

**Future Contactless Payment Options for Transport for London:  
Demand, Cost, Equity, and Fare Policy Implications**

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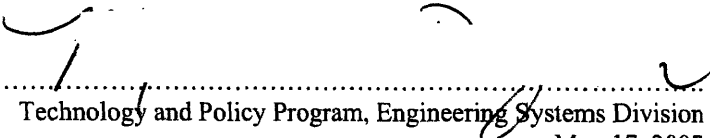
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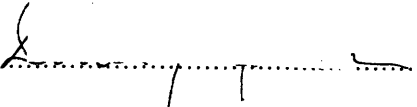
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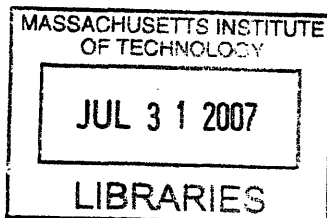
  
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**Abstract**

This thesis assesses fare payment technologies for Transport for London in 2015. Based on a survey of technical literature, feasible payments technologies in 2015 include current smartcard technology, contactless bankcards and near-field communication (NFC) mobile phones. Five fare payment options based on these three technologies are proposed. Options 1-3 use contactless bankcards and NFC phones as the fare medium. Option 1 requires tap-in only and uses flat fares; it is a standard retail transaction. Option 2 is like Option 1 but adds a rebate program to approximate the effects of passes and transfer discounts. Option 3 requires users to tap-in and tap-out, and supports traditional transit fares. Option 4 continues the current use of a proprietary smartcard to implement traditional transit fare structures. Option 5 uses a vehicle-based smartcard reader that does not require barriers or fareboxes; it supports traditional transit fare structures and path- and service-based pricing.

The five options are evaluated on four dimensions: cost, demand, equity, and fare policy. Options 1-3 have significantly lower costs due to the use of commercial payment media. Option 4's costs are similar to current costs. Option 5 is significantly more expensive and offers few benefits for London. To analyze demand, an incremental logit demand model was created. It shows that under conservative assumptions about passenger behavior, option 1 generates a moderate loss in revenue and ridership, while under more generous assumptions, a moderate gain occurs. Options 2 through 5 result in small changes in ridership or revenue. All five options maintain or potentially improve passenger equity, especially if passes requiring up-front payment are de-emphasized, allowing lower income travelers to obtain the best fares.

Options 2 and 3 offer the greatest opportunity for customer service improvement and cost savings. Option 1 has a higher demand risk and decreased fare policy flexibility. Option 4 has limited potential for cost saving or revenue increase, and Option 5 is prohibitively expensive.

Peak pricing is also investigated, and is shown to offer some benefits in creating available capacity.

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# 1 Summary and Conclusions

## 1.1 Problem Statement

The goal of this research is to analyze fare collection technology strategies for Transport for London (TfL) over the next 10 years. This technology will be applied to all of TfL's transport modes. However, in this thesis, the two modes that will be specifically analyzed are bus and Underground rail (which will be abbreviated with TfL's internal abbreviation, LUL). Technologies that appeared technically feasible and cost-effective were selected for further study. Five fare collection options were formulated based on these technologies, and guidelines were developed for technical and financial implementation of the options. Finally, the major policy implications of these options were analyzed.

The technologies that would be feasible for transit fare payment by 2015 were identified by surveying the technical literature. One conclusion was that smartcards, the current state-of-the-art fare collection technology, will still be viable and effective in 2015. While current smartcards are proprietary, transit-agency-issued implementations, by 2015 the emergence of contactless bankcards will allow generic, commercial payment tools to be considered for transit payment. By 2015 mobile phone contactless proximity payments will probably become widespread based on Near Field Communications (NFC) technology. A less conventional use of contactless technology, the so-called "Be-in Be-out" long-distance smartcard, may or may not hold some potential as a fare payment technology. Other emerging technologies do not appear to provide viable fare payment tools in the next ten years. For example, biometric-based payments – in which fares are paid by an electronic fingerprint analysis or iris scan – will not be sufficiently mature technologies to consider for fare payment in 2015.

Five different fare payment options were developed: three options based on commercially issued generic fare payment technologies (smart bankcards and NFC mobile phones), one option based on a proprietary smartcard similar to London's current Oystercard system, and a final option based on the long-distance smartcard. The three options based on commercial fare payment technologies vary in their fare structure and interface with commercial payments networks.

The policy implications of these options were evaluated using four measures: equity, demand/revenue, fare policy, and cost. The equity implications were evaluated by determining which social groups would be significantly affected by the changes in technology and fare policy. The demand/revenue implications were determined by creating a model to show what passenger demand and revenue would be under the various potential fare policy alternatives. The fare policy implications of the options were determined by combining the results of the demand and equity implications with a qualitative analysis of the implications of various fare policies. The cost implications were determined by creating a cost model of TfL's current ticketing system, and modifying it to account for changes in each of the options.

## **1.2 Commercial Fare Options**

This section summarizes the five fare payment options analyzed in this research.

Option 1: Passengers tap-in with smart bankcards and/or NFC mobile phones. The tap-in immediately becomes a transaction on the payments network as a normal retail purchase. There are no passes, discounts for frequent travelers, or transfer discounts.

Option 2: Similar to option 1, except that participating banks offer a rebate program via post-processing similar to rewards and frequent-flyer programs on credit cards today. The rebate program can be used to give rebates to frequent travelers, passengers who transfer between modes or vehicles, and passengers who live outside the central congested area.

Option 3: Passengers tap in and out with a smart bankcard and/or NFC mobile phone, and a charge-routing body connects tap-ins and tap-outs, aggregates charges, and routes the charges to the banks or mobile phone companies. Because a tap-out is included, all fare options are possible, including zone fares, distance-based fares, transfer discounts, and others.

Option 4: This option is essentially the same as the Oystercard program today. The transit agency, TfL, continues to issue proprietary smartcards which are used for tap-in and tap-out. Any standard fare option is possible.

Option 5: In this option, a new type of smartcard, called long-distance smartcard or “Be-in Be-out” smartcard is used, which can be read at a distance of up to 3 meters. Passengers walk into the system, and gates, if present, open automatically. All passengers’ movements are recorded by readers in each vehicle. Any standard fare option is possible, and in addition, path-based pricing—discounts or surcharges for using specific lines or services—is possible.

## **1.3 Fare Policies**

The fare policy is the basic rule by which fares are calculated. The four major fare policies analyzed are:

Flat fare: Passengers pay a single fare, independent of trip distance or frequency. The fare can vary by mode and time of day. Concessionary passengers can carry a special smartcard that identifies them as paying a lower flat fare. No other fare variation is possible.

Flat fare with rebates: All passengers pay a single fare, independent of trip distance. After a processing period, rebates can be given to each passenger. Rebates can be given to frequent travelers, to all travelers who transfer on the transit system within a time window, and to passengers whose trips always originate outside the central business

district. These policies approximate the effects of passes, transfer discounts and zone fares. Concessionary discounts can be given immediately, as with flat fare.

Zonal: Each station is associated with a zone, a geographical grouping of stations. The fare paid is calculated based on the zone of the station of entry and the zone of the station of exit. The zones and the fares are typically chosen to approximate a distance-based fare. However, variations occur, especially due to the central business district being charged a higher fare in order to reduce congestion on the transit system. Passes, transfer discounts, and concessionary discounts are possible.

Distance-based: The fare charged is based on the distance traveled. Typically, the final fare charged is comprised of a “flat” component, a flat fare that is charged to everyone who enters a given mode, and a per-kilometer component, a fare that is charged based on the exact distance of each trip. Passes are possible, but seldom used. Transfers are typically free, with the highest flat component charged only once, and the per-km fares of all modes taken being added together to form the final fare. Concessionary discounts are possible.

Option 1 is capable only of supporting flat fares. Option 2 can support a flat fare structure with rebates. Options 3-5 can implement all fare policies.

## **1.4 Summary of Results**

### **1.4.1 Equity**

This thesis shows that neither the use of commercial fare media nor a switch to flat fares will harm equity. In fact, such a switch may have positive equity effects. As long as commercial fare media are conveniently available to travelers of all incomes and ethnicities, using commercial fare media on public transit will not affect equity negatively. Commercial fare media are likely to be conveniently available to everyone because of the high penetration of pay-as-you-go mobile phones, and the potential for readily-available prepaid contactless bankcards.

A flat fare structure will not harm equity because, among public transit passengers, trip length and trip frequency do not vary significantly by income, ethnicity, or gender. The variation of trip length by income, gender, and ethnicity is small, so allowing long and short trips for the same fare will not harm equity. The variation of trip frequency by income, gender, and ethnicity is small, so eliminating travelcards (passes) or replacing them with price caps will not harm equity, with one possible exception. In a pure flat fare scheme, the elimination of bus-to-bus transfers will make the relative cost of taking a linked bus journey significantly more than that of taking a simple bus journey. The demand model shows that the price of a linked bus journey can remain low in a flat fare system (it will be the same as the current cost of a bus journey). However, the price of a linked journey relative to the price of a single journey will go up significantly.

One significant positive equity effect that occurs with flat fares is to make it possible for people of all income levels all get the best fare possible. In a system with period passes that exceed £900 for the cheapest annual pass that includes the central business district, it is not possible for many low income passengers to get the best fare. That is because they cannot afford to pay the £900 up front for an annual pass, which gives the cheapest fares to frequent riders. A flat fare structure eliminates up-front payment, thus making it possible for everyone to get the cheapest fare possible.

### **1.4.2 Cost**

This research indicates that a change to commercial fare media could bring significant cost savings. Using commercial fare media (options 1-3) could save TfL £120 million/year-£140 million/year when compared with the current ticketing system. The majority of these savings will come from the elimination of ticketing staff and commissions to third party ticket retailers. The number of staff positions that can be eliminated depends on the regulations for minimum station staffing, and thus the entire savings may be unachievable. However, the staff members that are retained at stations can be reassigned to increase the level of customer service.

TfL-issued cards (option 4) would result in relatively small changes in cost.

Long-distance smartcards (option 5) will cost at least £100 million/year more than the current ticketing system. This substantial cost, combined with technical risk of these devices, will outweigh their potential benefits.

### **1.4.3 Demand/Revenue**

Demand and revenue will change significantly only when the fare policy changes. How demand changes under flat fare is a function of how the market for transit in London responds to fare policy, which is unknown.

Single and pay-as-you-go passengers pay significantly higher average fares than travelcard and bus pass passengers, which assumes that these markets have different fare elasticities. If this is the case, then current fare policies are likely to perform well in matching fare policy to demand, and obtaining appropriate revenues from each market segment. If, however, single and travelcard passengers are a single market with a single fare elasticity, then current fare policies may be suboptimal. If the distinction between single and multiple fares is based on the historical cost of selling and accounting for tickets, which no longer exists, then a more uniform set of prices would improve revenue and possibly ridership.

Based on previous elasticity estimates, a multinomial logit demand model was developed that predicts ridership, revenue, and passenger-km under a variety of flat and distance-based fare scenarios. This demand model assumes that there are two different markets for transit, one for single and pay-as-you-go passengers, and one for travelcard passengers, with different fare elasticities.

### Option 1

With a pure flat fare, under the assumption that there are multiple markets for transit with separate elasticities, option 1 causes a significant ridership and/or revenue loss. If today's ridership numbers are maintained, the model shows a £160 million/year loss in revenue. However, if there is a single transit market, then there is no loss in revenue and possibly a modest gain. For example, if there is a single market for transit at the current average fares of bus and LUL, then charging flat fares of £0.75 for bus and £1.55 for LUL would generate ridership nearly identical to today's 2.3 billion, but revenue of £2.3 billion, £100 million or 4.3% more than today's revenue of £2.2 billion.

### Option 2

With a flat-fare fare that also includes rebates for frequent travelers, transfer trips, and passengers not entering zone 1, option 2 yields a slight gain in revenue and ridership. If fares equivalent to today's fares are maintained, the model shows a 20 million passenger-trip/year gain in ridership and a negligible gain in revenue. If there is a single market versus multiple markets, there is a greater gain in revenue and ridership.

### Option 3

Option 3 can support all fare policies, including those in place today, which causes no change in revenue and ridership. Option 3 can also support a distance-based fare. With a distance-based fare but no discount for frequent travelers, option 3 shows a slight loss in revenue and ridership.

Options 4 and 5, like option 3, can accommodate any fare structure. If the fare structure remains the same, there is no change in revenue or ridership.

The multinomial logit model was then extended to include time-of-day choice to evaluate peak pricing. The time-of-day choice model is implemented by creating shoulder periods during which passengers can choose to switch between peak and offpeak periods. In addition, the peak and offpeak periods outside of the shoulder periods are modeled as in the standard demand model. Time-of-day choice can be used with all fare options, though its results only apply if there are no unlimited travel period passes. While the accuracy of the time-of-day model is sensitive to the choice of shoulder length, a shoulder length in the range of 15-30 minutes results in an available capacity increase of 3% to 10% at the periods of greatest congestion. This result suggests that peak pricing can be used to create a small but significant amount of capacity at peak hours.

## **1.4.4 Fare Policy**

### **Flat Fares**

Flat fares have several key advantages. Flat fares take the greatest advantage of cost savings possible from the use of commercial payment media. Flat fares may make better use of TfL infrastructure by encouraging longer journeys (and thus increasing ridership in

places where the trains are now emptiest) and discourage the shortest journeys (thus reducing crowding). Flat fares eliminate inequities created by the fare zones, in which those who live just beyond a zone border pay significantly more to travel to central London than those who live just inside the border – under flat fares, everybody pays the same. Also, because flat fares typically do not allow for period passes, they eliminate the inequity created by requiring passengers to pay large sums up front to purchase the period pass, which in turn offers the best per-journey prices for frequent passengers.

Finally, flat fares are easily comprehensible by all members of the public, and make it clear to everyone what it costs to use transit. The comprehensibility of flat fares may increase travel demand and revenue. An increase in travel demand and revenue was noted in Baltimore, Maryland, when it switched from zonal to flat fares. In several other cases, such as the Connecticut bus system, no revenue loss occurred when the transit agency switched to flat fare (Multisystems et al. 2003).

A flat fare policy has several drawbacks. The first is that there may be a perception of inequity with long trips costing the same as short trips at the time of the change. The second drawback is the interface with national rail. Flat fare is clearly not appropriate for longer-distance trips, so journeys on national rail that are continued on TfL services will need to have a distance-based, National Rail component, and a flat, TfL component. The final drawback is that flat fares do not offer the possibility of transfer discounts, and this may cause equity issues because rail (underground) transfers are free based on the physical structure of the system, while bus transfers are not. Also, flat fares do not encourage intermodal travel (journeys including legs on both bus and Underground) as distance-based fares do. The fact the bus passengers have lower incomes complicates the issue.

### **Flat Fares with Rebates**

Flat fares with rebates retain most of the advantages of flat fare: they retain most of the cost savings, the encouragement of longer journeys, and the elimination of zonal inequities. Flat fares with rebates can be fairly simple, so most of the benefits of the comprehensibility of flat fares are retained. In addition, flat fares with rebates allow the transit agency to serve two separate transit markets – frequent travelers (who may receive rebates that can approximate the effect of period passes) and infrequent travelers (who may receive rebates on transfers and non-central trips). Finally, flat fares with rebates allow transfer discounts and so eliminate potential equity issues resulting from the elimination of transfer discounts.

Flat fares with rebates have the difficulty that not everyone may benefit from the rebates: only passengers whose banks have the appropriate agreements with the payment firms who process the rebates will obtain the rebates. However, the rebate program could be nearly universal for London area residents.

## **Distance-based Fares**

Distance-based fares have the advantages of offering clear value for money (since you pay by the kilometer, you get what you pay for), and like flat fares, distance-based fares eliminate zonal inequities. This is, of course, a different view of value than if a flat fare policy is proposed. Distance-based fares will have little impact on equity because there is little variation in trip length across income, gender, and ethnic lines. However, because lower-income Londoners tend to use bus more than LUL, it is important to keep bus flat and per-km fares below the levels of LUL flat and per-km fares for equity reasons. Distance-based fares encourage intermodal travel, by making the marginal cost of continuing a journey on a different mode very low.

However, distance-based fares have several drawbacks. Distance-based fares are more complicated; passengers will not immediately comprehend how much they have to pay for a journey, which will discourage some passengers from using transit. It is very hard to implement distance-based fares on buses because passengers must be required to tap out, so it will be difficult to prevent fraud. It is not clear that the “value-for-money” aspect of distance-based fares offers passengers or the transit agency any real benefit. Finally, distance-based fares encourage short journeys by making them cheaper than they are today under a zonal system; encouraging short journeys could worsen congestion on the transit system.

## **Zonal Fares**

Zonal fares have the advantages of continuity – they are the system that TfL already has in place. Also, zonal fares can approximate distance-based pricing, which gives some passengers the feeling of “value-for-money,” while allowing for a higher charge in congested areas.

Zonal fares have the disadvantages of creating zonal inequities and of discouraging travel because they are more difficult to comprehend. Zonal inequities refer to the fact that passengers living one station outside a fare zone can pay significantly more than passengers just inside the fare zone for a trip that is only slightly different – and perhaps even shorter. Zonal fares may discourage some travel because, as with distance-based fares, some passengers are unsure of how much they will pay for a given journey.

### **1.4.5 Revenue and Cost Effect of Fare Options**

Option 1: Option 1 may lead to loss in ridership and revenue because only one price level is possible. However, option 1 offers the greatest cost savings of all the options, and this cost savings offsets the revenue loss. Option 1 creates no major issues with equity, although it is a radical change from current pricing. If current differential pricing for singles and travelcards is incorrect (because these users are in fact one market), then option 1 results in no revenue or ridership loss, and perhaps some gain, in addition to its substantial cost savings. This is, however, a highly risky option.

Option 2: Option 2 can approximate current TfL prices, so there is little change in ridership or revenue. Because there is a cost savings of £140 million/year, there is a net gain of £140 million/year. Option 2 creates no major issues with equity.

Option 3: Option 3 causes no change in revenue because no change in fare structure is necessary. However, Option 3 brings a cost savings of £120 million/year, there is a net gain of £120 million/year. Option 3 creates no issues with equity.

Option 4: Option 4 causes no change in revenue because it is the same as today. Some cost savings are possible, but they will be incremental, because all the basic systems and structures in place today must be retained in order to serve proprietary smartcards.

Option 5: The additional infrastructure and technology requirements of Option 5 will cause a cost increase of roughly £100 million/year. Because of this large cost increase, option 5 was not analyzed in greater detail.

## **1.5 Summary of Conclusions**

Emerging technologies will soon offer tools for fare payment that were not available at the start of the Oystercard program. Of the emerging payment technologies, NFC mobile phones and contactless bankcards are the two that will be feasible for use in transit applications in the next decade; other technologies such as biometrics and long-distance smartcards must mature before they are technically and financially feasible for transit use. NFC mobile phones and smart bankcards are commercial payment devices, not primarily issued for transit applications. It is likely that a large majority of TfL passengers will already possess these devices within the next 5 to 10 years. The conclusion of this research is that as long as supplemental ticket media can be made easily and economically available to the small number of passengers who will not have commercial payment devices, then the benefits of switching to commercial devices – convenience and simplicity for the customer, cost and administration reduction for TfL – far outweigh the costs.

The benefits of commercial ticketing are significant, and it is very likely that the remaining impediments to their use in transit payment can be overcome. Passengers will be able to pay for ticketing in the same way that they will make their other retail purchases, with a contactless bankcard or mobile phone. Using these contactless tools already possessed by customers may reduce TfL's ticketing costs by about £100 million/year. Issues that could potentially complicate the implementation of commercial ticketing systems—issues involving equity, demand, and fare policy—were analyzed and found not to be significant in the ten year time frame examined. In the next few years, there are significant uncertainties about the rate of introduction of contactless bank cards and NFC phones, their performance at fare barriers and bus fareboxes, and their transaction costs. These issues are expected to be resolved over time.

Adequate supplementary tickets must be available to users without commercial media. Both pay-as-you-go mobile phones and stored-value bankcards both will likely be able to serve as supplementary fare media.

## **1.6 General Policy Implications**

This research has led to several general transit payment policy implications in addition to the policy implications described above in the sections on equity and fare policy.

### **1.6.1 Currency Barrier**

The “currency barrier” of the public transportation system has significant consequences. The currency barrier is that potential transit passengers in London and other smartcard-focused transit systems cannot pay for transit with the same form of payment that they use for everything else. Rather, they must obtain a special currency – the smartcard. The need for this special currency may deter some passengers from using transit because of the unknown nature and perceived or actual inconvenience of the process of obtaining this currency. Some passengers will feel this way in spite of TfL’s attempts to educate the public about Oystercard and introduction of easy payment services like auto top-up.

Using commercial fare media will eliminate passenger losses arising from the currency barrier. A number of potential passengers may choose to take public transit so long as they do not need to obtain a separate form of payment. The advent of Oyster may have increased the number of such individuals, despite the massive advertising campaign and word-of-mouth that Oyster has received. Passengers must obtain another “currency” – the Oystercard, load it with prepay or passes, and maintain it, if they want to pay a reasonable fare for use of the transit system. Some people will find the complications of dealing with this other currency too complicated, and choose – in most cases, quite irrationally – to avoid public transit. Many such people will already possess a car, but will choose to use it even when transit would provide a much cheaper, possibly faster service. Switching to a commercial fare payment medium – a smart bankcard or NFC mobile phone – will eliminate this currency barrier for the vast majority of passengers.

### **1.6.2 Conversion to Commercial Fare Media**

Switching to commercial media will have many advantages, but TfL will need to remain an issuer of proprietary smartcards (Option 4) until a supplementary fare medium is mature enough to be widespread. There are several reasons for this, including the need to provide some disadvantaged groups without access to commercial payment media, as well as the need to provide a fare payment medium to visitors and children. The research in this paper does not attempt to analyze the nature of a possible conversion from the current option to a commercial fare payment option.

The availability of commercial media will probably take 5-6 years, until 2012-2013. NFC may not be available in contract mobile phones until 2008 or 2009; it may be another year or two after that until NFC is commonly available in prepaid mobile phones, and it

may be another year until NFC is available in the cheapest mobile phones, which is necessary to consider them a supplementary fare medium. It is unclear how long it will take for the banking industry to roll out prepaid contactless bankcards. It is likely that banks will issue contactless cards to their account-holding customers first, and only focus on issuing prepaid contactless bankcards later. But contactless bankcards may allow banks to serve the “unbanked” and “underbanked” members of the population better, and banks may wish to gain market share in this area before NFC mobile phones become available.

The final decision to switch to entirely commercial fare media must wait until it is clear that contactless bankcards or prepaid NFC mobile phones will have deep market penetration. Therefore, TfL should be proactive in encouraging the banking and mobile phone industries to issue these prepaid contactless devices.

### **1.6.3 Zero Marginal Cost Travel and Peak Pricing**

The results of the demand model show eliminating zero marginal cost travel may not have a significant effect on demand for travel in London as long as the overall fare structure allows people to pay roughly what they are currently paying. The equity analysis shows that eliminating zero marginal cost travel will have little impact on equity because there is little variation in trip frequency across income, gender, and ethnic lines.

By eliminating zero cost travel, TfL could introduce a peak-hour pricing scheme applied to all users and could flatten the peak period. More rigorous peak hour pricing may have progressive distributional effects, since fewer lower-income passengers travel on the peaks relative to the numbers of high-income passengers.

The results of the time-of-day model show that eliminating (or significantly reducing) zero marginal cost travel at peak hours can have a modest effect on ridership and revenue. Higher peak fares result in little ridership loss, somewhat higher revenues, and improved operations in the peak period. The time-of-day model shows that between 3% and 10% additional capacity can be gained during peak periods by moving some users from the peak hour to adjacent periods through peak pricing.

## 2 Literature Review

### 2.1 TCRP Reports on Media, Policy, and Equity

The Transit Cooperative Research Program (TCRP) reports on fare collection issues provide an overview of technology and policy issues in fare collection. The TCRP is a program run by the Transportation Research Board (TRB) of the National Research Council, but funded to a large extent by the Federal Transit Administration (FTA). With FTA funding, the TCRP identifies and sponsors research by into issues common to many U.S. transit agencies. U.S. transit agencies generally cooperate by providing data to the TCRP-sponsored researchers. TCRP reports cover a wide variety of current transit related issues, but five of their reports since 1996 have focused on fare collection issues. While the reports are compiled by and for U.S. transit agencies, they also analyze significant issues facing transit agencies worldwide.

#### TCRP Report 10: Fare Policies, Structures, and Technologies

Fleishman, Daniel, Nicola Shaw, Ashok Joshi, Richard Freeze, and Richard Oram. *TCRP Report 10: Fare Policies, Structures, and Technologies* (Washington, D.C.: National Academy Press, 1996). Available at: [http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp\\_rpt\\_10-a.pdf](http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_10-a.pdf).

*TCRP Report 10: Fare Policies, Structures, and Technologies* is a comprehensive survey of issues related to fare collection. It includes a list of transit operator fare policies in the U.S. by mode and fare strategy. The report was compiled in 1996, so this list is now outdated, given the relatively high number of agencies that primarily used cash or tokens.

The report includes a ranking of fare strategies, which the authors developed by asking a number of U.S. transit professionals to rank fare policies on several different dimensions (impact on ridership, fare evasion, cost of implementation, etc.). They define “flat fares” as fares that do not vary by time of day or mode, and do not include passes. “Distance-based fares,” as used in this report, are actually zone fares. Fares that include passes are called “market-based” strategies, because different market segments are targeted, and fare policies that give different prices for different modes are called “service-based” strategies. The parties that were surveyed favored distance-based fares, although service-based and market-based were not far behind.<sup>1</sup> Few U.S. transit properties have significant distance-based fares, either in 1996 or now, and it is possible that the survey captured operator preferences for complex or seemingly-modern or seemingly-flexible fare policies. There was no discussion of the costs and operational or implementation issues of the fare policy options.

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<sup>1</sup> The survey did not consider a combination of service- and market-based products. This combination might have achieved a ranking close to, or even greater than, the ranking of distance-based fares.

The report also includes brief case studies of fare collection policies in the U.S. and an introduction to “electronic fare media,” which essentially means smartcards. It includes a cost breakdown of electronic fare media. The most significant cost elements are the following: the media itself, distribution of the media, life-cycle/replacement of media, equipment maintenance, and fare collection labor cost savings. The study apparently omits the significant transaction processing and server costs of smartcard systems.

The report states that the key issues in any fare collection technology are the impacts on ridership, revenue, and cost. It also states that smartcard based systems seem to have many advantages, especially for larger transit systems.

### **TCRP Report 32: Multipurpose Transit Payment Media**

Fleishman, Daniel; Carol Schweiger, David Lott, and George Pierlott. *TCRP Report 32: Multipurpose Transit Payment Media* (Washington, D.C.: National Academy Press, 1998). Available at:  
[http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp\\_rpt\\_32.pdf](http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_32.pdf).

*TCRP Report 32: Multipurpose Transit Payment Media* was compiled in 1998, two years after report 10, and focuses almost exclusively on electronic fare payment media, i.e., smartcards. The purpose of the report was both to give more detail on the emerging use of smartcards and to promote the use of interoperable smartcards before agencies implemented their own proprietary smartcards. It includes much more detail on smartcards than TCRP Report 10 did, including details on the emerging ISO standards and introducing the concept of financial (bank-issued) smartcards. It contained an even more detailed cost breakdown of the smartcard fare payment for a transit agency, and also a list of revenue improvements that come with smartcards: ridership improvements from increased passenger throughput, ridership improvements from increased payment comfort, reduced fare evasion, interest earned on unused stored value, and the collection of stored value that remains unused for a long time. The report also discusses customer acceptance issues with smartcards, most of which seem now to be unfounded concerns.

The report seems to promote a card interoperability standard along the lines of what would become UTFS<sup>2</sup> and greater involvement of financial institutions in smartcard transit fare payment. While succeeding at detailing the issues related to smartcard fare payment adoption, the report failed to usher in an era of fare payment cooperation among transit agencies or between transit agencies and financial institutions. The report is also typical of its period in its predictions of revenue and ridership improvements from the adoption of smartcards, which have proved elusive in practice.

### **TCRP Report 94: Fare Policies, Structures, and Technology Updates**

Multisystems, Inc., Mundle & Associates, Inc., and Simon & Simon Research Associates, Inc. *TCRP Report 94: Fare Policies, Structures, and Technology Updates*

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<sup>2</sup> Universal Transit Farecard Standards, a body that has published an interoperable transit farecard standard for North America. No agency has yet adopted this standard.

(Washington, D.C.: National Academy Press, 2003). Available at:  
[http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp\\_rpt\\_94.pdf](http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_94.pdf).

*TCRP Report 94: Fare Policies, Structures, and Technology Updates* is a follow-up to both TCRP reports 10 and 32. Like report 32, the clear focus is on smartcard and mag-stripe fare payment, but Report 94 focuses more on fare policy than report 32 did. Report 94 also includes more information about worldwide smartcard ticketing programs. The report indicates that U.S. fare levels are rising faster than they had in recent years. Finally, the report includes the first indication of fare equity as a driving force in the choice of fare policy, indicating that transit equity relates not only to service offerings but also to fare levels.

The section on fare policy includes several case studies to illustrate fare policy trends. All the case studies emphasize the trend towards simplifying fare structures. Notably in the Maryland MTA (a bus, light rail, and subway operating agency that services Baltimore and surrounding areas) and Connecticut Transportation (a bus-operating agency), the elimination of fare zones and introduction of free transfers in both cases resulted in stable or improved ridership and revenue numbers. In Maryland, ridership and revenues rose after the change, while in Connecticut, ridership and revenues were stable. Nowhere did fare simplifications result in revenue loss. Along with its discussion of fare policy, Report 94 discusses the various fare enforcement techniques, such as proof-of-payment and barriers, but offers no global recommendation, stating that the enforcement method must be chosen according to the restrictions of each service. It is noteworthy that Report 94 documents systems moving away from distance based fares, which were the stated preference of transit operators in Report 10.

Report 94 offers more technical detail on the smartcard, magnetic-stripe, and bankcard fare payment systems than either of the preceding reports. It also mentions the continued interest of financial institutions in transit ticketing, and illustrates this position with the SmartTrip credit card, a smartcard for the Washington DC transit agency (WMATA) that also includes a magnetic-stripe credit card.

Report 94 concludes that smartcard use is gradually spreading across the U.S., but without any real interagency integration. Report 94 illustrates its conclusions with very detailed case studies of 13 U.S. transit agencies.

### **TCRP Report 95: Traveler Response to Transportation System Changes: Chapter 12 “Transit Pricing and Fares”**

McCollom, Brian E., and Richard H. Pratt. *TCRP Report 95: Traveler Response to Transportation System Changes: Chapter 12 “Transit Pricing and Fares”* (Washington, D.C.: National Academy Press, 2004). Available at:  
[http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp\\_rpt\\_95c12.pdf](http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_95c12.pdf).

Chapter 12 of the mammoth *TCRP 95: Traveler Response to Transportation System Changes* concerns traveler response to changes in fares. It states that fare changes are

done most often to raise revenue, but occasionally changes are made to increase ridership. It states that fare equity is always a concern when fare changes are made. It indicates that fare equity is usually determined by setting fares at levels that correspond to the cost of providing the service or to the benefit that the user obtains, but does not really mention fare equity dealing with the implications of fare structure for the various social groups.

The majority of the report deals with models of the revenue gain and ridership loss that result from a fare increase. The models presented are very simple -- empirically derived linear or exponential models. It does not include more sophisticated mathematical demand models like logit. The report also includes a survey of the price elasticities of demand that are used in such calculations in U.S. cities. Elasticity values vary widely from city to city, but long-run elasticity values typically fall between -0.3 and -0.6. Elasticities vary by mode, time-of-day, base fare, population, and other factors, so aggregate values for multiple cities have little meaning.

### **TCRP Report 115: Smartcard Interoperability Issues for the Transit Industry**

Acumen Building Enterprise, Inc., and Booz Allen Hamilton. *TCRP Report 115: Smartcard Interoperability Issues for the Transit Industry* (Washington, D.C.: National Academy Press, 2006). Available at:  
[http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp\\_rpt\\_115.pdf](http://onlinepubs.trb.org/onlinepubs/tcrp/tcrp_rpt_115.pdf).

*TCRP Report 115: Smartcard Interoperability Issues for the Transit Industry* is an even more explicit endorsement of a UTFS-like smartcard standard that would allow interoperability of smartcards between transit agencies. The report acknowledges the possibility of using media issued by financial institutions directly as fare media, but states that institutional barriers will make doing this difficult. It concedes that direct bankcard transit fare payment might serve as a supplementary fare payment medium, but never states what institutional barriers will prevent financial media from becoming the primary fare payment media, or discusses how these barriers might be overcome.

The report outlines management and organizational issues that need to be resolved to implement an interoperable smartcard. The report suggests that there should be only one governing body to make strategic decisions about an interoperable smartcard, and implies that a nationwide interoperable smartcard would be the ultimate form of interoperability. That governing body will need to resolve the revenue distribution method among participating transit agencies. The report emphasizes the convenience for passengers of having an interoperable smartcard, and the cost savings potential that arises when multiple agencies can purchase common equipment. The report also discusses what data should be stored on such a card and how passenger data should flow between participating agencies. Finally the report presents an interoperable transit farecard simulator that the researchers developed, a laboratory setup with a server and cardreader that can simulate different data structures on a smartcard. The report concludes that an interoperable smartcard is the best way forward for transit agencies.

This report represents the opinions of transit professionals from regions with zonal/distance-based fares. The report committee chair is from the San Francisco Bay Area Rapid Transit District (SFBART). The only other member of the committee from a large metropolitan transit agency is from the WMATA. Both SFBART and the WMATA have distance-based fares.

While the report concludes that smart bankcards may make a good supplementary ticket medium, it does not recommend smart bankcards as the primary fare medium. However, the report does not mention the fact that flat fares can be used to simplify the use of financial bankcards as transit fare media. The report does not mention two significant cases of using financial smartcards for fare payment: the New York City MTA Citibank/Paypass trial, a currently ongoing trial of using the MasterCard Paypass at some MTA fare barriers; and the Seoul / Korea Smartcard Corporation program by which Koreans can pay fares with special bankcards directly at the fare barrier. The Seoul program is noteworthy because it uses distance-based fares and achieved a rapid penetration among the Korean transit-riding public.

The report does not mention several very significant international card integration achievements: the integration of JR East's Suica Card with JR West's ICOCA card in 2004 and the introduction of a nationwide transit smartcard in the Netherlands, the OV-Chipkaart, in 2006.

## **2.2 Other Articles on Transit Smartcard Interoperability:**

Yoh, Allison C., Hiroyuki Iseki, Brian D. Taylor, and David A. King, "Inter-Operator Transit Smart Card Systems: Are We Moving Too Slow? Or Too Fast?" *Transportation Research Board 85th Annual Meeting* (Washington, D.C.: Research Board, 2006)

This paper presents an analysis of why countries such as the US and the UK have been slow to adopt an interoperable smartcard standard (such as UTFS and ITSO, respectively). It outlines three main reasons for the slow movement towards adoption of an interoperability standard. The first reason is that transit agencies feel that any standard adopted will limit their flexibility in changing fare policy. The second reason is that the inter-organizational bodies that govern the standards (UTFS and ITSO) are basically collegial bodies, and thus less capable of making binding decisions. The third reason is that individual agencies do not have the capacity to comprehensively evaluate the costs and benefits of a switch to a common standard. The paper concludes that without detailed agency-by-agency cost-benefit analyses the business case for interoperable smartcards remains unclear. The paper is neutral as to whether interoperable smartcards are a worthwhile goal – it suggests that closer analysis of the issue is worthwhile, but that the analysis could show the standards not to be worthwhile. The paper does not consider using generic financial smartcards for fare payment.

## 2.3 Other Articles on Fare Equity

Literature on fare equity in transit is relatively sparse, in comparison with literature on the equity of service provision. Much modern research cites Robert Cervero's 1981 article "Flat versus differentiated pricing: what's a fair fare?"

Cervero, Robert. "Flat versus differentiated pricing: what's a fair fare?" *Transportation* 10, 3 (Dordrecht: Springer Netherlands, September, 1981) pp. 211-232.

Robert Cervero's 1981 article "Flat versus differentiated pricing: what's a fair fare?" is one of the few numerical examinations of fare equity. The article analyzes flat fares (that do not vary by distance or time-of-day) and compares them with a fare that varies by distance traveled and a fare that varies by time-of-day. It finds that with flat fares, off-peak riders subsidize peak riders, since more drivers must be hired to serve peak periods, and that short-distance riders subsidize longer-distance riders. He mentions that some studies find that lower income groups travel shorter distances and in the off-peak, but does not do a rigorous analysis of the effects of fares on certain social groups.

Cervero drew his conclusions based a metric that will inevitably lead to the result he reaches: the ratio of costs recovered per passenger mile. By allocating all transit costs by passenger mile, a 4 mile trip, for example, will cost twice as much to provide as a 2 mile trip. This is not a realistic cost model, since many transit costs are fixed, and many more are a function of route length, service density and other measures only partially related to passenger miles.

There are two significant effects that Cervero's model does not consider. He does not consider the effect of passes on the equity of fare structures, which is understandable since that would have complicated his analysis considerably. Also, Cervero does not consider the effect of crowding resulting from his implied recommendation of lower distance-based fares. Cervero notes that low distance-based fares will increase overall ridership, most especially on short-distance journeys, but does not extensively discuss the implications of this result for the service.

Cervero concludes that under pure flat fares, offpeak riders subsidize peak riders, since it is the peak ridership that determines the amount of rolling stock and size of the labor force. This is likely to be true in many cases, but it depends on the demand characteristics of the area. But his conclusion that short-trip riders subsidize long-trip riders is a result of his choice of a metric that will inevitably lead to that conclusion.

Luhrson, Kurt F., and Brian D. Taylor. "The High Cost of Flat Fares: An Examination of Ridership Demographics and Fare Policy at the Los Angeles MTA." *Working Paper* (Los Angeles: UCLA, 1997). Available at: <http://www.uctc.net/papers/703.pdf>

"The High Cost of Flat Fares: An Examination of Ridership Demographics and Fare Policy at the Los Angeles MTA" is a 1997 article by UCLA researchers Kurt Luhrson

and Brian Taylor that draws on Cervero's research to reach similar conclusions. The core of Lührson and Taylor's research is a tabulation of distance traveled and frequency of travel by race, gender, and income level in the Los Angeles area. Lührson and Taylor find that lower-income, minority passengers tend to take shorter trips than higher-income white passengers, and that a distance-based fare structure is therefore more equitable. They also find that lower-income and minority passengers are less likely to use period passes, and therefore the existence of such passes forces lower-income, minority passengers to subsidize higher income, white passengers. Lührson and Taylor's analysis is sound, but they acknowledge its demographic analysis applies only to the LA area.

Nuworsoo, Cornelius Kofi, Elizabeth Deakin, and Aaron Golub. "Analyzing Equity Impacts of Transit Fare Changes: Case Study of Alameda-Contra Costa Transit, California" *Transportation Research Board 85th Annual Meeting* (Washington, D.C.: Research Board, 2006).

This paper presented at the 2006 TRB Annual Meeting presents an analysis of Alameda-Contra Costa Transit that is similar to Taylor and Lührson's analysis of LA transit. It contains a longer discussion of transit fare equity, but draws from another paper by Cervero in which he reaches the same conclusions as the one included here: that distance-based and time-varying fares are more equitable than flat fares. As in Lührson and Taylor, Nuworsoo et al. find that lower income and minority passengers tend to take shorter trips and thus subsidize higher-income and white passengers. In contrast to Lührson and Taylor's L.A. study, Nuworsoo et al. also find that lower-income and minority passengers use passes more frequently than higher-income and white passengers. Nuworsoo et al.'s methodology is sound, but limited to the Alameda-Contra Costa Transit district demographics.

Streeting, Mark, and Phil Charles. "Developments in Transit Fare Policy Reform" 29<sup>th</sup> *Australasian Transport Research Forum* (Queensland: ATRF, 2006). Available at:  
[http://134.7.85.34/atrf/papers/2006/1552\\_Streeting%20&%20Charles%20\(2006\).pdf](http://134.7.85.34/atrf/papers/2006/1552_Streeting%20&%20Charles%20(2006).pdf)

Streeting and Charles' paper, presented in fall of 2006 at the Australasian Transport Research Forum, suggests that fare structure trends have not kept pace with technology. It indicates that smartcard-based automatic fare collection systems allow for more differentiated fare structures. It cites Cervero's paper and the fact that many surveys suggest that passengers perceive fares as equitable when they establish a strong link between fare and distance, and uses the economic rule-of-thumb that marginal cost equal marginal price to prove that flat fares are inefficient. The paper states that the trend towards fare structure simplification is harming fare equity and efficiency. The paper does not see any cost savings from simple fare structures. The paper is interesting for its explicit evocation of smartcards as justification for switching fare structures, albeit to distance-based fares, and for its neglecting to mention the potential to use smart bankcards directly for transit fare payment.

## 2.4 Additional Ticketing Cost Articles

In addition to the TCRP reports there is one article in the literature on the relevance of barrier-based fare enforcement and one article on the economic advantages of smartcard-based systems that are worthy of note.

Clarke, Ronald v. "Fare evasion and automatic ticket collection in the London underground." *Crime Prevention Studies* 1. (Monsey, NY: Criminal Justice Press, 1993). Available at:  
<http://www.popcenter.org/Library/CrimePrevention/Volume%2001/07clarke.pdf>.

Clarke's analysis confirms that barrier-based fare enforcement significantly reduces the losses due to fare evasion, more than compensating for the cost of installing the barriers on 63 central London stations and the cost of the ticketing system. The installation of barriers and a magnetic-strip ticketing system reduced fare evasion on the Underground from 6% in 1989, before the barriers were installed, to 2% in 1990, after the installation of the barriers. Clarke suggests that it will be cost-effective to install barriers in further high evasion-risk stations, but that it would not be cost-effective to put barriers on every station, since the marginal benefit of evasion loss reduction decreases with each station on which barriers are installed. This paper is a strong endorsement for a barrier-based fare enforcement strategy.

Moreau, B. "The case for contactless smart cards is overwhelming." *International Railway Journal* 43, 1 (New York: Simmons-Boardman, January 2003). A slightly modified form of this article is available at  
[http://www.findarticles.com/p/articles/mi\\_m0BQQ/is\\_1\\_43/ai\\_99555309](http://www.findarticles.com/p/articles/mi_m0BQQ/is_1_43/ai_99555309)

Moreau's article concludes that the cost savings and performance improvements from switching to a purely smartcard-based fare collection system clearly justify the elimination of magnetic-stripe or paper tickets, especially because they should eliminate the use of fraudulent tickets, a major source of revenue loss. He mentions the Paris Metro's (RATP's) plan to switch to a pure smartcard system. That plan was, as of 2002, to eliminate all magnetic-stripe tickets by 2005; as of March 2007, the RATP is still using magnetic-stripe tickets, which suggests that the difficulties of eliminating mag-stripe tickets are greater than Moreau expected they would be. Still, Moreau's case for the eventual elimination of magnetic-stripe tickets is quite compelling, even if their elimination will take much longer than Moreau foresaw.

## 2.5 Demand Modeling

There is a great deal of literature available on demand modeling in public transit. This literature review will include one basic reference and two recent research articles to indicate the scope of what is available.

Ben-Akiva, Moshe, and Stephen R. Lerman. *Discrete Choice Analysis*. (Cambridge: MIT Press, 1985).

Ben-Akiva and Lerman's *Discrete Choice Analysis* is a thorough but concise introductory text on demand modeling. It presents a rigorous mathematical derivation of probit, logit, and nested logit demand models. Ben-Akiva and Lerman discusses sampling, aggregation, and practical issues in formulating an accurate demand model. Basic information on demand modeling used in this thesis is taken from this book.

Hess, Stephane; Polack, John W.; Daly, Andrew; and Hyman, Geoffery. "Flexible substitution patterns in models of mode and time of day choice: new evidence from the UK and the Netherlands" *Transportation* 34, 2 (Dordrecht: Springer Netherlands, March, 2007) pp. 213-238.

Hess et al. present a logit model that uses time of day as a choice. They create a logit model with the two standard variables (time of travel, fare cost), and introduce four new variables to model time of day choice: amount of time earlier than intended departure time, amount of time later than intended departure time, amount total away time shorter than intended away time, and amount total away time is longer than intended away time. Earlier and later (and shorter and longer) are modeled as separate variables because they fit the data with significantly different magnitudes. Hess et al.'s model is especially valuable, because it forms the basis for forecasting travel choice when fares vary by time-of-day. The time-of-day analysis in this thesis draws heavily from this paper.

## **2.6 Payments**

There is a vast amount of literature on the payments industry. The most relevant aspect of payments to the research in this paper is the penetration and use of electronic payment devices. The following paper presents a summary of a significant survey of payment device penetration in the U.S.

Mester, Loretta J. "Changes in the Use of Electronic Means of Payments: 1995-2004" *Business Review*, (Philadelphia: Federal Reserve Bank of Philadelphia, Q2 2006) pp. 26-30.

Mester summarizes statistics from the U.S. Federal Reserve's Survey of Consumer Finances, the definitive public survey on U.S. banking habits on the penetration and use of payment devices in U.S. households. ATM and debit card penetration has continued to rise over the decade. ATM cards had an overall penetration of 74.4% in 2004. Groups with lower-than average penetration included the over-60 population and the low-income population. Debit cards exhibited penetration patterns similar to those of ATM cards, with a somewhat lower overall level, achieving a 59.3% overall penetration in 2004. The survey results indicate a 1-2% increase in penetration each year for the last 10 years, with no leveling-off effects yet discernable. Credit cards are not considered in the survey, which is meant to cover direct banking instruments. As a whole the survey indicates that the already-high penetration of payment cards in the U.S. will continue to grow.

## **3 Framework**

### ***3.1 Background and Research Question***

The purpose of this research is to explore technical and business options for the successor to the current Automatic Fare Collection (AFC) system in London. TfL has promoted the AFC system in London under the name Oystercard. The Oystercard is run under a public-private partnership. The private contract for operation and infrastructure of the Oystercard was put up for bid in 1998, and the contract was granted to the TranSys consortium, which is comprised of the ticketing hardware integrator Cubic, the IT provider EDS, and two members who were primarily involved in the initial setup, Fujitsu and WS Atkins. The concession contract that grants the operating duties for Oystercard to the TranSys consortium will expire in 2015 (Bennett 2001). Transport for London (TfL) may, at its option, exit this contract at any time. Since the TranSys contract was signed in 1998, automatic fare collection technologies have evolved, new technologies have begun to enter the market, and new opportunities for collaboration with businesses not traditionally involved in transit have emerged. This research assesses the automatic fare collection options available to TfL when the contract for the successor to the current contract is put up for bid. This research evaluates the major transportation policy aspects of all relevant fare collection options.

The successor to the current Oystercard will be based on a contactless AFC technology. Contactless AFC technologies have been very successful worldwide, and an increasing number of transit agencies are adopting this technology (Multisystems et al. 2003). London's Oystercard program is part of this trend. The major advantages of contactless AFC include faster passenger throughput times, increased passenger convenience, fraud reduction, and gate staff reduction. In much of the developed world, transit systems limit access in order to prevent fare evasion. At transit system, barriers, the means of fare collection include cash, token, and magnetic stripe cards, but the fastest is contactless AFC. Contactless AFC has many other advantages, including easy and comprehensive data collection, reusability of fare media, etc. Contactless AFC will remain the basis for transit fare collection at least until 2015, but probably much longer.

However, new technologies that can be used to implement contactless AFC are becoming available. These technologies may supplement or replace a contactless ticket directly issued by the transit agency. MasterCard and Visa have been distributing contactless credit cards, and in 2006, the New York City Metropolitan Transit Authority (MTA) began a trial for payment of subway fares with the MasterCard Paypass directly at the transit gate (Hope 2006). Mobile phone providers that have been experimenting with mobile phone-based contactless payment for years, and starting in 2004 on the Seoul transit system, and in 2006 on the Tokyo transit system, passengers could pay with electronic purses stored on their mobile phones. Mobile phone companies in Europe and the U.S. have been performing increasing numbers of trials of mobile phone payments based on the new Near Field Communication standard. At the same time, some transit agencies in Switzerland and Germany have been experimenting with "Be-in Be-out"

smartcards that allow users to enter and exit transit systems and have their journeys recorded on smartcards in their possession without even tapping the cards on readers. All of these technologies hold the potential to allow greater service and passenger comfort than today's transit-agency-issued tap-based smartcards, and all may be ready for use when TfL puts the Oyster successor contract up for bid.

This chapter first discusses the analysis of technologies that could be used in a future fare payment system. It then explains the five fare collection options that are based on the technologies. The next chapter will discuss the dimensions upon which the technologies will be analyzed, and discuss the methods of analysis.

## **3.2 Technologies**

### **3.2.1 Smartcards**

The basic medium for contactless automatic fare collection is the smartcard, a plastic card with an embedded antenna and integrated circuit (IC) that stores ticket and possibly ticketholder information. The cards are typically the size of a credit card, although other sizes are also in use. Passengers tap the cards on cardreaders to pass through a fare barrier. Most smartcards in use today are inductively powered by radio frequency (RF) energy transmitted by the card reader; this channel is also used for communication between the reader and the card. Most, if not all smartcards used as transit tickets follow the ISO14443 standard. This standard specifies many characteristics of the card: transmission frequency (13.56 MHz), power level (chosen so that communication is possible at no more than 10 cm), data rate (106 kbit/s, with options for 212 kbit/s and 424 kbit/s), and other physical characteristics (International Standards Organization 2001).

There are several varieties of ISO 14443 smartcard used in public transit: read-only cards, read/write smartcards with logic-only chips; and read/write smartcards with microcontrollers. Read-only cards typically have no cryptographic capabilities, and are only capable of repeating their contents to the reader, essentially a long serial number. As such, they are only suitable for low-value cards. Read/write smartcards with logic-only chips can have writeable memories from 1kB to 4kB, and have basic cryptography. Oystercards are of this variety. Read/write smartcards with microcontrollers have 2kB to 32 kB of writeable memory, and are capable of advanced cryptography (Kocur and Dorfman 2007).

Smartcards can support any fare structure. The most common ticket products are prepaid stored value (e.g. £5 of stored value, from which £1.50 is deducted for a given journey) and period passes (e.g., a 1-week travelcard). Smartcards are used in transit systems that have a flat fare structure (the fare does not vary by distance traveled, though it can vary by time-of-day and mode), distance-based fare structure (fare varies by precise distance of journey taken), and zonal fare structure (each station belongs to a zone, and fare varies by the combination of zones of entry and exit station). Flat fare structures require the card be tapped on the reader only upon entering the system (tap-in), while distance-based and zonal fare structures require that the card also be tapped on the reader on exit (tap-

out). Fares may also vary by time of day, mode and passenger type (elderly, student, etc.)

### **3.2.2 Smart Bankcards**

Smart bankcards are smartcards used in the financial industry. They are typically debit or credit cards, which are linked to a bank account, although prepaid smart bankcards are also available. Smart bankcards are ISO 14443 smartcards with microcontrollers. They implement strict communication and data storage security standards. In Europe, the contactless card security standard adopted by banks is called contactless EMV (Gauthier 2005).

Contactless EMV is a rigorous security standard, and includes encryption and authentication requirements. It is intended to make the contents of the cards unreadable to unauthorized readers, which will not have a cryptographic key for the card. It should make the cards immune to replay fraud, in which the responses of a card to an authorized receiver are recorded, and replayed to a reader (Gauthier 2005).

In the United States, MasterCard is rolling out “PayPass,” a contactless credit card, in conjunction with many banks. Visa is also issuing the “Wave” card and American Express the “Blue” card, although these are not currently as widespread as the PayPass. In the UK, Barclay’s bank is trialing a Barclaycard Visa Wave card, which will be available in mid 2007 as one of the first contactless bankcards available in the U.K.

Transit authorities have recently been interested in using contactless bankcards directly for transit payment. There are many practical implementation issues associated with using smart bankcards directly for transit fare payment, but there appear to be solutions for these issues. A discussion of their solutions is beyond the scope of this paper. The New York City MTA began a trial of direct payment at fare barriers with the MasterCard PayPass in 2006 that continues as this paper is being written. Published accounts suggest that this trial is succeeding from an implementation standpoint (despite minor glitches) and from a customer acceptance standpoint (Monter 2006).

The Seoul, South Korea, transit system has accepted credit cards directly for payment at fare gates since 2004. Although the Seoul transit system accepts cards from several different Korean banks, it should be emphasized that these cards are not generic payment cards because they have a special interface for Seoul’s transit system. This system has proved extremely popular, rapidly achieving a 60% share of fare payments in the Seoul transit region (Kocur and Dorfman 2007).

TfL has begun to explore integration of financial payment media into its system. Starting in mid 2007, there will be a combined Oystercard/Barclaycard Visa Wave card available to customers of Barclay’s bank. This program represents a significant step towards the convergence of transportation and financial services. However, there will be separate Visa and Oystercard programs on the card, and the payment process will not be integrated (Knights 2006).

If transit agencies accept contactless bankcards directly at the fare gate, there are several issues that must be resolved, but two bear special mention: payment network interface and use of prepaid cards. The interface to the payments network can be direct or indirect: the transactions can be routed to the bankcard network as customers tap, or the payments can be stored (aggregated) on a TfL server, and routed later. Direct payment will require less complicated infrastructure: the payments network itself will supply all the necessary processing at the fare gates. However, direct payment may lead to higher charges for the transit agency, since every single tap-in will generate a transaction. Direct payment may not be possible with fares that require tap-outs as well as tap-ins; some extensions to current bankcard processing would be required. Indirect payment will allow for some form of payment aggregation, by which multiple small payments are combined on a regular basis to form a larger payment, which will likely have lower transaction fees than a small payment.

Prepaid bankcards would be very useful to a transit agency accepting bankcards as a fare medium. Prepaid bankcards are bankcards that are not associated with a registered bank account, but rather hold only a certain amount of “stored value” electronic cash. It would be a medium available to those without a bank account, or who have cash but have forgotten their normal bankcard or mobile phone. Prepaid bankcards are not yet common, but they are being introduced. Banks have great interest in serving the “unbanked” or “underbanked,” which represents thirteen percent of U.K. residents (Brown and Thomas 2005).

However, prepaid bankcards may create a special difficulty for transit agencies using indirect payments. If prepaid bankcards allow TfL to write the location and time of a tap-in, then TfL can compute the fare and deduct it at tap-out. If the prepaid cards do not allow TfL to write information on them, then the list of the identifying numbers of all prepaid cards tapped in to a given system (but not out) must be transmitted to every fare gate in the system frequently, so the correct fare can be immediately computed when a passenger taps out. Moreover, if a transit system gives rebates (e.g., for customers who travel a certain amount in a given period), it will be impossible to send customers who use prepaid cards their rewards without those customers tapping in again, since the transit agency will have no way of contacting the prepaid bankcard holder. In contrast, a transit agency can send a bankcard user with a bank account a rebate directly to that bank account.

### **3.2.3 Near Field Communication**

Near Field Communication (NFC) is an emerging standard of for mobile phone proximity communication, especially intended for proximity payments. NFC is essentially the incorporation of an ISO14443 smartcard into the mobile phone electronics, and the NFC standard, ISO18092, is based on the ISO14443 standard. Users can tap their phones on cardreaders to make a payment with an NFC phone in the same way they would tap their smartcards. The phones have functionality that the cards do not, such as the potential for

downloading tickets or value to the phone over-the-air (OTA), and the ability for the user to interact over a user interface with the transit agency (NFC Forum 2006).

NFC is a mobile phone proximity payment standard that is likely to succeed where other mobile phone proximity payment technologies such as Bluetooth and IrDA have failed. Unlike Bluetooth payments, which require the user to type in a device address and wait for a secure connection, NFC payments can be completed quickly by simply tapping the phone on a the reader. Unlike the infrared IrDA standard, passengers are not required to aim their phone at a specific target for a half second; they just tap it, and the reader is not as easily damaged as the infrared reader.<sup>3</sup> SMS payment is also used for mobile ticketing, but does not allow proximity transactions, and is not appropriate for payment at fare gates. Thus while these earlier mobile payment technologies failed to achieve widespread adoption, many in the industry believe NFC will succeed (NFC Forum 2006).

NFC has a significant further advantage over the other technologies: NFC payments are compatible with ISO14443 smartcard readers. In most cases, a software update to current ISO14443 smartcard reader servers (to manage the different memory addressing in the NFC memory) is all that will be necessary to make the current cardreaders recognize NFC phones. The cardreaders will still be able to recognize smartcards, so customers can choose which contactless technology they prefer.

The technical and financial considerations for transit payment with bankcards also apply to mobile phones. NFC payments may be credit, debit, or prepaid. The difference from bankcard payments is that the institution wielding the financial power may be the mobile phone network operator.<sup>4</sup> The network operator may provide the payment service directly; however, an institution providing a payment service will probably be required to register as a bank, and is likely to be an existing bank. More likely, the NFC memory on a phone will house the program for a payment service offered by a third party. For example, it could electronically house an existing credit card, and the bank would pay the mobile network operator a fee (e.g., 0.1%) per transaction. A single phone could house multiple payment tools – for example, two different credit cards. For transit payment, the phone could store a special transit payment program, or the transit agency could recognize a generic payment tool, such as a credit card.

There are two additional considerations for transit agencies accepting NFC payment: user interface and battery life. The mobile phone provides an effective user interface, so users can get information from the transit authority (such as schedules or locations of the nearest station) or purchase tickets over the air (OTA), if the transit agency continues to offer tickets. Mobile phone networks will need to negotiate the appropriate infrastructure for secure OTA downloads; however, when this infrastructure is in place, a transit agency may use it to place tickets or prepaid stored value on a passenger's phone.

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<sup>3</sup> Scratches in the glass covering IrDA readers could make them fail to read signals, and it would be difficult to harden them for use in a transit environment.

<sup>4</sup> A recent decision on high-speed SIM architecture for mobile phones virtually guarantees that network operators will control the security “master key”, though banks may still manage the payment process.

Battery life is also a concern for transit agencies accepting NFC payments: if a passenger relies on his or her phone for transit payment, it would be catastrophic if passengers who talk on the phone were to find that they could not pay transit fares because their battery was low. One proposed solution is a battery cutoff: when battery power drops below a certain percentage, all services except for NFC payments and emergency calls will be disabled. This solution should be available on the next generation of NFC phones, and seems satisfactory. Mobile phone companies are also working on “passive-mode” NFC, by which the mobile phone’s NFC electronics are powered by the cardreader similarly to how smartcards are powered by the cardreader. However, since mobile phone handset manufacturers have not finalized the designs of their next-generation NFC mobile phones, it is unclear if a passive power scheme will work (Kocur and Dorfman 2007).

Although a few models of mobile phones with NFC are available today, NFC is unlikely to be widely rolled out in Europe until 2009 or 2010. The reason for the delay in rollout is that the mobile phone industry internal conflict delayed the adoption of a new high-speed SIM standard. A critical part of the new standard – the use of USB as the main communications protocol – was decided in the fall of 2006. It will take mobile phone handset manufacturers until at least 2008 to develop handsets that comply with the new standard. Network operators want to issue NFC phones with part of the NFC implementation located on the (high-speed) SIM, which means the next generation of NFC phones will not be available until 2009 or 2010. Mobile network operators plan to wait until the new high-speed SIM and NFC phones are available before rolling out an NFC payment service (Kocur and Dorfman 2007).

Mobile phone transit payment is used in several major transit agencies today. In Seoul, transit fare payment by mobile phones of several networks has been possible since 2004. Tokyo introduced the “mobile Suica” payment by mobile phone in January 2006 (Kocur and Dorfman 2007). Tokyo and Seoul continue to expand their customer base. Both of these cities use technologies are very similar to NFC, but not identical.<sup>5</sup> In Hanau, Germany (a suburb of Frankfurt) an NFC payment trial began in 2005 that became available for all customers in 2006. However, it required customers to purchase special, somewhat outdated mobile phones in order to participate. While they received a good level of participation in Hanau, the local RMV transit authority is waiting on the German mobile operators to provide more widespread support of NFC before expanding the service area where NFC can be used for payment (Kocur and Dorfman 2007). NFC payments are currently being trialed in several parts of the U.S., and NFC has been proposed for transit fare payment on San Francisco’s BART transit system.

### **3.2.4 Long-distance Smartcards**

Starting in the late 90’s, a new type of smartcard technology, specifically intended for transit fare payment, was developed in Switzerland and Germany. These so-called long-distance smartcards were active – powered by a battery – and did not need to be tapped

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<sup>5</sup> Tokyo’s system is based on the Sony Felica chip, which was designed to be compatible with NFC, although it does not fully meet the NFC specification. Seoul’s system is based on a unique chip called Moneta.

on a reader. Rather, when passengers entered a vehicle, readers near the door of the vehicle would note the presence of the card, and switch it into active mode automatically, without the holder of the card taking any action. The card would remain in active mode as long as the holder was on the vehicle, i.e., as long as the card was within a fixed proximity of the cardreaders. When the card was more than a certain distance from the readers for a given length of time, the card would turn off. These cards were called “Be-in, Be-out” smartcards, and operated at nonstandard frequencies. They were also of nonstandard size – the same length and width as a credit card, but about three times as thick. These cards were trialed in 2001 in Basel, Switzerland and 2005 in Dresden Germany. The latter trial of the so-called “AllFa-Ticket” was considered a success, and Siemens AG, which had supported the project, said that they could produce such tickets as early as 2011 (Kocur and Dorfman 2007).

These cards have unique advantages and disadvantages in comparison with conventional ISO 14443 smartcards. The advantages of this card are comfort for passengers (they do not have to tap their cards at fare barriers), and the ability to collect perfect passenger path data and to charge path-based prices for the transit agency. The disadvantages are technology risk (since none of this technology is currently in production, potential cost (since the equipment would be manufactured in smaller quantities than ISO 14443 equipment would be, and the card would be significantly more complex than an ISO 14443 card), fraud potential (if fare barriers are eliminated), and passenger privacy (because the cards can be read at a long distance). Another disadvantage is the battery life. In the German trial, it was hypothesized that potential battery life for a card was about 1 year, which would mean that either passengers or the transit agency would need to service the card – replace the battery – every year.

### **3.2.5 Other Technologies**

No other technologies were found that will be mature enough for use as transit payment media by 2015. Transit payment literature contains little on what may follow ISO14443 smartcards. It is highly unlikely that other smartcard technologies will replace ISO 14443 by 2015. The main non-smartcard technology mentioned in payments literature is biometric payments – payments that occur when a fingerprint or iris-scan is connected to an individual’s bank account. Currently, there is no way to perform such a scan with an accuracy that prevents available fraud techniques from tricking the system. Transit payment processing requires a combination of high processing speed and fraud resistance, ability to “harden” for use in exposed and unattended environments, and relatively low infrastructure cost that is unlikely to be fulfilled by a non-smartcard technology (or the very similar NFC technology) in the next 10 years.

### **3.3 Options**

This section describes the five fare payment options that will be analyzed in the remainder of the thesis. In Options 1, 2, and 3, commercial payment tools (smart bankcards and NFC mobile phones) are used as the exclusive fare media. The motivations for switching to options 1, 2, and 3 are increasing customer convenience

(because customers will already be carrying a credit card or mobile phone, and don't need to obtain an extra fare medium for transit) coupled with the potential for cost savings (because much of the network administration charges will be covered by banks or mobile phone network operators). However, options 1-3 will require a supplementary fare medium for passengers who do not already have. Option 4 represents the continuation of the contactless AFC systems that exists today, which is clearly motivated by continuity and desire for the transit agency to retain complete control. Option 5 implements the long-distance smartcards described above. Like option 4, it requires the transit agency to administer a complete smartcard system. Option 5 gives passengers increased convenience – they do not have to tap – and allows the transit agency to implement path-based pricing.

### **3.3.1 Option 1: Tap-in = Transaction, Pure Flat Fare**

Option 1 is the simplest of the options for using a bankcard for transit fare payment. Option 1 makes the transit agency just like any other retailer from the perspective of payment. The entire transaction takes place when the passenger taps in at the gate or on the bus card reader. Because this tap in is the only contact between the transit authority and the passenger, the only fare scheme possible is a purely flat fare. There can be no free or discounted transfers. Distance-based and zonal fares are not supported. However, the fare can vary by mode, allowing subway to be more expensive than bus, and it can vary by time of day, allowing peak pricing.

The fare can also vary by station of entry – stations could have differing entry prices. However, experience of transit systems that have used fares that vary by station of entry (such as Braintree in Boston's MBTA network) has shown that such policies cause confusion and passenger discontent.

With option 1, the TfL gate and bus card readers are connected directly to the commercial payment network. No intermediate network is necessary, so network operation and maintenance costs become part of the fees to the payment network making. Thus option 1 offers great cost savings – the most cost savings of all the options. However, passenger data collection is difficult. The transit agency will need to arrange with the payment network to receive data on transactions, and it must track raw tap-ins for audit purposes.

In option 1, banks or payment processors will charge the transit agency fees for each transaction. For normal retailers, such fees typically have a minimum of 30 cents per transaction, an unacceptably high fee. But by having a third-party micropayment firm aggregate passenger taps (or by aggregating charges itself) and negotiating with the banks, the transit agency should be able to arrange fees that are in the 1-1.5% range on aggregate. This is the range of fees currently paid to the banks in the Seoul bankcard transit fare payment program.

Option 1 and the other financial bankcard options (options 2 and 3) are capable of serving those who do not possess a contactless payment device or who are currently paying a concessionary fare. Prepaid cards and/or mobile phones can be used as a supplementary

fare medium. Such cards can be sold via vending machines for visitors who do not already possess a contactless payment device. Concessionary fares can be charged to passengers who have specially-issued cards that identify them as concessionary fare passengers.

### **3.3.2 Option 2: Tap-in = Transaction + Post-processing, Flat Fare + Rebates**

Option 2 retains all the features and considerations of option 1, and adds another significant feature: the ability of the banks to perform post-processing on bankcard transactions. Post-processing means that at regular intervals, the bank reviews all charges on each card during the interval. The bank applies a set of rules to determine if the card qualifies for rebates or loyalty bonuses, and sends the rebate to the account associated with the card.

Post-processing is used today on many bankcards. Typical post-processing schemes involve giving passengers “points” for every dollar (or pound) spent at certain shops. The points can be converted into frequent flyer miles or reward items. Alternatively, many cards offer “cash-back,” rewarding users with a percentage of their total card purchases each month.

The options for post-processing presented in this section are more complicated than the post-processing programs in use today. However, they are based on the same principle, and banks will be motivated to support transit post-processing. Banks will be interested in the volume of business that a transit agency brings as well as the “top-of-the-wallet” effect that supporting the transit agency will give their cards. Banks will charge the transit agency for post-processing in addition to the standard credit processing fees. Post-processing fees are difficult to estimate for this option; an initial guess is 0.5%, but they could be lower or higher.

The post-processing would best be done by Visa, MasterCard or other card processors, so that the maximum number of bank cards would be included under the program. However, individual large banks may be the ones performing the post processing. They may request periods of exclusivity in exchange for writing the software and performing the processing.

Post-processing would give the transit agency several fare options not possible with Option 1. First, it would allow a frequent traveler discount. Such a discount would create a fare similar to a period pass. One way of implementing a frequent traveler discount would be a weekly journey threshold. For every journey taken using a given bankcard beyond that threshold in a one-week period, the passenger earns a rebate. The rebate could be partial, for example offering a 50% of journey fare. Or the rebate can be complete, giving the passenger full reimbursement for each journey taken beyond the threshold during the week. The period need not be a week: it could be 3 days, a month, etc.

Another fare policy possible with option 2 is transfer discounts. If free transfers are offered, then only the most expensive journey is charged during a given time period (such as an hour). If a passenger taps into a subway, and within an hour boards a bus, the entire bus fare will be rebated to his or her account. Alternatively, the rebate might be only for a portion of the flat fare, allowing discounted but not free travel.

A final fare policy possible with option 2 is to offer discounts for taking journeys that do not include stations in the central business district. Passengers who make two or more tap-ins per day outside of the central business district are rewarded with a fare discount. Such a scheme would allow a fare that does not vary between stations, but still rewards those who do not tap-in in central London.

The frequency of post-processing and the rebate program rules will determine how much cash users will have to front. For example, if post-processing occurs daily, then users will receive rebates to their accounts overnight. However, if the only cap is a monthly one, the rebate will be issued only once a month. Less frequent post-processing will mean lower total post-processing fees. But it is likely that some passengers will not be willing to wait a week to have their charges reimbursed. It may be desirable for to introduce a new discount period, perhaps 3 days.

### **3.3.3 Option 3: Charge Routing Entity, Flexible Fare Policy**

In option 3, passengers must tap-out as well as tap-in with their bankcards. This allows for a completely flexible fare policy, which can take any form: zonal, distance-based, time-based, or some other option. There is no reason to use a flat fare policy with option 3, because options 1 and 2 offer cheaper ways of implementing a flat fare policy.

In option 3, a third party, which we call an “intermediate processor” or “charge-routing entity” must collect the tap-ins and tap-outs, turn them into transactions, and route the charges on to the banks. The reason that this function will probably be done by a third party, instead of by TfL directly, is that this third party may need to be registered as a bank, due to the size and volume of transactions that will need to be routed. A bank may well perform this function, or a bank card company such as MasterCard or Visa or others.

The intermediate processor collects all taps and turns them into transactions, perhaps once a day. It must decide whether to place a temporary charge on customers’ accounts when the first tap is recorded, to ensure funds are available to cover likely transit transactions that day. It must handle the situation when a user does not tap out, probably by applying the maximum fare. It must handle prepaid contactless bank cards (and pay as you go mobile phones) by debiting the balance on the device when the passenger exits the system, either by tapping out or tapping in on a bus, under current fare policy.

Option 3 allows the possibility of passes or price caps. If price caps are offered, then transactions occur at the standard fare for each passenger, until he or she exceeds the threshold number of journeys in a given time period. After that, each additional journey on the card is charged at the discounted rate, or given free. This differs from the way the

cap is implemented in option 2, because passengers do not have to pay for anything up front for the discounted journeys: they are simply not charged. Passes would work as they do today: passengers purchase them in advance, and the network maintains a list of cards containing passes which are not charged when they are tapped in.

An example of a charge routing entity is the Korea Smartcard Corporation, which aggregates bankcard fare payment charges in Seoul transit and routes them to participating banks.

### **3.3.4 Option 4: Transit Authority Issued Smartcard**

Option four is to maintain a system similar to the system similar to the contactless AFC systems in place in many transit agencies around the world, including London. The transit agency issues its own, specialized smartcard. This is the lowest risk option, since the infrastructure is already in place

The transit agency can stay with option four but make several incremental changes to increase customer service. First, the transit agency could create a program to emulate its own smartcard on NFC phones. This would not require the agency to accept generic payment devices at gates. Second, the transit agency could change its smartcard to integrate with other regional smartcard programs. Programs for regional smartcard integration have been proposed in the U.S. and the U.K. (called UTFS and ITSO, respectively). Finally, the transit agency could accept generic credit cards and mobile phones in addition to its own smartcards for payment directly in at the fare gates. Doing so would require a charge-routing entity similar to the one described in Option 3. Doing this might create a system that is more expensive to operate than option 3, since the transit agency will still have to administer its own fare media.

The main benefit of remaining with option four is continuity: no significant changes are necessary, but some of the benefits. However, the major cost savings that are possible with options 1-3 may not be possible with option 4, because it is typically not possible to achieve significant cost savings from labor and infrastructure when only partial changes are made.

### **3.3.5 Option 5: Long-distance Smartcards**

Option 5 is an implementation of the long-distance smartcards described above. Custom equipment, or, potentially, special new equipment from Siemens, is necessary to implement this option. Customers carry long-distance smartcards, which turned on when passengers enter vehicles, and turn off after a delay when customers exit vehicles. Passenger's path through the transit network is recorded precisely. Any fare structure is feasible, and path-based pricing is possible.

## 4 Dimensions of Analysis and Methods

Transportation research literature, such as the series of TCRP reports cited in the literature review, suggests that the four dimensions along which ticketing options are analyzed are cost, demand/revenue, equity, and fare policy. Cost typically includes all costs associated with the ticketing system, including infrastructure, the ticket medium, and labor. Fraud losses and enforcement costs are sometimes also considered, but they will not be included in this analysis, as discussed below. Passenger demand shifts from fare changes will be analyzed with an incremental logit model. While some evidence supports that passenger demand increases when fare structures are simplified, there has been little quantitative research on this phenomenon. Equity considerations – the effect of a new fare media and fare policy on various social groups in the greater London area – will be analyzed with travel survey and TfL ticketing data. Other fare policy concerns will be considered under the fare policy rubric. Such concerns include differences between zonal, distance-based, and flat fare structures on congestion and public behavior, as well as the implications of eliminating fare products such as free transfers or passes.

This thesis will not consider technical or financial implementation issues. While there would be technical and financial issues to resolve, options 1-4 all appear feasible, though options 1 and 2 have substantial revenue and operational risks. Option 5 may not be feasible; it has significantly more technical and financial risk than the other options.

### 4.1 Cost

The first dimension on which the five ticketing options are analyzed is cost. Computing the cost of transit ticketing requires adding up the costs of the components of the ticketing system.

The main categories of cost are infrastructure, media, labor, and service fees. Infrastructure includes the cardreaders, servers on vehicles or in stations, hardening measures, the fare gates, station and vehicle networking, back-office servers, and ticket vending machines. Operation and maintenance costs are added to the capital costs of infrastructure to yield the total costs. Infrastructure is amortized over its lifetime. Media includes the cost of the smartcards themselves, which includes the cost of the physical card and its programming costs.<sup>6</sup> Labor includes ticket sales staff. Service fees include commissions paid to third-party merchants who sell tickets, as well as fees for other services not run directly by the sales staff, which includes web sales and telephone sales.

Fraud losses and enforcement costs are not estimated in this thesis.

The method used to determine the costs is to compute the cost of ticketing today, according to the categories listed above, and then to modify these costs to account for the

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<sup>6</sup> Currently, TfL returns the deposit on cards when their owners return them, so all the cards belong to TfL on the books.

differences of each of the five ticketing options. The option 1 costs include the readers at each gate and on the bus, and the credit card processing fees. Option 2 costs include all option 1 costs plus the additional rebate processing fees. Option 3 costs include all option 1 costs plus the additional charge routing entity fees. Option 4 costs will be the approximately the same as today. However, technology progress since the signing of the Transys contract in option 4 could lead to reductions in cost. In option 5, the media and card reader infrastructure costs are completely new, but most other costs remain the same. These costs will be determined and illustrated in detail in the numerical results section.

## 4.2 Demand

A multinomial logit demand model was used to predict the effects of a fare change on revenue, ridership, and passenger-km travelled in TfL services. Multinomial logit is the standard econometric model for consumer (passenger) choice among discrete (mode) choice alternatives – in this case, between underground rail (LUL), bus, car, network rail and walk (Ben-Akiva and Lerman 1985).

The multinomial logit model predicts how a consumer will choose to travel based on his or her socio-economic characteristics and the attributes, such as travel time, waiting time, walking time and fare or cost of the modes available to the traveller. Multinomial logit models are available to predict trip frequency, choice of destination and time of day choice. The basic model presented here focuses exclusively on the choice of mode of travel. The model is then extended to include a simple form of time-of-day choice. The other choices, such as trip frequency and destination choice, are likely to be secondary, because the analysis presented here focuses only on fare changes for public transport.

Because this analysis is only concerned with the response to the change of one variable, fare a simple form of multinomial logit called the incremental logit can be used effectively (Ben-Akiva and Lerman 1985). This form requires fewer inputs than the standard model: only the base mode shares and the *changes* in utility variables are needed—the values of the unchanging utility variables are not required. Incremental logit predicts changes in mode share caused by changes in independent utility variables such as fare. Once mode share and thus ridership is predicted (we assume total travel stays approximately the same), revenue is predicted as the product of fare times ridership, by fare category.

The incremental logit equation implemented in the model has the following form:

$$P'(i) = \frac{P(i)e^{\Delta V_i}}{\sum_{j \in C} P(j)e^{\Delta V_j}}$$

where

$P'(i)$  is the new mode share of alternative  $i$  (LUL, bus, or transfer),

$\Delta V_i$  = coefficient (as defined above, in utility/pound) \* change in fare (in pounds)

$C$  is the set of all modes available.

Because only the public transportation fare is changing,  $\Delta V_j = 0$  for all alternatives  $j \neq \text{bus, LUL}$ , so this reduces to

$$P'(i) = \frac{P(i)e^{\Delta V_i}}{\sum_{j \in C, j \neq \text{bus, LUL}} P(j) + P(\text{bus})e^{\Delta V_{\text{bus}}} + P(\text{LUL})e^{\Delta V_{\text{LUL}}}}$$

where  $i = \text{bus, LUL}$ .

Transfers are computed based on mode share of LUL.

Many researchers have estimated (calibrated) logit mode choice models for London and many other urban areas around the world. Most of these models use a single fare level for public transportation. The fare level used is typically the average fare paid by all users, whether they use single tickets or a form of season ticket or pass. Some assumptions must be made in order to use these models to predict shifts in ridership that result from changes in fare structure (for example, from season tickets to single tickets). In the model, each ticket type (single, Oyster pay as you go, weekly travelcards or bus passes, and monthly travelcards or bus passes) is treated as a separate market segment because each of these ticket types has a distinct average fare. In these market segments, the model computes the change in average fare from the current fare policy to the proposed future policy. Based on each market segment's fare coefficient (explained below), the demand model estimates the change in ridership in that market segment. When mode shares rise and fall, it means that existing riders are switching to a different mode (e.g., from LUL to bus or walk or network rail, for example), or a different ticket type on the same mode. Passengers may also make more or fewer trips, or change the time of day they travel. The logit model will accurately predict the aggregate effect of all these changes on the mode shares of all modes (Ben-Akiva and Lerman 1985).

Fare coefficients are the scalar multipliers that determine the effect of each independent utility variable on the overall utility of a given mode. Previous studies of the London transportation market have estimated fare coefficients based on fare elasticities. A fare elasticity is the price elasticity of demand for transit, i.e., the percent change in ridership that occurs with a given percent change in fare. For example if an elasticity is 0.4, a 10% change in fare will produce a 4% change in ridership. Logit demand model coefficients and elasticities are related through the following formula:

$$\text{coefficient} = \frac{\text{elasticity}}{\text{average fare}(1 - \text{market share})}$$

#### 4.2.1 Model

An individual logit formula is computed for each market segment based on the fares that TfL passengers paid in 2006. Peak and offpeak passengers are treated as separate groups, since they pay different fares when using Oyster pay-as-you-go. The market segments included in the logit demand model include the following:

- Passengers using LUL only:
  - Single cash fare tickets, peak and offpeak
  - Oyster pay-as-you-go, peak and offpeak; this category also includes day travelcards
  - 7-day travelcards; this category also includes 3 day travelcards
  - Monthly travelcards; this category also includes 3 month, 6 month, 9 month and annual travelcards. There is no peak or offpeak distinction in current travelcards, but separate peak and offpeak market segments for travelcards are created to model future differences between the two segments.
- Passengers using bus only:
  - Single tickets, peak and offpeak. It is assumed that all users making bus-bus transfers use bus passes to obtain free transfers.
  - Oyster pay-as-you-go, peak and offpeak
  - 7-day bus passes
  - Monthly bus passes; this category also includes annual bus passes. The same peak and offpeak distinction is made for bus as for LUL. The small number of bus-only passengers using travelcards is ignored since bus passes are a cheaper option for these passengers.
- Passengers transferring between bus and LUL:
  - Single cash fare tickets, peak and offpeak. Passengers pay a separate LUL and bus fare.
  - Oyster pay-as-you-go, peak and offpeak. Again, passengers pay a separate LUL and bus fare.
  - 7-day travelcards; this category also includes 3-day travelcards.
  - Monthly travelcards; this also includes longer duration travelcards.

The demand model does not include concessionaire travel (discounted fares for children, pensioners, etc.). The existing concession arrangements are assumed to continue.

In the main model data from passengers of all fare zones is aggregated into one mean fare. In order to estimate the aggregation error from eliminating the other fare zones, a detailed demand model, that includes each zonal distance (and, consequently, fare) separately was created for a few of the ticket types/market segments. The detailed models also allow for a detailed examination of the shifts in trip lengths and ridership in each market segment modelled in detail. In all the market segments examined, the detailed demand analyses gave ridership numbers that closely followed the aggregate analyses.

The model was implemented as an Excel spreadsheet. The spreadsheet contains worksheets that model fare policy options 1, 2 and 3 (tap in only, tap in with post-processing, and tap in and tap out, all with commercial fare media). Option 1 allows only flat fares, which can vary by mode and time of day. Option 2 allows a range of loyalty and rebate options that can approximate the effects of season tickets (period passes), zones (two zones—trips that cross central London, and those that do not), and transfer

discounts. Option 3 allows a full range of fare policies, but the spreadsheet contains a distance-based fare system. TfL can also retain the current LUL zonal fare system under option 3's technology.

In option one, the only user inputs are the flat fares that will be charged in the future. There are separate fares for bus and LUL, and each can have separate peak and off-peak fares. Transfer passengers pay the sum of the bus and LUL fares.

Option two, which includes rebates via post-processing, allows discount fares for riders who make more than a certain threshold level of journeys in a given time period (one week is assumed in the model). Option two has the following additional inputs: the discounted journey fare, and the threshold number of journeys (in a given week) that a passenger must make before the discount takes effect. For transfer journeys, a transfer discount can be given with post-processing; this transfer discount is also a separate, additional input into the model, and is typically set to the bus fare, so that transfer passengers pay only the LUL fare, the more expensive of the two modes. Option two also allows for discounts roughly based on station of origin. For example, if a passenger makes two LUL journeys in a given day that do not enter central London (the current zone 1), he or she can receive a discount for not having used the congested portion of LUL. So in option two, it is possible to enter a number that indicates the number of passengers who do not enter central London. All these rebates, discounts or loyalty rewards are issued at the end of the fixed time period (week or month) to the passenger, before he or she must pay the TfL bill on the bankcard or mobile phone account used.

Option three is analyzed as a distance-based fare that includes a fixed fare. Thus there is a fixed or minimum fare and a per-km fare for each mode. The effect of a season ticket is simulated with a discounted flat fare and a threshold number of journeys after which that fare is charged; no discount is offered on the per-km fare. Transfer journeys are charged the LUL (higher) fixed fare, plus the per-km charges from both modes. The model allows for an arbitrary choice of transfer journey discount, but it is typically taken to be the fixed bus fare.

## 4.2.2 Source Data

### Base Mode Shares

The base mode shares for bus, LUL, and other modes in the greater London area are taken from the London Travel Report, which states that they were computed from the LATS 2001 survey:

Car/taxi/motorcycle	44%
Walk/bike	23%
LUL	10%
Bus	18%
Network rail	5%

Table 4.1 Base Mode Shares

These averages are used as the base mode shares in the incremental logit model. These mode shares vary by origin, destination and time of day, but the model does not include variations, using mean values as base shares for simplicity. In the detailed demand models, these base mode shares vary by number of zones, which is closely related to trip length. The mode shares of walk/bike and bus decrease sharply with trip length, while national rail increases with trip length (Transport for London 2007).

### **LUL Base Ridership by Fare Level**

In the detailed demand models, in which the fares for all trips are not aggregated, passenger trips are differentiated by fare category, i.e., by number of zones crossed in a given trip. The Oystercard usage data provided by Prestige was used to determine the distribution of trips by fare category.

The following table contains the percent of LUL journeys in the main fare categories, as well as the annual number of journeys and annual revenue. The values are scaled to the 2004/2005 ridership.<sup>7</sup>

Fare(£)	Journeys	Percent of LUL journeys	LUL annual revenue(£)
1	209,320,000	22	144,600,000
1.5	197,100,000	21	204,200,000
1.8	56,500,000	6	70,300,000
2	216,800,000	23	299,600,000
2.5	204,500,000	22	353,200,000
3.5	49,900,000	5	120,600,000
4	2,700,000	0.3	7,400,000
5.5	2,200,000	0.2	8,200,000
Total	939,000,000	100	1,208,000,000

Table 4.2 LUL Ridership and Revenue by Zone

Buses use a flat fare system, so there is no zonal distribution for bus trips.

### **TfL Base Ridership and Revenue**

Table 4.3 gives revenue and ridership for calendar year 2006. The numbers provided span from 8 Jan 2006 to 9 Dec 2006 (inclusive) and were scaled by the remaining days in the year (365/336) to obtain the whole year values. The holiday period may have slightly lower-than average ridership, but no significant bias is being introduced.<sup>8</sup>

<sup>7</sup> Data on ridership by zone and ticket type was derived from raw data on Oystercard usage provided to the MIT transit research program by TfL.

<sup>8</sup> This data was compiled from TfL ticket sales data provided by TfL to the MIT transit research program. The data included all tickets, including paper ticket and travelcard sales as well as Oystercard product sales.

	Revenue	Ridership	Avg. fare	Passenger kilometres
Bus	826,989,271	1,326,302,427	0.62	5,002,019,021
LUL	1,385,642,965	992,466,429	1.40	7,577,900,778
TfL total	2,212,632,237	2,318,768,856	0.95	12,579,919,798

Table 4.3 2006 TfL Revenue and Ridership by Mode

For comparison, the numbers from the 05/06 travel report are as follows (Transport for London 2007):

	Revenue	Ridership	Avg. fare
Bus	788,000,000	1,406,000,000	0.56
LUL	1,266,000,000	935,000,000	1.35
TfL total	2,054,000,000	2,341,000,000	0.88

Table 4.4 2005 TfL Revenue and Ridership by Mode

Both of these tables exclude concessionaire travel, as does the model. The 2006 data is used as the base case in the model.

### **Base Ridership by Ticket Type**

Using data from TfL Fares and Ticketing, the number of journeys by ticket type could be determined. For simplicity, some ticket categories were eliminated:

- Day travelcards are grouped with pay-as-you-go singles because the average revenue per journey from day travelcards is nearly the same as the average revenue from pay-as-you-go trips.
- Annual, 9 month, 6 month, and 3 month travelcards are grouped with monthly travelcards because their average revenues per journey are close, and because there are relatively few annual, 9 month, 6 month, and 3 month travelcards.
- Other groupings of minor ticket types are described below.

Table 4.5 below shows the base ridership by ticket type:<sup>9</sup>

	Ticket type	Percent
LUL	Cash single	2.7%
	Pay as you go single	15.8%
	7-day travelcard	5.3%
	Monthly travelcard	5.9%
Bus	Cash single	4.7%
	Pay as you go single	13.3%
	Bus pass weekly	15.3%
	Bus pass monthly	10.8%
LUL-bus	Pay as you go single	1.8%
	7-day travelcard	7.2%
	Monthly travelcard	4.1%
Total	Linked trips	86.9%
Total	Unlinked trips	100.0%

Table 4.5 Ridership by Ticket Type, All TfL

LUL-bus (transfer) journeys are journeys that include both a LUL and a bus stage. The sum of all the LUL, bus and LUL-bus percentages adds to 86.9%, which is the percentage of *linked* trips as a percentage of the total, the number of unlinked trips. In a linked trip, the bus leg and the LUL leg of a single passenger journey are counted as just a single passenger trip. This measure is passenger-centric. When twice the LUL-bus transfer percentages are added to the LUL and bus trips, the percentages add to 100%, which is the number of *unlinked* trips. In an unlinked trip, the bus leg and the LUL leg of a single passenger journey are counted as two trips. This measure is TfL-centric.

TfL generally reports ridership totals by mode, and thus it reports unlinked trips in its ridership totals. In the model used in this paper, both ridership totals are reported – with linked trips counted once and with linked trips counted twice.

#### Average Number of Trips per Ticket

In order to determine the current average fare per trip, which is needed by the demand model as a basis for the change in utility due to change in fare, the average number of trips per ticket on the period passes – the 7-day and monthly travelcards – is needed. TfL data shows the following number of trips per ticket:<sup>10</sup>

- Travelcards used on LUL: 16 trips per week
- Bus passes: 27 trips per week
- Bus-LUL transfer passengers using travelcards: 16 trips per week

<sup>9</sup> This data was compiled from sales data and Oystercard usage data provided to the MIT transit research program to TfL.

<sup>10</sup> This table was compiled from ticket sales data and Oystercard usage data provided to the MIT transit research program by TfL.

Because passengers making bus-to-bus transfers must tap in at the transfer point, the higher number of weekly trips on bus passes reflects both the number of transfers and, possibly, a higher underlying rate of travel than LUL. The data shows that approximately one-third of bus trips involve a transfer, which suggests that buspass holders make an average of about 20 linked bus trips per week.

In the model, it is assumed that monthly pass holders make the same number of trips per week as weekly pass holders.

### **Time-of-day Choice Model**

A time-of-day choice model is created to illustrate the effects of peak pricing on bus and LUL. The additional data needed to create the time-of-day choice model are the number of TfL tap-ins (by minute), and the mode shares in central London (the current zone 1). The minute-by-minute tap-in data is taken from the Oyster sample data from June 2006. The mode shares for central London are needed because transit has a higher mode share in central London than in the entire TfL service area, and the peak pricing will be focused on trips to and from central London, the congested area. The modal data is presented in the 2005/2006 London Travel Report (Transport for London 2007). The modes shares are as follows:

Car/taxi/motorcycle	11%
Walk/bike	1%
LUL	51%
Bus	11%
Network rail	25%

Table 4.6 Base Mode Shares, Morning Peak into Central London Only

Data on transfer journeys was not available, so it was assumed that the percent of journeys in central London that are transfer trips is the same as the overall number (13.1%). This gives the following ticket distribution, which is used in the time-of-day choice model.<sup>11</sup>

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<sup>11</sup> This table was compiled from ticket sales data and Oystercard usage data provided to the MIT transit research program by TfL.

	Ticket type	Percent
LUL	Cash single	6.1%
	Pay as you go single	35.6%
	7-day travelcard	12.0%
	Monthly travelcard	13.3%
Bus	Cash single	0.7%
	Pay as you go single	2.1%
	Bus pass weekly	2.4%
	Bus pass monthly	1.7%
LUL-bus	Pay as you go single	1.8%
	7-day travelcard	7.2%
	Monthly travelcard	4.1%
Total	Linked trips	87.1%
Total	Unlinked trips	100.0%

Table 4.7 Ridership by Ticket Type, Morning Peak into Central London

### 4.2.3 Assumptions

#### Multinomial Logit Demand Model

A multinomial logit mode choice model is the basis for the revenue and ridership analysis. The model has five alternatives: bus, LUL, national rail, walk and car. The incremental version of the logit model is used.

The price elasticity of demand for travel in the greater London area was computed by the Steer Davies Gleave transportation consultancy for TfL (Mitrani et al. 2002). This value is -0.4 for LUL and -0.6 for bus. For transfer riders, who use LUL and bus, the model uses the LUL elasticity value. As indicated above, the formula for finding the coefficient in the multinomial logit model, given an elasticity, the average value of the quantity changing (fare in this case) and the market share of the alternative (LUL or bus) is the following, as above:

$$\text{coefficient} = \frac{\text{elasticity}}{\text{average fare}(1 - \text{market share})}$$

Bus and LUL have separate cost coefficients, because they have different elasticities and mode shares. In addition, the model assumes that there are separate cost coefficients for single/pay-as-you-go market segment and the travelcard/buspass market segments. This assumption is justified by the fact that the average costs and conditions of use are significantly different for these two markets. Using a single coefficient for the entire range of LUL and bus fares would imply elasticities lower than 0.4 or 0.6 for travelcard/buspass users, and higher than 0.4 or 0.6 for single/pay-as-you-go users, which seems to contradict the numbers computed by Steer Davies Gleave. The coefficients for the two markets are calculated for both bus and LUL based on their average fares, giving a total of four coefficients.

Using a single cost coefficient for all LUL and for all bus fares would make flat fares quite attractive, because many riders would be gained by reducing the high single/pay as you go fares, because the single cost coefficient would imply a relatively high elasticity with respect to the fares being paid by the single/pay-as-you-go segment. At the same time, few riders would be lost by increasing the low travelcard/bus pass fares, because the single cost coefficient would imply a relatively low elasticity with respect to the fares being paid by the travelcard segment. It is possible that the market would respond in this way. However, further market research is needed to establish the distribution of the transit market in London. It is more conservative to assume that TfL has priced responsively in these markets over a long period of time, and that the behaviours of the two market segments are in fact different.

### **Revenue Distribution**

In the current fare structure, travelcard revenue is split between LUL, bus, and the Network Rail train operating companies according to number of passenger-km provided. Network Rail revenues may be ignored, and, the passenger-km numbers scaled by the LUL average trip distance of 7.8 km and the bus average trip distance of 3.8 km. Doing this give the split in trips between LUL and bus on travelcards is 74% LUL and 26%. These figures are used to divide revenue between bus and LUL on transfer trips.

### **Time-of-day Choice**

The demand model can be extended to include time of day choice as well as mode choice. If TfL considers using peak pricing, it will be desirable to model passengers' time of day choice in order to determine peak fare levels. Peak pricing means charging higher fares during peak hours, when demand equals or exceeds capacity, and lower fares during offpeak hours, when demand is significantly lower than capacity. Peak pricing is an effective way to expand capacity on the Underground. Peak pricing expands capacity by "spreading" the peaks: moving some passengers from the capacity-constrained peak hours to the offpeak hours. After TfL's current program of infrastructure upgrades finishes around 2015, trains will be running at minimum feasible headways. Once these upgrades are made, peak pricing may be the only way to further expand capacity.

Peak pricing can be implemented with any ticketing option. However, the use of unlimited period passes significantly reduces the efficacy of peak pricing, because passengers who hold unlimited passes are unaffected by higher fares at peak hours. If unlimited passes are sold, peak pricing may induce many passengers to shift to unlimited passes, significantly reducing the capacity-generating effects of peak pricing. Thus it is more natural to consider peak pricing in the context of a flat fare scenario, such as options 1, or any option where a price-cap or rebates replace period passes, which can be done on options 2-5. There is a further discussion of the effects of unlimited passes and peak pricing in chapter 6.

To get the greatest amount of capacity on the transit network, the peak price should apply only to the highest points of the peak period. If the peak price applies to a wider peak, it

will either push passengers off to other modes who could be accommodated on the existing service, or be so low that it is ineffective at decreasing peak ridership.<sup>12</sup> The following charts show the number of tap-ins, by minute for the 5% sample of Oystercard passengers whose data was made available to MIT on weekdays during the month of June, 2006.<sup>13</sup> The time-of-day model developed here accepts any two periods for peak pricing, but results will only be presented for the very highest peaks on the two modes: 8-8:45 AM and 5-5:45 PM on LUL, and 8-9:15 AM and 5-6:15 PM on buses as the periods of peak pricing. These periods roughly correspond to the highest 15% of system loadings on the two modes.

Note that the Oyster data represents only about 70% of TfL passengers. Most of the remaining passengers use National Rail travelcards, which are magnetic-stripe based, and a few use the paper or cash tickets. However, these passengers likely behave in similar ways to those of the Oystercard passengers, so it seems reasonable to infer that the Oyster time of day distribution is a good description of the total distribution.

It should also be noted that bus ridership throughout the day remains at a steady level much closer to the level of the peaks than does LUL ridership. The ratio of peak to mid-day ridership is about 1.5 on bus, 4 on the underground.

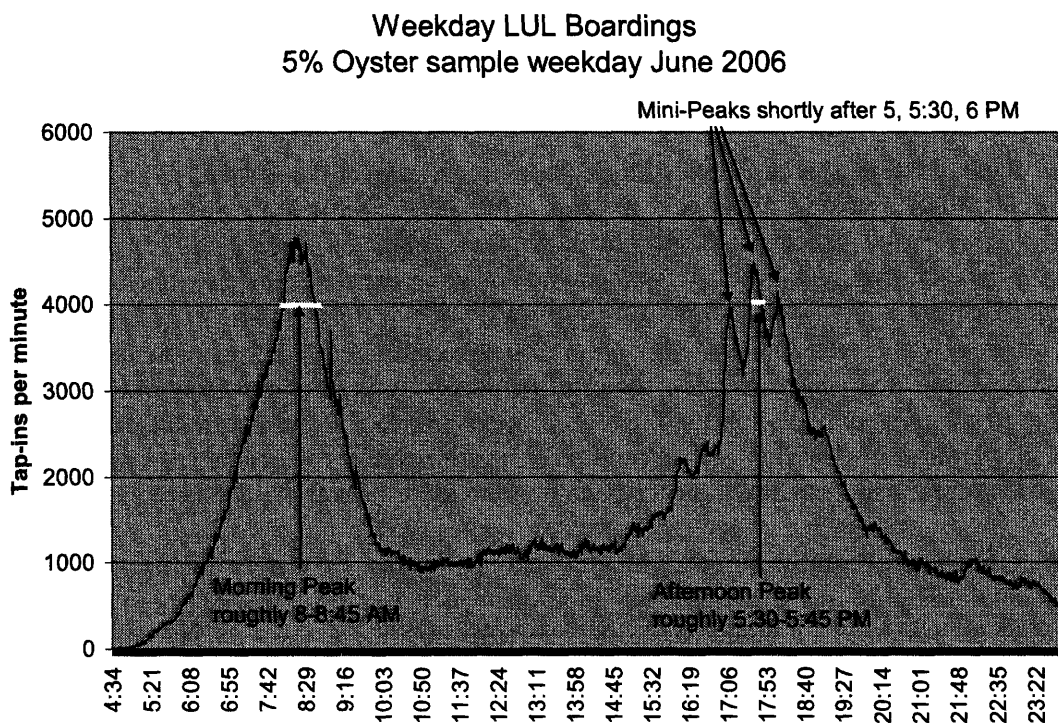


Figure 4.1 Weekday LUL Boardings, 5% Oyster Sample, June 2006

<sup>12</sup> If a broader time would benefit from a peak price, a pricing system with several tiers can be used. However, this is more complicated, and will not be considered here.

<sup>13</sup> The graphs were compiled from Oystercard usage data for June 2006 provided by TfL to the MIT transit research program.

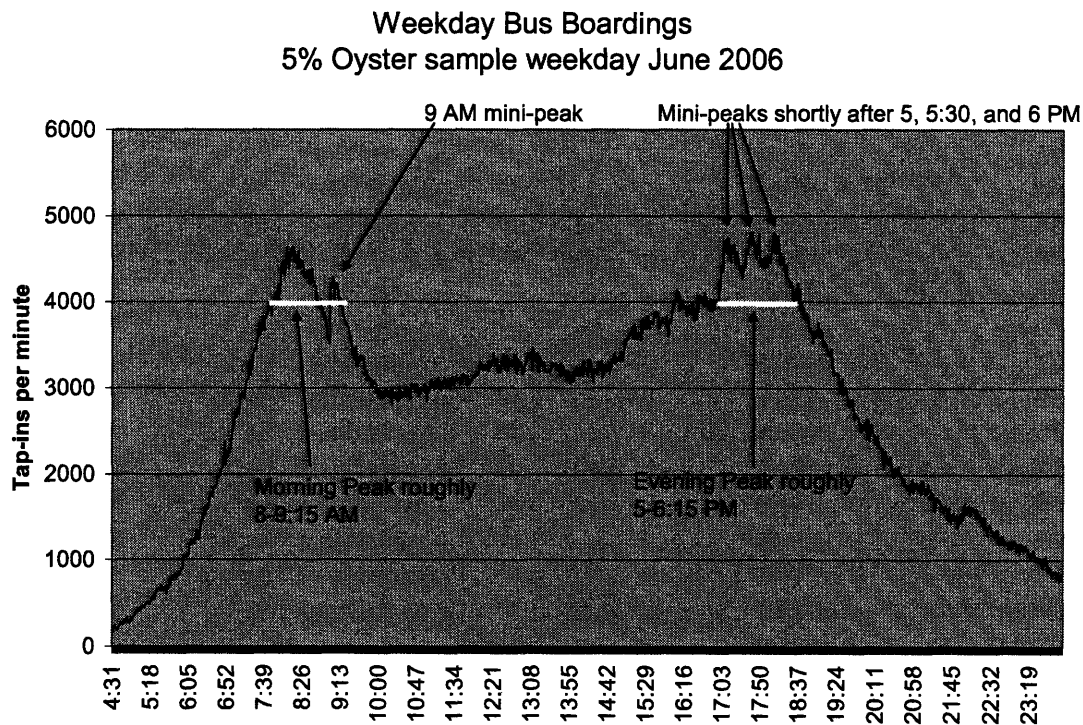


Figure 4.2 Weekday Bus Boardings, 5% Oyster Sample, June 2006

The time-of-day choice model is also a multinomial logit model. In order to accurately model which passengers may choose to switch to the offpeak, periods that include the times immediately before and after the start and end of the peak pricing will be modeled separately. These periods will be called shoulder periods. Shoulder periods are periods that include a portion of the peak hour, from which passengers may switch to a portion of the offpeak hour.<sup>14</sup> The length of shoulder periods is an input to the time-of-day choice model; shoulder periods will be assumed to be symmetrical – each shoulder period will include as much time after the start/finish of peak pricing period as before it. In addition, the early morning and late afternoon shoulders (centered at 8AM and 5:45/6:15 PM LUL/bus) will be assumed to be the same length, because these times are outside of the most common working hours, so people may be more flexible; likewise, the late morning and early afternoon shoulders (centered at 8:45/9:15 AM LUL/bus and 5 PM) are assumed to be the same, because these times are the start and end of the most common working hours, and thus people may be less flexible at these times. Results will be presented with different lengths of shoulder period.

The length of shoulder period is a parameter that must be fit to the behavior of passengers. There is no data with which to determine the most realistic shoulder length. Thus the length is left as an input to the model, and results for several values are presented.

<sup>14</sup> In this thesis, the term “shoulder period” will be used to refer to the entire period being modeled, including peak and offpeak portions.

Transportation literature provides possible guidelines for setting the length of the shoulder period. One way to determine the best length for the shoulder period is to use a value for the “disutility of schedule delay.” The length of the shoulder period would be the time at which the disutility of the schedule delay from moving to the offpeak equals the increased utility from the cheaper fare in the offpeak. A value for disutility of schedule delay has been computed by Hess et al. in a recent publication. However, this value implies a value of time for schedule delay of London residents equal to £1.20 per hour. Because the average hourly wage in London was over £17 in 2005 (GMB 2006), a value of £1.20 per hour is too low.

While it is generally agreed that people value their transportation time spent in a vehicle at somewhere between  $\frac{1}{4}$  to  $\frac{1}{2}$  of their average hourly wage, there is less agreement on how people value schedule delay – being forced to leave home earlier or later than they would otherwise choose. One recent study found that people value schedule delay in a highly nonlinear way: adjusting a schedule by 5 minutes leads to a valuation of far less than  $\frac{1}{4}$  average hourly wage, by around 15 minutes can lead to a value in the  $\frac{1}{4}$ - $\frac{1}{2}$  hourly wage range, and adjustments of over 25 minutes can lead to a value far greater than  $\frac{1}{2}$  hourly wage. In addition, shifting a departure time later is often given greater value than shifting a departure time earlier (Tseng et al. 2005).

Instead of trying to resolve these conflicting results for the value of schedule delay, the model presented in this research will present results for different shoulder periods, which represent different valuations of schedule delay.

A single-step price increase to a peak price – shifting directly from an offpeak fare to a peak fare without any intermediate step – may lead to large queues immediately before the peak pricing becomes effective, which is not desirable. It may be preferable to include a stepwise or linear continuous increase to a peak price over a period of 10-30 minutes. However, for simplicity, an incremental change from offpeak to peak prices is not modeled here.

The peak pricing model used here can be summarized as follows: Peak prices are 8-8:45/9:15 AM and 5-5:45/6:15 PM (LUL/bus), the current ridership peaks; shoulders are chosen by the model user, and are symmetrical, including equal time in peak and offpeak periods; the length of the early morning shoulder and the late afternoon shoulder are equal, as are the lengths of the late morning and early afternoon shoulders; separate multinomial logit models are computed for each of the shoulder periods, in which shifting times as well as modes is possible, and for the pure peak and pure offpeak periods, in which only shifting modes is possible.

Finally, it should be noted that the model only computes time and mode shifts due to fare changes. The reduced congestion at peak hours due to peak pricing could, in fact, cause a few passengers who are not sensitive to price, but who dislike the extreme crowding at peak hours, to switch from the offpeak to the peak. However, the model does not account

for such passengers, which is reasonable because the number of such passengers is probably small.

### **4.3 Equity**

Fare equity is a major consideration in choosing a fare structure, and must be considered when making any fare structure changes (McCollom 2004). This thesis will take fare equity to mean that changes in fare structures do not increase the degree of disadvantage experienced by disadvantaged social groups. This formulation of fare equity can be viewed as application of John Rawls' second principle of justice. Simply stated, Rawls' second principle of justice says that social and economic inequalities should be arranged so that they are of greatest benefit to the least advantaged members of society (Rawls 1971). Thus when a change is made to a service that affects economic distribution, the change should, at a minimum, not increase the degree of economic inequality, and perhaps even reduce economic inequality. Rawls' work is considered one of the most influential writings on distributive justice. Recent research by Nuworsoo et al. also invokes Rawls and concludes "whenever new pricing policies are introduced, it is prudent to ensure that the incidence of fare increases is not any more onerous on members of disadvantaged groups than others." (Nuworsoo 2006). This policy will also be adopted in this thesis. Other definitions of fare equity are possible, but are not considered in this thesis.

The fundamental measurement of fare equity is the difference of the effects of fares on different social groups. The major social groups are defined by income, gender, ethnicity, age, and physical disability. This thesis will analyze the affect of the fare options on social groups defined by income, gender, and ethnicity. TfL offers concessionary fares to young and disabled passengers, and residents of London over 60 can apply for a "Freedom Pass" which allows unlimited travel on TfL services after 9:30 AM. These concessions will not be changed under a new fare structure, so age and physical disability will not be considered in the analysis of equity of the ticketing options.

There is one dimension of equity analysis independent of fare structure: access to fare media. When a fare medium is distributed externally to the transit system, as is the case with bank cards and mobile phones, the various social groups may not have equal access to the fare medium. Access to fare media will be studied by examining other research on penetration of fare media in the London population. Recommendations will be made on how to remedy inequities.

There are four dimensions of equity analysis that relate to equitable fare structures. Two dimensions deal with effective transit value from fare by social group: average trip length and trip frequency. The other two equity dimensions deal with the effect on the effects of fare products by social group: free transfers and passes (advance payment products). Average trip length affects fare equity when fares are changed from distance-based/zonal to flat because those taking the longest trips will now pay no more than those paying the shortest trips, and if one social group is over-represented in passengers taking the shortest trips, that social group is disadvantaged by the change. Trip frequency

affects fare equity when period pass tickets are removed or changed, because the groups taking the most trips will now pay significantly more than they were paying with period passes, and if any social group takes significantly more trips than the other group, then that group will be disadvantaged by such a change. Free transfers affect fare equity because if they are eliminated, and one social group was using free transfers more than other social groups, that group is disadvantaged. Passes affect equity because different social groups may have different trip frequencies as already discussed, but also because different groups may be more prone to purchasing passes when they would have been more economically served by using prepaid tickets, or because some social groups are more likely to share one pass among several people.

The equity consequences of fare changes on travelers with different trip lengths and trip frequencies will be analyzed based on data from the London Area Travel Survey (LATS). TfL provided the MIT transit research team with a database containing the LATS survey data. LATS was a comprehensive survey of the travel habits of around 30,000 London households conducted in 2001 (SRA Statistics Team 2005). At TfL, London census data was used to assign weights to each individual and household in the survey. The weights represent the portion of the entire London population that each person or household reflects in the survey. Thus by summing the weights of each person, trip, or household, an accurate result can be calculated for the entire London population. All queries of the LATS database included the following steps: removal passengers over 60 or under 5, and removal of those not residing in one of the 33 London boroughs. Passengers under 5 never pay a fare, and London residents over 60 travel free after 9:30AM; most of those over 60 who need to travel before 9:30 will still work, and thus exhibit the same characteristics as those under 60.

Trip length is relevant to equity because any fare change should not cause disadvantaged social groups to pay more for transit than they are now with respect to advantaged social groups. Trip lengths, by social group can be measured from the LATS database. This is done by summing up trip length by social group, and dividing by the number of trips by social group, to get the average trip length by social group

Trip frequency is relevant to equity because if a fare change eliminates zero marginal cost travel products, social groups that rely on those products will be disadvantaged. Trip frequencies, by social group, are measured from the LATS database by summing up all trips taken, by social groups, and dividing by the number of members of each social group.

Free transfers (from bus to subway or bus to bus) are relevant to equity because if they are eliminated, it may affect one social group more than others. The equity effects of free transfers will be investigated by determining mode share by social group for bus and subway (from the LATS database), correlating it with the frequency of transfers by mode (from Oyster data).

Advance payment products such as passes raise a significant equity issues because they require passengers to pay for passes up front, before they can be used, but in turn grant

those passengers the cheapest per-journey fares offered, if those passengers are traveling frequently. The most extreme case is annual travelcards that include zone 1. In 2007, an annual travelcard covering zones 1 and 2 cost £928, a one-time payment beyond the means of many lower-income Londoners. Oyster data available for research was cleansed of demographic information and LATS does not contain ticket information, so the analysis of advance payment products will be based on relative cost and ticket sales rather than a strict data analysis.

#### **4.4 Fare Policy**

The three primary fare structures – flat, zonal, and distance-based – have different effects on the transit-riding public. Some of these effects are captured in the demand and equity sections of this analysis, but other effects are not. These effects not captured include the demand induced by the transparency/simplicity of the fare structure; the possible congestion effects of increased demand, and the connection with national rail services. Arguments about the congestion-causing effects of the fare policies will be based on the demand model. Other analysis of fare policy is necessarily of a more qualitative nature.

The analysis will attempt to answer whether period passes or free transfers are necessary travel products. Period passes make it convenient for passengers to budget their travel, but also have negative implications. Period passes, for example, have the undesirable property of encouraging passengers to make more trips than they really need to make, even at peak hours, because they have zero marginal cost. The analysis will be made on the basis of numbers already computed in the demand and equity sections, and combined with arguments on the qualitative effects of these policies.

## 5 Numerical Results

### 5.1 Cost

#### 5.1.1 Cost of Options 1-3

The cost of options 1-3 based is determined based on current costs compiled from TfL internal cost data. Costs are divided into “TranSys costs,” and “Own Costs.” TfL pays the TranSys costs to TranSys, the private consortium that runs Oystercard under the current public/private partnership concession contract. “Own Costs” are costs that TfL pays directly. Costs incurred from the 17-year TranSys concession contract are amortized over the 17 years, and include operation and maintenance costs. The costs in this chapter do not include fare enforcement costs or fare evasion losses.

There are several cost categories that are eliminated by the use of bankcards as the fare payment medium. For these categories, a cost of 0 is used. In the remaining categories, high and low cost estimates are made to indicate the range of costs possible.

Cost savings in options 1-3 are achieved primarily by two means: the use of commercial equipment and the elimination of the ticket sales system. Smart bankcards and mobile phones allow the use of the same readers, servers, and other networking equipment in widespread use in the payments industry. Some parts of current fare collection equipment, such as fare gates, can be replaced by commodity items. These commercial products benefit from greater economies of scale and more competition, and thus are cheaper than the current bespoke ticketing equipment used by the TranSys consortium.

The second means of cost savings is the elimination of the ticket sales system. This entails the elimination of the sales staff; the network of third-party retailer “Ticket Stops” that sell TfL ticket media in return for commissions, and other related costs detailed below. There will probably need to be a supplemental ticket medium available: customers paying with cash will be able to obtain a pay-as-you go mobile phone, or a prepaid bankcard, or both, at many or all LUL stations, and at other locations throughout London. The cost for selling these devices will be borne by the bankcard or mobile phone company. The opportunity to put their device in another customer’s hands will justify their installation of card or phone-selling vending machines. TfL may need to pay for the installation and O&M of such machines at outlying stations, where the business case for installing and maintaining a vending machine is less favorable; this cost is also accounted for below in the “Residual Ticket Program” category. Although the cost savings indicates the elimination of ticketing staff, some of these employees may remain at stations, to provide information or to fulfill a minimum station staffing requirement. However, these employees will be able to provide additional services not currently provided, so their elimination can be treated as cost savings for fare collection.

The following table lists the current costs of the ticketing system.<sup>15</sup> The costs are divided into several categories, described below. It also lists the costs of options 1-3 for the same cost categories as the current ticketing system. Additional cost categories for options 1-3 appear at the bottom.

<b>TfL ticketing costs (million £/year)</b>	<b>Option 1-3</b>		
	<b>Current</b>	<b>Low</b>	<b>High</b>
<i>LUL Transys costs</i>			
LUL ticket machines	16.8	0	0
LUL gates	19.7	4.9	19.7
LUL other	4.2	2.1	4.2
<i>LUL Own Costs</i>			
LUL ticket staff	60.0	0	0
LUL rent foregone	7.5	0	0
<i>Bus Transys Costs</i>			
Bus Equipment	14.4	7.2	14.4
<i>Bus Own Cost</i>			
RTMs	4.4	0	0
<i>TfL-wide Transys costs</i>			
Sales agents	11.3	0	0
Ticket media	13.7	0	0
<i>TfL-wide Own Costs</i>			
Agent commissions	38.3	0	0
Web and telesales	1.2	0	0
Credit, cash handling fees	6.0	0	0
<b>Intermediate Total</b>	<b>197.5</b>	<b>14.2</b>	<b>38.3</b>
<b>New Costs for Options 1-3</b>			
Residual ticket program	0	0	10
<b>New Costs for Option 1</b>			
Credit card fees (1-1.5%)	0	20	30
<b>Option 1 Total Cost</b>	<b>197.5</b>	<b>34.2</b>	<b>78.3</b>
<b>New Costs for Option 2</b>			
Credit card fees (1.5-2%)	0	30	40
<b>Option 2 Total Cost</b>	<b>197.5</b>	<b>44.2</b>	<b>88.3</b>
<b>New Costs for Option 3</b>			
Option 3 int. proc fees (2-3%)	0	40	60
<b>Option 3 Total Cost</b>	<b>197.5</b>	<b>54.2</b>	<b>108.3</b>

Table 5.1 TfL Ticketing Costs, Current and Estimated under Options 1-3

#### LUL Transys Costs

LUL TranSys Costs are the costs paid by the Underground division of TfL to the TranSys consortium. These cost categories include ticket (vending) machines, gates (including cardreaders and servers, and other costs (which is comprised mostly of station servers and networking). Cost savings from the implementation of options 1-3 include the

<sup>15</sup> Current cost data was provided by TfL to the MIT transit research program.

elimination of ticket machines, as described above, and reduction in the price of gates and other items through the use of commercial equipment.

Gate prices are reduced both by the purchase of commercial equipment and by a change of enforcement strategy. If the fraud enforcement strategy changes from preventing fraudulent access with barriers to recording fraudulent access with cameras, the swinging doors are eliminated, their capital and maintenance costs are eliminated, and the purchase of more commercial parts for the gates is possible. This alternate enforcement strategy is feasible because many TfL gates are supervised by station personnel. When fraudulent access occurs, they will direct passengers to tap again. When personnel are not present, the passengers are photographed, and enforcement officers can be sent to stations at times when fraud occurs. Clearly, switching enforcement strategies carries some risk, and not all the savings can be possible. However, if the swinging doors can be eliminated, and the purchase of nearly all parts of the gates from commercial sources is possible, the cost of the gates can be reduced by 75%, from £19.7 million to £4.9 million.

LUL Other, the category that refers to station servers and networking, can be reduced by half if more commercial products are used. In the high scenario, no cost savings from LUL Other costs can assumed.

#### LUL Own Costs

LUL Own Costs are costs incurred by the Underground that are not covered under TranSys contract. These costs include the cost of labor for the TfL ticketing staff and the rent foregone of the ticket sales locations in the Underground stations. As discussed above, a full implementation of Options 1-3 entails the elimination of the ticketing staff, so this cost is reduced to zero. The rent foregone is actually not a cost, it is a lost profit. It refers to the rents TfL could earn by leasing their ticket office locations in their stations to third party retailers. These retailers would be mobile phone companies, but could also include newspaper/snack kiosks that would also sell prepaid bankcards.

#### Bus Transys Costs

The only cost from paid by the Surface division of TfL, which is responsible for Bus services, to the TranSys consortium, is for the smartcard reader, server, and related equipment installed on buses. These can be replaced with commercial equipment, which gives the potential to cut their cost 50%, from £14.4 million to £7.2 million.

#### Bus Own Costs

The only bus Own Costs are for the Roadside Ticket Machines (RTMs). These will be eliminated under options 1-3, as discussed above. In some high-demand locations, it may be desirable to provide a prepaid bankcard vending machine in their place. However, if cash payment on buses is still allowed under the new ticketing regime, this may not be necessary.

#### TfL-wide Transys Costs

TfL-wide TranSys costs include the costs of the farecard itself as well as ticket office Oystercard sales equipment (readers, servers, and networking). The costs of the farecard

are clearly eliminated in Options 1-3. The cost of the sales equipment is also eliminated, as discussed above.

#### TfL-wide Own Costs

TfL-wide own costs include agent commissions, the cost of web sales, and credit card and cash handling fees. Agent commissions and web sales will be eliminated, so their cost is reduced to zero. Credit card and cash handling fees will become much more significant parts of the cost of ticketing, and they are included individually in the options described below.

#### Residual Ticket Program

Under an ideal implementation of Options 1-3, no residual ticketing program will be necessary. Thus the low estimate of this cost is zero, relying on the broad availability of pay-as-you-go NFC-enabled mobile phones and prepaid bankcards. It may be necessary to have a residual program for the small number of passengers who do not have access to these payment media, and the likely implementation is to place vending machines with bankcards or mobile phones at stations. In many cases, a third party will find this profitable. However, there may be some stations where it is not economical for third parties to install bankcard or mobile phone vending machines. TfL will probably wish to provide ticket sales at these sites. The £10 million “high” estimate in the Residual Ticket Program category covers these costs. It applies to all options 1-3.

#### Option 1

The additional cost of option 1 is the fee charged by the credit card company. Today, this value is around 1% for many purchases. However, the increased volume of business under the new ticketing regime could be a sufficient bargaining lever for credit card companies to drop their fees somewhat, so the low estimate is a flat 1% charge. Conversely, the increased volume of low-value transactions may cause credit card companies to raise their rates from their current levels, which results in a high estimate of 1.5%.

Note that many credit card companies charge a minimum fee of \$0.30 per purchase in the U.S., and a similar value in the U.K. This minimum charge may need to be eliminated for options 1-2 to be financially viable. However, the elimination of this charge, either directly by the credit card companies, or by the use of payment aggregation, either by TfL or a third party, should be possible. Aggregation means that TfL or the third party would accumulate charges until a given purchase amount or time period had passed before sending the total charge to a bank card company, thus raising the average transaction amount substantially and lowering the percentage commission.

#### Option 2

The additional cost of option 2 is, like option 1, the fee charged by the credit card company. However, this fee is a greater percentage than in option 1, because the credit card companies will need to provide post-processing, a service for which we estimate they might charge 0.5%. Thus, the range of fees for option 2 is the range of fees for option 1 (1-1.5%) plus 0.5%.

### Option 3

In option 3, an intermediate charge processor routes charges to the various banks. The intermediate charge processor will charge fees in addition to the standard 1% credit card fees. The charge processor may be structured in a way similar to the Korea Smartcard Corporation, whose total charges, including the credit card fees, are about 3%. However, it may be possible to optimize certain business activities of the Korea Smartcard Corporation, allowing total costs as low as 2% (Kocur and Dorfman 2007). It is also possible that the bank card processors will handle option 3 charges directly. Since no detailed discussions have occurred with banks, we still assume that a 3% commission might apply.

### **5.1.2 Cost of Option 4**

The cost of the current ticketing system is included in the above table of ticketing costs. Under a future ticketing regime, costs would not change substantially. Some cost savings are possible by purchasing more commercially available equipment than was possible when the original TranSys contract was signed in 1998. Some cost savings are possible from reassigning ticketing staff. Some cost savings are possible if a significant number of passengers adopt a mobile-phone based Oystercard, eliminating the capital and administration costs for those cards. However, the core structure of the proprietary smartcard will remain intact, so none of the current cost categories can be eliminated, or even cut by half. It would require a detailed analysis to estimate the total cost savings possible with the current system with any degree of accuracy, so this paper will consider that with Option 4, incremental improvements are possible, but not attempt to quantize them.

### **5.1.3 Cost of Option 5**

Professor Bachmann, inventor of the Be-In Be-Out (BIBO) concept, has said that under a scenario of mass production, the card-reading system for one bus would cost £1360, and each card would cost £7. It is unclear how many cities would need to adopt the BIBO system in order to achieve the economies of scale needed to lower the prices to these levels (Kocur and Dorfman 2007). Thus these estimates must be treated as very low, possibly unrealistically low.

However, these numbers are sufficient to make a back of the envelope computation

#### Bus:

£1360\*7500 buses \* 1 reader/ bus = £10.2 million for buses

£1360\*1000 buses \* 2 readers/bus = £2.7 million for articulated buses

Underground:

The increased number of doors will result in an increased number of low-frequency antennas, which will undoubtedly raise the cost of the system significantly. The readers will now be assumed to cost £2720, twice the amount of the basic system.

$$4000 \text{ tube cars} * 2 \text{ readers/car} * £2720/\text{reader} * = £21.8 \text{ million}$$

Media:

$$£7/\text{card} * 8 \text{ million cards} = £56 \text{ million}$$

Due to frequent replacement needed for new electronics, an average annual cost, including capital amortization and maintenance, is 40% of the total capital costs excluding ticket media. This brings the total annual cost to  $£10.2 + £2.7 + £21.8 \text{ million} * 40\% = £13.9 \text{ million/year}$ , *in addition to current infrastructure costs*. Current ticket media only last a year, and that seems reasonable or optimistic for these cards, so the costs will be £56 million in cards plus the annual charge of the other capital costs, 14 million, bringing the total additional cost of the long-distance smartcard system to £70 million per year.

**5.2 Demand**

This section presents various results from the demand model. The demand model was created to determine the effects of pure flat fares, rebated flat fares, and distance-based fares will have on ridership levels in London. The first three subsections present the main effects on revenue and ridership for a range of fares for options 1-3. Option 1 analysis shows the demand effects of pure flat fares; the Option 2 analysis shows the demand effects of pure flat fares with frequent traveller, transfer, and station-of-origin rebates; and the option 3 analysis shows the demand effects of distance-based fares.

The next three subsections present the effects of fares for options 1-3 on detailed demand models for each ticket type. Unlike the main demand model, the detailed demand models compute demand changes for each zonal fare category separately. However, the detailed demand models include only one ticket type in each analysis, whereas the main demand model included all the major ticket categories.

In each of the models, the demand results for a range of fares are presented. However, care was taken that the middle of the range gives ridership levels that are roughly comparable to today's ridership levels, in order to clearly illustrate the effects of the fare policies.

**5.2.1 Option 1: Tap-in = Transaction, Pure Flat Fare**

Figure 1 below shows an example of the revenue and ridership that are predicted at different levels of flat fares for bus and LUL in the peak and offpeak. In option 1, passengers tap in only with a contactless bank card or mobile phone; they do not tap out. There is no post-processing; the tap is a transaction, so only flat fares that vary by mode

or time of day are possible. There are no transfer discounts between bus and LUL (or national rail).

In this figure, the bus fares vary from £0.55 to £1.00 in the peak, and £0.35 to £0.80 in the offpeak (always £0.20 less than peak fares). The LUL fares vary from £1.30 to £1.75 in the peak and £1.10 to £1.55 in the offpeak (always £0.20 less than peak fares). The discount (dsc) and threshold parameters do not apply to option 1, so their values are not relevant.

The model shows that in option 1, a flat fare of £0.65/0.45 peak/offpeak for bus and £1.40/1.20 for LUL produces approximately the same ridership as the current TfL fare policy, 2.3 billion passengers per year. However, the revenue generated at this ridership is approximately £2.05 billion, which is £150 million or 7.5% less than the current revenue.

The revenue loss occurs because a single fare is charged to all passengers: option 1 does not allow any price differentiation by market segment for a given mode. However, the revenue loss results from the assumption that there are two markets for transit in London: single/pay-as-you-go and travelcard. As explained in Chapter 4, this is a conservative assumption. It is equivalent to assuming that the ridership gain from fare reductions of single and pay-as-you-tickets is substantially less than the ridership loss from increases in travelcard tickets. In contrast, if a model is used that assumes the same fare response (fare coefficient) for all fare media, the flat fare policy produces essentially the same revenue as the current TfL fare policy.

At low levels of flat fare (e.g., £0.55/0.35 bus and £1.30/0.10 LUL), ridership reaches 2.4 million per year, 100 million trips more than the current ridership. Revenue declines to about £1.9 billion, £300 million less than current. TfL gains about 5% more riders but at about a 15% reduction in revenue.

At high levels of flat fare (e.g., £1.00/0.80 bus and £1.75/1.55 LUL), ridership declines to about 1.9 million per year, 400 million trips less than the current ridership. Revenue increases to about £2.45 billion, £250 million more than current. TfL loses about 17% of its riders but gains about 10% in revenue.

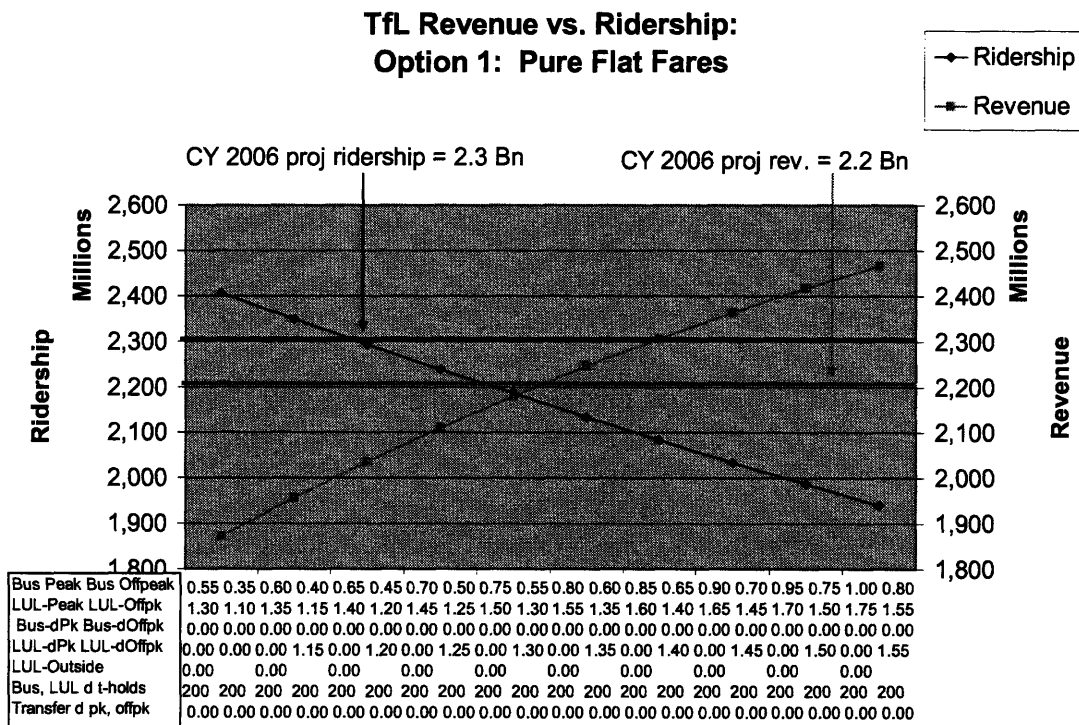


Figure 5.1 Option 1 Ridership and Revenue

### 5.2.2 Option 2: Tap-in = Transaction + Post-processing, Flat Fare + Rebates

In option 2, passengers only tap-in and do not tap out, but the bankcard or mobile phone carrier post-processes TfL charges on a monthly (or more frequent) basis to allow TfL to apply a more complex set of fare policies that allows individual market segments to be served. In this option, TfL provides rebates or loyalty rewards, which are taken as credit against the TfL portion of the credit card or mobile phone bill.

The analysis here presents the conservative option of attempting to replicate the current TfL fare structure with the rebate system. The following flat fares and rebates are set. (The same peak and offpeak fares are used to keep the scheme simple.):

- LUL
  - Flat fare: £1.90 peak, which is close to the current average pay-as-you-go fare.
  - Frequent traveler rebate: After 12 trips per week, the cost is zero for further travel. 12 trips at £1.90 cost £22.80, very close to the current average £22.59 weekly travelcard cost. The cost of trips over 12 per week is rebated to users on their monthly bill. Current monthly travelcard users see a small increase in price.

- Transfer discount (bus-LUL or bus-bus): Only one tap-in within any one hour period is charged, at the highest fare (LUL or bus, peak or offpeak) of any of the tap-ins. The cost of all other tap-ins is rebated on the monthly bill. Figure 2 below was computed assuming that 20% of bus journeys are bus-to-bus transfers.
- Boarding station rebate (optional): Passengers who tap in two or more times, always in stations outside and on the same side of central London, receive an additional rebate for each such day. This approximates lower fares currently paid outside the current zone 1. Figure 2 below was computed assuming 15% of journeys occur entirely outside central London.
- Bus
  - Flat fare: £0.95, which is close to the current pay-as-you-go fare
  - Frequent passenger rebate: After 14 trips per week, the cost is zero for further travel. 14 trips at £0.95 cost £13.30, very close to the current average £13.50 weekly bus pass cost. The cost of trips over 14 per week is rebated to users on the monthly bill. Monthly bus pass users would see a small increase in price.
- Transfer (LUL-bus)
  - Flat fare: The sum of the bus and LUL fares, £2.85 is initially charged to passengers using both LUL and bus on a journey. If the second tap-in is within an hour of the first, the £0.95 bus fare is rebated, resulting in an actual fare of £1.90.
  - Frequent passenger rebate: After 14 linked (LUL-bus) trips per week, the cost for further travel is zero, the same as for LUL-only or bus-only trips. The user receives a rebate both for the transfer fare on all trips and the full fare on trips over 14 per week. For the 12<sup>th</sup> and 13<sup>th</sup> linked (LUL-bus) trips per week, passengers are charged the bus fare, but not the LUL fare.

This fare structure can be tailored to the fare levels that passengers in the various fare categories (are accustomed to paying by varying the threshold number of journeys before the fare rebate takes effect. Oystercard data shows that single trip cash or PAYG riders take about 10 journeys per week on LUL, while travelcard holders take an average of 16 trips per week. Thus any level of threshold between 11 and 15 journeys per week will produce a fare that is lower for travelcard holders than for single riders, on the average. By setting the base fare and discount threshold appropriately, the resulting rebated fare for the travelcard holders can be set to be roughly equivalent to what they are paying today. The demand model assumes the number of trips per week taken by passengers under the new fare structure will not change under the new fare structure. This assumption is reasonable because the model includes a structure where the average per-trip fare for passengers in each fare category is roughly the same as today.

For option two, the model predicts a small overall gain in revenue and ridership over current levels. This gain is due to bus fares being slightly lower which, because of bus riders having a high elasticity, results in a ridership gain without much revenue loss. The following table illustrates the ridership and revenue of bus and LUL under current fares,

and under a future fare scenario where the model predicts a ridership gain of 40 million trips per year for equal revenue. Bus is gaining about 90 million trips per year because the fare drops for cash single passengers and 7-day passengers (after the rebate), while rising only slightly for pay-as-you-go and monthly passengers; at the same time LUL is losing 50 million trips per year due to slightly higher prices in each category. The reason that the option 2 rebated fares can create the situation that revenue and ridership simultaneously increase is that the two new fare levels (full price and rebated) are more optimally tuned to the demand elasticities of the two market segments.

	Current Fares		Future fares: LUL flat £1.90, bus flat £0.95, disc. thresh. 14 (bus), 12 (LUL), trips after thresh. free, transfers free.	
	Bus	LUL	Bus	LUL
Ridership	1,326 million	992 million	1,413 million	946 million
Revenue	£815 million	£1,405 million	£810 million	£1,400 million

Table 5.2 Ridership and Revenue by Mode, Current Fares and Option 2 Fares

The model behaves as expected for fare levels significantly below and significantly above current levels. Thus at fares significantly below current levels, the model predicts less revenue but significantly more ridership than current fares. One such fare is £0.80 bus, £1.75 LUL, with discount thresholds of 14 and 12 trips. Single fares for bus and LUL are slightly lower than today's levels, and weekly travelcard prices are much lower: about  $14 \times £0.80 = £11.20$  for bus, and  $12 \times £1.75 = £21$  for LUL. At these low fares, the model predicts annual ridership of 2.45 billion, which is 150 million or 7% more than today's ridership of 2.3 billion. At the same time, the model predicts revenue of £2.05 billion, a loss of £150 million, or about 7% less than today's revenue of £2.2 billion.

At fares significantly above current levels, the model predicts more revenue but less ridership than current fares achieve, which is also expected. One such fare is £1.25 for bus and £2.20 for LUL. The single values are clearly higher than current single fare values, and the travelcard equivalent thresholds set to 14 and 12 trips/week as above, a bus pass would cost  $14 \times £1.25 = £17.50$  and a LUL travelcards would cost  $12 \times £2.20 = £26.40$ , above today's levels. These fares give a ridership of 2.2 million, which is a loss of 100 million riders, or 4% less than today's level, but revenue of £2.5 billion, which is £300 million or 14% more than today's level of £2.2 billion.

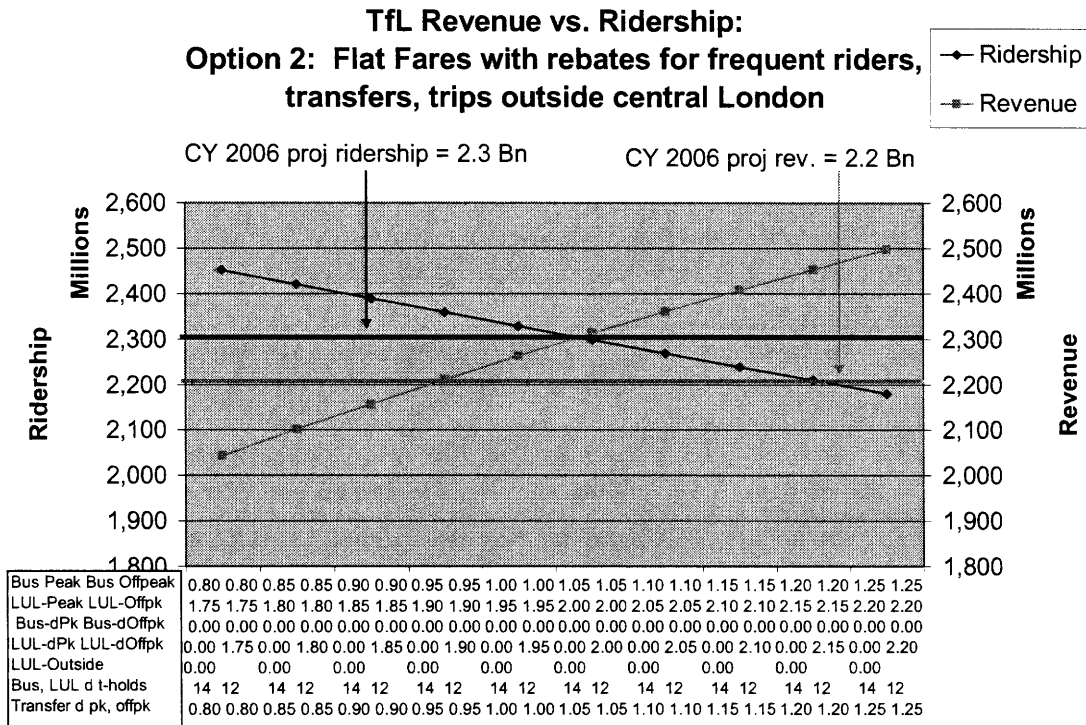


Figure 5.2 Option 2 Ridership and Revenue

### 5.2.3 Option 3: Charge Routing Entity, Flexible Fare Policy

In this option, TfL has the same flexibility to set fares as in the current Oyster system. If TfL maintains the same fare structure and level as today, clearly, the revenue and ridership will remain at current levels.

However, other fare structures are possible with option 3. To illustrate the flexibility of the demand model and of option 3 pricing, distance-based fares are analyzed here. One representative set of distance-based fares plus for option 3 is the following:

- LUL: peak/offpeak base fare of £0.60/0.50 plus £0.10 to 0.19 per kilometer
- Bus: peak/offpeak base fare of £0.30/0.20 plus £0.05 to 0.14 per kilometer
- LUL-bus transfer: free; the passenger pays the higher of the bus or LUL base fare plus the mileage charge on each mode used
- Bus-bus transfer: free; 20% of bus trips were taken to be bus-bus transfer trips in the example below
- No frequent travellers rebates, though these are certainly possible with option 3
- LUL passengers outside central London always pay offpeak flat fares (£0.50) but receive no discount on per-km charges.

Distance-based fares replace the zonal fare system with a more finely graduated system based on station-to-station distances. The distance-based fares modelled here assume include distance-based pricing on buses, which mean tap-in and tap-out on the bus system. However, option 3 allows bus fares to retain their current flat fare structure.

The following graph shows the revenue and ridership levels that result from the representative range of distance-based fares described above. Bus fare has a fixed component of £0.30/0.20 peak/offpeak, plus a variable component that ranges from £0.05 /km to 0.14 /km. LUL fare is fixed at £0.60/0.50 peak/offpeak, plus £0.10/km to 0.19/km. For both modes, the distance-based fare is increased by one pence per kilometer at each step in the chart.

The average bus trip length is 3.8km; and no data on bus journey length variability is available, so this pricing scheme is the same as a bus flat fare that ranges from £0.49 to £0.83. The change in LUL distance based fare is modelled by accounting for changes in the average trip length of an LUL journey. The changes in the average trip length of an LUL journey is determined using a detailed model of LUL journeys, which includes separate fare categories for travellers in separate zones, thus paying different fares presently and in the future. The change in average distance of 7-day travelcard passenger journeys is used as the basis; all LUL fare types give similar results. However, because the current zonal fare structure approximates a distance-based fare structure, the change in passenger-km from switching to distance-based fares is relatively small. The detailed model is described below, in the next section.

Fares that achieve rough parity with current fares are 0.09 pence per km on bus and 0.14 pence per km on LUL, added to the base fares (£0.60/0.50 LUL and £0.30/0.20 bus) described above. These fares achieve slightly less ridership and revenue than the present: 2,250 ridership, a 50 million or 2.2% loss, and £2,150, a £50 million or 2.3% loss. These slight losses occur because the distance-based fare is not perfectly calibrated to the demand elasticities of the two passenger groups.

The model behaves as expected for fare levels significantly below and significantly above current levels. Thus at significantly lower fares, the model predicts revenue loss and ridership gain. For example, bus fares of £0.30/0.20 + £0.06/km and LUL fares of £0.60/0.50 + £0.11/km give a ridership of about 2.45 billion, a 150 million, or 6.5% increase, but a revenue of £1.85 billion, a 350 million or 16% loss.

At significantly higher fares, the model predicts revenue gain and ridership loss, which is also an expected result. For example, bus fares of £0.30/0.20 + £0.14/km and LUL fares of £0.60/0.50 + £0.19/km give a ridership of about 1.95 billion, a 350 million, or 15% loss, when compared with today's values, while revenue increases to £2.5 billion, a £300 million or 14% gain, when compared with today's values.

The distance-based model, shown here without any rebates for frequent trip takers, produces a revenue loss (at current ridership levels) roughly equal to the revenue loss (at current ridership levels) that the flat fare model exhibits. As noted above, this is based on



Option	LUL Fare (£)	Bus Fare (£)	Revenue (£)	Cost (£)	Net Revenue (£)	Net Revenue Change (£)	Net Ridership Change
1	1.40 /1.20	0.65 /0.45	2.05 Bn	56 Mn	2.00 Bn	0 Mn	0
2	1.90	0.95	2.21 Bn	66 Mn	2.14 Bn	+140 Mn	+20 Mn
3	Current	Current	2.20 Bn	81 Mn	2.12 Bn	+120 Mn	0

Table 5.3 Option 1-3 Cost, Revenue, and Ridership Summary

### 5.2.5 Detailed Demand Model Analyses

In the following detailed analyses, passenger numbers from all zonal fare categories are not aggregated, as they were in the main demand model, but instead, the demand of each zonal fare category is modelled separately. However, for simplicity, only for one ticket type is analyzed in each detailed model (whereas the main model included all the primary ticket types).

The detailed models serve three main purposes: they demonstrate that the loss of accuracy from aggregating passengers in all zones as paying a single (average fare) is small; they allow the computation of a change in average trip length under a new fare policy by accurately modelling the passenger response in each of the zonal fare categories, and they illustrate. The aggregation error is less than 1% for a reasonable range of fares around current levels. For typical values, average trip length changes are small (0.1-0.2 km); however, these have significant effects on annual passenger-km totals and for pricing on distance-based fares. Thus, the outputs of the detailed models are fed back into the passenger-km computations and distance-based pricing computation in the main model.

To create this model, the percentage of riders in each of the major zonal fare categories was obtained from the Oyster data for June 2006 and August 2005 (the distributions of these two months were virtually identical). There are only a few zonal fare categories with more than 0.5% of travelcard journeys. For weekly travelcards, there are seven fare categories with major usage including £14, £18.40, £22.20, £26, £31.60, £37.80, and £41. These seven categories are retained. The remaining categories are aggregated into the nearest of the seven categories. The logit computation is performed separately for each fare category in the current zonal structure. The ridership from each fare category is summed to obtain the new ridership for the new flat fare. In all the detailed analyses of LUL and LUL-bus transfer fares, bus fares are assumed to maintain equivalent levels to today's fares (about £0.60 per journey).

The main results presented for options 1 and 3 are the change in ridership numbers by zonal fare category. These results illustrate the effect that flat fares have on the ridership levels in each of the zones. The option 1 analysis also presents a passenger-km chart. Because each of these analyses only includes one ticket type, the results for option 2

would look very similar to the results for option 1—the differences, such as a frequent traveller rebate or a transfer discount, would be the same for all passengers, so it would appear as flat fare, slightly modified from the option 1 flat fare. Instead of presenting repetitive results, the results presented for option 2 illustrate the changes in ridership of the individual ticket types.

### **5.2.6 Option 1: Detailed Analysis**

The figure below shows an example of the changes in ridership for 7-Day Peak LUL passengers in several existing zonal fare categories if flat fares are adopted. In this figure, a £1.50 flat LUL fare is charged in peak periods. There are no rebates or post-processing.

The number of passengers formerly purchasing a £14 travelcard (£0.88 per journey, on average) decreases substantially, by over 20%. An increase from £0.88 per journey to £1.50 per journey is quite substantial, resulting in this loss. The number of passengers formerly paying a nominal £1.50 also decreases by about 15%. Those formerly paying £18.40, £22.20 and £26.00 had all been paying close to 1.50, on average, for their journeys, and see relatively little change in per-journey fare, so the ridership at these levels is relatively constant. The number of passengers buying travelcards in the most expensive fare categories -- £31.60, £37.80, and £41 – travelcards increases substantially in percentage terms because their average per-journey fare decreases substantially. However these categories make up a small percentage of LUL ridership. Thus, there is a net loss of 2.3 million in ridership, which is consistent with the average fare being raised from £1.42, as it is under current fares, to £1.50.

Thus, the net effect of moving to flat fares is relatively balanced: shorter-distance passengers pay somewhat more, while longer distance passengers pay somewhat less than under zonal fares. At a flat fare that is near the average of the current actual fares, ridership and revenue are relatively close to current values. The users currently buying £14 travelcards see a large cost increase (almost a doubling); most other users see modest changes; and the small number of users currently buying travelcards costing £31.60 or more sees large decreases in per-journey cost.

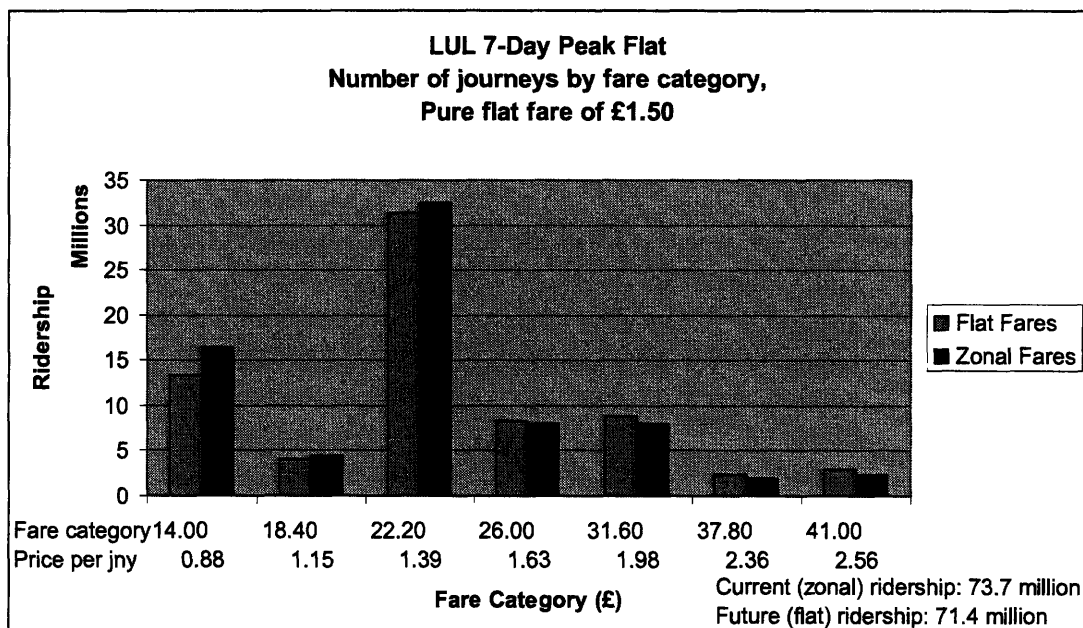


Figure 5.4 Option 1 Changes in Ridership by Current Fare Category

In this more detailed model, the fares paid under the current zonal structure reflect the various numbers of kilometres being travelled by the passengers. The accurate correspondence of fares to distance travelled in the model allows the accurate prediction of the change in passenger-km travelled by passengers. The following two charts illustrate the changes in passenger kilometres travelled by LUL passengers travelling in peak hours holding a 7-day travelcard. Other market segments show similar behaviour.

The first chart below shows the total passenger-km travelled by 7-day travelcard holders, while the flat fare is varied from £1 to £2. The same fare is charged in peak and offpeak periods. Unsurprisingly, passenger-km travelled falls linearly with increasing fare. At £1, a flat fare significantly lower than the average per-journey fare currently being paid by LUL 7-day travelcard holders, about 100 million more passenger-km per year are travelled than at the current fares. At £1.50, parity in passenger-km with current fares is achieved. When the flat fare reaches £2, passengers are travelling 100 million passenger-km per year less than they are now.

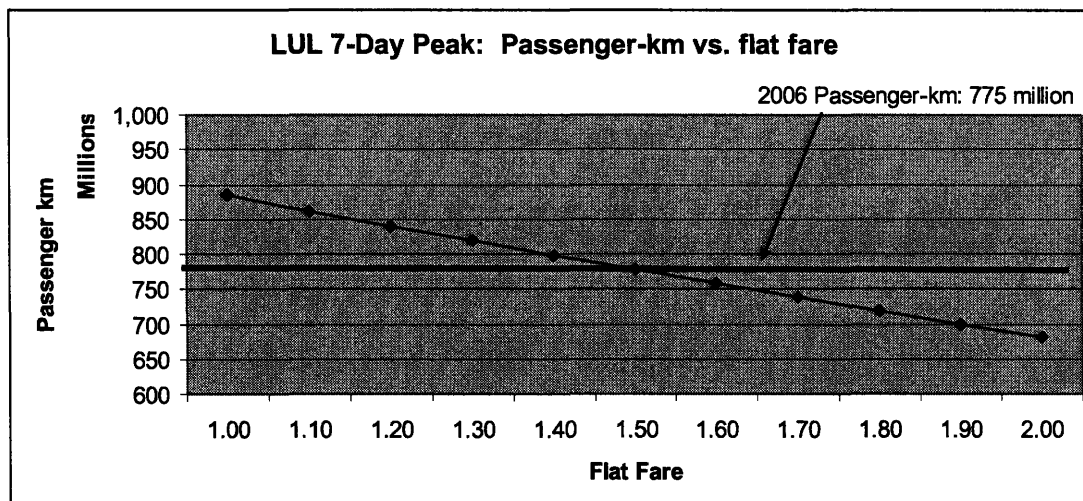


Figure 5.5 Option 1 LUL 7-Day Peak Passenger-km vs. Flat Fare

The second chart illustrates the change in annual passenger-km traveled by passengers in the current fare categories. Passenger-km fall in the shorter distance fare categories, but rise in the longer-distance fare categories. Because flat fares eliminate any distance-based component from fares, the logit model would predict that at fare levels that achieve approximate parity with current revenue and ridership levels, there will be fewer trips by passengers in the lower fare zones. That happens because the average price per trip of the shorter trips is increasing. Likewise, logit predicts more trips by passenger trips in the higher fare zones, where the average price per trip is decreasing. This is exactly the behavior that the model exhibits. Travelers in the lower fare categories (£14, £18.40, and £22.20), who have shorter trips, will travel fewer passenger-km under a flat fare than they were under current fares, while passengers in the higher fare categories (£26, £31.60, £37.80, and £41), who have longer trips, will travel more passenger-km than under current fares.

This model demonstrates that flat fares discourage the shorter trips that may cause congestion in central London by raising the price of short trips, while encouraging longer trips by lowering their price. They thus encourage more use of LUL outside the central zone. By discouraging the shortest trips, flat fares may also have a decongesting effect on LUL. However, pure flat fares also discourage short trips outside central London, which shows the advantages of a more complex fare structure, such as option 2.

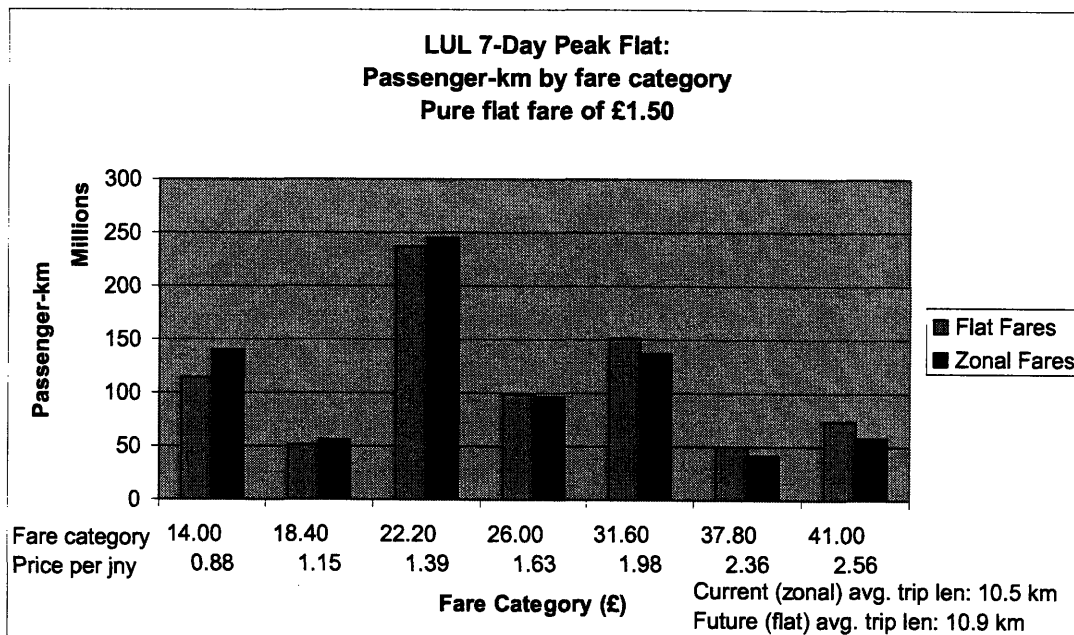


Figure 5.6 Option 1 LUL 7-Day Peak Passenger-km by Fare Category

### 5.2.7 Option 2: Detailed Analysis

Option two is able to treat passengers who currently buy different ticket types differently. Passengers who purchase different ticket types represent different market segments as explained in chapter 4. Thus the effects of option 2 can best be seen by comparing the change in ridership of holders of tickets of different types. The following table shows the effect of the following fare scheme on the holders of different ticket types/ market segments on LUL, which achieves rough parity with today's revenue and ridership: LUL flat fare of £1.90 (peak and offpeak), a bus flat fare of £0.95 (peak and offpeak), free transfers with 20% of bus journeys being linked journeys, and free travel after weekly discount thresholds are reached (14 trips on bus, 12 trips on LUL)

With these fares, the fare level for the 7-day and monthly ticket holders is reasonably close to the fare value they currently pay, and the fare level for PAYG and cash single ticket holders is close to the fare value they currently pay. By giving each customer segment a fare that is more closely linked to its willingness to pay, option 2 may generate more revenue than option 1.

Because of the threshold of 12 LUL journeys per week, monthly and 7-day travelcard holders pay only £1.43 per journey while PAYG users and cash single users pay the full £1.90. Monthly travelcard holders, used to paying £1.26 per journey, thus experience a 13% increase in fare, and a corresponding 5% decrease in ridership. 7-day ticket holders, used to paying £1.41 per journey, experience very little increase in fare, and very little loss of ridership. Offpeak PAYG ticket holders were used to paying £1.30 per ticket, but

now must pay the full £1.90 per ticket, so they experience a 45% increase in fare, and a corresponding 13% decrease in ridership. Peak PAYG passengers had been paying £1.60, but now pay £1.90, so experience an 18% increase in fare and a 7% decrease in ridership. In contrast, cash single users had been paying an average of £2.60 per trip, so by reducing their fare to £1.90, they experience a 27% drop in ticket price, and a 17% increase in revenue.

Because option 2 is also flat fare, it will have the same effect as option 1 on the zonal market segments: at values that resemble today's fare levels, there will be fewer short journeys and more long journeys. This effect is decoupled from the fact that option 2 allows for different fares for passengers with different usage patterns/willingness to pay.

Ticket type	Peak/Offpeak	Current Fare	Effective New fare	% Change Fare	% Change Ridership
cash single	Peak	2.60	1.90	-26.9%	16.7%
cash single	Offpeak	2.60	1.90	-26.9%	16.7%
PAYG sgl	Peak	1.60	1.90	18.8%	-6.5%
PAYG sgl	Offpeak	1.30	1.90	46.2%	-12.6%
7-Day	Peak	1.41	1.43	0.9%	-0.4%
7-Day	Offpeak	1.41	1.43	0.9%	-0.4%
Monthly	Peak	1.26	1.43	13.3%	-5.0%
Monthly	Offpeak	1.26	1.43	13.3%	-5.0%

Table 5.4 Option 2 LUL: Percent Change in Fare and Ridership by Ticket Type

### 5.2.8 Option 3: Detailed Analysis

The detailed analysis of option 3 will present a distance-based fare structure, as did the basic analysis of option 3. The distance-based fare structure also has significant impacts on different zonal market segments. By making short trips much less expensive than the current policy, more short trips will be attracted to the network. Correspondingly, longer trips will become more expensive, so fewer long trips will be taken. Thus average trip lengths will decrease.

The figure below shows the change in number of journeys by zonal fare category for current LUL 7-day travelcard peak travelers. The distance-based fare of £0.30+£0.10/km is illustrated because it approximates current overall ridership levels. This fare gives equal or less ridership in all fare categories, except the category £22.2, which is the price paid by holders of zone 1 and 2 travelcards. These users pay, by far, the highest per-km price under the current fare structure – on average, 18 pence per km. Reducing the per-km price to 10 pence, and adding the 30 pence base flat fare gives a net per-km price of 0.16. This price is lower than the 18 pence per km passengers in this category currently pay. Thus the distance-based price is cheaper for these users than their former zonal travelcard fare, so distance-based fare encourages them to make more of their shorter journeys.

The reason that holders of £22.2 pound travelcards have the highest net per-km fare currently is because they take the shortest journeys, on average. Thus, this example fare illustrates the fact that distance-based fares encourage shorter journeys.

Fare zone (£)	14	18.4	22.2	26	31.6	37.8	41
Avg. trip length (km)	8.53	12.63	7.55	11.96	17.03	21.03	25.02

Table 5.5 Average Trip Length (km) by 7-Day Travelcard Fare Zone

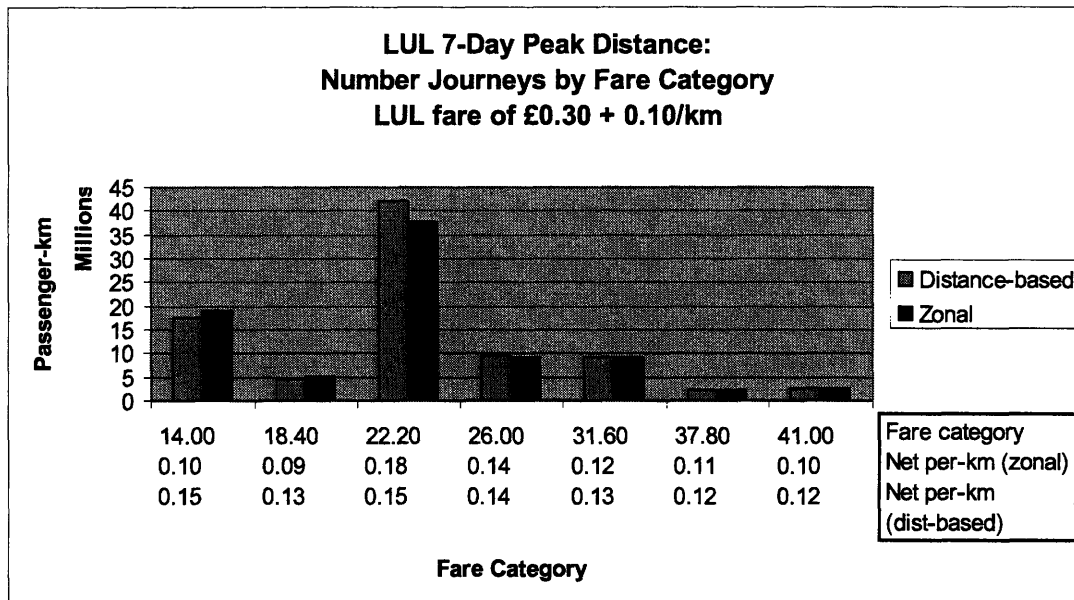


Figure 5.7 Option 3 Changes in Ridership by Current Fare Category, Distance-based Fare

The chart below shows the average trip length as the per-km fare is varied from £0.05 to 0.15, with a flat base fare of £0.30. These fares represent a minimal flat fare and the range of per-km fares that generate revenues and ridership in the same range as today's fares. Logically, the average trip length decreases as the per-km fare increases. Only the very lowest fares gives a trip length that is longer than today's trip length, and this represents a £30 million loss in revenue and a 13 million loss in ridership in this ticket category (LUL 7-Day peak distance) alone. (Revenue and ridership could not be shown in this graph for space considerations.) For this fare category, the fare that gives nearly identical revenue and ridership to today's fares is £0.30+0.11/km, which gives an average trip length of 10.3 km, 0.2km or 2% shorter than today's fares generate. The excessive per-km fare of £0.15/km generates an average trip length of 10.2 km, which is 0.3km or 3% shorter than the average trip length under current fares. These results show that distance-based fares reduce trip length by at least 2% if revenue and ridership are maintained.

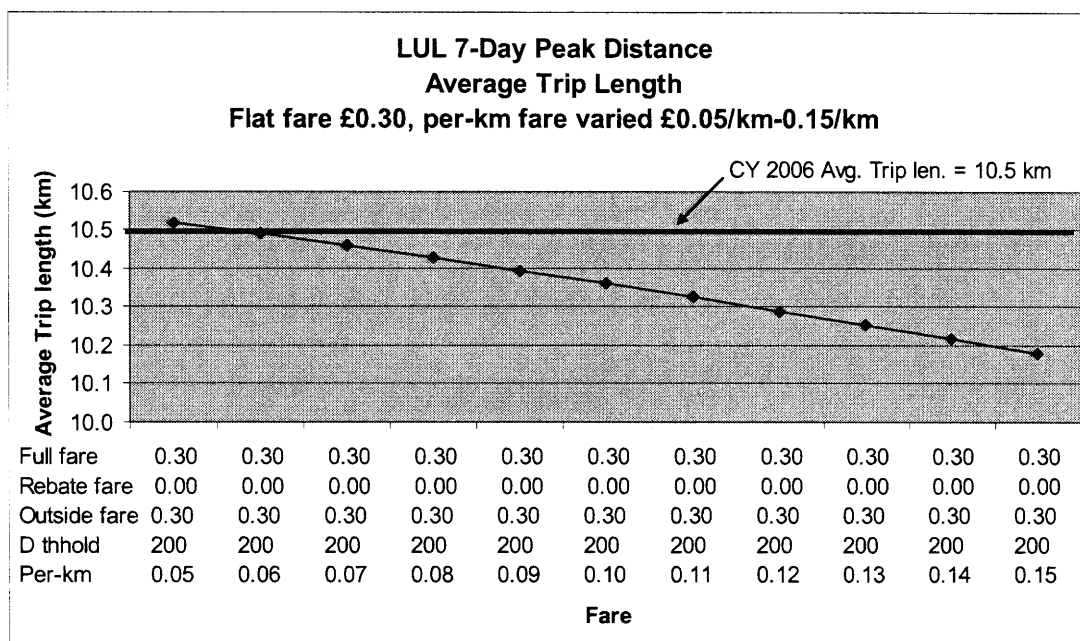


Figure 5.8 Option 3 Average Trip Length vs. Distance-based Fare

### 5.2.9 Time-of-day Choice Model Results

The time-of-day choice model is used to illustrate the effects of peak pricing on ridership at the peak hours. As stated in chapter 4, the examples here use the peak price charged between 8 AM and 8:45 AM and 5 PM and 5:45 PM (LUL) and 8 AM and 9:15 AM and 5 PM and 6:15 PM (bus). The most essential illustration is the change in ridership between the various time segments of the shoulder periods. 15-minute time segments are illustrated in the charts; the model can also compute results at a higher resolution. Only results from the morning peak are illustrated; the afternoon peak is approximately the mirror-image of the morning peak, because the morning late shoulder is equal to the afternoon early shoulder.

After each of the charts, the overall revenue and ridership for the case illustrated in the chart is listed. For comparison, the ridership and revenue for central London alone without peak pricing (for the reference flat fare of £1.40 LUL, £0.50 bus with no discounts, in option 1) is as follows. Note that LUL-bus transfers are included in LUL numbers, but not in bus numbers, to avoid duplication.

	LUL	Bus
Ridership	841,067,349	74,584,111
Revenue	£1,126,965,772	£37,292,055

Table 5.6 Ridership and Revenue by Mode, £1.40 LUL, £0.50 Bus, No Peak Pricing

The first set of charts below illustrates the case in which both the morning early and afternoon late shoulders are 15 minutes long. The level of the LUL peak fare and the bus peak fare have been set high enough to create a significant reduction in ridership during the peak shoulder period, but not so high that the offpeak shoulder period significantly exceeds the peak, creating an artificial peak in ridership before the peak pricing period begins. The peak LUL fare is £1.70 and the peak bus fare is £0.70.

This means that the person moving from the peak to the offpeak period with the lowest value of schedule delay values his time at £1.20 per hour. While this is a low value of time, it should be remembered that the passengers who shift are distributed in a nonlinear way over the shoulder period: many more passengers will shift who are close to the start of peak pricing than those who are near the end. Also, this value of schedule delay corresponds well to the value computed by Hess et al.

The first chart shows the annual ridership by 15-minute period from 7:30-9:30, including the morning peak, and a half-hour before and after it. The second chart shows a stacked graph with the composition of the change in ridership. The base, in dark grey, is the minimum of the ridership before and after the peak prices are introduced. On top of that are one or two of four possible sources of ridership change: dark blue is mode shift loss (passengers switching to other modes), while light blue is mode shift gain (passengers switching from other modes to transit); orange is time shift loss (people switching from a peak period to the offpeak), while red is time shift gain (where those passengers switching from the peak end up).

In this case, only passengers in the period 7:45-8:15 and 8:30-9:00 can switch time; all others can only switch mode. In the first graph, for each 15 minute period the annual ridership is shown before and after the peak fares are introduced. In a pure offpeak period, such as 7:30-7:45 overall ridership increases slightly, because the £1.40 fare is less than the aggregate central London fares of £1.50. Thus, the second chart shows a thin light blue column to represent mode shift gain. In an offpeak shoulder period, such as 7:45-8:00, there is a significant increase in ridership: a slight increase from mode shift gain, similar to that in the 7:30-7:45 period, and a large increase from time shift gain. The second chart confirms that this is the case: ridership increases from about 23 million to 24.8 million, a 7.4% gain, most of which comes from passengers shifting time periods, represented by the red column stack. The third period, 8:00-8:15, shows the same number of passenger shifting time away from this period as are gained by 7:45-8:00. These passengers are shown in the orange column stack in the second chart. Also, a reasonably large number are shifting modes away from the peak period, shown by the dark blue column stack. In total, ridership decreases from 28.2 million to 25.9 million in this period, a loss of 2.3 million rides, or 8.9%. The next 15-minute period, from 8:15-8:30, experiences only a loss of mode share, decreasing its ridership from 29.8 to 28.5 million, a loss of 1.3 million, or 4.4%. In the model using 15-minute shoulders, it is this period of the peak, in which passengers will not switch to the offpeak, that becomes the limiting time for system capacity. During this period, a 4.4% decrease in ridership was created at the point of highest loading; this allows additional ridership to be accommodated in future years.

The 15-minute periods surrounding the end of the morning peak are similar to the periods surrounding the start of the morning peak, but in reverse order.

In this configuration, ridership has fallen by 14 million to 827 million, a 1.7% drop, while revenue has risen by £21 million to £1,148 million, a 1.8% gain, illustrating that peak pricing causes a slight decrease in ridership, but a greater increase in revenue, which is to be expected with the relatively inelastic passengers on LUL.

**Annual Ridership in Central London,  
Before and After Peak Pricing  
Shoulders: 15 min. morn. early/aft. late,  
15 min. morn. late/aft. early  
LUL: £1.40 Offpeak, £1.70 Peak, Peak 8-8:45**

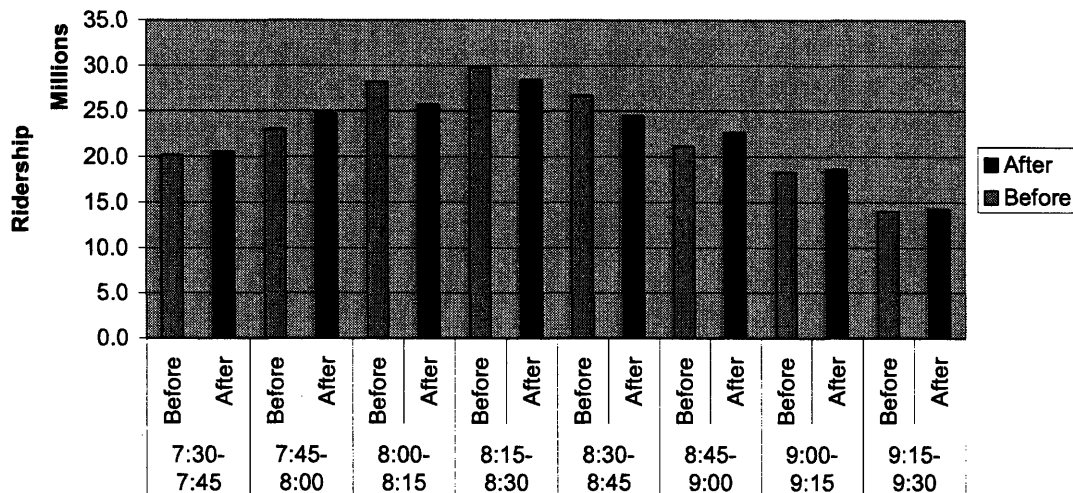


Figure 5.9 LUL Morning Peak Before and After Peak Pricing, 15 Minute Shoulders

**Annual Ridership in Central London with Peak Pricing**  
**Breakdown of Ridership shifts (Mode and Time)**  
**Shoulders: 15 min. morn. early/aft. late,**  
**15 min. morn. late/aft. early**  
**LUL: £1.40 Offpeak, £1.70 Peak, Peak 8-8:45**

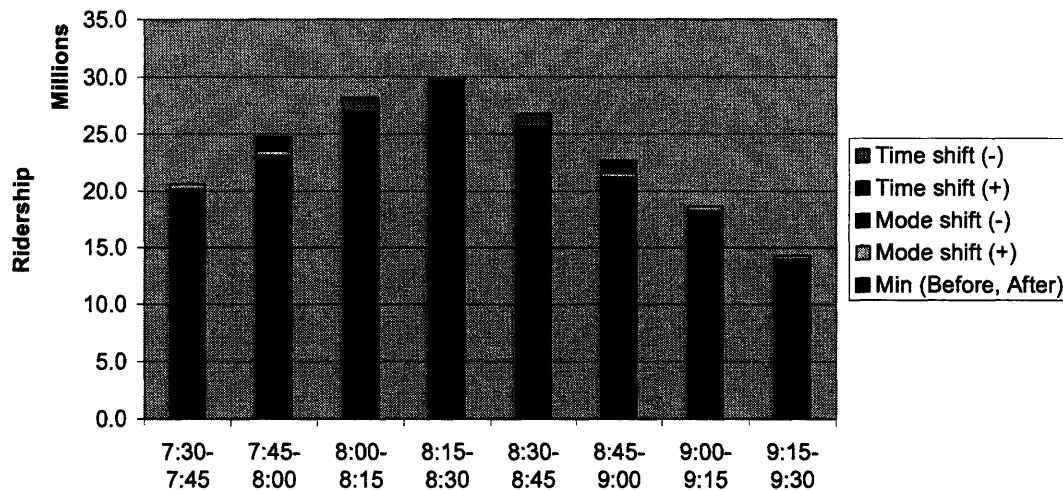


Figure 5.10 LUL Morning Peak after Peak Pricing, Breakdown of Ridership Shifts,  
15 Minute Shoulders

Ridership: 827,050,229  
 Revenue: £1,148,352,369

The next two charts illustrate bus ridership for the morning peak under the scenario illustrated above for LUL. The major difference is that the bus peak period is 8-9:15 AM, 30 minutes longer than the LUL peak. The changes in ridership in the 15-minute times segments are similar to the changes in the LUL case, however, the purely peak period – the period in which passengers do not have the option of switching to the offpeak– contains 3 15-minute segments instead of just one. Also, there is the unintuitive phenomenon that there is a positive mode shift to bus, even during the peak hour, despite the fact that bus fares have gone up. This results from passengers switching from LUL to bus. While the percentage of LUL passengers switching to bus is relatively small, the fact that LUL enjoys a mode share nearly 5 times that of bus means that this small percentage outweighs the number of bus riders leaving bus for other modes. Note that the model presumes that the bus and LUL peaks are of the same length, thus causing the positive mode shift in the 8:45-9 and 9-9:15 time periods. It would be possible to create a model for, however, doing so would have made the model extremely complicated, and the general trend is still visible in this model.

Available capacity on the bus network is basically unchanged, with the influx of LUL passengers offsetting the loss of bus passengers.

Bus ridership has risen by 2.8 million to 77.4 million or 3.6%, while bus revenue has fallen by £0.5 million to £36.8 million or 1.4%. This relatively high increase in ridership with relatively low drop in revenue is caused by the influx of LUL riders. LUL riders switch to bus in equal numbers as bus riders leave for other modes, causing no change in ridership, while fares increase, leading to a revenue gain without ridership loss.

**Annual Bus Ridership in Central London,  
Before and After Peak Pricing  
Shoulders: 15 min. morn. early/aft. late,  
15 min. morn. late/aft. early  
Bus £0.50 offpeak, £0.65 Peak (Peak 8-9:15)**

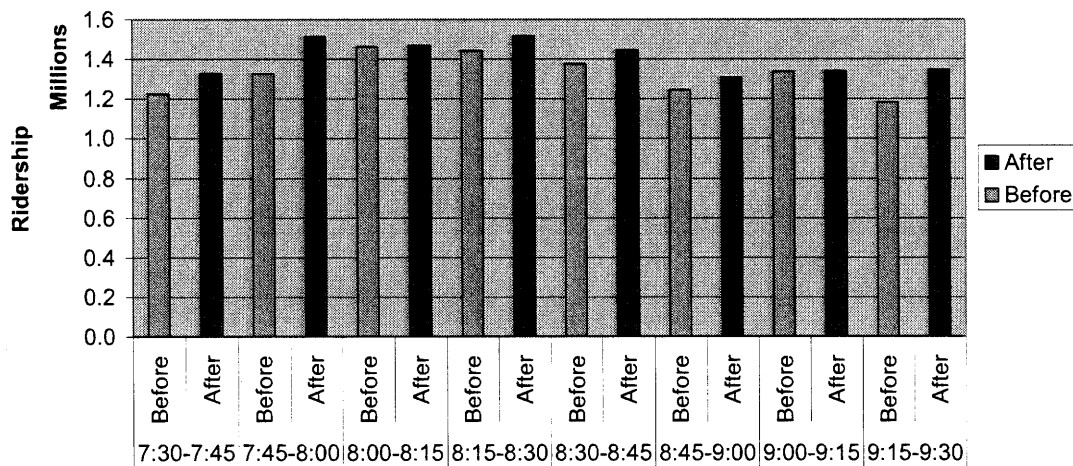


Figure 5.11 Bus Morning Peak Ridership Before and After Peak Pricing, 15 Minute Shoulders

**Annual Bus Ridership in Central London with Peak Pricing  
Breakdown of Ridership shifts (Mode and Time)  
Shoulders: 15 min. morn. early/aft. late,  
15 min. morn. late/aft. early  
Bus £0.50 offpeak, £0.65 Peak, Peak 8-9:15**

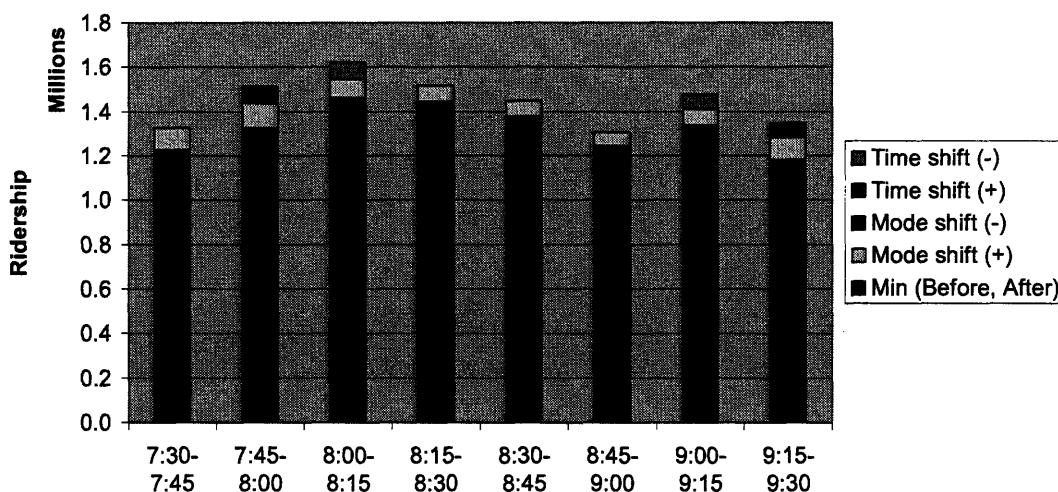


Figure 5.12 Bus Morning Peak After Peak Pricing, Breakdown of Ridership Shifts,  
15 Minute Shoulders

Ridership: 77,358,166

Revenue: £36,800,577

The second choice of shoulder lengths is more inclusive: 30 minutes for the early shoulder length on LUL and bus, and a 15-minute late shoulder on LUL but a 30 minute late shoulder on bus. This longer shoulder allows all of the passengers on LUL, and most of the passengers on bus, to switch time periods as a result of peak pricing.

Now on LUL, all periods of the peak include a portion of riders switching time and switching mode. At the highest point, the center of the peak, ridership drops from nearly 30 million to just 27 million, resulting in a 10% increase in available capacity at the highest point.

Ridership has dropped by 14 million to 827 million, a 1.7% drop, while revenue has risen by £21 million to £1148 million, a 1.8% gain. These numbers are very similar to the numbers seen for the 15-minute window case above, illustrating that the longer window has little overall effect on ridership – passengers switch from the peak to the offpeak, but remain on the system. The loss of 30 pence per rider from those who switch to the offpeak is very small in comparison with the entire revenue of the system, leaving revenue unchanged.

**Annual Ridership in Central London,  
Before and After Peak Pricing  
Shoulders: 30 min. morn. early/aft. late,  
15 min. morn. late/aft. early  
LUL: £1.40 Offpeak, £1.70 Peak, Peak 8-8:45 AM, 5-5:45 PM**

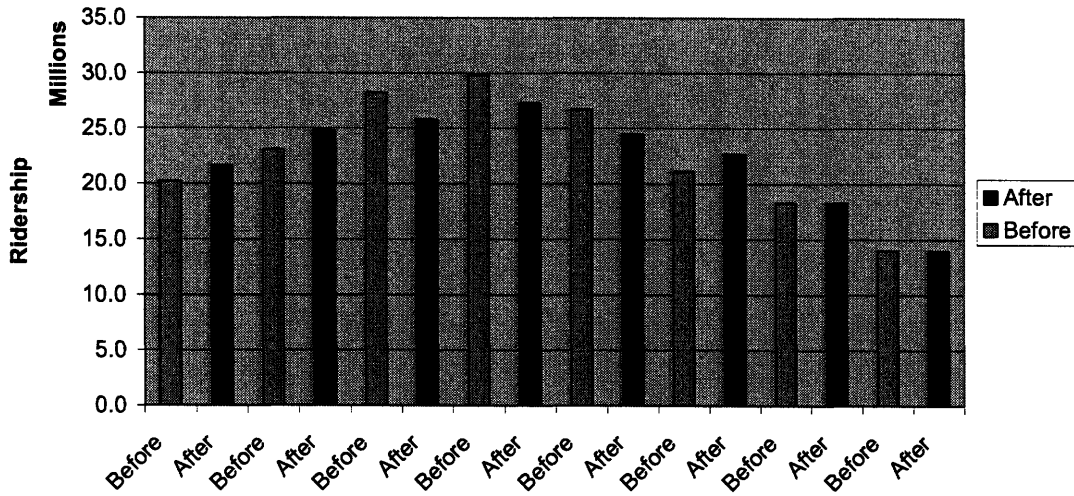


Figure 5.13 LUL Morning Peak Ridership Before and After Peak Pricing, 30/15 Minute Shoulders

**Annual Ridership in Central London with Peak Pricing  
Breakdown of Ridership shifts (Mode and Time)  
Shoulders: 30 min. morn. early/aft. late,  
15 min. morn. late/aft. early  
LUL: £1.40 Offpeak, £1.70 Peak, Peak 8-8:45 AM, 5-5:45 PM**

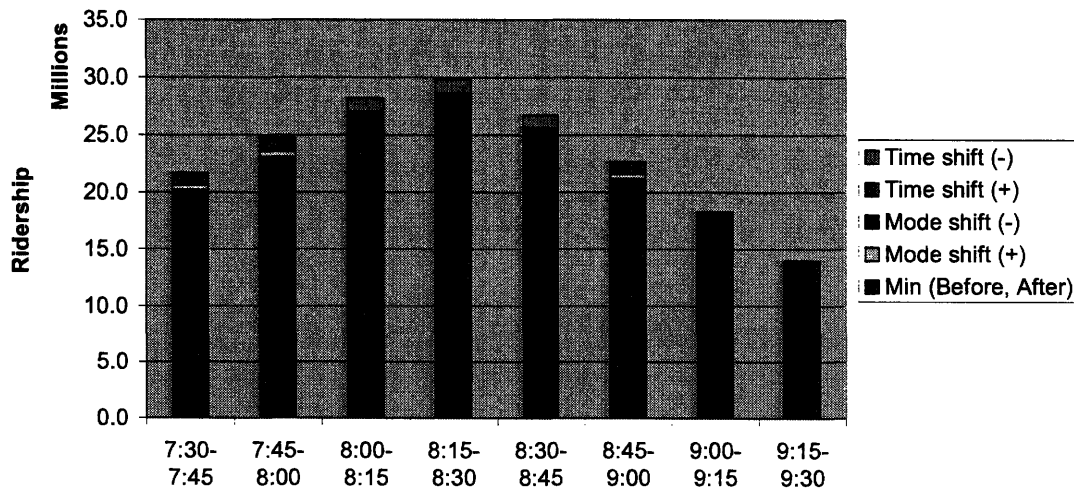


Figure 5.14 LUL Morning Peak After Peak Pricing, Breakdown of Ridership Shifts, 30/15 Minute Shoulders

Ridership: 827,169,190  
 Revenue: £1,147,904,066

On bus, a similar phenomenon occurs as on LUL, as the following charts show. The only difference is that in the center of the peak, from 8:30-8:45, no time shift is possible, because this period is not part of a shoulder period. However, this period already had lower ridership than the two earlier peak period segments, meaning that it is not the constraining segment for capacity. Again, the influx of passengers from LUL prevents any increase in available capacity on the bus system. As with bus, revenue and ridership are very similar to the case of 15-minute shoulders.

**Annual Bus Ridership in Central London,  
 Before and After Peak Pricing  
 Shoulders: 30 min. morn. early/aft. late,  
 30 min. morn. late/aft. early  
 Bus £0.50 offpeak, £0.65 Peak (Peak 8-9:15)**

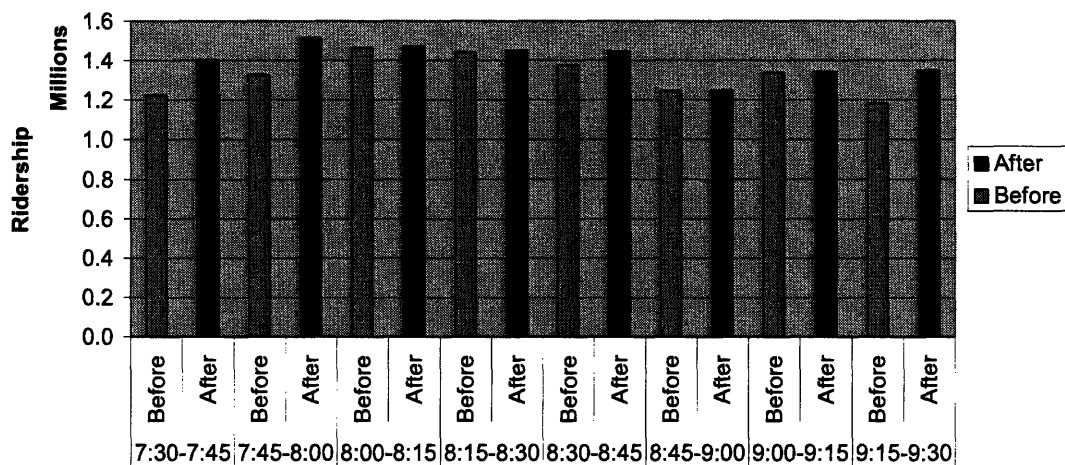


Figure 5.15 LUL Morning Peak Ridership Before and After Peak Pricing,  
 30 Minute Shoulders

**Annual Bus Ridership in Central London with Peak Pricing**  
**Breakdown of Ridership shifts (Mode and Time)**  
**Shoulders: 30 min. morn. early/aft. late,**  
**30 min. morn. late/aft. early**  
**Bus £0.50 offpeak, £0.65 Peak, Peak 8-9:15**

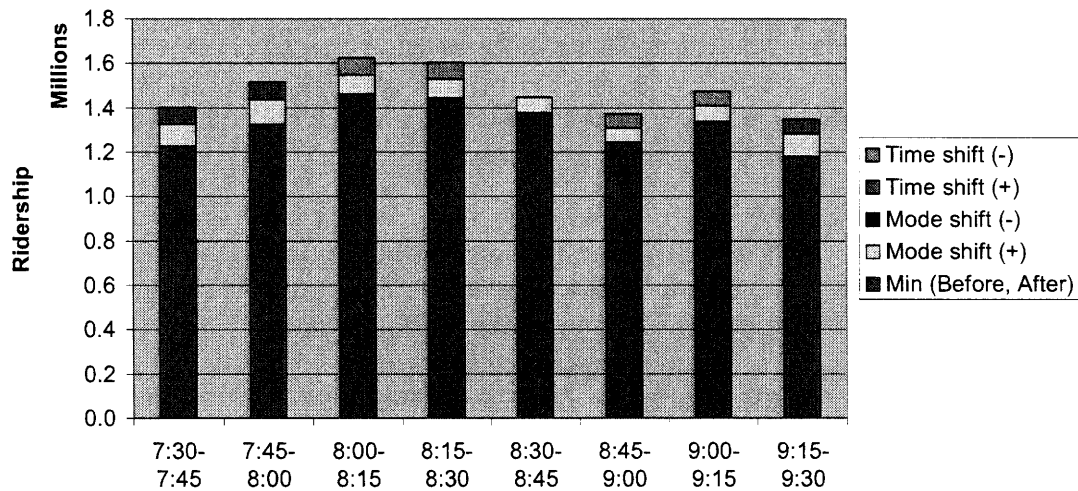


Figure 5.16 LUL Morning Peak After Peak Pricing, Breakdown of Ridership Shifts, 30 Minute Shoulders

Ridership: 77,381,888

Revenue: £36,776,072

The next chart shows the number of passengers who choose to shift from the peak to the offpeak on LUL as the shoulder length is varied from 5 minutes to 20 minutes. The early and late shoulders are assumed to be equal length. Clearly, as the shoulder length increases, the number of time-shifting passengers increases in a nearly linear fashion. This result is intuitive: the more passengers who the model considers capable of switching departure times, the more passengers who will actually switch. However, it illustrates that the accuracy of this time-of-day choice model is sensitive to the accuracy of the choice of length of shoulder period.

**Shoulder length vs. annual number of time-shifting passengers**

**LUL only, Fare £1.40 offpeak, £1.70 peak  
Peak 8-8:45, 17-17:45**

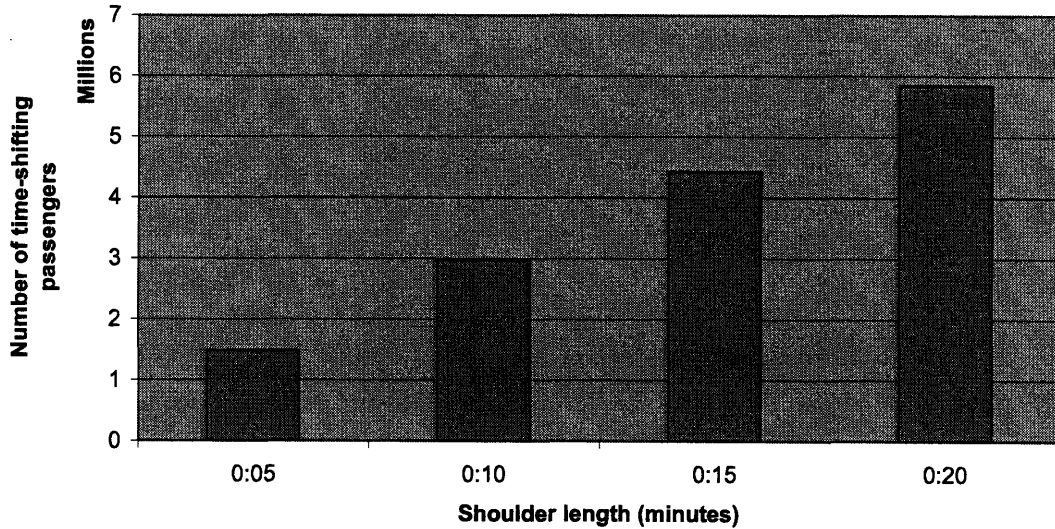


Figure 5.17 Number of Time-shifting Passengers vs. Shoulder Length

The last chart illustrates revenue vs. ridership as LUL peak fare is raised from being identical to offpeak fare to being £1 more than the offpeak fare. Because raising the peak fare raises the overall average fare, it is expected that raising the peak fare will lead to a revenue increase and ridership decrease. This is precisely what occurs. Revenue increases faster than ridership decreases due to the relatively inelastic cost coefficient used for LUL passengers. This chart shows that peak pricing will increase revenue, while slightly decreasing overall ridership (i.e., losing riders to other modes). Because the ridership loss that does occur happens at the peak hours, this ridership loss may be desirable.

**LUL Revenue vs. Ridership, Peak Pricing,  
Peak 8-8:45AM, 5-5:45 PM  
Offpeak fare £1.40, Peak fare varied £1.40-2.40**

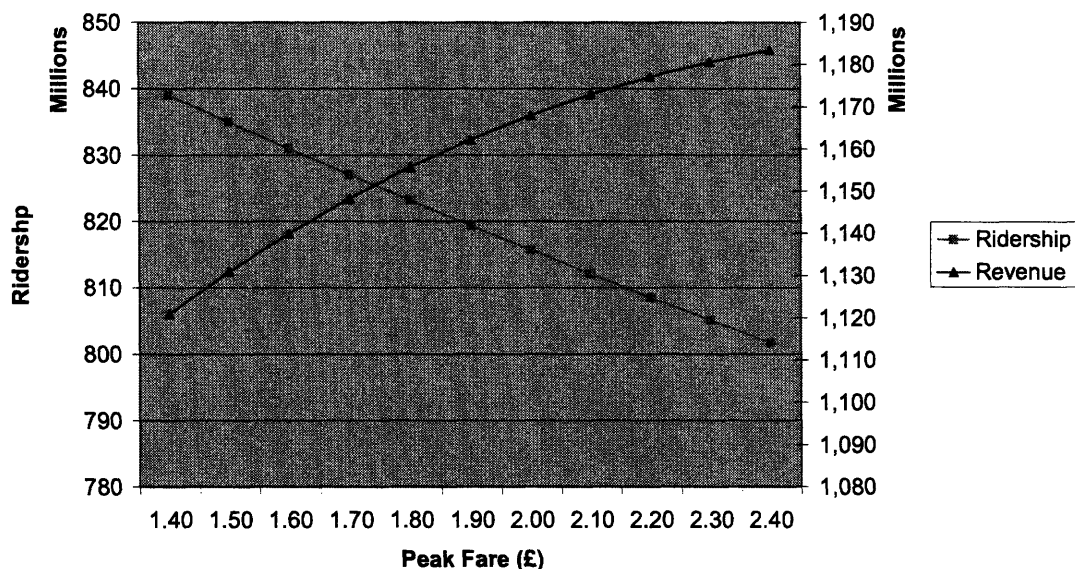


Figure 5.18 LUL Revenue vs. Ridership, Peak Price Varied

## 5.3 Equity

### 5.3.1 Flat Fares and Trip Frequency Equity Impacts

A flat fare structure has two major effects on equity, based on trip length and trip frequency. Flat fares mean that the longest trips cost no more than the shortest trips, so if less advantaged groups generally take shorter trips, they will be disadvantaged by flat fares. Because flat fares generally cannot be coupled with travelcards, those who take advantage of travelcards will be disadvantaged by flat fares. Trip frequency impacts equity in a similar way: If less advantaged groups use travelcards more than others, there will be a negative impact on them.

The effects on social groups can be determined by appropriate queries of the LATS survey. Based on the LATS database, there is little correlation of trip frequency with income level, ethnicity, or gender. Transit users of almost all groups took about two trips per day on transit, with only small differences due to income, ethnicity, and gender.

Thus, the elimination of travelcards in a switch to flat fares likewise will cause little social inequity. What social inequity is caused can be eliminated via credit card or mobile phone billing postprocessing. A benefit of elimination of travelcards for low income groups is that they will not need to pay relatively large, fixed sums in advance to obtain the lowest fares per trip. Rather, they can pay by the trip, which may be a significant improvement in equity, since some, perhaps many, low income users may find

it difficult to pay for a month's travel in advance. Even though most low income users can and do pay for a week's travel in advance, this is a less advantageous fare and it may still be a burden on their finances to prepay transit fares every week.

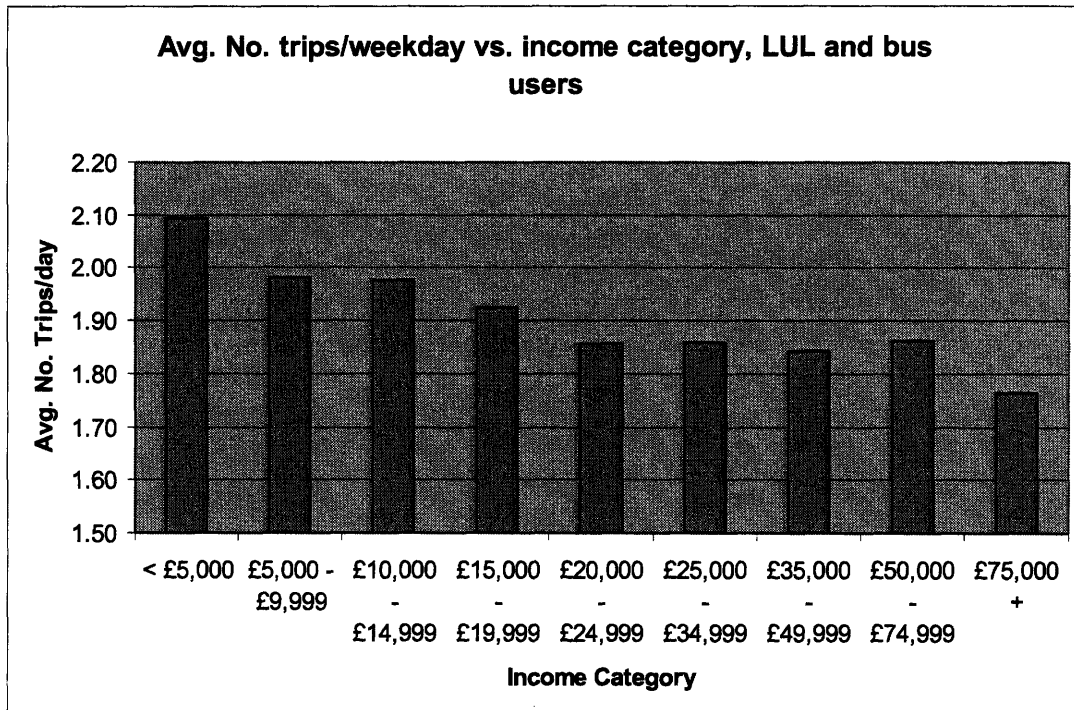


Figure 5.19 Trips by Income Level

< £5,000	£5,000 - £9,999	£10,000 - £14,999	£15,000 - £19,999	£20,000 - £24,999	£25,000 - £34,999	£35,000 - £49,999	£50,000 - £74,999	£75,000 +
8%	11%	10%	11%	11%	14%	14%	11%	10%

Figure 5.19 above shows the number of trips per weekday by income level from the 2002 LATS survey. Usage of public transport is quite even except by commuters with incomes over £75,000. Low income users take about 5% more trips per week on average (2.15 versus 2.04) than middle income users, so flat fares and elimination of travel cards might increase the price per trip as much as 5% for low income users. However, because some low income users cannot afford weekly or monthly tickets, low income users as a whole are likely to be paying more per trip than middle income users under current fare policies. Pay-as-you-go flat fares would eliminate this source of inequality.

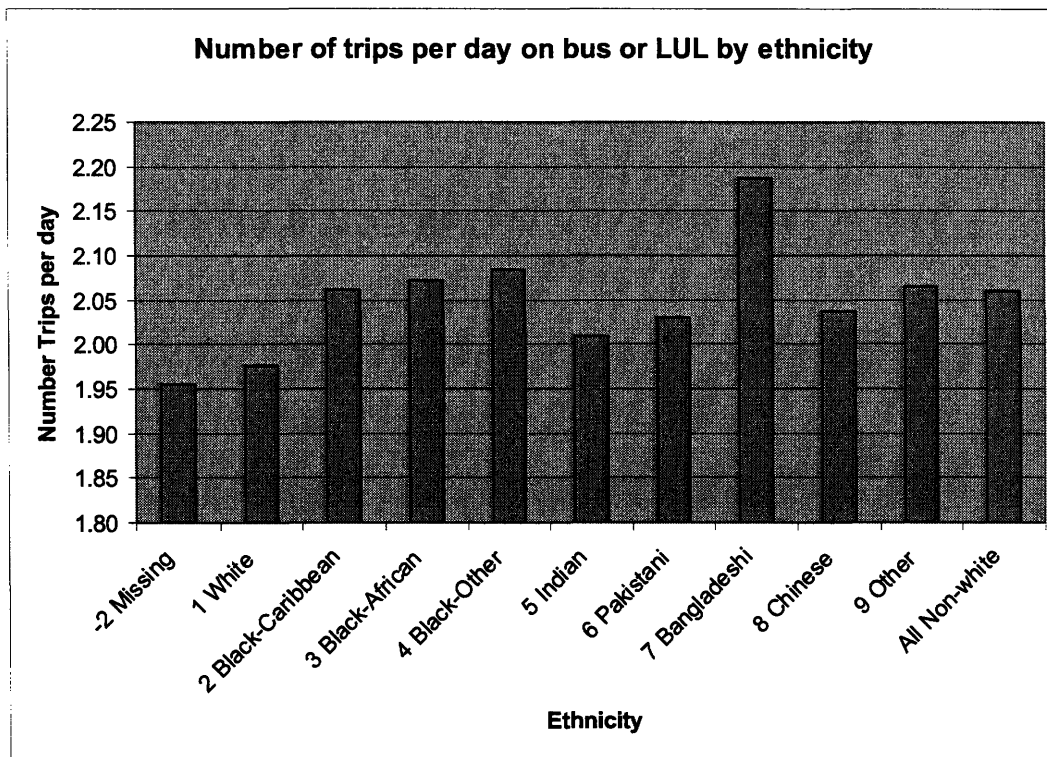


Figure 5.20 Trips by Ethnicity

-2 Missing	1 White	2 Black- Caribbean	3 Black- African	4 Black- Other	5 Indian	6 Paki- stani	7 Bangla- deshi	8 Chinese	9 Other
1%	66%	6%	7%	2%	6%	2%	1%	1%	8%

Figure 5.20 above shows the average number of trips per day by ethnicity. There is about a +/-5% range of variation by ethnic group, from 1.98 trips per day for white passengers to 2.17 trips per day for Bangladeshi users. However, Bangladeshi users represented a very small portion of respondents, and their trip numbers may not be statistically significant. A realistic range of variation is about +/-3%, and so there appears to be no reason to expect inequities by specific ethnic group.

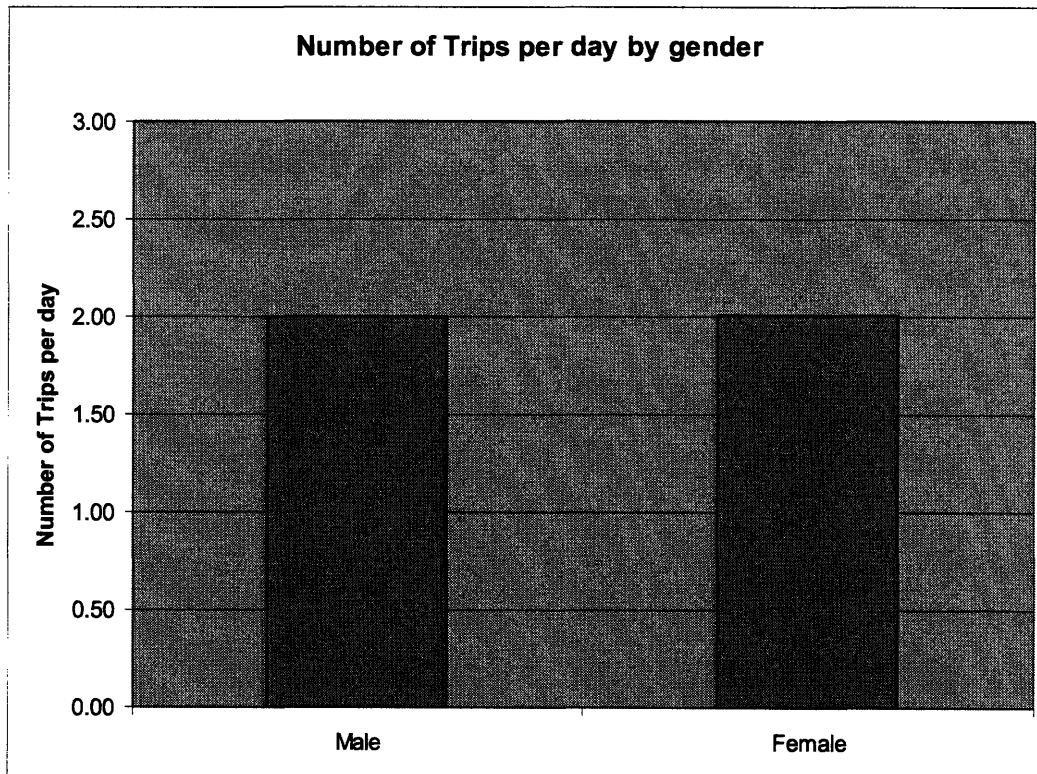


Figure 5.21 Trips by Gender

Male	Female
48%	52%

Figure 5.21 above shows essentially no difference in number of trips per day by gender.

Thus, the average number of trips varies by no more than 5% across the socio-economic groupings examined, and a change to a flat fare policy without travelcards or bus passes is unlikely to have a major impact on equity. Allowing low income and other disadvantaged groups to pay by the trip is likely to offset any disadvantages of flat fares by allowing members of these groups to obtain the most advantageous fares without an up-front outlay of funds.

### 5.3.2 Flat Fares and Trip Length Equity Impacts

Based on the LATS database, when all modes of transit are taken together, income, ethnicity, and gender correlate with trip length: the highest-income transit users took about 4 km longer trips than the lowest income; white transit users took about 1.8 km longer trips than non-white, and male transit users took about 1.5 km longer trips than female. However, when the modes are examined in isolation, the differences in trip lengths are negligible. The differences in trip lengths correlate closely to transit mode choice: lower income passengers are more likely to take bus than higher income

passengers; non-white passengers are more likely to take bus than white passengers, and female passengers are more likely to take bus than male passengers.

Thus, the switch to flat fare will not cause inequity among social groups due to offering longer trips at the same price as shorter trips on a single mode (LUL or bus). However, TfL should account for equity considerations in its choice of bus prices, knowing that bus is more likely to be used by disadvantaged groups.

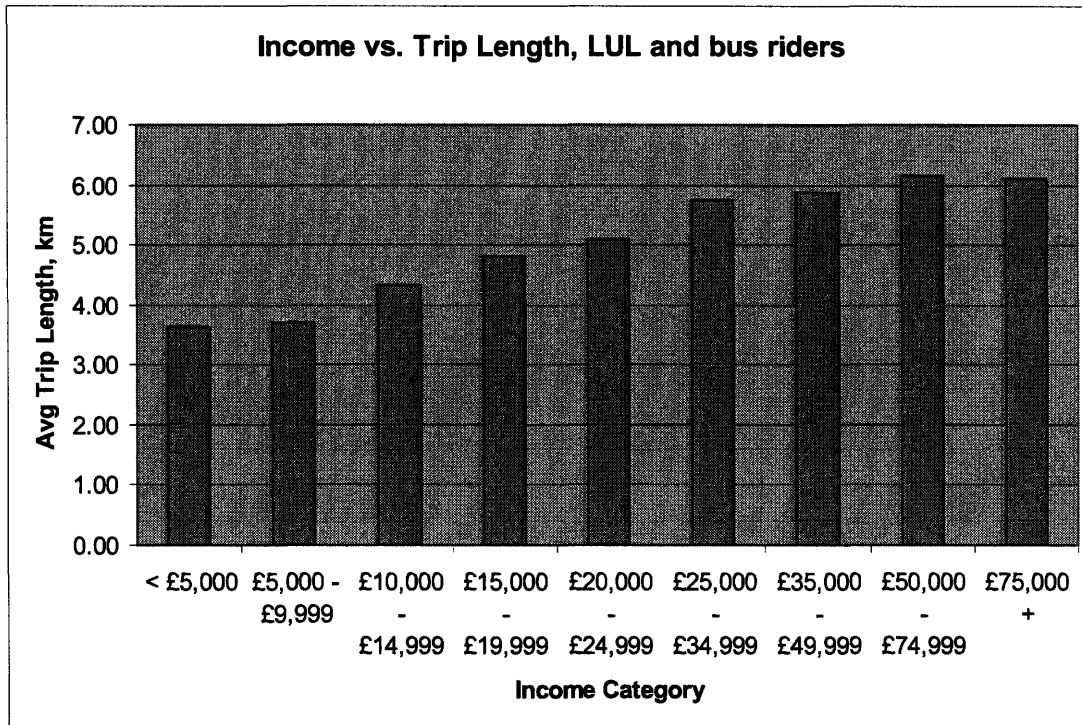


Figure 5.22 Trip Length by Income, LUL and Bus

< £5,000	£5,000 - £9,999	£10,000 - £14,999	£15,000 - £19,999	£20,000 - £24,999	£25,000 - £34,999	£35,000 - £49,999	£50,000 - £74,999	£75,000 +
8%	11%	10%	11%	11%	14%	14%	11%	10%

Figure 5.22 shows the aggregate correlation between income and trip length. However, as shown in the figures below, this is due to the disproportional use of LUL and bus by users with different incomes.

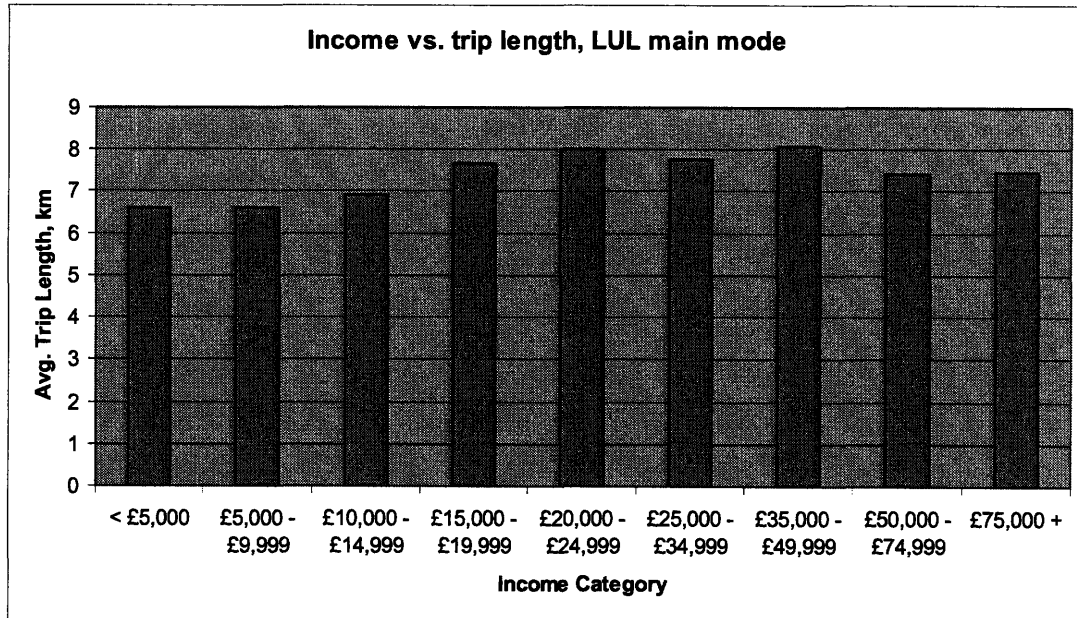


Figure 5.23 Trip Length by Income, LUL

< £5,000	£5,000 - £9,999	£10,000 - £14,999	£15,000 - £19,999	£20,000 - £24,999	£25,000 - £34,999	£35,000 - £49,999	£50,000 - £74,999	£75,000 +
5%	6%	7%	10%	10%	15%	17%	15%	15%

Figure 5.23 shows the trip length by income for LUL users (those with LUL as their main mode, by km traveled in total average daily journey). Average trip length varies from about 6.5 km for low income users to about 8 km for middle income users, dropping to 7.2 km for high income users. The range of variation in trip length is about 20%. Due to the structure of zonal fares, the variation in current fares paid by LUL users is considerably less, perhaps between 5% and 10%. A flat fare policy, while creating changes between users taking short trips and those taking long trips, is not likely to create any systematic equity impacts by income level.

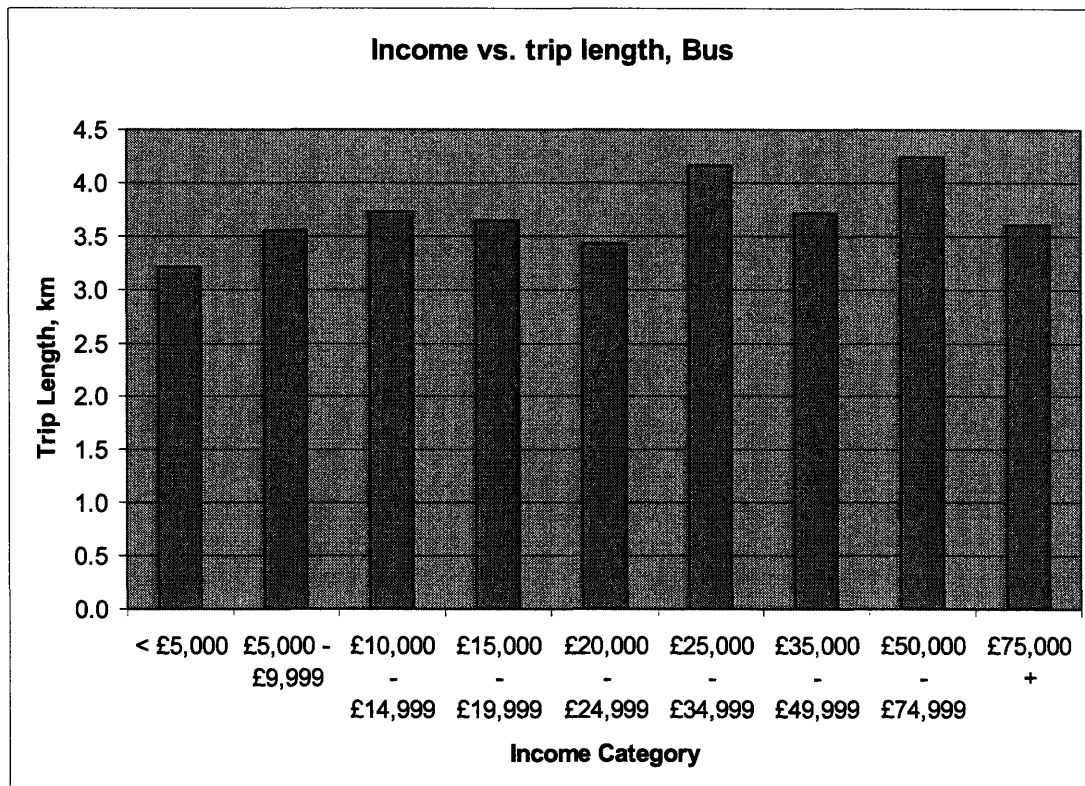


Figure 5.24 Trip Length by Income, Bus

< £5,000	£5,000 - £9,999	£10,000 - £14,999	£15,000 - £19,999	£20,000 - £24,999	£25,000 - £34,999	£35,000 - £49,999	£50,000 - £74,999	£75,000 +
11%	14%	12%	12%	11%	13%	12%	8%	6%

Figure 5.24 above shows the variation in bus trip length by income. Low income users take the shortest trips, 3.2 km on average, while middle and upper income bus users take 4.2 km trips on average. Similar to LUL, this is a 20% variation in trip lengths across income groups. Since bus fares are flat currently and the flat fare policy has generated no significant controversy, to our knowledge, flat fares are expected to be acceptable in the future also.

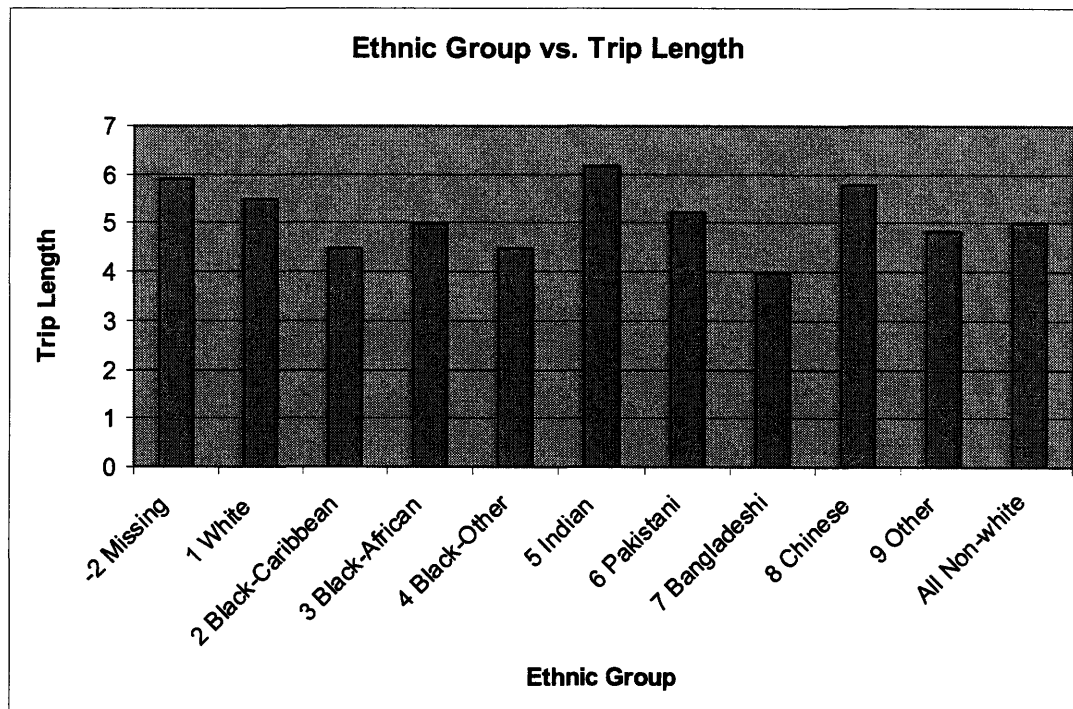


Figure 5.25 Trip Length by Ethnicity

-2 Missing	1 White	2 Black-Caribbean	3 Black-African	4 Black-Other	5 Indian	6 Pakistani	7 Bangladeshi	8 Chinese	9 Other
1%	66%	6%	7%	2%	6%	2%	1%	1%	8%

Figure 5.25 shows trips lengths on bus and LUL by ethnicity. The variations are mostly due to the use of bus versus LUL, in common with the overall pattern of trip lengths. The difference in average trip length between white (5.5 km) and all non-white (5.0 km) is about 10%, and is due to the higher use of LUL than bus by white travelers. This is most likely due to income and residential and job location differences. Since LUL fares are higher than bus fares, and future fare policies propose to maintain these differences, there should be no negative equity impact from flat fares on each mode.

The following table shows the ethnic makeup of bus and LUL journeys. Whites travel on LUL in greater proportion than their portion of the Tfl-traveling population: 72% of LUL journeys are taken by whites, although they make up only 65% of the population of bus and LUL users. In contrast, non-whites travel on bus in greater proportion than their percentage of the Tfl-traveling population: 40% of bus journeys are made by non-whites, though non-whites comprise only 35% of the population. Since bus journeys are average about 4 km shorter than LUL journeys, this fact confirms that the shorter journey lengths on bus accounts for the total journey length difference between ethnicities.

	LUL	Bus	Percent of sample
White	72%	60%	65%
Non-White	28%	40%	35%

Table 5.7 Ethnicity Split by Mode and as Percentage of Sample

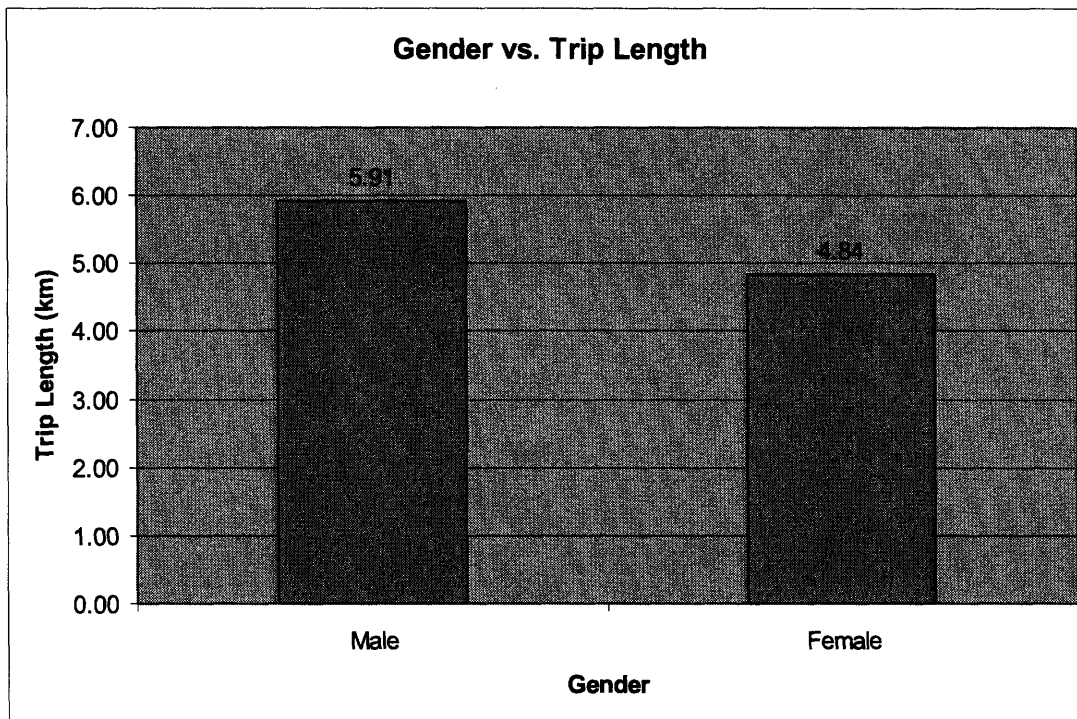


Figure 5.26 Trip Length by Gender

Male	Female
48%	52%

Figure 5.26 shows that there is a significant (20%) difference in trip length by gender. This difference is most likely primarily due to income differences. Again, this is due to higher use of bus over LUL by female passengers. As long as LUL-bus fare differentials are maintained, there will be no negative equity impact.

The following table shows that male passengers are overrepresented by 8% on LUL, and underrepresented by 6% on bus, while female passengers are overrepresented by 6% on bus, and underrepresented by 8% on LUL. Since bus journeys are average about 4 km shorter than LUL journeys, this fact confirms that the shorter journey lengths on bus accounts for much of the total journey length difference between men and women.

Gender	LUL	Bus	Percent of Sample
Male	56%	42%	48%
Female	44%	58%	52%

Table 5.8 Gender Split by Mode and as a Percentage of Sample

### 5.3.3 Choice of Transit Mode by Socio-economic Group

The usage of LUL, bus and national rail by socio-economic group is discussed in this section.

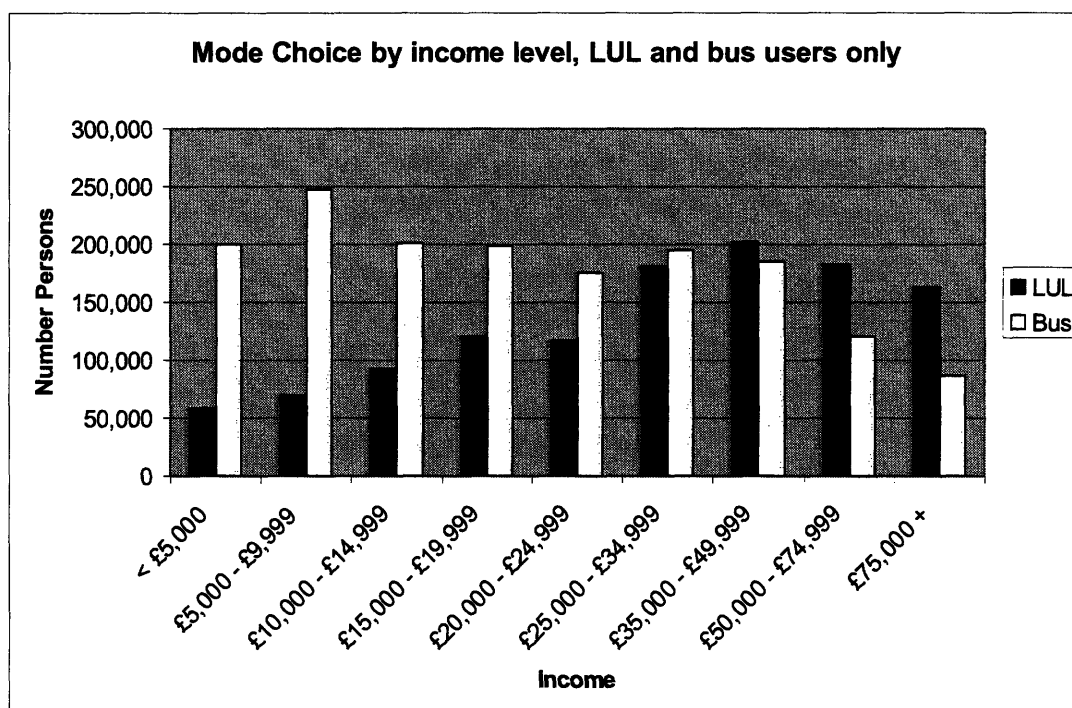


Figure 5.27 Transit Mode by Income

< £5,000	£5,000 - £9,999	£10,000 - £14,999	£15,000 - £19,999	£20,000 - £24,999	£25,000 - £34,999	£35,000 - £49,999	£50,000 - £74,999	£75,000 +
8%	11%	10%	11%	11%	14%	14%	11%	10%

Figure 5.27 shows the public transport mode used by income group. The percentages add to 100% in each income group. The mode shown is the 'main mode' used. Bus is the dominant mode for users with income levels less than £25,000, while usage of the two transit modes is somewhat balanced at incomes above that level. The bottom table lists the percentage of each income group as a percentage of the entire population of the greater London area. It illustrates that the income levels are roughly evenly represented

in the greater London area, which means that the modal splits in this table can be legitimately compared between income groups.

An issue that is difficult to address is the extent to which lower income users use bus rather than LUL or national rail for trips where LUL or NR offer significantly faster trip times, better headways or fewer transfers. If bus users are making shorter trips that are roughly as well served by bus as LUL or NR, or have a different pattern or origins and destinations, the dominance of bus trips may not be an issue. If, however, lower income users would choose LUL or NR if fares were the same, then there is a potential issue here. Mode-independent distance-based fares would be more equitable than the current system, in which even short LUL or NR trips have relatively high prices. While in fact bus users pay about the same price per km of travel as LUL or NR users, they must use the bus mode only to obtain the same price per km. If low income users chose LUL or NR for their shorter average trips, they would be paying significantly more per km than higher income users.

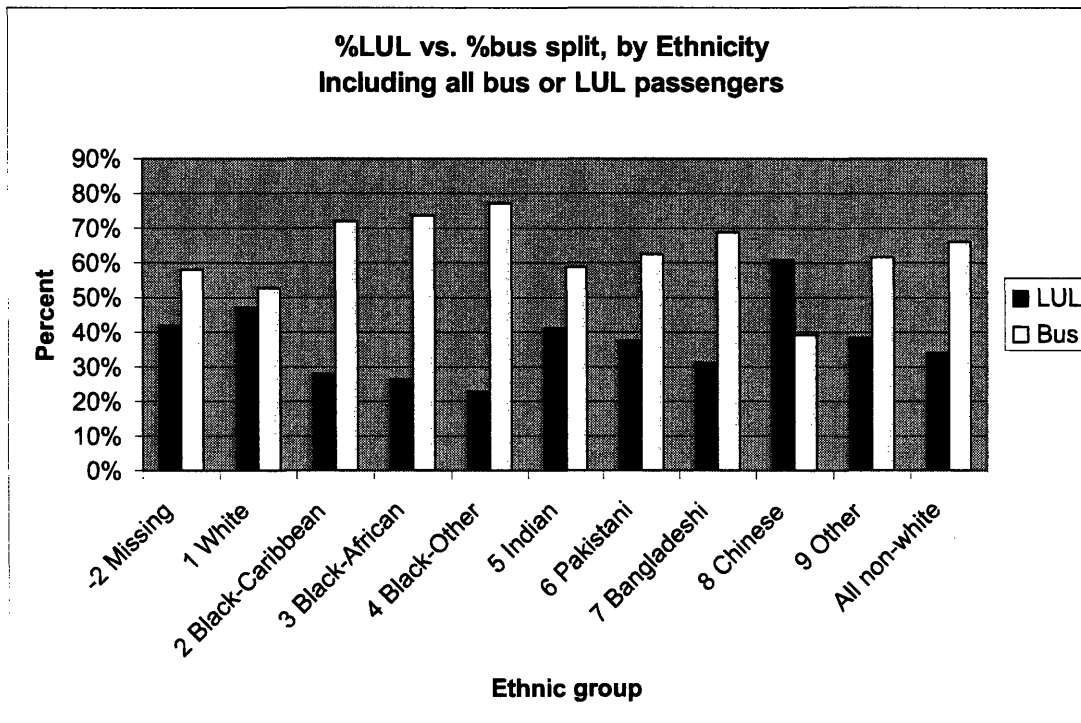


Figure 5.28 Transit Mode by Ethnic Group

-2 Missing	1 White	2 Black-Caribbean	3 Black-African	4 Black-Other	5 Indian	6 Pakistani	7 Bangladeshi	8 Chinese	9 Other
1%	66%	6%	7%	2%	6%	2%	1%	1%	8%

Figure 10 shows transit mode by ethnic group. While white users' use of LUL, NR and bus is relatively balanced, nonwhite users use bus for nearly 60% of their transit trips. This is consistent with the income group pattern.

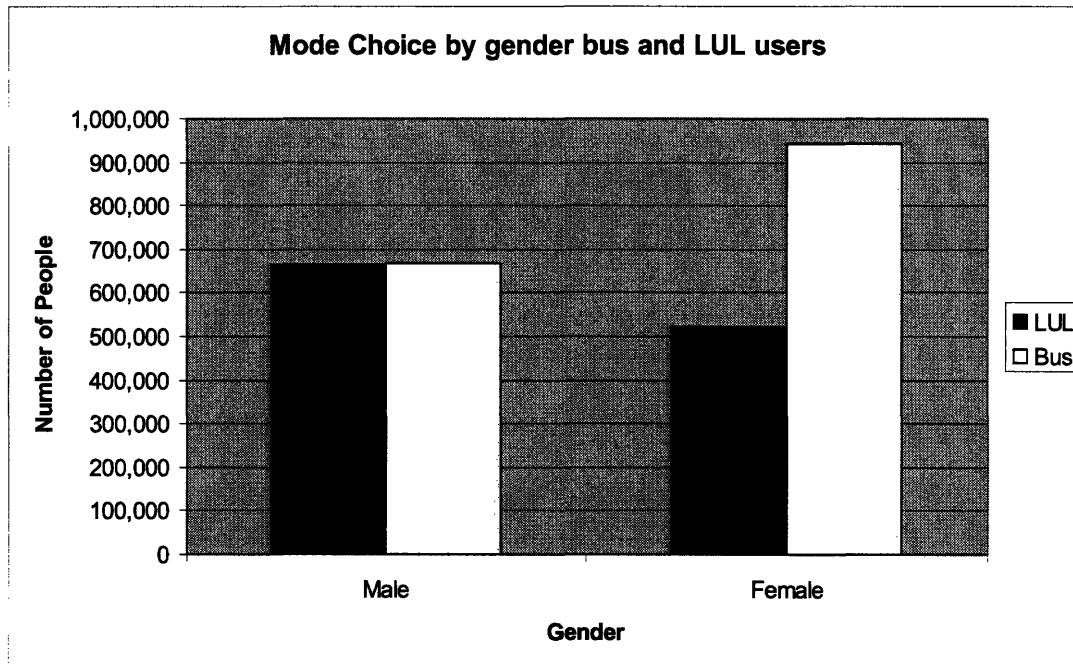


Figure 5.29 Transit Mode by Gender

Male	Female
48%	52%

Figure 5.29 shows the same differentials in mode use as the income and ethnic group comparisons: women use bus much more than men.

In summary, disadvantaged users use the bus mode disproportionately. Bus is the lower priced, lower service level mode. If, over time, disadvantaged users gain increased access to autos for commuting, their traditional relegation to bus services may make it more difficult for Tfl to attract them to a higher priced service on LUL (or the TOCs to attract them to national rail services). If there are opportunities to handle disadvantaged group travelers on LUL or NR on route segments and times of day that are not congested or capacitated through a fare policy that provides lower fares for the typically shorter trips taken by members of these groups, it would improve equity.

## 6 Analysis and Conclusions

### 6.1 Overall Summary of Conclusions

The main conclusion of this research is that commercial payment systems offer many advantages and few disadvantages for public transport fare payment. A flat fare structure, which is necessary for commercial payment options 1 and 2, has many attractive features, including the fact that it takes maximum advantage of cost savings possible with commercial payment systems, it does not harm equity, and that it may generate equal or greater demand and revenue when compared with current fares. Distance-based fares, possible in option 3, have little effect on overall demand, but are complicated to implement on buses and may cause congestion. “Be-in, be-out” long-distance smartcards, option 5, are too expensive to implement at the present time.

The specific conclusions of each category of analysis are summarized as follows:

**Cost:** The commercial payment options, option 1, 2, and 3, will generate maximum savings of £160, £140, £120 million/year in ticketing costs for TfL; actual savings will likely be lower but still very substantial. Little improvement in ticketing cost is possible with Option 4, the option similar to the current Oystercard system. Option 5, Be-in Be-out long distance smartcards, will increase ticketing costs by £100 million/year.

**Demand:** A demand model was created based on the assumption that there are two markets for transit in London, one for single or pay-as-you-go fares, and one for travelcard fares. If this assumption is correct then option 1, pure flat fares, will give revenue losses for fare levels that give current ridership levels, while option 2 will give revenue gains for fare levels that give current ridership levels. Distance-based fares will give revenue losses if the assumption is correct.

**Equity:** Based on demographic data of London transit users, neither flat fares nor distance-based fares will disadvantage any one social group, though eliminating free transfers on bus trips may harm lower-income passengers. The use of commercial fare media will not harm any social group because mobile phone penetration is high; but a supplementary fare medium such as a PAYG mobile phone is still necessary. The up-front payment currently required of travelcard holders is regressive; but the regressivity is eliminated with flat fares.

**Fare Policy:** Flat fares are attractive to a transit agency because they reduce congestion, allow for ticketing cost reduction, and may generate ridership because they are so simple. Distance-based fares give passengers a greater sense of value-for-money, but this perception may not translate into any quantifiable advantage. Zero marginal cost travel products, such as travelcards (passes) may not be needed, and prevent effective peak pricing on congested portions of the system.

## 6.2 Cost

The cost analysis of options 1-3 shows that significant reductions in ticketing cost are possible if these options are adopted. The major sources of these savings are the elimination of sales channels and the use of commercial, commodity hardware. The elimination of sales channels means saving the cost of wages for ticketing staff at LUL stations and the commissions to third-party ticket retailers (Ticket Stops). Achieving these savings requires the full elimination of the ticketing staff and vendor commissions.<sup>16</sup> In order to be able to eliminate the ticket staff and third-party ticket vendors, a supplementary ticket medium must be available. This supplementary ticket medium will allow the small number of passengers who come to the station without the necessary fare medium to obtain a ticket with cash.

The supplementary ticket medium will consist of cheap NFC-equipped pay-as-you-go mobile phones, prepaid smart bankcards, or both. The ticket medium will need to be sold from vending machines located in the Underground stations, and from vendors (such as mobile phone retailers) located in or near the stations. It is likely that one or both of these ticket mediums will be available in the next five years: mobile phone handset manufacturers are targeting the low-end handset market, and prices continue to drop; and banks are pursuing prepaid bankcards as an opportunity to provide services to the currently un-banked or under-banked populations.

There are other risks in the cost reductions outlined in the preceding chapter, such as the negotiation with banks over payment fees. However, these risks appear to be minor. The experience of bankcard and mobile phone payment in Seoul shows that negotiations can produce payment fees for the transit agency close to the fees outlined in the preceding chapter.

The cost analysis of option 4 stated that only incremental improvements are possible in the cost of a transit-agency-issued smartcard. Staffing can be reduced, but not significantly, because passengers will want to service their cards at many stations. Third-party retailer commissions cannot be significantly reduced because they allow ticket sales in areas where TfL has no real estate. Indeed, some more commercial hardware can be used, and some number of passengers can switch to mobile phone ticketing, allowing for some reduction in ticket administration costs. But these cost reductions will only be incremental.

Option 5, the use of long-distance Be-in Be-out smartcards, is simply too expensive to be considered for implementation in a gated transit system. That is because it presents very significant costs in addition to the current cost of gates. For barrierless travel systems, such as those in some continental European countries, the Be-in Be-out smartcards may hold some promise. In barrierless transit systems, there is no gate hardware, so if the cost of the Be-in Be-out systems can offset other ticketing costs, it may not cause such a large increase in the cost of ticketing as it will cost in transit systems with fare barriers.

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<sup>16</sup> Of course, the ticketing staff may be reassigned to other duties.

However, before these tickets can go into widespread service, the equipment must reach technical maturity, and an effective fraud reduction strategy must be found. And even for gateless travel systems, cost will be an issue. The prices used for computing the cost in the last chapter were extremely ambitious estimates, and prices are likely to be much higher, at least for the initial installations of such a system.

### **6.3 Demand**

The demand analysis is based on an incremental logit demand model created for the London area. The model presented here is based on the assumption that there are two “markets” for transit – two basic groups of passengers with different elasticities of demand. One market is the group that currently buys cash fare or pay-as-you-go tickets, and the other market is the group currently purchases weekly or monthly travelcards. While TfL currently offers many different travel products, there was no strong evidence that these products cater to actual market demands.

If the assumption of two transit markets is correct, then if TfL switches to a pure flat fare – one price for all travel, as in option 1 – TfL will incur revenue and ridership losses. The model demonstrates this expected phenomenon, and the details of potential losses were presented in chapter 5. It should be emphasized that if there is, in reality, just one market for transit in London, then a single price will not induce a revenue/ridership loss, but rather a gain. However, the risk of incurring a revenue loss with a single price is significant, given that there appears to be no solid marketing or demand data on the use of passes and single tickets.

If the assumption of two transit markets is correct, then if TfL switches to a flat fare with pass-like products, as in option 2, TfL will at least break even, or even experience revenue and ridership gains. The model demonstrates this expected phenomenon, and the details of potential gains were presented in chapter 5. There is still some risk associated with switching to option 2. However, there is significantly less risk than is associated with option 1.

But if the assumption of two transit markets is wrong, and there is just one transit market, then if TfL implements a flat-fare with pass-like products, as in option 2, TfL will essentially mimic the current fare policy and have about the same ridership and revenue, potentially missing the opportunity to increase ridership and revenue. There is still much less risk with option 2 than with option 1 because option 2 can approximate the current fare policy while option 1 cannot.

In option 3, if the flat and per-km prices are set correctly, distance-based prices will not have a large effect on revenue and ridership. That is because the current fare zones are roughly comparable to distance based pricing. Sample distance-based fares were presented in chapter five. Distance based fares will have a significant effect on passenger trips taken: increased numbers of the shortest trips and decreased number of the longest trips, and consequently, a reduction in average trip length. This result can be seen from the option 3 detail graphs presented in chapter 5, which show that the number of trips in

the shortest average trip length category (the current zone 1) increase, and that distance-based fares will cause a decrease in average trip length if they are set so that revenue and ridership are maintained.

It is hard to know the true nature of the demand for transit in London without detailed market research. However, it is unlikely that the nearly 200 ticket products currently offered by TfL are tailored to the demand for transit in an optimal way. Often, a significant simplification of the fare structure will have either little effect or a positive effect on revenue and ridership. This was the case in both the Baltimore metropolitan transit fare simplification and the Connecticut bus fare simplification (Multisystems et al. 2003). A well-planned fare simplification would likely have a similar effect on TfL's revenue and ridership.

The time-of-day choice model shows that time of day choice can be modeled by an incremental logit model. The model shows that between 3% and 10% available capacity can be created during peak hours in zone 1. This increase in capacity occurs with a slight increase in revenue, and a slight decrease in ridership.

## **6.4 Equity**

### **6.4.1 Market Penetration**

The use of new fare media – contactless bankcards and NFC mobile phones – itself carries equity considerations. Members of the lowest income portion of the London population are often unable to obtain bank accounts, either due to their lack of income or their lack of a stable residence. Thirteen percent of U.K. residents, more than one in eight individuals does not have access to a bank account (Brown and Thomas 2005). Without a bank account, these individuals will be unable to obtain contactless bankcards. Thus, a pricing scheme that would advantage only those users with contactless bankcards would be inherently regressive, disadvantaging the lowest-income users.

In contrast to bankcards, mobile phones have a very high penetration in all income groups. While a bank account may be necessary to obtain a mobile phone with a contract, good value prepaid mobile phones are available for small amounts and require no special financial background. Prepaid phones are widely used among the entire London population. In fact, mobile phone hardware manufacturers planning to offer even more low-cost mobile phones, perhaps for as little as \$20, or £10 (Nystedt 2006). NFC mobile phone payment services will most likely be first offered on mobile phones with contracts, but mobile network providers are likely to offer NFC payments on prepaid mobile phones as part of their effort to penetrate the payments business. Because prepaid mobile phones make up 75% of mobile phones in the UK, the network providers will likely move to offer payment services on prepaid mobile phones shortly after introducing those services, so that they can attain significant payment revenues (J.D. Power and Associates 2003).

A small portion of London residents possess neither mobile phones nor bankcards, and some tourists will be in this situation. Thus, in order to eliminate equity concerns arising from using new fare media, a supplementary ticket medium will need to be available at Underground stations and other locations near transit services. This supplementary ticket medium should be obtainable by users with any form of payment – especially cash. It will consist of pay-as-you-go NFC mobile phones and / or prepaid contactless bankcards, and should be available from vending machines and / or vendor kiosks.

These supplementary fare media are not without potential difficulties. A potential problem with using mobile phones exclusively as the supplementary medium is that their basic price will be relatively high, say £10. Must passengers purchase new phones every time they go to the station having forgotten their normal phone? This problem is solved if mobile phone vendors will purchase back barely used mobile phones, presumably to be placed in the low-cost phone pool again.

Using mobile phones as payment media will have additional equity benefits. It could make the very cheap mobile phones widely available in London, and thus put mobile phones into the hands of even more lower-income citizens than today. TfL may provide emergency contact by having users dial E112 in addition to (and in some cases instead of) provided emergency landline telephones in stations. All users will have access to mobile phone information services which will be private, can be provided in their chosen language (addressing ethnic group based issues), and provide emergency service access universally to all passengers.

### **6.4.2 Up-front Payment**

Time-period passes, such as travelcards used on TfL's network today, are an inherently regressive form of payment: they make the cheapest form of transit payment available only to higher-income users. That is because purchasing time-period passes requires a significant up-front outlay of cash. This outlay is so significant that it prevents the lowest income users from purchasing these products.

The cheapest per-day rate is given for the longest duration period pass, which is in turn the most expensive. Currently, the cost of an annual travelcard for zones 1 and 2 is £928. This is nearly 10% of the pre-tax annual income of almost 20% of the population (in the 2001 LATS survey, 20.6% of the Underground and bus-riding population made less than £10,000 per year). Such a sum is clearly beyond the means of lower income individuals. A weekly pass for zones 1 and 2 costs £23.20. If one purchases a year's worth of weeklies, the cost is  $52 * 23.20 = £1206.4$ ; an annual ticket represents a  $928 / 1206.4 = 23\%$  savings over that. If one presumes four weeks of vacation, an annual ticket still represents  $1 - 928 / (48 * 23.2) = 17\%$  savings. Thus TfL is currently offering significant discounts to its richest patrons—those able to afford a thousand pound outlay of cash.

Indeed, TfL's largest sources of ticket income are from Pay-as-you-go and weekly passes. Annual passes make up a very small amount of ticket sales – a very small amount

that clearly benefits those in the higher income categories. This fact underlines the regressivity of the period pass product.

A pure flat fare structure, such as is used in option 1, eliminates the regressivity of the time-period pass. Under a flat fare policy, all passengers to pay the best price without being required to pay a large sum upfront.

The use of period price caps instead of passes, as in option 2, also eliminates the regressivity from the fare structure. Price caps, as discussed in chapter 3, do require some up-front payment: if refunds are made on a weekly basis, passengers will have to pay the full fare for every trip that they take in one week, and are refunded the fare for each trip taken beyond the threshold number of trips after the week is over. However, all passengers pay the same amount for each trip. A price cap can be used with any of the payment options except option 1, which permits no unlimited travel products at all. Thus the inequity of up-front payment is eliminated with the commercial fare payment options, options 1-3.

Passes are an accepted fare payment product, although some literature does point to their regressive nature (Luhrson 1997). But even though passes are generally accepted, eliminating the regressivity of up-front payment is clearly an improvement in the equity of the fare structure.

The elimination of travelcards has other equity implications, beyond the elimination of up-front payment, discussed ahead in the section titled "Elimination of Travelcards."

### **6.4.3 Elimination of Zones**

This examination of equity is based on the idea that charges need not be based on distance traveled in order to be equitable. The principle is used that to establish the equity of eliminating a zonal fare structure, it must be established that this change does not further disadvantage already disadvantaged social groups, or further advantage already advantaged social groups. There are other measures of equity, but an incremental equity measure such as this seems most relevant to the fare changes being analyzed in this thesis.

Under the current fare structure, there is only a small relationship between distance traveled and social group. The analysis in chapter 5 established that the relationship between income and distance traveled on a given transit mode is small: +/- 10%, by income. The longer trips were taken by individuals in mid-upper income categories, while the trip length of those in the highest income categories is lower than those in some of the middle categories. Thus the differences between income categories are small, and the relationship between income and distance traveled on a given mode is not direct. Moreover, distances traveled don't necessarily correlate with fares paid because of the irregular zonal boundaries. The irregularities in zonal boundaries, combined with the geographic distributions of the various social groups, could easily offset the +/- 10% difference. In addition, travelcard purchasers are now required to purchase a ticket for at

least two zones. The distance across two zones is usually greater than the average trip length of all social groups, indicating that most travelcard purchasers all pay the same amount, regardless of trip length already under the current system.

There are other reasons to believe that zonal fare payments are not linked to equity. The current zones are a historical artifact, created to simplify London's then massively complex point-to-point fare structure and allow travelcards that could be used on TfL as well as network rail services. Moreover, when people choose a place of residence, the location of a job, family, friends, and affordable housing all play a greater role than the cost of transportation. Thus there is no reason to believe that the current zones are strongly related to passengers' ability to pay for transit.

Finally, a zonal payment structure creates zonal inequities. A zonal inequity means that people living on one side of a zonal boundary pay significantly more for a trip than those living on just on the other side. For example, people traveling from the first LUL station inside zone 1 (for example, Euston station) to a LUL station in zone 2 must pay £2, while people starting from the next station, the first station outside zone 1 (Mornington Crescent) pay only £1.<sup>17</sup> There is no reason to believe that the current zonal boundaries would allocate these zonal disadvantages to any given social group. However, the zonal boundaries allocate the disadvantages in an arbitrary way. Thus eliminating the arbitrariness of the zonal disadvantages does not rectify inequities among social groups, but it does improve social fairness to the disadvantaged individuals.

These considerations, taken together, make the case that eliminating the TfL zonal fare structure would not have negative equity implications. Whether flat fares or distance-based fares are chosen, they will be no more – and perhaps less – inequitable than the current structure.

Zones, in the current fare structure, have one important function beyond correlating pricing with distance traveled: zonal pricing can be used to reduce congestion. Most congestion on the underground occurs within zone 1, and TfL prices trips including zone 1 higher in order to reduce congestion. Single trips within zone one are priced 50% more than single trips in all other zones, and multizone trips including zone 1 are more expensive than those not including it. The phenomenon of congestion is not directly linked with equity, and so this issue will be treated in depth in the fare policy section below.

#### **6.4.4 Elimination of Travelcards**

Eliminating travelcards will disadvantage passengers who now travel very frequently with travelcards. However, the numerical analysis in chapter 5 showed that there is little correlation between trip frequency and social group. The  $\pm 5\%$  variation was not a linear correlation, and may even fall within the statistical error of the LATS survey data. Thus the elimination of travelcards should have negligible negative effects on equity.

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<sup>17</sup> The fares quoted are those paid by Oyster pre-pay passengers.

If TfL switches to flat fares, it could approximately simulate current season tickets by creating a price-capping or loyalty scheme (with post-processing by banks or NFC payment providers). TfL could create several different price-capped fares. There could be two different price cap thresholds (e.g., each journey after 15 journeys is half price, each journey after 30 journeys is quarter price), or the price cap threshold can be continuously decreasing (e.g., each journey after 15 journeys costs 10 pence less than the preceding journeys). If TfL chooses flat fares without post-processing, these more frequent users will pay more than users who do not travel so frequently. Again, there appears to be no systematic effect by income group, ethnicity or gender from a change to flat fares.

Eliminating travelcards (and optionally introducing price caps) may have positive equity effects. By eliminating travelcards, passengers who regularly buy travelcards will no longer run the risk of paying for travel that they do not actually use. Because travelcard users typically have the lowest per-journey fare of all passengers, eliminating travelcards and making appropriate changes in the fare structure may benefit infrequent travellers.

There are many reasons why users may purchase a travelcard but take fewer trips than are needed to make the purchase economically sensible. The most obvious reason is an unexpected event that keeps one from using the transportation system. Such an event could be illness or unexpected travel. Some users may be so risk-averse that they purchase travelcards in order to guarantee a maximum cash outlay per period, instead of using PAYG, which would give them better value for money under most circumstances. Other users may worry about running out of stored value when the line at the ticket machine is long, or simply not want to have to think about maintaining a sufficient balance on their card, and have reasons for not using auto top-up (either because they don't trust the security of the auto top-up system, or because they do not have bank accounts). Thus many users may choose to purchase travelcards when they know it is likely that they will not be economically advantageous for them, but simply because they are more convenient, so eliminating travelcards (and possibly providing price caps) may be an improvement for these users.

Travelcards may be shared among several passengers, whether a transit agency permits this practice or not. It appears that the number of trips on weekly and monthly fare media are very high, suggesting that the ticket media are being shared among several people. 2006 data provided by TfL suggest that bus pass users take an average of 27 trips per week, and LUL travelcard users take an average of 16 trips per week. Oyster data suggests that 40% of bus journeys are bus-bus transfers. Removing the bus-bus transfers gives bus pass users an average of  $27 \times 0.8 = 21.6$  trips per week. This is still an average of over 4 trips per weekday, which is a very high number. Although the Oyster data allow no way of confirming the fact that travelcards are shared among several users, the numbers of high weekly trips and anecdotal evidence suggests that this is indeed occurring with some frequency.

The equity implications of the ability to share fare media are unclear. The sharing of fare media could have positive equity implications if lower-income households are more likely to share fare media. Lower-income people are more likely to live in large households in order to reduce the rental burden in a city as notoriously expensive as London, and living in a large household will give more opportunities for sharing of fare media. This is difficult to investigate and no data could be found to support or reject this thesis, but it seems plausible. But a transit agency may not want to allow users to share payment media, because it views sharing as a fraudulent misuse of the medium that harms honest transit users and benefits dishonest ones. This is a legitimate perspective, and will not harm equity if the transit agency equates equity with honesty.

All of the commercial fare payment options (options 1-3), discourage sharing of fare media. That happens because most individuals want to have their mobile phone or bank card with them, and will not be as willing to share them as they would their transit smartcard, which has no use other than transit payment. However, option 1 will absolutely eliminate any positive or negative equity implications associated with sharing fare media, because with option 1, every payment is made completely and immediately, there is no way to avoid paying for every trip properly.

#### **6.4.5 Elimination of Free Transfers**

TfL does not currently offer transfer discounts for single ticket purchasers, but travelcards and bus passes give their holders the ability to transfer without paying an additional fare. If travelcards are eliminated, the equity implications of the elimination of free transfers must be considered.

The elimination of free transfers in option one will have negative equity impacts on individuals in disadvantaged social groups. That occurs because disadvantaged groups are more likely to choose bus, as shown in chapter 5, and all transfers on bus will require a second tap, and hence a second payment. LUL, in contrast to bus, offers free internal transfers: the transfer from one LUL line to another requires no taps/payments and is consequently always free. TfL Oyster data show that 40% of current bus journeys are linked bus-bus journeys, whose price will double under the pure flat fare regime of option 1. Individuals making linked bus journeys are more likely to be from lower income groups. The chapter on the demand and revenue model shows that in a pure flat fare scenario, the price of a bus journey might be £0.45, roughly half of what a single bus journey costs today, so a linked journey would be no more expensive than a single journey costs today. However, individuals requiring transfers on bus will be forced to pay twice as much as those who do not need to transfer. Thus eliminating free transfers will create arbitrary advantages among disadvantaged social groups. This may create the perception of inequity, which may alone justify using a fare payment option that allows free transfers, such as option 2

Eliminating passes will cause the elimination of free transfers within TfL modes, but eliminating transfer discounts other than bus-bus discounts should not have aggregate negative equity effects. That is because other transfer passengers do not

disproportionately represent disadvantaged groups. For example, Bus-LUL passengers have roughly the same income, ethnic, and gender makeup as standard LUL riders, who are disproportionately white, male, upper-income when compared with bus. So eliminating these free transfers does not have negative equity impacts.

## **6.5 Fare Policy**

### **6.5.1 Flat Fares: Definition**

A flat fare is a fare in which a single fare is charged for a journey, regardless of destination. Passengers pay the flat fare when entering the transit system. Payment can vary by time of day, mode of travel, and possibly station of entry. However, varying payment by entry station adds significant complication to a fundamentally simple system, making communicating the fare structure to passengers more difficult. In systems where payment has varied by entry stations in limited locations, such as Boston's Braintree, complications and confusion have been frequent. In January 2007, Boston abolished all fare differences by boarding station. Varying payment by time of day presents few complications, and can be used with a flat fare structure to achieve the benefits of peak pricing. Varying payment by mode of travel allows TfL to continue differentiating between bus and tube.

### **6.5.2 Flat Fares: Advantages**

The major advantage of a flat fare is the opportunity to reduce the cost of ticketing by maximally leveraging the commercial payment system. The commercial payment system is based on a one-time interface between the payer (passenger) and the payment network: this occurs, for example, when any retail purchase is made by credit card. Traditional public transport fare policies cannot take advantage of the commercial payment system because they require intermediate processing to convert tap-ins and tap-outs on access gates to fare charges on fare media.

Commercial payment firms such as credit card companies are not currently equipped to handle "two-part" transactions requiring intermediate processing to connect tap-ins and tap-outs. If TfL wishes to take advantage of the presence of generic contactless payment tools without fully leveraging the commercial payment infrastructure but retaining a zonal or distance-based fare structure, TfL can set up a third-party payment-resolving firm with the primary task of connecting tap-ins and tap-outs and routing payments. Such a firm would be similar to the Korea Smart card Corporation which performs this function for bank card payment in Seoul. It is possible that banks or bank card companies would be willing to perform this function.

The emerging technologies of contactless bank cards and NFC mobile phone will put a commercial contactless payment tool in the hands of most customers in the next five years, thus making it feasible for TfL to use commercial payment services directly at fare gates. Passengers would swipe their mobile phone or contactless bank card directly at the fare gate, the fare payment would be directly billed to the phone payment provider or the

bank card, and all payment processing would be handled by the commercial payment network. TfL could potentially save a maximum of £150 million of the approximately £200 million it spends on fare collection by moving to commercial media. Achieving this level of savings would not be easy, of course.

A second advantage of the flat fare structure is its simplicity and consequent ease of explanation to passengers. A single fare for all destinations is immediately comprehensible by all passengers, and should reduce any uncertainties that passengers may have about how much a trip will cost, and any reluctance to use public transportation that arises from these uncertainties. In countries such as Japan where contactless payment has been introduced, spending at shops accepting such payment has increased, often by 10-20%. It is possible that public transport would benefit somewhat from this effect, based on ease of use of the payment media.

A third advantage of flat fares is to allow passengers to pay the best price without being required to pay a large sum up front. Under the current fare structure, those passengers who purchase annual passes receive the best fare; this requires them to front over a thousand pounds. Under a flat fare system, this regressive aspect of fare pricing is not present.

A fourth advantage of flat fares is that they eliminate zonal inequities. Zonal inequities refer to the fact that passengers living one station outside a fare zone can pay significantly more than passengers just inside the fare zone for a trip that is only slightly different – and perhaps even shorter. Zonal inequities are described in greater detail below, in the section on the advantages of distance-based fares.

### **6.5.3 Flat Fares: Demand and Revenue Effects**

There will be changes in demand with a flat fare, as described in the previous chapter. Based on the demand modeling results, it appears possible for TfL to retain the same levels of revenue and ridership under a flat fare as under the current fare policy. With annual revenue of roughly £2 billion and annual ridership of 2 billion, the overall average TfL transit fare is £1. With a flat fare of £1.30 for LUL and £0.60 for bus, the demand model shows the revenue and ridership under these flat fares to be only incrementally less than they are under the current fare policy. Because many trips are made under travelcards and bus passes, and because there are few long LUL trips at very high fares, most existing TfL travelers pay fares that are not very different from these flat fares. While flat fares result in increases for some users and decreases for others, the net effect is closely balanced.

In theory, some revenue will be lost from less flexible pricing with flat fares. With a zonal or distance-based fare structure, more revenue could be extracted from given market segments based on trip length and destination. This result derives from the simple economics of being able to apply the most appropriate fare to a given customer group with a more varied fare structure. However, the loss of revenue from less flexible pricing is quite small because the actual average fares paid by most passengers under the current

policy are quite similar. Varying fare by time-of-day and mode should allow TfL to extract much of the revenue from market segments.

Another impact of flat fares will be lessened integration with National Rail services (NR). Flat fares would lead to the elimination of joint ticketing with national rail. On one hand, this would reduce complexity and allow greater flexibility for each TOC (and TfL) to price as it wishes. On the other hand, this would create a less integrated public transport network in the perception of users (although with a low flat fare, the total price paid by most users transferring between national rail and TfL would probably not change much). Many National Rail Train Operating Companies (TOCs) have not yet integrated their pricing with TfL nor adopted the zonal fare system; in these cases, the introduction of a flat fare will have no negative impact. TOCs would be able to absorb part of the TfL flat fare for transfer trips if their users registered their mobile phones or bank cards with the TOC. TfL could negotiate a lower fare for some of these transfers if appropriate. Monthly post-processing provides a relatively flexible mechanism for adjusting fares for regular users.

At stations where national rail services communicate with LUL service without gates, gates will have to be installed. At stations where LUL and NR services share the same platforms, an alternative solution will have to be found, probably in the use of platform-based fare collection devices that TfL, but not TOC, users must tap before boarding. With clear signage, some initial advertising and assistance, and enforcement, this appears to be feasible.

#### **6.5.4 Flat Fares: Disadvantages**

A flat fare policy has several drawbacks. The most prominent disadvantage of flat fares is that some passengers will feel it is unfair for short trips to cost the same as long trips. The equity analysis showed that this change will not particularly disadvantage any social groups. But some passengers who make short trips will complain that they are paying the same as those who take longer trips, and there will be public relations and political issues to resolve. The second potential drawback is the changed interface with National Rail that is necessary with flat fares. TfL may view this as an advantage, as it would force a clear boundary between National Rail and TfL's services. Another drawback is that pure flat fares do not offer the possibility of transfer discounts, and this may cause equity issues because rail (underground) transfers are free based on the physical structure of the system, while bus transfers are not. Also, flat fares do not encourage intermodal (bus and underground) travel. This issue is complicated by the fact the bus passengers have, on average, lower incomes.

#### **6.5.5 Zonal Fares: Definition, Advantages, and Disadvantages**

In a zonal fare structure, each station is associated with a zone, a geographical grouping of stations. Passengers pay fares based on the zone of the station where they enter the system and the zone of the station where they exit the system. The zones and the fares

are typically chosen to approximate a distance-based fare for most journeys. However, variations occur, especially due to the central business district being charged a higher fare in order to reduce congestion on the transit system. Passes, transfer discounts, and concessionary discounts are possible.

In London, zonal fares have the advantages of continuity: TfL has used zonal fares for over two decades. Also, zonal fares can approximate distance-based pricing, which gives some passengers the feeling of “value-for-money,” while at the same time allowing TfL to charge a higher fare in the congested central district.

Zonal fares have the disadvantages of creating zonal inequities. Also, zonal fares discourage some travel because the fare system is more difficult to comprehend. Some very price-sensitive passengers are unsure of how much they will pay for a given journey, and choose not to travel instead of risking paying too much.

### **6.5.6 Distance-based Fares: Definition**

A distance-based fare consists of a flat base-fare to which a per-km fare is added for each trip. As with zonal fares, passengers must tap in and out, indicating their points of entry to and exit from the system. Both the flat base fare and the per-km fare could vary by mode, but it seems desirable to make the per-km fare constant across modes, and only vary the flat entry fare by mode. Both the flat base fare and the per-km fare can be varied by time of entry.

### **6.5.7 Distance-based Fares: Advantages**

One advantage of distance-based fares is the elimination of zonal inequities. All zonal fare structures, including TfL’s current structure, create fare structures that are inequitable to people living on the border of fare zones. For example, thousands of people living just outside zone one currently pay 2 pounds for a single fare to travel less than a kilometer into zone 1.

The following chart indicates the range of trip distances traveled by passengers paying each fare category. The dot indicates the average distance traveled at each fare, and the line indicates the minimum and maximum distances that LUL users actually travel at this fare, as recorded in Oyster data. This suggests that the zonal fare structure is an imperfect approximation to charging proportional to distance, if that is the intent.

**Range of Underground journey distances by fare  
June 26-August 31 2005  
Mode distances by fare highlighted**

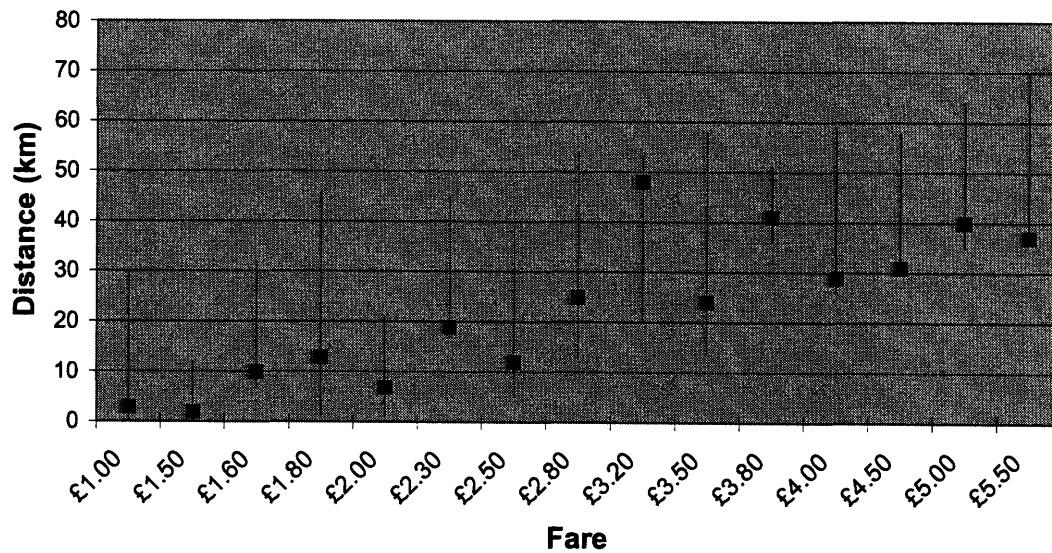


Figure 6.1 Range of Journey Distances by Fare

The following chart illustrates the annual number of journeys by distance. The large majority of trips are between 2 and 20 kilometers. A flat fare based on an average distance of 10 km is not likely to be viewed as inappropriate by most travelers. The very long trips on TfL appear, from LATS data, to be made by lower income travelers, since higher income travelers making such trips would either use national rail or auto because of significantly lower trip times. However, the number of trips and thus the sample size is small, so it is difficult to draw conclusions with certainty.

**Number of Oyster Underground Journeys by distance  
June 26-August 31 2005**

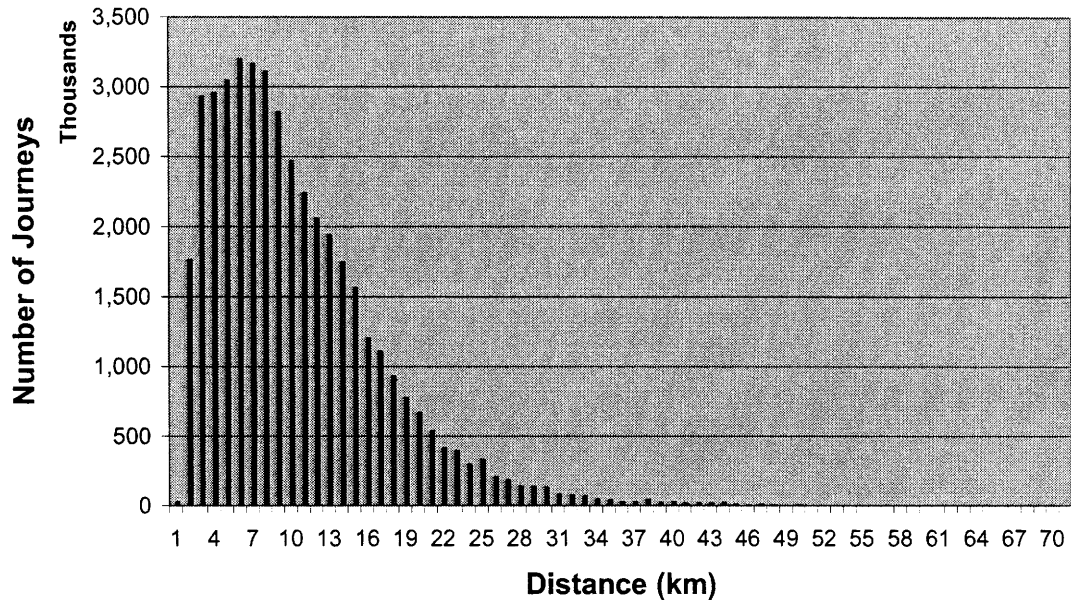


Figure 6.2 Number of LUL Journeys by Distance

Another advantage of distance-based fares is their implicit encouragement of intermodal travel. Under distance-based fares, when a passenger transfers from rail to bus or vice-versa, only one (the higher) base fare is charged, and the per-km charges continue to accrue on the new mode. Thus if after a tube journey, a passenger takes a 1 km bus trip, the additional cost of that bus trip will only be the cost of 1 km on bus, perhaps 15 pence.

A third advantage of distance-based fares is the perception by passengers of real value-for-money. That is, the fare they pay is a function of distance traveled, so passengers perceive that their fare is proportional to the cost of the service and its value to them.

Contactless payment eases the collection of distance-based fares on buses by providing a means for passengers to tap in and out. Fraud can possibly be reduced by using the system used in Japan by which passengers board at the back of the bus and are responsible for tapping in, but are only allowed to exit the bus in the front, with the driver verifying their tap-outs. This may be infeasible in peak periods on busy bus lines with articulated buses. Camera enforcement of fare payment on buses is likely to be difficult as well.

### 6.5.8 Distance-based Fares: Disadvantages

Distance-based fares require customers to tap in and tap out, which slows bus operations, and requires more readers on buses and gates at LUL stations. Thus, it is less convenient

and more expensive than a flat fare system, but provides greater control of pricing to TfL. The number of taps is doubled when tapping in and tapping out are required, which doubles the transactions and also requires processing of taps to create a transaction that is not necessary with flat fares. With tap in and tap out, commercial payment systems cannot be used directly; a processing entity that processes taps to turn them into transactions is required.

Two disadvantages of distance-based fares, with respect to zonal fares, are the interface to National Rail and the transparency of the fares, problems that distance-based fares share with flat fares. However, the difficulties of interfacing with National Rail are not as severe as with flat fares: tap-ins and outs will still be required, so the difficulty of distance-based fares will be negotiating a new fare structure with the train operating companies. As with flat fares, distance-based fares will create greater transparency, which in turn may make it politically more difficult for TfL to raise fares.

### **6.5.9 Congestion and Balancing Use of the Transit System**

Congestion on a transit system occurs when a transit vehicle become filled to capacity so that not all passengers wishing to board a transit vehicle are able to board the vehicle. Congestion occurs in heavily used areas of a transit system, which are typically the central business district of major cities. This is the case in London: in peak hours in zone 1 (the zone including the central business district), certain train and bus lines fill so that not all passengers can board them at certain stops. As noted in the preceding chapters on demand modeling, decreasing prices increase demand for travel. If a zonal fare structure is retained, fares will remain the same, so congestion will not change. If a flat fare is adopted, chapter 5 showed that the flat fare will need to be as high as the current fare in zone 1 to ensure that no revenue is lost. Thus flat fares will not affect congestion.

Distance-based fares will tend to worsen congestion. Distance-based fares have this effect because they make shorter trips cheaper than they are now. Longer trips, of course, become more expensive, and some riders from longer trips will leave the system. As shown in chapter 5, the distance-based fares can be chosen so that overall revenue remains constant. But the source of revenue in distance-based fares is from shorter trips: Figure 9 in chapter 5 shows that with a reasonable choice of flat and per-km fare that gives ridership levels similar to today's levels, the revenue from trips in zone 1 (which includes the most short trips) increases, while the revenue from trips in all other zones decreases. Thus the current level of congestion in zone 1 will increase.

It should be re-emphasized that the demand model did not account for congestion effects. The effect of crowding to discourage new trips may prevent the short-trip ridership growth that the demand model predicts. That in turn implies a greater revenue loss than the demand model predicts.

There is no way to avoid this congestion causing effect of distance-based pricing, except to create a pricing scheme in which all trips in the areas affected by congestion (today's

zone 1) are given a minimum charge that is as high as today's fare. This creates a hybrid pricing scheme, in which there is a central flat fare zone, and distance-based fares outside of it, which is complicated and eliminates some of the benefits of distance-based pricing: precise value-for-money and an intermodal, uniform pricing scheme.

A closely related issue is the need to balance the use of the transit systems with an appropriate fare policy. Today, a very high percentage of trips (85%) originate or terminate in zone 1. Thus, the use of the system at the outer portions, away from zone 1, is significantly less than in zone 1. There is significant available travel capacity outside of zone 1. Because most trains run to the end of each line, this capacity often cannot be reduced, and even if the capacity could be reduced, this might be undesirable, since it would reduce the quality of service for passengers traveling from central areas to outer areas.

Given that there is unused capacity outside of zone 1, it is advantageous for the fare scheme to encourage use of this capacity. In the current system, the lower prices of trips excluding zone 1 serve just this purpose as well as decreasing further congestion in zone 1. Indeed, all zonal fare schemes can introduce similar measures, eliminating the congestion-causing effects of distance-based fares. Also, with a pure flat fare, congestion will not be an issue, since the demand model shows that to break even financially, the fare will be as high as the current zone 1 fare. However, a pure flat fare would reduce ridership outside of zone 1 because the fare will go up to equal the current zone 1 fare.

There are two ways to maintain a tap-in only flat fare scheme, but encourage transit usage outside of the central zone and not encourage congestion in the central zone. One way is that instead of having a pure flat fare, have a two-zone system, in which the entry fare in the current zone 1 is higher than the entry fare in all other areas. There would be no zonal or distance-based pricing – simply two different entry fares. This makes trips including zone one more expensive than those not including it, but makes a round-trip inside zone one more expensive than a trip into or out of zone one, which may not be desirable. A resolution for this problem would be to rebate the difference in cost of a trip starting in zone 1 and a trip starting outside zone 1 to passengers who take multiple trips in zone 1 in a given day. Another possible way have tap-in only flat fares but to charge more for trips within zone 1 is by charging the same flat fare across the system, but giving a rebate to passengers who board two or more trains outside of zone 1 in a given day. Option 1 does not allow for rebates, so the only solution would be to charge different entry fares.

#### **6.5.10 Effects of Fare Policy Simplicity**

Very simple fare structures – fare structures that have only one or two values that determine the price of the overall fare – can have two distinct effects on passenger response that more complex fare structures do not have. Simple fare structures encourage more travel because passengers are certain of the fare that they will pay. Such an effect was observed in Baltimore, Maryland, when the transit agency there switched from a zonal to a flat fare structure (Multisystems et al. 2003). Conversely, complex fare

structures will discourage some demand because passengers will be unsure of the fare that they must pay. A distance-based fare, though based on just two base numbers (flat and a per-km fare), may appear complex to some passengers who are unsure of the distances between stations. Thus a distance-based fare may discourage some demand. The model does not account for these effects.

### **6.5.11 Peak Pricing and Zero Marginal Cost Travel**

Peak pricing – increasing fares during peak hours to incentivize passengers switching to off-peak, not capacity-constrained, hours – is an effective way of increasing capacity on a transit system without increasing infrastructure capacity. There will always be some price sensitive passengers who are willing to shift their travel times to offpeak hours, freeing capacity in peak hours. The time-of-day choice demand model has shown that 3%-10% capacity can be gained by introducing peak pricing.

TfL practices a very limited form of peak pricing today, in which some pay-as-you-go fares (notably excluding fares into zone 1) are lower when travel occurs before 7 AM or after 7 PM. However, this form of peak pricing does not extend to travelcards or buspasses, TfL's current offer of zero marginal cost travel.

Zero marginal cost travel complicates the implementation of peak pricing. Once travelcards are purchased, they may be used for unlimited travel during their period of validity, irrespective of travel hour. Travelcards offer the cheapest way for frequent passengers to travel, because they set a maximum price that passengers might pay for transit during their period of validity. Passengers may even feel compelled to get the most value for their money, by using their travelcards to take trips they would not take if they even entailed paying a slight marginal cost. Travelcards create the perverse situation that the cheapest travel is available at peak hours, when congestion is worst, and the effects of peak pricing are most needed.

There are many reasons to believe that zero marginal cost travel is not needed to retain revenue and ridership numbers. Travelcards were introduced for several reasons: to simplify administration, to increase the ease of intermodal travel, to give passengers an easy way of budgeting their travel by giving a maximum charge for a given time period, and to give passengers a zero-marginal cost travel that is analogous to how passengers view automotive travel. Given the power of today's data management systems, travelcards no longer provide a significant source of administrative simplification. If passengers will be able to pay for all modes with mobile phones or smart bankcards, then intermodal travel will be simple without a zero marginal cost travel product. Most regular price-sensitive travelers are capable of budgeting their own travel without zero-marginal cost product like a travelcard: already with the current fare structure, for passengers in a given zone that travel only twice daily on the underground (do not use bus), then it about the same price to use prepay as purchase a travelcard. Given the high cost of gasoline, it is hard to believe that passengers view automotive travel as zero-marginal cost travel (automotive maintenance and distance-based depreciation only increase the marginal cost of automotive travel). Moreover, for most commuters in

London, auto is simply not an option due to the high price of parking, congestion charges, and automotive operating and maintenance costs.

There are several fare options that a transit agency can take when eliminating zero marginal cost travel. A transit agency can eliminate period passes entirely, offer period passes only for offpeak travel, or offer period passes for offpeak travel and premium-priced period passes that allow zero marginal cost travel for a much higher price. Alternatively, if a transit agency uses price caps, the agency can offer no price caps, price caps only in the offpeak, or price caps that are valid for peak travel only after a significantly greater threshold number of journeys is exceeded in a given period.

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