wait until the resource becomes available. Doing so leaves the lower priority consist(s) waiting on the tracks for longer periods of time, increasing the risk of incurring additional delays. The RPM will reveal the magnitude of eroded profits, which are driven out of the supply chain and out of the pockets of the rail service providers because rail operators arbitrarily increase speed to arrive on time for customers not paying for this enhanced level of service. The losses may be staggering industry wide, with the magnitude of lost profits potentially reaching into the tens-of-thousands for a single inefficiently managed service.

Tornquist et al. (2004) go on to state that all identified customer demands have to be fulfilled in the long run in order to make the railroad a competitive alternative to road transport, yet, at the same time, Tornquist discusses how rail transport can increase average transit speeds to become better, acknowledging that it depends on the strain in the network. It must be noted that increasing transit speeds, especially in excess of most efficient speed, markedly erodes profits. If the desire to increase speed becomes necessary, the additional costs incurred by the rail service provider should be taken into account in customer pricing. Further, if a network is strained and routinely imposes network delays, the rail service provider needs to exercise free market principles to create balance between network supply and customer demand.

The rail industry, much like other transportation providers, serves a major role in the supply chain. The effectiveness of operations can have a significant impact on upstream as well as downstream customers. In the extreme case of just-in-time (JIT) manufacturers, delivery schedules for parts and raw materials are highly critical to maintaining a fully operating production line. Delays of just a few hours could be devastating and cost a manufacturer thousands of dollars in lost productivity. Conversely, the delivery of bulk materials, such as coal, are transported and deposited into large stock piles, and a delivery delay of two hours would have little effect on a customer or to the overall supply chain. Nevertheless, the self-imposed mandate to deliver on time compels rail operators to make similar decisions for both coal and JIT parts in the name of maintaining a schedule.

Wen (2012) emphasized that supply chain collaboration and collaborative transportation management (CTM) has become a means of addressing issues with short term planning time windows and overuse of expedited services. A highly integrated relationship with supply chain partners improves its service capability and enhances the cost-leadership advantage. Similarly, the RPM integrates customer needs in the form of opportunity costs, providing a systemic means to segregate customer needs along service standards, with associated premiums paid. This provides a significant opportunity to align expectations and maximize profitability not only for the rail service provider but also to maximize profitability across the supply chain.

## 1.3 PROBLEM STATEMENT

Resources are scarce and schedules often conflict in the rail transportation industry. Operations managers assign resources and make scheduling decisions with little visibility of the revenue, cost, and profitability characteristics of the route they are manipulating. Transit speed decisions focus on ensuring consists safely reach their destination, on time, with little regard given to the actual service needs of the customer. Although all customers want on-time deliveries, few actually pay a premium to garner this level of preferential treatment. Operating in this type of environment results in decisions that severely erode profits. The RPM will reveal the impacts these decisions have on supply chain and rail service provider profits within the rail transportation industry.

# CHAPTER 2

# STUDY BACKGROUND

## 2.1 LITERATURE REVIEW

A Rail Profit Model (RPM) does not exist in the literature. The current literature optimizes profits from narrow perspectives, such as locomotive assignment, fleet sizing, and efficiency frontiers. Locomotive assignments and fleet sizing attempt to achieve lowest cost by focusing on the movement of resources prior to forming a consist, with the assumption that the lowest cost strategy automatically results in maximized profits. Two complications arise from this notion.

1) Lowest cost strategies ignore revenues in the profit equation.

$$\text{Profit} = \text{Revenue} - \text{Cost}$$

2) Lowest cost does not take into account the financial impacts operations have on the supply chain, especially downstream customers. These oversights are prevalent throughout the literature.

Shaoni et al. (2008) utilized regression analysis to confirm that locomotive fuel consumption cost is significant in the production expense of rail operations, estimating that running fuel costs used in internal combustion engines account for an average 80% of direct production expense. Three important fuel consumption factors were also identified: 1) average traction weight 2) way parking time 3) technical speed. Tolliver et al. (2014) observed that energy efficiencies varied significantly amongst different regions, reflecting the differences in terrain, geography and network. For example, railroads in the central or plains region do not cross mountain ranges. In contrast, western railroads encounter substantial grades while crossing the Rocky Mountains and coastal ranges. Similarly, Eastern railroads operate in the Appalachian Mountains.

**FRONTIERS**

The use of frontier models dates back to 1977. These models are used to describe firm efficiency and productivity. A production frontier shows the maximum output for a given unit of input and is often used to compare efficiencies of like companies in an industry. Likewise, a cost frontier shows the minimum cost, given a level of output and given input of prices. The deviation from the actual maximum output is a measure of inefficiency and is the focus of interest in many applications (Griffin et al., 2004). One application is to the rail industry. Cantos and Maudos (2001) examined the European rail industry utilizing efficiency frontiers in order to explain why the industry improved productivity but also concurrently experienced significant declines in financial performance. A key result was that cost efficiency and revenue efficiency were negatively correlated with a correlation factor of -0.64. One plausible explanation provided was that firms with high revenue efficiency (having revenues close to the frontier) may have less competition and may not be as inclined to control costs, resulting in lower cost efficiency. Although these authors did not make the connection between revenue, cost and profit, and did not attempt to examine profit efficiency, they did reveal one fact; the efficiency analyses overlooked the route/train level of operations where transit speeds have a dramatic impact on real profits. This is where the RPM proves most valuable.

Research on profit efficiency frontiers revealed numerous papers, with the clear majority targeting the banking industry. Maudos, et al. (2004) concluded that analyzing cost efficiencies provides a partial snapshot. Further, the few available studies that estimate profit frontier functions report efficiency levels much lower than cost efficiency levels, suggesting that the most important inefficiencies are on the revenue side, either by incorrectly choosing output or mispricing output. The same can be applied to the rail industry by examining how it allocates (prioritize & discriminate) locomotives to various competing sectors (coal, steel, intermodal, automotive, etc.) and how pricing schemes are developed for each sector. Beling et al. (2005) examined the interactions between expected volume E[V] and expected profit E[P] showing the tradeoffs between expected profits and expected market share.

Lim et al. (2009) used a three-stage profit decomposition model to conclude that one key source for profit declines was attributed to a negative price effect. Further, he claimed that pricing power had not contributed to profit growth to the degree that AAR (2006) claims was necessary to finance investment in infrastructure and equipment needed to meet expected demand growth. Although the rail industry is considered capital intensive, labor and energy variable costs play a critical role in reducing firm profits. Similarly, the RPM will examine the tradeoff between increasing speed to arrive on time (maintain service levels) versus maintaining most efficient speed to maximize profit and revealing the profit characteristics of the route. This will enable rail service providers to choose the most profitable transit strategy and better tie pricing to expected service levels of downstream customers, garnering the premiums necessary to support the costly endeavor of arriving on time.

Shi (2010) utilized a logarithmic version of the Fisher Index to link performance and productivity and the Malmquist Productivity Index to identify the sources of economic growth that can be attributed to technical change and efficiency change. Shi concluded that railroad profitability was primarily driven by productivity improvement through technological change and that productivity growth was unsustainable. Coupled with rising input prices (such as fuel and labor), lower output prices (revenues) resulted in low price recovery. These results clearly indicate that controlling input prices, such as fuel costs, significantly impacts a firm’s bottom line, profits.

## LOCOMOTIVE ASSIGNMENT

The locomotive assignment problem attempts to minimize costs of directing resources (cars and locomotives) to meet demand and provide sufficient power. Vaidyanathan et al. (2008) developed a Locomotive Planning Problem (LPP) that focuses on routing groups of locomotives rather than routing each individual locomotive. In their research they conducted case studies to demonstrate the usefulness of their model. As they increased the mean tonnage, the solution cost increased in a quadratic fashion, but they failed to indicate that although it increased in an exponential fashion, it still increased less than the linear tonnage rate. They also failed to include the change in revenues associated with the varied tonnage. Even though costs changed in a less than linear fashion, it may prove unprofitable to increase loading of the consist due to the pricing scheme used. Without analyzing the exact nature of the revenues, in direct relation to costs, a decision about increasing or decreasing load remain just a guess from a profitability perspective. The same can be said for the case study that varied train speed; even though the subject was cursorily mentioned, increased transit speeds come with increased fuel costs. The nuances of these changes play an important role in the RPM. The reality that these characteristics and impacts are overlooked in very recent literature substantiates the need for integration. In fact, Marin et al. (1996) included as a possible extension to her locomotive assignment research with the inclusion of price policy (revenue) in the assignment of demand.

List et al. (2003) introduced the theory of robust optimization in fleet planning under uncertainty where tradeoffs are made among postponed shipments, shipments carried, vehicle flows (loaded and unloaded across the network) and fleet size to optimize the two objective functions: total cost and penalties for late service. France's state-owned railway company calculated that a one minute delay on their high speed passenger railway network costs (everything included) around $1,200 (SNFC, 2008). In a similar fashion, the RPM implements the concept of Customer Opportunity Cost of Delay (COCD) which was based on List's theory, to represent the financial effects late deliveries impose on downstream customers. Two additional differences warrant visibility.

1) COCD will vary non-linearly over a 12-hour period for each customer/route, providing more accurate impacts for operations to take into account when allocating and prioritizing resources, versus only two values (deferred or delayed).

2) Instead of having to implement robust techniques to balance two competing objective functions, the RPM will entail the optimization of a single objective function, profit. This simplifies the decision process by establishing direct comparisons between competing demands.

Cacchiani et al. (2010) maximized expected profit using stochastic optimization, branch-and-bound and column generation, by minimizing overall number of train units (TUs). Again, minimizing costs were expected by the author to generate maximum profits, ignoring the impacts of revenues.

According to Caprara et al. (2007), the optimal allocation of trains and tracks are found by optimizing the overall system profit, taking into account Langrangian profit paths and a cost penalty function for not arriving according to established timetables. This method behaves in a similar manner as the opportunity costs within the RPM. Overall, the author also recommends that if the profit of a train turns out to be negative, the trip should be cancelled. This may be possible with passenger rail service but is not likely to be well received with typical freight customers. In contrast, should the RPM reflect negative profits, marketing must swiftly engage the customer to renegotiate the pricing terms of the contract. Only after failed negotiations should the rail service provider drop a customer.

Despite technological development, the rescheduling process in still heavily under the manual control of train dispatchers (Marinov, et al., 2013). Caprara also mentions that the rail industry is moving away from planning in detail and moving towards real-time control, mostly in conjunction with advancing technologies and increased computing power. This scenario places an extreme burden on the network and exacerbates the focus on service levels, which erodes profits. In order to preserve profits the rail transportation industry should deploy similar methodologies offered by the RPM.

**FLEET SIZING**

The fleet sizing problem focuses on the number of resources in order to provide the capacity needed to satisfy demand. Determining the optimal number of cars requires a tradeoff between the capital cost of purchasing and maintaining cars and the potential costs or penalties of not satisfying demand. Bojovic (2002) mentioned in his problem statement that rail car fleets are composed of many different car types and that a given type may not be compatible with some commodities. In practice, the unavailability of a desired car type frequently forces operations to replace one car type by another. The same can be said for locomotives. Each train can be assigned multiple types of locomotives, and each comes with its own set of characteristics, such as fuel efficiency and horsepower rating. In a generalizable fashion, the RPM assumes a basic assignment of locomotives and estimates fuel consumption and costs based on averages. In order to operationalize the model, fuel consumption curves must be tailored to the exact specifications of the locomotives used, taking into consideration actual load and specific characteristics of the route (terrain, grades, curvature, speed limits, etc.).

Sayarshad et al. (2009) utilized an objective function that included the difference between revenues generated by servicing demands and costs of car ownership, car movement, and unmet demand. Although revenues for each loaded car were included in their objective function, the value assigned remained constant for each car, which does not sufficiently reflect the dynamic contract pricing schemes used in the United States. Further, the model focuses on optimizing the fleet size of cars, ignoring the dynamic nature and significant cost driver locomotives entail. One interesting attribute of the fleet sizing model are the variables for the cost of moving empty cars and the cost of holding empty cars at either the origin or destination. While outside the scope of this dissertation, addressing all route activity, such as the return train of "empties," remains a viable future research topic.

Godwin et al. (2008) utilized simulation for tactical fleet sizing of locomotives and developed customer-focused and system-focused performance measures. In summary, the larger the number of locomotives in a fleet, orders delivered per day increases, locomotive utilization declines, total flow time per order initially declines but then increases, and deadheading per order increases slightly. At what cost does the corporation pay to have these additional locomotives, though? Typical fleet sizing decisions for locomotives are made with an idea of how many locomotives will generate an expected service level. The decision to invest capital is important, usually costing upwards of $2 million each locomotive. Considering the magnitude of the decision, it is no wonder why so much effort is dedicated to determining the right fleet size. Oftentimes these fleet size recommendations do not have sufficient insight into the exact make/models necessary to maintain customer service levels leading management to default to larger models using the rational that larger engines are more versatile. Unfortunately, larger engines are usually less efficient and more expensive to maintain, especially if they are under-loaded. The RPM will provide a means for capturing the impact of tardy service levels on profits, enabling management to quantify the profit losses incurred by operating consists at speeds in excess of most efficient. Further, this will assist management in determining whether larger locomotives with increased horsepower would preserve more profits in excess of the requisite capital investments required to upgrade the locomotive fleet.

**TRAIN CONTROL TECHNOLOGIES**

Train control technologies have made significant advancements in recent years. Early commercial efforts patented theories of how control theories would work even though the technology did not exist at the time. Houpt (2005) is an example of a patent that did such a thing. Four years later, Houpt (2009) discussed a new technology called "Trip Optimizer" that was installed on General Electric's Evolution series locomotives, which generated up to 13% fuel savings. Likewise, Dominguez (2010) achieved similar savings developing and implementing an Automatic Train Operations (ATO) methodology, again minimizing fuel consumption. Other systems and technologies have emerged, from regenerative braking systems that capture energy dissipated from brake systems, to fuel additives, to start-stop systems. A recurring theme is to minimize energy costs.

Jonkeren, et al. (2012) studied the effect of freight prices and fuel prices on the navigational speed in the inland waterway transport of dry bulk market in northwest Europe. They concluded that fuel costs have a negative effect on speed. Specifically, fuel prices had a statistically significant negative effect with an elasticity of -0.110, meaning that a 10% increase in fuel price led to a 1.1% decrease in navigational speed. Stopford (2009) explains that increasing navigational speed is economically justified when the ratio of freight prices to fuel prices increase.

De Martinis, et al. (2015) proposed a simulation based framework that considered the operational requirements and passenger rail traffic flows for developing energy efficient speed profiles that minimize energy consumption. They realize that especially in rail systems, the reduction of operating costs can improve competitiveness against other passenger transit modes and that the solution must take into account rail services and operational requirements in order to generate feasible solutions. Since these technological systems already exist onboard locomotives, the RPM is designed to assume the train will transit at most economical speed. Only when the train is behind schedule will speeds be evaluated. The need for increased speed above most economical will be balanced against the opportunity costs of maintaining most efficient speed and arriving late, which remains a gap in the literature. The RPM also identifies the transit strategy that preserves the most profit, both across the supply chain and for the rail service provider.

**REVENUE MANAGEMENT**

An additional area of research that logically follows the implementation of the RPM involves revenue management (RM). RM is a tool that maximizes the revenue of a firm, helps determine the level of inventory to allocate to each market segment, and indicates what prices to charge. Revenue management is commonly used in the airline industry. Unlike the airline industry, the rail industry remains heavily regulated, especially when it comes to setting prices. In fact, less than half of the Class I railroads have achieved revenue adequacy in any year since 2003 (Bitzen et al., (2014)).

Huneke (2006) hypothesized that a railroad has two basic pricing strategies: price to maximize profit or price to avoid litigation. Although the STB collects rate data for regulatory purposes in an annual waybill sample, rail rates remain confidential; therefore, there is no direct way to estimate commodity specific rail rates using public data (Ivaldi et al., 2007). The RPM will enable to the rail service provider to quantify operating profit, estimate lost profits due to the perceived need to increase speed and arrive on time, and provide a sound basis for customers to be charged a “premium” for enhanced service levels. This partitioning of profits will also aid the rail service provider when presenting their case to the Surface Transportation Board should they be taken to court for perceived excessive pricing, especially for customers who also demand high service levels.

Crevier et al. (2012) declared that profit maximization relies heavily on integrated operations planning and improved revenue management techniques. To examine the impacts on the revenue interactions between tariffs, they developed two pricing policies, called disjoint, involving a rail freight carrier, resulting in 14% more revenue. Saeed (2013) introduced the concept of cooperation amongst freight forwarding companies to examine the impact on profits of the companies involved. The results demonstrated that in all cases of cooperation, profits increased for each participating member. Kuo et al. (2012) utilized Combinatorial Auction (CA) framework to analyze the effects of collaboration amongst competing rail transport providers for one off-loads. The results reflected increased utilization of assets as well as increased profits for participants as well. In addition, Kuo suggested that time-insensitive loads be transferred to allow room for higher priority one off-loads as an extension of her work. These concepts validate the need for the integration of supply chain considerations. By utilizing the profit characteristics generated by the RPM to balance the need for supply chain profit retention with rail service provider profits, rail operators (who dictate transit strategies) and marketing (whom manage customer pricing & contracts) can work in unison to appropriately prioritize consists and manipulate transit speeds to maximize profitability across the industry.

One characteristic of rail operations that the RPM reveals is the cost associated with on-time service, a key aspect that Crevier et al. (2012) overlook when describing “appropriate pricing” which only takes into account the type of freight, origin and destination of the transit, and the type of equipment used. As demonstrated by the RPM, increased services levels in the form of on-time delivery comes at a cost that should be included in all rail pricing methodologies.

## 2.2 RESEARCH CONTRIBUTION

The literature in the rail industry is dominated by cost analysis. Few papers focus on profits and those that do have not targeted profits at the consist level. This is a notable research gap filled by this dissertation.

The RPM reveals the profit characteristics of each consist, providing unpresented insights into how transit speed decisions impact supply chain and rail service provider profits, illuminating the transit strategy that maximizes profitability - knowledge that does not currently exist in the literature.

The RPM also lays the groundwork to challenge the cultural premise that the rail industry must behave like the trucking industry in order to thrive. In fact, the model demonstrates that most consists, with few exceptions, should maintain most economical speed to maximize profits, regardless how late or behind schedule it is. This knowledge, including the magnitude of the eroded profits from attempting to arrive on time, directly contributes to the ability to leverage revenue management techniques to ensure customers pay an adequate premium for the enhanced services on-time delivery requires. Only then will all three variables of the profit equation be addressed and profits truly optimized.

The RPM enables operations to deconflict consists competing for the same rail line. Rather than rely on assumptions such as the load that has greatest value goes first, the RPM quantifies the impacts on profitability of the various sequencing combinations available to operations. One clear, profit optimizing solution is identified, and should be the sequence operations chooses.

In an effort to integrate the supply chain and incorporate the unique characteristic between customers, "opportunity costs" of delay are deployed within the RPM. They not only quantify the financial impact delays impose on upstream & downstream customers but also quantify the unique characteristics, sensitivities, and needs of customers in a non-linear fashion which imparts a more realistic consequence experienced in rail operations.

The RPM implements the profit frontier graph which represents the profit characteristics by revealing the difference between the Expected Service Profit (ESP) and the profit remaining after implementing the various transit strategies in response to the delays induced into the model during a simulated transit. The observed gaps from the ESP form the "eroded profits" that are consumed and taken from rail transport stockholders.

# CHAPTER 3

# METHODOLOGY

The Rail Profit Model (RPM) for the rail transportation industry integrates labor costs, fuel costs, and various supply chain opportunity costs to assist rail service providers with a means to recognize and implement the transit strategy that maximizes profitability through simulation. It provides the construct to quantify the financial impact delays have on the rail service provider and to the overall supply chain. Decisions whether to increase speed to reach the destination on time are quantified in terms of their impacts on profitability. Although Datta (2000) estimated that only 11 percent of research work is implemented, the RPM shows true potential to make an immediate impact on rail operations by providing rail service providers the ability to examine and test transit strategies and their corresponding impacts on profits involving trains that are competing for network resources. For example, if three trains are competing for the same track, the RPM can be used to test and observe various sequences to determine the solution combination that results in maximum profits. Equipped with this knowledge, operations can not only make transit speed decisions that maximize profitability at the train level but also give priority to traffic that contributes most to the profitability of the rail network, the rail company, and the entire rail network.

The product of this dissertation is a RPM that reveals the profit characteristics of a train route and how operational decisions regarding transit strategy impacts the supply chain and the overall profitability of the rail service. Further, once operations understands the profit characteristics of a route, marketing can apply revenue management techniques to ensure customers who demand increased service levels, in the form of greater on-time delivery rates, are properly charged a premium commensurate with the increased operating cost characteristics that particular route depletes profits. In a $71 Billion dollar industry, just a one percent increase in efficiency returns up to $710 million in additional profits for shareholders.

### 3.1 THE RAIL PROFIT MODEL (RPM)

The RPM is based on the principle of stochastic simulation of an 800 mile consist transit consisting of a bulk commodity, such as coal. Each hour, risk of delay is induced into the model, forcing the consist behind schedule.

$$Probability\ of\ Delay\ D\ = d\%$$

If the random number generated is less than *d*, a 1-hour delay is imposed on the consist as well as an $80 penalty for fuel to idle the locomotive engines. Each transit hour (*t*), a new random number (*r*) is generated, for a maximum possible transit time of 80 hours ($t_{1\text{-}80}$).

$$In\ Transit\ Random\ Number\ Generator\ r_{1-80} = RANDBETWEEN\ (0{,}99)$$

$$In\ Transit\ Delay\ d_{1-80} = r_{1-80}$$

$$If\ r_{1-80} \leq\ d \qquad \text{Delay imposed}$$

$$If\ r_{1-80} > d \qquad No\ delay, continue\ transit$$

For example, at hour twenty (20) of the transit ($t_{20}$), a new random number is generated ($r_{20}$) and compared to the probability of delay *D* to determine if the consist will be delayed an hour or is allowed to continue transit without delay. See Appendix A: Master Variable List and Appendix

B: Definitions & Equations for a detailed breakdown of variables, definitions and equations used in the Rail Profit Model.

Huisman and Boucherie (2001) identified two types of delays, primary and secondary. Primary delays arise due to external influences such as weather conditions with secondary delays caused by the interference of other trains that have been delayed or have slower transit speeds. Additional sources of primary delays can be attributed to upstream customer delays in readying the load, resource delays (crews, cars, and locomotives), yard delays, signal failures, switch delays, derailments, equipment malfunctions and accidents (Kuo et al. (2007)).

The RPM aggregates these delays into a single stochastic delay that is calculated at the beginning of each hour's transit. Should a delay arise, the delay will last an entire hour with the consist placed into an idle state. The model recalculates the distance remaining in the transit, the time remaining to achieve on-time arrival, and recalculates the necessary transit speed to arrive at the destination on time. Depending on the transit strategy, the consist may change speed, up to maximum safe speed. The model will continue to induce risk of delay, recalculate remaining distances and time remaining to arrive on time, and evaluates and selects the transit strategy each hour until the consist arrives at its destination. Final profit calculations are performed for each of the three transit strategies. The transit strategy that preserves the most profit is considered the optimal transit strategy for that instance/scenario.

As the consist completes the transit, each hour a new transit speed is selected based on three pre-established transit strategies:

- Most Efficient Speed (MES),
- Avoid Downstream Customer Opportunity Cost of Delay (DCOCD),
- Minimized Tardiness (MT).

**MOST EFFICIENT SPEED TRANSIT STRATEGY (MES)**

Most Efficient Speed (MES) will maintain most efficient speed regardless how tardy the consist becomes. The goal of this transit strategy is to minimize fuel consumption, irrespective of downstream customer or supply chain needs. Service standards should be flexible in order for this strategy to be successful. For example, downstream customers should have wide delivery windows and not expect on-time delivery very often. If customer sensitivities to delay are high in the event, Downstream Customer Opportunity Cost of Delay (DCOCD) quantifies the costs incurred by downstream customers for being tardy. The most severe costs are incurred by just-in-time (JIT) customers, leading us to the second transit strategy.

**AVOID DCOCD TRANSIT STRATEGY**

Avoid DCOCD will maintain most efficient speed, similar to MES, until DCOCD penalties arise. The goal of this transit strategy is to avoid increasing speed until penalties for being tardy are detected. For JIT customers, penalties are imposed the very first hour of delay; hence, DCOCD would immediately increase speed to arrive on time and avoid any tardiness penalty. When DOCDs are low, delay penalties do not arise until a consist arrives seven hours or more late, allowing the Avoid DCOCD transit strategy to remain at most efficient speed through the first six hours of delay.

**MINIMIZE TARDINESS TRANSIT STRATEGY (MT)**

Minimize Tardiness (MT) will increase speed as necessary to arrive at its destination on time. At the very first delay, the MT transits strategy calculates what speed it needs to make good through the duration of the transit and will increase speed accordingly, up to maximum safe speed. The goal of this transit strategy is arrive on time, every time, similar to industry culture today. Regardless of whether the downstream customer desires this level of service, the MT transit strategy will increase speed to arrive on time. More importantly, regardless of whether the customer pays for such service levels, the rail service provider will increase speed to arrive on time. This is where the RPM demonstrates that on-time, every time is not only detrimental to profits but is inefficient from a supply chain perspective as well. Customers that demand high levels of service should pay for it, and others that have the flexibility in their operations should encourage the rail service provider to exercise that flexibility to reduce operating costs and, in turn, reduce rates.

**DOWNSTREAM CUSTOMER OPPORTUNITY COST OF DELAY (DCOCD)**

As mentioned previously, DCOCD quantifies the cost incurred by downstream customers for being tardy. Delivery delays of a few hours could be detrimental to production, inflicting stock outs and work stoppages for time sensitive customers. To differentiate customer needs, the RPM implements DCOCDs, which capture the costs incurred for tardiness. For many downstream customers a delay of a couple hours for a rail delivery is more of an inconvenience and results in minor costs, such as additional labor. More substantial costs may arise with JIT customers, who can absorb tardiness of just a couple hours before incurring significant costs due to extended delays. These costs are quantified in dollars ($), by the hour, and integrated into the DCOCD methodology. As delays grow, these costs can quickly escalate in a non-linear fashion. Lastly, delays can propagate through the supply chain and affect downstream operations, similar to falling dominoes, forming the Opportunity Cost of Cascading Delay (OCCD). All these potential cost drivers must be accounted for in balancing the needs of the rail service provider and the needs of downstream customers in the supply chain. The RPM model does this with DCOCD; see Table 1.

For example, downstream customer one (DC1) is highly sensitive (High) to delays and incurs increased labor costs of $100 for the first hour of tardiness, $400 for seventh hour and $500 for 12$^{th}$ hour as shown in the first table. Table B represents stock-out risks, highly sensitive DC1 reflects $4,000 when a consist is delayed 6 hours and $100,000 when delayed 12 hours, reflecting a JIT customer that is heavily reliant on timely services. The third table, representing cascading delays, highly sensitive DC1 reflects $0 through the first four hours of delay, reflecting that there is no adverse costs imposed on the supply chain if the consist arrives up to four hours late. Should the consist arrive 12 hours late, $2,500 cost is incurred. The last table, table D, summarizes these costs, forming the DCOCD valuations for both highly sensitive customers (High) and insensitive customers (Low). In this case, DC1 represents a highly sensitive customer, with a composite DCOCD of $200 for the first hour of delay, $5,850 for the sixth hour of delay, and $103,000 for the 12$^{th}$ hour of delay.

Table 1: Downstream Customer Opportunity Cost of Delay (DCOCD) and its components

**A. Downstream Hourly Labor Costs incurred by various downstream customers due to delays in the transport of their goods**

| Customer | No delay | 1 Hr | 2 Hr | 3 Hr | 4 Hr | 5 Hr | 6 Hr | 7 Hr | 8 Hr | 9 Hr | 10 Hr | 11 Hr | 12 Hr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DC1 | $0 | $100 | $150 | $200 | $250 | $300 | $350 | $400 | $450 | $500 | $500 | $500 | $500 |
| Low | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| High | $0 | $100 | $150 | $200 | $250 | $300 | $350 | $400 | $450 | $500 | $500 | $500 | $500 |

**B. Downstream Costs incurred by various downstream customers due to the stock-out risk (& subsequent production stoppages) caused by the delay (in hours) in receipt of their goods**

| Customer | No delay | 1 Hr | 2 Hr | 3 Hr | 4 Hr | 5 Hr | 6 Hr | 7 Hr | 8 Hr | 9 Hr | 10 Hr | 11 Hr | 12 Hr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DC1 | $0 | $100 | $300 | $600 | $1,000 | $2,000 | $4,000 | $8,000 | $10,500 | $15,000 | $25,000 | $50,000 | $100,000 |
| Low | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $1,000 | $1,000 | $1,000 | $1,000 | $1,000 | $1,000 |
| High | $0 | $100 | $300 | $600 | $1,000 | $2,000 | $4,000 | $8,000 | $10,500 | $15,000 | $25,000 | $50,000 | $100,000 |

**C. Opportunity Cost of Cascading Delay (OCCD). OCCD represents the costs imposed on the service provider for future system delays (cascading delays) due to the current service delay.**

| Customer | No delay | 1 Hr | 2 Hr | 3 Hr | 4 Hr | 5 Hr | 6 Hr | 7 Hr | 8 Hr | 9 Hr | 10 Hr | 11 Hr | 12 Hr |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| DC1 | $0 | $0 | $0 | $0 | $0 | $1,000 | $1,500 | $2,000 | $2,500 | $2,500 | $2,500 | $2,500 | $2,500 |
| Low | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 | $0 |
| High | $0 | $0 | $0 | $0 | $0 | $1,000 | $1,500 | $2,000 | $2,500 | $2,500 | $2,500 | $2,500 | $2,500 |

**D. Composite DCOCD Valuations for various customers (incremental cost per hour)**

| **Customer** | **No delay** | **1 Hr** | **2 Hr** | **3 Hr** | **4 Hr** | **5 Hr** | **6 Hr** | **7 Hr** | **8 Hr** | **9 Hr** | **10 Hr** | **11 Hr** | **12 Hr** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **DC1** | ***$0*** | ***$200*** | ***$450*** | ***$800*** | ***$1,250*** | ***$3,300*** | ***$5,850*** | ***$10,400*** | ***$13,450*** | ***$18,000*** | ***$28,000*** | ***$53,000*** | ***$103,000*** |

Other opportunity costs include Upstream Customer Opportunity Cost of Delay (UCOCD), which represents upstream opportunity costs of delay. These costs are incurred by the upstream customer when transportation services are delayed (deliberate or otherwise) and include customer hourly labor and in extreme cases, costs incurred by the customer due to production stoppages due to full output buffers.

Additional Labor Costs of Delay (ALCOD) represents the additional cost of labor incurred by the rail service provider due to arriving at the destination late. Crew costs may range from $400 per hour (when labor set to low) to $800 (when labor set to high).

Idle Fuel Costs (IFC) are real costs incurred when a delay arises. Idling locomotives can consume up to 7 gallons of fuel an hour. As such, when a delay arises and the consist placed into an idle state, the RPM imposes an $80 penalty to cover the fuel costs associated with idling locomotives, taking them offline and restarting.

**IN TRANSIT CALCULATIONS**

Each transit strategy operates under a different premise. MES maintains most efficient speed, Avoid DCOCD increases speed to avoid DCOCD penalties and MT increases speed to arrive on time. Most efficient speed $S_e$ for the RPM is set to 20 MPH, which represents the average speed for a consist delivering bulk cargo such as coal (Crevier et al., 2012). As the model is operationalized, this speed must be tailored to each consist and must take into consideration numerous factors, such as number and models of locomotives used, load, terrain, cars, including environmental factors such as elevation changes, radius of turns, traffic density, and weather conditions.

Each hour, the RPM will evaluate the distance remaining and in the case of the Avoid DCOCD and MT transit strategies, recalculate the speed necessary to arrive at its destination at its appointed on-time. One constraint imposed on the RPM is maximum safe speed ($S_m$), which is set at 25MPH. Like most efficient speed $S_e$, $S_m$ must be tailored to each consist and its operating environment, likely changing along its route.

The transit hour is used to determine how many hours remain in the transit. A delay free transit takes 40 hours to complete the 800 mile transit, for example 20MPH * 40 Hours = 800 miles, with the model capable of managing up to 80 hours of transit time.

$$Transit\ Hour\ t_{1-80}$$

Maximum Safe Speed ($S_m$) is dependent upon many conditions, such as total load, locomotives and their configuration (push/pull), terrain, curvature of the track, etc. and often varies along a consists route. In the RPM, $S_m$ is set to 25MPH.

As the consist progresses, each hour, average speed *B* required to reach the destination at the appointed time is calculated utilizing the distance remaining *M* and transit hour t.

For MT transit strategy & Avoid DCOCD (when DCOCD is high):

$$Speed\ to\ arrive\ on - time\ \ B_t = \frac{M_t}{40 - t_t}$$

$$Min\left\{\frac{M_t}{40 - t_t}, S_m\right\}$$

For Avoid DCOCD transit strategy, when DCOCD is low which allows up to 6 hours additional transit time before imposing a penalty:

$$Speed\ to\ arrive\ on - time\ \ B_t = \frac{M_t}{(40 + 6) - t_t}$$

$$Min\left\{\frac{M_t}{(40 + 6) - t_t}, S_m\right\}$$

As speeds increase above most efficient, so do fuel costs, which are dependent upon numerous factors, such as number and models of locomotives used, load, terrain, and elevation changes. To account for these increased fuel costs, the RPM adopted the "Increased Transit Speed Fuel Costs" (ITSFC) table, based on the C44AC & SD70ACE locomotives and industry data. See Appendix D for ITSFC calculation tables that show the hourly fuel costs for increased speeds above most efficient.

For example, should the consist increase speed to 22MPH, 2MPH over most efficient speed, the consist would incur $139.33 in additional fuel costs each hour. Likewise, if the consist increased to maximum safe speed, $S_m$ = 25MPH, the consist would incur $661.83 in additional fuel costs each hour it traveled at that speed.

Expected Service Profit (ESP) P is based on the revenue per ton-mile of coal over the normal range of 100 to 190 cars for the typical coal consist (calculated in Appendix D), which equates to $12,800 to nearly $25,000 in profit per load. The RPM utilizes a randomized range between these two figures to generate the ESP P for each instance.

$$Expected\ Service\ Profit\ (ESP)\ \ P = RANDBETWEEN\ (12800 - 25000)$$

As the consist makes way towards the destination, each of the three simulation models executes its transit strategy until it reaches the destination. Once there, two profits are calculated:

- Service Profit (SP),
- Rail Service Profit (RSP).

**SERVICE PROFIT (SP)**

Service Profit (SP) takes into account fuel costs, labor costs, and opportunity costs incurred by the supply chain when a delivery is late and is calculated upon arrival.

$$Service\ Profit\ (SP) = ESP - UCOCD - DCOCD - ITSFC - ALCOD - IFC$$

Where:

ESP: Expected Service Profit

UCOCD: Upstream Customer Opportunity Cost of Delay

DCOCD: Downstream Customer Opportunity Cost of Delay

ITSFC: Increased Transit Speed Fuel Cost

ALCOD: Additional Labor Costs of Delay

IFC: Idle Fuel Cost

The RPM enables rail service providers to account for costs that their behavior and decisions impose on downstream customers; when maximizing SP, profitability is not localized only to the service provider, but is improved across the supply chain. Although opportunity costs are not real, tangible costs to the rail service provider, they are real, tangible costs that downstream customers incur should the rail service provider deliver late. In some cases, especially for JIT customers, opportunity costs can be substantial. Taking into account opportunity costs balances the needs of downstream customers with the profitability of the service provider, improving reliability, increasing performance, and enhancing efficiency of the supply chain.

**RAIL SERVICE PROFIT (RSP)**

Rail Service Profit (RSP) accounts for the real, tangible costs that detract from profitability, such as fuel and labor costs and is calculated upon arrival.

$$Rail\ Service\ Profit\ (RSP) = ESP - ITSFC - ALCOD - IFC$$

Where:

ESP: Expected Service Profit

ITSFC: Increased Transit Speed Fuel Cost

ALCOD: Additional Labor Costs of Delay

IFC: Idle Fuel Cost

The RPM enables rail service providers to account for costs that detract from their profitability. Costs, particularly fuel, can have a dramatic detrimental effect on profitability, particularly when a consist increases speed to arrive on time. Until the advent of the RPM, the rail service provider increased speed with little awareness of its impact on profitability.

**RPM FUNCTIONAL LOGIC DIAGRAM**

The RPM functional logic diagram is provided as Figure 1 below. At the beginning of each simulation, the consist is at risk of a departure delay, preventing the consist from making way until the delay passes. Thereafter, hourly, the consist is subjected to a 10% probability of encountering a delay. If a delay arises, the consist remains idle for the hour and incurs an idle fuel charge (IFC) of $80. Once released from the delay, each transit strategy calculates the remaining distance, remaining time, and transit speed necessary for an on-time arrival. For MES transit strategy, transit speeds remains at 20MPH. For the "Avoid DCOCD" transit strategy, the arrival time is allowed to slip to as late at 6 hours without incurring a DCOCD penalty, as such, the simulation model will not increase speed until tardiness reaches 7 hours (when DCOCD is set to low). When DCOCD is set to high, DCOCD penalties arise with the first delay, forcing the Avoid DCOCD transit strategy to increase speed immediately upon incurring a delay. MT transit strategy acts similar, increasing speed immediately upon the first delay in an effort to arrive on time. All three simulation models continue implementing their individual transit strategies until arrival, then calculates their respective profits - SP & RSP. The transit strategy that preserves the greatest profit is the most desirable.

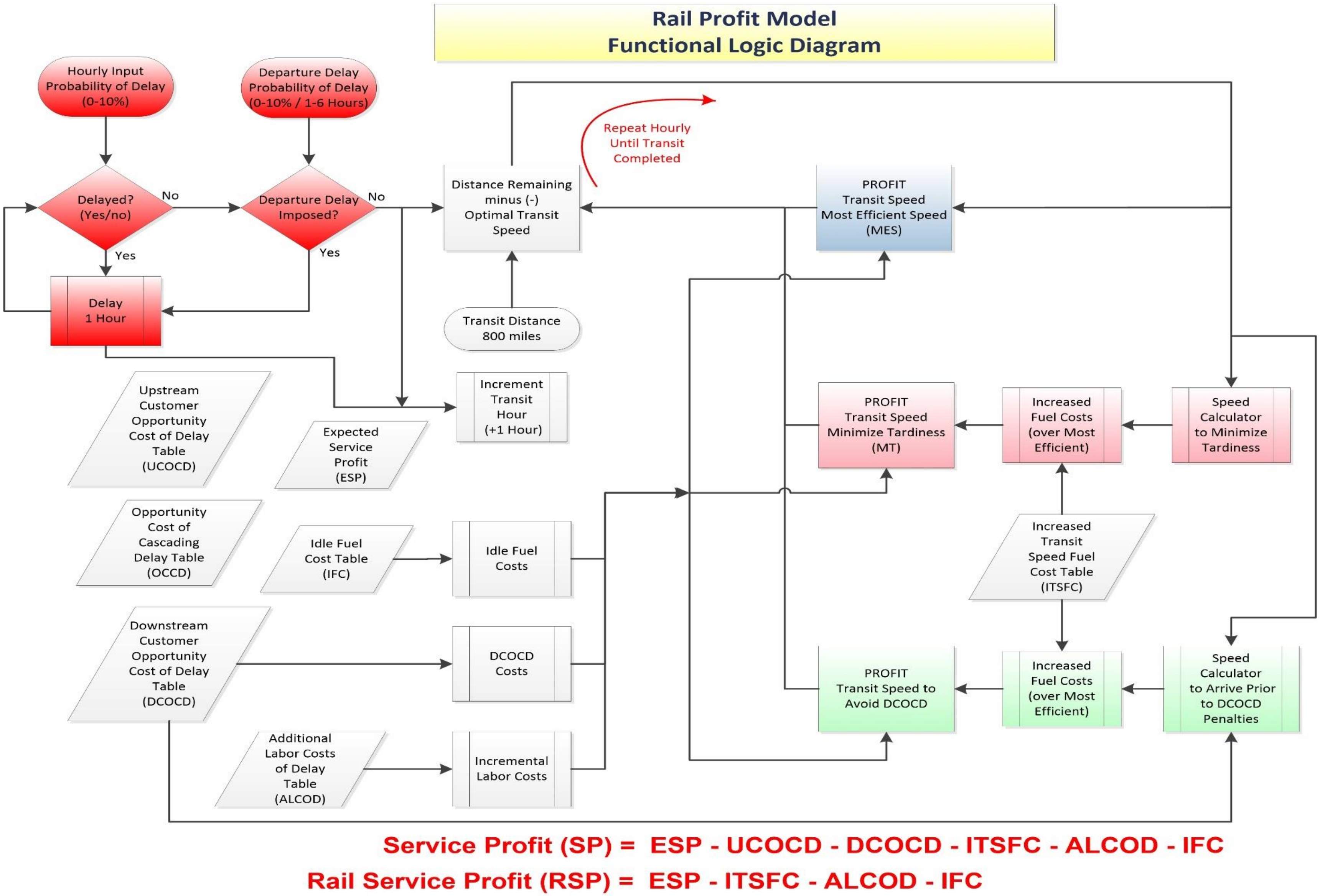


Figure 1: Functional logic diagram of the RPM

## 3.2 THE PROFIT FRONTIER

Profit efficiency is defined by Ali et al. (1989) as the ability of a firm to achieve the highest possible profit, given the prices and levels of fixed factors of that firm. Profit inefficiency is the profit loss (or eroded profits) from not operating on the profit frontier. The profit frontier graph demonstrates the magnitude of various suboptimal transit strategies has on profits and provides a means to visually identify the "optimal solution." Rungsuriyawiboon (2003) developed a dynamic efficiency model that determined that deregulation of energy generation provides incentives for the efficient operation of electrical generators and to lower costs, which maximize profits. It should be noted, that lowering costs do not necessarily optimize profits, especially when the approached is examined generally. The level of capital investment used to lower costs, the propagation of downstream impacts, and the influences on revenue should also be assessed before true optimization can be qualified.

Rahman (2003) developed a stochastic profit frontier to estimate profit efficiency in modern rice production and attributed profit inefficiency to infrastructure, soil fertility, experience, and other effects. He concluded that a considerable amount of profit could be retained by improving the areas.

- Technical Efficiency: getting the most production from available resources, best use of input resources; what society values most.
- Allocative Efficiency: cost to produce is in line with price paid by customers, obtaining the most satisfaction from resources.
- Scale Efficiencies: increasing production results in decreasing marginal costs.

The RPM involves two of the three types of efficiencies, specifically technical efficiency by quantifying the costs of additional fuel consumed to arrive on time versus the value of the on-time service. The RPM also involves allocative efficiency by how service levels are apportioned to its customers. For example, who gets the on-time service in a constrained network? Together, the process of determining the most profitable of alternatives serves to increase the efficiency of the rail service provider as well as to the benefit of the customer whom receives services more in line with what they are paying for.

Herr et al. (2003) conducted a stochastic frontier analysis on hospitals and determined that private hospitals are less cost efficient, but more profit efficient than publically owned. This again demonstrates that although cost efficiencies are desired, they may not necessarily translate to profit efficiencies, especially in a linear fashion. Another example is that firms with higher profits have greater opportunities to invest in their operations by improving technologies, which usually improves organizational efficiencies and profit by greater amounts than what was invested. The same concept holds true in the rail transportation industry, where technological advancements often reap significant return on investment.

Kumbhakar et al. (2001) utilized a trans-log profit function augmented to incorporate both technical and allocative inefficiencies to demonstrate that a profit function framework cannot always be independent, an assumption that is widely used in the literature, but may lead to incorrect models. Bos et al. (2007) derived a Meta-Frontier for a profit maximization model to assess the European banking industry, establishing a framework where the efficiency of banks in multiple groups can be compared without having to assume that they operate under a single, identical frontier due to differences in technology, competition, supervision, etc. The same could be extended across the rail transport industry within the U.S. and Europe.

In this specific case, the profit frontier graph reflects the difference between the Expected Service Profit (ESP) and the profit remaining after implementing the various transit strategies in response to the delays induced into the model during the simulated transit. The ESP forms the "frontier" and serves as the profit maxima for the transit, void of any inefficiencies (delays). As the consist completes its journey (minimum of 40 hours), risk of stochastic delays are imposed hourly on the consist. If a delay arises, the consist must remain idle and make no way for the hour. Profit calculations are performed hourly, reflecting losses as the consists transit progresses until it reaches its destination. The transit strategy that preserves the most profits and remains closest to the profit frontier maximizes profitability. The observed gaps from the ESP form the "eroded profits" that are consumed by suboptimal operations and taken from rail transport stockholders.

Figure 2 below provides a sample Profit Frontier Graph.

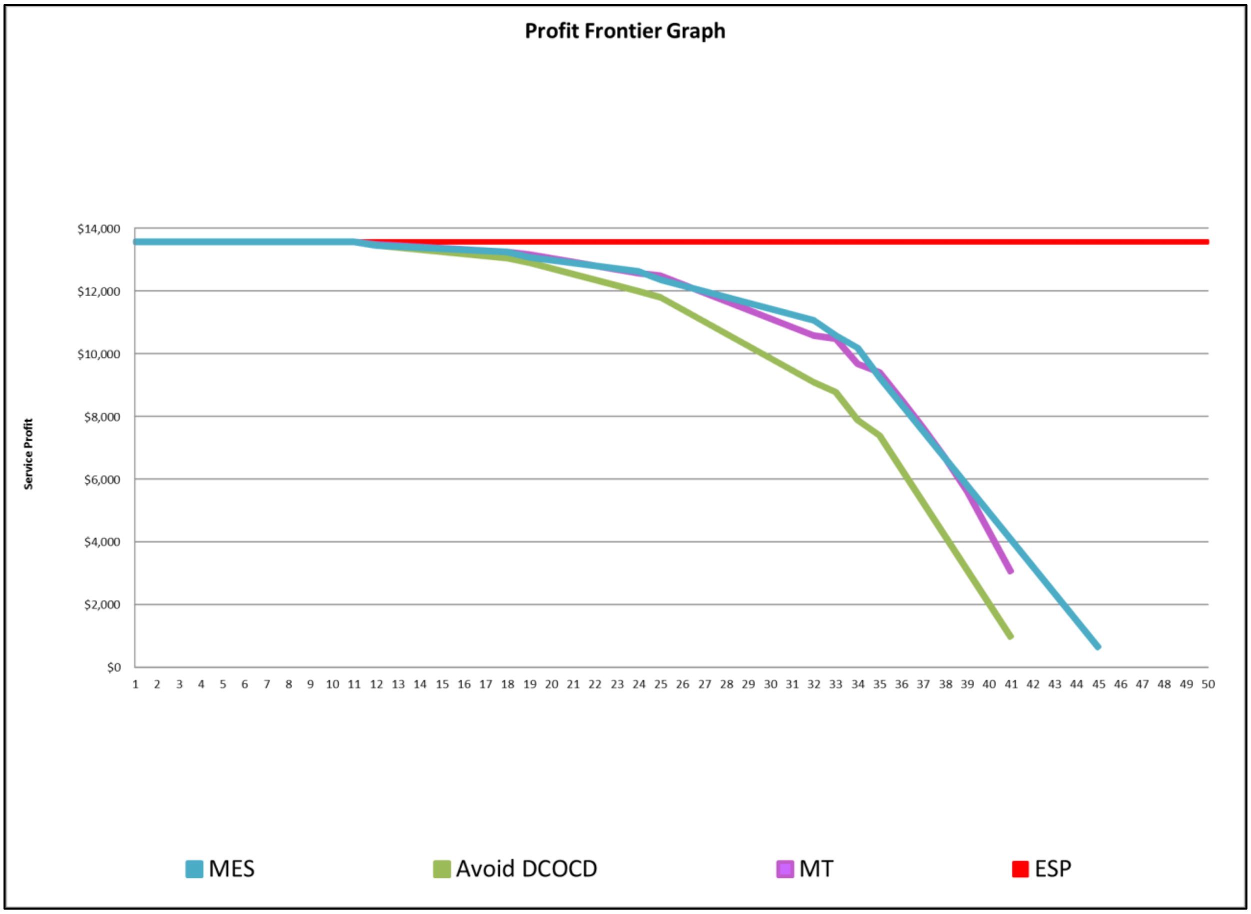


Figure 2: Sample profit frontier graph

## 3.3 FUNCTIONAL ASPECTS OF THE RAIL PROFIT MODEL (RPM)

The rail industry is capital intensive. For example, locomotives cost upwards of $2 million each. The high capital cost of these locomotives compels management to limit the number of locomotives in its fleet to the smallest number capable of meeting expected demand; a problem known as fleet sizing.

Demand for rail transportation services is dynamic and sensitive to economic trends. The normal ebbs and flows within the multiple supply chains served causes container quantities and the intervals between shipments to vary. This variability is one of the most challenging aspects of managing rail operations. Unanticipated variability in demand for locomotives often results in locomotives being out of position (i.e. not near the demand location). This requires locomotive(s) to be relocated within the network, oftentimes at substantial personnel and operating costs. The transit time required to relocate a locomotive to the point of demand may also result in a service delays which may (or may not) propagate through the supply chain to downstream customers, delaying downstream operations. Oftentimes within the rail industry, engineers attempt to make up time by accelerating transit speeds to deliver on time, increasing operating costs. Should the engineer try to make-up this time or are they simply depleting profits? The analysis within the RPM will identify circumstances where allowing the train to maintain economical speed and deliver late is the right and most profitable answer.

A primary competitor to rail transportation industry is trucking. One competitive advantage of the trucking industry is their flexibility and responsiveness to customer demands. For example, a truck pick-up or delivery can be adjusted much more easily than train service, yet the rail industry continues to try to attain similar customer service levels. This puts a tremendous strain on network resources (cars, locomotives, rail lines, crews, etc.) and results in costly unloaded transfers of locomotives. With the exception of “just-in-time” service delivery agreements with manufacturers, the majority of service requests are treated with the similar priority. Treating all customers and all demands with the same priority is a very costly and inefficient presumption. Few commodities are highly sensitive to service delays. For example, coal is usually stored at shipping and receiving points in large piles that can exceed 30 days. Further, coal cars are often set aside waiting to be filled and once filled, set aside again awaiting transit. Delays of a couple hours, or even days, may prove negligible, while a consumer goods retail customer could experience a stock out within a day, resulting in lost sales. These distinctions between customers should be captured and evaluated when making resourcing decisions. This is especially true when multiple loads compete for a single resource, often leaving the remaining loads waiting, causing additional tardiness. Unique characteristics between customers is captured by the Downstream Customer Opportunity Cost of Delay (DCOCD) and quantifies the financial impact delays impose on downstream customers. Similarly, Kwon et al. (1998) implemented a linear penalty cost ($9/hr for high priority and $3/hr for low priority) when assessing late arrivals in the freight car scheduling model. In contrast, the RPM utilizes DCOCD, which is expressed in dollars per hour ($/hr) and its function quantifies the unique characteristics, sensitivities, and needs of downstream customers in a non-linear fashion. For example, a coal producer may not incur costs or penalties for the first six hours of a delay; then experiences $200/hr (for crew overtime) for the next six hours. Using non-linear costs for delays imparts a more realistic consequence experienced in terminal operations (Kwon et al. 1998).

From the example above, JIT customers are at relative high risk of experiencing real and significant financial penalties with only minor delays. As such, JIT customers should garner higher priority when operations assign resources. The JIT customer may have a DCOCD that is more exponential in nature, with quickly escalating costs as delays accumulate. The RPM takes these financial nuances into account. What remains are the profit characteristics for consists, operating under the various scenarios, which ultimately form the profit frontier graph, identifying the transit strategy that maximizes overall profitability (the preferred solution). Lowest cost solutions, when pursued in isolation, ignores these very real and oftentimes significant customer impacts, resulting in solutions sets that unknowingly assign a constrained resource to a customer that may not be sensitive to service delays, while a customer whom is highly sensitive to the point of incurring late charges or spoilage is forced to wait.

Homer et al. (1999) indicated that train delays are a chronic problem and have a self-perpetuating and self-reinforcing tendency. When trains are delayed, they absorb more resources (crew time, locomotive and car time, track time, and terminal time). The extra absorption of assets increases the possibility of imposing delays to follow-on services due to unavailability. Larsen et al. (2014) classify delays into two parts: primary and consecutive. Consecutive delays are the delays imparted by the interaction with other trains running in the network, likened to the domino effect. The RPM takes this phenomena into consideration through the Opportunity Cost of Cascading Delay (OCCD) variable, which reflects the costs incurred by the supply chain for these propagated delays.

## 3.4 RAIL PROFIT MODEL ASSUMPTIONS

The RPM and the variables involved are well defined. Baseline industry data was used to establish most of the model variables either directly or through data extrapolation. Train configurations are highly variable, involving different models and number of locomotives, varying number and models of cars, and each route has its own unique operating characteristics, including terrain and speed limits. The RPM parameters were established to accommodate average operating conditions. Before the model is operationalized; parameters that detail the consist configuration and route should be tailored to that particular service. Details such as the fuel consumption tables for the specific model locomotives, the total load carried, terrain and distance of route, optimal and max safe speeds need to be customized for the model to specifically determine optimal transit strategies that maximize profitability. Basic assumptions used in the RPM are documented below:

- Average speed of a freight train: 20MPH (Crevier et al., 2012);
- Transit distance set to 800 miles (Tolliver et al., 2014);
- Delays randomly imposed, with 10% probability, hourly throughout the transit;
- Utilized coal traffic data for 2009 to extrapolate operating statistics, including profit margins & revenue statistics to establish Expected Service Profits (ESPs) (AAR, 2011);
- Average fuel consumption rates used in the RPM are based on locomotive models C44AC and SD70ACE average fuel burn rates in (gallons/hour) at various throttle positions (over level ground) (ARAIL);
- Maximum safe speed of transit set to 25MPH (terrain & horsepower dependent);
- ESPs are randomly generated based on typical loading characteristics of coal trains, ranging from 100 to 152 cars.

# CHAPTER 4

# RESULTS

## 4.1 SIMULATION MODEL VARIABLES

The Rail Profit Model (RPM) integrates fuel costs, supply chain opportunity costs and labor costs through simulation to assist rail service providers with a means to recognize and implement the transit strategy that maximizes profitability. Three variables are used to create twelve combinations of inputs, known as scenarios, shown in Table 2.

Table 2: The twelve scenarios of the RPM

| Scenario | Fuel ($/Gallon) | DCOCD | Labor |
|---|---|---|---|
| **1** | 4 | Low | Low |
| **2** | 2 | Low | Low |
| **3** | 6 | Low | Low |
| **4** | 4 | Low | High |
| **5** | 2 | Low | High |
| **6** | 6 | Low | High |
| **7** | 4 | High | Low |
| **8** | 2 | High | Low |
| **9** | 6 | High | Low |
| **10** | 4 | High | High |
| **11** | 2 | High | High |
| **12** | 6 | High | High |

Labor is represented by two settings: Low - $400/Hr; High - $800/Hr.

DCOCD values of Low/High are defined and provided in Table1.

## 4.2 TRANSIT STRATEGIES

Simulation models are used to examine the effects of three transit strategies on profits:

1) Most Efficient Speed (MES),
2) Speeds to Avoid DCOCD penalties (Avoid DCOCD),
3) Speeds to Minimize Tardiness (MT).

For the RPM, 20MPH is the most efficient speed. In practical applications this value varies substantially due to the following characteristics and would have to be calculated for each consist/cargo/route combination:

- Make, model and number of locomotives used;
- Load/number of cars;
- Cargo type;
- Terrain/grades/curvature of the route;
- Weather;
- Speed limits.

Maximum safe speed is closely monitored by operators because it commonly varies along a route. The RPM utilizes a 25MPH maximum safe speed. This value would be based on the above characteristics and portion of the track being traversed.

Huisman and Boucherie (2001) identified numerous causes of rail delays, such as weather conditions, traffic, slower trains, upstream customer delays in readying the load, resource delays (crews, cars, and locomotives), yard delays, signal failures, switch delays, derailments, equipment malfunctions and even accidents (Kuo et al. (2007)). The RPM aggregates these delays into a single stochastic delay that is calculated at the beginning of each hour's transit (0-99). When delays arise, represented by values between 0-10 and appear in red/bold text, the delay will last an entire hour with the consist placed into a state of idle. Thirty instances with these random delays were developed, appearing in Tables 3-5.

Table 3: Instances 1 thru 10 with random delays imposed (<=10 results in 1 hour delay)

| INSTANCE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **TRANSIT HOUR** *(t)* | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ |
| **1** | 53 | 51 | 77 | 72 | **5** | 87 | 94 | 26 | 45 | 35 |
| **2** | 51 | 83 | 47 | **3** | 48 | 86 | 43 | 53 | 18 | 56 |
| **3** | 66 | 58 | 85 | 38 | 77 | **6** | 45 | 17 | 56 | 91 |
| **4** | 63 | 67 | **2** | 84 | 38 | **5** | 99 | 33 | 57 | 26 |
| **5** | 43 | 33 | **1** | 20 | 31 | 46 | 53 | 94 | 29 | 83 |
| **6** | 74 | 86 | 77 | 35 | 94 | 76 | 82 | 78 | 37 | 51 |
| **7** | 68 | 90 | 36 | 87 | 99 | 58 | 75 | 43 | 75 | 96 |
| **8** | 96 | 33 | 46 | 78 | 26 | 88 | 90 | 66 | 51 | 21 |
| **9** | 85 | 44 | 65 | 28 | 36 | 25 | 67 | 62 | 43 | 25 |
| **10** | 80 | **4** | **1** | 18 | 82 | 38 | 21 | 17 | 88 | **3** |
| **11** | 32 | 71 | 44 | 57 | 58 | 98 | 50 | 92 | 55 | 65 |
| **12** | **1** | 16 | 51 | 43 | 53 | 90 | **1** | 93 | 42 | 29 |
| **13** | 68 | 57 | 70 | 72 | 21 | 25 | 43 | 71 | 42 | **1** |
| **14** | 58 | 98 | 14 | 90 | 80 | 33 | 70 | 37 | 65 | 47 |
| **15** | 75 | 15 | 23 | 35 | 82 | 59 | 69 | 30 | 71 | **2** |
| **16** | 16 | 63 | **4** | 59 | 40 | **7** | 11 | 21 | **8** | 46 |
| **17** | 36 | 77 | **4** | 57 | 77 | 19 | 61 | 89 | 88 | **8** |
| **18** | 96 | 20 | 57 | 35 | 35 | 70 | 30 | 32 | 55 | 45 |
| **19** | 58 | 20 | 48 | **6** | 43 | 57 | **6** | 45 | 42 | 17 |
| **20** | 95 | 33 | **5** | 27 | 73 | 12 | 68 | 51 | 16 | 76 |
| **21** | 86 | 33 | 75 | 95 | 23 | 17 | 48 | 11 | 13 | 48 |
| **22** | 38 | 81 | 47 | 69 | 49 | 47 | 88 | **4** | 39 | 84 |
| **23** | 58 | 50 | 14 | 66 | **9** | 22 | 16 | 37 | 75 | 22 |
| **24** | 75 | 52 | 30 | 64 | 68 | 24 | 52 | 23 | 75 | 98 |
| **25** | 74 | 74 | 72 | 47 | 34 | 53 | **4** | 31 | 90 | 13 |
| **26** | 82 | 94 | 81 | 79 | 52 | 29 | 58 | 84 | **4** | 14 |
| **27** | 21 | 61 | 30 | 12 | 52 | 44 | 28 | 17 | 71 | 17 |
| **28** | 91 | **9** | 31 | 17 | 29 | 72 | 63 | 50 | 75 | 25 |
| **29** | 80 | 75 | 14 | **3** | 11 | 55 | 95 | 21 | 16 | 36 |
| **30** | 20 | 95 | 92 | 14 | 56 | 52 | 17 | 55 | 81 | 79 |
| **31** | 32 | 16 | 30 | 58 | 52 | 98 | 55 | **4** | 26 | 99 |
| **32** | 12 | 56 | 80 | 82 | 19 | 17 | 86 | 35 | 92 | 75 |
| **33** | 34 | 21 | 80 | 32 | 96 | 81 | **9** | 24 | 46 | 31 |
| **34** | 62 | 73 | 73 | 50 | 99 | 71 | 71 | 86 | 76 | 33 |
| **35** | 98 | 48 | 72 | 47 | 30 | 49 | **7** | 95 | 59 | 20 |
| **36** | 68 | 44 | 99 | 95 | 35 | 72 | 38 | 40 | 16 | 47 |
| **37** | 45 | 46 | 86 | 12 | 50 | 94 | 80 | 58 | 75 | 61 |
| **38** | 64 | 37 | 49 | 77 | 29 | 24 | 95 | **7** | 30 | 67 |
| **39** | 52 | 94 | 22 | 39 | 36 | 13 | 58 | 33 | **3** | 54 |
| **40** | 47 | 60 | 56 | 66 | 34 | 99 | 43 | **6** | 22 | 92 |
| **ESP ($)** | $15,784 | $20,573 | $18,547 | $21,243 | $20,528 | $19,977 | $13,561 | $16,541 | $13,817 | $22,043 |

Table 4: Instances 11 thru 20 with random delays imposed (<=10 results in 1 hour delay)

| INSTANCE | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
|---|---|---|---|---|---|---|---|---|---|---|
| TRANSIT HOUR (*t*) | Random # (0-99) $r_{1\text{-}80}$ | Random # (0-99) $r_{1\text{-}80}$ | Random # (0-99) $r_{1\text{-}80}$ | Random # (0-99) $r_{1\text{-}80}$ | Random # (0-99) $r_{1\text{-}80}$ | Random # (0-99) $r_{1\text{-}80}$ | Random # (0-99) $r_{1\text{-}80}$ | Random # (0-99) $r_{1\text{-}80}$ | Random # (0-99) $r_{1\text{-}80}$ | Random # (0-99) $r_{1\text{-}80}$ |
| 1 | 90 | 39 | 49 | **7** | 16 | 59 | 11 | 96 | 10 | 20 |
| 2 | 15 | 44 | 29 | **1** | 72 | 68 | **10** | **6** | **3** | 34 |
| 3 | 54 | 72 | 29 | 52 | 97 | 62 | 56 | 42 | 30 | 97 |
| 4 | 79 | **5** | 25 | 24 | **2** | **8** | 65 | 78 | 84 | 37 |
| 5 | 40 | 64 | 76 | 42 | 36 | 20 | 38 | 28 | 92 | 90 |
| 6 | 25 | 61 | 63 | 13 | 56 | 82 | 94 | 66 | 98 | **6** |
| 7 | 29 | 34 | 17 | 36 | 39 | **9** | **0** | 62 | 90 | 57 |
| 8 | 40 | **5** | 42 | 26 | **2** | 52 | 12 | 36 | 74 | **5** |
| 9 | 42 | 40 | 13 | 24 | 27 | 46 | 33 | 27 | 98 | 27 |
| 10 | 64 | 49 | 31 | 97 | 13 | 50 | 48 | **2** | **5** | 94 |
| 11 | 39 | 73 | 83 | 76 | 53 | 57 | 37 | 29 | **10** | **3** |
| 12 | 73 | 72 | 67 | 81 | 18 | 32 | 79 | 99 | 53 | **9** |
| 13 | 95 | 74 | **5** | 53 | 78 | 89 | 40 | 72 | 69 | 45 |
| 14 | **2** | 20 | 68 | 79 | **7** | 32 | 67 | 91 | 39 | 50 |
| 15 | 82 | 20 | 58 | 82 | 16 | 65 | 21 | 16 | 41 | **9** |
| 16 | 63 | 15 | **5** | 48 | **0** | 11 | **9** | 42 | 65 | 93 |
| 17 | 56 | 11 | 76 | 46 | 25 | 77 | **8** | 62 | 38 | 95 |
| 18 | 54 | 92 | 26 | 84 | 46 | 28 | 39 | 16 | 13 | 60 |
| 19 | 37 | 63 | 39 | 78 | 64 | 99 | 91 | 93 | 69 | 49 |
| 20 | 90 | **0** | 61 | 34 | 16 | 95 | 95 | 54 | 65 | **10** |
| 21 | 24 | 68 | 21 | 57 | 67 | 48 | 43 | **6** | 56 | 97 |
| 22 | 75 | 78 | 14 | 74 | 22 | 63 | **0** | 37 | 67 | 32 |
| 23 | 17 | 68 | 23 | 64 | 55 | 86 | 13 | 90 | 23 | 44 |
| 24 | 80 | 31 | 96 | 70 | 88 | 74 | 75 | **2** | 36 | 36 |
| 25 | **4** | 46 | 29 | 96 | 86 | **3** | 94 | 33 | 33 | **4** |
| 26 | 23 | 98 | 47 | 24 | 72 | 93 | 34 | 91 | **10** | 72 |
| 27 | 58 | 64 | **9** | 78 | 89 | 24 | 56 | 51 | 79 | **6** |
| 28 | 68 | 29 | 47 | 74 | **6** | 73 | 16 | 75 | 68 | **6** |
| 29 | 50 | 45 | 17 | 62 | 98 | 19 | 68 | 50 | 18 | 83 |
| 30 | 51 | **9** | 11 | 67 | 56 | 17 | **2** | 57 | 99 | 58 |
| 31 | 36 | 88 | 77 | 27 | 42 | 80 | 48 | 84 | 47 | 73 |
| 32 | 75 | 50 | 94 | 80 | 74 | 87 | **4** | 75 | 77 | 17 |
| 33 | 27 | **3** | 74 | 13 | 80 | 57 | 52 | 44 | 83 | 18 |
| 34 | 62 | 8 | 95 | 94 | 40 | 50 | 55 | 26 | **5** | 44 |
| 35 | 65 | 39 | 38 | 82 | 45 | 56 | 83 | 14 | 80 | 98 |
| 36 | 56 | 81 | **4** | 37 | 52 | 94 | 90 | 89 | **8** | 16 |
| 37 | 16 | 68 | 50 | 52 | 40 | 97 | 85 | 20 | 46 | 15 |
| 38 | 11 | 83 | 51 | 13 | 46 | 84 | 56 | 30 | 18 | 78 |
| 39 | 29 | 30 | **8** | 74 | 29 | 95 | 16 | 16 | 29 | 67 |
| 40 | 91 | 67 | 73 | 32 | **4** | 24 | 77 | 49 | 92 | 18 |
| ESP ($) | $24,118 | $14,338 | $23,439 | $15,354 | $14,086 | $16,727 | $14,924 | $13,866 | $13,232 | $22,327 |

Table 5: Instances 21 thru 30 with random delays imposed (<=10 results in 1 hour delay)

| INSTANCE | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
|---|---|---|---|---|---|---|---|---|---|---|
| TRANSIT HOUR (t) | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ | Random # (0-99) $r_{1-80}$ |
| **1** | 83 | 69 | 75 | 23 | 50 | 65 | 60 | 55 | 16 | 98 |
| **2** | 65 | 13 | 40 | 98 | 49 | 21 | **5** | 45 | 35 | 50 |
| **3** | 21 | 70 | 78 | 28 | 38 | 42 | 21 | 20 | 40 | 61 |
| **4** | 42 | 46 | 14 | 51 | 36 | 21 | 25 | 69 | 94 | 34 |
| **5** | 21 | 97 | 23 | 78 | 82 | 82 | 42 | 28 | 57 | 86 |
| **6** | 82 | 22 | 55 | **3** | 78 | 84 | **5** | 49 | 98 | 34 |
| **7** | 84 | 93 | 47 | 77 | 28 | 99 | 22 | 16 | 67 | 75 |
| **8** | 99 | 64 | **2** | 34 | 67 | 11 | 44 | 88 | 62 | 22 |
| **9** | 11 | 79 | 59 | 74 | 54 | 36 | 66 | 40 | **9** | **0** |
| **10** | **5** | 12 | 84 | 15 | 86 | 79 | 76 | 81 | 98 | 36 |
| **11** | 79 | 13 | 51 | 54 | 21 | 63 | 19 | 81 | 64 | **3** |
| **12** | 63 | 79 | **6** | 23 | 41 | 32 | 32 | 58 | 35 | 24 |
| **13** | 32 | 44 | 21 | 93 | **7** | 96 | 55 | 70 | 87 | 23 |
| **14** | 96 | **8** | 18 | 27 | 12 | 85 | 68 | 54 | 78 | 81 |
| **15** | 85 | 71 | 83 | **6** | **2** | 45 | 92 | 12 | 28 | 21 |
| **16** | 45 | 22 | 74 | 84 | 60 | 34 | 66 | 22 | 18 | 54 |
| **17** | 34 | 69 | 71 | 30 | 73 | 28 | **3** | 14 | 57 | 54 |
| **18** | 28 | 16 | 11 | 35 | 40 | 14 | **1** | 59 | 43 | 26 |
| **19** | 14 | 76 | 12 | 21 | 67 | 47 | 78 | 48 | 72 | 76 |
| **20** | 47 | 27 | **0** | 91 | 34 | 65 | 46 | 84 | 90 | 98 |
| **21** | 65 | 98 | 43 | 81 | 88 | 45 | 73 | 19 | 80 | 31 |
| **22** | 45 | **7** | 39 | 65 | 92 | 91 | 40 | 17 | 98 | 16 |
| **23** | 91 | 49 | 27 | 66 | 97 | 38 | 37 | 93 | 37 | 33 |
| **24** | 38 | 38 | 61 | 46 | 48 | 66 | 87 | 15 | 52 | 23 |
| **25** | 66 | 81 | 52 | **0** | 49 | 49 | 69 | 65 | 52 | 69 |
| **26** | 49 | 62 | 77 | 81 | 65 | 46 | 75 | 56 | 39 | **5** |
| **27** | 19 | **8** | 54 | 75 | 26 | 89 | 54 | 60 | 59 | 54 |
| **28** | 82 | 70 | 38 | 42 | **3** | 34 | 60 | 29 | 95 | 39 |
| **29** | 64 | 43 | 47 | 97 | 90 | 58 | 88 | 43 | 45 | 54 |
| **30** | **2** | 52 | 64 | 43 | **2** | 23 | 16 | 13 | 13 | 92 |
| **31** | 44 | 96 | 85 | 84 | 69 | 49 | 33 | 95 | 20 | 84 |
| **32** | 57 | **2** | 33 | 47 | 25 | 79 | 34 | 45 | 19 | 11 |
| **33** | 26 | 83 | **7** | 11 | 12 | 24 | 17 | 13 | 77 | 42 |
| **34** | 57 | 76 | 87 | 20 | 23 | 75 | 55 | 20 | 12 | 75 |
| **35** | **9** | 64 | **3** | 97 | 72 | 91 | 44 | 19 | 18 | 55 |
| **36** | 39 | 80 | **0** | 34 | 50 | 27 | 95 | 77 | 77 | 41 |
| **37** | 41 | 55 | **3** | 81 | 34 | **5** | 24 | 12 | 56 | 24 |
| **38** | 76 | 88 | 95 | 34 | **3** | 81 | 98 | 18 | 13 | 71 |
| **39** | 71 | 80 | **5** | 33 | 15 | 26 | 90 | 77 | 37 | 37 |
| **40** | 19 | 73 | 55 | 47 | 30 | 99 | 67 | 66 | 15 | 29 |
| **ESP ($)** | $21,047 | $22,757 | $13,394 | $14,782 | $19,592 | $16,166 | $24,171 | $18,403 | $18,180 | $22,651 |

Each hour, the RPM calculates the remaining distance and time, recalculating the necessary transit speed to arrive at the destination on time. The three transit strategies respond accordingly, until the train arrives and final profit calculations are performed, forming the Profit Frontier.

The MES transit strategy, regardless how far behind schedule or how great the opportunity cost of delay, will continue to travel at most efficient speed until arrival.

Similarly to the MES strategy, the Avoid DCOCD strategy will transit at MES. As delays accumulate, the simulation model determines when DCOCD penalties arise, at which time it would increase transit speeds to arrive early enough to avoid any DCOCD penalty. For example, when DCOCD costs are low, penalties for late arrival do not arise until a consist arrives 7 hours or more late. The Avoid DCOCD transit strategy would keep transit speed at most efficient, until delays mount to 7 hours, then respond by increasing speed to arrive only 6 hours late, avoiding penalty. Likewise, when DCOCD costs are high, DCOCD penalties occur quickly, forcing transit speeds to increase in response to the first delay.

The MT simulation model responds to delays immediately, increasing speeds to ensure on-time arrival. As delays accumulate, speeds increase up to maximum safe speed. In a few instances where there were substantial delays or delays that arose very close to the destination, the consist arrived late. Otherwise, the consist successfully increased speed to arrive on time, but at what impact to profits?

## 4.3 RESULTS – INDIVIDUAL INSTANCES

Three simulation models were developed to examine transit strategies (MES, Avoid DCOCD, and MT). Running each of the 30 instances through all 12 scenarios produced the 30 tables found in Appendix C. The following six tables (involving Instances 1, 7, 9, 15, 21, & 28) provide a representative cross-section of notable results.

Table 6: Instance 1 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 1 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 3 | $15,784 | 5 | 5 | $12,384 | $13,384 | 5 | $12,384 | $13,384 | 0 | $3,959 | $3,959 |
| **2** | 2 | L | L | 3 | $15,784 | 5 | 5 | $12,384 | $13,384 | 5 | $12,384 | $13,384 | 0 | $9,671 | $9,671 |
| **3** | 6 | L | L | 3 | $15,784 | 5 | 5 | $12,384 | $13,384 | 5 | $12,384 | $13,384 | 0 | -$1,754 | -$1,754 |
| **4** | 4 | L | H | 3 | $15,784 | 5 | 5 | $9,384 | $11,384 | 5 | $9,384 | $11,384 | 0 | $3,959 | $3,959 |
| **5** | 2 | L | H | 3 | $15,784 | 5 | 5 | $9,384 | $11,384 | 5 | $9,384 | $11,384 | 0 | $9,671 | $9,671 |
| **6** | 6 | L | H | 3 | $15,784 | 5 | 5 | $9,384 | $11,384 | 5 | $9,384 | $11,384 | 0 | -$1,754 | -$1,754 |
| **7** | 4 | H | L | 3 | $15,784 | 5 | 5 | $6,384 | $13,384 | 0 | $4,055 | $4,255 | 0 | $3,959 | $3,959 |
| **8** | 2 | H | L | 3 | $15,784 | 5 | 5 | $6,384 | $13,384 | 0 | $9,420 | $9,620 | 0 | $9,671 | $9,671 |
| **9** | 6 | H | L | 3 | $15,784 | 5 | 5 | $6,384 | $13,384 | 0 | -$1,309 | -$1,109 | 0 | -$1,754 | -$1,754 |
| **10** | 4 | H | H | 3 | $15,784 | 5 | 5 | $3,384 | $11,384 | 0 | $3,655 | $3,855 | 0 | $3,959 | $3,959 |
| **11** | 2 | H | H | 3 | $15,784 | 5 | 5 | $3,384 | $11,384 | 0 | $9,020 | $9,220 | 0 | $9,671 | $9,671 |
| **12** | 6 | H | H | 3 | $15,784 | 5 | 5 | $3,384 | $11,384 | 0 | -$1,709 | -$1,509 | 0 | -$1,754 | -$1,754 |
| | | | | **3** | **$15,784** | **5** | **5** | **$7,884** | **$12,384** | **2.50** | **$7,370** | **$8,220** | **0.00** | **$3,959** | **$3,959** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **8** | **12** | | **5** | **6** | | **4** | **0** |

**Analysis:** Instance 1 involved a three-hour departure delay, plus two other delays while in transit, for a total of 5 hours. Maximum Rail Service Profit was achieved by the MES transit strategy across all 12 scenarios, meaning that it was most profitable for the rail service provider to remain at most efficient speed, regardless of the delays imposed by Instance 1. Avoid DCOCD transit strategy resulted in maximum Rail Service Profit only when DCOCD were low; when DCOCD were high, it forced the Avoid DCOCD transit strategy to increase speed, which reduced profitability. Service Profit, which accounts for the impacts of DCOCD and the overall profitability of the supply chain, favored the MES transit strategy in most cases (8 of 12). When fuel costs decreased to $2/gallon, Service Profit advantage shifted to the MT transit strategy – indicating that cheaper fuel reduces operating costs of running the consist at inefficient speeds, especially so when DCOCD is high. In 4 scenarios, where fuel was set to $6/gallon, Rail Service Profit fell below zero for the MT transit strategy, indicating that the rail service provider lost money providing that particular service.

Table 7: Instance 7 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 7 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $13,561 | 5 | 5 | $10,161 | $11,161 | 5 | $10,161 | $11,161 | 1 | -$2,203 | -$2,003 |
| **2** | 2 | L | L | 0 | $13,561 | 5 | 5 | $10,161 | $11,161 | 5 | $10,161 | $11,161 | 1 | $5,179 | $5,379 |
| **3** | 6 | L | L | 0 | $13,561 | 5 | 5 | $10,161 | $11,161 | 5 | $10,161 | $11,161 | 1 | -$9,584 | -$9,384 |
| **4** | 4 | L | H | 0 | $13,561 | 5 | 5 | $7,161 | $9,161 | 5 | $7,161 | $9,161 | 1 | -$2,803 | -$2,403 |
| **5** | 2 | L | H | 0 | $13,561 | 5 | 5 | $7,161 | $9,161 | 5 | $7,161 | $9,161 | 1 | $4,579 | $4,979 |
| **6** | 6 | L | H | 0 | $13,561 | 5 | 5 | $7,161 | $9,161 | 5 | $7,161 | $9,161 | 1 | -$10,184 | -$9,784 |
| **7** | 4 | H | L | 0 | $13,561 | 5 | 5 | $4,161 | $11,161 | 1 | -$2,403 | -$2,003 | 1 | -$2,403 | -$2,003 |
| **8** | 2 | H | L | 0 | $13,561 | 5 | 5 | $4,161 | $11,161 | 1 | $4,979 | $5,379 | 1 | $4,979 | $5,379 |
| **9** | 6 | H | L | 0 | $13,561 | 5 | 5 | $4,161 | $11,161 | 1 | -$9,784 | -$9,384 | 1 | -$9,784 | -$9,384 |
| **10** | 4 | H | H | 0 | $13,561 | 5 | 5 | $1,161 | $9,161 | 1 | -$3,003 | -$2,403 | 1 | -$3,003 | -$2,403 |
| **11** | 2 | H | H | 0 | $13,561 | 5 | 5 | $1,161 | $9,161 | 1 | $4,379 | $4,979 | 1 | $4,379 | $4,979 |
| **12** | 6 | H | H | 0 | $13,561 | 5 | 5 | $1,161 | $9,161 | 1 | -$10,384 | -$9,784 | 1 | -$10,384 | -$9,784 |
| | | | | **0** | **$13,561** | **5** | **5** | **$5,661** | **$10,161** | **3.00** | **$2,979** | **$3,979** | **1.00** | **-$2,603** | **-$2,203** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **10** | **12** | | **8** | **6** | | **2** | **0** |

**Analysis:** Instance 7 involved five hours of delay. Maximum Rail Service Profit was achieved by the MES transit strategy across all 12 scenarios, meaning that it was most profitable for the rail service provider to remain at most efficient speed, regardless of the delays imposed by Instance 7. Avoid DCOCD transit strategy resulted in maximum Rail Service Profit only when DCOCD were low; when DCOCD were high, it forced the Avoid DCOCD transit strategy to increase speed to avoid penalty, substantially reducing profitability. Service Profit, which accounts for the impacts of DCOCD and the overall profitability of the supply chain, favored the MES transit strategy in most cases (10 of 12). When fuel costs decreased to $2/gallon, coupled with high DCOCD, Service Profit advantage shifted to the Avoid DCOCD and MT transit strategies – indicating that cheaper fuel reduces operating costs of running the consist at inefficient speeds and hereby avoiding substantial penalties can be an effective strategy to preserve supply chain profitability as demonstrated by scenarios # 8 & 11. In 8 of 12 scenarios, Rail Service Profit fell below zero for the MT transit strategy, indicating that the rail service provider lost money in all scenarios except where fuel was set to $2/gallon in an attempt to arrive on time.

Table 8: Instance 9 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 9 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $13,817 | 4 | 4 | $11,097 | $11,897 | 4 | $11,097 | $11,897 | 1 | $8,678 | $8,678 |
| **2** | 2 | L | L | 0 | $13,817 | 4 | 4 | $11,097 | $11,897 | 4 | $11,097 | $11,897 | 1 | $11,088 | $11,088 |
| **3** | 6 | L | L | 0 | $13,817 | 4 | 4 | $11,097 | $11,897 | 4 | $11,097 | $11,897 | 1 | $6,269 | $6,269 |
| **4** | 4 | L | H | 0 | $13,817 | 4 | 4 | $8,697 | $10,297 | 4 | $8,697 | $10,297 | 1 | $8,678 | $8,678 |
| **5** | 2 | L | H | 0 | $13,817 | 4 | 4 | $8,697 | $10,297 | 4 | $8,697 | $10,297 | 1 | $11,088 | $11,088 |
| **6** | 6 | L | H | 0 | $13,817 | 4 | 4 | $8,697 | $10,297 | 4 | $8,697 | $10,297 | 1 | $6,269 | $6,269 |
| **7** | 4 | H | L | 0 | $13,817 | 4 | 4 | $8,397 | $11,897 | 1 | $8,527 | $8,527 | 1 | $8,678 | $8,678 |
| **8** | 2 | H | L | 0 | $13,817 | 4 | 4 | $8,397 | $11,897 | 1 | $11,012 | $11,012 | 1 | $11,088 | $11,088 |
| **9** | 6 | H | L | 0 | $13,817 | 4 | 4 | $8,397 | $11,897 | 1 | $6,043 | $6,043 | 1 | $6,269 | $6,269 |
| **10** | 4 | H | H | 0 | $13,817 | 4 | 4 | $5,997 | $10,297 | 1 | $8,527 | $8,527 | 1 | $8,678 | $8,678 |
| **11** | 2 | H | H | 0 | $13,817 | 4 | 4 | $5,997 | $10,297 | 1 | $11,012 | $11,012 | 1 | $11,088 | $11,088 |
| **12** | 6 | H | H | 0 | $13,817 | 4 | 4 | $5,997 | $10,297 | 1 | $6,043 | $6,043 | 1 | $6,269 | $6,269 |
| | | | | **0** | **$13,817** | **4** | **4** | **$8,547** | **$11,097** | **2.50** | **$9,212** | **$9,812** | **1.00** | **$8,678** | **$8,678** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **6** | **10** | | **5** | **5** | | **6** | **2** |

**Analysis:** Instance 9 involved four hours of delay. Maximum Service Profit, which accounts for the impacts of DCOCD and the overall profitability of the supply chain, was achieved by the MT transit strategy in 6 of the 12 scenarios – the most occurrences of any instance experiencing delays. When fuel was low and/or DCOCD high, increasing speed to arrive on time in Instance 9 often optimized supply chain Service Profit. Further, the MT transit strategy maximized Rail Service Profit twice, both when fuel was $2/gallon, reflecting that increasing speeds above most efficient can be a profit-preserving strategy, albeit in only two of 360 test instances.

Table 9: Instance 15 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 15 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $14,086 | 6 | 6 | $10,006 | $11,206 | 6 | $10,006 | $11,206 | 1 | -$6,371 | -$6,371 |
| **2** | 2 | L | L | 0 | $14,086 | 6 | 6 | $10,006 | $11,206 | 6 | $10,006 | $11,206 | 1 | $3,618 | $3,618 |
| **3** | 6 | L | L | 0 | $14,086 | 6 | 6 | $10,006 | $11,206 | 6 | $10,006 | $11,206 | 1 | -$16,359 | -$16,359 |
| **4** | 4 | L | H | 0 | $14,086 | 6 | 6 | $6,406 | $8,806 | 6 | $6,406 | $8,806 | 1 | -$9,725 | -$9,325 |
| **5** | 2 | L | H | 0 | $14,086 | 6 | 6 | $6,406 | $8,806 | 6 | $6,406 | $8,806 | 1 | $3,618 | $3,618 |
| **6** | 6 | L | H | 0 | $14,086 | 6 | 6 | $6,406 | $8,806 | 6 | $6,406 | $8,806 | 1 | -$16,359 | -$16,359 |
| **7** | 4 | H | L | 0 | $14,086 | 6 | 6 | -$1,844 | $11,206 | 0 | -$8,535 | -$8,135 | 1 | -$6,371 | -$6,371 |
| **8** | 2 | H | L | 0 | $14,086 | 6 | 6 | -$1,844 | $11,206 | 0 | $2,135 | $2,535 | 1 | $3,618 | $3,618 |
| **9** | 6 | H | L | 0 | $14,086 | 6 | 6 | -$1,844 | $11,206 | 0 | -$19,206 | -$18,806 | 1 | -$16,359 | -$16,359 |
| **10** | 4 | H | H | 0 | $14,086 | 6 | 6 | -$5,444 | $8,806 | 0 | -$9,135 | -$8,535 | 1 | -$6,371 | -$6,371 |
| **11** | 2 | H | H | 0 | $14,086 | 6 | 6 | -$5,444 | $8,806 | 0 | $1,535 | $2,135 | 1 | $3,618 | $3,618 |
| **12** | 6 | H | H | 0 | $14,086 | 6 | 6 | -$5,444 | $8,806 | 0 | -$19,806 | -$19,206 | 1 | -$16,359 | -$16,359 |
| | | | | **0** | **$14,086** | **6** | **6** | **$2,281** | **$10,006** | **3.00** | **-$315** | **$835** | **1.00** | **-$6,650** | **-$6,617** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **10** | **12** | | **6** | **6** | | **2** | **0** |

**Analysis:** Instance 15 involved six hours of delay. The most notable observation was that maximum Rail Service Profit was achieved by the MES transit strategy across all 12 scenarios, meaning that it was most profitable for the rail service provider to remain at most efficient speed, regardless of the delays imposed by Instance 15. Service Profit, which accounts for the impacts of DCOCD and the overall profitability of the supply chain, favored the MES transit strategy in most cases (10 of 12). When fuel costs decreased to $2/gallon, coupled with high DCOCD, Service Profit advantage shifted to the MT transit strategy – indicating that cheaper fuel reduces operating costs of running the consist at inefficient speeds and hereby avoiding substantial penalties can be an effective strategy to preserve supply chain profitability, as demonstrated by scenarios # 8 & 11. Except where fuel was set to $2/gallon, Rail Service Profit also fell below zero for the MT transit strategy, indicating that the rail service provider not only eroded all of its profit but also actually lost money on the service. This is an example where rail service providers may unknowingly lose money on a service simply by trying to be on time.

Table 10: Instance 21 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 21 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 5 | $21,047 | 8 | 8 | $13,607 | $17,207 | 5 | $11,123 | $12,323 | 1 | -$8,965 | -$8,765 |
| **2** | 2 | L | L | 5 | $21,047 | 8 | 8 | $13,607 | $17,207 | 5 | $13,965 | $15,165 | 1 | $5,421 | $5,621 |
| **3** | 6 | L | L | 5 | $21,047 | 8 | 8 | $13,607 | $17,207 | 6 | $7,096 | $8,096 | 1 | -$23,351 | -$23,151 |
| **4** | 4 | L | H | 5 | $21,047 | 8 | 8 | $8,807 | $14,007 | 5 | $7,523 | $9,923 | 1 | -$9,565 | -$9,165 |
| **5** | 2 | L | H | 5 | $21,047 | 8 | 8 | $8,807 | $14,007 | 6 | $10,970 | $12,970 | 1 | $4,821 | $5,221 |
| **6** | 6 | L | H | 5 | $21,047 | 8 | 8 | $8,807 | $14,007 | 5 | $4,682 | $7,082 | 1 | -$23,951 | -$23,551 |
| **7** | 4 | H | L | 5 | $21,047 | 8 | 8 | -$11,093 | $17,207 | 1 | -$9,165 | -$8,765 | 1 | -$9,165 | -$8,765 |
| **8** | 2 | H | L | 5 | $21,047 | 8 | 8 | -$11,093 | $17,207 | 1 | $5,221 | $5,621 | 1 | $5,221 | $5,621 |
| **9** | 6 | H | L | 5 | $21,047 | 8 | 8 | -$11,093 | $17,207 | 1 | -$23,551 | -$23,151 | 1 | -$23,551 | -$23,151 |
| **10** | 4 | H | H | 5 | $21,047 | 8 | 8 | -$15,893 | $14,007 | 1 | -$9,765 | -$9,165 | 1 | -$9,765 | -$9,165 |
| **11** | 2 | H | H | 5 | $21,047 | 8 | 8 | -$15,893 | $14,007 | 1 | $4,621 | $5,221 | 1 | $4,621 | $5,221 |
| **12** | 6 | H | H | 5 | $21,047 | 8 | 8 | -$15,893 | $14,007 | 1 | -$24,151 | -$23,551 | 1 | -$24,151 | -$23,551 |
| | | | | **5** | **$21,047** | **8** | **8** | **-$1,143** | **$15,607** | **3.17** | **-$119** | **$981** | **1.00** | **-$9,365** | **-$8,965** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **6** | **12** | | **6** | **0** | | **4** | **0** |

**Analysis:** Instance 21 involved a five-hour departure delay, plus three other delays while in transit, for a total of 8 hours. The most notable observation was that maximum Rail Service Profit was achieved by the MES transit strategy across all 12 scenarios, meaning that it was most profitable for the rail service provider to remain at most efficient speed, regardless of the delays imposed by Instance 21. Service Profit, which accounts for the impacts of DCOCD and the overall profitability of the supply chain, favored the MES transit strategy when fuel costs were high. When fuel costs decreased to $2/gallon with DCOCD low, Service Profit advantage shifted to the Avoid DCOCD transit strategy. Additionally, when DCOCD was high and fuel below $6/gallon, Service Profit advantage shifted to the MT transit strategy – indicating that cheaper fuel reduces operating costs of running the consist at inefficient speeds. When fuel was set at $4/gallon or above, Rail Service Profit fell below zero for the MT transit strategy, indicating that the rail service provider not only eroded all of its profit but also actually lost money on the service.

Table 11: Instance 28 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 28 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| **1** | 4 | L | L | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **2** | 2 | L | L | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **3** | 6 | L | L | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **4** | 4 | L | H | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **5** | 2 | L | H | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **6** | 6 | L | H | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **7** | 4 | H | L | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **8** | 2 | H | L | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **9** | 6 | H | L | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **10** | 4 | H | H | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **11** | 2 | H | H | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **12** | 6 | H | H | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| | | | | **0** | **$18,403** | **0** | **0** | **$18,403** | **$18,403** | **0.00** | **$18,403** | **$18,403** | **0.00** | **$18,403** | **$18,403** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **12** | **12** | | **12** | **12** | | **12** | **12** |

**Analysis:** Instance 28 involved no delays. Maximum profit is achieved in all twelve scenarios by all three transit strategies because with no delays most efficient speed is always maintained, preserving maximum profits.

## 4.4 RESULTS – SIMULATION MODEL SUMMARIES

Each of the 12 scenarios ran the same 30 instances. Table 12 reflects the counts when a transit strategy resulted in maximum profits, for both Service Profit (SP) and Rail Service Profit (RSP).

The most notable observation was that maximum Rail Service Profit, which represents the real profits of the rail service provider, was achieved by the MES transit strategy 98.7% of the time (352 out of 360 test instances). This is representative of the fact that increasing speed above most efficient erodes rail service provider profits, acting as a strong incentive for the rail service provider to maintain most efficient speed, regardless of tardiness. This is reinforced by the MT transit strategy results, where the MT simulation model achieved maximum Rail Service Profit just 14 times or less than 4% of the time. Taking into account that one instance had no delays, making all three transit strategies optimal makes the MT transit strategy truly optimal on only two occasions (or 0.5% of the time).

When DCOCD is low, the Avoid DCOCD transit strategy mirrors similar operating characteristics as the MES, generating similar results. Exceptions arise when delays exceeded 6 hours (where DCOCD penalties arise) and the Avoid DCOCD transit strategy increases speed to avoid these penalties. When DCOCD penalties are high, the Avoid DCOCD transit strategy acts similar to the MT transit strategy, achieving similar results.

Table 12: Counts of achieving maximum profit by scenario & transit strategy

| | | | | | **Traveling at Most Efficient Speed Only (MES)** | | | **Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD)** | | | **Traveling at Speeds to Minimize Tardiness (MT)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario # | Fuel $/Gal | DCOCD | Labor Cost | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) [supply chain perspective] | Rail Service Profit ($) [real residual profits] | Arrival Delay (Hrs) | Service Profit ($) [supply chain perspective] | Rail Service Profit ($) [real residual profits] | Arrival Delay (Hrs) | Service Profit ($) [supply chain perspective] | Rail Service Profit ($) [real residual profits] |
| 1 | $4 | L | L | 4.17 | 4.17 | 29 | 29 | 3.87 | 27 | 27 | 0.47 | 1 | 1 |
| 2 | $2 | L | L | 4.17 | 4.17 | 27 | 29 | 3.87 | 29 | 27 | 0.47 | 1 | 1 |
| 3 | $6 | L | L | 4.17 | 4.17 | 29 | 29 | 3.90 | 27 | 27 | 0.47 | 1 | 1 |
| 4 | $4 | L | H | 4.17 | 4.17 | 29 | 29 | 3.87 | 27 | 27 | 0.47 | 1 | 1 |
| 5 | $2 | L | H | 4.17 | 4.17 | 16 | 28 | 3.90 | 18 | 26 | 0.47 | 12 | 2 |
| 6 | $6 | L | H | 4.17 | 4.17 | 29 | 29 | 3.87 | 27 | 27 | 0.47 | 1 | 1 |
| 7 | $4 | H | L | 4.17 | 4.17 | 24 | 30 | 0.47 | 4 | 1 | 0.47 | 7 | 1 |
| 8 | $2 | H | L | 4.17 | 4.17 | 14 | 30 | 0.47 | 10 | 1 | 0.47 | 16 | 1 |
| 9 | $6 | H | L | 4.17 | 4.17 | 28 | 30 | 0.53 | 3 | 1 | 0.47 | 2 | 1 |
| 10 | $4 | H | H | 4.17 | 4.17 | 21 | 30 | 0.47 | 4 | 1 | 0.47 | 10 | 1 |
| 11 | $2 | H | H | 4.17 | 4.17 | 3 | 29 | 0.47 | 13 | 1 | 0.47 | 24 | 2 |
| 12 | $6 | H | H | 4.17 | 4.17 | 28 | 30 | 0.47 | 2 | 1 | 0.47 | 3 | 1 |
| **Total Count or Average:** | | | | **4.17** | **4.17** | **277** | **352** | **2.17** | **191** | **167** | **0.47** | **79** | **14** |
| | | | | Avg hrs of Delay Imposed by the 30 instances | Avg hrs of Arrival Delay | # Occurrences as Max Service Profit (360 possible) | # Occurrences as Max Rail Service Profit (360 possible) | Avg hrs of Arrival Delay | # Occurrences as Max Service Profit (360 possible) | # Occurrences as Max Rail Service Profit (360 possible) | Avg hrs of Arrival Delay | # Occurrences as Max Service Profit (360 possible) | # Occurrences as Max Rail Service Profit (360 possible) |

Maximum Service profit was achieved by the MES transit strategy 77% of the time (277 out of 360 test instances). When fuel was set to $6/gallon, the MES transit strategy achieved maximum Service Profit 95% of the time (114/120 instances), versus 50% of the time when fuel was set to $2/gallon. This demonstrates that as fuel costs increase, remaining at most efficient speed increases in importance to preserve supply chain profits. Conversely, when fuel costs are low, as in the case of $2/gallon, the MT transit strategy achieved maximum Service Profit 44% of the time (53 out of 120 instances). When DCOCD is high, the MES transit strategy achieved maximum Service Profit 66% of the time (118 out of 180 instances). In contrast, the MT transit strategy achieved maximum Service Profit just 62 times, for 34%. This demonstrates that even though DCOCD is high, it remains profitable for the supply chain to maintain most efficient speed for the majority of instances.

Table 13 partitions the results by input and their combinations. Similar to the results mentioned previously, maximum Rail Service Profit is achieved most by the MES transit strategy, maintaining at least a 95% success rate in every subcategory. This demonstrates that maintaining most efficient speed preserves the most profit for rail service providers, independent of supply chain influences. This would lead one to expect that the rail industry would forgo "service" and focus on profit maximizing strategies, instead, industry practice indicates otherwise.

Particularly when DCOCD was low, Avoid DCOCD mirrored the results of MES. When DOCD was high, Avoid DCOCD transit strategy mirrored MT due to the substantial penalties for arriving late, causing Avoid DCOCD to increase speed in response to delays.

As noted earlier, maximum Service profit was achieved by the MES transit strategy 77% of the time (277 out of 360 instances). Service Profit is profit from the supply chain

Table 13: Counts of achieving maximum profit by input variables & transit strategy

| | **Traveling at Most Efficient Speed Only (MES)** | | | | **Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD)** | | | | **Traveling at Speeds to Minimize Tardiness (MT)** | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **# Occurrences as Max Service Profit** | | **# Occurrences as Max Rail Service Profit** | | **# Occurrences as Max Service Profit** | | **# Occurrences as Max Rail Service Profit** | | **# Occurrences as Max Service Profit** | | **# Occurrences as Max Rail Service Profit** | |
| Fuel $2/Gal: | 60/120 | 50% | 116/120 | 97% | 70/120 | 58% | 55/120 | 46% | 53/120 | 44% | 6/120 | 5% |
| Fuel $4/Gal: | 103/120 | 86% | 118/120 | 98% | 62/120 | 52% | 56/120 | 47% | 19/120 | 16% | 4/120 | 3% |
| Fuel $6/Gal: | 114/120 | 95% | 118/120 | 98% | 59/120 | 49% | 56/120 | 47% | 7/120 | 6% | 4/120 | 3% |
| DCOCD H: | 118/180 | 66% | 179/180 | 99% | 36/180 | 20% | 6/180 | 3% | 62/180 | 34% | 7/180 | 4% |
| DCOCD L: | 159/180 | 88% | 173/180 | 96% | 155/180 | 86% | 161/180 | 89% | 17/180 | 9% | 7/180 | 4% |
| Labor H: | 126/180 | 70% | 175/180 | 97% | 91/180 | 51% | 83/180 | 46% | 51/180 | 28% | 8/180 | 4% |
| Labor L: | 151/180 | 84% | 177/180 | 98% | 100/180 | 56% | 84/180 | 47% | 28/180 | 16% | 6/180 | 3% |
| Fuel $2/Gal & DCOCD H: | 17/60 | 28% | 59/60 | 98% | 23/60 | 38% | 2/60 | 3% | 40/60 | 67% | 3/60 | 5% |
| Fuel $2/Gal & DCOCD L: | 43/60 | 72% | 57/60 | 95% | 47/60 | 78% | 53/60 | 88% | 13/60 | 22% | 3/60 | 5% |
| Fuel $4/Gal & DCOCD H: | 45/60 | 75% | 60/60 | 100% | 8/60 | 13% | 2/60 | 3% | 17/60 | 28% | 2/60 | 3% |
| Fuel $4/Gal & DCOCD L: | 58/60 | 97% | 58/60 | 97% | 54/60 | 90% | 54/60 | 90% | 2/60 | 3% | 2/60 | 3% |
| Fuel $6/Gal & DCOCD H: | 56/60 | 93% | 60/60 | 100% | 5/60 | 8% | 2/60 | 3% | 5/60 | 8% | 2/60 | 3% |
| Fuel $6/Gal & DCOCD L: | 58/60 | 97% | 58/60 | 97% | 54/60 | 90% | 54/60 | 90% | 2/60 | 3% | 2/60 | 3% |
| Fuel $2/Gal & Labor H: | 19/60 | 32% | 57/60 | 95% | 31/60 | 52% | 27/60 | 45% | 36/60 | 60% | 4/60 | 7% |
| Fuel $2/Gal & Labor L: | 41/60 | 68% | 59/60 | 98% | 39/60 | 65% | 28/60 | 47% | 17/60 | 28% | 2/60 | 3% |
| Fuel $4/Gal & Labor H: | 50/60 | 83% | 59/60 | 98% | 31/60 | 52% | 28/60 | 47% | 11/60 | 18% | 2/60 | 3% |
| Fuel $4/Gal & Labor L: | 53/60 | 88% | 59/60 | 98% | 31/60 | 52% | 28/60 | 47% | 8/60 | 13% | 2/60 | 3% |
| Fuel $6/Gal & Labor H: | 57/60 | 95% | 59/60 | 98% | 29/60 | 48% | 28/60 | 47% | 4/60 | 7% | 2/60 | 3% |
| Fuel $6/Gal & Labor L: | 57/60 | 95% | 59/60 | 98% | 30/60 | 50% | 28/60 | 47% | 3/60 | 5% | 2/60 | 3% |
| DCOCD H & Labor H: | 52/90 | 58% | 89/90 | 99% | 19/90 | 21% | 3/90 | 3% | 37/90 | 41% | 3/90 | 3% |
| DCOCD H & Labor L: | 66/90 | 73% | 90/90 | 100% | 17/90 | 19% | 3/90 | 3% | 25/90 | 28% | 3/90 | 3% |
| DCOCD L & Labor H: | 74/90 | 82% | 86/90 | 96% | 72/90 | 80% | 80/90 | 89% | 14/90 | 16% | 4/90 | 4% |
| DCOCD L & Labor L: | 85/90 | 94% | 87/90 | 97% | 83/90 | 92% | 81/90 | 90% | 3/90 | 3% | 3/90 | 3% |

perspective, taking into account the financial impacts of tardiness on both upstream and downstream customers. The few shortcomings of the MES transit strategy arise when fuel is set to $2/gallon, shifting profitability to Avoid DCOCD and MT strategies. In particular, when $2/gallon fuel is in conjunction with high DCOCD or high labor, the maximum profitability results for MT increase from the teens to the 60-67% range. This indicates that cheaper fuel makes it more cost effective to increase speed to minimize the cost penalties of arriving late (namely DCOCD and labor). Similarly, as prices fall making it more cost effective to increase speed, emission of greenhouse gasses becomes a more prominent factor and could be considered a cost to the environment in future iterations of the RPM.

## 4.5 REGRESSION ANALYSIS

The RPM has identified MES as the most profitable transit strategy for both the rail service provider and the supply chain. Regression analysis is used to identify the specific input variables that contribute most to profit loss. The following were included as input regression variables:

- Fuel (as $/gallon),
- Fuel (as paired dummy variables),
- DCOCD,
- Labor,
- Total Delays (hours).

The multi-variable regression results are contained in the following six tables.

Table 14: Regression analysis of the Service Profit (SP) loss for MES transit strategy

SUMMARY OUTPUT - MES Service Profit Loss (delays of 0 - 3 hrs)

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.962 |
| R Square | 0.926 |
| Adjusted R Square | 0.924 |
| Standard Error | 405.976 |
| Observations | 144 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3 | 288718419 | 96239473 | 584 | 6.446E-79 |
| Residual | 140 | 23074356 | 164817 | | |
| Total | 143 | 311792775 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -1197.12 | 94.31 | -12.69 | 4.76E-25 | -1383.58 | -1010.67 | -1383.58 | -1010.67 |
| **Total_Delays** | 1254.62 | 35.47 | 35.37 | 1.11E-71 | 1184.49 | 1324.75 | 1184.49 | 1324.75 |
| **Labor** | 1250.00 | 67.66 | 18.47 | 2.30E-39 | 1116.23 | 1383.77 | 1116.23 | 1383.77 |
| **DCOCD** | 854.17 | 67.66 | 12.62 | 7.20E-25 | 720.39 | 987.94 | 720.39 | 987.94 |

Table 15: Regression analysis of the Rail Service Profit (RSP) loss for MES transit strategy

SUMMARY OUTPUT - MES Rail Service Profit Loss (delays of 0-3 hrs)

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.971 |
| R Square | 0.942 |
| Adjusted R Square | 0.941 |
| Standard Error | 192.777 |
| Observations | 144 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2 | 8.56E+07 | 4.28E+07 | 1.15E+03 | 4.60E-88 |
| Residual | 141 | 5.24E+06 | 3.72E+04 | | |
| Total | 143 | 9.08E+07 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -416.67 | 41.80 | -9.97 | 4.83E-18 | -499.31 | -334.03 | -499.31 | -334.03 |
| **Total_Delays** | 680.00 | 16.84 | 40.37 | 2.32E-79 | 646.70 | 713.30 | 646.70 | 713.30 |
| **Labor** | 833.33 | 32.13 | 25.94 | 1.58E-55 | 769.82 | 896.85 | 769.82 | 896.85 |

Table 16: Regression analysis of the Service Profit (SP) loss for Avoid DCOCD transit strategy

SUMMARY OUTPUT - Avoid DCOCD Service Profit Loss (delays of 0 - 3 hrs)

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.848 |
| R Square | 0.719 |
| Adjusted R Square | 0.713 |
| Standard Error | 1722.090 |
| Observations | 144 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3 | 1063469502 | 354489834 | 120 | 1.96E-38 |
| Residual | 140 | 415183360 | 2965595 | | |
| Total | 143 | 1478652862 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -4454.12 | 512.85 | -8.69 | 8.87E-15 | -5468.04 | -3440.19 | -5468.04 | -3440.19 |
| **Fuel** | 666.28 | 87.88 | 7.58 | 4.28E-12 | 492.54 | 840.02 | 492.54 | 840.02 |
| **Total_Delays** | 1838.72 | 150.46 | 12.22 | 7.92E-24 | 1541.25 | 2136.19 | 1541.25 | 2136.19 |
| **DCOCD** | 3535.94 | 287.02 | 12.32 | 4.39E-24 | 2968.50 | 4103.39 | 2968.50 | 4103.39 |

Table 17: Regression analysis of the Rail Service Profit (RSP) loss for Avoid DCOCD transit strategy

SUMMARY OUTPUT - Avoid DCOCD Rail Service Profit Loss (delays of 0-3 hrs)

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.854 |
| R Square | 0.729 |
| Adjusted R Square | 0.724 |
| Standard Error | 1758.609 |
| Observations | 144 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 3 | 1167335100 | 389111700 | 126 | 1.47E-39 |
| Residual | 140 | 432978631 | 3092705 | | |
| Total | 143 | 1600313731 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -4766.62 | 523.72 | -9.10 | 8.09E-16 | -5802.04 | -3731.19 | -5802.04 | -3731.19 |
| **Fuel** | 666.28 | 89.74 | 7.42 | 1.01E-11 | 488.85 | 843.71 | 488.85 | 843.71 |
| **Total_Delays** | 1688.72 | 153.65 | 10.99 | 1.20E-20 | 1384.95 | 1992.50 | 1384.95 | 1992.50 |
| **DCOCD** | 4160.94 | 293.10 | 14.20 | 6.75E-29 | 3581.46 | 4740.42 | 3581.46 | 4740.42 |

Table 18: Regression analysis of the Service Profit (SP) loss for MT transit strategy

SUMMARY OUTPUT - MT Service Profit Loss (delays of 0 - 3 hrs)

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.895 |
| R Square | 0.801 |
| Adjusted R Square | 0.798 |
| Standard Error | 1642.952 |
| Observations | 144 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2 | 1528614687 | 764307344 | 283 | 4.20E-50 |
| Residual | 141 | 380599922 | 2699290 | | |
| Total | 143 | 1909214609 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -5088.49 | 469.73 | -10.83 | 2.84E-20 | -6017.12 | -4159.86 | -6017.12 | -4159.86 |
| **Fuel** | 1241.86 | 83.84 | 14.81 | 1.58E-30 | 1076.11 | 1407.61 | 1076.11 | 1407.61 |
| **Total_Delays** | 2673.60 | 143.55 | 18.63 | 7.79E-40 | 2389.82 | 2957.38 | 2389.82 | 2957.38 |

Table 19: Regression analysis of the Rail Service Profit (RSP) loss for MT transit strategy

SUMMARY OUTPUT - MT Rail Service Profit Loss (delays of 0-3 hrs)

| *Regression Statistics* | |
|---|---|
| Multiple R | 0.895 |
| R Square | 0.801 |
| Adjusted R Square | 0.798 |
| Standard Error | 1642.952 |
| Observations | 144 |

ANOVA

| | *df* | *SS* | *MS* | *F* | *Significance F* |
|---|---|---|---|---|---|
| Regression | 2 | 1.53E+09 | 7.64E+08 | 2.83E+02 | 4.20E-50 |
| Residual | 141 | 3.81E+08 | 2.70E+06 | | |
| Total | 143 | 1.91E+09 | | | |

| | *Coefficients* | *Standard Error* | *t Stat* | *P-value* | *Lower 95%* | *Upper 95%* | *Lower 95.0%* | *Upper 95.0%* |
|---|---|---|---|---|---|---|---|---|
| Intercept | -5088.49 | 469.73 | -10.83 | 2.84E-20 | -6017.12 | -4159.86 | -6017.12 | -4159.86 |
| **Fuel** | 1241.86 | 83.84 | 14.81 | 1.58E-30 | 1076.11 | 1407.61 | 1076.11 | 1407.61 |
| **Total_Delays** | 2673.60 | 143.55 | 18.63 | 7.79E-40 | 2389.82 | 2957.38 | 2389.82 | 2957.38 |

**Analysis:** The MES transit strategy maintains most efficient speed, irrespective the magnitude of tardiness or penalties. Service Profit takes the supply chain perspective and includes opportunity costs of delay (for the upstream customer, downstream customer and the cascading delay through the downstream supply chain) when calculating profit. Rail Service Profit takes into account only real, tangible costs that are incurred by the rail service provider, ignoring the supply chain costs imposed on customers. These differences in profit were reflected in the regression analysis. Table 20 provides a summary of significant profit detractors identified in our regression results.

Table 20: Regression analysis reflecting significant profit detractors

| **Profit Loss Drivers** | **Transit Strategy** | | |
|---|---|---|---|
| | **MES** | **Avoid DCOCD** | **MT** |
| **Service Profit ($) [supply chain perspective]** | Total Delays<br>Labor<br>DCOCD | Fuel<br>Total Delays<br>DCOCD | Fuel<br>Total Delays |
| **Rail Service Profit ($) [real residual profits]** | Total Delays<br>Labor | Fuel<br>Total Delays<br>DCOCD | Fuel<br>Total Delays |

Immediate observations identify that DCOCD does not significantly impact profitability of the MT transit strategy. Since MT increases speed as necessary to arrive on time, and does so with relative reliability (arriving on time 66% of the time), DCOCD does not have much of an opportunity to impact profits. Likewise, fuel does not adversely impact profits of MES, since it always maintains most efficient speed, additional fuel costs are mostly avoided.

DCOCD does not impact the Rail Service Profit for MES, which appears rational since DCOCD is not part of the Rail Service Profit calculation. That said, although DCOCD is not part of the Rail Service Profit calculation, it appears to be a significant profit loss driver for the Avoid DCOCD transit strategy. To understand why it would appear in the regression analysis, you have to look into how Avoid DCOCD transit strategy operates. Avoid DCOCD maintains most efficient speed until a sufficient number of delays arise to cause DCOCD to impose penalties for excessive tardiness. In response, Avoid DCOCD increases speed to ensure the consist arrives not on time, but in time to avoid DCOCD penalties. Hence, when it does increase speed, it does so because DCOCD penalties are in play. Although the loss of profits are a direct result of additional fuels costs, they are attributed to DCOCD in the regression analysis.

Labor appears as a significant profit loss driver for the MES transit strategy only. This holds true because MES is the only transit strategy that arrives late as a norm, incurring additional labor charges for the period of tardiness.

Total delays are a significant profit loss driver for all transit strategies. This holds true since it is the “delay” that is the stimulus for profit loss; either in the form of labor (to cover additional time required to complete the transit), fuel (because the consist had to increase speed to arrive on time or to avoid DCOCD costs), or DCOCD penalties that arise when the consist is forced to arrive late.

## 4.6 SENSITIVITY ANALYSIS – PROFIT FRONTIER

The RPM implements the Profit Frontier Graph which represents the profit characteristic of the rail service by revealing the difference between the Expected Service Profit (ESP) and the profit remaining after implementing the various transit strategies in response to the delays induced into the model during the simulated transit. The ESP forms the "frontier" and serves as the profit maxima for the transit, void of any inefficiencies (delays). As the consist completes its journey (minimum of 40 hours) risk of stochastic delays are imposed on the consist, and if a delay occurs the consist must remain idle and make no ground for the hour. The three simulation models determine when to change speed and by how much. The transit strategy that preserves the most profits and is closest to Profit Frontier maximizes profitability, with the observed gaps from the ESP forming the "eroded profits" that are consumed and taken from stockholders.

Instance 7 readily demonstrates the impacts fuel prices have on profits. As previously revealed, the MT transit strategy tends to become most profitable when fuel costs are low and DCOCD's are high. As shown in Figure 3, the MT transit strategy travels at varied speeds to minimize tardiness, achieving maximum Service Profit (SP) of $3,036, shown in the circle. In fact, as the each consist progressed, it can be observed that maximum profitability alternates between MES and MT until the MT consist arrives 1 hour late, while the MES consist has to continue an additional 4 hours, depleting Service Profit (SP) by an additional $4,000.

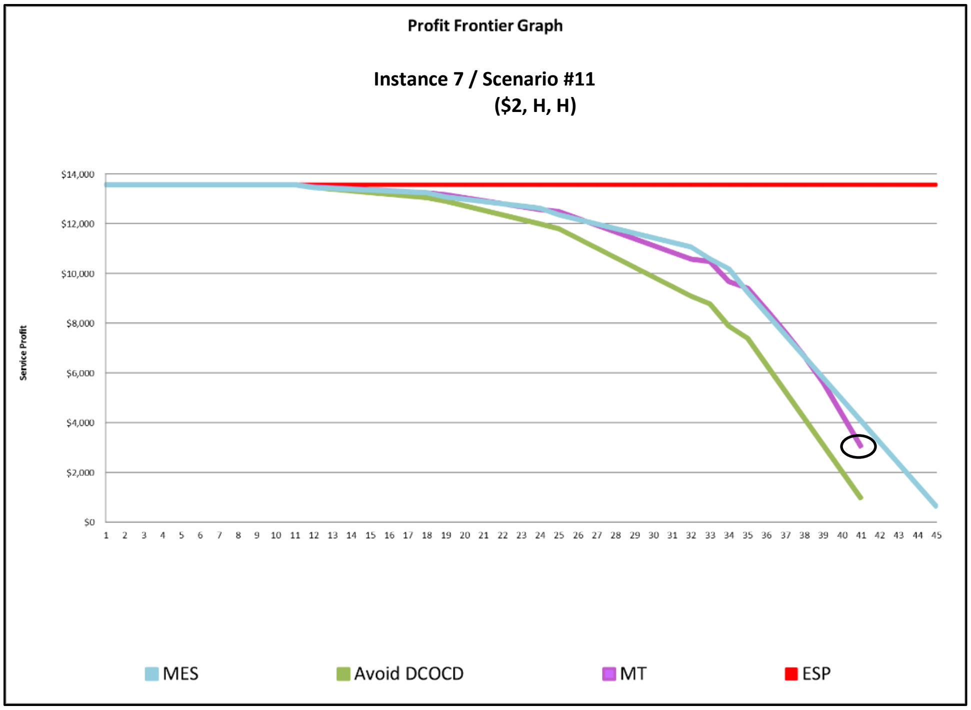


Figure 3: Profit frontier graph of Service Profits (SP) with inputs ($2, H, H)

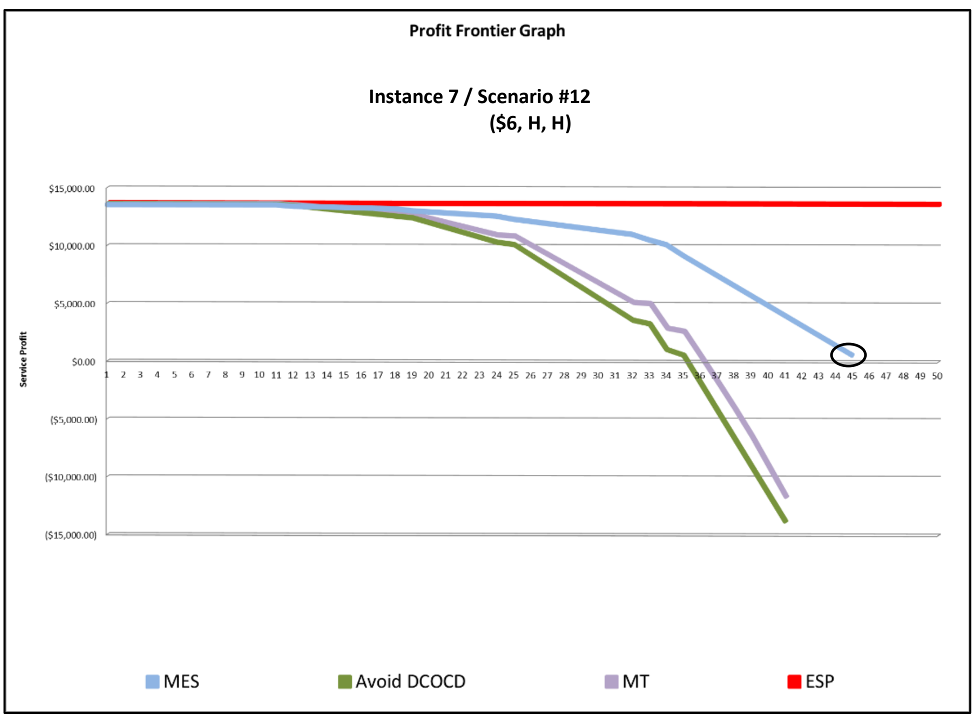


Figure 4: Profit frontier graph of Service Profits (SP) with inputs ($6, H, H)

When fuel prices reach $6/gallon, the profit frontier changes substantially, as shown in Figure 4. Although the "Avoid DCOCD" and MT transit strategies arrive much earlier than MES, they do so by increasing speed to minimize tardiness. The higher cost of fuel erodes Service Profit to the point where profits turn into substantial losses on the order of $10,000 to $15,000. Meanwhile, the MES transit strategy is able to preserve a Service Profit (SP) of $625 by arriving 5-hours late, as shown in the circle.

Profit frontier graphs demonstrating similar characteristics can be produced for each of the 30 instances.

## 4.7 SENSITIVITY ANALYSIS – FUEL COST BREAK-EVEN POINT

Fuel costs have proven to be a major profit detractor. So much so, that it not only changes profitability but also changes the outcome of the RPM. To demonstrate this, sensitivity analysis is conducted, varying fuel pricing to determine at what point fuel cost will change the profit outcome & optimal transit strategy.

Utilizing Instance 25, Figure 5 demonstrates that $0.58/gallon is the break-even point with DCOCD and labor set to low. At prices above $0.58/gallon, MES generates the most Service Profit, but as the price of fuel drops below $0.58 MT assumes the most profitable transit strategy for Service Profit.

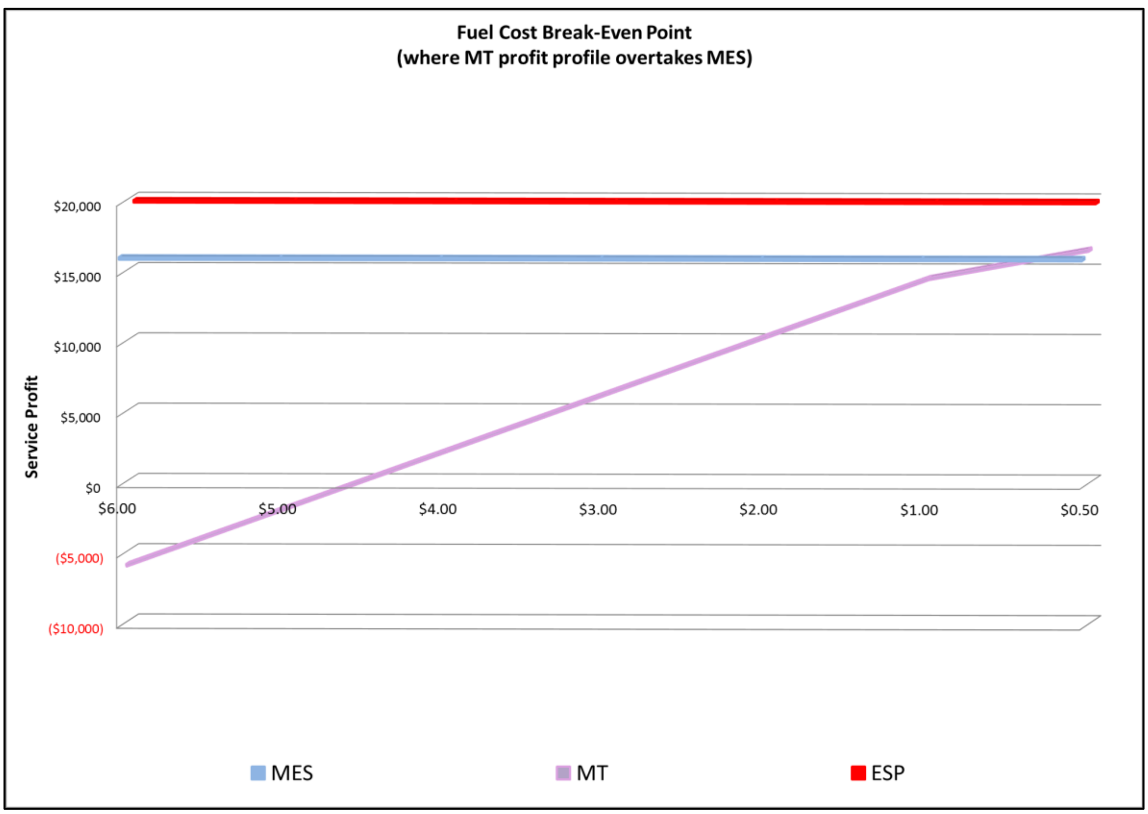


Figure 5: Fuel cost break-even point example using Instance 25 and inputs ($__, L, L)



$0.58

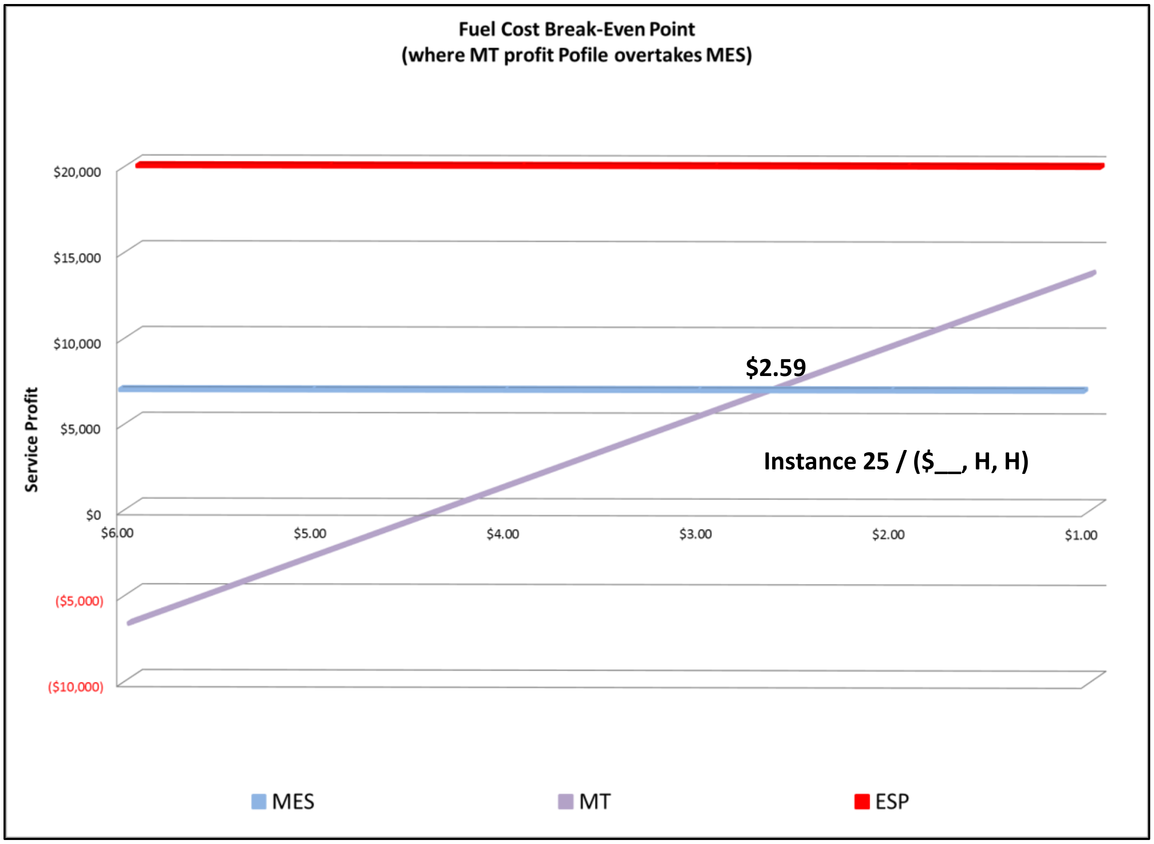


Figure 6: Fuel cost break-even point example using Instance 25 and inputs ($__, H, H)

Examining the effects of fuel pricing on Instance 25, this time with DCOCD and labor set to high, dramatically changes the profitability landscape. Figure 6 demonstrates that $2.59/gallon is the new break point. At fuel prices above $2.59/gallon, MES maintains the most Service Profit. As the price of fuel drops below $2.59, MT assumes the role as most profitable transit strategy for Service Profit.

The primary difference between the two simulation models are the DCOCD and labor costs. When these costs are set to high, Service Profit loss starts sooner after the first delay and decreases at a more substantial rate. In Instance 25, there are 5 delays imposed on the consist, causing the MES transit strategy to arrive 5 hours late, incurring substantial DCOCD penalty and additional labor costs, to the point where Service Profit is reduced by $9,000.  This reduction in Service Profit shifts the MES profitability line down to $7,192, increasing the break-even point from $0.58/gallon to $2.59, enabling the MT transit strategy to become most profitable at higher fuel prices.

The same phenomena occurs with each of the other 29 instances.

## 4.8 SENSITIVITY ANALYSIS – DELAY HOURS

Even though instances may involve similar total delay times, they do not produce identical results.  For example, Instances 26 & 29 imposed only a one hour delay yet yielded slightly different service profit results, as shown in Table 21.

Table 21: Instances 26 & 29 imposed one hour of delay

| | | | | | | Most Efficient Speed Only (MES) | | | Avoid DCOCD Penalty | | | Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel | DCOCD | Labor | Expected Service Profit (ESP) ($) | Instance | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hours) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hours) | Service Profit ($) | Rail Service Profit ($) |
| 2 | H | H | $16,166.00 | 26 | 1 | 1 | $14,686.00 | $15,286.00 | 0 | $14,100.51 | $14,100.51 | 0 | $14,100.51 | $14,100.51 |
| 2 | H | L | $16,166.00 | 26 | 1 | 1 | $15,286.00 | $15,686.00 | 0 | $14,100.51 | $14,100.51 | 0 | $14,100.51 | $14,100.51 |
| 2 | L | H | $16,166.00 | 26 | 1 | 1 | $14,886.00 | $15,286.00 | 1 | $14,886.00 | $15,286.00 | 0 | $14,100.51 | $14,100.51 |
| 2 | L | L | $16,166.00 | 26 | 1 | 1 | $15,486.00 | $15,686.00 | 1 | $15,486.00 | $15,686.00 | 0 | $14,100.51 | $14,100.51 |
| 4 | H | H | $16,166.00 | 26 | 1 | 1 | $14,686.00 | $15,286.00 | 0 | $12,114.99 | $12,114.99 | 0 | $12,114.99 | $12,114.99 |
| 4 | H | L | $16,166.00 | 26 | 1 | 1 | $15,286.00 | $15,686.00 | 0 | $12,114.99 | $12,114.99 | 0 | $12,114.99 | $12,114.99 |
| 4 | L | H | $16,166.00 | 26 | 1 | 1 | $14,886.00 | $15,286.00 | 1 | $14,886.00 | $15,286.00 | 0 | $12,114.99 | $12,114.99 |
| 4 | L | L | $16,166.00 | 26 | 1 | 1 | $15,486.00 | $15,686.00 | 1 | $15,486.00 | $15,686.00 | 0 | $12,114.99 | $12,114.99 |
| 6 | H | H | $16,166.00 | 26 | 1 | 1 | $14,686.00 | $15,286.00 | 0 | $10,129.50 | $10,129.50 | 0 | $10,129.50 | $10,129.50 |
| 6 | H | L | $16,166.00 | 26 | 1 | 1 | $15,286.00 | $15,686.00 | 0 | $10,129.50 | $10,129.50 | 0 | $10,129.50 | $10,129.50 |
| 6 | L | H | $16,166.00 | 26 | 1 | 1 | $14,886.00 | $15,286.00 | 1 | $14,886.00 | $15,286.00 | 0 | $10,129.50 | $10,129.50 |
| 6 | L | L | $16,166.00 | 26 | 1 | 1 | $15,486.00 | $15,686.00 | 1 | $15,486.00 | $15,686.00 | 0 | $10,129.50 | $10,129.50 |
| 2 | H | H | $18,180.00 | 29 | 1 | 1 | $16,700.00 | $17,300.00 | 0 | $17,142.16 | $17,142.16 | 0 | $17,258.25 | $17,258.25 |
| 2 | H | L | $18,180.00 | 29 | 1 | 1 | $17,300.00 | $17,700.00 | 0 | $17,142.16 | $17,142.16 | 0 | $17,258.25 | $17,258.25 |
| 2 | L | H | $18,180.00 | 29 | 1 | 1 | $16,900.00 | $17,300.00 | 1 | $16,900.00 | $17,300.00 | 0 | $17,258.25 | $17,258.25 |
| 2 | L | L | $18,180.00 | 29 | 1 | 1 | $17,500.00 | $17,700.00 | 1 | $17,500.00 | $17,700.00 | 0 | $17,258.25 | $17,258.25 |
| 4 | H | H | $18,180.00 | 29 | 1 | 1 | $16,700.00 | $17,300.00 | 0 | $15,620.94 | $15,620.94 | 0 | $12,648.51 | $12,648.51 |
| 4 | H | L | $18,180.00 | 29 | 1 | 1 | $17,300.00 | $17,700.00 | 0 | $16,184.08 | $16,184.08 | 0 | $16,416.32 | $16,416.32 |
| 4 | L | H | $18,180.00 | 29 | 1 | 1 | $16,900.00 | $17,300.00 | 1 | $16,900.00 | $17,300.00 | 0 | $16,416.32 | $16,416.32 |
| 4 | L | L | $18,180.00 | 29 | 1 | 1 | $17,500.00 | $17,700.00 | 1 | $17,500.00 | $17,700.00 | 0 | $16,416.32 | $16,416.32 |
| 6 | H | H | $18,180.00 | 29 | 1 | 1 | $16,700.00 | $17,300.00 | 0 | $15,226.25 | $15,226.25 | 0 | $15,574.59 | $15,574.59 |
| 6 | H | L | $18,180.00 | 29 | 1 | 1 | $17,300.00 | $17,700.00 | 0 | $15,226.25 | $15,226.25 | 0 | $15,574.59 | $15,574.59 |
| 6 | L | H | $18,180.00 | 29 | 1 | 1 | $16,900.00 | $17,300.00 | 1 | $16,900.00 | $17,300.00 | 0 | $15,574.59 | $15,574.59 |
| 6 | L | L | $18,180.00 | 29 | 1 | 1 | $17,500.00 | $17,700.00 | 1 | $17,500.00 | $17,700.00 | 0 | $15,574.59 | $15,574.59 |

**Analysis:** Instance 26 imposed the delay at hour 36, forcing the Avoid DCOCD and MT transit strategies to markedly increase speed to arrive on time and avoid DCOCD penalties. In doing so, quickly eroded profits, allowing MES to maintain optimal profits. In addition, when DCOCD was low, enabled Avoid DCOCD to mimic MES and maintain optimal profits.

In contrast, Instance 29 imposed the one hour delay earlier in the transit, at hour 9. By imposing the delay early in the transit, the MT transit strategy increase speed only slightly (0.65 MPH) for the duration of the transit to arrive on time. The cost of operating at an increased speed of only 20.65 MPH is relatively low compared to the DCOCD and labor penalties for arriving one hour late. In fact, in scenario (2, H, H), service profit was maximized when the consist increase speed and arrived on time by a $558 margin. In scenario (2, L, H) service profit was again maximized by increasing speed and arriving on time by a $358 margin. In both cases, the cost of labor ($400/hr) for arriving one hour late exceeded the cost of increasing speed by 0.65 MPH at $2/gallon. When fuel increased above $2/gallon, MES transit strategy generated maximum service profit (& rail service profit) by substantial margins, on the order of $28,410 total (or $1,775 average per scenario).

Similar results were seen when delays totaled two and three hours. When delays totaled four hours, substantial changes in optimal transit strategies arose again, as shown in Table 22.

Table 22: Instances 9 & 22 imposed four hours of delay

| | | | | | | Most Efficient Speed Only (MES) | | | Avoid DCOCD Penalty | | | Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fuel | DCOCD | Labor | Expected Service Profit (ESP) ($) | Instance | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hours) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hours) | Service Profit ($) | Rail Service Profit ($) |
| 2 | H | H | $13,817.00 | 9 | 4 | 4 | $5,997.00 | $10,297.00 | 1 | $11,012.22 | $11,012.22 | 1 | $11,087.70 | $11,087.70 |
| 2 | H | L | $13,817.00 | 9 | 4 | 4 | $8,397.00 | $11,897.00 | 1 | $11,012.22 | $11,012.22 | 1 | $11,087.70 | $11,087.70 |
| 2 | L | H | $13,817.00 | 9 | 4 | 4 | $8,697.00 | $10,297.00 | 4 | $8,697.00 | $10,297.00 | 1 | $11,087.70 | $11,087.70 |
| 2 | L | L | $13,817.00 | 9 | 4 | 4 | $11,097.00 | $11,897.00 | 4 | $11,097.00 | $11,897.00 | 1 | $11,087.70 | $11,087.70 |
| 4 | H | H | $13,817.00 | 9 | 4 | 4 | $5,997.00 | $10,297.00 | 1 | $8,527.47 | $8,527.47 | 1 | $8,678.41 | $8,678.41 |
| 4 | H | L | $13,817.00 | 9 | 4 | 4 | $8,397.00 | $11,897.00 | 1 | $8,527.47 | $8,527.47 | 1 | $8,678.41 | $8,678.41 |
| 4 | L | H | $13,817.00 | 9 | 4 | 4 | $8,697.00 | $10,297.00 | 4 | $8,697.00 | $10,297.00 | 1 | $8,678.41 | $8,678.41 |
| 4 | L | L | $13,817.00 | 9 | 4 | 4 | $11,097.00 | $11,897.00 | 4 | $11,097.00 | $11,897.00 | 1 | $8,678.41 | $8,678.41 |
| 6 | H | H | $13,817.00 | 9 | 4 | 4 | $5,997.00 | $10,297.00 | 1 | $6,042.69 | $6,042.69 | 1 | $6,269.11 | $6,269.11 |
| 6 | H | L | $13,817.00 | 9 | 4 | 4 | $8,397.00 | $11,897.00 | 1 | $6,042.69 | $6,042.69 | 1 | $6,269.11 | $6,269.11 |
| 6 | L | H | $13,817.00 | 9 | 4 | 4 | $8,697.00 | $10,297.00 | 4 | $8,697.00 | $10,297.00 | 1 | $6,269.11 | $6,269.11 |
| 6 | L | L | $13,817.00 | 9 | 4 | 4 | $11,097.00 | $11,897.00 | 4 | $11,097.00 | $11,897.00 | 1 | $6,269.11 | $6,269.11 |
| 2 | H | H | $22,757.00 | 22 | 4 | 4 | $14,937.00 | $19,237.00 | 0 | $14,872.40 | $14,872.40 | 0 | $14,872.40 | $14,872.40 |
| 2 | H | L | $22,757.00 | 22 | 4 | 4 | $17,337.00 | $20,837.00 | 0 | $14,872.40 | $14,872.40 | 0 | $14,872.40 | $14,872.40 |
| 2 | L | H | $22,757.00 | 22 | 4 | 4 | $17,637.00 | $19,237.00 | 4 | $17,637.00 | $19,237.00 | 0 | $14,872.40 | $14,872.40 |
| 2 | L | L | $22,757.00 | 22 | 4 | 4 | $20,037.00 | $20,837.00 | 4 | $20,037.00 | $20,837.00 | 0 | $14,872.40 | $14,872.40 |
| 4 | H | H | $22,757.00 | 22 | 4 | 4 | $14,937.00 | $19,237.00 | 0 | $7,307.68 | $7,307.68 | 0 | $7,307.68 | $7,307.68 |
| 4 | H | L | $22,757.00 | 22 | 4 | 4 | $17,337.00 | $20,837.00 | 0 | $7,307.68 | $7,307.68 | 0 | $7,307.68 | $7,307.68 |
| 4 | L | H | $22,757.00 | 22 | 4 | 4 | $17,637.00 | $19,237.00 | 4 | $17,637.00 | $19,237.00 | 0 | $7,307.68 | $7,307.68 |
| 4 | L | L | $22,757.00 | 22 | 4 | 4 | $20,037.00 | $20,837.00 | 4 | $20,037.00 | $20,837.00 | 0 | $7,307.68 | $7,307.68 |
| 6 | H | H | $22,757.00 | 22 | 4 | 4 | $14,937.00 | $19,237.00 | 0 | -$256.92 | -$256.92 | 0 | -$256.92 | -$256.92 |
| 6 | H | L | $22,757.00 | 22 | 4 | 4 | $17,337.00 | $20,837.00 | 0 | -$256.92 | -$256.92 | 0 | -$256.92 | -$256.92 |
| 6 | L | H | $22,757.00 | 22 | 4 | 4 | $17,637.00 | $19,237.00 | 4 | $17,637.00 | $19,237.00 | 0 | -$256.92 | -$256.92 |
| 6 | L | L | $22,757.00 | 22 | 4 | 4 | $20,037.00 | $20,837.00 | 4 | $20,037.00 | $20,837.00 | 0 | -$256.92 | -$256.92 |

**Analysis:** Both Instances 9 & 22 imposed four hours of delay, yet they produced very different optimal strategies. The primary difference between the two instances, was the timing of the delays, shown in Table 23.

Table 23: Timing of delays

| Instance | Total delay (hrs) | Hour of transit delay imposed |
|---|---|---|
| **9** | 4 | 16, 26, 39, 43 |
| **22** | 4 | 14, 22, 27, 32 |

The key delay in Instance 9 arose late in the transit at hour 39, preventing on-time delivery for all transit strategies. At hour 43, another critical delay arose, extending the transit by an additional hour for MES. MT and Avoid DCOCD (when DCOCD was high) both arrived prior to hour 43; hence, they were not impacted by the fourth delay. These very late delays provided a significant advantage to MT and proved to be the only time where Rail Service Profit was maximized by the MT transit strategy (outside of Instance 28), beating MES by $790 and Avoid DCOCD by $75. In both instances, fuel was set at $2/gallon and labor was high, providing the advantage of avoiding that additional delay and the costs associated with an additional hour of labor and fuel consumed to idle the locomotives.

As in real-time scenarios, the longer a consist remains away from its destination, the more at risk it is of incurring delay. As demonstrated by Instance 9, the mere fact that the consist was still in transit at hour 43, with just one hour left, placed the consist at risk for further delay. When delay struck, it caused even greater DCOCD and labor penalties to be incurred, depleting supply chain profits even more.

In contrast to Instance 9, Instance 22 delays arose more in the middle of transit, between the hours of 14 and 32. Although this provided eight hours for the consist to adjust speed and allowed an on-time arrival for the MT and Avoid DCOCD (when DCOCD was high) transit strategies, MT Service Profits were eroded by an average of $2,615 when fuel was priced at $2/gallon; $10,179 when $4/gallon, and $17,743 at $6/gallon. Rail Service Profit erosion was even greater, keeping optimal profits with the MES transit strategy.

## 4.9 PROFIT LOSS

The RPM is utilized to identify the transit strategy that maximizes profitability. Each of the 30 instances are ran through the 12 scenarios. Both Rail Service Profit and Service Profit are outputs of the models that simulate the three transit strategies; Most Efficient Speed (MES), Avoid Downstream Customer Opportunity Cost of Delay (DCOCD), and Minimize Tardiness (MT). A summary table of the average profit loss as a percentage of the Expected Service Profit (ESP) is provided in Table 24.

**Analysis:** If a single transit strategy has to be chosen, it would clearly be MES, contrary to industry practice. Service Profit losses of greater than 10% arose with MES with scenarios (2, H, H) and (2, H, L) only – at 32.2% & 20.5% respectively. In all other cases, MES was the optimal transit strategy. For Rail Service Profit, MES was also the clear choice, experiencing a maximum loss of 0.3%. As a general rule for MES, as fuel prices increased, profit losses decreased, representing the fact that MES was often the most profitable transit strategy, losing an average Service Profit of 6.1% and Rail Service Profit of 0.1%.

MT transit strategy incurred much greater losses, with an average Service Profit loss of 32.5% and Rails Service Profit loss of 52.9%, a staggering result in an industry where increasing speed to arrive on time is commonplace. One area where increasing speed is desirable, in fact generated the most Service Profit, was when fuel prices were set to $2/gallon and DCOCD is high, losing only a meager 1.1%, while MES lost 26.3% and Avoid DCOCD lost 2.6%. This represents the fact that cheaper fuel allows for less economical speeds, especially if these increased speeds result in on-time arrivals and avoid large tardiness penalties.

Table 24: Total Profit Loss - by percentage of ESP (%)

| Scenario (Fuel, DCOCD, Labor) | MES Service Profit (%) | MES Rail Service Profit (%) | Avoid DCOCD Service Profit (%) | Avoid DCOCD Rail Service Profit (%) | MT Service Profit (%) | MT Rail Service Profit (%) |
|---|---|---|---|---|---|---|
| **(2, , )** | **-13.8%** | **-0.1%** | **-1.7%** | **-11.4%** | **-7.2%** | **-20.0%** |
| **(2, H, )** | -26.3% | -0.1% | -2.6% | -21.3% | -1.1% | -20.2% |
| **(2, H, H)** | -32.2% | -0.2% | -2.0% | -17.1% | -0.4% | -15.8% |
| **(2, H, L)** | -20.5% | 0.0% | -3.1% | -25.4% | -1.9% | -24.5% |
| **(2, L, )** | -1.3% | -0.2% | -0.9% | -1.4% | -13.3% | -19.9% |
| **(2, L, H)** | -2.2% | -0.3% | -1.3% | -1.3% | -7.7% | -15.7% |
| **(2, L, L)** | -0.4% | -0.1% | -0.4% | -1.6% | -18.9% | -24.1% |
| **(4, , )** | **-3.4%** | **-0.1%** | **-9.1%** | **-29.1%** | **-30.9%** | **-54.0%** |
| **(4, H, )** | -6.6% | 0.0% | -16.3% | -54.7% | -14.7% | -53.4% |
| **(4, H, H)** | -8.9% | 0.0% | -12.4% | -50.6% | -10.7% | -49.3% |
| **(4, H, L)** | -4.2% | 0.0% | -20.2% | -58.8% | -18.7% | -57.6% |
| **(4, L, )** | -0.3% | -0.1% | -1.9% | -3.4% | -47.1% | -54.6% |
| **(4, L, H)** | -0.4% | -0.1% | -1.6% | -3.2% | -42.8% | -52.4% |
| **(4, L, L)** | -0.3% | -0.1% | -2.3% | -3.6% | -51.4% | -56.8% |
| **(6, , )** | **-1.0%** | **-0.1%** | **-23.9%** | **-46.3%** | **-59.3%** | **-84.8%** |
| **(6, H, )** | -1.6% | 0.0% | -43.6% | -87.1% | -41.0% | -84.4% |
| **(6, H, H)** | -1.6% | 0.0% | -38.6% | -84.1% | -34.9% | -80.7% |
| **(6, H, L )** | -1.7% | 0.0% | -48.7% | -90.0% | -47.1% | -88.1% |
| **(6, L, )** | -0.3% | -0.1% | -4.1% | -5.5% | -77.6% | -85.2% |
| **(6, L, H)** | -0.4% | -0.1% | -3.6% | -5.2% | -71.2% | -80.9% |
| **(6, L, L)** | -0.3% | -0.1% | -4.5% | -5.9% | -84.0% | -89.4% |
| **Overall** | **-6.1%** | **-0.1%** | **-11.6%** | **-28.9%** | **-32.5%** | **-52.9%** |

Avoid DCOCD transit strategy performed well when fuels costs were low, losing 0.9% when fuel was $2/gallon and DCOCD was low. As fuel increased in cost, so did the profit loss, losing an average of 23.9% of Service Profit and 46.3% of Rail Service Profit when fuel reached $6/gallon.

If only one transit strategy could be selected for all 12 scenarios, MES would be the obvious choice for optimizing Service Profit, losing just 6.1%. However, by selecting the optimal transit strategy for each of the 12 scenarios shown in the two far right columns, yields a more profitable 1.8% loss, as demonstrated in Table 25. In a multi-billion dollar industry, increasing profit by 4.3% would be remarkable. Using the same methodology for Rail Service Profit did not appreciably reduce profit loss, and remained nearly identical to MES transit strategy.

As mentioned previously, optimizing rail profitability is highly dynamic, involving real-time inputs that shape and reshape the profit frontier. Whichever transit strategy served you well yesterday, may not tomorrow due to the ever changing landscape of fuel costs. To optimize profitability, transit speed decisions must be based on real-time profit calculations, not cultural norms or past industry practices.

Table 25: Minimized profit loss calculations

| Scenario (Fuel, DCOCD, Labor) | MES Service Profit (%) | MES Rail Service Profit (%) | Avoid DCOCD Service Profit (%) | Avoid DCOCD Rail Service Profit (%) | MT Service Profit (%) | MT Rail Service Profit (%) | Minimized Service Profit Loss (%) | Minimized Rail Service Profit Loss (%) |
|---|---|---|---|---|---|---|---|---|
| (2, , ) | **-13.8%** | **-0.1%** | **-1.7%** | **-11.4%** | **-7.2%** | **-20.0%** | | |
| (2, H, ) | -26.3% | -0.1% | -2.6% | -21.3% | -1.1% | -20.2% | | |
| (2, H, H) | -32.2% | **-0.2%** | -2.0% | -17.1% | -0.4% | -15.8% | **-0.4%** | **-0.2%** |
| (2, H, L) | -20.5% | **0.0%** | -3.1% | -25.4% | -1.9% | -24.5% | **-1.9%** | **0.0%** |
| (2, L, ) | -1.3% | -0.2% | -0.9% | -1.4% | -13.3% | -19.9% | | |
| (2, L, H) | -2.2% | **-0.3%** | -1.3% | -1.3% | -7.7% | -15.7% | **-1.3%** | **-0.3%** |
| (2, L, L) | -0.4% | **-0.1%** | -0.4% | -1.6% | -18.9% | -24.1% | **-0.4%** | **-0.1%** |
| (4, , ) | **-3.4%** | **-0.1%** | **-9.1%** | **-29.1%** | **-30.9%** | **-54.0%** | | |
| (4, H, ) | -6.6% | 0.0% | -16.3% | -54.7% | -14.7% | -53.4% | | |
| (4, H, H) | -8.9% | **0.0%** | -12.4% | -50.6% | -10.7% | -49.3% | **-8.9%** | **0.0%** |
| (4, H, L) | -4.2% | **0.0%** | -20.2% | -58.8% | -18.7% | -57.6% | **-4.2%** | **0.0%** |
| (4, L, ) | -0.3% | -0.1% | -1.9% | -3.4% | -47.1% | -54.6% | | |
| (4, L, H) | -0.4% | **-0.1%** | -1.6% | -3.2% | -42.8% | -52.4% | **-0.4%** | **-0.1%** |
| (4, L, L) | -0.3% | **-0.1%** | -2.3% | -3.6% | -51.4% | -56.8% | **-0.3%** | **-0.1%** |
| (6, , ) | **-1.0%** | **-0.1%** | **-23.9%** | **-46.3%** | **-59.3%** | **-84.8%** | | |
| (6, H, ) | -1.6% | 0.0% | -43.6% | -87.1% | -41.0% | -84.4% | | |
| (6, H, H) | -1.6% | **0.0%** | -38.6% | -84.1% | -34.9% | -80.7% | **-1.6%** | **0.0%** |
| (6, H, L ) | -1.7% | **0.0%** | -48.7% | -90.0% | -47.1% | -88.1% | **-1.7%** | **0.0%** |
| (6, L, ) | -0.3% | -0.1% | -4.1% | -5.5% | -77.6% | -85.2% | | |
| (6, L, H) | -0.4% | **-0.1%** | -3.6% | -5.2% | -71.2% | -80.9% | **-0.4%** | **-0.1%** |
| (6, L, L) | -0.3% | **-0.1%** | -4.5% | -5.9% | -84.0% | -89.4% | **-0.3%** | **-0.1%** |
| Overall | **-6.1%** | **-0.1%** | **-11.6%** | **-28.9%** | **-32.5%** | **-52.9%** | **-1.8%** | **-0.1%** |

## 4.10 DECONFLICTION METHODOLOGY

Rail lines get congested, especially during peak usage. Selecting which consist has priority over others when conflicts arise over the same rail line is usually left to operations. Decisions are often dependent upon some predetermined operations planning norms such as relying upon the type of goods shipped. Coviello (2015) modelled periodic operations on a single track to analyze timetable stability in response to random delays, finding that increasing speed was an effective means to recover from delays and added to timetable robustness. Unfortunately, he gave little consideration to the fact that increasing speed increases fuel costs, and may quickly outweigh the value of maintaining any schedule. Another common practice is to give preference to the higher value freight. A new methodology based upon the RPM is proposed, where priority is given to consists in a sequence that optimizes profitability.

The following demonstrates the value of such a methodology and quantifies the impacts these decisions have on rail service provider profits. Given three consists in conflict for the same rail line, utilizing Instances #14, #24 and #27, the following scenario is provided:

**Conflict Scenario:** Only one consist may pass without delay. A second consist must be delayed 1 hour to allow safe passage of the first. The third consist must be delayed two hours before being allowed to proceed. For this example, fuel is set to $1.25/gallon. For Instances 24 & 27, DCOCD and labor are both high, with Instance 14, both low. The hour in which the conflict arises is also an important factor, with details summarized in Table 26.

Table 26: Scenario with three consists in conflict

| Instance | Hour conflict arises in transit | Input variables |
|---|---|---|
| 14 | 35 | (1.25, L, L) |
| 24 | 10 | (1.25, H, H) |
| 27 | 20 | (1.25, H, H) |

**Analysis:** Each instance is examined using the RPM, generating the Service Profit (SP) and Rails Service Profit (RSP) for each transit strategy. Delays are introduced into each instance at the designated time. For example, the consist operating under Instance 14 encounters the conflict at hour 35 of its transit, just five hours from its destination; Instance 24 encounters the conflict at hour 10, and Instance 27 at hour 20. Under each transit strategy (MES, Avoid DCOCD, and MT), the remaining transit for each consist is simulated to generate the SP and RSP for each instance. Table 27 provides the simulation outputs by transit strategy.

For example, as shown in Table 27, Instance 24, when no delay is imposed (i.e. given highest priority), generates $9,492 SP and $12,142 RSP when utilizing the MES transit strategy. Likewise, when Instance 14 has lowest priority (i.e. selected last of the three consists to proceed and delayed two hours), generates $12,634 SP and $13,434 RSP when utilizing the same MES transit strategy.

Table 27: Profit maxima by transit strategy

| | | | MES | | | | | | Avoid DCOCD | | | | | MT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Delay | Scenario # | ESP ($) | Sum of Delays (Hours) | Arrival Delay (Hours) | SP | | RSP | | Arrival Delay (Hours) | SP | | RSP | | Arrival Delay (Hours) | SP | | RSP | |
| Instance 24 (1.25,H,H) Hour 10 | | | | | | | | | | | | | | | | | | |
| None | 24 | $14,782.00 | 3 | 3 | $9,492.00 | 0 | $12,142.00 | 0 | 0 | $11,965.75 | 0 | $11,965.75 | 0 | 0 | $12,060.10 | 0 | $12,060.10 | 0 |
| 1 | 24 | $14,782.00 | 4 | 4 | **$6,962.00** | 1 | **$11,262.00** | 1 | 0 | **$10,441.70** | 1 | **$10,441.70** | 1 | 0 | **$10,336.51** | 1 | **$10,336.51** | 1 |
| 2 | 24 | $14,782.00 | 5 | 5 | $2,382.00 | 0 | $10,382.00 | 0 | 0 | $8,293.46 | 0 | $8,293.46 | 0 | 0 | $8,257.18 | 0 | $8,257.18 | 0 |
| | | | | | | | | | | | | | | | | | | |
| Instance 27 (1.25,H,H) Hour 20 | | | | | | | | | | | | | | | | | | |
| None | 27 | $24,171.00 | 5 | 5 | **$11,771.00** | 1 | **$19,771.00** | 1 | 0 | **$20,064.55** | 1 | **$20,064.55** | 1 | 0 | **$20,249.61** | 1 | **$20,249.61** | 1 |
| 1 | 27 | $24,171.00 | 6 | 6 | $4,641.00 | 0 | $18,891.00 | 0 | 0 | $17,566.20 | 0 | $17,566.20 | 0 | 0 | $17,613.37 | 0 | $17,613.37 | 0 |
| 2 | 27 | $24,171.00 | 8 | 8 | -$12,769.00 | 0 | $17,131.00 | 0 | 0 | $15,040.47 | 0 | $15,040.47 | 0 | 0 | $15,040.47 | 0 | $15,040.47 | 0 |
| | | | | | | | | | | | | | | | | | | |
| Instance 14 (1.25,L,L) Hour 35 | | | | | | | | | | | | | | | | | | |
| None | 14 | $15,354.00 | 2 | 2 | $13,994.00 | 0 | $14,394.00 | 0 | 2 | $13,994.00 | 0 | $14,394.00 | 0 | 0 | $14,091.01 | 0 | $14,091.01 | 0 |
| 1 | 14 | $15,354.00 | 3 | 3 | $13,314.00 | 0 | $13,914.00 | 0 | 3 | $13,314.00 | 0 | $13,914.00 | 0 | 0 | $12,813.63 | 0 | $12,813.63 | 0 |
| 2 | 14 | $15,354.00 | 4 | 4 | **$12,634.00** | 1 | **$13,434.00** | 1 | 4 | **$12,634.00** | 1 | **$13,434.00** | 1 | 1 | **$12,287.34** | 1 | **$12,287.34** | 1 |
| | | **$54,307.00** | **Transit Strategy Profit Maxima** | | **$31,367.00** | | **$44,467.00** | | | **$43,140.25** | | **$43,940.25** | | | **$42,873.46** | | **$42,873.46** | |

The optimal sequence is based on the combination of delays that preserves the most profit (shown in yellow fill). For the MES transit strategy, SP is maximized when the consist operating under Instance 24 is delayed one hour, Instance 27 is granted highest priority and not delayed, with Instance 14 designated to go last and delayed two hours; culminating in a maximum profit of $31,367.

Table 27 also demonstrates that the optimal sequence of consists remains the same, regardless of transit strategy. The transit strategy that retained the most overall profit was MES, preserving $44,467 in RSP, more than $1,593 (or 3.7%) better than MT. Avoid DCOCD preserved $43,140.25 in SP, $11,770 or 38% more than MES.

Opening the decision spectrum to allow selection of transit strategy in conjunction with the combination of delays, increases RSP by an additional $478.61, as shown in Table 28 below. By changing the transit strategy of Instance 27 from MES to MT, results in this 1% increase in RSP for the rail service provider.

Table 28: RSP Maxima

| | | | MES | | | | | | Avoid DCOCD | | | | | MT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Delay | Scenario # | ESP ($) | Sum of Delays (Hours) | Arrival Delay (Hours) | SP | | RSP | | Arrival Delay (Hours) | SP | | RSP | | Arrival Delay (Hours) | SP | | RSP | |
| Instance 24 (1.25,H,H) Hour 10 | | | | | | | | | | | | | | | | | | |
| None | 24 | $14,782.00 | 3 | 3 | $9,492.00 | | $12,142.00 | 0 | 0 | $11,965.75 | | $11,965.75 | 0 | 0 | $12,060.10 | | $12,060.10 | 0 |
| 1 | 24 | $14,782.00 | 4 | 4 | $6,962.00 | | **$11,262.00** | 1 | 0 | $10,441.70 | | $10,441.70 | 0 | 0 | $10,336.51 | | $10,336.51 | 0 |
| 2 | 24 | $14,782.00 | 5 | 5 | $2,382.00 | | $10,382.00 | 0 | 0 | $8,293.46 | | $8,293.46 | 0 | 0 | $8,257.18 | | $8,257.18 | 0 |
| | | | | | | | | | | | | | | | | | | |
| Instance 27 (1.25,H,H) Hour 20 | | | | | | | | | | | | | | | | | | |
| None | 27 | $24,171.00 | 5 | 5 | $11,771.00 | | $19,771.00 | 0 | 0 | $20,064.55 | | $20,064.55 | 0 | 0 | $20,249.61 | | **$20,249.61** | 1 |
| 1 | 27 | $24,171.00 | 6 | 6 | $4,641.00 | | $18,891.00 | 0 | 0 | $17,566.20 | | $17,566.20 | 0 | 0 | $17,613.37 | | $17,613.37 | 0 |
| 2 | 27 | $24,171.00 | 8 | 8 | -$12,769.00 | | $17,131.00 | 0 | 0 | $15,040.47 | | $15,040.47 | 0 | 0 | $15,040.47 | | $15,040.47 | 0 |
| | | | | | | | | | | | | | | | | | | |
| Instance 14 (1.25,L,L) Hour 35 | | | | | | | | | | | | | | | | | | |
| None | 14 | $15,354.00 | 2 | 2 | $13,994.00 | | $14,394.00 | 0 | 2 | $13,994.00 | | $14,394.00 | 0 | 0 | $14,091.01 | | $14,091.01 | 0 |
| 1 | 14 | $15,354.00 | 3 | 3 | $13,314.00 | | $13,914.00 | 0 | 3 | $13,314.00 | | $13,914.00 | 0 | 0 | $12,813.63 | | $12,813.63 | 0 |
| 2 | 14 | $15,354.00 | 4 | 4 | $12,634.00 | | **$13,434.00** | 1 | 4 | $12,634.00 | | $13,434.00 | 0 | 1 | $12,287.34 | | $12,287.34 | 0 |
| | | **$54,307.00** | | | **$0.00** | | **$24,696.00** | | | **$0.00** | | **$0.00** | | | **$0.00** | | **$20,249.61** | |
| | | | | | **RSP Maxima** | | **$44,945.61** | | | | | | | | | | | |

Should operations choose the worst sequence and worst transit strategies (achieving global profit minimas), profitability can dramatically decline. As demonstrated in Table 29 using pink fill, granting the consist operating under Instance 14 with highest priority and proceeding without delay, and in turn, delay Instance 24 one hour and Instance 27 two hours, drives SP down to only $8,187, from its high of $43,140. Correspondingly, RSP erodes to $39,467, down from the models global maximum RSP of $44,945.61. The loss of $5,478.61 RSP represents a real loss of profits to the rail service provide on the order of 12%, caused by choosing the least profitable sequence.

Table 29: Profit Minima

| | | | MES | | | | | | Avoid DCOCD | | | | | MT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Delay | Scenario # | ESP ($) | Sum of Delays (Hours) | Arrival Delay (Hours) | SP | | RSP | | Arrival Delay (Hours) | SP | | RSP | | Arrival Delay (Hours) | SP | | RSP | |
| Instance 24 (1.25,H,H) Hour 10 | | | | | | | | | | | | | | | | | | |
| None | 24 | $14,782.00 | 3 | 3 | $9,492.00 | 0 | $12,142.00 | 0 | 0 | $11,965.75 | 0 | $11,965.75 | 0 | 0 | $12,060.10 | 0 | $12,060.10 | 0 |
| 1 | 24 | $14,782.00 | 4 | 4 | **$6,962.00** | 1 | **$11,262.00** | 1 | 0 | **$10,441.70** | 1 | **$10,441.70** | 1 | 0 | **$10,336.51** | 1 | **$10,336.51** | 1 |
| 2 | 24 | $14,782.00 | 5 | 5 | $2,382.00 | 0 | $10,382.00 | 0 | 0 | $8,293.46 | 0 | $8,293.46 | 0 | 0 | $8,257.18 | 0 | $8,257.18 | 0 |
| Instance 27 (1.25,H,H) Hour 20 | | | | | | | | | | | | | | | | | | |
| None | 27 | $24,171.00 | 5 | 5 | $11,771.00 | 0 | $19,771.00 | 0 | 0 | $20,064.55 | 0 | $20,064.55 | 0 | 0 | $20,249.61 | 0 | $20,249.61 | 0 |
| 1 | 27 | $24,171.00 | 6 | 6 | $4,641.00 | 0 | $18,891.00 | 0 | 0 | $17,566.20 | 0 | $17,566.20 | 0 | 0 | $17,613.37 | 0 | $17,613.37 | 0 |
| 2 | 27 | $24,171.00 | 8 | 8 | **-$12,769.00** | 1 | **$17,131.00** | 1 | 0 | **$15,040.47** | 1 | **$15,040.47** | 1 | 0 | **$15,040.47** | 1 | **$15,040.47** | 1 |
| Instance 14 (1.25,L,L) Hour 35 | | | | | | | | | | | | | | | | | | |
| None | 14 | $15,354.00 | 2 | 2 | **$13,994.00** | 1 | **$14,394.00** | 1 | 2 | **$13,994.00** | 1 | **$14,394.00** | 1 | 0 | **$14,091.01** | 1 | **$14,091.01** | 1 |
| 1 | 14 | $15,354.00 | 3 | 3 | $13,314.00 | 0 | $13,914.00 | 0 | 3 | $13,314.00 | 0 | $13,914.00 | 0 | 0 | $12,813.63 | 0 | $12,813.63 | 0 |
| 2 | 14 | $15,354.00 | 4 | 4 | $12,634.00 | 0 | $13,434.00 | 0 | 4 | $12,634.00 | 0 | $13,434.00 | 0 | 1 | $12,287.34 | 0 | $12,287.34 | 0 |
| | | **$54,307.00** | **Transit Strategy Profit Minima** | | **$8,187.00** | | **$42,787.00** | | | **$39,476.17** | | **$39,876.17** | | | **$39,467.99** | | **$39,467.99** | |

When fuel prices increase to $6/gal, profit losses are magnified ten-fold. For example, Table 30 and Table 31 show the profit maxima and minima sequences when fuel costs are adjusted to $6/gallon. Remarkably, real net profit losses on the order of -$12,665.38 are realized when MT transit strategy is selected with suboptimal selection of consist priority. This is in stark contrast to the optimal profit sequencing that achieves $42,487 in RSP, representing a total profit reduction of $55,152.

Table 30: Profit maxima with fuel set to $6/gallon

| | | | MES | | | | | | Avoid DCOCD | | | | | MT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Delay | Scenario # | ESP ($) | Sum of Delays (Hours) | Arrival Delay (Hours) | SP | | RSP | | Arrival Delay (Hours) | SP | | RSP | | Arrival Delay (Hours) | SP | | RSP | |
| Instance 24 (6,H,H) Hour 10 | | | | | | | | | | | | | | | | | | |
| None | 24 | $14,782.00 | 3 | 3 | $9,492.00 | 0 | $12,142.00 | 0 | 0 | $2,176.12 | 0 | $2,176.12 | 0 | 0 | $2,628.97 | 0 | $2,628.97 | 0 |
| 1 | 24 | $14,782.00 | 4 | 4 | **$6,962.00** | 1 | **$11,262.00** | 1 | 0 | **-$4,835.60** | 1 | **-$4,835.60** | 1 | 0 | **-$5,340.68** | 1 | **-$5,340.68** | 1 |
| 2 | 24 | $14,782.00 | 5 | 5 | $2,382.00 | 0 | $10,382.00 | 0 | 0 | -$14,843.18 | 0 | -$14,843.18 | 0 | 0 | - $15,017.35 | 0 | - $15,017.35 | 0 |
| Instance 27 (6,H,H) Hour 20 | | | | | | | | | | | | | | | | | | |
| None | 27 | $24,171.00 | 5 | 5 | **$11,771.00** | 1 | **$19,771.00** | 1 | 0 | **$5,979.97** | 1 | **$5,979.97** | 1 | 0 | **$6,868.20** | 1 | **$6,868.20** | 1 |
| 1 | 27 | $24,171.00 | 6 | 6 | $4,641.00 | 0 | $18,891.00 | 0 | 0 | -$5,708.35 | 0 | -$5,708.35 | 0 | 0 | -$5,481.94 | 0 | -$5,481.94 | 0 |
| 2 | 27 | $24,171.00 | 8 | 8 | -$12,769.00 | 0 | $17,131.00 | 0 | 0 | -$17,223.97 | 0 | -$17,223.97 | 0 | 0 | - $17,223.97 | 0 | - $17,223.97 | 0 |
| Instance 14 (6,L,L) Hour 35 | | | | | | | | | | | | | | | | | | |
| None | 14 | $15,354.00 | 2 | 2 | $13,994.00 | 0 | $14,394.00 | 0 | 2 | $13,994.00 | 0 | $14,394.00 | 0 | 0 | $9,899.27 | 0 | $9,899.27 | 0 |
| 1 | 14 | $15,354.00 | 3 | 3 | $13,314.00 | 0 | $13,914.00 | 0 | 3 | $13,314.00 | 0 | $13,914.00 | 0 | 0 | $4,071.77 | 0 | $4,071.77 | 0 |
| 2 | 14 | $15,354.00 | 4 | 4 | **$12,634.00** | 1 | **$13,434.00** | 1 | 4 | **$12,634.00** | 1 | **$13,434.00** | 1 | 1 | **-$135.98** | 1 | **-$135.98** | 1 |
| | | **$54,307.00** | **Transit Strategy Profit Maxima** | | **$31,367.00** | | **$44,467.00** | | | **$13,778.37** | | **$14,578.37** | | | **$1,391.54** | | **$1,391.54** | |

Table 31: Profit minima with fuel set to $6/gallon

| | | | MES | | | | | | Avoid DCOCD | | | | | MT | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Delay | Scenario # | ESP ($) | Sum of Delays (Hours) | Arrival Delay (Hours) | SP | | RSP | | Arrival Delay (Hours) | SP | | RSP | | Arrival Delay (Hours) | SP | | RSP | |
| Instance 24 (6,H,H) Hour 10 | | | | | | | | | | | | | | | | | | |
| None | 24 | $14,782.00 | 3 | 3 | $9,492.00 | 0 | $12,142.00 | 0 | 0 | $2,176.12 | 0 | $2,176.12 | 0 | 0 | $2,628.97 | 0 | $2,628.97 | 0 |
| 1 | 24 | $14,782.00 | 4 | 4 | **$6,962.00** | 1 | **$11,262.00** | 1 | 0 | **-$4,835.60** | 1 | **-$4,835.60** | 1 | 0 | **-$5,340.68** | 1 | **-$5,340.68** | 1 |
| 2 | 24 | $14,782.00 | 5 | 5 | $2,382.00 | 0 | $10,382.00 | 0 | 0 | -$14,843.18 | 0 | -$14,843.18 | 0 | 0 | - $15,017.35 | 0 | -$15,017.35 | 0 |
| Instance 27 (6,H,H) Hour 20 | | | | | | | | | | | | | | | | | | |
| None | 27 | $24,171.00 | 5 | 5 | $11,771.00 | 0 | $19,771.00 | 0 | 0 | $5,979.97 | 0 | $5,979.97 | 1 | 0 | $6,868.20 | 0 | $6,868.20 | 0 |
| 1 | 27 | $24,171.00 | 6 | 6 | $4,641.00 | 0 | $18,891.00 | 0 | 0 | -$5,708.35 | 0 | -$5,708.35 | 0 | 0 | -$5,481.94 | 0 | -$5,481.94 | 0 |
| 2 | 27 | $24,171.00 | 8 | 8 | **-$12,769.00** | 1 | **$17,131.00** | 1 | 0 | **-$17,223.97** | 1 | **-$17,223.97** | 1 | 0 | **-$17,223.97** | 1 | **-$17,223.97** | 1 |
| Instance 14 (6,L,L) Hour 35 | | | | | | | | | | | | | | | | | | |
| None | 14 | $15,354.00 | 2 | 2 | **$13,994.00** | 1 | **$14,394.00** | 1 | 2 | **$13,994.00** | 1 | **$14,394.00** | 1 | 0 | **$9,899.27** | 1 | **$9,899.27** | 1 |
| 1 | 14 | $15,354.00 | 3 | 3 | $13,314.00 | 0 | $13,914.00 | 0 | 3 | $13,314.00 | 0 | $13,914.00 | 0 | 0 | $4,071.77 | 0 | $4,071.77 | 0 |
| 2 | 14 | $15,354.00 | 4 | 4 | $12,634.00 | 0 | $13,434.00 | 0 | 4 | $12,634.00 | 0 | $13,434.00 | 0 | 1 | -$135.98 | 0 | -$135.98 | 0 |
| | | **$54,307.00** | **Transit Strategy Profit Minima** | | **$8,187.00** | | **$42,787.00** | | | **-$8,065.57** | | **-$1,685.60** | | | **-$12,665.38** | | **-$12,665.38** | |

This can be devastating to the industry, especially when the Expected Service Profit (ESP) for the three consists totaled only $54,307. Unfortunately, industry practice is to increase speed to arrive on time, coupled with the potential to suboptimally select consist priorities when deconflicting, raises genuine concerns that profit losses may be arising with little awareness.

The RPM simulation results demonstrate that transit strategy has a marked impact on the profitability of the rail service provider and the profitability of the supply chain. Adjusting speed to arrive on time, especially when not warranted, severely erodes profits. Further, the RPM has demonstrated its value to operations as a tool to deconflict consists in a profit preserving manner. In a multi-billion dollar industry, fundamental improvements in the management of resources can generate millions in profits.

### 4.11 PRICING STRATEGIES

The RPM has demonstrated that increasing speed to arrive on time significantly erodes profits, by up to 67%. Further, the RPM also demonstrated that in only a few situations is it in the best interest of the rail service provider to increase speed to arrive on time. In the cases where it is desirable for the rail service provider to do so, for JIT customers for example, what premium should be levied upon the customer for the increased level of service? Using the RPM and the profit calculations generated by the 360 simulations, baseline costs associated with rail operations can be obtained. Table 32 summarizes the operating costs incurred by the rail service provide for each hour of delay imposed by the RPM. Additionally, profit loss for each hours of delay "avoided" by increasing speed is provided. Armed with this knowledge, marketing can now make real-case revenue management decisions and begin to appropriately charge customers for increased levels of service.

Table 32: Profit Summary Statistics of the RPM

| | |
|---|---|
| **Most Efficient Speed (MES) Transit Strategy** | |
| Rail Service Profit loss per hour of delay imposed | $680 |
| **Avoid DCOCD Transit Strategy:** | |
| Rail Service Profit loss per hour of delay imposed | $1,889 |
| Rail Service Profit loss per hour of delay avoided by increasing speed | $3,638 |
| **Minimize Tardiness (MT) Transit Strategy:** | |
| Rail Service Profit loss per hour of delay imposed | $2,907 |
| Rail Service Profit loss per hour of delay avoided by increasing speed | $3,274 |

**Analysis:** The MES transit strategy will not increase speed; hence, it only incurs labor and idle fuels costs associated with delays, amounting to $685 per hour of delay.

The Avoid DCOCD transit strategy will maintain most efficient speed until it detects DCOCD charges due to late arrival. Should DCOCD arise, the consist will increase speed, up to max safe speed, in an attempt to arrive without DCOCD penalty. When DCOCD charges are low, DCOCD penalties do not arise until the consist is delayed seven hours or more. When DCOCD is high, penalties arise immediately. Therefore, rail service profit loss per hour of delay imposed increases to $1,889. Additionally, for each hour of delay avoided, costs the rail service provider $3,638, mostly in additional fuel costs.

The MT transit strategy responds to each delay by increasing speed to arrive on time, causing the rail service profit loss per hour of delay imposed to rise to $2,907. Dependent upon the timing of the delay, the consist may still arrive late. This is especially true if the consist is already operating at maximum safe speed and encounters a delay or when a delay arises too close to the end of a transit and cannot make up the lost time. Throughout the 360 simulations, over 88% of the imposed delays were overcome by the MT transit strategy but by doing so, sustained an average Rail Service Profit loss of $3,274 per hour of avoided tardiness.

Suppose a customer behaves as a JIT and provides a narrow delivery window of two hours. The rail service provider will need to analyze the characteristics of the route to determine how many hours of delay are normally encountered along a route. In our scenario, based on the RPM, if three hours of delay are normally encountered, then a minimum of one hour's premium should be routinely charged to the customer in order to deliver on time. This would equate to approximately, $3,274 additional cost.

Although this example is a simplification, the premise holds true – if a customer requires increased service levels, then a premium should be charged equating to the additional costs incurred by the rail service provider to provide the enhanced level of service. Otherwise, the rail service provider should maintain most efficient speed as an operational norm until compelled to increase speed to avoid some other, more significant real/tangible costs.

The last piece to truly optimizing profit is to closely link marketing with operations to ensure customers are afforded the service level considerations that are paid for, not simply expected. Only after this is accomplished, will the rail service provider safeguard its sustainability and long-term profitability.

# CHAPTER 5

# CONCLUSION & FUTURE RESEARCH

## 5.1 CONCLUSION

The Rail Profit Model (RPM) thoroughly explored the tradeoffs between increasing speed to arrive on time versus maintaining most efficient speed and arriving late. It effectively quantified the impacts on profitability and demonstrated how speed decisions must take into account more than just arrival time. Customer needs, expressed in the form of opportunity costs, provide a systemic means to not only segregate customer needs along service standards but also provide a sound basis with which to compare and contrast transit strategies in an effort to maximize profitability.

Through simulation the RPM clearly demonstrates that on-time, every time is not only detrimental to profits but also inefficient from a supply chain perspective. The analysis identified that allowing the train to maintain economical speed and deliver late is the right and most profitable solution in 77% of all instances for Service Profit and 98% of all instances for Rail Service Profit. Only when fuel prices dropped to $2/gallon did Minimize Tardiness begin to appear optimal for Service Profit (in only 44% of the instances). The model also revealed the magnitude of eroded profits, profits that were driven out of the supply chain and out of the pockets of the rail service providers. The magnitude of losses across the industry is likely staggering, considering lost profits can reach into the tens-of-thousands for a single inefficiently managed consist.

Service levels should also be a primary discriminating factor in the pricing decision. Customers that demand high levels of service, such as the customer segment that falls under just-in-time (JIT), should pay a premium to support the costly endeavor of arriving on time. Others that have the flexibility in their operations, should encourage the rail service provider to exercise that flexibility to reduce operating costs and in turn, reduce rates.

The RPM proved valuable when deconflicting consists. When examining transit strategy and alternative sequencing of three consists in conflict, the difference between the optimal profit solution of $42,487 and the minima solution of -$12,665.38 provides a stark difference in profit outcomes. The RPM can easily be used to deconflict any scenario combination and readily identify the most profitable sequence.

Transit speed decisions must be based on real-time profit calculations, not cultural norms or past industry practices. In fact, a vital aspect of optimizing profit is to closely link marketing with operations to ensure customers are afforded the service levels that are paid for, not simply expected. More importantly, customers that do not pay service level premiums should not receive consideration regarding increasing speed, unless the rail service provider is compelled to do so by other downstream opportunity cost penalties (such as cascading delays). Only after implementing the Rail Profit Model, with marketing and operations are in lock-step, will the rail service provider be effectively poised to maximize its long-term profitability and safeguard its sustainability.

## 5.2 FUTURE RESEARCH SUGGESTIONS

Currently, the RPM utilizes three distinct transit strategies to determine the optimal solution. The model could be enhanced to optimize while the consist is in transit. For example, on an hourly basis, should conditions substantially change, the model could change transit strategy mid-transit. Anticipate this capability would preserve additional profits that would have otherwise been lost using a dedicated, and partially suboptimal, transit strategy. Other research opportunities are described below.

- Expand the scope of the RPM to include return transit of empties to determine if outcomes substantially change. Further, explore the opportunity to integrate Rail Profit Model methodologies to locomotive assignment and fleet sizing problems.

- Revise the RPM to reflect contemporary locomotives and operationalize the model by conducting real world testing and integration into train control technologies.

- Explore generalizability opportunities to other industries, such as passenger rail and maritime cargo.

- Integrate environmental impacts of burning fossil fuels, such as of greenhouse gasses, as an opportunity cost within the RPM.

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# APPENDICES

## APPENDIX A – MASTER VARIABLE LIST

| | | | | |
|---|---|---|---|---|
| **Character / Symbol** | $a_{1-78}$ | $b_{1-78}$ | $c_{1-78}$ | $d_0$ / $d_{1-80}$ |
| **Cells** | Q5-Q82 | R5-R82 | S5-S82 | E3 / E5-E84 |
| **Title** | Estimated Arrival Hour (Traveling At Most Efficient Speed) | Forecasted Arrival Delay | Forecasted Arrival Delay (Max of 12 Hours) | Departure Delay / In Transit Delay Calculation |
| **Character / Symbol** | $A_{1-78}$ | $B_{1-78}$ | $C_{1-78}$ | D |
| **Cells** | Y5-Y82 | J5-J82 | O5-O82 , W5-W82, AD5-AD82 | D2 |
| **Title** | Average Speed Remaining to Arrive On-Time (Minimize Tardiness) | Average Speed Remaining to Arrive Destination Defore any DCOCD Penalty is Imposed | DCOCD Costs 1/2/3 | Probability of Delay |
| | | | | |
| | | | | |
| **Character / Symbol** | g | $h_{0-80}$ | i | j |
| **Cells** | | F3, F5-F84 | | |
| **Title** | | Realized Transit Hours | | |
| **Character / Symbol** | G | H | $I_{1-78}$ | J |
| **Cells** | | | Z5-Z82 | AL37 |
| **Title** | | | Increased Speed for On-Time Arrival (Minimize Tardiness) | Additional Labor Costs of Delay (ALCOD) |
| | | | | |
| | | | | |
| **Character / Symbol** | $m_{1-78}$ | n | o | p |
| **Cells** | AA5-AA82 | | | AL62 |
| **Title** | Speed in Excess of "Most Efficient" Required to Minimize Tardiness | | | Service Profit (SP) |
| **Character / Symbol** | $M_0$ / $M_{1-80}$ | N | O | P |
| **Cells** | K1 / I5-I84 | | | AL58 |
| **Title** | Transit Distance / Distance Remaining | | | Expected Service Profit (ESP) |
| | | | | |
| | | | | |
| **Character / Symbol** | $s_{1-78}$ | t | u | $v_{1-78}$ |
| **Cells** | L5-L82 | C5-D84 | | V5-V82 |
| **Title** | Speed in Excess of Most Efficient (Required to Avoid DCOCD Penalties) | Transit Hour | | Forecasted Incremental Increase in Labor Costs Due to Delays Beyond Normal Transit Time 1 |
| **Character / Symbol** | $S_e$ / $S_m$ / $S_{1-78}$ | $T_{1-80}$ | U | V |
| **Cells** | F1, H5-H84 / I1 / K5-K84 | G5-G84 | | |
| **Title** | Most Efficient Speed / Maximum Safe Speed / Most Efficient Speed (Default), Otherwise, Increased Speed to Arrive prior to Incurring DCOCD Penalties) | Sum of Tardiness | | |

## APPENDIX B – DEFINITIONS & EQUATIONS

| Cell | Definitions & Equations |
|---|---|
| D2 | **Probability of Delay** (set to <10%, can be varied)<br>**Symbol:** D<br>**Explanation:** Threshold to produce a delay. If the In Delay Random Number Generator is less than 10, a 1.0 hour delay is imposed. |
| C5-C84 | **Transit Hour**<br>**Symbol:** $t_{1\text{-}80}$<br>**Explanation:** Represents each hour of transit time. A trip that has no delays will take 40 hours when traveling the most efficient speed. |
| D5-D84 | **In Transit Delay Random Number Generator** (0,99)<br>**Symbol:** $r_{1\text{-}80}$<br>**Calculation:** RANDBETWEEN(0,99)<br>**Explanation:** Emulates a transit where each hour an unexpected delay may occur. If the randomly generated number falls below the "Probability of Delay, D" than a one-hour delay is imposed. If number is 10 or greater, than the train travels normally that hour. |
| E5-E84 | **In Transit Delay Calculation**<br>**Symbol:** $d_{1\text{-}80}$<br>**Calculation:** $=\text{IF}(r_{1\text{-}80}<D,1,0)$<br>**Excel Equation:** $=\text{IF}(D_{5\text{-}84}<D\$2,1,0)$<br>**Explanation:** Determines if a delay is incurred that hour. If the randomly generated number ($r_{1\text{-}80}$) falls below the "Probability of Delay, D" than a one-hour delay is imposed (cell fills with pink & text turns red, showing a 1.0 hour delay). If the number is 10 or greater, no delay is incurred, cell reflects 0.0, and the train travels normally that hour. |
| D3 | **Departure Delay Random Number Generator** (0-99)<br>**Symbol:** $r_0$<br>**Calculation:** RANDBETWEEN(0,99)<br>**Explanation:** Emulates a departure delay. If the randomly generated number falls below the "Probability of Delay, D" than a delay is imposed, randomly between 1.0 and 6.0 hours, otherwise, the train will depart on time |
| E3 | **Departure Delay**<br>**Symbol:** $d_0$<br>**Calculation:** $\text{IF}(r_0<D,\text{RANDBETWEEN}(1,6),0)$<br>**Excel Equation:** `=IF(D3<D$2,RANDBETWEEN(1,6),0)`<br>**Explanatio**n: Determines if a delay is incurred before the train departs. If the Delay Random Number Generator $r_0$ is less than "Probability of Delay, D" than a random number of hours delay (anywhere from 1.0 to 6.0) is imposed, otherwise, no delay is imposed (cell indicates 0.0). |
| F1,<br>H5-H84 | **Most Efficient Speed**<br>**Symbol:** $S_e$<br>**Hourly Calculation:** IF(Realized Transit Hours $H_{0\text{-}80}>0$, IF(In Transit Delay $r_{1\text{-}80}>0$, Most Efficient Speed $S_e=20$, Else $S_e=0$)<br>**Excel Equation:** `=IF(F6>0,IF(E6<1,F$1,0),0)`<br>**Explanation:** Most Efficient Speed is dependent upon many variables, including total tonnage load, number of cars, type and number of locomotives, terrain, etc. For this model's purposes, 20MPH is Most Efficient Speed. In cases where In Transit Delays occur ($D_{1\text{-}80}>0$), $S_e$ is set to 0. |

| Cell | Definitions & Equations |
|---|---|
| I1 | **Maximum Safe Speed**<br>**Symbol:** $S_m$<br>**Explanation:** Maximum Safe Speed is dependent upon many variables, including total tonnage load, number of cars, type and number of locomotives, terrain, etc. For this model's purposes, 25MPH is Maximum Safe Speed. |
| F3, F5-F84 | **Realized Transit Hours** (Initial setting is 0.0)<br>**Symbol:** $h_{0\text{-}80}$<br>**Initial Calculation:** IF(Departure Delay $d_0$>0, $h_0$=(0-$d_0$), $h_0$=0.0)<br>**Hourly Calculation:** =IF(In Transit Delay $d_2$=0, SUM(Previous Transit Hours $h_1$+1), SUM(Previous Transit Hours $h_1$ – In Transit Delay $d_2$ + 1))<br>**Sample Excel Equation:** =IF(E6=0,SUM(F5+1),SUM(F5-E6+1))<br>**Explanation:** Realized Transit Hours determines how many hours the train has made positive progress despite delays. The key purpose of this calculation is to track cumulative delays and reflect when the train is in a positive status to continue the transit. For example, when this variable is negative due to a departure delay, the train is still serving out its departure delay and cannot transit that hour. If a delay is incurred during transit, Realized Transit Hours $h_x$ remains unchanged. |
| K1 | **Transit Distance**<br>**Symbol:** $M_0$<br>**Explanation:** Transit Distance to be traveled. In this case it is 800 miles, which is the average transit for coal trains in 2010. |
| I5-I84 | **Distance Remaining**<br>**Symbol:** $M_{1\text{-}80}$<br>**Calculation:** IF($d_1$<0.1, IF(In Transit Delay d2>0.1, SUM(Previous Distance Remaining $M_1$ – Speed to Maximize Profit $S_2$), Previous Distance Remaining $M_1$), Previous Distance Remaining $M_1$)<br>**Sample Excel Equation:** =IF(E6<0.1,IF(F6>0.1,SUM(I5-AF6),I5),I5)<br>**Explanation:** Each hour, Distance Remaining ($M_{1\text{-}80}$) is decremented by the Optimal Speed that maximizes profit. If an in transit delay occurs, Distance Remaining does not change. Also, in cases where a Departure Delay occurs (where Realized Transit Hours is negative) Distance Remaining remains at $M_0$ = 800 until the delay expires. |
| G5-G84 | **Sum of Tardiness**<br>**Symbol:** $T_{1\text{-}80}$<br>**Calculation:** $T_2$ = Previous Sum of Tardiness $T_1$ – In Transit Delay $d_2$<br>**Sample Excel Equation:** =G5-E6<br>**Explanation:** Sums delays incurred on the train. Not used for any other calculation purposes. |
| J5-J82 | **Average Speed Remaining to Arrive Destination Before any DCOCD Penalty is Imposed**<br>Symbol: $B_{1\text{-}78}$<br>**Calculation:** IF (Transit Hour $t_{40}$ + Slack Time s – Transit Hour $t_1$)=0, then Distance Remaining $M_1$, otherwise IF (Transit Hour $t_1$ > (Transit Hour $t_{40}$ + Slack Time s), then Max Safe Speed $S_m$, Otherwise ((Distance Remaining $M_1$)/(Transit Hour $t_{40}$ + Slack Time s – Transit Hour $t_1$))<br>**Excel Equation:** =ABS(IF((C$44+AM$2-C5)=0,I5,IF(C5>SUM(C$44+AM$2),I1, SUM(I5/SUM(C$44+AM$2-C5)))))<br>**Explanation:** Calculates the average speed remaining to reach the destination before incurring any DCOCD Penalties. If incurring penalty, then transit speed increases to max safe speed. |

| Cell | Definitions & Equations |
|---|---|
| K5-K82 | **Most Efficient Speed (Default), Otherwise, Increased Speed to Arrive prior to Incurring DCOCD Penalties**<br>**Symbol:** $s_{1-78}$<br>**Calculation:** IF Delayed, Speed=0, Most Efficient Speed Se is default. If Average Speed Remaining $B_{1-78}$ is greater that Most Efficient Speed $S_e$, then Average Speed Remaining $B_{1-78}$ (up to Maximum Safe Speed $S_M$).<br>**Excel Equation:**<br>=IF(F5<0.1,0,IF(E5>0.1,0,IF(J5=F$1,J5,IF(K4=I$1,I$1,IF(J5>I$1,I$1,IF(J5>F$1, J5, IF(J5<F$1,F$1,J5)))))))<br>**Explanation:** The default speed is the Most Efficient Speed $S_e$. If the train is experiencing a delay, speed will read zero (0). Speed will increase, if need to avoid DCOCD Penalties. |
| L5-L82 | **Speed, in Excess of Most Efficient (Required to avoid DCOCD Penalties)**<br>**Symbol:** $s_{1-78}$<br>**Calculation:** IF Most Efficient Speed (Default) $s_{1-78}$ >0, then (Most Efficient Speed (Default) $s_{1-78}$ – Most Efficient Speed $S_e$), otherwise Zero (0).<br>**Excel Function:** IF(K5>0,ROUNDUP(SUM(K5-F$1),2),0)<br>**Explanation:** Reflects speeds in excess of Most Efficient to quantify increased fuel costs. |
| M5-M82 | **Increased Fuel Cost (over Most Efficient) to Arrive Prior to DCOCD Penalty**<br>**Symbol:** $F_{1-78}$<br>**Calculation:** IF No Delays, Look Up Speed In Excess of Most Efficient $S_x$ * Fuel Cost Per Hour of Typical Coal Train Haul<br>**Excel Function:** IF(E5<1,IF(F5>0.1,LOOKUP(L5,ITSFC!I$7:J$57)*'Avg Fuel Burn Rates'!H$35, 0),0)<br>**Explanation:** Translates speeds in excess of Most Efficient into additional fuel cost. |
| N5-N78 | **Forecasted Incremental Increase in Labor Costs Due to Delays Beyond Normal Transit Time**<br>**Symbol:** $L_{1-78}$<br>**Calculation:** If delayed, Lookup Transit Hour $t_{1-80}$ to Capture Hourly Labor Costs and add to previous Hourly Labor Costs, otherwise, Previous Labor Costs.<br>**Excel Function:** IF(E6=1,(HLOOKUP(C6,'Incremental Labor Costs'!$B$4:$CD$5,2,FALSE)+ N5), N5)<br>**Explanation:** Calculates the hourly labor costs of a delay. For example, if a train is delayed the first hour of an 80 hour transit, the Hourly Labor Cost would be divided by 80 and would be charged to each hour remaining in the transit. If another delay is experienced, the additional cost would be calculated, charged to the expected remaining hours of transit time and added to the previously calculated hourly labor costs already incurred. |
| O5-O82<br>W5-W82<br>AD5-<br>AD82 | **DCOCD Costs (Downstream Customer Opportunity Cost of Delay)**<br>**Symbol:** $C_{1-78}$<br>**Calculation:** If delayed, Lookup Forecasted Arrival Delay and Transit Hour $t_{1-80}$ to Capture Hourly Labor Costs and add to previous Hourly Labor Costs, otherwise, Previous calculated Labor Costs.<br>**Excel Function:** IF(E6=1,(((HLOOKUP(S6,AL$17:AX$22,2,FALSE)-HLOOKUP(S5, AL$17:AX$22 ,2,FALSE))/(IF(C6=SUM(40+SUM(E$5:E6)+E$3),1,ABS(SUM((K$1/F$1)-C6+SUM(E$5:E6)+ E$3)))))+W5),W5)<br>**Explanation:** Calculates the hourly labor costs of a delay. For example, if a train is delayed the first hour of an 80 hour transit, the Hourly Labor Cost would be divided by 80 and would be charged to each hour remaining in the transit. If another delay is experienced, the additional cost would be calculated, charged over the expected remaining hours of transit time and added to the previously calculated hourly labor costs already incurred. |

| Cell | Definitions & Equations |
|---|---|
| P5-P82 | **Total Incremental Cost Increase (Traveling at Varied Speeds to Arrive Prior to Incurring DCOCD Penalty)**<br>**Symbol:** $x_{1\text{-}78}$<br>**Calculation:** Sum of Incremental Costs such as: Increased Fuel Costs Due to Idling ($f_{1\text{-}78}$), plus Increased Fuel Cost (over Most Efficient) to Arrive Prior to DCOCD Penalty ($F_{1\text{-}78}$), plus Forecasted Incremental Increase in Labor Costs Due to Delays Beyond Normal Transit Time ($L_{1\text{-}78}$), plus DCOCD Costs ($C_{1\text{-}78}$).<br>**Excel Function:** U6+M6+N6+O6<br>**Explanation:** Calculates the incremental hourly costs incurred by traveling at speeds necessary to arrive at the destination prior to incurring any DCOCD penalties. |
| Q5-Q82 | **Estimated Arrival Hour (Traveling At Most Efficient Speed)**<br>**Symbol:** $a_{1\text{-}78}$<br>**Calculation:** Distance Remaining ($M_{1\text{-}80}$) divided by the Most Efficient Speed ($S_e$) plus Transit Hour ($t_{1\text{-}80}$)<br>**Excel Function:** =(I6/F$1)+C6<br>**Explanation:** Calculates the estimated Arrival Hour, traveling at the Most Efficient Speed (& assumes no additional delays). |
| R5-R82 | **Forecasted Arrival Delay**<br>**Symbol:** $b_{1\text{-}78}$<br>**Calculation:** Sum of Departure Delay ($d_0$) plus cumulative sum of In Transit Delays ($d_{1\text{-}\ldots2}$)<br>**Excel Function:** =SUM(E$3+SUM(E$5:E6))<br>**Explanation:** Calculates the running total of delays to formulate the Forecasted Arrival Delay (assumes traveling at Most Efficient Speed ($S_e$) and assumes no other delays will be encountered). |
| S5-S82 | **Forecasted Arrival Delay (Max of 12 Hours)**<br>**Symbol:** $c_{1\text{-}78}$<br>**Calculation:** IF the Forecasted Arrival Delay ($b_{1\text{-}78}$) is less 12, round it, otherwise set Forecasted Arrival Delay ($b_{1\text{-}78}$) to equal 12 Hours.<br>**Excel Function:** =IF(R6<12,ROUND(R6,0),12)<br>**Explanation:** Used to ensure the Forecasted Arrival Delay does not exceed 12 hours which is the models current upper limit for estimating cost penalties for tardiness. |
| T5-T82 | **Forecasted DCOCD Penalty**<br>**Symbol:** $e_{1\text{-}78}$<br>**Calculation:** IF no delay is imposed that hour (In Transit Delay Calculation ($d_{1\text{-}80}$) =0), then LOOKUP Forecasted Arrival Delay (Max of 12 Hours) ($c_{1\text{-}78}$) in "Cumulative DCOCD Cost for Duration of Delay, by Downstream Customer" Chart, otherwise set $e_{1\text{-}78} = 0$.<br>**Excel Function:** =IF(E6<1,HLOOKUP(S6,AL$17:AX$22,2,FALSE),0)<br>**Explanation:** Calculates the DCOCD Costs of delay. |
| U5-U82 | **Increased Fuel Costs (Due to Idling)**<br>**Symbol:** $f_{1\text{-}78}$<br>**Calculation:** IF "In Transit Delay" occurs ($d_{1\text{-}80} = 1.0$) then an Idling Fuel Cost is incurred (lookup "Idle Fuel Costs (IFC) Caused by Delay(s)" Table).<br>**Excel Function:** =IF(E6>0.1,AQ$37,0)<br>**Explanation:** Imposes an Idling Fuel Cost when the train is delayed and forced to Idle for the hour. |

| Cell | Definitions & Equations |
| --- | --- |
| V5-V82 | **Forecasted Incremental Increase in Labor Costs Due to Delays Beyond Normal Transit Time 1**<br>**Symbol:** $v_{1-78}$<br>**Calculation:** IF "In Transit Delay" occurs ($d_{1-80}$ = 1.0) then LOOKUP Transit Hour ($t_{1-80}$) to determine Incremental Labor Costs from Table which is added to the previous Incremental Labor Costs, otherwise, maintain previous Incremental Labor Costs.<br>**Excel Function:** =IF(E6=1,(HLOOKUP(C6,'Incremental Labor Costs'!$B$4:$CD$5,2,FALSE)+'C1 Maximized SC Profit'!V5),'C1 Maximized SC Profit'!V5)<br>**Explanation:** When a delay is imposed, the rail service provider incurs additional labor costs (due to the resulting tardiness). Depending on the transit time remaining, these additional labor costs are incrementalized and distributed across the remaining hours of the transit (& added to previously incurred labor costs). |
| X5-X82 | **Total Incremental Cost Increase (Traveling at most Efficient Speed)**<br>**Symbol:** $y_{1-78}$<br>**Calculation:** Sum of Incremental Costs such as: Increased Fuel Costs Due to Idling ($f_{1-78}$), plus Forecasted Incremental Increase in Labor Costs Due to Delays Beyond Normal Transit Time 1 ($v_{1-78}$), plus DCOCD Costs ($C_{1-78}$).<br>**Excel Function:** =SUM(U6+V6+W6)<br>**Explanation:** Calculates the incremental hourly costs incurred by traveling at Most Efficient Speed only, regardless of delay(s), extent of tardiness, DCOCD Costs, etc. |
| Y5-Y82 | **Average Speed Remaining to Arrive On Time (Minimize Tardiness)**<br>**Symbol:** $A_{1-78}$<br>**Calculation:** IF Transit Hour ($t_{40}$) is equal to current Transit Hour ($t_{1-80}$) then the Average Speed Remaining to Arrive On Time (Minimize Tardiness) ($A_{1-78}$) is equal to the Distance Remaining ($M_{1-80}$), otherwise, IF Transit Hour ($t_{40}$) is less than the current Transit Hour ($t_{1-80}$) (i.e. already late) then set speed to the Maximum Safe Speed ($S_m$), otherwise divide Distance Remaining ($M_{1-80}$) by the difference in current Transit Hour and Transit Hour at ($t_{40}$) to guarantee an on-time arrival.<br>**Excel Function:** =IF(C$44=C6,I6,IF(C$44<C6,I$1,SUM(I6/ABS(SUM(C$44-C6)))))<br>**Explanation:** Calculation determines the speed necessary to minimize Tardiness. If the train is already late, proceed at Max Safe Speed. If it is not already late, proceed at speed required to arrive on time. *Although this calculation has no upper limit on speed, the speed will be limited to Max Safe Speed before being implemented by the model.* |
| Z5-Z82 | **Increased Speed for On-Time Arrival (Minimize Tardiness)**<br>**Symbol:** $I_{1-78}$<br>**Calculation:** IF Realized Transit Hours ($h_{0-80}$) is less than zero, then set Increased Speed for On-Time Arrival (Minimize Tardiness) ($I_{1-78}$) equal to zero. Otherwise, IF In Transit Delay Calculation ($d_{1-80}$) is greater than 0.1, then set Increased Speed for On-Time Arrival (Minimize Tardiness) ($I_{1-78}$) equal to zero. Otherwise, IF Average Speed Remaining to Arrive On Time (Minimize Tardiness) ($A_{1-78}$) is equal to Most Efficient Speed ($S_e$), then set Increased Speed for On-Time Arrival (Minimize Tardiness) ($I_{1-78}$) equal to $S_e$. Otherwise, IF previous Increased Speed for On-Time Arrival (Minimize Tardiness) ($I_{1-78}$) is equal to Maximum Safe Speed ($S_m$), then set speed to $S_m$. Otherwise, IF Average Speed Remaining to Arrive On Time (Minimize Tardiness) ($A_{1-78}$) is greater than Maximum Safe Speed ($S_m$), then set speed to $S_m$. Otherwise, IF Average Speed Remaining to Arrive On Time (Minimize Tardiness) ($A_{1-78}$) is greater than Most Efficient Speed (Se), then set speed to Average Speed Remaining to Arrive On Time (Minimize Tardiness) ($A_{1-78}$). Otherwise, IF Average Speed Remaining to Arrive On Time (Minimize Tardiness) ($A_{1-78}$) is less than Most Efficient Speed (Se), then set speed to Average Speed Remaining to Arrive On Time (Minimize Tardiness) ($A_{1-78}$).<br>**Excel Function:** =IF(F6<0.1,0,IF(E6>0.1,0,IF(Y6=F$1,F$1,IF(Z5=I$1,I$1,IF(Y6>I$1,I$1, IF(Y6>F$1,Y6,IF(Y6<F$1,F$1,Y6)))))))<br>**Explanation:** Calculation determines the speed necessary to minimize Tardiness, but limits speed to no more than Max Safe Speed ($S_e$). |

| Cell | Definitions & Equations |
| --- | --- |
| AA5-AA82 | **Speed in Excess of "Most Efficient" Required to Minimize Tardiness**<br>**Symbol:** $m_{1-78}$<br>**Calculation:** IF Increased Speed for On-Time Arrival (Minimize Tardiness) $I_{1-78}$ >0, then (Increased Speed for On-Time Arrival (Minimize Tardiness) $I_{1-78}$ – Most Efficient Speed $S_e$), otherwise Zero (0).<br>**Excel Function:** IF(Z5>0,ROUNDUP(SUM(Z5-F$1),2),0)<br>**Explanation:** Reflects speeds in excess of Most Efficient to quantify increased fuel costs. |
| AB5-AB82 | **Increased Fuel Cost, Over Most Efficient, Required to Minimize Tardiness**<br>**Symbol:** $k_{1-78}$<br>**Calculation:** IF No Delays, Look Up Speed in Excess of "Most Efficient" Required to Minimize Tardiness $m_x$ * Fuel Cost Per Hour of Typical Coal Train Haul<br>**Excel Function:** IF(E5<1,IF(F5>0.1,LOOKUP(AA5,ITSFC!I$7:J$57)*'Avg Fuel Burn Rates'!H$35,0),0)<br>**Explanation:** Translates speeds in excess of Most Efficient into additional fuel cost. |
| AC5-AC82 | **Forecasted Incremental Increase in Labor Costs Due to Delays Beyond Normal Transit Time 2**<br>**Symbol:** $q_{1-78}$<br>**Calculation:** IF Increased Speed for On-Time Arrival (Minimize Tardiness) $I_x$ = Maximum Safe Speed $S_m$, IF Average Speed Remaining to Arrive On-Time (Minimize Tardiness) $A_x$ > Maximum Safe Speed $S_m$, IF previous Forecasted Incremental Increase in Labor Costs Due to Delays Beyond Normal Transit Time 2 $q_{x-1}$ < ((Additional Labor Costs of Delay ALCOD J) / (Distance Remaining $M_x$ / Maximum Safe Speed $S_m$)), otherwise previous Forecasted Incremental Increase in Labor Costs Due to Delays Beyond Normal Transit Time 2 $q_{x-1}$.<br>**Excel Function:** IF(Z6=I$1,IF(Y6>I$1,IF(AC5<(AL$37/(I6/I$1)),(AL$37/(I6/I$1)),AC5),AC5),AC5)<br>**Explanation:** Only after the train is so far behind schedule, where transit speeds must meet or exceed the Maximum Safe Speed $S_m$, are delays actually incurred; hence hourly labor costs of a delay are incurred. Unlike the other two transit schemes, this scheme assumes it can still make it on time, until the Average Speed Remaining to Arrive On Time (Minimize Tardiness) $A_{1-78}$ exceeds Maximum Safe Speed $S_m$. For example, if a train is delayed and Average Speed Remaining to Arrive On Time (Minimize Tardiness) $A_{1-78}$ exceeds 25.0, then the Additional Labor Cost of Delay J would be divided by the quotient of the Distance Remaining $M_{1-80}$ and Maximum Safe Speed $S_m$. Each hour thereafter, this calculation will be recalculated, reflecting the additional delays that are incurred by not transiting the Maximum Safe Speed $S_m$. |
| AE5-AE82 | **Total Incremental Cost Increase (Traveling at Varied Speeds to Minimize Tardiness)**<br>**Symbol:** $w_{1-78}$<br>**Calculation:** Sum of Incremental Costs such as: Increased Fuel Costs Due to Idling ($f_{1-78}$), plus Increased Fuel Cost, Over Most Efficient, Required to Minimize Tardiness ($k_{1-78}$), plus Forecasted Incremental Increase in Labor Costs Due to Delays Beyond Normal Transit Time 2 ($q_{1-78}$), plus DCOCD Costs ($C_{1-78}$),.<br>**Excel Function:** =Sum(U5+AB5+AC5+AD5)<br>**Explanation:** Calculates the incremental hourly costs incurred by traveling at speeds to minimize tardiness. |
| AF5-AF82 | **Optimal Transit Speed (for Maximum Profit)**<br>**Symbol:** $z_{1-78}$<br>**Calculation:** Minimized incremental cost between the three transit schemes: 1) Traveling at Most Efficient Speed ($y_{1-78}$) 2) Traveling at Varied Speeds to Arrive Prior to DCOCD Penalty ($x_{1-78}$) 3) Traveling at Speeds to Minimize Tardiness ($w_{1-78}$).<br>**Excel Functions:** =IF(G5=L5,F5,IF(I5=L5,H5,J5)) calculated in Tab Titled "Optimal Speed Selection" and is carried over to the Tab Titled "C1 Maximized SC Profit" cells (AF5-AF82)<br>**Explanation:** Selects the Optimal Transit Speed ($z_{1-78}$) based on the corresponding Optimal Cost ($Z_{1-78}$). |

| Cell | Definitions & Equations |
|---|---|
| AG5-AG82 | **Optimal Cost**<br>**Symbol:** $Z_{1\text{-}78}$<br>**Calculation:** Minimized incremental cost between the three transit schemes: 1) Traveling at Most Efficient Speed ($y_{1\text{-}78}$) 2) Traveling at Varied Speeds to Arrive Prior to DCOCD Penalty ($x_{1\text{-}78}$) 3) Traveling at Speeds to Minimize Tardiness ($w_{1\text{-}78}$).<br>**Excel Functions:** =MIN(G5,I5,K5) calculated in Tab Titled "Optimal Speed Selection" And in Tab Titled "C1 Maximized SC Profit" an additional calculation is performed: =IF(I5=0,0,IF(I5<0,0,'Optimal Speed Selection'!L5))<br>**Explanation:** Calculates the optimal incremental hourly cost amongst the three transit schemes: 1) Traveling at Most Efficient Speed ($y_{1\text{-}78}$) 2) Traveling at Varied Speeds to Arrive Prior to DCOCD Penalty ($x_{1\text{-}78}$) 3) Traveling at Speeds to Minimize Tardiness ($w_{1\text{-}78}$). The original calculation is performed in Tab Titled, "Optimal Speed Selection" and is carried over to the Tab Titled "C1 Maximized SC Profit", where the Optimal Cost is driven to zero when the train reaches its destination. |
| AL56 | **Increased Transit Speed Fuel Costs (ITSFC)**<br>**Symbol:** K<br>**Calculation:** Sums the hourly increased fuel costs incurred during the transit due to "increased transit speeds" in excess of most efficient speed.<br>**Excel Function:** =SUM(AI5:INDEX(AI:AI,(J84+44)))<br>**Explanation:** Calculates the additional fuel costs incurred during the transit caused by increasing transit speed over most efficient. |
| AL58 | **Expected Service Profit (ESP)**<br>**Symbol:** P<br>**Calculation:** Estimates the Expected Service Profit (ESP) by taking a random value within an established range between the Maximum and Minimum Service Profit Calculation for Coal.<br>**Excel Function:** ='Network Details'!R4<br>**Explanation:** Estimates the expected service profit the train delivery is expected to generate. Total Load size of coal trains vary, depending on terrain of route, delivery requirements and locomotive horsepower available. Car lengths range between 100 to 190 cars (norm 125). From the number of cars the total load is calculated, which provides the revenue expected, expressed as a Max/Min range. From that revenue Max/Min range, service profit range is calculated to be ~6% of revenue (see cell F10 of tab titled Fuel Traffic Profile). The Expected Service Profit is calculated via a random number between the Max/Min Service Profits (see cell R4 of tab titled Network Details). |
| AL62 | **Service Profit (SP)**<br>**Symbol:** p<br>**Calculation:** SP = ESP - UCOCD - DCOCD - ITSFC - ALCOD - IFC - OCCD<br>Estimates the Service Profit (SP) by starting with the ESP and subtracting the following costs: Upstream Customer Opportunity Cost of Delay, Downstream Customer Opportunity Cost of Delay, Increased Transit Speed Fuel Costs, Additional Labor Cost of Delay, Idle Fuel Costs, and Opportunity Cost of Cascading Delay.<br>**Excel Function:** ='Network Details'!R4-AX5-AX16-AL56-AM38-AR38-AX45<br>**Explanation:** Estimates the service profit of the train delivery, taking into account costs such as fuel, labor, and opportunity costs incurred by downstream and upstream members of the supply chain (caused by pick-up and delivery tardiness). |

| Cell | Definitions & Equation |
|---|---|
| AL64 | **Rail Service Profit (RSP)**<br>**Symbol:** R<br>**Calculation:** RSP = ESP - ALCOD - IFC - ITSFC<br>Estimates the real profit generated for the Rail Service Provider and does not take into account any opportunity costs. Starts with the ESP and subtracts the following costs: Additional Labor Cost of Delay, Idle Fuel Costs, and Increased Transit Speed Fuel Costs.<br>**Excel Function:** =AL58-AM38-AR38-AL56<br>**Explanation:** Rail Service Profit estimates the profit the rail service provider realizes in providing the delivery service, ignoring all opportunity costs. Costs such as fuel & labor are deducted from Expected Service Profits (ESP) due to the delays incurred and increased speeds transited. |

**APPENDIX C – RPM INSTANCE RESULTS OUTPUT TABLES**

Table C1: Instance 1 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 1 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| 1 | 4 | L | L | 3 | $15,784 | 5 | 5 | $12,384 | $13,384 | 5 | $12,384 | $13,384 | 0 | $3,959 | $3,959 |
| 2 | 2 | L | L | 3 | $15,784 | 5 | 5 | $12,384 | $13,384 | 5 | $12,384 | $13,384 | 0 | $9,671 | $9,671 |
| 3 | 6 | L | L | 3 | $15,784 | 5 | 5 | $12,384 | $13,384 | 5 | $12,384 | $13,384 | 0 | -$1,754 | -$1,754 |
| 4 | 4 | L | H | 3 | $15,784 | 5 | 5 | $9,384 | $11,384 | 5 | $9,384 | $11,384 | 0 | $3,959 | $3,959 |
| 5 | 2 | L | H | 3 | $15,784 | 5 | 5 | $9,384 | $11,384 | 5 | $9,384 | $11,384 | 0 | $9,671 | $9,671 |
| 6 | 6 | L | H | 3 | $15,784 | 5 | 5 | $9,384 | $11,384 | 5 | $9,384 | $11,384 | 0 | -$1,754 | -$1,754 |
| 7 | 4 | H | L | 3 | $15,784 | 5 | 5 | $6,384 | $13,384 | 0 | $4,055 | $4,255 | 0 | $3,959 | $3,959 |
| 8 | 2 | H | L | 3 | $15,784 | 5 | 5 | $6,384 | $13,384 | 0 | $9,420 | $9,620 | 0 | $9,671 | $9,671 |
| 9 | 6 | H | L | 3 | $15,784 | 5 | 5 | $6,384 | $13,384 | 0 | -$1,309 | -$1,109 | 0 | -$1,754 | -$1,754 |
| 10 | 4 | H | H | 3 | $15,784 | 5 | 5 | $3,384 | $11,384 | 0 | $3,655 | $3,855 | 0 | $3,959 | $3,959 |
| 11 | 2 | H | H | 3 | $15,784 | 5 | 5 | $3,384 | $11,384 | 0 | $9,020 | $9,220 | 0 | $9,671 | $9,671 |
| 12 | 6 | H | H | 3 | $15,784 | 5 | 5 | $3,384 | $11,384 | 0 | -$1,709 | -$1,509 | 0 | -$1,754 | -$1,754 |
| | | | | 3 | $15,784 | 5 | 5 | $7,884 | $12,384 | 2.50 | $7,370 | $8,220 | 0.00 | $3,959 | $3,959 |
| # Scenarios where strategy resulted in maximum profits: | | | | | | | | 8 | 12 | | 5 | 6 | | 4 | 0 |

Table C2: Instance 2 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 2 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $20,573 | 2 | 2 | $19,213 | $19,613 | 2 | $19,213 | $19,613 | 0 | $16,448 | $16,448 |
| **2** | 2 | L | L | 0 | $20,573 | 2 | 2 | $19,213 | $19,613 | 2 | $19,213 | $19,613 | 0 | $18,430 | $18,430 |
| **3** | 6 | L | L | 0 | $20,573 | 2 | 2 | $19,213 | $19,613 | 2 | $19,213 | $19,613 | 0 | $14,465 | $14,465 |
| **4** | 4 | L | H | 0 | $20,573 | 2 | 2 | $18,013 | $18,813 | 2 | $18,013 | $18,813 | 0 | $16,448 | $16,448 |
| **5** | 2 | L | H | 0 | $20,573 | 2 | 2 | $18,013 | $18,813 | 2 | $18,013 | $18,813 | 0 | $18,430 | $18,430 |
| **6** | 6 | L | H | 0 | $20,573 | 2 | 2 | $18,013 | $18,813 | 2 | $18,013 | $18,813 | 0 | $14,465 | $14,465 |
| **7** | 4 | H | L | 0 | $20,573 | 2 | 2 | $18,563 | $19,613 | 0 | $15,792 | $15,792 | 0 | $16,448 | $16,448 |
| **8** | 2 | H | L | 0 | $20,573 | 2 | 2 | $18,563 | $19,613 | 0 | $16,651 | $16,651 | 0 | $15,954 | $15,954 |
| **9** | 6 | H | L | 0 | $20,573 | 2 | 2 | $18,563 | $19,613 | 0 | $13,481 | $13,481 | 0 | $14,465 | $14,465 |
| **10** | 4 | H | H | 0 | $20,573 | 2 | 2 | $17,363 | $18,813 | 0 | $15,792 | $15,792 | 0 | $16,448 | $16,448 |
| **11** | 2 | H | H | 0 | $20,573 | 2 | 2 | $17,363 | $18,813 | 0 | $18,102 | $18,102 | 0 | $18,430 | $18,430 |
| **12** | 6 | H | H | 0 | $20,573 | 2 | 2 | $17,363 | $18,813 | 0 | $13,481 | $13,481 | 0 | $14,465 | $14,465 |
| | | | | **0** | **$20,573** | **2** | **2** | **$18,288** | **$19,213** | **1.00** | **$17,081** | **$17,381** | **0.00** | **$16,241** | **$16,241** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **10** | **12** | | **5** | **6** | | **2** | **0** |

Table C3: Instance 3 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 3 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| 1 | 4 | L | L | 0 | $18,547 | 7 | 7 | $12,787 | $15,187 | 6 | $14,387 | $15,587 | 0 | -$7,755 | -$7,755 |
| 2 | 2 | L | L | 0 | $18,547 | 7 | 7 | $12,787 | $15,187 | 6 | $14,387 | $15,587 | 0 | $5,116 | $5,116 |
| 3 | 6 | L | L | 0 | $18,547 | 7 | 7 | $12,787 | $15,187 | 6 | $14,387 | $15,587 | 0 | -$20,626 | -$20,626 |
| 4 | 4 | L | H | 0 | $18,547 | 7 | 7 | $8,587 | $12,387 | 6 | $10,787 | $13,187 | 0 | -$7,755 | -$7,755 |
| 5 | 2 | L | H | 0 | $18,547 | 7 | 7 | $8,587 | $12,387 | 6 | $10,787 | $13,187 | 0 | $5,116 | $5,116 |
| 6 | 6 | L | H | 0 | $18,547 | 7 | 7 | $8,587 | $12,387 | 6 | $10,787 | $13,187 | 0 | -$20,626 | -$20,626 |
| 7 | 4 | H | L | 0 | $18,547 | 7 | 7 | -$8,463 | $15,187 | 0 | -$9,369 | -$9,369 | 0 | -$7,755 | -$7,755 |
| 8 | 2 | H | L | 0 | $18,547 | 7 | 7 | -$8,463 | $15,187 | 0 | $4,309 | $4,309 | 0 | $5,116 | $5,116 |
| 9 | 6 | H | L | 0 | $18,547 | 7 | 7 | -$8,463 | $15,187 | 0 | -$23,047 | -$23,047 | 0 | -$20,626 | -$20,626 |
| 10 | 4 | H | H | 0 | $18,547 | 7 | 7 | -$12,663 | $12,387 | 0 | -$9,369 | -$9,369 | 0 | -$7,755 | -$7,755 |
| 11 | 2 | H | H | 0 | $18,547 | 7 | 7 | -$12,663 | $12,387 | 0 | $4,309 | $4,309 | 0 | $5,116 | $5,116 |
| 12 | 6 | H | H | 0 | $18,547 | 7 | 7 | -$12,663 | $12,387 | 0 | -$23,047 | -$23,047 | 0 | -$20,626 | -$20,626 |
| | | | | 0 | $18,547 | 7 | 7 | $62 | $13,787 | 3.00 | $1,609 | $2,509 | 0.00 | -$7,755 | -$7,755 |
| # Scenarios where strategy resulted in maximum profits: | | | | | | | | 2 | 6 | | 6 | 6 | | 4 | 0 |

Table C4: Instance 4 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 4 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| 1 | 4 | L | L | 0 | $21,243 | 3 | 3 | $19,203 | $19,803 | 3 | $19,203 | $19,803 | 0 | $11,801 | $11,801 |
| 2 | 2 | L | L | 0 | $21,243 | 3 | 3 | $19,203 | $19,803 | 3 | $19,203 | $19,803 | 0 | $16,402 | $16,402 |
| 3 | 6 | L | L | 0 | $21,243 | 3 | 3 | $19,203 | $19,803 | 3 | $19,203 | $19,803 | 0 | $7,200 | $7,200 |
| 4 | 4 | L | H | 0 | $21,243 | 3 | 3 | $17,403 | $18,603 | 3 | $17,403 | $18,603 | 0 | $11,801 | $11,801 |
| 5 | 2 | L | H | 0 | $21,243 | 3 | 3 | $17,403 | $18,603 | 3 | $17,403 | $18,603 | 0 | $16,402 | $16,402 |
| 6 | 6 | L | H | 0 | $21,243 | 3 | 3 | $17,403 | $18,603 | 3 | $17,403 | $18,603 | 0 | $7,200 | $7,200 |
| 7 | 4 | H | L | 0 | $21,243 | 3 | 3 | $17,753 | $19,803 | 0 | $12,364 | $12,364 | 0 | $9,433 | $9,433 |
| 8 | 2 | H | L | 0 | $21,243 | 3 | 3 | $17,753 | $19,803 | 0 | $16,684 | $16,684 | 0 | $16,402 | $16,402 |
| 9 | 6 | H | L | 0 | $21,243 | 3 | 3 | $17,753 | $19,803 | 0 | $8,045 | $8,045 | 0 | $7,200 | $7,200 |
| 10 | 4 | H | H | 0 | $21,243 | 3 | 3 | $15,953 | $18,603 | 0 | $12,364 | $12,364 | 0 | $11,801 | $11,801 |
| 11 | 2 | H | H | 0 | $21,243 | 3 | 3 | $15,953 | $18,603 | 0 | $16,684 | $16,684 | 0 | $16,402 | $16,402 |
| 12 | 6 | H | H | 0 | $21,243 | 3 | 3 | $15,953 | $18,603 | 0 | $8,045 | $8,045 | 0 | $7,200 | $7,200 |
| | | | | 0 | $21,243 | 3 | 3 | $17,578 | $19,203 | 1.50 | $15,334 | $15,784 | 0.00 | $11,604 | $11,604 |
| # Scenarios where strategy resulted in maximum profits: | | | | | | | | 11 | 12 | | 7 | 6 | | 0 | 0 |

Table C5: Instance 5 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 5 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $20,528 | 2 | 2 | $19,168 | $19,568 | 2 | $19,168 | $19,568 | 0 | $15,752 | $15,752 |
| **2** | 2 | L | L | 0 | $20,528 | 2 | 2 | $19,168 | $19,568 | 2 | $19,168 | $19,568 | 0 | $18,060 | $18,060 |
| **3** | 6 | L | L | 0 | $20,528 | 2 | 2 | $19,168 | $19,568 | 2 | $19,168 | $19,568 | 0 | $13,445 | $13,445 |
| **4** | 4 | L | H | 0 | $20,528 | 2 | 2 | $17,968 | $18,768 | 2 | $17,968 | $18,768 | 0 | $15,752 | $15,752 |
| **5** | 2 | L | H | 0 | $20,528 | 2 | 2 | $17,968 | $18,768 | 2 | $17,968 | $18,768 | 0 | $18,060 | $18,060 |
| **6** | 6 | L | H | 0 | $20,528 | 2 | 2 | $17,968 | $18,768 | 2 | $17,968 | $18,768 | 0 | $13,445 | $13,445 |
| **7** | 4 | H | L | 0 | $20,528 | 2 | 2 | $18,518 | $19,568 | 0 | $15,631 | $15,631 | 0 | $15,752 | $15,752 |
| **8** | 2 | H | L | 0 | $20,528 | 2 | 2 | $18,518 | $19,568 | 0 | $17,999 | $17,999 | 0 | $18,060 | $18,060 |
| **9** | 6 | H | L | 0 | $20,528 | 2 | 2 | $18,518 | $19,568 | 0 | $13,262 | $13,262 | 0 | $13,445 | $13,445 |
| **10** | 4 | H | H | 0 | $20,528 | 2 | 2 | $17,318 | $18,768 | 0 | $14,806 | $14,806 | 0 | $12,681 | $12,681 |
| **11** | 2 | H | H | 0 | $20,528 | 2 | 2 | $17,318 | $18,768 | 0 | $17,999 | $17,999 | 0 | $18,060 | $18,060 |
| **12** | 6 | H | H | 0 | $20,528 | 2 | 2 | $17,318 | $18,768 | 0 | $12,026 | $12,026 | 0 | $13,445 | $13,445 |
| | | | | **0** | **$20,528** | **2** | **2** | **$18,243** | **$19,168** | **1.00** | **$16,928** | **$17,228** | **0.00** | **$15,497** | **$15,497** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **10** | **12** | | **5** | **6** | | **2** | **0** |

Table C6: Instance 6 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 6 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| 1 | 4 | L | L | 0 | $19,977 | 3 | 3 | $17,937 | $18,537 | 3 | $17,937 | $18,537 | 0 | $12,242 | $12,242 |
| 2 | 2 | L | L | 0 | $19,977 | 3 | 3 | $17,937 | $18,537 | 3 | $17,937 | $18,537 | 0 | $15,990 | $15,990 |
| 3 | 6 | L | L | 0 | $19,977 | 3 | 3 | $17,937 | $18,537 | 3 | $17,937 | $18,537 | 0 | $8,495 | $8,495 |
| 4 | 4 | L | H | 0 | $19,977 | 3 | 3 | $16,137 | $17,337 | 3 | $16,137 | $17,337 | 0 | $12,242 | $12,242 |
| 5 | 2 | L | H | 0 | $19,977 | 3 | 3 | $16,137 | $17,337 | 3 | $16,137 | $17,337 | 0 | $15,990 | $15,990 |
| 6 | 6 | L | H | 0 | $19,977 | 3 | 3 | $16,137 | $17,337 | 3 | $16,137 | $17,337 | 0 | $8,495 | $8,495 |
| 7 | 4 | H | L | 0 | $19,977 | 3 | 3 | $16,487 | $18,537 | 0 | $12,265 | $12,265 | 0 | $12,242 | $12,242 |
| 8 | 2 | H | L | 0 | $19,977 | 3 | 3 | $16,487 | $18,537 | 0 | $16,001 | $16,001 | 0 | $15,990 | $15,990 |
| 9 | 6 | H | L | 0 | $19,977 | 3 | 3 | $16,487 | $18,537 | 0 | $8,529 | $8,529 | 0 | $8,495 | $8,495 |
| 10 | 4 | H | H | 0 | $19,977 | 3 | 3 | $14,687 | $17,337 | 0 | $12,265 | $12,265 | 0 | $12,242 | $12,242 |
| 11 | 2 | H | H | 0 | $19,977 | 3 | 3 | $14,687 | $17,337 | 0 | $16,001 | $16,001 | 0 | $15,990 | $15,990 |
| 12 | 6 | H | H | 0 | $19,977 | 3 | 3 | $14,687 | $17,337 | 0 | $8,529 | $8,529 | 0 | $8,495 | $8,495 |
| | | | | 0 | $19,977 | 3 | 3 | $16,312 | $17,937 | 1.50 | $14,651 | $15,101 | 0.00 | $12,242 | $12,242 |
| # Scenarios where strategy resulted in maximum profits: | | | | | | | | 11 | 12 | | 7 | 6 | | 0 | 0 |

Table C7: Instance 7 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 7 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| 1 | 4 | L | L | 0 | $13,561 | 5 | 5 | $10,161 | $11,161 | 5 | $10,161 | $11,161 | 1 | -$2,203 | -$2,003 |
| 2 | 2 | L | L | 0 | $13,561 | 5 | 5 | $10,161 | $11,161 | 5 | $10,161 | $11,161 | 1 | $5,179 | $5,379 |
| 3 | 6 | L | L | 0 | $13,561 | 5 | 5 | $10,161 | $11,161 | 5 | $10,161 | $11,161 | 1 | -$9,584 | -$9,384 |
| 4 | 4 | L | H | 0 | $13,561 | 5 | 5 | $7,161 | $9,161 | 5 | $7,161 | $9,161 | 1 | -$2,803 | -$2,403 |
| 5 | 2 | L | H | 0 | $13,561 | 5 | 5 | $7,161 | $9,161 | 5 | $7,161 | $9,161 | 1 | $4,579 | $4,979 |
| 6 | 6 | L | H | 0 | $13,561 | 5 | 5 | $7,161 | $9,161 | 5 | $7,161 | $9,161 | 1 | -$10,184 | -$9,784 |
| 7 | 4 | H | L | 0 | $13,561 | 5 | 5 | $4,161 | $11,161 | 1 | -$2,403 | -$2,003 | 1 | -$2,403 | -$2,003 |
| 8 | 2 | H | L | 0 | $13,561 | 5 | 5 | $4,161 | $11,161 | 1 | $4,979 | $5,379 | 1 | $4,979 | $5,379 |
| 9 | 6 | H | L | 0 | $13,561 | 5 | 5 | $4,161 | $11,161 | 1 | -$9,784 | -$9,384 | 1 | -$9,784 | -$9,384 |
| 10 | 4 | H | H | 0 | $13,561 | 5 | 5 | $1,161 | $9,161 | 1 | -$3,003 | -$2,403 | 1 | -$3,003 | -$2,403 |
| 11 | 2 | H | H | 0 | $13,561 | 5 | 5 | $1,161 | $9,161 | 1 | $4,379 | $4,979 | 1 | $4,379 | $4,979 |
| 12 | 6 | H | H | 0 | $13,561 | 5 | 5 | $1,161 | $9,161 | 1 | -$10,384 | -$9,784 | 1 | -$10,384 | -$9,784 |
| | | | | **0** | **$13,561** | **5** | **5** | **$5,661** | **$10,161** | **3.00** | **$2,979** | **$3,979** | **1.00** | **-$2,603** | **-$2,203** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **10** | **12** | | **8** | **6** | | **2** | **0** |

Table C8: Instance 8 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 8 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $16,541 | 4 | 4 | $13,821 | $14,621 | 4 | $13,821 | $14,621 | 1 | $8,004 | $8,204 |
| **2** | 2 | L | L | 0 | $16,541 | 4 | 4 | $13,821 | $14,621 | 4 | $13,821 | $14,621 | 1 | $11,813 | $12,013 |
| **3** | 6 | L | L | 0 | $16,541 | 4 | 4 | $13,821 | $14,621 | 4 | $13,821 | $14,621 | 1 | $4,196 | $4,396 |
| **4** | 4 | L | H | 0 | $16,541 | 4 | 4 | $11,421 | $13,021 | 4 | $11,421 | $13,021 | 1 | $7,404 | $7,804 |
| **5** | 2 | L | H | 0 | $16,541 | 4 | 4 | $11,421 | $13,021 | 4 | $11,421 | $13,021 | 1 | $11,213 | $11,613 |
| **6** | 6 | L | H | 0 | $16,541 | 4 | 4 | $11,421 | $13,021 | 4 | $11,421 | $13,021 | 1 | $3,596 | $3,996 |
| **7** | 4 | H | L | 0 | $16,541 | 4 | 4 | $11,121 | $14,621 | 1 | $7,804 | $8,204 | 1 | $7,804 | $8,204 |
| **8** | 2 | H | L | 0 | $16,541 | 4 | 4 | $11,121 | $14,621 | 1 | $11,613 | $12,013 | 1 | $11,613 | $12,013 |
| **9** | 6 | H | L | 0 | $16,541 | 4 | 4 | $11,121 | $14,621 | 1 | $3,996 | $4,396 | 1 | $3,996 | $4,396 |
| **10** | 4 | H | H | 0 | $16,541 | 4 | 4 | $8,721 | $13,021 | 1 | $7,204 | $7,804 | 1 | $7,204 | $7,804 |
| **11** | 2 | H | H | 0 | $16,541 | 4 | 4 | $8,721 | $13,021 | 1 | $11,013 | $11,613 | 1 | $10,978 | $11,578 |
| **12** | 6 | H | H | 0 | $16,541 | 4 | 4 | $8,721 | $13,021 | 1 | $3,396 | $3,996 | 1 | $3,396 | $3,996 |
| | | | | **0** | **$16,541** | **4** | **4** | **$11,271** | **$13,821** | **2.50** | **$10,063** | **$10,913** | **1.00** | **$7,601** | **$8,001** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **10** | **12** | | **8** | **6** | | **1** | **0** |

Table C9: Instance 9 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 9 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $13,817 | 4 | 4 | $11,097 | $11,897 | 4 | $11,097 | $11,897 | 1 | $8,678 | $8,678 |
| **2** | 2 | L | L | 0 | $13,817 | 4 | 4 | $11,097 | $11,897 | 4 | $11,097 | $11,897 | 1 | $11,088 | $11,088 |
| **3** | 6 | L | L | 0 | $13,817 | 4 | 4 | $11,097 | $11,897 | 4 | $11,097 | $11,897 | 1 | $6,269 | $6,269 |
| **4** | 4 | L | H | 0 | $13,817 | 4 | 4 | $8,697 | $10,297 | 4 | $8,697 | $10,297 | 1 | $8,678 | $8,678 |
| **5** | 2 | L | H | 0 | $13,817 | 4 | 4 | $8,697 | $10,297 | 4 | $8,697 | $10,297 | 1 | $11,088 | $11,088 |
| **6** | 6 | L | H | 0 | $13,817 | 4 | 4 | $8,697 | $10,297 | 4 | $8,697 | $10,297 | 1 | $6,269 | $6,269 |
| **7** | 4 | H | L | 0 | $13,817 | 4 | 4 | $8,397 | $11,897 | 1 | $8,527 | $8,527 | 1 | $8,678 | $8,678 |
| **8** | 2 | H | L | 0 | $13,817 | 4 | 4 | $8,397 | $11,897 | 1 | $11,012 | $11,012 | 1 | $11,088 | $11,088 |
| **9** | 6 | H | L | 0 | $13,817 | 4 | 4 | $8,397 | $11,897 | 1 | $6,043 | $6,043 | 1 | $6,269 | $6,269 |
| **10** | 4 | H | H | 0 | $13,817 | 4 | 4 | $5,997 | $10,297 | 1 | $8,527 | $8,527 | 1 | $8,678 | $8,678 |
| **11** | 2 | H | H | 0 | $13,817 | 4 | 4 | $5,997 | $10,297 | 1 | $11,012 | $11,012 | 1 | $11,088 | $11,088 |
| **12** | 6 | H | H | 0 | $13,817 | 4 | 4 | $5,997 | $10,297 | 1 | $6,043 | $6,043 | 1 | $6,269 | $6,269 |
| | | | | **0** | **$13,817** | **4** | **4** | **$8,547** | **$11,097** | **2.50** | **$9,212** | **$9,812** | **1.00** | **$8,678** | **$8,678** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **6** | **10** | | **5** | **5** | | **6** | **2** |

Table C10: Instance 10 results, showing profit outputs for each scenario, by transit strategy

| **Instance # (1 to 30)** | | | | **10** | | | **Traveling at Most Efficient Speed Only (MES)** | | | **Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD)** | | | **Traveling at Speeds to Minimize Tardiness (MT)** | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $22,043 | 4 | 4 | $19,323 | $20,123 | 4 | $19,323 | $20,123 | 0 | $9,938 | $9,938 |
| **2** | 2 | L | L | 0 | $22,043 | 4 | 4 | $19,323 | $20,123 | 4 | $19,323 | $20,123 | 0 | $15,830 | $15,830 |
| **3** | 6 | L | L | 0 | $22,043 | 4 | 4 | $19,323 | $20,123 | 4 | $19,323 | $20,123 | 0 | $4,045 | $4,045 |
| **4** | 4 | L | H | 0 | $22,043 | 4 | 4 | $16,923 | $18,523 | 4 | $16,923 | $18,523 | 0 | $9,938 | $9,938 |
| **5** | 2 | L | H | 0 | $22,043 | 4 | 4 | $16,923 | $18,523 | 4 | $16,923 | $18,523 | 0 | $15,830 | $15,830 |
| **6** | 6 | L | H | 0 | $22,043 | 4 | 4 | $16,923 | $18,523 | 4 | $16,923 | $18,523 | 0 | $4,045 | $4,045 |
| **7** | 4 | H | L | 0 | $22,043 | 4 | 4 | $16,623 | $20,123 | 0 | $8,695 | $8,695 | 0 | $9,938 | $9,938 |
| **8** | 2 | H | L | 0 | $22,043 | 4 | 4 | $16,623 | $20,123 | 0 | $15,209 | $15,209 | 0 | $15,830 | $15,830 |
| **9** | 6 | H | L | 0 | $22,043 | 4 | 4 | $16,623 | $20,123 | 0 | $2,182 | $2,182 | 0 | $4,045 | $4,045 |
| **10** | 4 | H | H | 0 | $22,043 | 4 | 4 | $14,223 | $18,523 | 0 | $8,695 | $8,695 | 0 | $9,938 | $9,938 |
| **11** | 2 | H | H | 0 | $22,043 | 4 | 4 | $14,223 | $18,523 | 0 | $15,209 | $15,209 | 0 | $15,830 | $15,830 |
| **12** | 6 | H | H | 0 | $22,043 | 4 | 4 | $14,223 | $18,523 | 0 | $2,182 | $2,182 | 0 | $4,045 | $4,045 |
| | | | | **0** | **$22,043** | **4** | **4** | **$16,773** | **$19,323** | **2.00** | **$13,409** | **$14,009** | **0.00** | **$9,938** | **$9,938** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **11** | **12** | | **6** | **6** | | **1** | **0** |

Table C11: Instance 11 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 11 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| 1 | 4 | L | L | 0 | $24,118 | 2 | 2 | $22,758 | $23,158 | 2 | $22,758 | $23,158 | 0 | $19,581 | $19,581 |
| 2 | 2 | L | L | 0 | $24,118 | 2 | 2 | $22,758 | $23,158 | 2 | $22,758 | $23,158 | 0 | $21,769 | $21,769 |
| 3 | 6 | L | L | 0 | $24,118 | 2 | 2 | $22,758 | $23,158 | 2 | $22,758 | $23,158 | 0 | $17,392 | $17,392 |
| 4 | 4 | L | H | 0 | $24,118 | 2 | 2 | $21,558 | $22,358 | 2 | $21,558 | $22,358 | 0 | $19,581 | $19,581 |
| 5 | 2 | L | H | 0 | $24,118 | 2 | 2 | $21,558 | $22,358 | 2 | $21,558 | $22,358 | 0 | $21,769 | $21,769 |
| 6 | 6 | L | H | 0 | $24,118 | 2 | 2 | $21,558 | $22,358 | 2 | $21,558 | $22,358 | 0 | $17,392 | $17,392 |
| 7 | 4 | H | L | 0 | $24,118 | 2 | 2 | $22,108 | $23,158 | 0 | $18,152 | $18,152 | 0 | $16,016 | $16,016 |
| 8 | 2 | H | L | 0 | $24,118 | 2 | 2 | $22,108 | $23,158 | 0 | $21,601 | $21,601 | 0 | $21,769 | $21,769 |
| 9 | 6 | H | L | 0 | $24,118 | 2 | 2 | $22,108 | $23,158 | 0 | $16,887 | $16,887 | 0 | $17,392 | $17,392 |
| 10 | 4 | H | H | 0 | $24,118 | 2 | 2 | $20,908 | $22,358 | 0 | $19,244 | $19,244 | 0 | $19,581 | $19,581 |
| 11 | 2 | H | H | 0 | $24,118 | 2 | 2 | $20,908 | $22,358 | 0 | $21,601 | $21,601 | 0 | $19,987 | $19,987 |
| 12 | 6 | H | H | 0 | $24,118 | 2 | 2 | $20,908 | $22,358 | 0 | $16,887 | $16,887 | 0 | $17,392 | $17,392 |
| | | | | 0 | $24,118 | 2 | 2 | $21,833 | $22,758 | 1.00 | $20,610 | $20,910 | 0.00 | $19,135 | $19,135 |
| # Scenarios where strategy resulted in maximum profits: | | | | | | | | 10 | 12 | | 6 | 6 | | 1 | 0 |

Table C12: Instance 12 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 12 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $14,338 | 6 | 6 | $10,258 | $11,458 | 6 | $10,258 | $11,458 | 1 | -$2,620 | -$2,420 |
| **2** | 2 | L | L | 0 | $14,338 | 6 | 6 | $10,258 | $11,458 | 6 | $10,258 | $11,458 | 1 | $5,319 | $5,519 |
| **3** | 6 | L | L | 0 | $14,338 | 6 | 6 | $10,258 | $11,458 | 6 | $10,258 | $11,458 | 1 | -$10,559 | -$10,359 |
| **4** | 4 | L | H | 0 | $14,338 | 6 | 6 | $6,658 | $9,058 | 6 | $6,658 | $9,058 | 1 | -$3,220 | -$2,820 |
| **5** | 2 | L | H | 0 | $14,338 | 6 | 6 | $6,658 | $9,058 | 6 | $6,658 | $9,058 | 1 | $4,719 | $5,119 |
| **6** | 6 | L | H | 0 | $14,338 | 6 | 6 | $6,658 | $9,058 | 6 | $6,658 | $9,058 | 1 | -$11,159 | -$10,759 |
| **7** | 4 | H | L | 0 | $14,338 | 6 | 6 | -$1,592 | $11,458 | 1 | -$3,058 | -$2,658 | 1 | -$2,820 | -$2,420 |
| **8** | 2 | H | L | 0 | $14,338 | 6 | 6 | -$1,592 | $11,458 | 1 | $5,000 | $5,400 | 1 | $4,919 | $5,319 |
| **9** | 6 | H | L | 0 | $14,338 | 6 | 6 | -$1,592 | $11,458 | 1 | -$11,116 | -$10,716 | 1 | -$10,759 | -$10,359 |
| **10** | 4 | H | H | 0 | $14,338 | 6 | 6 | -$5,192 | $9,058 | 1 | -$3,658 | -$3,058 | 1 | -$3,420 | -$2,820 |
| **11** | 2 | H | H | 0 | $14,338 | 6 | 6 | -$5,192 | $9,058 | 1 | $4,400 | $5,000 | 1 | $4,519 | $5,119 |
| **12** | 6 | H | H | 0 | $14,338 | 6 | 6 | -$5,192 | $9,058 | 1 | -$11,716 | -$11,116 | 1 | -$11,359 | -$10,759 |
| | | | | **0** | **$14,338** | **6** | **6** | **$2,533** | **$10,258** | **3.50** | **$2,550** | **$3,700** | **1.00** | **-$3,037** | **-$2,637** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **9** | **12** | | **7** | **6** | | **2** | **0** |

Table C13: Instance 13 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 13 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| 1 | 4 | L | L | 0 | $23,439 | 5 | 5 | $20,039 | $21,039 | 5 | $20,039 | $21,039 | 1 | $10,131 | $10,331 |
| 2 | 2 | L | L | 0 | $23,439 | 5 | 5 | $20,039 | $21,039 | 5 | $20,039 | $21,039 | 1 | $16,285 | $16,485 |
| 3 | 6 | L | L | 0 | $23,439 | 5 | 5 | $20,039 | $21,039 | 5 | $20,039 | $21,039 | 1 | $3,977 | $4,177 |
| 4 | 4 | L | H | 0 | $23,439 | 5 | 5 | $17,039 | $19,039 | 5 | $17,039 | $19,039 | 1 | $9,531 | $9,931 |
| 5 | 2 | L | H | 0 | $23,439 | 5 | 5 | $17,039 | $19,039 | 5 | $17,039 | $19,039 | 1 | $15,685 | $16,085 |
| 6 | 6 | L | H | 0 | $23,439 | 5 | 5 | $17,039 | $19,039 | 5 | $17,039 | $19,039 | 1 | $3,377 | $3,777 |
| 7 | 4 | H | L | 0 | $23,439 | 5 | 5 | $14,039 | $21,039 | 1 | $9,931 | $10,331 | 1 | $9,931 | $10,331 |
| 8 | 2 | H | L | 0 | $23,439 | 5 | 5 | $14,039 | $21,039 | 1 | $16,085 | $16,485 | 1 | $16,085 | $16,485 |
| 9 | 6 | H | L | 0 | $23,439 | 5 | 5 | $14,039 | $21,039 | 1 | $3,777 | $4,177 | 1 | $3,777 | $4,177 |
| 10 | 4 | H | H | 0 | $23,439 | 5 | 5 | $11,039 | $19,039 | 1 | $9,331 | $9,931 | 1 | $9,331 | $9,931 |
| 11 | 2 | H | H | 0 | $23,439 | 5 | 5 | $11,039 | $19,039 | 1 | $15,485 | $16,085 | 1 | $15,485 | $16,085 |
| 12 | 6 | H | H | 0 | $23,439 | 5 | 5 | $11,039 | $19,039 | 1 | $3,177 | $3,777 | 1 | $3,177 | $3,777 |
| | | | | 0 | $23,439 | 5 | 5 | $15,539 | $20,039 | 3.00 | $14,085 | $15,085 | 1.00 | $9,731 | $10,131 |
| # Scenarios where strategy resulted in maximum profits: | | | | | | | | 10 | 12 | | 8 | 6 | | 2 | 0 |

Table C14: Instance 14 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 14 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| **1** | 4 | L | L | 0 | $15,354 | 2 | 2 | $13,994 | $14,394 | 2 | $13,994 | $14,394 | 0 | $11,664 | $11,664 |
| **2** | 2 | L | L | 0 | $15,354 | 2 | 2 | $13,994 | $14,394 | 2 | $13,994 | $14,394 | 0 | $13,429 | $13,429 |
| **3** | 6 | L | L | 0 | $15,354 | 2 | 2 | $13,994 | $14,394 | 2 | $13,994 | $14,394 | 0 | $9,899 | $9,899 |
| **4** | 4 | L | H | 0 | $15,354 | 2 | 2 | $12,794 | $13,594 | 2 | $12,794 | $13,594 | 0 | $6,161 | $6,161 |
| **5** | 2 | L | H | 0 | $15,354 | 2 | 2 | $12,794 | $13,594 | 2 | $12,794 | $13,594 | 0 | $13,429 | $13,429 |
| **6** | 6 | L | H | 0 | $15,354 | 2 | 2 | $12,794 | $13,594 | 2 | $12,794 | $13,594 | 0 | $9,899 | $9,899 |
| **7** | 4 | H | L | 0 | $15,354 | 2 | 2 | $13,344 | $14,394 | 0 | $11,049 | $11,049 | 0 | $11,664 | $11,664 |
| **8** | 2 | H | L | 0 | $15,354 | 2 | 2 | $13,344 | $14,394 | 0 | $13,121 | $13,121 | 0 | $13,429 | $13,429 |
| **9** | 6 | H | L | 0 | $15,354 | 2 | 2 | $13,344 | $14,394 | 0 | $8,976 | $8,976 | 0 | $9,899 | $9,899 |
| **10** | 4 | H | H | 0 | $15,354 | 2 | 2 | $12,144 | $13,594 | 0 | $11,049 | $11,049 | 0 | $11,664 | $11,664 |
| **11** | 2 | H | H | 0 | $15,354 | 2 | 2 | $12,144 | $13,594 | 0 | $13,121 | $13,121 | 0 | $13,429 | $13,429 |
| **12** | 6 | H | H | 0 | $15,354 | 2 | 2 | $12,144 | $13,594 | 0 | $8,976 | $8,976 | 0 | $9,899 | $9,899 |
| | | | | **0** | **$15,354** | **2** | **2** | **$13,069** | **$13,994** | **1.00** | **$12,221** | **$12,521** | **0.00** | **$11,206** | **$11,206** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **9** | **12** | | **5** | **6** | | **3** | **0** |

Table C15: Instance 15 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 15 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $14,086 | 6 | 6 | $10,006 | $11,206 | 6 | $10,006 | $11,206 | 1 | -$6,371 | -$6,371 |
| **2** | 2 | L | L | 0 | $14,086 | 6 | 6 | $10,006 | $11,206 | 6 | $10,006 | $11,206 | 1 | $3,618 | $3,618 |
| **3** | 6 | L | L | 0 | $14,086 | 6 | 6 | $10,006 | $11,206 | 6 | $10,006 | $11,206 | 1 | -$16,359 | -$16,359 |
| **4** | 4 | L | H | 0 | $14,086 | 6 | 6 | $6,406 | $8,806 | 6 | $6,406 | $8,806 | 1 | -$9,725 | -$9,325 |
| **5** | 2 | L | H | 0 | $14,086 | 6 | 6 | $6,406 | $8,806 | 6 | $6,406 | $8,806 | 1 | $3,618 | $3,618 |
| **6** | 6 | L | H | 0 | $14,086 | 6 | 6 | $6,406 | $8,806 | 6 | $6,406 | $8,806 | 1 | -$16,359 | -$16,359 |
| **7** | 4 | H | L | 0 | $14,086 | 6 | 6 | -$1,844 | $11,206 | 0 | -$8,535 | -$8,135 | 1 | -$6,371 | -$6,371 |
| **8** | 2 | H | L | 0 | $14,086 | 6 | 6 | -$1,844 | $11,206 | 0 | $2,135 | $2,535 | 1 | $3,618 | $3,618 |
| **9** | 6 | H | L | 0 | $14,086 | 6 | 6 | -$1,844 | $11,206 | 0 | -$19,206 | -$18,806 | 1 | -$16,359 | -$16,359 |
| **10** | 4 | H | H | 0 | $14,086 | 6 | 6 | -$5,444 | $8,806 | 0 | -$9,135 | -$8,535 | 1 | -$6,371 | -$6,371 |
| **11** | 2 | H | H | 0 | $14,086 | 6 | 6 | -$5,444 | $8,806 | 0 | $1,535 | $2,135 | 1 | $3,618 | $3,618 |
| **12** | 6 | H | H | 0 | $14,086 | 6 | 6 | -$5,444 | $8,806 | 0 | -$19,806 | -$19,206 | 1 | -$16,359 | -$16,359 |
| | | | | **0** | **$14,086** | **6** | **6** | **$2,281** | **$10,006** | **3.00** | **-$315** | **$835** | **1.00** | **-$6,650** | **-$6,617** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **10** | **12** | | **6** | **6** | | **2** | **0** |

Table C16: Instance 16 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 16 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $16,727 | 3 | 3 | $14,687 | $15,287 | 3 | $14,687 | $15,287 | 0 | $9,520 | $9,520 |
| **2** | 2 | L | L | 0 | $16,727 | 3 | 3 | $14,687 | $15,287 | 3 | $14,687 | $15,287 | 0 | $13,004 | $13,004 |
| **3** | 6 | L | L | 0 | $16,727 | 3 | 3 | $14,687 | $15,287 | 3 | $14,687 | $15,287 | 0 | $6,037 | $6,037 |
| **4** | 4 | L | H | 0 | $16,727 | 3 | 3 | $12,887 | $14,087 | 3 | $12,887 | $14,087 | 0 | $5,265 | $5,265 |
| **5** | 2 | L | H | 0 | $16,727 | 3 | 3 | $12,887 | $14,087 | 3 | $12,887 | $14,087 | 0 | $13,004 | $13,004 |
| **6** | 6 | L | H | 0 | $16,727 | 3 | 3 | $12,887 | $14,087 | 3 | $12,887 | $14,087 | 0 | $6,037 | $6,037 |
| **7** | 4 | H | L | 0 | $16,727 | 3 | 3 | $13,237 | $15,287 | 0 | $8,957 | $8,957 | 0 | $9,520 | $9,520 |
| **8** | 2 | H | L | 0 | $16,727 | 3 | 3 | $13,237 | $15,287 | 0 | $12,722 | $12,722 | 0 | $13,004 | $13,004 |
| **9** | 6 | H | L | 0 | $16,727 | 3 | 3 | $13,237 | $15,287 | 0 | $5,192 | $5,192 | 0 | $6,037 | $6,037 |
| **10** | 4 | H | H | 0 | $16,727 | 3 | 3 | $11,437 | $14,087 | 0 | $8,957 | $8,957 | 0 | $9,520 | $9,520 |
| **11** | 2 | H | H | 0 | $16,727 | 3 | 3 | $11,437 | $14,087 | 0 | $12,722 | $12,722 | 0 | $13,004 | $13,004 |
| **12** | 6 | H | H | 0 | $16,727 | 3 | 3 | $11,437 | $14,087 | 0 | $5,192 | $5,192 | 0 | $6,037 | $6,037 |
| | | | | **0** | **$16,727** | **3** | **3** | **$13,062** | **$14,687** | **1.50** | **$11,372** | **$11,822** | **0.00** | **$9,166** | **$9,166** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **10** | **12** | | **5** | **6** | | **2** | **0** |

Table C17: Instance 17 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 17 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $14,924 | 6 | 6 | $10,844 | $12,044 | 6 | $10,844 | $12,044 | 1 | -$6,476 | -$6,276 |
| **2** | 2 | L | L | 0 | $14,924 | 6 | 6 | $10,844 | $12,044 | 6 | $10,844 | $12,044 | 1 | $3,684 | $3,884 |
| **3** | 6 | L | L | 0 | $14,924 | 6 | 6 | $10,844 | $12,044 | 6 | $10,844 | $12,044 | 1 | -$16,635 | -$16,435 |
| **4** | 4 | L | H | 0 | $14,924 | 6 | 6 | $7,244 | $9,644 | 6 | $7,244 | $9,644 | 1 | -$7,076 | -$6,676 |
| **5** | 2 | L | H | 0 | $14,924 | 6 | 6 | $7,244 | $9,644 | 6 | $7,244 | $9,644 | 1 | $3,084 | $3,484 |
| **6** | 6 | L | H | 0 | $14,924 | 6 | 6 | $7,244 | $9,644 | 6 | $7,244 | $9,644 | 1 | -$17,235 | -$16,835 |
| **7** | 4 | H | L | 0 | $14,924 | 6 | 6 | -$1,006 | $12,044 | 1 | -$6,676 | -$6,276 | 1 | -$6,676 | -$6,276 |
| **8** | 2 | H | L | 0 | $14,924 | 6 | 6 | -$1,006 | $12,044 | 1 | $3,484 | $3,884 | 1 | $3,484 | $3,884 |
| **9** | 6 | H | L | 0 | $14,924 | 6 | 6 | -$1,006 | $12,044 | 1 | -$16,835 | -$16,435 | 1 | -$16,835 | -$16,435 |
| **10** | 4 | H | H | 0 | $14,924 | 6 | 6 | -$4,606 | $9,644 | 1 | -$7,276 | -$6,676 | 1 | -$7,276 | -$6,676 |
| **11** | 2 | H | H | 0 | $14,924 | 6 | 6 | -$4,606 | $9,644 | 1 | $2,884 | $3,484 | 1 | $2,884 | $3,484 |
| **12** | 6 | H | H | 0 | $14,924 | 6 | 6 | -$4,606 | $9,644 | 1 | -$17,435 | -$16,835 | 1 | -$17,435 | -$16,835 |
| | | | | **0** | **$14,924** | **6** | **6** | **$3,119** | **$10,844** | **3.50** | **$1,034** | **$2,184** | **1.00** | **-$6,875** | **-$6,475** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **10** | **12** | | **8** | **6** | | **2** | **0** |

Table C18: Instance 18 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 18 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| 1 | 4 | L | L | 0 | $13,866 | 6 | 6 | $9,786 | $10,986 | 6 | $9,786 | $10,986 | 0 | $509 | $509 |
| 2 | 2 | L | L | 0 | $13,866 | 6 | 6 | $9,786 | $10,986 | 6 | $9,786 | $10,986 | 0 | $6,930 | $6,930 |
| 3 | 6 | L | L | 0 | $13,866 | 6 | 6 | $9,786 | $10,986 | 6 | $9,786 | $10,986 | 0 | -$5,929 | -$5,929 |
| 4 | 4 | L | H | 0 | $13,866 | 6 | 6 | $6,186 | $8,586 | 6 | $6,186 | $8,586 | 0 | $509 | $509 |
| 5 | 2 | L | H | 0 | $13,866 | 6 | 6 | $6,186 | $8,586 | 6 | $6,186 | $8,586 | 0 | $6,948 | $6,948 |
| 6 | 6 | L | H | 0 | $13,866 | 6 | 6 | $6,186 | $8,586 | 6 | $6,186 | $8,586 | 0 | -$5,929 | -$5,929 |
| 7 | 4 | H | L | 0 | $13,866 | 6 | 6 | -$2,064 | $10,986 | 0 | -$1,614 | -$964 | 0 | $509 | $509 |
| 8 | 2 | H | L | 0 | $13,866 | 6 | 6 | -$2,064 | $10,986 | 0 | $5,161 | $5,811 | 0 | $6,948 | $6,948 |
| 9 | 6 | H | L | 0 | $13,866 | 6 | 6 | -$2,064 | $10,986 | 3 | $989 | $989 | 0 | -$2,741 | -$691 |
| 10 | 4 | H | H | 0 | $13,866 | 6 | 6 | -$5,664 | $8,586 | 0 | -$2,414 | -$1,764 | 0 | $509 | $509 |
| 11 | 2 | H | H | 0 | $13,866 | 6 | 6 | -$5,664 | $8,586 | 0 | $4,361 | $5,011 | 0 | $6,948 | $6,948 |
| 12 | 6 | H | H | 0 | $13,866 | 6 | 6 | -$5,664 | $8,586 | 0 | -$9,189 | -$8,539 | 0 | -$5,929 | -$5,929 |
| | | | | 0 | $13,866 | 6 | 6 | $2,061 | $9,786 | 3.25 | $3,767 | $4,938 | 0.00 | $774 | $944 |
| # Scenarios where strategy resulted in maximum profits: | | | | | | | | 6 | 12 | | 6 | 6 | | 5 | 0 |

Table C19: Instance 19 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 19 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $13,232 | 4 | 4 | $10,512 | $11,312 | 4 | $10,512 | $11,312 | 0 | $2,555 | $2,555 |
| **2** | 2 | L | L | 0 | $13,232 | 4 | 4 | $10,512 | $11,312 | 4 | $10,512 | $11,312 | 0 | $7,733 | $7,733 |
| **3** | 6 | L | L | 0 | $13,232 | 4 | 4 | $10,512 | $11,312 | 4 | $10,512 | $11,312 | 0 | -$2,624 | -$2,624 |
| **4** | 4 | L | H | 0 | $13,232 | 4 | 4 | $8,112 | $9,712 | 4 | $8,112 | $9,712 | 0 | $2,555 | $2,555 |
| **5** | 2 | L | H | 0 | $13,232 | 4 | 4 | $8,112 | $9,712 | 4 | $8,112 | $9,712 | 0 | $7,733 | $7,733 |
| **6** | 6 | L | H | 0 | $13,232 | 4 | 4 | $8,112 | $9,712 | 4 | $8,112 | $9,712 | 0 | -$2,624 | -$2,624 |
| **7** | 4 | H | L | 0 | $13,232 | 4 | 4 | $7,812 | $11,312 | 0 | $2,555 | $2,555 | 0 | $2,555 | $2,555 |
| **8** | 2 | H | L | 0 | $13,232 | 4 | 4 | $7,812 | $11,312 | 0 | $7,733 | $7,733 | 0 | $7,733 | $7,733 |
| **9** | 6 | H | L | 0 | $13,232 | 4 | 4 | $7,812 | $11,312 | 0 | -$2,624 | -$2,624 | 0 | -$2,624 | -$2,624 |
| **10** | 4 | H | H | 0 | $13,232 | 4 | 4 | $5,412 | $9,712 | 0 | $2,555 | $2,555 | 0 | $2,555 | $2,555 |
| **11** | 2 | H | H | 0 | $13,232 | 4 | 4 | $5,412 | $9,712 | 0 | $7,733 | $7,733 | 0 | $7,733 | $7,733 |
| **12** | 6 | H | H | 0 | $13,232 | 4 | 4 | $5,412 | $9,712 | 0 | -$2,624 | -$2,624 | 0 | -$2,624 | -$2,624 |
| | | | | **0** | **$13,232** | **4** | **4** | **$7,962** | **$10,512** | **2.00** | **$5,933** | **$6,533** | **0.00** | **$2,555** | **$2,555** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **11** | **12** | | **7** | **6** | | **1** | **0** |

Table C20: Instance 20 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 20 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $22,327 | 8 | 8 | $14,887 | $18,487 | 5 | $12,908 | $14,108 | 2 | -$7,089 | -$6,689 |
| **2** | 2 | L | L | 0 | $22,327 | 8 | 8 | $14,887 | $18,487 | 5 | $15,498 | $16,698 | 2 | $6,699 | $7,099 |
| **3** | 6 | L | L | 0 | $22,327 | 8 | 8 | $14,887 | $18,487 | 5 | $10,319 | $11,519 | 2 | -$20,878 | -$20,478 |
| **4** | 4 | L | H | 0 | $22,327 | 8 | 8 | $10,087 | $15,287 | 5 | $9,308 | $11,708 | 2 | -$8,289 | -$7,489 |
| **5** | 2 | L | H | 0 | $22,327 | 8 | 8 | $10,087 | $15,287 | 5 | $11,898 | $14,298 | 2 | $5,499 | $6,299 |
| **6** | 6 | L | H | 0 | $22,327 | 8 | 8 | $10,087 | $15,287 | 5 | $6,719 | $9,119 | 2 | -$22,078 | -$21,278 |
| **7** | 4 | H | L | 0 | $22,327 | 8 | 8 | -$9,813 | $18,487 | 2 | -$7,739 | -$6,689 | 2 | -$7,739 | -$6,689 |
| **8** | 2 | H | L | 0 | $22,327 | 8 | 8 | -$9,813 | $18,487 | 2 | $6,049 | $7,099 | 2 | $6,049 | $7,099 |
| **9** | 6 | H | L | 0 | $22,327 | 8 | 8 | -$9,813 | $18,487 | 2 | -$21,528 | -$20,478 | 2 | -$21,528 | -$20,478 |
| **10** | 4 | H | H | 0 | $22,327 | 8 | 8 | -$14,613 | $15,287 | 2 | -$8,939 | -$7,489 | 2 | -$8,939 | -$7,489 |
| **11** | 2 | H | H | 0 | $22,327 | 8 | 8 | -$14,613 | $15,287 | 2 | $4,849 | $6,299 | 2 | $4,849 | $6,299 |
| **12** | 6 | H | H | 0 | $22,327 | 8 | 8 | -$14,613 | $15,287 | 2 | -$22,728 | -$21,278 | 2 | -$22,728 | -$21,278 |
| | | | | **0** | **$22,327** | **8** | **8** | **$137** | **$16,887** | **3.50** | **$1,385** | **$2,910** | **2.00** | **-$8,014** | **-$7,089** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **6** | **12** | | **6** | **0** | | **4** | **0** |

Table C21: Instance 21 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 21 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| 1 | 4 | L | L | 5 | $21,047 | 8 | 8 | $13,607 | $17,207 | 5 | $11,123 | $12,323 | 1 | -$8,965 | -$8,765 |
| 2 | 2 | L | L | 5 | $21,047 | 8 | 8 | $13,607 | $17,207 | 5 | $13,965 | $15,165 | 1 | $5,421 | $5,621 |
| 3 | 6 | L | L | 5 | $21,047 | 8 | 8 | $13,607 | $17,207 | 6 | $7,096 | $8,096 | 1 | -$23,351 | -$23,151 |
| 4 | 4 | L | H | 5 | $21,047 | 8 | 8 | $8,807 | $14,007 | 5 | $7,523 | $9,923 | 1 | -$9,565 | -$9,165 |
| 5 | 2 | L | H | 5 | $21,047 | 8 | 8 | $8,807 | $14,007 | 6 | $10,970 | $12,970 | 1 | $4,821 | $5,221 |
| 6 | 6 | L | H | 5 | $21,047 | 8 | 8 | $8,807 | $14,007 | 5 | $4,682 | $7,082 | 1 | -$23,951 | -$23,551 |
| 7 | 4 | H | L | 5 | $21,047 | 8 | 8 | -$11,093 | $17,207 | 1 | -$9,165 | -$8,765 | 1 | -$9,165 | -$8,765 |
| 8 | 2 | H | L | 5 | $21,047 | 8 | 8 | -$11,093 | $17,207 | 1 | $5,221 | $5,621 | 1 | $5,221 | $5,621 |
| 9 | 6 | H | L | 5 | $21,047 | 8 | 8 | -$11,093 | $17,207 | 1 | -$23,551 | -$23,151 | 1 | -$23,551 | -$23,151 |
| 10 | 4 | H | H | 5 | $21,047 | 8 | 8 | -$15,893 | $14,007 | 1 | -$9,765 | -$9,165 | 1 | -$9,765 | -$9,165 |
| 11 | 2 | H | H | 5 | $21,047 | 8 | 8 | -$15,893 | $14,007 | 1 | $4,621 | $5,221 | 1 | $4,621 | $5,221 |
| 12 | 6 | H | H | 5 | $21,047 | 8 | 8 | -$15,893 | $14,007 | 1 | -$24,151 | -$23,551 | 1 | -$24,151 | -$23,551 |
| | | | | 5 | $21,047 | 8 | 8 | -$1,143 | $15,607 | 3.17 | -$119 | $981 | 1.00 | -$9,365 | -$8,965 |
| # Scenarios where strategy resulted in maximum profits: | | | | | | | | 6 | 12 | | 6 | 0 | | 4 | 0 |

Table C22: Instance 22 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 22 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $22,757 | 4 | 4 | $20,037 | $20,837 | 4 | $20,037 | $20,837 | 0 | $7,308 | $7,308 |
| **2** | 2 | L | L | 0 | $22,757 | 4 | 4 | $20,037 | $20,837 | 4 | $20,037 | $20,837 | 0 | $14,872 | $14,872 |
| **3** | 6 | L | L | 0 | $22,757 | 4 | 4 | $20,037 | $20,837 | 4 | $20,037 | $20,837 | 0 | -$257 | -$257 |
| **4** | 4 | L | H | 0 | $22,757 | 4 | 4 | $17,637 | $19,237 | 4 | $17,637 | $19,237 | 0 | $7,308 | $7,308 |
| **5** | 2 | L | H | 0 | $22,757 | 4 | 4 | $17,637 | $19,237 | 4 | $17,637 | $19,237 | 0 | $14,872 | $14,872 |
| **6** | 6 | L | H | 0 | $22,757 | 4 | 4 | $17,637 | $19,237 | 4 | $17,637 | $19,237 | 0 | -$257 | -$257 |
| **7** | 4 | H | L | 0 | $22,757 | 4 | 4 | $17,337 | $20,837 | 0 | $7,308 | $7,308 | 0 | $7,308 | $7,308 |
| **8** | 2 | H | L | 0 | $22,757 | 4 | 4 | $17,337 | $20,837 | 0 | $14,872 | $14,872 | 0 | $14,872 | $14,872 |
| **9** | 6 | H | L | 0 | $22,757 | 4 | 4 | $17,337 | $20,837 | 0 | -$257 | -$257 | 0 | -$257 | -$257 |
| **10** | 4 | H | H | 0 | $22,757 | 4 | 4 | $14,937 | $19,237 | 0 | $7,308 | $7,308 | 0 | $7,308 | $7,308 |
| **11** | 2 | H | H | 0 | $22,757 | 4 | 4 | $14,937 | $19,237 | 0 | $14,872 | $14,872 | 0 | $14,872 | $14,872 |
| **12** | 6 | H | H | 0 | $22,757 | 4 | 4 | $14,937 | $19,237 | 0 | -$257 | -$257 | 0 | -$257 | -$257 |
| | | | | **0** | **$22,757** | **4** | **4** | **$17,487** | **$20,037** | **2.00** | **$13,072** | **$13,672** | **0.00** | **$7,308** | **$7,308** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **12** | **12** | | **6** | **6** | | **0** | **0** |

Table C23: Instance 23 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 23 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| 1 | 4 | L | L | 0 | $13,394 | 8 | 8 | $5,954 | $9,554 | 6 | -$437 | $763 | 4 | -$4,758 | -$3,958 |
| 2 | 2 | L | L | 0 | $13,394 | 8 | 8 | $5,954 | $9,554 | 6 | $4,359 | $5,559 | 4 | $2,798 | $3,598 |
| 3 | 6 | L | L | 0 | $13,394 | 8 | 8 | $5,954 | $9,554 | 6 | -$5,232 | -$4,032 | 4 | -$12,314 | -$11,514 |
| 4 | 4 | L | H | 0 | $13,394 | 8 | 8 | $1,154 | $6,354 | 6 | -$4,037 | -$1,637 | 4 | -$7,158 | -$5,558 |
| 5 | 2 | L | H | 0 | $13,394 | 8 | 8 | $1,154 | $6,354 | 6 | $759 | $3,159 | 4 | $398 | $1,998 |
| 6 | 6 | L | H | 0 | $13,394 | 8 | 8 | $1,154 | $6,354 | 6 | -$8,832 | -$6,432 | 4 | -$14,714 | -$13,114 |
| 7 | 4 | H | L | 0 | $13,394 | 8 | 8 | -$18,746 | $9,554 | 4 | -$7,458 | -$3,958 | 4 | -$7,458 | -$3,958 |
| 8 | 2 | H | L | 0 | $13,394 | 8 | 8 | -$18,746 | $9,554 | 4 | $98 | $3,598 | 4 | $98 | $3,598 |
| 9 | 6 | H | L | 0 | $13,394 | 8 | 8 | -$18,746 | $9,554 | 4 | -$15,014 | -$11,514 | 4 | -$15,014 | -$11,514 |
| 10 | 4 | H | H | 0 | $13,394 | 8 | 8 | -$23,546 | $6,354 | 4 | -$9,858 | -$5,558 | 4 | -$9,858 | -$5,558 |
| 11 | 2 | H | H | 0 | $13,394 | 8 | 8 | -$23,546 | $6,354 | 4 | -$2,302 | $1,998 | 4 | -$2,302 | $1,998 |
| 12 | 6 | H | H | 0 | $13,394 | 8 | 8 | -$23,546 | $6,354 | 4 | -$17,414 | -$13,114 | 4 | -$17,414 | -$13,114 |
| | | | | 0 | $13,394 | 8 | 8 | -$8,796 | $7,954 | 5.00 | -$5,447 | -$2,597 | 4.00 | -$7,308 | -$4,758 |
| # Scenarios where strategy resulted in maximum profits: | | | | | | | | 6 | 12 | | 6 | 0 | | 6 | 0 |

Table C24: Instance 24 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 24 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $14,782 | 3 | 3 | $12,742 | $13,342 | 3 | $12,742 | $13,342 | 0 | $6,600 | $6,600 |
| **2** | 2 | L | L | 0 | $14,782 | 3 | 3 | $12,742 | $13,342 | 3 | $12,742 | $13,342 | 0 | $10,571 | $10,571 |
| **3** | 6 | L | L | 0 | $14,782 | 3 | 3 | $12,742 | $13,342 | 3 | $12,742 | $13,342 | 0 | $2,629 | $2,629 |
| **4** | 4 | L | H | 0 | $14,782 | 3 | 3 | $10,942 | $12,142 | 3 | $10,942 | $12,142 | 0 | $6,600 | $6,600 |
| **5** | 2 | L | H | 0 | $14,782 | 3 | 3 | $10,942 | $12,142 | 3 | $10,942 | $12,142 | 0 | $10,571 | $10,571 |
| **6** | 6 | L | H | 0 | $14,782 | 3 | 3 | $10,942 | $12,142 | 3 | $10,942 | $12,142 | 0 | $2,629 | $2,629 |
| **7** | 4 | H | L | 0 | $14,782 | 3 | 3 | $11,292 | $13,342 | 0 | $6,298 | $6,298 | 0 | $6,600 | $6,600 |
| **8** | 2 | H | L | 0 | $14,782 | 3 | 3 | $11,292 | $13,342 | 0 | $10,420 | $10,420 | 0 | $10,571 | $10,571 |
| **9** | 6 | H | L | 0 | $14,782 | 3 | 3 | $11,292 | $13,342 | 0 | $2,176 | $2,176 | 0 | $2,629 | $2,629 |
| **10** | 4 | H | H | 0 | $14,782 | 3 | 3 | $9,492 | $12,142 | 0 | $6,298 | $6,298 | 0 | $6,600 | $6,600 |
| **11** | 2 | H | H | 0 | $14,782 | 3 | 3 | $9,492 | $12,142 | 0 | $10,420 | $10,420 | 0 | $10,571 | $10,571 |
| **12** | 6 | H | H | 0 | $14,782 | 3 | 3 | $9,492 | $12,142 | 0 | $2,176 | $2,176 | 0 | $2,629 | $2,629 |
| | | | | **0** | **$14,782** | **3** | **3** | **$11,117** | **$12,742** | **1.50** | **$9,070** | **$9,520** | **0.00** | **$6,600** | **$6,600** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **11** | **12** | | **6** | **6** | | **1** | **0** |

Table C25: Instance 25 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 25 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $19,592 | 5 | 5 | $16,192 | $17,192 | 5 | $16,192 | $17,192 | 1 | $2,220 | $2,420 |
| **2** | 2 | L | L | 0 | $19,592 | 5 | 5 | $16,192 | $17,192 | 5 | $16,192 | $17,192 | 1 | $10,406 | $10,606 |
| **3** | 6 | L | L | 0 | $19,592 | 5 | 5 | $16,192 | $17,192 | 5 | $16,192 | $17,192 | 1 | -$5,965 | -$5,765 |
| **4** | 4 | L | H | 0 | $19,592 | 5 | 5 | $13,192 | $15,192 | 5 | $13,192 | $15,192 | 1 | $1,620 | $2,020 |
| **5** | 2 | L | H | 0 | $19,592 | 5 | 5 | $13,192 | $15,192 | 5 | $13,192 | $15,192 | 1 | $9,806 | $10,206 |
| **6** | 6 | L | H | 0 | $19,592 | 5 | 5 | $13,192 | $15,192 | 5 | $13,192 | $15,192 | 1 | -$6,565 | -$6,165 |
| **7** | 4 | H | L | 0 | $19,592 | 5 | 5 | $10,192 | $17,192 | 1 | $2,020 | $2,420 | 1 | $2,020 | $2,420 |
| **8** | 2 | H | L | 0 | $19,592 | 5 | 5 | $10,192 | $17,192 | 1 | $10,206 | $10,606 | 1 | $10,206 | $10,606 |
| **9** | 6 | H | L | 0 | $19,592 | 5 | 5 | $10,192 | $17,192 | 1 | -$6,165 | -$5,765 | 1 | -$6,165 | -$5,765 |
| **10** | 4 | H | H | 0 | $19,592 | 5 | 5 | $7,192 | $15,192 | 1 | $1,420 | $2,020 | 1 | $1,420 | $2,020 |
| **11** | 2 | H | H | 0 | $19,592 | 5 | 5 | $7,192 | $15,192 | 1 | $9,606 | $10,206 | 1 | $9,606 | $10,206 |
| **12** | 6 | H | H | 0 | $19,592 | 5 | 5 | $7,192 | $15,192 | 1 | -$6,765 | -$6,165 | 1 | -$6,765 | -$6,165 |
| | | | | **0** | **$19,592** | **5** | **5** | **$11,692** | **$16,192** | **3.00** | **$8,206** | **$9,206** | **1.00** | **$1,820** | **$2,220** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **10** | **12** | | **8** | **6** | | **2** | **0** |

Table C26: Instance 26 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 26 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $16,166 | 1 | 1 | $15,486 | $15,686 | 1 | $15,486 | $15,686 | 0 | $12,115 | $12,115 |
| **2** | 2 | L | L | 0 | $16,166 | 1 | 1 | $15,486 | $15,686 | 1 | $15,486 | $15,686 | 0 | $14,101 | $14,101 |
| **3** | 6 | L | L | 0 | $16,166 | 1 | 1 | $15,486 | $15,686 | 1 | $15,486 | $15,686 | 0 | $10,130 | $10,130 |
| **4** | 4 | L | H | 0 | $16,166 | 1 | 1 | $14,886 | $15,286 | 1 | $14,886 | $15,286 | 0 | $12,115 | $12,115 |
| **5** | 2 | L | H | 0 | $16,166 | 1 | 1 | $14,886 | $15,286 | 1 | $14,886 | $15,286 | 0 | $14,101 | $14,101 |
| **6** | 6 | L | H | 0 | $16,166 | 1 | 1 | $14,886 | $15,286 | 1 | $14,886 | $15,286 | 0 | $10,130 | $10,130 |
| **7** | 4 | H | L | 0 | $16,166 | 1 | 1 | $15,286 | $15,686 | 0 | $12,115 | $12,115 | 0 | $12,115 | $12,115 |
| **8** | 2 | H | L | 0 | $16,166 | 1 | 1 | $15,286 | $15,686 | 0 | $14,101 | $14,101 | 0 | $14,101 | $14,101 |
| **9** | 6 | H | L | 0 | $16,166 | 1 | 1 | $15,286 | $15,686 | 0 | $10,130 | $10,130 | 0 | $10,130 | $10,130 |
| **10** | 4 | H | H | 0 | $16,166 | 1 | 1 | $14,686 | $15,286 | 0 | $12,115 | $12,115 | 0 | $12,115 | $12,115 |
| **11** | 2 | H | H | 0 | $16,166 | 1 | 1 | $14,686 | $15,286 | 0 | $14,101 | $14,101 | 0 | $14,101 | $14,101 |
| **12** | 6 | H | H | 0 | $16,166 | 1 | 1 | $14,686 | $15,286 | 0 | $10,130 | $10,130 | 0 | $10,130 | $10,130 |
| | | | | **0** | **$16,166** | **1** | **1** | **$15,086** | **$15,486** | **0.50** | **$13,651** | **$13,801** | **0.00** | **$12,115** | **$12,115** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **12** | **12** | | **6** | **6** | | **0** | **0** |

Table C27: Instance 27 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 27 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $24,171 | 5 | 5 | $20,771 | $21,771 | 5 | $20,771 | $21,771 | 0 | $12,502 | $12,502 |
| **2** | 2 | L | L | 0 | $24,171 | 5 | 5 | $20,771 | $21,771 | 5 | $20,771 | $21,771 | 0 | $18,137 | $18,137 |
| **3** | 6 | L | L | 0 | $24,171 | 5 | 5 | $20,771 | $21,771 | 5 | $20,771 | $21,771 | 0 | $6,868 | $6,868 |
| **4** | 4 | L | H | 0 | $24,171 | 5 | 5 | $17,771 | $19,771 | 5 | $17,771 | $19,771 | 0 | $8,375 | $8,375 |
| **5** | 2 | L | H | 0 | $24,171 | 5 | 5 | $17,771 | $19,771 | 5 | $17,771 | $19,771 | 0 | $18,137 | $18,137 |
| **6** | 6 | L | H | 0 | $24,171 | 5 | 5 | $17,771 | $19,771 | 5 | $17,771 | $19,771 | 0 | $6,868 | $6,868 |
| **7** | 4 | H | L | 0 | $24,171 | 5 | 5 | $14,771 | $21,771 | 0 | $11,910 | $11,910 | 0 | $12,502 | $12,502 |
| **8** | 2 | H | L | 0 | $24,171 | 5 | 5 | $14,771 | $21,771 | 0 | $17,841 | $17,841 | 0 | $18,137 | $18,137 |
| **9** | 6 | H | L | 0 | $24,171 | 5 | 5 | $14,771 | $21,771 | 0 | $5,980 | $5,980 | 0 | $6,868 | $6,868 |
| **10** | 4 | H | H | 0 | $24,171 | 5 | 5 | $11,771 | $19,771 | 0 | $11,910 | $11,910 | 0 | $12,502 | $12,502 |
| **11** | 2 | H | H | 0 | $24,171 | 5 | 5 | $11,771 | $19,771 | 0 | $17,841 | $17,841 | 0 | $18,137 | $18,137 |
| **12** | 6 | H | H | 0 | $24,171 | 5 | 5 | $11,771 | $19,771 | 0 | $5,980 | $5,980 | 0 | $6,868 | $6,868 |
| | | | | **0** | **$24,171** | **5** | **5** | **$16,271** | **$20,771** | **2.50** | **$15,591** | **$16,341** | **0.00** | **$12,158** | **$12,158** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **8** | **12** | | **5** | **6** | | **4** | **0** |

Table C28: Instance 28 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 28 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Scenario** | **Fuel $/Gal** | **DCOCD** | **Labor Cost** | **Departure Delay (Hrs)** | **Expected Service Profit (ESP) ($)** | **Sum of Delays (Hrs)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** | **Arrival Delay (Hrs)** | **Service Profit ($)** | **Rail Service Profit ($)** |
| **1** | 4 | L | L | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **2** | 2 | L | L | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **3** | 6 | L | L | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **4** | 4 | L | H | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **5** | 2 | L | H | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **6** | 6 | L | H | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **7** | 4 | H | L | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **8** | 2 | H | L | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **9** | 6 | H | L | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **10** | 4 | H | H | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **11** | 2 | H | H | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| **12** | 6 | H | H | 0 | $18,403 | 0 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 | 0 | $18,403 | $18,403 |
| | | | | **0** | **$18,403** | **0** | **0** | **$18,403** | **$18,403** | **0.00** | **$18,403** | **$18,403** | **0.00** | **$18,403** | **$18,403** |
| **# Scenarios where strategy resulted in maximum profits:** | | | | | | | | **12** | **12** | | **12** | **12** | | **12** | **12** |

Table C29: Instance 29 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 29 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| 1 | 4 | L | L | 0 | $18,180 | 1 | 1 | $17,500 | $17,700 | 1 | $17,500 | $17,700 | 0 | $16,416 | $16,416 |
| 2 | 2 | L | L | 0 | $18,180 | 1 | 1 | $17,500 | $17,700 | 1 | $17,500 | $17,700 | 0 | $17,258 | $17,258 |
| 3 | 6 | L | L | 0 | $18,180 | 1 | 1 | $17,500 | $17,700 | 1 | $17,500 | $17,700 | 0 | $15,575 | $15,575 |
| 4 | 4 | L | H | 0 | $18,180 | 1 | 1 | $16,900 | $17,300 | 1 | $16,900 | $17,300 | 0 | $16,416 | $16,416 |
| 5 | 2 | L | H | 0 | $18,180 | 1 | 1 | $16,900 | $17,300 | 1 | $16,900 | $17,300 | 0 | $17,258 | $17,258 |
| 6 | 6 | L | H | 0 | $18,180 | 1 | 1 | $16,900 | $17,300 | 1 | $16,900 | $17,300 | 0 | $15,575 | $15,575 |
| 7 | 4 | H | L | 0 | $18,180 | 1 | 1 | $17,300 | $17,700 | 0 | $16,184 | $16,184 | 0 | $16,416 | $16,416 |
| 8 | 2 | H | L | 0 | $18,180 | 1 | 1 | $17,300 | $17,700 | 0 | $17,142 | $17,142 | 0 | $17,258 | $17,258 |
| 9 | 6 | H | L | 0 | $18,180 | 1 | 1 | $17,300 | $17,700 | 0 | $15,226 | $15,226 | 0 | $15,575 | $15,575 |
| 10 | 4 | H | H | 0 | $18,180 | 1 | 1 | $16,700 | $17,300 | 0 | $15,621 | $15,621 | 0 | $12,649 | $12,649 |
| 11 | 2 | H | H | 0 | $18,180 | 1 | 1 | $16,700 | $17,300 | 0 | $17,142 | $17,142 | 0 | $17,258 | $17,258 |
| 12 | 6 | H | H | 0 | $18,180 | 1 | 1 | $16,700 | $17,300 | 0 | $15,226 | $15,226 | 0 | $15,575 | $15,575 |
| | | | | 0 | $18,180 | 1 | 1 | $17,100 | $17,500 | 0.50 | $16,645 | $16,795 | 0.00 | $16,102 | $16,102 |
| # Scenarios where strategy resulted in maximum profits: | | | | | | | | 10 | 12 | | 5 | 6 | | 2 | 0 |

Table C30: Instance 30 results, showing profit outputs for each scenario, by transit strategy

| Instance # (1 to 30) | | | | 30 | | | Traveling at Most Efficient Speed Only (MES) | | | Traveling at Speeds to Avoid DCOCD Penalty (Avoid DCOCD) | | | Traveling at Speeds to Minimize Tardiness (MT) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Scenario | Fuel $/Gal | DCOCD | Labor Cost | Departure Delay (Hrs) | Expected Service Profit (ESP) ($) | Sum of Delays (Hrs) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) | Arrival Delay (Hrs) | Service Profit ($) | Rail Service Profit ($) |
| 1 | 4 | L | L | 0 | $22,651 | 3 | 3 | $20,611 | $21,211 | 3 | $20,611 | $21,211 | 0 | $15,485 | $15,485 |
| 2 | 2 | L | L | 0 | $22,651 | 3 | 3 | $20,611 | $21,211 | 3 | $20,611 | $21,211 | 0 | $18,948 | $18,948 |
| 3 | 6 | L | L | 0 | $22,651 | 3 | 3 | $20,611 | $21,211 | 3 | $20,611 | $21,211 | 0 | $12,022 | $12,022 |
| 4 | 4 | L | H | 0 | $22,651 | 3 | 3 | $18,811 | $20,011 | 3 | $18,811 | $20,011 | 0 | $9,714 | $9,714 |
| 5 | 2 | L | H | 0 | $22,651 | 3 | 3 | $18,811 | $20,011 | 3 | $18,811 | $20,011 | 0 | $18,948 | $18,948 |
| 6 | 6 | L | H | 0 | $22,651 | 3 | 3 | $18,811 | $20,011 | 3 | $18,811 | $20,011 | 0 | $12,022 | $12,022 |
| 7 | 4 | H | L | 0 | $22,651 | 3 | 3 | $19,161 | $21,211 | 0 | $14,330 | $14,330 | 0 | $15,485 | $15,485 |
| 8 | 2 | H | L | 0 | $22,651 | 3 | 3 | $19,161 | $21,211 | 0 | $18,370 | $18,370 | 0 | $18,948 | $18,948 |
| 9 | 6 | H | L | 0 | $22,651 | 3 | 3 | $19,161 | $21,211 | 0 | $10,289 | $10,289 | 0 | $12,022 | $12,022 |
| 10 | 4 | H | H | 0 | $22,651 | 3 | 3 | $17,361 | $20,011 | 0 | $14,330 | $14,330 | 0 | $15,485 | $15,485 |
| 11 | 2 | H | H | 0 | $22,651 | 3 | 3 | $17,361 | $20,011 | 0 | $18,370 | $18,370 | 0 | $18,948 | $18,948 |
| 12 | 6 | H | H | 0 | $22,651 | 3 | 3 | $17,361 | $20,011 | 0 | $10,289 | $10,289 | 0 | $12,022 | $12,022 |
| | | | | 0 | $22,651 | 3 | 3 | $18,986 | $20,611 | 1.50 | $17,020 | $17,470 | 0.00 | $15,004 | $15,004 |
| # Scenarios where strategy resulted in maximum profits: | | | | | | | | 10 | 12 | | 5 | 6 | | 2 | 0 |

# APPENDIX D – INCREASED TRANSIT SPEED FUEL COST (ITSFC) CALCULATIONS

| Increased Fuel Consumption (Costs) | | | |
|---|---|---|---|
| **Over Most Efficient Speed** | **Low Increase** | **Moderate Increase** | |
| 0-5MPH | 0-22% | 37-57% | |
| | (0-3 Mph) | 4-5 MPH | |
| 0-10MPH | 0-30% | 35-80% | 100% |
| | (0-5 Mph) | 5-10 MPH | >10MPH |
| | | | Double normal consumption rates * |
| Increased Speed over Optimal | | | |

| Speed Increased Over Most Efficient * | | 5 MPH Spread |
|---|---|---|
| | 0 | 0.0% |
| | 1 | 5.0% |
| | 2 | 12.0% |
| | 3 | 22.0% |
| | 4 | 37.0% |
| | 5 | 57.0% |
| | 6 | |
| | 7 | |
| | 8 | |
| | 9 | |
| | 10 | |
| | 10+ | |

* Based upon Fuel Consumption Charts published by ARAIL Etc. for Models C44AC & SD70ACE

**Increased Transit Speed Fuel Costs (ITSFC) ($)**: The additional costs incurred by increasing transit speed above most efficient.

| **Fuel Cost Per Hour of Typical Coal Train Haul** | $ 1,161.11 |
|---|---|

| Increase in Speed | **5 MPH Spread** % Cost Increase | Cost Increase per Hour |
|---|---|---|
| 0 | 0.00% | $ - |
| 0.1 | 0.50% | $ 5.81 |
| 0.2 | 1.00% | $ 11.61 |
| 0.3 | 1.50% | $ 17.42 |
| 0.4 | 2.00% | $ 23.22 |
| 0.5 | 2.50% | $ 29.03 |
| 0.6 | 3.00% | $ 34.83 |
| 0.7 | 3.50% | $ 40.64 |
| 0.8 | 4.00% | $ 46.44 |
| 0.9 | 4.50% | $ 52.25 |
| 1 | 5.00% | $ 58.06 |
| 1.1 | 5.75% | $ 66.76 |
| 1.2 | 6.50% | $ 75.47 |
| 1.3 | 7.25% | $ 84.18 |
| 1.4 | 8.00% | $ 92.89 |
| 1.5 | 8.75% | $ 101.60 |
| 1.6 | 9.50% | $ 110.31 |
| 1.7 | 10.25% | $ 119.01 |
| 1.8 | 11.00% | $ 127.72 |
| 1.9 | 11.75% | $ 136.43 |
| 2 | 12.0% | $ 139.33 |
| 2.1 | 13.00% | $ 150.94 |
| 2.2 | 14.00% | $ 162.56 |
| 2.3 | 15.00% | $ 174.17 |
| 2.4 | 16.00% | $ 185.78 |
| 2.5 | 17.00% | $ 197.39 |
| 2.6 | 18.00% | $ 209.00 |
| 2.7 | 19.00% | $ 220.61 |
| 2.8 | 20.00% | $ 232.22 |
| 2.9 | 21.00% | $ 243.83 |
| 3 | 22.0% | $ 255.44 |
| 3.1 | 23.50% | $ 272.86 |
| 3.2 | 25.00% | $ 290.28 |
| 3.3 | 26.50% | $ 307.69 |
| 3.4 | 28.00% | $ 325.11 |
| 3.5 | 29.50% | $ 342.53 |
| 3.6 | 31.00% | $ 359.94 |
| 3.7 | 32.50% | $ 377.36 |
| 3.8 | 34.00% | $ 394.78 |
| 3.9 | 35.50% | $ 412.19 |
| 4 | 37.0% | $ 429.61 |
| 4.1 | 39.00% | $ 452.83 |
| 4.2 | 41.00% | $ 476.06 |
| 4.3 | 43.00% | $ 499.28 |
| 4.4 | 45.00% | $ 522.50 |
| 4.5 | 47.00% | $ 545.72 |
| 4.6 | 49.00% | $ 568.94 |
| 4.7 | 51.00% | $ 592.17 |
| 4.8 | 53.00% | $ 615.39 |
| 4.9 | 55.00% | $ 638.61 |
| 5 | 57.0% | $ 661.83 |

| Model * | HP | N8 | N7 | N6 | N5 | N4 | N3 | N2 | N1 |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Normal Cruising Speeds | | | | |
| C44AC | 4380 | 210 | 171 | 140 | 109 | 79 | 53 | 27 | 12 |
| SD70ACE | 4000 | 187 | 164 | 133 | 86 | 64 | 47 | 23 | 12 |
| | **Avg** | **201** | **169** | **138** | **100** | **74** | **53** | **25** | **13** |

* Based upon Fuel Consumption Charts published by ARAIL Etc. for Models C44AC & SD70ACE

Average Fuel Burn Rates in (Gallons/Hour) at various Throttle Positions (on level ground)

Two ways that fuel consumption is computed are gallons per hour and ton miles per gallon.

Older units such as SD45s burned around 196 gallons per hour at full rack. Newer, more efficient prime movers are putting out comparably more horsepower at around 138 gallons per hour at full rack.

Ton miles per gallon varies, but recent reports have indicated that one ton of freight can be moved up to 479 miles on a gallon of fuel (AAR, 2014)

The majority of fuel is consumed accelerating the tonnage to the max authorized speed. Once there, inertia keeps the load rolling, requiring lower throttle positions (notch four or five, often including taking units off line).

Source: www.alkrug.vcn.com

**Typical Coal Train Profile**

| | | | |
|---|---|---|---|
| **Average Coal Train Haul (miles Hauled in 2009)** | 836 | | |
| **Length of Coal Train (# Cars)** | 190 (max) 100(Min)<br>125 Typical Average | | |
| **Average car of Coal (Tons) in 2010** | 100 | 115.3 | |
| **Typical Ton-Miles of Coal Haul** | 10,450,000 | | |
| **Most Efficient Fuel Consumption Rate (Ton-Miles per Gallon)** | 450 | | |
| **Gallons of Fuel Consumed during Typical Coal Train Haul** | 23,222.22 | | |
| **Cost of Fuel per Gallon** | $2.000 | | (L-$2; M-$4; H-$6) |
| **Fuel Cost for Typical Coal Train Haul** | $ 46,444.44 | | |
| **Transit Hours of Typical Coal Haul** | 40 | | |
| **Fuel Cost Per Hour of Typical Coal Train Haul** | **$ 1,161.11** | | |
| **Fuel Consumption per hour** | 581 | | |
| **Fuel Consumption per locomotive per hour** | 145 | | |
| **Fuel Cost per Locomotive per Hour for Typical Coal Train Haul** | $290.00 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Coal Traffic in 2010** | | CalculatedClass 1 Railroad Totals for 2010 | **Coal Traffic in 2010** | | | |
| **44%** | of total Tonnage | **1,850,000,000** | **814,000,000** | Tonnage of Coal Transported in 2010 | | |
| **24%** | of all Car Loads | **29,458,333** | **7,070,000** | Car Loads of Coal in 2010 | | |
| **24%** | of Gross Revenues | **$57,400,000,000** | **$13,776,000,000** | Gross Revenues For Coal in 2010 | | |
| | **Source:** | **Railroads and Coal (July 2011, by AAR)** | | | $1,948.51 | Industry Average Gross Revenue per Car Load of Cargo |
| | Average Revenue per Ton (all other traffic - other than Coal) | **$42.11** | $16.92 | Average Revenue per Ton of Coal | 15.7% | Industry Avg Profit Margin |
| | | | 40% | Only 40% the revenue rate ($/Ton) of other (non-Coal) Class 1 Traffic… | 6.28% | Estimated Coal Margin (40% of other traffic) |
| | | | $31.03 | Industry-wide Average Revenue per Ton Hauled | | |
| | | | 55% | Only 55% the revenue rate ($/Ton) of all Class 1 Rail Traffic | | |
| | | Average car of Coal (Tons) in 2010 | 115.3 | | | |
| | | | | 680,504,000,000 | Ton Miles of Coal Hauled | |
| | | | | 5,902,029,488 | Car Miles of Coal Hauled | |
| | | Average Coal Train Haul (miles Hauled in 2009) | 836 | 834.8 | Miles Hauled | |
| | | | | $0.0202 | Rev per Ton Mile | |
| | | Length of Coal Train (# Cars) | 190 (max) 100(Min) 125 Typical Average | Using 4 Locomotives. This is usually the heaviest and longest configuration. It really depends on the route and is generally limited by grades and siding lengths. On the Colorado Joint Line and BNSF's Brush Subdivision, coal trains can be up to 130 cars in length. For the UP lines in Colorado, typical train lengths are between 100 and 110 cars on the Moffat Route and 115 to120 cars on other routes. | | |
| | **170,000,000** | Average Tons of coal stockpiled at utility companies in 2010 | | Revenue per Ton*Mile for Coal in 2009 | $0.0221 | |
| | **814,000,000** | Tonnage of Coal Transported in 2010 | | only 45% of the revenue rate (per Ton*Mile) of all other commodities | 45% | |
| | 0.208845209 | Portion of a year (stockpiled) | | | | |
| | 76.22850123 | Average of Days stockpiled at Utility Companies | | Revenue per Ton*Mile for all Commodities (other than Coal) in 2009 | $0.0494 | |

# VITA

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