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Analyzing the Financial Relationship between Railway Industry Players in Shared Railway Systems: The Train Operator's Perspective

Sam Levy

M.S. in Transportation Candidate
Civil and Environmental Engineering
Massachusetts Institute of Technology
Cambridge, MA USA
Email: samlevy@mit.edu

Maite Peña-Alcaraz

Ph.D. Candidate
Engineering Systems Division
Massachusetts Institute of Technology
Cambridge, MA USA
Email: maitepa@mit.edu

Aleksandr Prodan

Ph.D. Candidate
Researcher in Railways
Instituto Superior Técnico
Universidade de Lisboa
Av. Rovisco Pais, 1049-001
Lisbon, Portugal
Email: aleksandr.prodan@ist.utl.pt

Joseph M. Sussman

JR East Professor of Civil and
    Environmental Engineering and
    Engineering Systems
Massachusetts Institute of Technology
Cambridge, MA USA
Email: sussman@mit.edu

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9   **Sam Levy**
10   M.S. in Transportation Candidate, *Massachusetts Institute of Technology*
11   Email: samlevy@mit.edu
12
13   **Maite Pena-Alcaraz**
14   Ph.D. Candidate, Engineering Systems Division, *Massachusetts Institute of Technology*
15   Email: maitepa@mit.edu
16
17   **Aleksandr Prodan**
18   Ph.D. Candidate, Researcher in Railways
19   *Instituto Superior Técnico, Universidade de Lisboa,* Av. Rovisco Pais, 1049-001 Lisbon,
20   Portugal
21   Email: aleksandr.prodan@ist.utl.pt
22
23   **Joseph M. Sussman**
24   JR East Professor of Civil and Environmental Engineering and Engineering Systems
25   *Massachusetts Institute of Technology*, 1-163,
26   77 Massachusetts Avenue, Cambridge, MA, 02139
27   Phone: (617) 253-5430
28   Email: sussman@mit.edu

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1   **Abstract**

2   Capacity pricing and allocation play an important role in efficient management of railway
3   corridors, especially shared ones. This paper analyzes how Train Operators (TOs) would respond
4   to different track-access charges, as a first step to understand the relationship between Train
5   Operators and Infrastructure Manger (IM) in railway systems with some level of vertical
6   separation. By modeling a corridor whose users are long-distance high-speed trains and freight
7   trains along the entire corridor, and commuter trains offering services around large urban areas in
8   the corridor, this paper narrows down the focus on each individual operator, looking at the
9   factors that drive each operator's ultimate service levels. Assuming an environment where the
10   TOs are competing for capacity, financial goals and boundary conditions of each TO are derived,
11   and a number of sensitivity analyses for various typical and extreme conditions are performed.
12   This model allows to anticipate how TOs would respond to track-access charges, and can thus
13   help the government, the regulators, and the IMs in the design of appropriate capacity pricing
14   and allocation schemes.

15

1 **INTRODUCTION**

2 The underlying motivation for this work is to improve capacity pricing and capacity allocation
3 regulation on shared railway systems. Defining appropriate track-access charges and track-access
4 rights as part of these regulations is important to a well-functioning railway network because it
5 helps prevent inefficient use of scarce rail infrastructure capacity. Urban density, narrow rail
6 rights-of-way, funding challenges, environmental concerns, and localized opposition can present
7 insurmountable obstacles to infrastructure expansion, making optimal use of existing capacity
8 critical.

9 In the last twenty years, several countries have promoted shared railway systems, where
10 different Train Operators (TOs) can access the same infrastructure (tracks, stations, etc.) to
11 provide rail services. These railway systems require the implementation of some level of vertical
12 separation between Infrastructure Manager (IM) and TOs, where the TO pays for infrastructure
13 capacity that is allocated by the IM. The overall goal of this work is to examine how TOs
14 respond to different track-access charges; this can help the government, the regulators, and the
15 IMs in the design of appropriate capacity pricing and allocation schemes.

16 In the U.S., plans to improve operations in the Northeast Corridor (NEC) between
17 Washington, DC and Boston, MA are being studied by the US Federal Railroad Administration
18 (FRA), under the NEC FUTURE program. Some of the alternatives that are being studied
19 include various degrees of separation of infrastructure management and train operations. The
20 corridor shares long-distance, commuter, and, in some parts, freight traffic. An analysis of TOs
21 in the NEC like Amtrak and MBTA is used to illustrate some of the conclusions of this research.

22 In California, the plan for a new high-speed line between San Francisco and Los Angeles
23 includes sharing track in the northern part of the corridor between commuter services and long-
24 distance trains. This mixed operation will also present a challenge to capacity pricing and
25 allocation.

26 Complete separation between infrastructure management and train operations is required
27 in the European Union, and has been put into practice, usually on a line-by-line (or corridor-by-
28 corridor) basis on a few other railway lines around the world. In the European Union this process
29 involved separating financial accounting of existing state-owned railway enterprises in order to
30 make railway operations more efficient. The final outcome of the railway reform sees a market
31 where TOs compete within or for the market, either unsubsidized, or subject to Public Service
32 Obligations (PSOs). IMs manage and maintain infrastructure in an efficient way with varying
33 levels of government subsidies (depending on budgetary restrictions and government goals). A
34 good understanding of the TO motivation and response to capacity pricing and allocation
35 regulation would allow for the design of access schemes that align the incentives of the system
36 players.

37

38 **System Players**

39 Five main players are being considered in this analysis: society, the government, the regulator,
40 the IM, and TOs. Behind each entity's actions are differing motivations.

41 *Society* represents the view of the best interests of the entire population.

1   The ***Government*** is usually the investor in the infrastructure and does not necessarily
2   represent the same views as society. The government is responsible for creating laws and
3   regulations that govern different aspects related to operating the railway, from financial
4   relationships between different players to safety of operations.

5   The ***Regulator*** is responsible for enforcing existing laws and regulations. In the EU, each
6   state's regulator is responsible for ensuring that the state's national legislation is followed by all
7   other entities. The European Commission (EC) is responsible for making sure European
8   legislation has been implemented in each state's national laws, and the EC is the only entity that
9   can enforce European legislation. In the US, the Federal Railroad Administration regulates safety
10   on US Railroads.

11   The ***Infrastructure Manager (IM)*** is the entity that, at a minimum, is responsible for
12   managing and maintaining the infrastructure.

13   ***Train Operators (TOs)*** are the entities providing passenger or freight services. They may
14   or may not receive subsidies, but it is assumed that any entity subsidizing rail operators is
15   separate from the IM; that is, the IM will be under no obligation to favor one operator over
16   another.

17   In the United States, commuter train services are sometimes planned and offered for bid
18   by railway agencies while railway operators provide operations staff, perform maintenance, and
19   collect fares. By our definition, the Massachusetts Bay Transportation Authority and Peninsula
20   Corridor Joint Powers Board in California are examples of railway agencies, while Veolia
21   Transportation or TransitAmerica Services are examples of railway operators. For the purposes
22   of this paper, all references to TOs would refer to both players.

23

24   **Focusing on the TO – Infrastructure Manager Relationship**

25   One of the key goals of this research is to understand how different players respond to capacity
26   pricing and allocation regulation. Therefore, the focus in our overall work will be primarily on
27   the Train Operator – Infrastructure Manager relationship. This paper in particular will focus on
28   the TO side as a first step to understanding TO – IM problem.

29

30   **Literature Review**

31   *a. Capacity Pricing and Allocation for Shared Railway Systems*

32   James McClellan discusses the challenges of adding physical capacity and the necessity of better
33   capacity management. He notes how commuter rail can often have a disproportionate impact on
34   freight capacity because the short length of track it occupies relative to the network tend to be a
35   capacity "chokepoints" [1].

36   Judi Drew and Chris Nash provide an overview of shared-use and vertical separation in
37   the railroad industry: the impetus behind vertical separation in Europe, studies of the economic
38   impact of competition and vertical separation, as well as their own analysis of vertical
39   separation's impact on rail market share in the transport industry. The authors' findings are
40   inconclusive and they warn against the European Council moving ahead quickly with unbundling

of rail infrastructure and operations before stablishing appropriate capacity pricing and allocation regulation [2].

Stephen Gibson describes the unique nature of railway capacity and the impact of heterogeneous service patterns and train speeds. Gibson provides a brief overview of capacity pricing and capacity allocation mechanisms which he divides into cost-based mechanisms in which the operator pays a track-access charge that reflects the value of "consumed infrastructure", and quantity-based mechanisms in which the TOs disclose their willingness to pay to access the infrastructure, and the IM makes decisions about who gets access to capacity and at what time [3].

b. Relevant Legislation

In the US, the Passenger Rail Investment and Improvement Act of 2008 is relevant to the NEC. Section 208 requires Amtrak to develop a plan to bring the corridor to a state of good repair. Section 209 of the law requires the establishment of the Northeast Corridor Infrastructure and Operations Advisory Commission. The role of this commission is to develop a plan for the future of the corridor, including a plan to charge infrastructure track-access charges (fees). Amtrak must not cross-subsidize commuter, intercity and freight services, and each service must pay the costs incurred by operating that service on the network (can be interpreted as "operating/marginal/direct cost recovery"), as well as proportionate costs that can be distributed to more than one service (can be interpreted as "fixed cost recovery"). This infrastructure charging formula must be implemented six years after the passage of the law, so some time in 2014. The law, however, does not change the status quo of having Amtrak be the sole operator on the NEC.

To date, a number of European Council directives have been adopted. The most recent one is directive 2001/14/EC, part of the First Railway Package. This directive governs the capacity allocation and pricing mechanism. A new directive 2012/34/EC is in the process of being implemented. However, as the implementation document has not been adopted at the time of this writing, the extent of the changes that this document will bring is not totally clear. Directive 2001/14/EC was vague in the way it was written by design, as each country's railways were in a different financial state. This resulted in having different charging systems in each country, with different cost recovery goals. In looking at competition, the international market has already been opened for competition, and domestic markets within each country are being opened one-by-one.

TRAIN OPERATOR MODEL

This problem analyzes a corridor capable of supporting high-speed or long-distance passenger service and freight rail service as well as commuter rail service around large urban areas along the corridor. This is not unlike the NEC or the California San Francisco-Los Angeles-San Diego Coast Line in the U.S. Rail capacity is fixed in our medium-term time horizon; that is, there is no opportunity to make infrastructure improvements that will increase the maximum train throughput of the corridor. TOs may be able to adjust their capacity to better serve the users in this time frame.

FIGURE 1 Prototypical rail corridor to be evaluated

Long-distance and high-speed operators are not differentiated, as their intercity operating patterns are very similar. If a high-speed line exists, TOs will operate at the maximum possible speed to compete with other modes, since a lower-speed long-distance operator is assumed to be less competitive, often including services with differing number of stops.

In order to analyze TO profits and cash flows, a simplified model that captures main revenue and cost streams is proposed for the medium-term time-horizon [4]. TOs are assumed to be rational entities, and will only operate if their cash flows (after recovering capital costs at an adequate rate of return) are positive in the medium term. TOs are driven by profit maximization. TOs' main decisions are about the number of services that they are willing to operate, their willingness to pay to access the infrastructure, and the fares or shipping rate that they will charge the final users. The authors acknowledge that passenger rail operators may have public service requirements, dictating minimum frequencies, service spans, or fare ceilings; but nevertheless, profit maximization is the operators' objective.

While there is intermodal competition (e.g. freight rail versus truck traffic or commuter rail versus automobile or bus traffic), it is assumed that there is no intra-modal competition: there is no direct competition for traffic in the corridor between operators. The only way that operators compete directly is for available track capacity where they can run scheduled services. We also assume that the services, offered by different TOs, are not substitutes.

Train Operator Profits and Cash Flow

TO profits and cash flow can be determined by analyzing TO revenues and costs for a given number of trains, n. A TO faces cost of accessing the tracks, $ac(n)$ or track-access charges, some fixed costs, fc, such as the cost of buildings and the purchase of trains, and variable costs of operating trains, $vc \cdot n$, such as fuel, personnel, train maintenance, and train lease, if trains are being leased.

The two main sources of revenue come from the government, s (subsidies), and from transporting users (cargo or passenger). The revenues obtained from transporting users can be determined by multiplying the fare or shipping rate (f) by the demand transported. The demand transported is limited by either the capacity (reduced by a reasonable average loading factor) of the trains ($c \cdot n$) by user demand (d). According to literature, user transportation demand depends fundamentally on the fare (f), the frequency of the service (proportional to $\frac{1}{n}$), and the travel time (tt) [5]. While intercity passengers are typically more sensitive to the fare and the travel time, commuter passengers are typically more sensitive to the fare and the frequency, and freight users tend to be sensitive to the fare.

1   Summarizing, the costs and revenues of a TO can be determined using the following
2   formulas:

3    $Cost(\boldsymbol{n}, \boldsymbol{ac}) = fc + vc \cdot \boldsymbol{n} + \boldsymbol{ac}(\boldsymbol{n})$ (1)

4    $Revenues(\boldsymbol{n}, \boldsymbol{f}) = s + \boldsymbol{f} \cdot min(d(\boldsymbol{f}, \boldsymbol{n}, tt), \boldsymbol{n} \cdot c)$ (2)

5   where bold letters are used to denote the main TOs' decision variables. Note that some of these
6   variables may be pre-determined or conditioned by regulations. For instance, the fare of
7   commuter services is typically set by the government. Likewise, access charges under cost-
8   allocation and priority-rule mechanisms are fixed inputs for TOs.

9   As a result the main decisions of the TO can be characterized knowing that:

10   The TO level of service and the fares, given the access charges (ac), can be determined
11   maximizing profits:

12   $\max_{n,f} revenues(\boldsymbol{n}, \boldsymbol{f}) - costs(\boldsymbol{n})$ (3)

13   $\boxed{\max_{n,f} s + \boldsymbol{f} \cdot min(d(\boldsymbol{f}, \boldsymbol{n}, tt), c \cdot \boldsymbol{n}) - fc - vc \cdot \boldsymbol{n} - \boldsymbol{ac}(\boldsymbol{n})}$ (4)

14   Equation (4) is equivalent to: $\max_{n,f} \boldsymbol{f} \cdot min(d(\boldsymbol{f}, \boldsymbol{n}, tt), c \cdot \boldsymbol{n}) - vc \cdot \boldsymbol{n} - ac(\boldsymbol{n})$.

15   The TO willingness to pay to access the infrastructure, given the level of service and the
16   fare (n,f), can be determined ensuring that the resulting cash flow is positive:

17   $revenues - costs(\boldsymbol{ac}) \geq 0$ (5)

18   Note that CAPEX and financing costs are also required to compute cash flows. However,
19   we will assume initially that TOs have almost no CAPEX and negligible financing costs.

20   $s + f \cdot min(d(f, n, tt), c \cdot n) - fc - vc \cdot n - \boldsymbol{ac}(n) \geq 0$ (6)

21   $\boxed{\boldsymbol{ac}(n) \leq s + f \cdot min(d(f, n, tt), c \cdot n) - fc - vc \cdot n}$ (7)

22

23   **RESULTS AND IMPLICATIONS**

24   The previous formulas can be further extended in different scenarios to understand the behavior
25   of different types of TOs operating in a shared railway system.

26

27   **Scenario 1: Determination of service level and fare when users' demand is a linear function**
28   **of the fare (with some elasticity e)**

29   In this scenario, the elasticity is defined as $e = -\dfrac{\Delta d / d_0}{\Delta f / f_0} = -\dfrac{(d - d_0) \cdot f_0}{(f - f_0) \cdot d_0}$, and the demand as a

30   function of the fare can be determined using $d(f) = -e \cdot \dfrac{d_0}{f_0} \cdot f + (1 + e) \cdot d_0$.

31   *Calculations:*

32   The optimal level of service and fare (n^*, f^*) to maximize profits can be determined separating
33   the problem in two subcases:

1   *Case 1:* If $d(\boldsymbol{f}, \boldsymbol{n}, tt) \geq c \cdot \boldsymbol{n}$, i.e., if the demand transported is determined by the
2 capacity of the trains scheduled then we can start computing which is the optimal fare for a given
3 level of service $f^*(n)$. In this case, obtaining the fare that maximizes profits is equivalent to
4 obtain the fare that maximizes revenues. That means to maximize the fare with the objective of
5 ensuring a demand $(d(f) = -e \cdot \frac{d_0}{f_0} \cdot f + (1 + e) \cdot d_0)$ still higher to or equal than the capacity
6 $(c \cdot n)$. Doing the computation we obtain:

7 $\quad f^*(n) = arg \max_f f \cdot c \cdot n : d(f) \geq c \cdot n \leftrightarrow f^*(n) = \frac{(1+e)}{e} \cdot f_0 - \frac{c \cdot f_0}{e \cdot d_0} \cdot n$ (8)

8   Given this, the optimal level of service can be obtained maximizing profits:

9 $\quad n^* = arg \max_n s + f^*(n) \cdot c \cdot n - fc - vc \cdot n - ac(n)$ (9)

10   Assuming that track-access charges are linear $(ac(n) = ac_f + ac_v \cdot n)$, the optimal level
11 of service is either:

12 $\quad n^* = 0, f^* = 0$ (10)

13 $\quad n^* = \frac{(1+e) \cdot d_0}{2 \cdot c} - \frac{e \cdot d_0 \cdot (vc + ac_v)}{2 \cdot c^2 \cdot f_0}, f^* = \frac{(vc + ac_v)}{2 \cdot c} + \frac{(1+e) \cdot f_0}{2 \cdot e}$ (11)

14   Note that these computations assume that any level of service is possible. Slight
15 adjustments should be made to obtain the optimal solutions considering that possible service
16 levels are discrete (integer number of trains).

17   *Case 2:* if, conversely, $d(\boldsymbol{f}, \boldsymbol{n}, tt) < c \cdot \boldsymbol{n}$, i.e., if the demand transported is constrained
18 by the users' demand, we can still compute the optimal fare for each level of service $f^*(n)$.
19 Again, maximizing profits is equivalent to maximize revenues. That means to maximize the
20 revenue with the objective of ensuring a demand $(d(f) = -e \cdot \frac{d_0}{f_0} \cdot f + (1 + e) \cdot d_0)$ lower than
21 the capacity $(c \cdot n)$. Doing the computation we obtain:

22 $\quad f^*(n) = arg \max_f f \cdot d(f) : d(f) \leq c \cdot n \leftrightarrow f^*(n) = \frac{(1+e)}{2e} \cdot f_0$ (12)

23   Given this, the optimal level of service can be obtained maximizing profits:

24 $\quad n^* = arg \max_n s + f^*(n) \cdot d(f^*(n)) - fc - vc \cdot n - ac(n)$ (13)

25   Assuming again that track-access charges are linear $(ac(n) = ac_f + ac_v \cdot n)$, we obtain
26 that the optimal level of service is:

27 $\quad n^* = \left\lceil \frac{(1+e) \cdot d_0}{2 \cdot c} \right\rceil, f^* = \frac{(1+e) \cdot f_0}{2 \cdot e}$ (14)

28   Summarizing, the optimal level of service and fare (n^*, f^*) to maximize profits are either:

29 $\quad n^* = \left\lceil \frac{(1+e) \cdot d_0}{2 \cdot c} \right\rceil, f^* = \frac{(1+e) \cdot f_0}{2 \cdot e},$

30 $\quad n^* = \frac{(1+e) \cdot d_0}{2 \cdot c} - \frac{e \cdot d_0 \cdot (vc + ac_v)}{2 \cdot c^2 \cdot f_0}, f^* = \frac{(vc + ac_v)}{2 \cdot c} + \frac{(1+e) \cdot f_0}{2 \cdot e},$ or   (15)

31 $\quad n^* = 0, f^* = 0$

Implications:

Despite the complex mathematical expressions, these formulas can be distilled to obtain some implications:

1. When variable costs are small with respect to the fares that users can afford, the optimal solution is to maximize revenues and offer the minimum number of trains that allow serving all the demand for the optimal fare.

2. When variable costs are comparable to the fares that users can afford, the optimal solution is a trade-off between maximizing revenues and covering variable costs. In this case, the capacity should be optimized in such a way that most demand is served without providing excess train capacity.

3. Finally, in those cases in which the users cannot viably accept a fare level that allows TOs to cover at least the variable costs, the TO should not operate any train.

We can illustrate these points with an example, inspired in the Amtrak intercity services of the NEC:

According to [6] a TO like Amtrak faces fixed operational (direct) costs of $fc = \$102.5m$ per year ($fc = \$281k$ per day) and variable operational costs of $vc = \$1.25m$ per train and per year ($vc = \$3,425$ per train and per day). The elasticity of the demand is estimated by [7] to be equal to $e = 0.67$. In 2013, Amtrak's average fare were equal to $f_0 = \$96.5$, the level of service averaged $n = 150$ trains per day, with a realized demand of $d_0 = 11.4m$ passengers per year ($d_0 = 31,250$ passengers per day), and with an average train capacity of $c = 250$ passengers, with 80% + load factor [6]. No subsidies are required for the operation of intercity services in the NEC [8][9].

FIGURE 2 represents the intercity TO expected profits when the strategies presented in equation 15 are used to determine the level of service and the fare. The profits obtained with these strategies are then compared to those obtained using current level of service and current fares. No fixed track-access charges are considered.

In this case, the revenue maximizing strategy (first alternative presented in equation 15) suggests operating 105 trains per day with fares on the order of $120. The no excess-capacity strategy proposes fares ranging from $127 and $137, and a level of service between 98 and 90 trains per day respectively.

Note that in the case of Amtrak intercity services in the NEC, when variable access charges are lower than $1,000 per train and per day; the variable access charges are low in comparison with potential revenues, an thus the profit maximizing strategy correspond to the first strategy (revenue maximizing strategies) as expected. However, as track-access charges increase, variable costs are comparable to revenues. It thus become worthy to avoid excess-capacity.
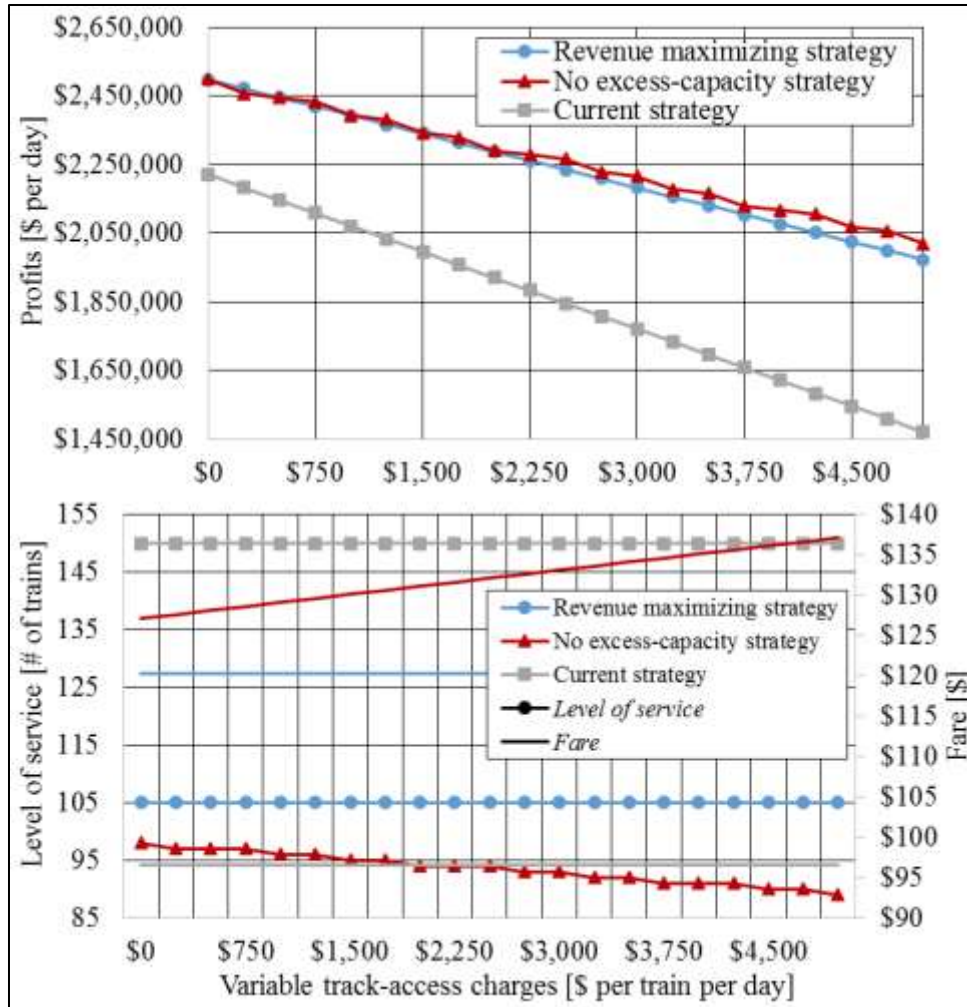
FIGURE 2 Amtrak's expected profits for different track-access variable charges using different strategies to determine the level of service and the user's fare

These formulas can also be used to determine maximum track-access charges that the TO would be able to bare. Considering these values, an operator like Amtrak would be able to continue operating trains with track-access charges around $50,000 per train and per day, but with a low level of service. The TO would not operate any service with track-access charges above $60,000 per train per day.

Note that although both strategies point out that a lower level of service than the one currently operated with higher fares would lead to higher profits, it also shows that any effort to reduce fares in the corridor would lead to higher demand from the TO to schedule trains in the infrastructure. Similar results are obtained for a broad range of fare elasticity values: lower elasticity representing business users willing to pay high fares to ride convenient Amtrak services, and higher elasticity representing additional users that start to ride Amtrak instead of other transportation alternatives.

1 **Scenario 2: Determining the level of service and track-access charges willingness to pay**
2 **when fares are constant (either because demand is very elastic to fares, i.e., almost all the**
3 **demand is lost if a user's fare is above certain fare threshold or fares are set by the**
4 **government (f_0)) and demand depends on level of service.**

5 In this scenario, the elasticity to the level of service can be defined as $e_n = -\frac{\Delta d/d_0}{\Delta h/h_0}$ where h is

6 the average headway between consecutive trains. Since the headway is proportional to $1/n$, the

7 elasticity can also be computed as $e_n = -\frac{(d-d_0)\cdot n}{(n-n_0)\cdot d_0}$. Therefore, the demand can be determined

8 by $d(n) = (1 + e_n) \cdot d_0 - \frac{e_n \cdot d_0 \cdot n_0}{n}$.

9 *Calculations:*

10 The optimal level of service and fare (n^*, f^*) to maximize profits can be determined repeating
11 the same type calculations carried out for Scenario 1. Assuming again that track-access charges
12 are linear $(ac(n) = ac_f + ac_v \cdot n)$, it is determined that the optimal level of service that a TO
13 can operate would be either:

14 $$n^* = \sqrt{\frac{f \cdot e_n \cdot d_0 \cdot n_0}{vc + ac_v}},$$

15 $$n^* = \frac{(1+e_n)\cdot d_0 \cdot n_0}{2\cdot c} - \frac{\sqrt{(1+e_n)^2 \cdot d_0^2 \cdot n_0^2 - 4\cdot c \cdot e_n \cdot d_0 \cdot n_0}}{2c}, \text{ or} \qquad (16)$$

16 $$n^* = 0$$

17   Again, the choice of one level of service over the other would depend on how revenues
18 and cost compare. If revenues obtained from fares are much higher than variable costs, then the
19 optimal strategy to maximize profit would be to maximize revenues. If revenues are comparable
20 to variable costs, the optimal strategy would be to ensure that there is no excess-capacity on the
21 trains. Finally, if variable costs are much higher than the revenues per train, the TO should not
22 operate any train.

23   Note that this level of service is independent on the level of subsides and the fixed costs
24 (from operations and access-charges). These values would only affect to whether the TO cash
25 flow are positive and hence the TO can sustainably operate these level of service.

26 *Implications*

27 This scenario is representative of the situation of the commuter rail TOs in the NEC. According
28 to [10][11] a TO like the MBTA, the commuter operator in the Boston area, faces fixed
29 operational (direct) costs of $fc = \$435.1k$ per day and variable operational costs of $vc = $
30 $\$1,666$ per train and per day. The elasticity of the demand with respect to the headway
31 (frequency) is estimated by [12] to be equal to $e = 0.41$. In 2014, MBTA's average fare ranged
32 from $f_0 = \$7 - \$25$ (average fare of $f_0 = \$13$ are considered), the level of service averaged
33 $n_0 = 485$ trains per day, with a realized demand of $d_0 = 130.6k$ passengers per day. The train
34 average capacity considered is $c = 350$ passengers, with $80\% +$ load factor. Subsidies $s = $
35 $\$234k$ per day are considered following [10][11].

36   Using these parameters as inputs in the formulas we obtain that:

1

2
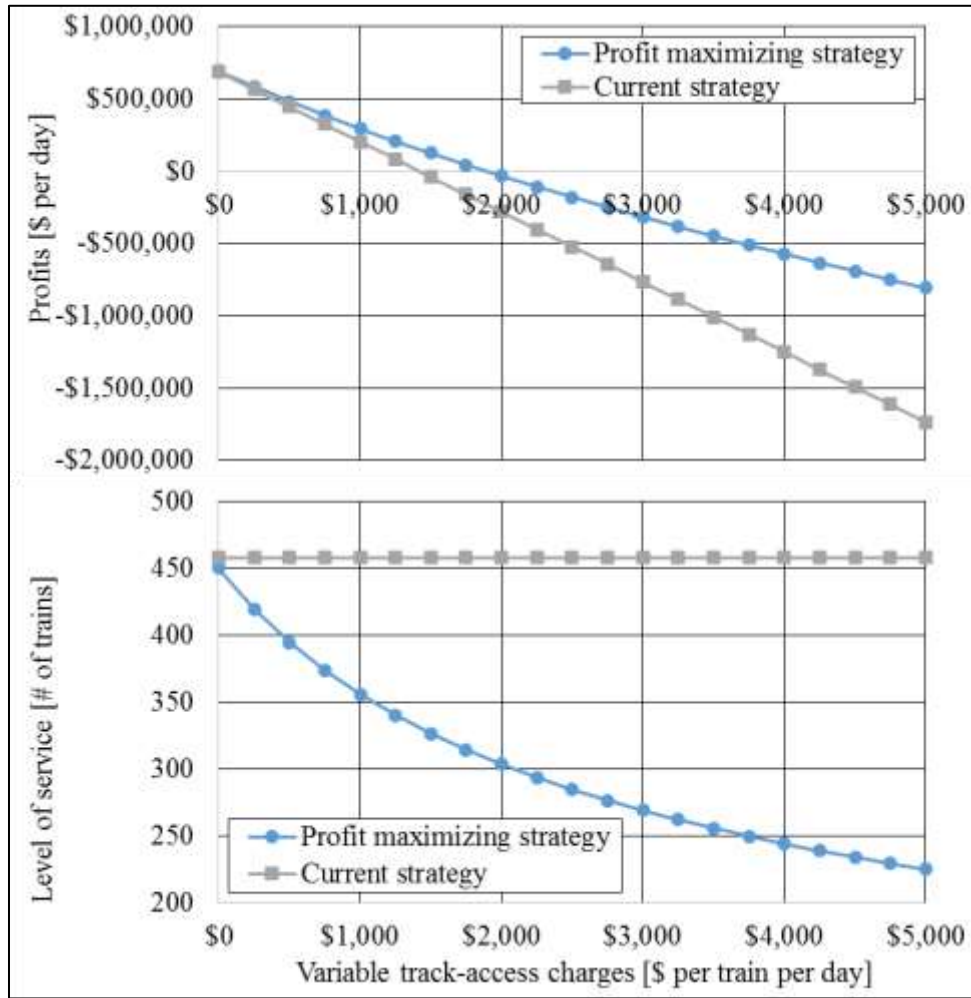
FIGURE 3 MBTA's expected profits for different track-access variable charges using different strategies to determine the level of service

In the case of MBTA, only the first part of equation 16 produces a non-zero level of service. **FIGURE 3** compares current MBTA profits with the expected profits when the profit maximizing strategy presented in equation 16 is used to determine the level of service. The results show that higher profits can be unlocked by reducing the number of services, especially when variable costs increase due to track-access charges. Note that, under both strategies, despite of the subsidy, the TO would not be able to operate if access charges exceed $2,000 per train per day.

1 **Scenario 3: Determination of track-access charges willingness to pay given a certain level of**
2 **service**

3 This scenario assumes again that the demand depends linearly on the fare with some elasticity
4 (e): $d(f) = (1 + e) \cdot d_0 - e \cdot \frac{d_0}{f_0} \cdot f$. The former equation can be rewritten as $d(f) = \bar{n} - e'f$,
5 where $\bar{n} = (1 + e) \cdot d_0$ is the highest possible expected demand, and a new elasticity $e' = e \cdot \frac{d_0}{f_0}$
6 is defined to simplify the calculations. This scenario has been designed to represent freight
7 operators in railway systems like the NEC. This scenario assumes zero subsidies. For simplicity,
8 we will also assume that the demand is expressed in terms of the number of trains (there is
9 demand for a freight train or not).

10 *Calculations*

11 In this case, $n \leq d(f) \leq \bar{n}$ since no operator will be interested in operating a freight train if there
12 is no demand for it. As a result, for a given number of trains (n), the fare (shipping rate) that a
13 monopolistic operator would charge to the users is: $f(n) = \frac{\bar{n} - n}{e}$.

14   The TO's willingness to pay to access the infrastructure can then be computed using
15 equation 7:

16 $ac(n) \leq f(n) \cdot n - fc - vc \cdot n$ (17)

17   Using the shipping rate determined above, $f(n)$, the average track-access charge that the
18 freight operator is willing to pay when he is able to schedule n_f trains is:

19 $$ac \leq \frac{\bar{n} - n}{e} - \frac{fc}{n} - vc$$ (18)

20 *Implications*

21 The implications of this formula can be better illustrated with some numbers and sensitivity
22 analysis.

23   *Case 1:* Assuming a maximum demand $\bar{n} = 25$ trains per day, a very high elasticity
24 (meaning that all demand is lost if shipping rate exceed a value of $f(n) = f = \$50k$ per train for
25 the calculations), variable costs of $vc = \$10k$ per train and per day and moderate fixed costs of
26 $fc = \$20k$ per day, we obtain the maximum access charges willingness to pay shown in
27 equation (19) and **FIGURE 4**.

28 $ac \leq 50 - \frac{20}{n} - 10 = \begin{cases} n = 1, \; af \leq \$20k \; per \; train, \; f = \$50k \\ n = 2, af \leq \$30k \; per \; train, \; f = \$50k \\ n = 5, \; af \leq \$36k \; per \; train, \; f = \$50k \\ n = 10, \; af \leq \$38k \; per \; train, \; f = \$50k \end{cases}$ (19)

29   In this case, shipping rates are constant due to the high elasticity. The operator cannot
30 raise rates because he will lose a significant part of demand nor can he lower rates because track
31 capacity is scarce and he will not be able to satisfy the increased demand.

32   Note that if the freight operator is not sure of which train (if any) would be scheduled, it
33 should ensure that the profits are positive even in the worst possible scenario (only one train
34 scheduled). As a consequence, if the demand is very elastic to the tariff, $ac \leq f - fc - vc$.

1   Conversely, if the freight operator is able to schedule n trains, then the track-access
2 charges he would be willing to pay would be: $ac \leq f - vc - fc/n$, that is, $\$(n-1)fc/n$, more
3 per train than for a single train if demand is very elastic to the shipping rate. As a result, ***if the***
4 ***fixed costs are high and the demand is extremely elastic, a regulation that ensures that the***
5 ***operator would be able to schedule at least n trains would be very beneficial.***
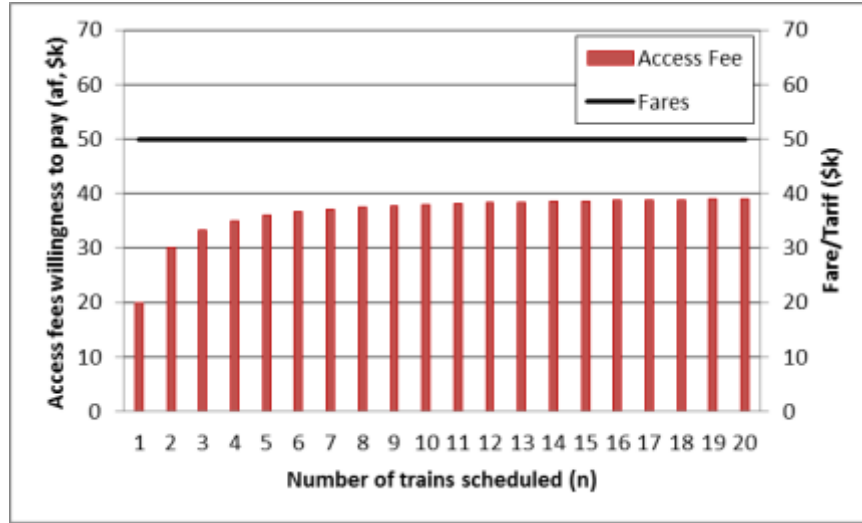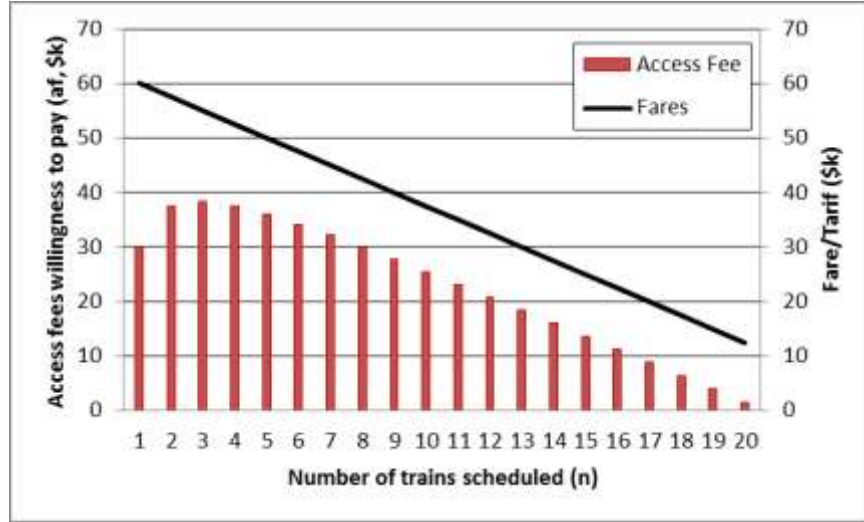

6
7 **FIGURE 4   Freight operator track-access charge: willingness to pay as a function of**
8 **number of trains scheduled for high demand elasticity**

9   With such regulation, track-access charges that the operators will be able to pay will be:
10 $ac \leq f - vc - fc/\underline{n}$, that is, the freight operator will be able to offer $\$(\underline{n}-1)fc/\underline{n}$ more per
11 train.

12   *Case 2:* Assuming a maximum demand $\bar{n} = 25$ trains per day, an elasticity of $e = 0.4$,
13 variable costs of $vc = \$10k$ per train and per day and moderate fixed costs of $fc = \$20k$ per
14 day, the optimal shipping rate as a function of the level of service is: $f(n) = f = \$((25 -$
15 $n)/0.4)k$ per train. Maximum access charges willingness to pay shown in equation (20) and
16 **FIGURE 5**.

17 $$ac \leq \frac{25-n}{0.4} - \frac{20}{n} - 10 = \begin{cases} n = 1, \ af \leq \$30k \ per \ train, \ f = \$60k \\ n = 2, \ af \leq \$38k \ per \ train, \ f = \$58k \\ n = 5, \ af \leq \$36k \ per \ train, \ f = \$50k \\ n = 10, \ af \leq \$26k \ per \ train, \ f = \$38k \end{cases} \qquad (20)$$

18   In this case, due to the lower level of the elasticity, the operator has power to increase
19 shipping rates without significantly impacting demand. Since the operator's total variable cost is
20 increasing and the fixed cost per train is decreasing with increasing freight service, there is an
21 optimal level of service at which the operator's track-access charges willingness to pay is
22 maximized. Note that operators should not necessarily respond to decreasing track-access
23 charges by increasing service; that is, the low demand elasticity to shipping rates corresponds to
24 a low derived demand to schedule trains elasticity to track-access charges.

1

2 **FIGURE 5   Freight operator track-access charge willingness to pay as a function of**
3 **number of trains scheduled for low demand elasticity**

4   *Case 3:* Finally, assuming a maximum demand $\bar{n} = 25$ trains per day, an elasticity of
5 $e = 0.4$, variable costs of $vc = \$10k$ per train and per day and no fixed costs ($fc = \$0$ per day),
6 the optimal shipping rate as a function of the level of service is: $f(n) = f = \$\left(\frac{25-n}{0.4}\right)k$ per train.
7 Maximum access charges willingness to pay shown in equation (21) and **FIGURE 6**.

8 $$ac \leq \frac{25-n}{0.4} - 10 = \begin{cases} n = 1, \ af \leq \$50k \ per \ train, \ f = \$60k \\ n = 2, \ af \leq \$48k \ per \ train, \ f = \$58k \\ n = 5, \ af \leq \$40k \ per \ train, \ f = \$50k \\ n = 10, \ af \leq \$28k \ per \ train, \ f = \$38k \end{cases}$$ (21)
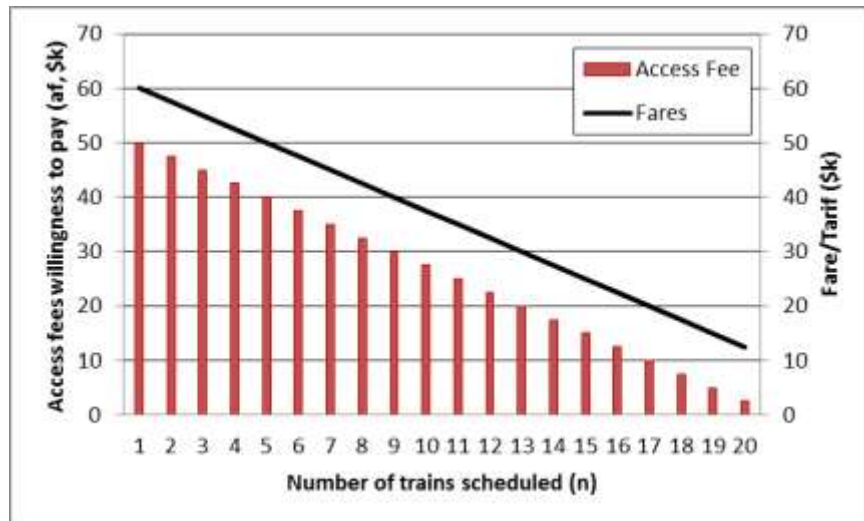
9

10 **FIGURE 6   Freight operator track-access charges willingness to pay as a function of**
11 **number of trains scheduled for low demand elasticity and no operators fixed cost**

12   This case shows that when operator fixed costs are low and demand elasticity is less than
13 1, the operator's track-access charges willingness to pay decreases by the inverse of elasticity

1   with each additional train scheduled. Similar results are obtained with $\bar{n} = 70\ to\ 100$ trains per
2   day, following the current level of freight service operated in the NEC today. Note again that the
3   use of this model allows the government, the regulator, or the IM to determine the maximum
4   access charges that a freight TO is able to pay without the need of extensive information about
5   the TO operation.

6

7   **CONCLUSIONS AND FURTHER RESEARCH**

8   This research is of use for train operators – both railway agencies and railway operators –
9   because it provides insight regarding fares and level of service that TOs could operate to
10 maximize profits for different levels of track-access charges. In the United States, railway
11 agencies, equipped with knowledge of budgetary constraints, cost data, and infrastructure
12 charges, could use this research as a starting point for cost-estimation and as a tool to check the
13 reasonableness of service level assumptions before tendering operating contracts. Railway
14 operators could likewise use the tool to measure the long term viability of their operating plans.

15   This research provides value to infrastructure managers in that it elucidates the challenges
16 of managing a corridor with multiple railroad operators. As shown in our scenarios, certain forms
17 of regulation and access charges can stifle operator service expansion and cost the IM revenues
18 needed to maintain the infrastructure in a state-of-good repair. In order for this research to add
19 value to IMs, they must anticipate and understand the service goals and infrastructure needs of
20 operators on their network.

21   It is worth noting that this research is a first step in that it does not consider infrastructure
22 constraints. The next step would be to consider how much of the services that the TOs would like
23 to provide can be scheduled in the existing infrastructure. Assuming there is more demand for
24 scheduling train paths than the infrastructure can allow, regulation is required to allocate capacity
25 between operators.

26   Government and regulators can use this research as a tool to help understand the industry
27 landscape. In the U.S. the use of these types of models is important to evaluate how the railway
28 system would respond to new capacity pricing and allocation regulation like the one to be
29 implemented in the Northeast Corridor. The European Union's stated goal of increasing rail
30 market share in the transportation sector depends on sound regulation of track access charges and
31 striking a balance between creating a competitive environment and one in which both TOs and
32 IMs with high fixed costs can thrive.

33   On the political side, institutional constrains play just as an important role as
34 infrastructure constrains. Certain agencies may have public service requirements that dictate
35 station stops or certain levels of service such as travel time or frequency of service. Further
36 research will reveal how these institutional constraints affect all of the aforementioned players.
37 Certain political requirements may lead to capacity inefficiencies; further research can quantify
38 those inefficiencies and lead to recommendations for improving regulation.

39   Further research directions would also include gathering additional real-world data to
40 validate the findings and evaluate train operators' historical decisions regarding service levels.
41 The assumption of no intra-modal competition could be changed to look at the resulting effects
42 on service plans as it already happens in countries like Italy, where Trenitalia and Italo provide

1 high-speed rail services in the same infrastructure. This would require better quantification of
2 demand cross-elasticity of fare, travel time, and frequency.

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