The Use of Passenger Transit Infrastructure for Goods Movement:
A Bay Area Economic Feasibility Study

by

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ABSTRACT

As demand for air cargo movement rises, so does truck traffic on California’s roads. In turn, traffic congestion, harmful emissions, maintenance costs, and accidents all increase. One potential alternative to truck transport of goods is mixed passenger-goods movement on urban rail networks, a concept motivated by several potential benefits to involved parties. These benefits include additional revenue to rail operators, more reliable travel times, reductions in harmful trucking externalities, and more efficient usage of existing facilities.

As a case study, the use of the Bay Area Rapid Transit (BART) system for FedEx Express cargo movement is examined in the following paper. FedEx Express was particularly selected due to the location of the company’s major hub at Oakland International Airport (OAK).

To analyze the potential costs and benefits of the use of BART for FedEx transport, two alternatives are compared against the status quo of truck-only transport. The first alternative assumes only minor capital investment, while the second assumes far greater capital investment, including a jointly operated BART/FedEx facility at OAK. Truck VMT, FedEx operating costs, BART operating costs, and CO₂ emissions are determined for the status quo and each alternative. Analysis shows that significant truck VMT savings can be accrued from mixed-goods service, as well as that given sufficient demand, such service can both be profitable for passenger rail systems and cost-effective for air cargo carriers. This study can provide motivation for similarly analyzing other metropolitan areas with major transit systems, such as Los Angeles, Washington D.C., and New York.
As demand for air freight movement increases, so does truck traffic on California’s roads. As truck transport grows, so do the problems attached with it, including traffic congestion, harmful emissions, maintenance costs, and accidents. There exists an imperative to explore alternatives to truck transport for freight movement, specifically the potential for existing passenger rail networks to operate as a mode of freight transport. This concept is motivated by several potential benefits to all parties. A passenger rail network offering service to both passengers and air freight carriers can provide itself with a) a more efficient use of its existing capacity, particularly during the off-peak periods, b) an additional source of revenue, and c) potential source of cross-subsidization, where revenue from freight revenue can be reinvested into improved passenger movement. The freight carrier, by shifting goods from truck transport to rail transport, can potentially benefit from a) more reliable travel times for goods movement, particularly during periods of non-recurrent congestion, b) fewer truck accidents, and c) cheaper transport costs. Society, as a whole, may benefit from reduced truck traffic through reductions in a) harmful emissions and GHGs, b) truck-induced delay, c) road maintenance costs, and d) other negative externalities, such as noise and truck-related accidents.

With this concept in mind, this paper provides a case study of the potential for the use of transit systems such as BART (the Bay Area Rapid Transit), in the movement of air cargo. The economic feasibility of such a system is presented from a purely operational perspective. A later report will include the required capital costs, but for the purposes of this paper, capital investments are considered sunk costs. Clearly, if mixed-goods service is found to be fiscally infeasible from an operational perspective, there will be no need to examine the required capital expenditure. The paper is structured as follows. Section 2 describes the critical characteristics of the system under analysis. Section 3 outlines the assumptions and methodology of the economic feasibility model. This model explores three different operation scenarios: the status quo, an alternative requiring minimal capital expenditure (Alternative A), and an alternative requiring significant capital expenditure (Alternative B). Section 4 discusses the quantitative results of the economic feasibility study. Section 5 discusses how this type of service might be further investigated.

2 SYSTEM CHARACTERISTICS

This section describes the characteristics of the system under analysis, specifically that of the major passenger rail operator in the Bay Area, BART, as well as one of the area’s major air cargo carriers, FedEx Express. These two parties present unique capabilities and restrictions which must be considered for accurate cost-benefit analysis.

2.1 Characteristics of the BART System

BART is the Bay Area’s primary passenger rail transit system which connects more than 26 cities across four counties. The system’s construction began in 1964, and now exhibits over 104 miles of track connecting 43 stations (see Figure 1). BART provides five lines of service at headways of approximately 15 minutes. However, due to the extensive overlaying of lines throughout the system, the frequency of service can be very high during peak periods. The system also has a high on-time reliability of nearly 95%. While the current BART system has few sidings to allow for passing, the system has interchanges at transfer stations which allow trains to travel between any two points seamlessly. The BART system is electrically powered and emits no air pollution.
Unlike many other urban passenger rail systems, BART utilizes a nonstandard gauge of 5 ft 6 in; the standard gauge most commonly found in the U.S. is 4 ft 8.5 in. Consequently, the system relies on custom-made rolling stock, which totals 669 cars. The dimensions for the vehicles currently used by BART are 70 ft X 10.5 ft X 7 ft (length X width X height). Door dimensions are approximately 4.5 ft X 6.5 ft (width X height). Due to each BART station’s length (~710 ft), BART typically does not operate trains longer than 10 cars. Each BART car has a load capacity of 30,000 lbs. BART trains are also able to operate in both directions without the need to turn around. During a typical morning peak-hour commute, 541 cars are in service, while the remainder are either used to build spare trains, in repair, or involved with other maintenance work. In lieu of the increased stress being placed on BART’s current vehicles, the transit agency is looking to purchase 700 new cars in an effort to upgrade its entire fleet by 2024.

Future planned BART extensions include a track extension of the Fremont line southward to San Jose (scheduled for construction by 2018), and potentially a connection to the Oakland International Airport (OAK).

These future projects have the potential to strengthen the viability of mixed-goods service by BART. Retired BART cars could be retrofitted and used for freight movement. If the Oakland Airport Connector project can accommodate existing BART vehicles, a truck transshipment link between OAK and the existing BART network could be eliminated for mixed-goods service. Currently, BART uses 30% of its capacity on average for daily passenger movement with the other 70% unused. Here, the capacity calculated is based on current operation with 15 minute headways and ten-car consists. However, if BART system adopts modern technologies in communication and control systems, the operation headway could be greatly reduced and the capacity could be doubled, or even tripled.
2.2 Characteristics of the Air Freight Carrier: FedEx Express

Air freight carriers, such as FedEx, DHL, and UPS all have a strong need for frequent, reliable, and cost-effective chain of transportation. With the recent withdrawal of DHL from the U.S. air and ground carrier markets, a significant portion of carrier market share will likely be subsumed by FedEx and UPS, which will further stress their existing transport chains. Furthermore, the overall market volume is expected to increase with the growing number of imports from rapidly emerging regions such as the Pacific Rim.

FedEx Express presents itself as a particularly promising participant in an economic feasibility study due to its strong presence in the Bay Area. The FedEx Western Regional Hub at OAK acts as a sorting and distribution center to seven states on the West Coast. Smaller distribution centers are scattered throughout the Bay Area, in cities such as Concord, Dublin, and San Jose. FedEx Express also maintains flights to and from the San Francisco International Airport (SFO). As traffic congestion continues to increase along the Bay Area’s urban corridors, FedEx has been exploring service alternatives which provide greater reliability.

All FedEx container types, other than the standard USPS container type, are transported throughout the FedEx transport chain using ball-bearings; that is, items are not lifted onto pallets in order to be loaded onto trucks. Rather, containers are simply slid across platforms and aboard trucks via the casters mounted throughout loading platforms.

FedEx utilizes two truck types, CTV4 and CTV5 (Figure 2), which differ in truck length (unpublished data – Michael Graham, FedEx). The CTV4 is approximately 45 feet long, and the CTV5 is approximately 53 feet long. Both trucks are 10.5 ft wide. As mentioned, truck beds are retrofitted with ball-bearings to allow for seamless loading and unloading of FedEx containers. It is also important to note that FedEx containers operate within a “closed loop” for security purposes – that is, once a container is initially filled and closed before distribution, it remains closed until it reaches its final local sorting center.

FIGURE 2 FedEx Long-Haul Truck, type CTV5 (unpublished data – Michael Graham, FedEx)

FedEx Express demand is time dependent. FedEx packages originating from locations outside the Bay Area and destined for the Bay Area are distributed in the morning between 3:00 AM and 7:00 AM. FedEx Express packages originating from the Bay Area and destined for locations outside the Bay Area are collected between 5:00 PM and 9:00 PM.

3 MODEL ASSUMPTIONS AND METHODOLOGY

This section outlines the assumptions used for this economic feasibility study.

3.1 Case Study Alternatives

This analysis examines two alternatives for BART mixed-goods service over the 20-year period between 2021 and 2040. Both will be compared against the status quo (SQ), where only
trucks will be used for transport of FedEx products. Alternative A will consider a scenario where little capital investment is required; only existing BART yards, maintenance areas, and those stations with adequate room for additional track siding (Milpitas and Dublin/Pleasanton), will be used as FedEx transfer terminals. Note that Alternative A requires FedEx truck transshipments at both ends. For Alternative B, a jointly operated BART/FedEx facility at the FedEx Oakland Regional Hub is assumed. This would require a connection between OAK and the existing BART network. The MTC, the Bay Area’s regional planning commission, has been considering a connection between OAK and the BART system; if BART freight trains could be accommodated along this connection, a truck transshipment link could be eliminated. Alternative B also includes sufficient capital investment to allow for retrofitting of existing BART stations, specifically the Glen Park and South San Francisco stations, so that these stations can adequately facilitate FedEx goods movement. Note that for all alternatives, only operating cost expenditures are considered (note also that all costs are expressed in 2008 $). Both alternatives will require certain capital expenditure towards loading/unloading platforms for containers, stripping and retrofitting of BART cars, and other station modifications to ensure segregation between passengers and FedEx containers. A future report is expected to outline the necessary capital expenditures for both alternatives in order to fully determine overall economic feasibility.

3.2 Exclusive Rights by FedEx Express to BART Freight Movement Services

Here, economic analysis only considers the transport of FedEx Express products. It may be beneficial to also consider UPS products, since inclusion of additional products could lead to the critical demand threshold for economic feasibility being passed. However, considering this additional demand source would require further inspection into UPS container types and handling requirements.

Interestingly, UPS actively participated in feasibility studies in 2008, and they maintain interest in the possibility of goods movement using BART. They are particularly interested in freight movement between SFO and OAK since they do not operate flights from SFO; all their products from the San Francisco area have to be transferred to OAK for air transport. However, due to limited data availability, economic analysis at this stage will focus on FedEx products.

3.3 Locations

A simple graphical depiction of the network for each alternative is shown in Figure 3. There are six FedEx Express distribution centers in the Bay Area (listed in the “Key” to the figure) which are located near the following existing/future BART facilities: Oakland, Concord, Hayward, Dublin, downtown San Francisco, South San Francisco, and Milpitas. The BART Milpitas station is scheduled for construction in 2018. The lone exception is node 4b in Alternative A; while there is no BART station at this location, there is a small BART maintenance facility known as the Oakland Annex Shop, where there is a spur track and adequate room for truck loading/offloading. Note also that node 4ab acts jointly as a BART station and FedEx center in Alternative B.

BART stations such as Colma, Union City, and Concord are of particular interest due to their proximity to BART maintenance yards, which are completely separated from passenger movements. Subsequently, these yards will behave as “depots” for freight consists in Alternatives A and B, meaning that all trains must be assembled in one of these yards before serving a particular route. Furthermore, while some node names correspond to BART station names, it is emphasized that the nodes themselves either 1) correspond to BART yards for
Alternative A, or 2) correspond to BART yards or loading facilities built in proximity to existing
stations for Alternative B. Segregating passengers and cargo movements will help mitigate both
station congestion and conflicts between passenger and freight consists, which could otherwise
be problematic during peak ridership hours.

3.4 Demand
An origin-destination (OD) demand matrix has been developed through communications
with FedEx, but scaled so that true demand is not disclosed (for proprietary reasons). This
matrix, shown in Table 2, roughly conveys the assumed daily demand, in [lbs] across the given
locations for the year 2009. A demand growth rate of 6% per year is also incorporated in order
to capture the expected future increases in goods movement. This growth rate value was
determined according to the Metropolitan Transportation Commission’s (MTC) current and
future estimates of Bay Area air cargo demand (1).

Demand patterns follow the time windows mentioned in Section 2, where all distribution
takes place during the AM period, and all collection takes place during the PM period.

<table>
<thead>
<tr>
<th>TABLE 1 O-D Demand Matrix (lbs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a: From OAK</td>
</tr>
<tr>
<td>-----------------</td>
</tr>
<tr>
<td>RHV</td>
</tr>
<tr>
<td>HWD</td>
</tr>
</tbody>
</table>

3.5 Container Type
Note that all FedEx container types, other than the USPS containers, would not be able to
both a) fit through existing BART car doors, and b) be transported via BART, because they
require caster decks for movement. Thus, rather than completely retrofitting BART cars to fit all
FedEx container types, which could be prohibitively expensive, it is more reasonable to only
consider transport of USPS containers using modified BART cars. The USPS container has size:
5.75 ft X 3.5 ft X 5 ft (length X width X height). A load density of 5.5 lbs/ft$^3$ is assumed, which
is roughly equivalent to the average load density of most existing FedEx container types
(unpublished data).

3.6 Vehicle Types and Capacities
All FedEx trucks are assumed to be of type CTV5 for analysis (Figure 2). Truck capacity
is constrained both by container shape and weight; when considering both of these constraints,
trucks have a capacity limit of 16 USPS containers.

All BART cars are assumed to be retrofitted bi-directionally operable “C” cars freight
movement; these cars should be available after the agency begins fleet overhaul in 2018. A
BART “C” car could readily be stripped of all seating and fitted with locking mechanisms for
wheeled FedEx containers. A single BART car, when considering the weight and shape of USPS
containers as well as the dimensions of car doorways, can hold 24 USPS containers.

Note that if trucks and BART cars were completely packed with containers, they would
be able to carry 24 and 36 containers, respectively. However, some room must be within
vehicles for access to any container. Finally, while consolidation is the aim, vehicles may have
to leave their origin before being completely filled due to delivery time window limits. Thus,
slightly reduced capacity constraints are used.
FIGURE 3 System networks under consideration for Alternatives A and B.
3.7 Empty Container Returns

Empty container returns must also be considered, since the demand O-D table is likely to be unbalanced (Table 1). The number of empty containers which must be transported to/from a given location is simply the difference between the location’s outgoing and incoming demand.

3.8 Freight Car Storage Areas and Empty Train Travels

For Alternative A, it is assumed that there is no storage space for BART cars at the Oakland Annex Shop; thus, all freight consists must be assembled at one of BART’s four yards before leaving for a particular route. During AM operations, since all movement is from OAK, the Union City BART yard is assumed to supply freight consists to the Oakland Annex Shop station. After unloading all goods at a final destination, the empty train will then depart for the nearest yard. During PM operations, each route’s origin (node 1b, 3b, 5b, 6b/7b, or 7b) will have trains supplied from the nearest yard. After unloading goods at OAK, each empty train will return to the Union City yard. However, a new train must then be assembled which returns empty containers to a given location (trains may be either originating from or destined for OAK). Empty container returns simultaneously help ensure that the same number of freight cars will be in each yard at the beginning of each day.

For Alternative B, it is assumed that there is adequate BART car storage at the jointly-operated FedEx/BART facility at node 4ab. Thus, this facility will assume the role played by the Union City yard in Alternative A. All other procedures from Alternative A are adopted for Alternative B.

3.9 Link Travel Times

In order to determine the operating costs incurred for BART cars, the travel times across the system network must be considered. Since it is infeasible for a single train to transport all goods throughout the network due to FedEx delivery time window, particular routes have been assigned for BART freight trains, as seen in Table 2. Route travel times were approximated from BART schedules (2). However, those provided times include the dwell times across intermittent stops; thus, an assumed 40 second dwell time per stop has been subtracted from the provided BART trip times. Furthermore, the aforementioned empty train travel times (from/to the yards corresponding to the beginning and end of a particular route) should be added to all route travel times in order to calculate the true cost of service. The resulting total service times, as well as the route travel times, are given in Table 2.

<table>
<thead>
<tr>
<th>Route</th>
<th>Route Travel Time [hrs]</th>
<th>Total Service Time [hrs]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1b ↔ 2b ↔ 4b</td>
<td>0.66</td>
<td>1.33</td>
</tr>
<tr>
<td>3b ↔ 4b</td>
<td>0.51</td>
<td>1.34</td>
</tr>
<tr>
<td>5b ↔ 4b</td>
<td>0.52</td>
<td>0.92</td>
</tr>
<tr>
<td>6b/7b ↔ 4b</td>
<td>0.56</td>
<td>0.96</td>
</tr>
<tr>
<td>1b ↔ 2b ↔ 4ab</td>
<td>0.66</td>
<td>0.93</td>
</tr>
<tr>
<td>3b ↔ 4ab</td>
<td>0.46</td>
<td>0.90</td>
</tr>
<tr>
<td>5b ↔ 4ab</td>
<td>0.65</td>
<td>0.65</td>
</tr>
<tr>
<td>7b ↔ 6b ↔ 4ab</td>
<td>0.72</td>
<td>0.77</td>
</tr>
</tbody>
</table>

TABLE 2 BART Travel Times for Alternatives A and B
It is also necessary to determine the link travel distances and times across the road network for truck transport of FedEx goods. Travel distances for all links are determined according to the locations of BART stations and FedEx distribution centers. These distances are listed in Table 3. While it can safely be assumed that transshipment travel times between local FedEx distribution centers and BART stations will remain constant, the line-haul travel times in the Status Quo might be expected to change over time due to rising freeway demand over time (and subsequently, reduced travel speeds). Thus, analysis makes use of the predicted inter-regional travel speeds given by the Bay Area Metropolitan Transportation Commission (3).

### Table 3: Truck Travel Distances for Various Alternatives

<table>
<thead>
<tr>
<th>Link</th>
<th>Truck Travel Distance [mi]</th>
</tr>
</thead>
<tbody>
<tr>
<td>STATUS QUO</td>
<td></td>
</tr>
<tr>
<td>4a ↔ 1a</td>
<td>33.1</td>
</tr>
<tr>
<td>4a ↔ 2a</td>
<td>15.5</td>
</tr>
<tr>
<td>4a ↔ 3a</td>
<td>20.9</td>
</tr>
<tr>
<td>4a ↔ 5a</td>
<td>31.6</td>
</tr>
<tr>
<td>4a ↔ 6a</td>
<td>22.4</td>
</tr>
<tr>
<td>4a ↔ 7a</td>
<td>28.6</td>
</tr>
<tr>
<td>ALTERNATIVE A</td>
<td></td>
</tr>
<tr>
<td>1b ↔ 1a</td>
<td>3</td>
</tr>
<tr>
<td>2b ↔ 2a</td>
<td>4</td>
</tr>
<tr>
<td>3b ↔ 3a</td>
<td>3.6</td>
</tr>
<tr>
<td>5b ↔ 5a</td>
<td>4</td>
</tr>
<tr>
<td>6b/7b ↔ 6a</td>
<td>8.6</td>
</tr>
<tr>
<td>6b/7b ↔ 7a</td>
<td>4.9</td>
</tr>
<tr>
<td>4a ↔ 4b</td>
<td>8.8</td>
</tr>
<tr>
<td>ALTERNATIVE B</td>
<td></td>
</tr>
<tr>
<td>1b ↔ 1a</td>
<td>3</td>
</tr>
<tr>
<td>2b ↔ 2a</td>
<td>4</td>
</tr>
<tr>
<td>3b ↔ 3a</td>
<td>2.6</td>
</tr>
<tr>
<td>5b ↔ 5a</td>
<td>4</td>
</tr>
<tr>
<td>6b ↔ 6a</td>
<td>3.8</td>
</tr>
<tr>
<td>7b ↔ 7a</td>
<td>3.4</td>
</tr>
</tbody>
</table>

**3.10 Handling**

A handling time of 0.025 hrs (1.5 minutes) per container is assumed. This handling time is defined as the time to move one container from a BART vehicle across a station platform and secure the container onto a FedEx truck (and vice-versa). Compared to the status quo, Alternative A will require two additional handling movements (one movement at all BART stations connected to local distribution centers and one movement at node 4b), and Alternative B
will require one additional handling movement (at all BART stations connected to local distribution centers). Total handling cost is estimated by simply multiplying the assumed handling time per container by the number of containers handled, the number of handling movements, and the handler costs. Regardless of how responsibility is allocated for loading/offloading items at BART stations, BART must still incur some labor cost, since BART operators will be standing by until trains are loaded. Similarly, FedEx truck operators will at least be on standby while trucks are being offloaded. Therefore, this total handling time cost is assumed to be incurred by both FedEx and BART.

3.11 Truck VMT Estimation

The number of trucks required between any two points can be approximated as

\[ n_{ij} = \frac{D_{ij}}{K}, \]

where \( D_{ij} \) = demand originating from location \( i \) and destined for location \( j \), in [containers], and \( K \) = truck capacity, in [containers]. With these capacity considerations, the demand matrix provided earlier can be readily converted into a “Truck Trips” matrix. From the number of truck trips, the annual truck VMT, external social costs, and total truck operating costs can be calculated for each alternative. All trucks are assumed to travel round-trip.

3.12 External/Social Costs

There are four key external social costs that arise from heavy-duty truck VMT: 1) congestion/delay costs, 2) emissions costs, 3) accident costs, and 4) infrastructure maintenance costs.

The delay savings which arise from reduced truck VMT are difficult to estimate, given that the savings depend on the freeway’s total demand. While it should be noted that there may be some delay reduction from the proposed mixed-goods service, no quantification of these savings are included here.

To quantify reductions in harmful GHG’s, a CO\(_2\) emissions rate of 22.2 lbs/gallon diesel fuel is used (4). A constant fuel economy of 10 mpg has been assumed over the analysis period.

By reducing truck VMT, the number of freeway accidents will likely be reduced. To quantify this cost, a truck accident rate is used. This rate is derived from 2006 statistics for the United States (5). The average cost of all heavy truck accidents in 2005 was $91,112 (6). The annual accident cost is given by the product of these two factors together with the annual truck VMT. Half of this resulting cost is allocated to FedEx annual operating cost, and half to society.

The road damage unit cost due to urban truck travel is taken as $0.074 per truck-mile (7).

3.13 Operating and Labor Costs

Truck operating costs per-mile were given as $3.28/mile in an unpublished report by R. Rai (whose previous work is continued in this study), but because this per-mile cost included driver costs, a lower value of $2.70 is used so that the per-mile trucking cost only includes fuel, maintenance, and ownership/depreciation costs. The diesel fuel cost component is assumed to follow the same trend as gasoline costs, rising to roughly $7.50/gal by 2035 (8). The per-hour cost includes FedEx driver wages, which are taken as $22/hr (9), and both health insurance and worker’s compensation, leading to an hourly cost of $31 (10). Hourly handling labor cost is assumed to be the same as FedEx driver costs ($31/hr). Other components of driving cost include $8 bridge tolls, a $0.25/mile congestion charge, and a 20% carbon tax on all VMT traveled. All three of these charges are expected to be implemented by 2035 in the Bay Area (3). The congestion charge is only applied to the freeway travel component of each truck trip, and the
bridge toll cost only to those trucks which utilize links 4a↔6a and 4a↔7a (only these two links require travel across the Bay Bridge).

Difficulties arise in approximating BART operating cost due to data limitations; through communications with BART’s Financial Planning Office, an operating cost of $250/per car-hr, was obtained. This value is simply the total annual operating cost by the total annual car-hours. However, the operating cost for trains, which possess economies of scale, is required. Therefore, rather than directly apply the given operating cost per car-hr, the following methodology is applied for cost estimation. First, using BART’s weekly operating schedule and each route’s roundtrip travel time (2), the total number of trains required for each route during a given time period can be given by the equation: \( \# \text{ of trains} = \frac{\text{round trip time}}{\text{headway}} \). This number is then multiplied against the length of the service time period and then summed over all time periods to eventually obtain the total train-hours accumulated over the week. Dividing BART’s weekly operating cost \( (11) \) by the total weekly train-hrs, the hourly train operating cost is found to be roughly $1,500/train-hr. By dividing the hourly train operating cost by the hourly car operating cost, the average train length is found to be six cars. Assuming that BART freight trains will not require the same level of amenities, e.g. air conditioning, as BART passenger trains, a reduced operating cost value of $1,250/hr is used for a six-car train. Because the relationship between train length \( n \) and cost should show economies of scale, it is assumed that the hourly operating cost can be expressed as the concave function \( 1000n^{1/8} \), where \( 2 \leq n \leq 10 \). Using this function, the hourly freight train operating cost ranges from $1,090 for a 2-car train to $1,330 for a 10-car train.

Total BART train hours are determined similar to total truck VMT. The number of BART cars required is simply given by \( n_k = \frac{D_k}{K_{\text{BART}}} \), where \( D \) = demand for route \( k \), in [containers], and \( K_{\text{BART}} \) = BART car capacity, in [containers]. From the number of cars required, one can determine the number of trains required by dividing the required number of cars by the 10-car limit; the appropriate operating cost value (according to the function above) is then assigned to the required trains and their respective lengths. A single train’s daily operating cost is given by the product of its hourly operating cost and its total time in service. The annual operating cost is found by summing the operating cost over all trains and working days for the year.

3.14 Security

All FedEx goods, once containerized at their origin distribution center, are not opened until reaching their destination distribution center. Furthermore, all FedEx goods leaving the Oakland Regional Hub must pass airport security. Thus, it is reasonable to expect that FedEx containers, which meet stringent airport security requirements, will satisfy any requirements imposed by BART.

4 RESULTS

Figure 4 shows the net monetary benefit curves for Alternatives A and B, in comparison to the status quo. Here, net benefit is taken as the difference between the total cost of the status quo and the given alternative. A negative level of net benefit indicates a need for subsidies; when net benefit is positive, opportunities arise for BART profits and FedEx savings. The exact levels of profit for BART and savings for FedEx would simply depend on a mutually agreed-upon price for transported containers.
For Alternative A, which requires minimal capital investment, some subsidy is required throughout most of the timeline. However, after 2035, the simulation suggests mixed-goods service can become profitable, and remain that way, as container demand grows. Furthermore, tremendous savings in truck VMT can be achieved; the cumulative truck VMT savings over the analysis period amounts to nearly 70 million VMT. This translates to nearly 80,000 tons of CO₂ emission savings, as well as nearly $6M in accident savings and more than $5M in maintenance savings.

For Alternative B, which requires larger capital investment but eliminates one of the transshipments required in Alternative A, even greater savings in truck VMT are achieved. The cumulative VMT savings amount to more than 120 million VMT, which translates to nearly 140,000 tons of CO₂ emission savings. Accident and maintenance savings totaled more than $10M and $9M, respectively. Perhaps most interestingly, no subsidy is ever required for Alternative B. Thus, if container demand is sufficient, BART mixed-goods service can both be profitable for BART and beneficial for FedEx from solely a fiscal perspective. Assuming a discount rate of 5%, the accumulated amount of total cost savings compared to the status quo amounts to nearly $100M. Some of these savings can be channeled towards recovering the initial capital investment, as well as towards improvements in passenger service, which can further incentivize transit ridership. Note that a clear trend is established in the results: the higher the demand level, the more profitable mixed-goods operation becomes.

FIGURE 4 Net benefit curves for Alternatives A and B, in comparison to the Status Quo.

However, note that there exist other social benefits not included here, such as reductions in noise and particulate matter as well as more economic land use. Furthermore, improvements to BART, such as side tracks for train bypass and adoption of new control technologies, could benefit both cargo movers and passengers by increasing system capacity and reducing travel time. Transit ridership could rise as a result. Government agencies must weigh all of these benefits
against any required subsidies or start-up costs in order to determine whether or not mixed-goods service is worthy of fiscal support.

5 CONCLUDING REMARKS

The presented economic feasibility study shows significant promise for exploring the possibility of mixed-goods service on passenger-rail systems. Both service alternatives show a trend suggesting that the higher the demand, the lower the level of subsidy required. Furthermore, with significant capital investment, BART can actually derive profit from this service while the air freight carrier (FedEx, in this case study) can derive savings. The fact that economic feasibility is so closely linked to demand should motivate researchers to explore ways to tap into other demand sources so that mixed-goods service can become both profitable and environmentally sustainable.

There are several future extensions to this study which will be pursued. Given the high capital costs required for Alternative B, the government may be unwilling to fully cover capital expenditures for a service that primarily benefits a single private company, such as FedEx. Thus, it is of critical importance to determine a valid estimate of initial capital and other “start-up” costs, such that all future benefits can be discounted and compared against the full costs of the project. Furthermore, future studies should also consider latent demand, perhaps by assuming that cars fill the available road space left by the removal of trucks from freeway corridors; doing so would provide a more valid estimate of social benefits. For the preceding analysis, latent demand was assumed negligible because the daily truck flows were found to utilize a marginal percentage of freeway capacity (~1%). Future studies should also examine in greater detail the logistical issues inherent in mixed-goods service, including non-interference with existing passenger transport operations and routine maintenance activities. For example, because morning freight service would fall outside of current BART operating hours, analysis should also include the additional overhead and logistical costs required during this time period.

There are also other elements not included thus far that can contribute to the success of mixed-goods service. One such critical element is the inclusion of other cargo movers besides FedEx as BART “customers”. Once other customers have been identified, overlaps in demand patterns across different customers can lead to even greater economies of scale for BART cargo transport, particularly in comparison with truck transport. Some other potential demand sources in the Bay Area include UPS containers, produce from farmers, and containerized/non-containerized products from the Port of Oakland. However, there will also be additional costs when accommodating various demand sources due to their different characteristics. Another element not quantified here is the higher level of reliability afforded by rail transport in comparison to truck transport. Including this benefit to cargo movers may further skew the results in favor of mixed-goods service.

Note that the objective of this paper is not to make a case for implementation of mixed-goods service, but rather to make a case for analysis of mixed-goods service, and the results of this initial economic feasibility study make a strong case for future research in this area. The results should be of particular interest to other urban areas across the U.S., such as Los Angeles, Washington D. C., New York, and Chicago, where passenger rail systems exist in proximity to major air cargo terminals. Some of these systems may possess particularly favorable characteristics towards mixed-goods movement, such as intermodal transfer stations, containers which can interface between multiple modes, and standard gauge rails.
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