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Observed Customer Seating and Standing Behaviours and Seat Preferences Onboard Subway Cars in New York City

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ABSTRACT

Using an observational sampling methodology, this study explores seat occupancy patterns found in New York City subway cars under non-crowded conditions based on special attributes of otherwise highly homogenous plastic bench seats. Onboard seating patterns, measured as relative seat occupancy probabilities, are explained in terms of interactions between railcar design, layout, customer preferences, and resulting behaviours. Prior research has generally focused on passengers distribution between cars within long trains, or desirability of attributes common to all seats, rather than passengers seating patterns within a single car. Results, based on seating- and standing-room occupancy statistics, show customers have a clear preference for seats adjacent to doors, no real preference for seats adjacent to support stanchions, and disdain for bench spots between two other seats. On cars featuring transverse seating, customers prefer window seats, but have almost equal preference for backward- or forward-facing seats. No gender bias was detected amongst all seated passengers, but as load factor increased, men have higher probabilities of being standees compared to women. 90% seat utilization is only achieved at 120% load factor; furthermore, standing customers strongly prefer to crowd vestibule areas between doors (particularly in cars with symmetric door arrangements), and hold onto vertical poles. These findings are consistent with published anecdotes. Future cars should be designed with asymmetric doors, 2+2+2 partitioned longitudinal seats, and no stanchions or partitions near doorways. Further research should be conducted in commuter rail vehicles with suburban layouts, booth seating, and also other cities' subways, to further understand customer seating preferences.

BACKGROUND

Rapid transit systems around the world have differently designed rolling stock with different seating layouts. Within the U.S., most transit systems have commuter-style seating where majority of seats are transverse (that is, facing or back to direction of travel), with little longitudinal (i.e. sideways) seating available near access and egress points. This commuter-type seating is generally provided in newer systems where travel speeds are faster, stop spacing greater, and trip lengths longer, like metro systems in San Francisco, Atlanta, Miami, and the Port Authority Transit Co. (PATCO) Philadelphia–Lindenwold Speedline. Some older systems (e.g. Philadelphia) also feature this seating.

Chicago is in transition, with older 2200-series cars having almost entirely transverse seating, while its newest 5000-series cars (Figure 1(h)) mostly longitudinal. A vigorous debate in Washington (Figure 1(j)) about seating versus standee capacity culminated in a hybrid seating plan for their newest Kawasaki 7000-series cars. Boston Red Line's "South Shore cars" served Quincy on converted commuter rail alignments. With longer station spacing, cars initially had transverse seating, but as the system became more crowded, longitudinal seating was installed in 1985 *(1)*. Serious overcrowding resulted in one set having all but two of its seats removed in 2008 for standing-room-only peak-hour service *(2)*.

In contrast to the North American standard, and in common with virtually all metro systems in Asia and the former Soviet Union (e.g. Moscow in Figure 1(d)), most of New York City's rolling stock (including Port Authority Trans-Hudson (PATH) trains to New Jersey) offers only longitudinal seats. This was New York's practice for quite some time. In Washington's discussion, it was argued that standing capacity is more critical for providing adequate rush-hour service than seats, and transverse seats remove more standing room than sitting spaces they offer *(3)*. New York was cognizant of this effect when switching to hybrid seating in 1971:

> Usable standing space [...]: R-40, 304 sq. ft.; R-68, 309 sq. ft. R-68 only has 2% more usable standing space than R-40 even though it is 25% longer because it seats 59% more passengers. This increase in seating capacity is made at the expense of standing room *(4)*.

Seating does not exist in a vacuum. Within most transit cars, due to restrictive tunnel clearances, some equipment usually must be housed underneath seats, constraining layout. Older generation of New York railcars have door equipment and heaters hidden underneath bench seats. Boston's Kinkisharyo light rail cars have machinery housed under single transverse seats. Layout designs must also take safety, maintenance access, carbody structure, and passenger security into account.

However, even within railcars featuring entirely longitudinal bench seating, not all seats are created equal, and customers have distinct preferences. Standing spots within railcars can vary in popularity as well. Furthermore, on many systems like London, Tokyo, and New York, several different rolling stock types are used, each with its own unique seating layout. This paper measures quantitatively and illustrates how some seats and standing spots are preferred by more customers. We counted riders occupying different types of seats (and standing spots) in several railcars classes on New York City subways.

Obviously, relative popularity of seats is not the only variable considered by transit agencies in rolling stock design, nevertheless, understanding of customer preferences is an important input to design decision-making.

LITERANTURE REVIEW

Much research had been carried out in passenger responses to crowded conditions, customer preferences for railcar amenities, and safety impacts of seating hardware and plans.

Wardman and Whelan, in their review of over 20 years of research work, studied impacts of crowding within railcars on perceived values of time *(5)*. Most recent research measured passengers per square meter, providing more accurate measurements of discomforts of standing since, unlike load factor, it allows for carriage layouts and ease with which crowding is accommodated. However, their research focuses on fundamental questions of how much time passengers were willing to lose, and how much passengers were willing to pay to avoid crowding. It does not specifically focus on relationships between seating layout/railcar interior design and seat utilization, or address how seat layouts could be improved to discourage unproductive behaviors.

Pownall et al., in their study which utilized both stated and revealed preference methods *(6)*, examined strategies passengers uses to avoid crowding, including: travelling on slower but less crowded services; boarding where less crowded, but egress at the terminal is less convenient; travelling earlier or later; waiting for the next train; and arriving early in the afternoon to ensure they get a seat on the waiting train. While it addresses where passengers prefer to sit within a *train*, it does not address passenger distribution within a single *car*, and does not relate it to seating layouts.

New Jersey Transit (NJ Transit) conducted a study in 2003, prior to ordering new multi-level coaches, to understand customer interaction with railcar features *(7)*. The study informed multilevel car design so that they provide needed extra capacity but also reflect customers' preferences. It focused on interior issues, including seating configuration that relate directly to seated (and standee) capacity, and features like baggage racks and seat upholstery material. In separate efforts, NJ Transit convened a "customer design team" to provide feedback on seat design and legroom issues *(8)*. However, they did not address seat layouts in higher density subway duty cycles where average travel times are shorter, substantial standee room is provided, and station dwell times are an important consideration.

Washington Metro conducted extensive experiments on longitudinal versus transverse seating as crowding became an increasingly important issue on the successful system *(3)*. In 2005, certain Breda cars were modified in a pilot program to study passenger movements and improve seating arrangements for future railcars. Sixteen cars received new seating arrangements including modified handholds and seat positions, and longitudinal seating *(9)*. Washington Metropolitan Area Transit Authority (WMATA) researchers observed passenger movements in these cars (and "control" cars with original seating layout) using on-board cameras *(10)*. A hybrid seating plan resulted, which maintained original WMATA system's character, but provided more space near doors, and some longitudinal seats *(11)*.

Other work in designing railcar layouts were mostly from structural and safety points of view. Research was done to understand safety impacts of different seating layouts and develop standards *(12,14)*, but they generally do not address passenger behaviour. Some research has focused on ergonomics of seats themselves *(15)*, rather than how seats are laid out in limited available space in railcars.

Relating to passenger behaviour, there is a body of research examining pedestrian flows in railway environments *(16,17)*, but it tended to relate to train stations and dynamic passenger flow capacity—and not where passengers sit once they are onboard. Passenger seat-acquisition strategies and onboard dynamic is subject of recent discussions *(18,19)*, and could become an area of formal research.

Seating Layout in Commuter Cars

During design stages of Long Island Rail Road's (LIRR) double-decker fleet in 1989, airline-style seats in a three-by-two (3+2) configuration were tested in 10' width prototype C-1 cars *(20)*. Decision was eventually made in favour of 2+2 seating (Figure 1(c)). LIRR itself had actually pioneered the MP-70 bi-level electric multiple-unit (EMU) design in 1947 (Figure 1(a)), which utilized wasted space between passengers' heads and car ceiling with facing booths of 2+2 transverse seating setup in an unique zig-zag up-down pattern *(21)*; this layout was unanimously detested by passengers, operators, and maintainers alike.

Seating capacity, rather than passenger behavior, seemed to have been the driving factor behind seating layout design and research, as evidenced by continuing industry articles discussing how capacity of trains have been "optimized" by tweaking seating layouts *(22,23)*. Research concluded that 3+2 seating is universally unpopular *(24)*. Indeed, LIRR's single-level EMU fleets (10'6" width) use 3+2 seating, and passengers reportedly prefer to stand instead of sit in "middle" seats *(25)*. Passenger abhorrence and reluctant acceptance of 3+2 seating is well documented *(26)*. Some MBTA commuter rail and Metro-North 3+2 seating have a notched short seat (no headrest) in the aisle position, encouraging customers to occupy middle seats (Figure 1(f)).

Interestingly, Long Island's EMU and Boston's Kawasaki bilevels have fixed transverse seats oriented towards the car's center, creating a 'booth' mid-car; Metro-North's EMU and Boston's single-levels face 'outwards' to the doors (Figure 1(b)), resulting in back-to-back seats in the middle, whereas San Diego and Toronto's bilevels consist entirely of booth seating, similar to European designs. Boston specified hybrid seating with recent single-level purchases, installing five flip-down seats adjacent to each door, giving them a more urban feel.

In intercity sectors, interior space utilization was comprehensively researched, and several creative solutions were implemented. Sweden produced wide-body traincars *(27)* and proposed single-deck half-height sleepers *(28)*; Pullman's American roomette design orients beds parallel to travel direction, allowing midcar corridors and space-savings *(29)*; Japan's JR Hokkaido implemented carpet cars (Figure 1(e)), also called nobi-nobi "seats", best described as communal sleeping floor space (pillows provided) on specially-designed single-level cars divided into two bunks *(30)*—a holdover from that train's predecessor, the Seikan Ferry.

NJ Transit and WMATA conducted local and specific research to determine customer preferences when ordering new railcars, but that practice is far from universal and it is not clear that there is an accepted industry standard or norm. Train interiors were in recent industry discussions, with many operators departing from utilitarian designs of yesteryear *(31)*. As transit agencies continue to upgrade service for today's amenity-conscious customers, research is needed to understand driving factors behind customer seat preferences, and how layouts could be designed for maximum customer comfort and enjoyment within constraints imposed by engineering, functional, and capacity requirements.

SUBWAY CAR AND SEAT CLASSIFICATION IN NEW YORK CITY

New York's subway operates seven different types of rolling stock (known as "car classes"), some dating back to mid-1960s, others recently procured (Figure 2(a)). The system consists of two divisions: Interborough Rapid Transit (IRT) with smaller cars, and B-Division (amalgamated from Brooklyn-Manhattan Transit (BMT) and Independent Subway (IND) systems) with mainline railroad width cars *(32)*. A-Division cars all have longitudinal bench seats, but vary in door arrangements. Newer R-142 cars have asymmetric door arrangements (Figure 3(c)), i.e. doors on one side do not directly face doors on the other (technically, they have rotational rather than line symmetry.) B-Division stock is in two lengths. 60-footers have only longitudinal seats with varying door arrangements. Oldest car classes—R-32 "Budd" (Figure 3(d)) and R-42 "St. Louis"—are asymmetric, whereas newest R-143 "Kawasaki" (Figure 3(a)) and R-160 "Alskaw" are symmetric. 75-footers (R-46 and R-68) are only ones featuring some 2+2 (two on each side) transverse seating (Figure 3(b),(e)). These cars are completely symmetric, i.e. all doors and seats on one side are mirror images of the other.

Historically, seating layouts have not changed significantly for the past half-century. 60-foot cars (collectively known as 'Arnines') procured for then-new Independent Subway in the 1920s had seating layouts similar to current 75-foot cars (R-68), except areas adjacent to doors could only accommodate two longitudinal seats, not three. Since 1964, however, 60-foot cars have not sported transverse seats. Emergence of 75-footers in 1971 was a revolutionary rather than evolutionary step. Lau *(33)* noted that transit agencies rarely resort to radical changes in what customers are willing to accept or tolerate; instead, such changes come gradually. History of earliest 75-foot stock (R-44) is recounted in detail by Davis *(34)*. For forty years that followed, status quo remained unchanged: 75-footers come with miaxed transverse and longitudinal seats, while 60-footers have bench seats.

Acceptable crowding in New York's subway were determined with reference to standard pedestrian capacity literature *(35)* using level-of-service and floor-area-per-standee methods. Loading standards specify 3.0 sq. ft. of usable space (net of seats and 6" of knee room) per standing customer *(4)*, although theoretical maximum system capacity is about 2.36 sq. ft. per standee.

For this study, every subway car was divided into spaces, each representing either a seat or standing spot. For each car class, a data collection grid was laid out, with columns designated with letters, and rows designated with numbers. This is similar to seat designation on commercial airliners, except they only count seats, while this study counts standing spots also. Without physically marking test railcars, standing spot designation necessarily involves human judgment; other researches may select different criteria. Seats were divided into categories for easy differentiation (Figure 2(b)):

- **Door seat:** adjacent to door, has handrail separating sitting passengers from standees in door area. Excludes folding seats near operating cabs on New Technology cars.
- **Wall (or 'end-of-car') seat:** adjacent to bulkhead at the end of a car. Most wall seats are longitudinal, but R-68 has two transverse wall seats.
- **Mid-pole seat:** adjacent to pole in the middle of a bench.
- **Transverse seat:** perpendicular to direction of travel. Passengers in transverse seats face either forwards or backwards. Also divided into window and aisle seats.
- **Folding seat:** located near operating cabs on R-142, R-143, and Eastern Division R-160 cars. Not a door seat because they don't have handrails separating seated passenger from standees.
- **Legroom seat (75-footers only):** longitudinal seats adjacent to legroom of neighboring transverse seat. Features no handrail separating occupant from other customers' legs.
- **Middle seat:** longitudinal bench seat between two other seats. NYC subway does not have 3+2 seating, therefore no "middle" transverse seats.

Similar to seats, standing spots are categorized:

- **Door Area:** standing room adjacent to a door.
- **End-car Area:** standee space close to the end-car doors.
- **Middle Area:** standing room not near doors or bulkheads.
- **Pole:** could apply to any of above areas, a standing spot within proximity of a vertical support pole or post.

A single spot can belong in one or more categories. R-68's seat 41F is a transverse window seat, also a wall seat (Figure 2(d)). Location 17E on R-142 (B-car) is a door standing spot, also a pole spot, while adjacent 16E is a door spot but is not within proximity of any stanchions (Figure 2(e)). Most standing room has some form of holding device; spots without vertical poles nearby generally have overhead horizontal holding rails. Support posts are more convenient, therefore we designated it an extra feature.

Standing areas between longitudinal seats were divided into same number of standing spots as adjacent seats. R-62 offers eight seats between door areas, thus each middle column has capacity for eight standees. R-68 transverse seats have slightly different proportions; the car length occupied by 2+2 bidirectional benches (Figure 2(d), e.g. 33–35) can actually accommodate three standees, in spite of seats themselves only having room for two per column. First set of transverse seats from the right are marked as seats 8A–8F, while opposing seats are 10A–10F. Column 9 includes only standing spots adjacent to seat backs: 9C/9D.

In this study, doorways on most cars were considered to host two standees (except R-142 with wider doors hosting three standees, Figure 2(e), e.g. 25E–27E). While door width is sufficient to accommodate more than two standees, only two can stand longitudinally; third standee must stand with shoulders towards the door (i.e. facing or back to direction of travel), which is not preferred by most customers, perhaps because of perceived risk of falling over while braking or accelerating. Therefore, we designated door width on most railcars (except R-142) to have capacity for two standees. If more riders were observed here, both are assigned the same standing spot.

Unlike all other railcars, R-142's doorways are large enough to accommodate three longitudinal standees. These cars were specifically designed for the Lexington Avenue subway—the busiest in North America. Larger doors were designed to reduce dwell time in stations, and were an improvement over older designs. Also, non-cabbed R-142 "B-cars" have asymmetric door arrangements—doors on two sides are not directly opposite each other (Figure 3(c)).

Based on classification of seats and standing spots, availabilities are calculated (Figure 2(a)). These capacities are slightly different from MTA loading guidelines used for capacity planning derived from average floor space occupancies per passenger method *(4)*. They also differ from builders' theoretical design maximum specifications *(32)*. This study examines desirability of space relative to each other, rather than absolute space occupancies, therefore these small variations are of no consequence.

DATA COLLECTION METHODOLOGY

This study collected seating data on subway trains in-service, using one form for each railcar. Each customer's seated or standing position is recorded, along with their observable demographics. Data was collected on over sixty vehicles (assorted car classes) from February 21 through March 13, 2012. Each form is a snapshot of one subway car operating between two adjacent stations. While the ideal goal was to keep each sample to a ride between adjacent revenue stops (local or express), multi-stop samples were allowed if data collection took longer than inter-stop running times, although attempts were made to avoid such situations.

Customers were recorded as letters indicating gender and age group on railcar plan drawings depicting seats and installed hardware. Children were someone of elementary school age, and obviously travelling with adults. This is not consistent with Automated Fare Collection (AFC) system's definition of fare-exempt children—anyone under 44" in height travelling with fare-paying adults *(36)*. However, this study observed passengers whilst seated, making it impossible to accurately judge customers' heights. Atypical items, like luggage or baby strollers, were marked in an intelligible way.

Data collection was spread throughout the day, but excessive rush-period crowding was avoided. Riders in overcrowded cars have virtually no choice in seating (or even standing spots). Since the study is about preference, it only makes sense to conduct it where choice is available.

Although patterns of standees versus seated customers in overcrowded cars could yield interesting data about passenger densities when seats (due to blockade by other standees) become less desirable than standing room, data collection in very crowded railcars is difficult if not impossible. Data collectors must make their way through the car from one end to the other, to observe space occupancy patterns, which could cause unnecessary inconvenience to customers. Furthermore, data collection action could alter results as collectors try to make their way through cars. To collect this data, railcar-mounted cameras are required.

Winter of 2011-12 was considered mild—with few freezing days and only one snowfall, so weather was not expected to produce atypical seating patterns. Weather may impact seating patterns in two ways: (a) in hot weather, customers may prefer to sit near middle of railcars, close to air conditioning vents; in cold weather, customer may prefer to sit further away from doors; (b) in severe weather, customers might wait for trains in mezzanine areas at elevated stations, to minimize walking along platforms, increasing crowding in cars stopping next to stairways and decreasing crowding in other areas. Over time, data can be collected in varied weather conditions, to investigate this aspect of customer behavior.

SEATING PREFERENCES BY SEAT ATTRIBUTES

One way to visualize seating preferences is to plot probability of given type of seat being occupied in one car, against probability of any seat being occupied. Probability or fraction of seats occupied is total passengers occupying that seat-type divided by total seats (of that type) available in that car. Probability of any seat being occupied is in fact just seated load factor (seat utilization ratio), seated load divided by seating capacity.

In railcars with truly homogenous seats, only one seat type exists and occupied seats fraction is the seated load factor. However, total seat homogeneity is neither achievable nor necessarily desirable, due to locations of necessary hardware like doors, windows, heaters, and air conditioning equipment. As soon as customers perceive some seats as better than others, these seats will likely be occupied first.

This *probability snapshot* of seats occupied between any en-route station pairs is valid for assessing seat preferences because it captures results of complex customer behavioral dynamics in play onboard any train in-service:

- Boarding customers are more likely to choose seat-types most desirable to them personally, subject to constraints of seats already occupied;
- Most desirable seat-types could be a function of crowding levels, relative location where the passenger entered the car, customer's intended length of ride, other passengers and their observable behavior, and desired exit locations at customer's destination station (a smartphone application *(37)* exists that provides passengers with station exit information);
- Customers do change seats as seats become available due to passengers disembarking, but seat change maneuvers incur utility costs (movement effort, and risk of desired seat becoming occupied mid-maneuver); to find desirable seats often requires customers to relinquish their current less-desirable seats in advance of busy stops, and position themselves strategically close to where seat-turnover seem likely.

Rather than trying to model this complex behavior, probability snapshots examine seat choices between station stops, after dynamic phases of seat choice has played out and passengers are settled in their seats in equilibrium—at least until just before next stop's arrival. We cannot fully explain seating preference, only can describe it.

Results show in all car classes, New York customers overwhelmingly prefer door seats to middle seats, but show no specific preference for other seat types (Figure 4(a)). In 75-foot R-68 cars featuring both transverse and longitudinal seating, customers have no real specific preference for longitudinal over transverse seating (Figure 4(e)); the <8% difference shown in lines-of-best-fit is likely not significant, in any case it's a weak effect. However, passengers overwhelmingly prefer transverse window seats to transverse aisle seats (Figure 4(b)). This finding is perhaps perplexing as subways travel mainly underground and there may not be much to see, but part of this data is collected on trains travelling over Manhattan Bridge and on West End Line's elevated portion in Brooklyn—thus passengers may be anticipating views later on in their journey. However, a weak (likely not significant) effect seem to be observed at seated load factors of over 80% where curves reverse—customers seem to prefer aisle seats when car is crowded, probably due to ease of access, preferring not to be "boxed in" at window seats. This question should be settled by further research; this paper did not collect sufficient R-68 data for a definitive conclusion.

Data is fairly scattered regarding whether customers prefer backward-facing or forward-facing transverse seats (Figure 4(c)). This could be due to low sample—each car offers only 26 transverse seats and R-68 dataset is only 14 cars—but this same low sample showed an overwhelming effect in window-versus-aisle (Figure 4(b)). Lines of best fit suggests ridership effects—forward facing seats are marginally preferred at seated load factors <70%, above which seat-availability constraints come into play as customers gravitate towards nearest available seat regardless of direction. Alternatively, perhaps preference for window seats is so strong that it overrides travel direction. Since subways travel relatively slowly, the gentle backwards-motion may not be nausea-inducing, perhaps customers don't mind it too much. Future data collection could be focused on R-68 cars, to settle these research questions.

Anecdotal off-peak observations on Boston and New Jersey commuter rail systems suggest passengers there overwhelmingly prefer forward-facing seats; some railcars are equipped with "flippable" seats that crews must rotate at the terminus (Figure 1(g)). Whether this is a difference between urban and suburban passengers would be an interesting research question, or perhaps higher commuter train speeds may make backwards-motion more nauseating. Competitive behaviors driven by load factors of >70% is telling—typical off-peak commuter rail riders rarely encounter such high loads. During peak periods, disdain for middle-seats seem to trump a weak forward-facing preference, consistent with this study's findings.

New Technology cars have longitudinal bench seats, but have poles mid-bench dividing each bench into either 3+3 (R-143, R-160) or 3+4 (R-142) seating. Conversely, older cars (R-32, R-42, R-62) have bench seating without poles therefore seats are functionally 6- to 8-abreast. Figure 4(d) shows that when given choices, customers first flock to seats with adjacent partitions (i.e. door or wall seats); when partitioned seats are less available, customers will settle for pole seats—not truly partitioned but offers some degree of discrete separation between neighboring passengers. The dreaded middle seats are least preferred. This tends to suggest dividing bench seats into several compartments using devices simple as stanchions provides desirable railcar design. Indeed, on Boston Red Line's 01800-series cars, longitudinal seating accommodating seven passengers between doors are divided into 2+3+2 with two poles; on London's District Line C69-stock, cushioned longitudinal seats are split into 2+2 groups with an armrest.

CUSTOMER DEMOGRAPHICS AND STANDEES

To investigate relationships between loads and seating patterns, data was separated into three categories by overall seat occupancy: below 40% (light loading), between 40% and 80% (medium), and above 80% (heavy). Figure 5(a) shows collected data on customer demographics as fractions of all passengers (seated or standing), including other "customers" like bulk items, strollers, bags, and passengers' body parts (e.g. leg) occupying more than one seat. Age is often difficult to determine by observation, thus the study didn't differentiate between ages of adults; 20-year-old passengers fall into the same category as 70-year-old passengers.

Prior fare collection study *(38)* indicated 0.8% of customers entered New York's subways with bulk items that wouldn't fit through turnstiles, comparable to this study's 1.9% (Figure 5(a)). The 1.1% discrepancy perhaps indicates some bulk items or customers physically occupy more than one seat. In any case, capacity consumed is <2% and tends to be less problematic when loads are heavy (1.3% when seat utilization >80%), suggesting bulk items, inconsiderate, or oversized customers are not major capacity consumers in New York. That same study found 1.0% of passengers are children travelling with adults (both under and over 44") who did not pay a fare, comparable to this study's 1.7%. This suggests about half of all children travelling with adults are properly paying a fare.

Ratio between men and women riding subways is roughly half and half (Figure 5(a), both 48%). As seated load factors increase, both men and women are more likely to be standees, but the fall-off in being able to sit is quicker for men than women. However, children are almost always able to find seats, even under heavy loads. Children also account for larger ridership fraction when loads are high, likely due to school commuting hours coinciding with generally higher traffic loads. Figure 5(b) shows as load factors (including standees) grow, standees to seated passengers ratios grew much quicker for men than women, probably because New York's gentlemen do live up to cultural expectations regarding giving up seats to ladies and children. Interestingly, though, women seem a little more likely to stand at low load factors—further research would be needed to understand whether the effect is significant, and the probable reasons.

Figure 5(a) indicates fewer women are riding in near-empty cars (51% versus 45%). This could be time-of-day effects; perhaps fewer women travel when subway loads are light—or it could be women actively choosing to avoid lightly patronized cars, preferring middle cars close to the train conductor, due to personal security concerns. Both interpretations are consistent with common travel advice:

> Don't choose an empty car. Pick one with other people in it, preferably a mixed group of men and women. The same goes for the platform. Wait alongside others, exit with a crowd and don't get stranded on your own. When taking the subway late at night, stand in the Off-Hours Waiting Area or close to the station booth. Some areas can be dangerous […] at night, so ask for advice or don't travel alone after 11 p.m. *(39)*

Even in cars with <40% seat occupancy, standees constitute 2% of all passengers. Some people seem to prefer standing over sitting—perhaps they have reasons to stand, e.g. travelling only few short stops and wish to exit quickly, or needing to stabilize bulk items to prevent their rolling or falling over.

STANDING PREFERENCES AND "SPOT" ATTRIBUTES

In all car types, New Yorkers overwhelmingly prefer sitting to standing (Figure 5(c)), although at loads over 70% standing room is already being consumed in a significant way. More interesting is that seating utilization above 90% required load factors of 120% to achieve, and even then seats were still left vacant. This might be due to inaccessibility of certain seats from passenger congestion, or ridership patterns on lines with short-haul passengers (one or two stops) resulting in customers finding it "not worth it" to sit down.

Figure 5(e) shows standing customers are overwhelmingly attracted to vertical stanchions (poles), rather than other support structures. Holding on to overhead leather straps ("Straphangers"), ball-and-spring devices (London's retired 1938/1959 Northern Line Metro-Cammell stock), metal loop grabholds (Orion buses), or a horizontal bar (R-160) can be uncomfortable; on very crowded trains, sometimes the entire length of vertical pole (at arm level) is taken up by multiple hands, leading to development of branching grabpoles (also called split poles), installed on Singapore's Kawasaki C151 cars and being tested on the Queens Boulevard Line *(40)*.

When standing spots are further classified, Figure 5(d) shows passengers overwhelmingly prefer standing near doors, eschewing both end-car and mid-car spots. Besides having multiple poles, "doorway zone" has other desirable features that attract standees: ease of ingress and egress, partitions to lean against, and avoidance of sometimes-uncomfortable feeling of accidentally making eye contact with seated passengers. This could cause dwell time problems—Puong *(41)* found that on MBTA's Red Line, interference between boarding/alighting passengers and through-standees in doorways significantly contributes to dwell time. It could also cause loading issues with door standees blocking boarding passengers from entering, an occurrence widely considered routine based on anecdotal observations.

Figure 5(f) shows when cars are further subdivided into those having symmetrical and asymmetrical door arrangements, "door" standing spaces are occupied more quickly on symmetrical cars than asymmetrical ones. Although this may seem an artifact in the data, due to larger floor areas potentially considered "door" standing space in asymmetrical cars, Figure 3(e) actually shows same floor area in R-142 A-car (symmetrical) and B-car (asymmetrical). Symmetrical door arrangements may encourage standees to crowd door areas, exacerbating loading problems. Visually, asymmetrical arrangements make car interiors look a little more open, and perhaps more inviting—hence luring passengers away from doors with potential dwell time, loading, and capacity utilization benefits.

At busy stops, door standees may actually be preparing to disembark; luring them away could counterproductively lengthen dwell time. Further research could determine ratios of through versus disembarking door standees, whether dwell time changes (net positive or negative) is balanced by capacity utilization benefits.

CONCLUSIONS

New York customers have a clear preference for seats adjacent to doors, no real preference for seats adjacent to stanchions, and disdain for bench spots between two other seats. Standing customers strongly prefer to crowd the space between doors (particularly in cars with symmetric door arrangements), and to hold onto vertical poles. On R-68 cars featuring transverse seating, customers may prefer window seats, but have almost equal preference for backward- or forward-facing seats, although insufficient data was collected to reach a definitive conclusion.

Considering car interior layout from space utilization perspectives, this study's results suggest future car builders can maximize capacity by:

- Avoiding symmetrical door layouts;
- Installing stanchions only where they would not block passenger circulation;
- Where safe to do so, avoid installing poles or partitions in seats adjacent to doors; instead, install them in the middle of bench seats.

It is hereby specifically noted that this study is based on observed behavior of New York passengers, and drawing logical inferences based on such behavior. However, this observational study is not based on intervention experiments—while we have tested hypotheses about how customers do choose seats within existing car layouts, and drew inferences about how passengers *might* choose seats in proposed layouts; no proposed layouts were actually constructed and put in revenue service to gauge customer reactions. Inferences and design recommendations therefore are hypothetical.

The findings and recommendations of this study should be validated by a prototype or pilot test—an important step in any rolling stock procurement or car retrofits with layout modification. Indeed, various agencies have run pilot programs with respect to new car layouts or existing layout modifications in recent years: Boston's "Big Red" *(2)*, New Jersey Transit's Multilevels *(7)*, Washington's "America's Metro" car *(10)*, Long Island Railroad's Bi-levels *(20)*, New York's "Seatless Car" *(40)*, Singapore Mass Rapid Transit's C751B *(42)*.

Car Design Discussion

Car design is a complex endeavor. Space allocation concerns and customer preferences must interface with very real-world constraints of safety, comfort, seating capacity requirements, car body structure, equipment maintainability, and system security. When these issues added to the mix, car builders must wrestle with some multifaceted considerations:

- Where possible, designers should avoid creating “middle seats”; riders dislike them and they will rarely get used—many will stand rather than sit in middle seats. Partitions, poles, handrails, or even subtle visual cues like contoured seats or small gaps can segregate otherwise long benches, although physical barriers might be most effective.
- Mid-bench partitions, in addition to crowd-attraction benefits, may also discourage patrons from lying down.
- Vertical poles and branching poles can be used to entice standees to stand in areas that do not cause traffic congestion; for areas that become busy under heavy loading conditions, overhead supports should be used, to discourage users from standing there but nonetheless provide anchor points when needed.
- Where seating capacity requirements permits a choice of seat locations within the car, designer should avoid installing seats adjacent to doors.
- Longitudinal seating maximizes total combined seated and standing capacity, but 1+1 transverse seating provides customer-preferred window seats. Although unusual, it is found on MBTA’s Green Line cars, and urban versions of MBTA’s mid-1990s RTS buses.
- 2+2 or 2+1 transverse seating should be avoided in urban environments because aisle seats may create blocking problems for both window seats and standees wishing to utilize the space. 2+2 seats could also impede within-car circulation, contributing to door area crowding.

Figure 6 shows how hypothetical replacement subway cars might be redesigned to maximize space utilization. This conceptual redesign requires moving doors, and therefore is not feasible for retro-fit projects, but when ordering new or additional cars for capacity expansion, layouts similar to Figure 6(b) could be considered instead of Figure 6(a)’s more traditional layout. Alternatively, Figure 6(c) shows an example configuration with distinct seating zones: 2+2 airline seats at both ends, and standing room only mid-car. Figure 6(d) shows similar layouts in-service in London.

Open Research Questions

Future research, aside from building and testing prototype car layouts and operating them in service to observe actual customer reactions, could take a number of directions:

- Further observational research should be conducted in railcars with commuter-style layouts, booth seating, and in other cities, to further understand customer seating preferences.
    - What drives customer seat choices within railcars?
    - In commuter rail cars, what is a good ratio of airline-style versus booth seating?
    - Similarly, in subway cars, how does the ratio of transverse and longitudinal seats relate to duty cycles variables such as ridership, crowding, station spacing?
    - In cars with fixed forward-and-backward facing seats, should seats generally face towards door-and-vestibule areas, or away from them?
- What are trade-offs, constraints, and freedom in design choices in interior layout plans?

- What functional variables must be considered when specifying railcar interior layouts? Should standard guidelines for railcar seating design be produced?
    - Should seating be as homogenous as practicable, or could various seating options be provided within the same train or even a single car, allowing regular customers to gravitate towards layouts they prefer?
- Stated preference surveys could be conducted, to determine customer perceptions of how they *think they would* behave, rather than how they *actually* behave. Also, customer could be given renderings of the proposed layouts and asked to rate whether they liked it or rank them relatively.
- What other accessories (and their locations) should be considered when designing layouts?
    - Individual items of hardware (e.g. branching poles, mid-bench partitions, tables, fold-down seats) could be developed and tested in cars with existing layouts, to determine if they have expected effects.
- Specific issues within subway cars requires further study, via prototype testing or pedestrian simulations:
    - Finding good locations for central vertical poles may be quite difficult: when installed between doors, standees attracted to poles impede access and egress; in narrow-body cars (e.g. R-62), standees impede front-back circulation when poles are placed between bench seats. Research will determine optimal pole locations.
    - Hardware (including seats) immediately adjacent to doors might be detrimental to station dwell times, impeding smooth flow of passengers entering and exiting trains. Research can recommend optimal seat placements at given capacity requirements.

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LIST OF TABLES AND FIGURES

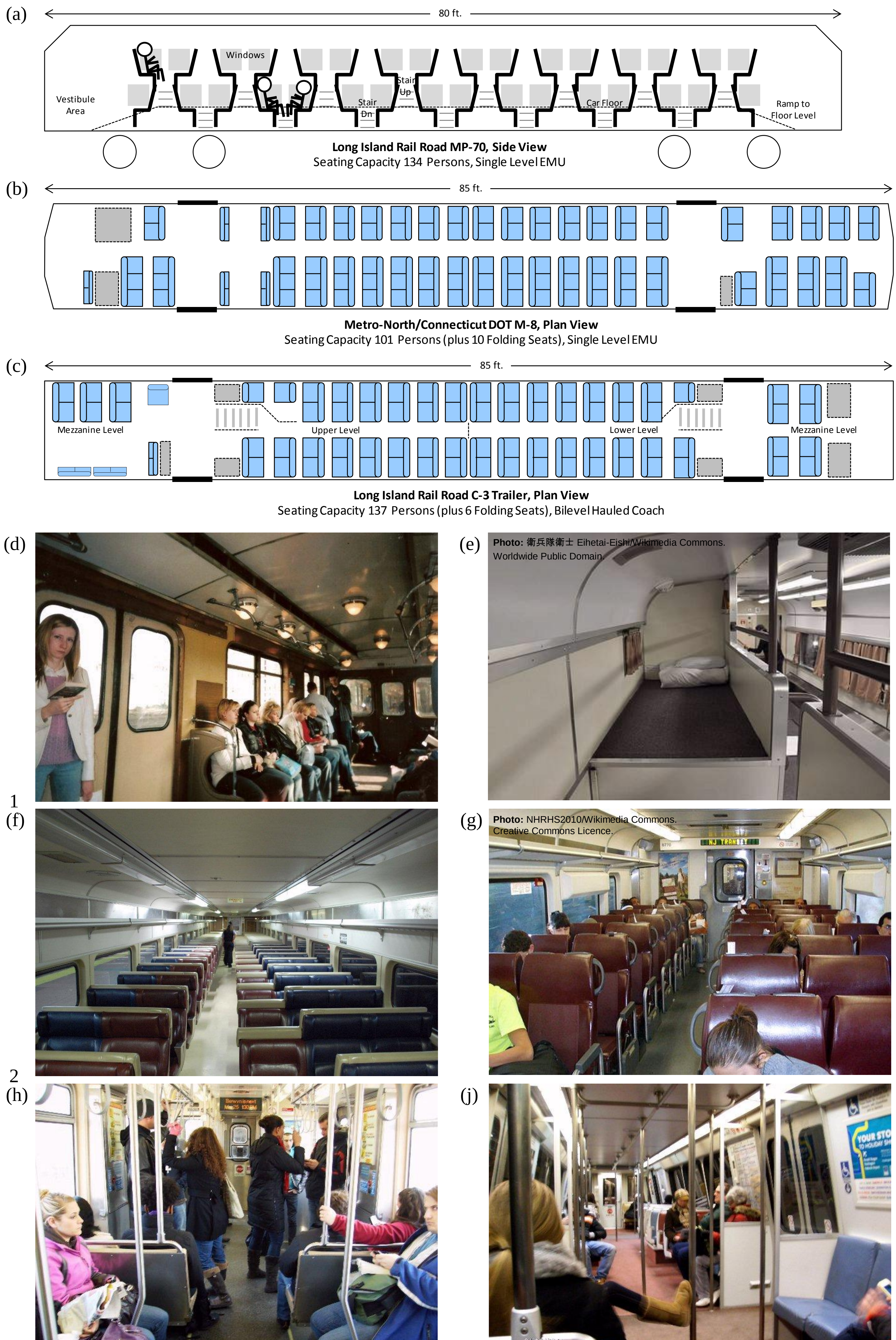
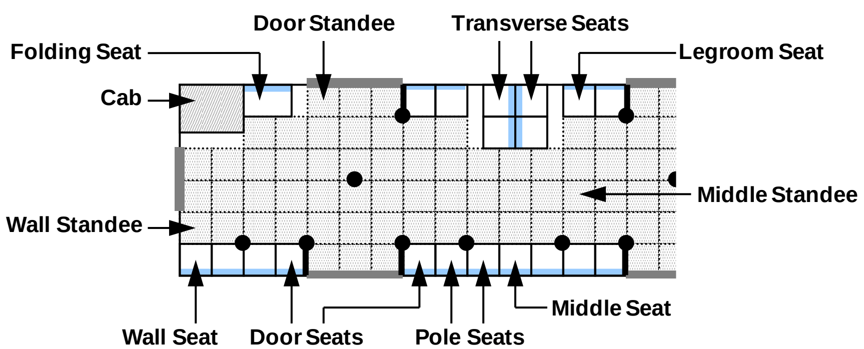


Figure 1 Seating Plans and Layouts: (a) Long Island's pioneering MP-70 bi-level EMU with unique zig-zag vertical arrangement; (b) Metro-North's M-8 is a representative design in New York; (c) Long Island's C-3 is designed for longer-haul service; (d) Moscow's (and other Soviet) subways standardized on longitudinal seats; (e) Unusual nobi-nobi "carpet car" bilevel communal sleeping space on JR Hokkiado's Hamanasu night train; (f) Metro-North's coaches have a "notched" aisle seat, encouraging patrons to first occupy middle seats; (g) NJ Transit's Comet cars feature "flippable" seating, which traincrews must manually rotate at terminus; (h) Chicago's 5000-series has limited transverse seating; (j) Washington Metro traditionally had commuter-style seats.

(a)

Car Identification				Dimensions and Configuration				*Seated Capacity*									*Standee Capacity*									
								Total Seats		*Longitudinal*					*Trans-verse*		**Total Standee Capacity**				*With Support Post or Pole*			*Without Adjacent Pole*		
Division	Car Class	Builder	In Svc. Yr.	Width (ft)	Length (ft)	Door Sym.	Seating	**Builder Spec.**	**This Study**	Pole	Middle	Door	Wall	Legroom	Window	Aisle	**Builder Spec.**	**MTA Guideline**	**MTA Crush**	**This Study**	Door	End	Middle	Door	End	Middle
IRT (A)	*R-62**	B,K	'83	9	51	L	B	**44**	**44**	0	28	12	4	0	0	0	**—**	**66**	**121**	**102**	12	0	48	0	6	36
IRT (A)	*R-142 (A)*	B,K	'00	9	51	L	U	**34**	**32**	8	12	10	2	0	0	0	**148**	**71**	**129**	**96**	18	3	45	0	3	27
IRT (A)	*R-142 (B)*	B,K	'00	9	51	R	U	**40**	**40**	8	16	12	4	0	0	0	**142**	**74**	**135**	**105**	18	0	44	0	6	37
IND (B2)	*R-32*	Budd	'64	10	60	R	U	**50**	**50**	0	30	16	4	0	0	0	**—**	**95**	**180**	**152**	0	0	32	16	6	98
BMT (B1)	*R-68*	St. L	'86	10	75	L	M	**70**	**72**	0	12	16	5	13	13	13	**—**	**105**	**205**	**158**	16	0	56	0	6	80
IND (B2)	*R-143 (A)*	K	'01	10	60	L	U	**42**	**40**	12	12	14	2	0	0	0	**198**	**102**	**187**	**132**	16	4	60	0	4	48
IND (B2)	*R-160 (A)*	A,K	'05	10	60	L	U	**42**	**40**	12	12	14	2	0	0	0	**198**	**104**	**189**	**134**	16	6	60	0	4	48
IND (B2)	*R-160 (B)*	A,K	'05	10	60	L	U	**44**	**44**	12	12	16	4	0	0	0	**202**	**102**	**187**	**136**	16	0	60	0	8	52

(b)



Builder Codes: **A** = *Alstom*, **B** = *Bombardier*, **K** = *Kawasaki*, **St. L** = *St. Louis Car Company*.

Door Symmetry Codes: **L** = *Line Symmetry* (Colloquially, "Symmetrical"); **R** = *Rotational Symmetry* ("Asymmetrical").

Seating Codes: **U** = *Unbucketed Bench*; **B** = *Bucketed (Lumbar Contour) Bench*; **M** = Mixed: *Bucketed Bench* and *2+2* Seating.

(c) (d) (e)

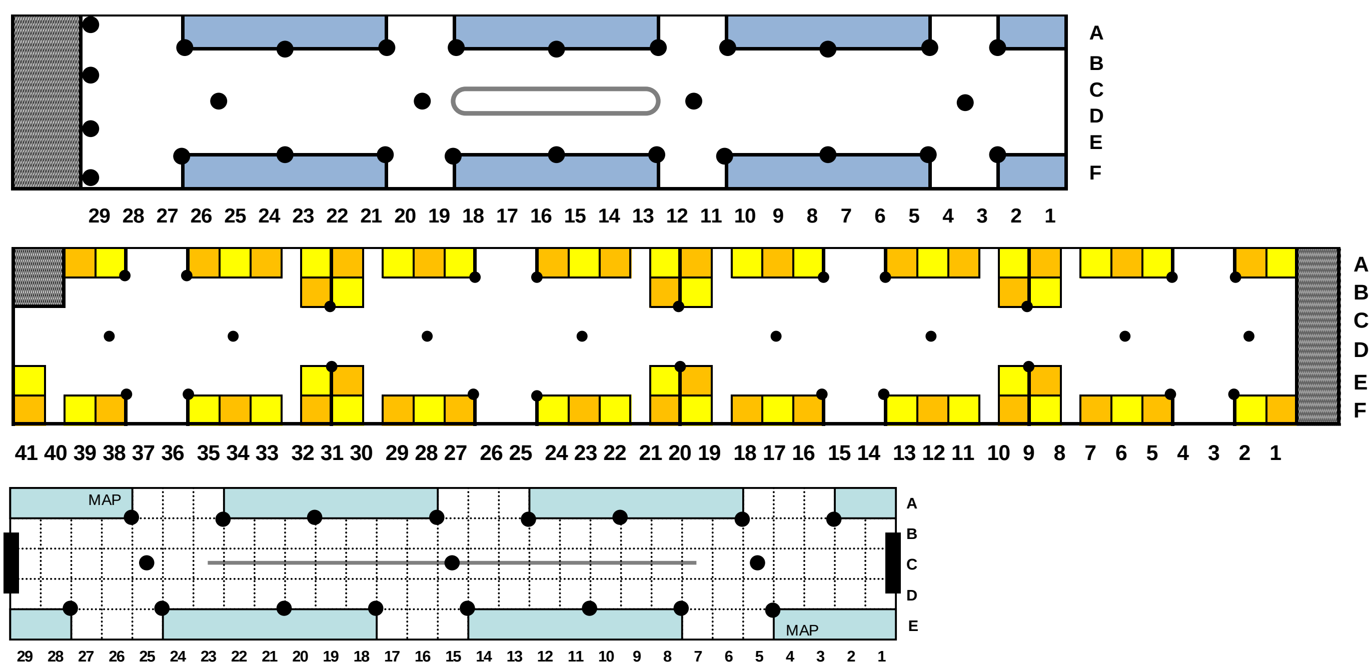


Figure 2 Seating Plans and Passenger Capacities for New York City Subway cars: (a) Basic data and seating capacity assumptions for various car classes based on this study's classification criteria; (b) Different types of seating in a hypothetical car, classified based on study criteria; (c) R-160 New Technology Car, newest car on the system (cabbed "A-car" version); (d) R-68, an extended-length 75-foot car; (e) R-142 New Technology Car, non-cabbed B-car version.

Figure 3 Typical New York City Subway Car Interior Layouts: (a) R-143's longitudinal seating; (b) R-68 (75') stock features both transverse and longitudinal seating; (c) non-cabbed R-142 cars feature asymmetric doors; (d) R-32 fleet—oldest still in service—is also asymmetric; (e) passengers sitting longitudinally in transverse seats in an R-46; (f) R-62 has symmetrical doors and bucketed bench seats.

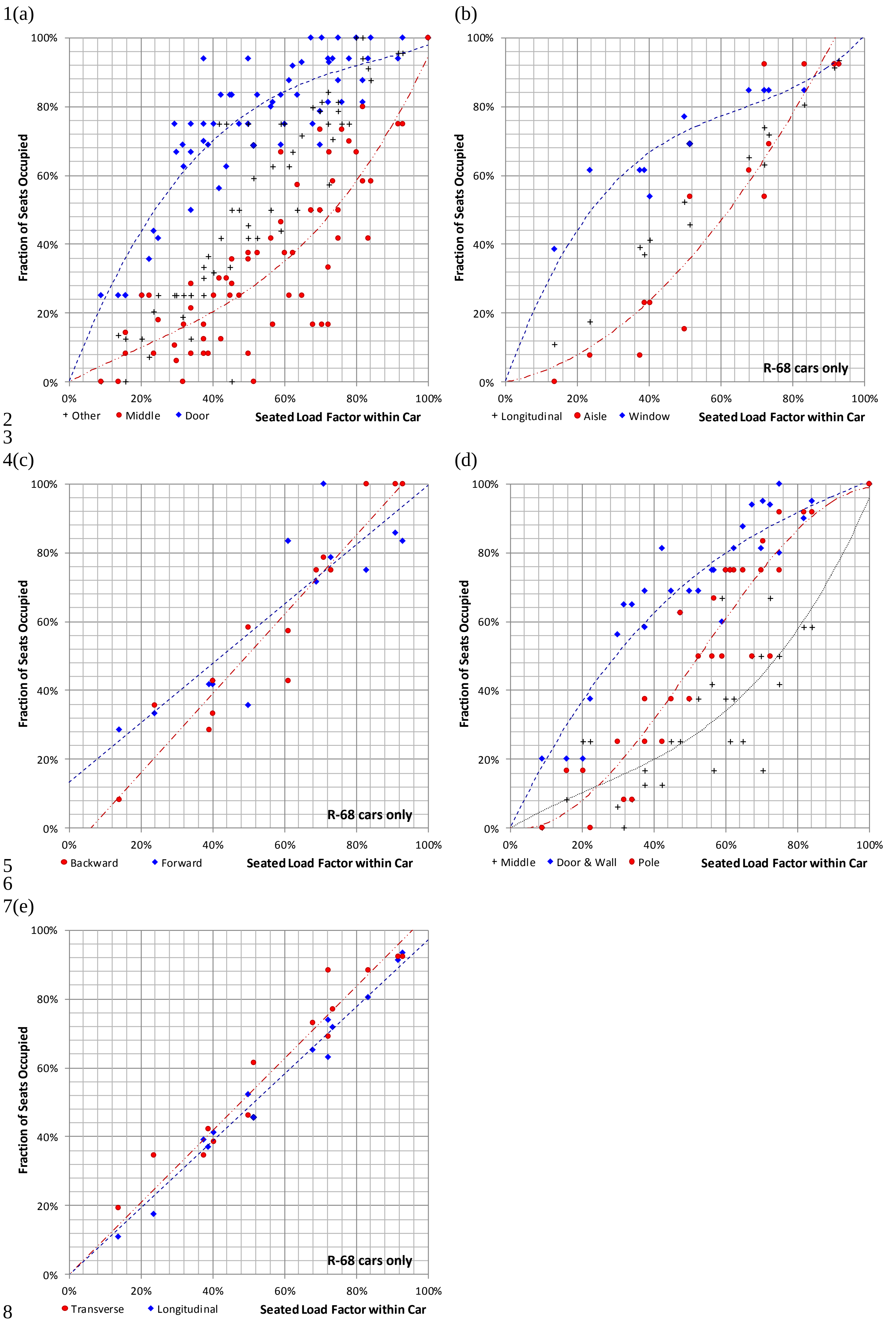
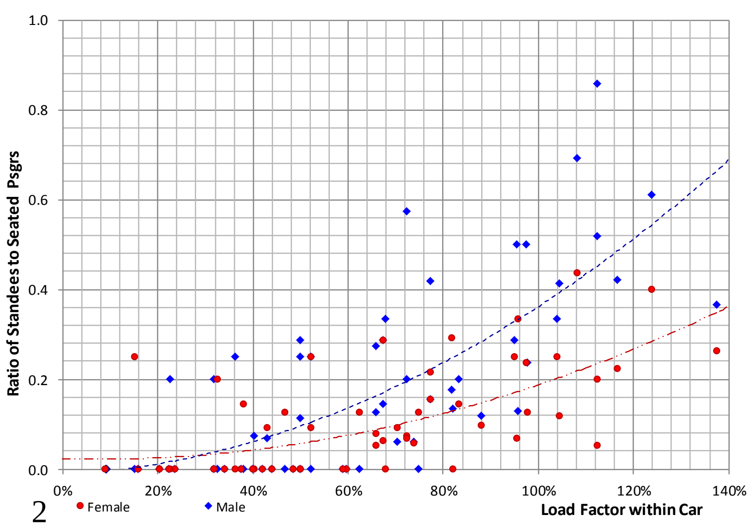


Figure 4 Probability Snapshot of Customer Seating Preferences in Subway Cars in service on the New York City subway system: (a) Middle versus Door Seats in all car classes; (b) Window versus Aisle seats in R-68 cars; (c) Backward versus Forward facing transverse seats in R-68 cars; (d) Door & Wall, Pole, and Middle seats in R-142, R-143, and R-160 New Technology cars; (e) Transverse versus Longitudinal Seats in R-68 cars.

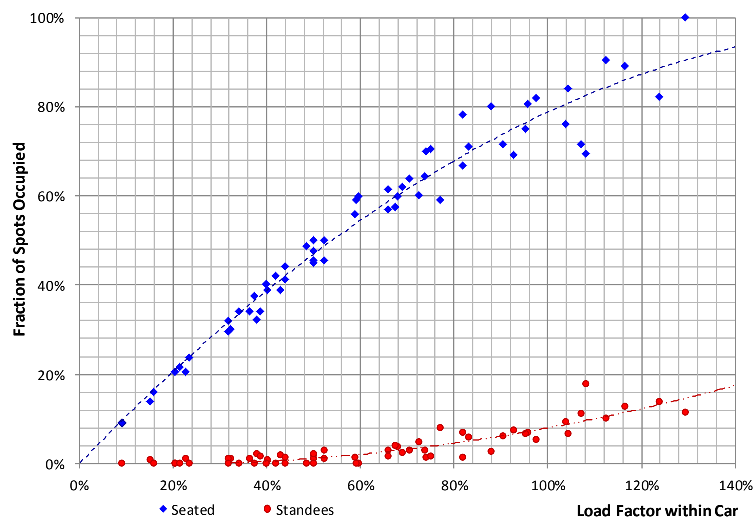
(a)

	Seated Load Factor	Percentage of All Passengers				Total
		Men	Women	Children	Other	
All Passengers	<40% (Light)	51%	45%	1.0%	3.5%	100%
	40%~80% (Medium)	47%	49%	1.6%	1.9%	100%
	>=80% (Heavy)	48%	48%	2.1%	1.3%	100%
	Overall	**48%**	**48%**	**1.7%**	**1.9%**	**100%**
of which: Seated	<40% (Light)	50%	45%	1.0%	2.5%	98%
	40%~80% (Medium)	39%	44%	1.5%	1.6%	87%
	>=80% (Heavy)	36%	41%	2.1%	0.4%	79%
	Overall	**39%**	**44%**	**1.6%**	**1.4%**	**86%**
of which: Standing	<40% (Light)	1%	0%	0.0%	1.0%	2%
	40%~80% (Medium)	8%	5%	0.2%	0.3%	13%
	>=80% (Heavy)	12%	8%	0.0%	0.8%	21%
	Overall	**8%**	**5%**	**0.1%**	**0.5%**	**14%**
	Total Observations	*920*	*930*	*32*	*37*	*1,919*

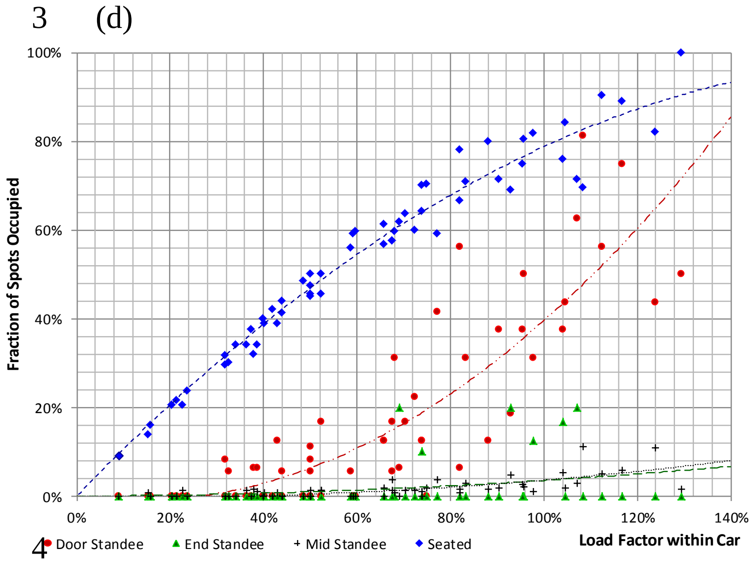
(b)



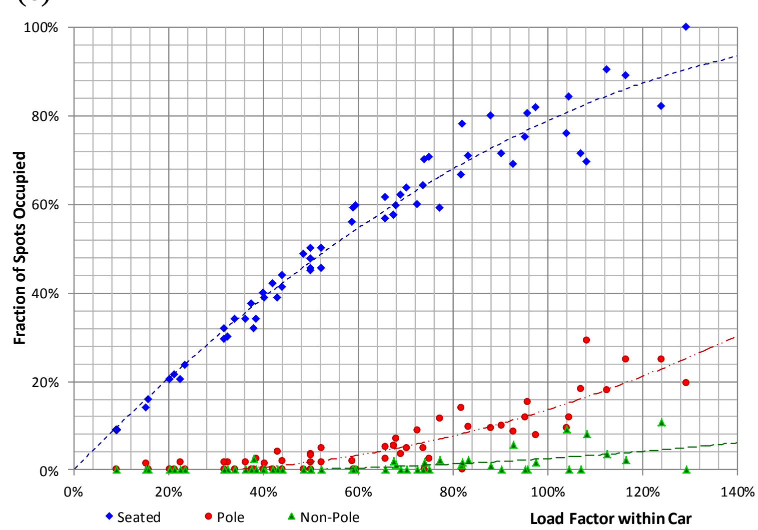
(c)



(d)



(e)



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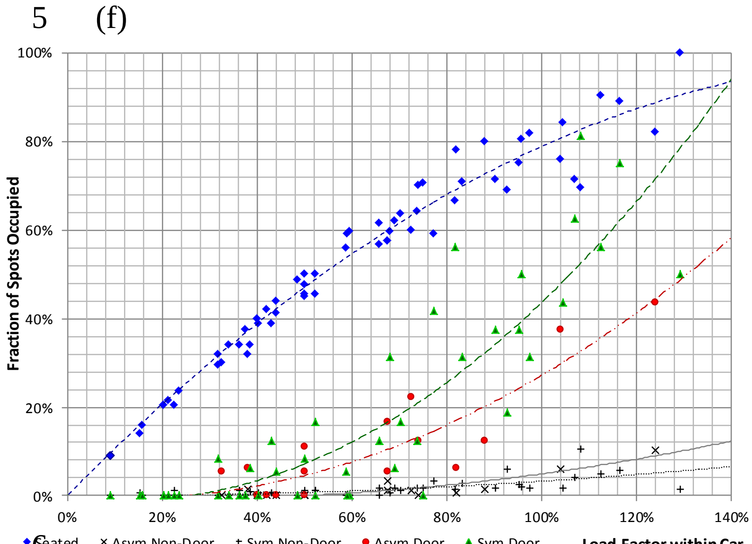

Figure 5 Probability Snapshot of Standee Demographics and Preferences in Subway Cars in service on the New York City subway system: (a) Demographics of Standees Under Different Loading Conditions; (b) Ratio of Male and Female Standing Passengers; (c) Capacity Consumption by Seated versus Standing Passengers; (d) Seated Customers versus Door, Car-End, and Mid-Car Standees; (e) Seated Customers versus Pole and Non-Pole Standees; (f) Seated Passengers versus Door and Non-Door Standees on Cars with Asymmetrical or Symmetrical Door Arrangements.

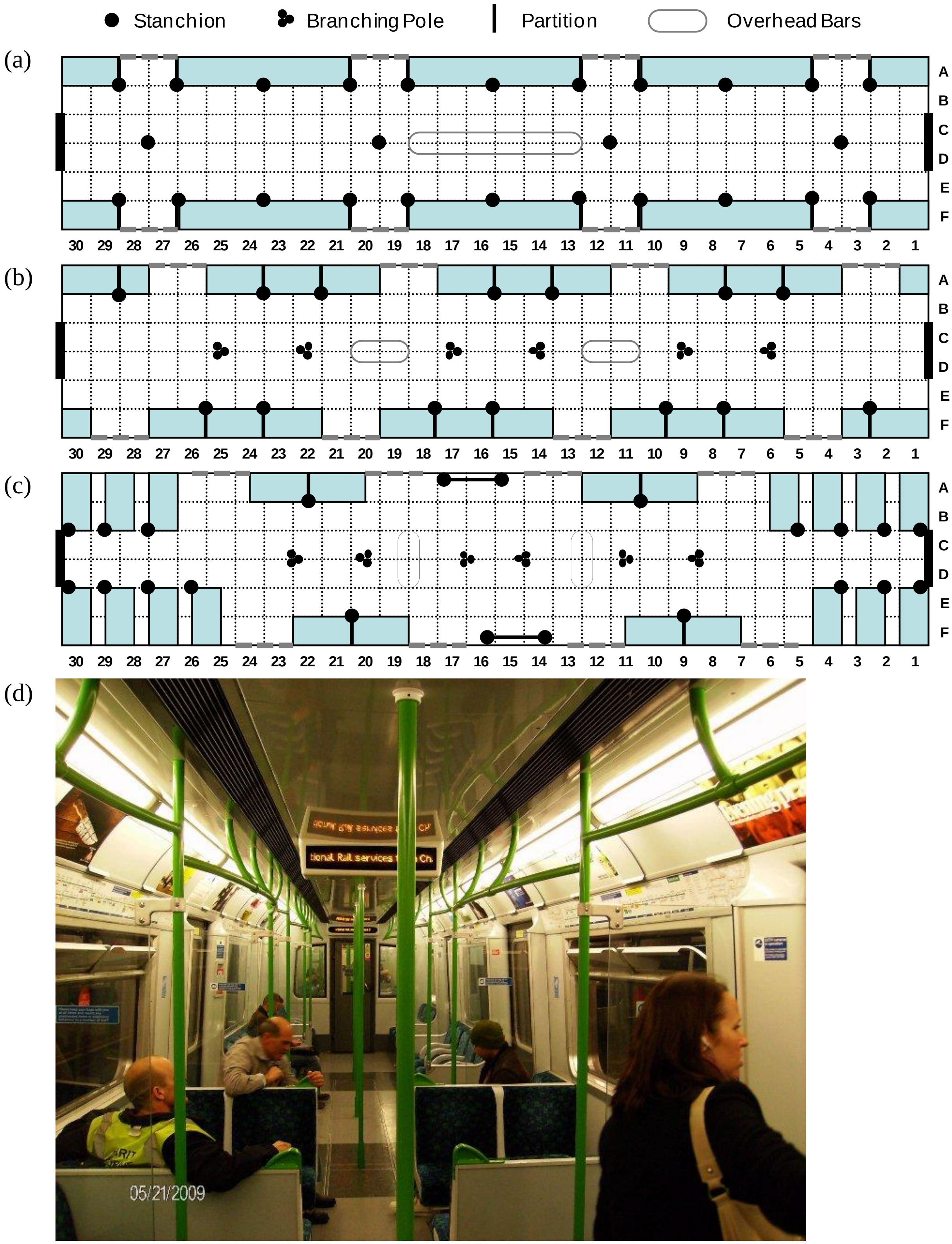

Figure 6 Three Hypothetical Fourty-Four Seater Subway Car Layouts: (a) This traditional layout might cause crowding around the door areas and contains 12 undesirable "middle" seats; (b) This revised layout has the same seated capacity and the same standing room, but may have higher effective capacity due to better space utilization; (c) This non-homogenous design offers a choice in seating layouts, allowing longer-distance passengers to gravitate towards commuter-style seats at car ends, and short-distance riders to stand in the middle zone with no seats; (d) London District Line's D78 stock has mixed seating layouts within a single car.