Boarding and Alighting Injury Experience with Different Station Platform and Car Entranceway Designs on U.S. Commuter Railroads

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ABSTRACT

Commuter railroad systems in the United States employ three combinations of station platforms and car entranceways. These are high level platforms with remotely controlled doors and level entranceway (HL-RC), low level platforms (just above the rail) with steps and remotely controlled doors (LL-RC), and a mixture of the two platform types with a correspondingly more complex, partly manual, door and entranceway arrangement (ML-MO). Much controversy exists over which type of platform/entranceway is better. This seemingly small feature significantly impacts many performance characteristics of these systems, including cost, speed, and boarding and alighting accidents. Northeastern systems are generally moving toward the mixed platform design or all high level platforms, while systems elsewhere are generally selecting the low-level design. Data on actual accident experience for 1995 to 2000 are analyzed to determine the effect of platform/entranceway type on passenger and employee injuries. Passenger injury rates on systems with the HL-RC design are lowest, with LL-RC systems next, and ML-MO systems having the highest rates. Employee injury rates are the least on LL-RC systems, but higher on ML-MO and HL-RC systems. Systems with a mixture of high and low platforms (ML-MO) experience a higher overall (combined passenger and employee) injury rate than the other two designs. The implications of these results for both the modernization of existing systems and the design of new systems, in the U.S. and abroad, are discussed.

INTRODUCTION

Commuter railroads in the United States employ two types platforms at stations—low level (LL) ones that are about 8 in (or 203 mm) above the rail, and high level (HL) ones at car floor height (4 ft or 1219 mm above the rail). Many systems use both. The platform configuration also imposes requirements on the design of the car entranceway (doors, steps, floor level trap door, etc.) With all one type of platform (either HL or LL) powered remotely controlled (RC) doors can be used on the cars, enabling the opening and closing of all doors at all stations. But if cars must stop at both HL and LL platforms, then a rather complex partly manually operated (MO) entranceway is used. All three platform/entranceway designs have safety implications, but the ML-MO is especially noteworthy in that it leads (for reasons that will be explained in the next section) to the unsafe practice of doors remaining open between stations, thus inviting accidents.

The combination of platform and entranceway employed significantly influences many important performance features of rail service, in addition to safety, including speed, labor requirements, investment and operating costs, ease of accommodating persons whose mobility is impaired, and compatibility with other rail services (freight and intercity passenger service) (Morlok 2001). All three platform/entranceway designs are used, and much controversy exists over which is better. With the planned expansion and modernization of commuter rail systems in many metropolitan areas, and the planned development of new systems in many others, the question of which platform/entranceway design to select is a significant one.

This paper examines the safety experience of these three platform/entranceway designs. It has long been contended that high level platforms are safer than low level ones, and this is often cited as one reason for incurring the extra expense of installing and maintaining them. While these platform configurations have been used on rail systems for about 100 years, reliable data on boarding and alighting accidents have been available only since 1995, when such data began to be gathered as part of the Federal Transit Administration's annual data series on urban public transportation.

The specific questions being asked are:

1. Is there a significant difference in the boarding and alighting accident experience between systems with the three platform/entranceway types: (1) all high-level platforms with remotely controlled doors (HL-RC), (2) all low-level platforms using steps on the car between the platform and car floor levels and remotely controlled doors (LL-RC), and (3) a mixture of the two platform levels with the partly manually operated entranceway configuration that permits both floor level and stairway access (ML-MO).
2. If the answer is affirmative, what are the implications for new systems and for the modernization of existing systems?

In the next section will be presented more information on the three designs, along with their operating features that relate to safety, leading to presentations of hypotheses to be tested. This is followed by a discussion of the data. Then the accident experience of the three platform/entranceway designs will be analyzed, for passengers, employees, and overall. Finally the implications will be presented.

PLATFORM AND ENTRANCEWAY DESIGNS

There are basically three combinations of station platform and railcar entranceway designs in use in the U.S. One uses the HL platform exclusively. With such platforms no steps are needed, as the platform is at car floor height. This platform and door arrangement is shown in Figure 1a. Doors are powered, and remotely controlled (RC) from one or more locations on the train. They are open only while the train is stopped (in contrast to the mixed platform/entranceway design to be described below). This design was used on very few commuter rail lines until the latter part of the 20th Century.

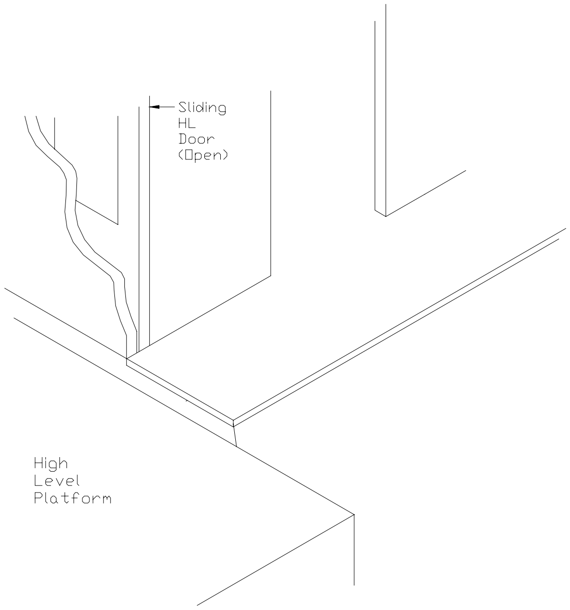
With the government takeover of most U.S. commuter rail service in the 1970s and 1980s, many were modernized with HL platforms and new cars with RC doors. The primary objective was to speed up service, since the time taken by passengers to board and alight trains is less with the platform at car floor height than it is with a low platform and steps. For example, New Jersey Transit estimates that HL platforms halve dwell time per passenger per lane compared to LL platforms (Lerner 1995, 54). Also, the remote control feature ensures that all doors can be opened at every station, further reducing station dwell time (i.e., time stopped at a station), and speeding service.

The second combination is all LL platforms and cars that have powered, remotely controlled doors close to the (low) platform level. Two versions of these are in widespread usage, as shown in Figures 1b and 1c. One design has the car floor at the usual height, with four steps between the center aisle and the station platform (Figure 1b). While the first commuter cars with this design had only one floor level, all cars built since about 1960 have had a partial second level (not extending over the center aisle of the car) to increase seating capacity, giving rise to the name “gallery car.” The other design has a low-level floor between the wheel assemblies, this floor being only two steps above the platform (Figure 1c). Normally there is a full-width second floor above this low center floor, resulting in a car that has three levels of seating (the other being at normal car floor height above the wheels). With these two types of (RC) entranceways, designed for use with LL platforms only, doors are opened only while the train is stopped at a station.

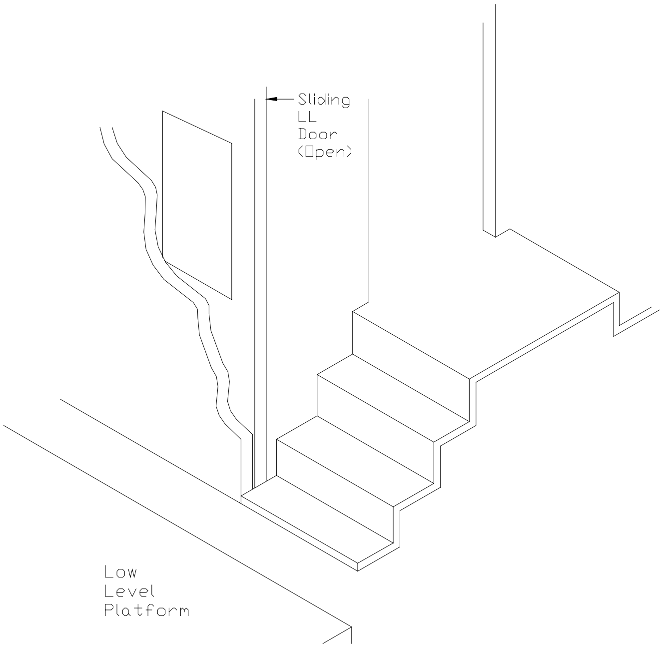
Many commuter rail systems in the U. S. have both HL and LL platforms. The previously described entranceway designs will not function with both platform types. Instead, such platform configurations require not only steps and doors, but also a manually operated platform called a trap. This is incorporated in the end vestibule of a car as shown in Figure 1d. At a LL platform, the door is open and the trap raised, permitting use of the steps. At HL platforms, the trap is lowered, providing a level walkway between the car floor and the platform. When traveling between two stations with HL platforms, the trap is left down. If the car is equipped with remotely controlled doors, the doors are almost always closed between stations. However, if the car has manual doors, then it is generally not possible to close all of these between closely spaced HL stations, due to limitations on the time available and the number of employees on the train.

When traveling between stations with LL platforms, time generally does not permit lowering the traps. Thus they are left in the raised position, and the doors—whether manual or remotely controlled--are therefore necessarily also left open. LL stations are much more numerous on most mixed platform lines, primarily in suburban

Figure 1. Railroad car entranceway designs (with walls and floor of car to the right of the entranceway omitted for clarity) (continues on next page).

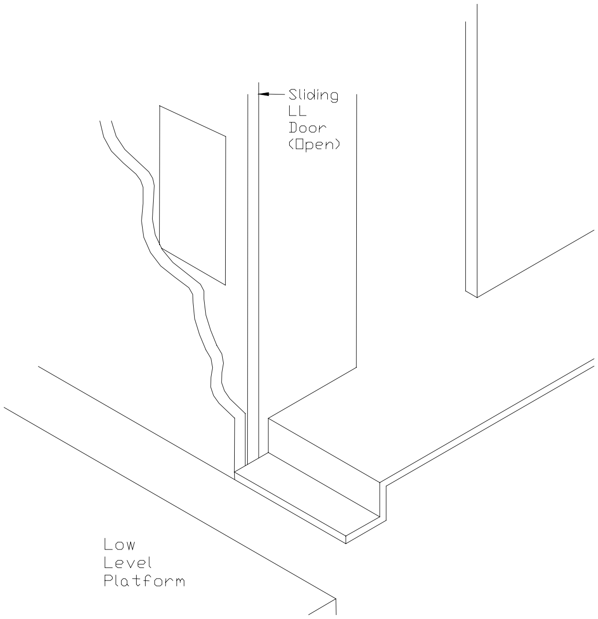


1a. Car entranceway with powered remotely controlled (RC) door for high level (HL) platforms only.

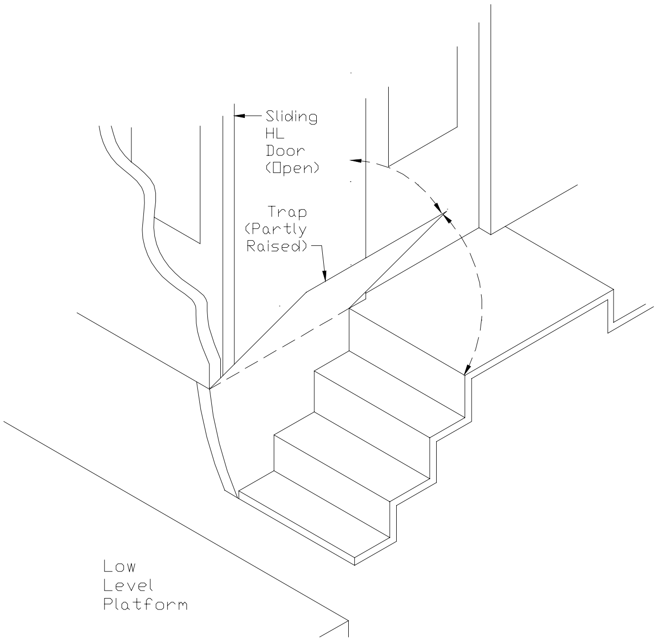


1b. Car entranceway for normal height car floor with remotely controlled (RC) door for low level (LL) platforms only.

Figure 1. Railroad car entranceway designs (with walls and floor of car to the right of the entranceway omitted for clarity) (continued).



1c. Car entranceway for low level car floor with powered remotely controlled (RC) door for low level (LL) platforms only.



1d. Traditional car entranceway with steps, manual trap, and door for use on lines with both high level (HL) and low level (LL) platforms.

areas, and thus the entranceways (doors and traps) generally remain open between many stations.

Commuter rail lines with a combination of LL and HL platforms and the corresponding entranceway consisting of steps, trap, and door, will be referred to as mixed level (ML) platform systems with partial or full manual operation (MO) of the entranceway. Such systems are now found primarily in the Northeastern U.S. These serve the New York City metropolitan area (from New Jersey primarily, but including some extensions through New Jersey into New York state), and the metropolitan areas of Philadelphia, Baltimore, Washington, New Haven, and Boston. The ML-MO design is also used on one system between Chicago and northern Indiana. Thus it is a very significantly represented among commuter lines. ML-MO platform/entranceway systems accounted for approximately 34% of all passenger trips on commuter rail systems in the US in 2000.

It is important to note that there are no plans to convert these ML platform systems to all one type of platform. Converting to all HL platforms is not possible, primarily for two reasons, among others. One is that many freight cars (or the cargo loads) are wider than passenger cars, and generally not compatible with HL platforms. Many newly rebuilt stations, and new stations on new lines or extensions, are built with LL platforms even though other stations on the same line have HL platforms. The second reason is the high initial investment cost—about \$1.5 to \$6.5 million per station (when no changes are necessary to the station building or other facilities). The former is an estimate (SYSTRA Consulting, Inc. 2002), while the latter is the amount budgeted per station for platform conversion at a group of New Jersey stations (New Jersey Transit 2001).

Conversely, it generally is not possible to convert to all LL platforms. Amtrak's new Acela high-speed trains, which share some stations with commuter trains in the northeast, require HL platforms. Thus a mixture of HL and LL platforms will continue for the foreseeable future, and along with them the practice designed into current cars and operations of leaving entranceways fully open between LL platform stations.

Clearly the three platform and entranceway designs in common usage differ with respect to passenger and employee safety features. Given the long-standing safety rationale for use of HL platforms, and the differences with other designs, it is important to ascertain the relative safety performance of the three types of platform and associated entranceway designs.

HYPOTHESES

From the foregoing description, the following hypotheses are posited, based on *a priori* expectations for boarding and alighting accident performance:

1. HL platform systems with RC doors (HL-RC systems), would be expected to be the safest, since all doors are closed as trains are moving, and there are no steps for passengers or employees to negotiate when entering or leaving a train at a station.
2. LL platform systems with RC doors (LL-RC systems) which also provide a secure entranceway between stations would seem to be the next safest.
3. Finally, systems with mixed HL and LL platforms and entranceways that, because of the manual operation, are not always closed while the train is moving (ML-MO systems) would seem to be the least safe.

All U.S. commuter rail systems can be classified into one of these three groups of platform/entranceway type, for all practical purposes. Thus it is possible to empirically test the hypotheses based on data reflecting actual experience. There are two groups of users of railcar entranceways and stations platforms—passengers and employees. Separate data are available for each, enabling distinct analyses of passenger and employee accident experience.

COMMUTER RAIL SYSTEMS AND DATA

Table 1 lists the major US commuter rail systems in 2000, and the area each serves. These are the systems for which complete, or almost complete data, are available. The type of platform/entranceway used on each of these is also given. Listed in a note are the other U. S. commuter rail systems. These other systems are all relatively new systems for which data are incomplete.

Table 2 presents overall statistics on boarding and alighting injuries in the US starting in 1995, the first year for which such data were collected, through 2000 (the last year for which data are available). The total annual injuries reported over this six-year period varied from 334 to 490, as given in Table 2a.

Boarding and alighting injuries are reported separately for three categories of persons--passengers, employees, and others. Passenger and employee injuries account for almost all injuries, with passenger injuries far outnumbering those to employees—a total 1975 for passengers vs. 504 for employees over the six year period. Only six injuries to “others” are reported over the same period. That the number of injuries to others (neither passengers nor employees) is very small is to be expected, for there is little reason for anyone other than a passenger or employee to board (or alight) a train. Not surprisingly, the data for many systems includes a blank entry (i.e., not zero) for the “injuries to others” category. The analysis in the following sections will focus on passenger and employee injuries. Inclusion of the six “other” injuries would make an imperceptible difference, for the total number of injuries to passengers and employees over the same period was 2,485.

Table 1. U.S. commuter rail systems in 2000.

System[a]	Area Served	Platform and Entranceway Type
LIRR	New York City-Long Island	HL – RC
METRA	Chicago-IL	LL – RC[b]
Metro North	New York City-NY and CT	HL – RC[c]
NJ Transit	New York City-All NJ	ML – MO
MBTA	Boston	ML – MO
SEPTA	Philadelphia	ML – MO
SF-Caltrain	San Francisco	LL – RC
SCRRA	Los Angeles	LL – RC
MARC	Washington-MD	ML – MO
NICTD	Chicago-IN	ML – MO
TCRA	Miami	LL – RC
VRE	Washington-VA	ML - MO[d]
NSDCT	San Diego	LL – RC

Note: HL means high level platforms, LL means low level platforms, ML means a mixture of both HL and LL platforms, RC means remotely controlled doors, and MO means manually operated doors or doorway traps.

[a] Source: Federal Transit Administration (2000), Table 28, pp. 472-505. Systems not listed here are new systems, some not fully operational in the period covered: Dallas Area RTA, ConnDOT (New Haven-New London), Central Puget Sound RTA (Tacoma-Seattle), Fort Worth Trans Auth (Fort Worth-Dallas), ACE (San Jose-Stockton, CA). Pennsylvania DOT operations are included with SEPTA

[b] METRA has all RC doors, and all lines are equipped with LL platforms only except one, which has HL platforms exclusively. It carries about 15% of METRA's traffic. Thus METRA is considered a LL system. The effect of excluding METRA from the LL-RC data is considered in the analysis.

[c] Metro-North operates trains at a few LL stations, but almost all traffic carried on its trains is on the HL-RC portion of the system. The only significant ML-MO service it funds is actually operated by NJ Transit under contract and is included in NJ Transit data.

[d] While VRE does not normally use the HL platforms at Washington Union Station, all of its cars in the period of analysis were of the MO type designed for ML platforms.

Table 2. Commuter rail boarding and alighting injuries from 1995 to 2000.

	1995	1996	1997	1998	1999	2000	Total
a. No. of Injuries to [a]							
Passengers	400	242	451	270	310	302	1975
Employees	90	92	103	81	76	62	504
Others	0	0	4	1	1	0	6
All Persons	490	334	558	352	387	364	2485
b. Injuries/Million Pass Trips to [b]							
Passengers	1.2439	0.8008	1.2719	0.7153	0.7888	0.7478	0.9175
Employees	0.2799	0.3044	0.3672	0.2631	0.2442	0.1539	0.2616
Others	0.0000	0.0000	0.0138	0.0032	0.0037	0.0000	0.0033
All persons[c]	1.5238	1.1052	1.6529	0.9816	1.0366	0.9017	1.1824

[a] Source: 2000: Federal Transit Administration (2000), Table 24, pp. 432-482. 1999: Federal Transit Administration (1999), Table 24, pp. 390-429. 1998: Federal Transit Administration (1998), Table 23, pp. 368-421. 1997: Federal Transit Administration (1997), Table 22, pp. 310-360. 1996: Federal Transit Administration (1996), Table 22, pp. 288-322. 1995: Federal Transit Administration (1995), Table 22, (T22-95.wk1).

[b] Rate is the total for injuries in the category in all systems divided by the sum of million passengers carried by systems reporting the data. For reasons explained in the text, many systems had a blank entry for injuries to "others". Sources for million passenger trip data are: 2000: Federal Transit Administration (2000), Table 28, pp. 528-568. 1999: Federal Transit Administration (1999), Table 28, pp. 472-505. 1998: Federal Transit Administration (1998), Table 27, pp. 470-512. 1997: Federal Transit Administration (1997), Table 26, pp. 402-442. 1996: Federal Transit Administration (1996), Table 26, pp. 364-404. 1995: Federal Transit Administration (1995), Table 26, (T26-95.wk1).

[c] Sum of the injury rates to passengers, employees, and others.

Also presented in Table 2 are overall injury rates per million passengers carried, for passengers, employees, and others. Employee injury rates average 28% of those for passengers. Both employee and passenger injury rates vary somewhat from year to year, probably reflecting many factors such as employee attention to safe practices, weather, employee vigilance in ensuring trains wait while passengers run to catch them (and try to board those with open doors), similar vigilance in connection with alighting passengers, media efforts to encourage safe conduct by passengers, etc. All of the yearly injury rates for “others” are close to zero, of course.

In this same six-year period there were four deaths attributed to boarding and alighting activity. All four were to passengers. Since the number of fatalities is so small, the ensuing analysis will be limited to injuries.

PASSENGER INJURIES

To compare the injury experience of the different types of platforms and entranceway designs, the rate injuries per million passenger trips will be used. Since most passengers ride only one train during a journey (i.e., unlike in much other public transit usage, do not transfer from one commuter train to another to complete their trip), the number of boarding and alighting cycles experienced by a passenger is generally one per passenger trip. Therefore a passenger is exposed to the situation in which the relevant accident (a boarding or alighting injury) could occur the same number of times on each trip. Thus the following measure will be used:

$$PIPT(j,t) = PINJ(j,t) / PASS(j,t) \quad (1)$$

where:

PIPT(j,t) = passenger injuries per million passenger trips for system j in year t

PINJ(j,t) = number of passenger boarding and alighting injuries reported for system j in year t

PASS(j,t) = million passenger trips reported on system j in year t

The average (mean) injury rate per million passenger trips is calculated for the three platform and entranceway groups: high level platform and remotely controlled doors (HL-RC), low level platforms and remotely controlled doors (LL-RC), and mixed high and low platforms with manually operated traps (and manual or remotely controlled doors) at the entranceway (ML-MO). These were calculated as follows:

$$PIPT(g) = \Sigma(j \text{ in } g,t)\ PIPT(j,t) / NP(g) \quad (2)$$

where:

PIPT(g) = mean value of passenger injuries per million passenger trips for the group of systems with platform/entranceway type g

NP(g) = number of data points of PIPT(j,t), i.e., systems and years of data, in the group

∑(j,t in g) = summation over all systems in group and over all years for which data were available

The results are presented in Table 3. They are as hypothesized. Systems with HL platforms and secure entranceways (HL-RC) have the lowest rates, with a mean of 0.1528 injuries/million pass trips, while systems with only LL platforms and secure entranceways (LL-RC) have 0.9016 injuries/ million passenger trips. The rate jumps to 2.4673 for the mixed platform and insecure entranceway (ML-MO) systems. Standard deviations (SDs) are also given in Table 3.

The statistical significance of these differences among the group means (values of PIPT(g)) must be tested. While it might seem natural to assume a Normal distribution about the mean, this is clearly inadvisable for these data. One reason is that zero is a

Table 3. Passenger injury rates per million passenger trips for the three platform/ entranceway types.

Platform and Entranceway Type	Mean of System Annual Injury Rates, injuries / million pass.[a]	Std. Dev. of System Annual Injury Rates, injuries / million pass.	No. of Data Points
HL-RC	0.1528	0.1397	12
LL-RC	0.9016	1.0247	19
ML-MO	2.4673	1.5840	34

[a] PIPT(g)

lower bound on the rate. The magnitude of the SD values in Table 3 indicates that with the Normal assumption a substantial portion of the distribution would have to lie below zero. The second reason is that there is no basis for believing that the underlying distribution is even close to Normal.

Unfortunately the number of data is insufficient to permit inferring a specific distribution. Therefore, non-parametric testing is indicated. Two tests seem appropriate. One is the Kruskal-Wallis test, which tests the hypothesis that k independent samples come from identical distributions. The other is the rank-sum test, which addresses differences in means. (These are described in Walpole and Meyers, 1989.)

Turning first to the Kruskal-Wallis test, the null hypothesis H_o was that the three group means are equal. At the 5% level of significance, the null hypothesis of equal means was rejected.

Strict inequality of each pair of means was tested using the rank-sum test, again with H_o that the two means are equal. At alpha = 0.05, the null hypothesis was rejected in all three comparisons. Thus the conclusions are: PIPT(HL-RC) < PIPT(LL-RC), PIPT(LL-RC) < PIPT(ML-MO), and PIPT(HL-RC) < PIPT(ML-MO). This result is consistent with the initial hypotheses.

It was noted in Table 1 that the METRA system (serving the Chicago area) was included in the LL-RC group even though it has one division with HL platforms with RC doors on the cars. This division carries about 15% of METRA passengers (Parkinson and Fisher, 1996, Table A 3.3, p. 169). Thus the data for this system involve a mixture of the LL-RC and HL-RC types. If the METRA data are omitted from the analysis, the resulting 13 data points yield LL-RC values (corresponding to those in Table 3) of 0.6661 for the mean of system annual injury rates, and a standard deviation of 1.146. However, applying the Kruskal-Wallis tests and the rank-sum tests to these reduced data yield the same conclusions as when the METRA data are included. Thus the conclusions about the ordering of the three platform/entranceway types with respect to injury rates remain unchanged regardless of whether METRA is included in the analysis or not).

As described in Figure 1, within the LL-RC platform group, there are two types of entranceways. Two systems use cars with two steps to the (low or drop-center) car floor, while the others use cars with four steps to a normal height floor. While the data are limited, the mean injury rate for the three systems with two steps is less than the mean for those with four steps. Specifically, the exclusively two-step entranceway systems--SCRRA, TCRA, and NSDCT—have a mean injury rate of 0.8048 injuries/million passenger trips. SF-Caltrain uses four-step cars exclusively, and METRA carries about 85% of its passengers on this type of car. These two systems have a mean injury rate of 0.9887 The rank sum test, at a 5% level of significance, indicates that there is no basis in the data for rejecting the hypothesis that these two means are equal. Using a variant of the prior notation, the hypothesis PIPT(2 step-RC) = PIPT(4 step-RC) can not be rejected. Thus there is no basis in the data for distinguishing between these two types of LL-RC designs.

EMPLOYEE INJURIES

As stated earlier, employee injury data are available for only some of the systems. Contractors operate some of the systems, and contractors are not required to report employee accidents. (These contractors are usually either Amtrak—the National Railroad Passenger Corp.--or the freight railroad over whose tracks the service is operated.)

The proper normalizing factor for employees is not so obvious as it is for passengers. One candidate factor is simply the number of train (vehicle) operating employees. Another, which permits comparison with the previously developed passenger injury rates, is the number of passengers (in millions). A third would be the number of employee boarding and alighting cycles. However, no data are available on the number of employee boarding and alighting cycles. It is often a matter of employee choice as to whether or not she steps outside the train at each station. Therefore the first two measures will be used.

Turning first to employee injuries per vehicle operating employee, the specific normalizing factor is million vehicle-operating employees. Such employees include persons operating trains in revenue service as well as non revenue service (i.e., repositioning empty trains), and both engineers (who are in the cab of the locomotive or first car, controlling train movement) and passenger car attending employees (i.e., conductors, trainmen, etc.). The computations follow those used for passengers above. For each system,

$$EIPE(j,t) = EINJ(j,t)/ OE(j,t) \tag{3}$$

where:

EIPE(j,t) = employee injuries per million vehicle-operating employees for system j in year t

EINJ(j,t) = employee boarding and alighting injuries on system j in year t

OE(j,t) = million vehicle-operating employees in system j in year t

These rates are then averaged to obtain mean values for the rates for each platform/entranceway type:

$$\mathrm{EIPE}(g) = \sum(j,t \text{ in } g)\ \mathrm{EIPE}(j,t)/\ \mathrm{NE}(g) \tag{4}$$

where:

EIPE(g) = mean value of employee injuries per million vehicle-operating employees for platform/entranceway type (group) g

NE(g) = number of data points of EIPE(j,t), i.e., systems and years of data, in the group

$\sum(j,t \text{ in } g)$ = summation over all systems in group and over all years for which data were available

The results by type of platform/entranceway are presented in Table 4. The values and ordering are quite different from those for passenger injuries. First, the lowest rate is for the LL-RC platform/entranceway group, at 2,497.2 injuries/million vehicle-operating employees. Much higher, at 14,083.1, is that for the HL-RC group. Still higher is that for the mixed platform levels–manual entranceway operation (ML-MO) group, at 31,727.2 injuries/million vehicle-operating employees.

There are factors that could explain why the ordering of platform/entranceway types for employees injuries differs so much from that for passenger injuries. First,

Table 4. Employee injury rate per million vehicle operating employees vs. platform and entranceway type.

Platform and Entranceway Type	Mean of System Annual Injury Rates, injuries / million operating employees[a]	Std. Dev. of System Annual Injury Rates, injuries / million operating employees	No. of Data Points
HL-RC	14,083.1	8,538.0	12
LL-RC	2,497.2	2,891.9	6
ML-MO	31,727.2	38,118.7	21

[a] EIPE(g)

in comparing the LL and the HL group, it may be significant that the two systems comprising the HL group both have underground terminals (at the central city end of each system). Boarding and alighting under such circumstances, where lighting may not be good, poses a safety hazard. Also, portions of both systems have an electrified third rail for power, which can make boarding and alighting at locations away from passenger platforms, as in storage yards, where a car-side ladder must be used, more hazardous. Interestingly, both are in the New York metropolitan area.

In contrast, all the LL systems are either entirely or almost entirely above ground, and the terminals tend to be more spacious than those in New York City. That the mixed systems are the least safe is not surprising. One factor is that employees must lean outside the envelope of the train to observe the passenger platform as the train departs a station. This is done to ensure that no one is trying to board the train, since the doors are still open. This poses a safety hazard of being struck by lineside structures (including the mini HL platforms used for wheelchair passengers at some LL platform stations).

The Kruskal-Wallis test was again used to test the null hypothesis H_o that the three group means are equal. The null hypothesis of equal means can not be rejected. Clearly the small number of data points had a major effect on this test.

Strict inequality of the means in pairwise comparisons was tested using the rank-sum test, again with H_o that the two means are equal. At alpha = 0.05, the null hypothesis was rejected in the comparison of HL-RC and LL-RC systems. Also, in the case of LL-RC vs. ML-MO systems, the hypothesis of equality was rejected, though the critical value and statistic were very close. The null hypothesis was accepted in the comparison of HL-RC and ML-MO systems. Thus it is concluded that EIPE(LL-RC) < EIPE(HL-RC), EIPE(LL-RC) < EIPE(ML-MO), and EIPE(HL-RC) = EIPE(ML-MO). The data indicate that LL-RC systems have a clear superiority with respect to employee injuries per million operating employees, while the data do not support differentiation between the mean rates for HL-RC and for ML-MO systems.

Normalizing the employee injuries by the number of passenger trips instead of employees produces no change in the ordering of the mean injury rates for three types of platforms and entranceways. These are shown in Table 5, the result of substituting

Table 5. Employee injury rate per million passengers vs. platform and entranceway type.

Platform and Entranceway Type	Mean of System Annual Injury Rates, injuries / million pass.[a]	Std. Dev. of System Annual Injury Rates, injuries / million pass.	No. of Data Points
HL-RC	0.2992	0.1934	12
LL-RC	0.0619	0.0623	9
ML-MO	0.7301	1.0769	31

[a] EIPT(g)

PASS(j,t) for OE(j,t) in eqtn. (3), with the corresponding change in NE(g) in eqtn. (4). However, both the Kruskal-Wallis and the rank-sum tests for differences in means uniformly indicated that the data do not support the conclusion that the means are unequal. Thus the null hypothesis that EIPT(LL-RC) = EIPT(HL-RC) = EIPT(ML-MO) can not be rejected. It should be noted that the normalization by employees rather than passengers is preferred, because these different platform and entranceway designs result in differing ratios of employees to passengers. All other factors being equal, the number of employees is reduced by having remotely controlled doors, and hence by having only one platform type—HL or LL.

No analysis of the effect of variations in the number of steps incorporated in LL-RC systems could be undertaken for employee injuries, due to insufficient reporting of data.

EMPLOYEE AND PASSENGER INJURIES COMBINED

The overall injury rate for the three types of platforms and entranceways is also important. For this rate passengers will be the normalizing factor, for two reasons. First, this is the appropriate factor for passengers, who experience more injuries than employees. Second, the number of vehicle-operating employees is, at least to some extent, related to the number of passengers carried.

The statistics to be compared are thus:

$$\mathrm{TIPT}(j,t) = (\mathrm{EINJ}(j,t) + \mathrm{PINJ}(j,t))/\ \mathrm{PASS}(j,t) \qquad (5)$$

$$\mathrm{TIPT}(g) = \Sigma(j,t \text{ in } g)\ \mathrm{TIPT}(j,t)/\ \mathrm{NTP}(g) \qquad (6)$$

where:

TIPT(j,t) = total (passenger plus employee) injuries per million passengers for system j in year t

TIPT(g) = mean value of total (passenger plus employee) injuries per million passenger trips for entranceway group g

NTP(g) = number of data points of TIPT(j,t), i.e., systems and years of data, in the group

Σ(j,t in g) = summation over all systems in group and over all years for which data were available

The results are shown in Table 6. As might be expected given the excess of passenger injuries over employee injuries, the ordering by platform/entranceway type is the same as that found for passenger injuries. HL systems have the lowest mean rate at 0.4521 injuries/million passengers, LL systems are next at 0.9050, and mixed systems

Table 6. Total (passenger plus employee) injury rate per million passengers vs. platform and entranceway type.

Platform and Entranceway Type	Mean of System Annual Injury Rates, injuries / million pass.[a]	Std. Dev. of System Annual Injury Rates, injuries / million pass.	No. of Data Points
HL-RC	0.4521	0.2518	12
LL-RC	0.9050	0.6135	9
ML-MO	3.4877	2.0717	28

[a] TIPT(g)

have the highest rate at 3.4877. The number of data points is less than that for the passenger analysis, however, because of the limited reporting of employee injury data. Standard deviations are also given in the table.

The same tests were performed on these data. The Kruskal-Wallis test led to the rejection of the hypothesis that all three means were equal. The rank-sum test led to the rejection of equal means for two pairwise comparisons, and supported acceptance of the inequalities TIPP(LL-RC) < TIPP(ML-MO) and TIPP(HL-RC) < TIPP(ML-MO). However, the null hypothesis TIPP(LL-RC) = TIPP(HL-RC) can not be rejected with the rank-sum test. (It should be noted that the statistic for this test was 32, close to the critical value of 30, but not less than it—the condition needed for rejection of the null hypothesis.) Thus only two of the three initial hypotheses for the overall injury rates are accepted. However, that the ML-MO systems are clearly inferior in terms of injuries compared to both the HL-RC and LL-RC systems is important.

SUMMARY AND USE OF ESTIMATED MEAN INJURY RATES

There are two important results from this study. One consists of conclusions regarding the relative safety of the three types of platform/entranceway designs. These will be covered in the Conclusions section below. The other consists of the specific mean injury rates estimated, which can be used to predict the boarding and alighting injuries on a system that would result from using any of the different platform and entranceway designs. This is a logical part of studies of modernization of existing systems, and also of the alternative design analysis for proposed systems.

Table 7 presents the mean injury rates for such analyses. In some cases, particularly for new systems, a forecast of the number passengers would be available, but a similar forecast for the number of vehicle operating employees is far less likely. In this case, the overall numbers of injuries could be estimated using the mean overall rate TIPT(g) for the particular design(s) under consideration. For existing systems, and where

Table 7. Summary of mean injury rates (with standard deviations in parentheses).

	Platform and Entranceway Type (g)		
	HL-RC	LL-RC	ML-MO
Total injuries / million pass. trips[a] (TIPT(g))	.4521 (.2518)	.9050 (.6135)	3.4877 (2.0717)
Pass. Injuries / million pass. trips (PIPT(g))	.1528 (.1397)	.9016 (1.0247)	2.4673 (1.5840)
Vehicle operating employee injuries / million vehicle operating employees[a] (EIPE(g))	14,083.1 (8,538.0)	2,497.2 (2,891.9)	31,727.2 (38,118.7)

[a] All differences are statistically significant, except neither TIPT(HL-RC) = TIPT(LL-RC) nor EIPE(HL-RC) = EIPE(ML-MO) can be rejected using available data.

more detailed employee data are available for new systems, the injuries for passengers and employees could be estimated separately. Thus the mean rates PIPT(g) and EIPE(g) are also given. Along with these means are the standard deviations. Finally, the table presents the conclusions and interpretations from the statistical tests regarding the differences among means.

CONCLUSIONS

The results of the analysis of injury data indicate that commuter railroad platform and entranceway types do have a significant effect on boarding and alighting injury rates of passengers and employees. Systems with only one type of platform—high level (HL) or low level (LL)—and with remotely controlled (RC) doors, have the lowest overall (passenger plus employee) injury rates. While the mean rate for HL-RC systems is less than that for LL-RC systems, the data do not support rejection of the hypothesis that the mean values of these rates are identical. But both of these mean rates are significantly less than the injury rate for systems with mixed high and low level platforms (ML) and the traditional partly manually operated trap, step, and door (MO) designs, and the difference is statistically significant.

These conclusions are very important for current and future systems. One implication, for both existing and new systems, is that mixing of platform types, along with the use of the traditional partly manually operated entranceway design, is to be avoided, if injuries are to be minimized. Unfortunately much of the modernization of commuter rail lines in the Northeast has resulted in adding to the number of systems and routes which have mixed platform types. Specifically, systems serving the metropolitan areas of New York (from New Jersey), Philadelphia, Boston, Baltimore, and Washington, all have seen the introduction of some HL platforms on routes where earlier only LL platforms existed. The same mixing is true on some new lines in the Northeast. While replacing some LL platforms with HL ones was intended to be an improvement in facilities, it has led to a mixing of the two types of platforms. This then has led to retaining the traditional door and trap arrangement. From the entranceway design of such cars follows the unsafe practice of keeping doors open while the train travels between LL platform stations (and between closely spaced HL platform stations if manual doors are used).

A second implication is that entranceway designs that enable closing doors after each station stop, no matter how close the next stop may be, should be introduced and used on mixed platform systems, just as they are already on exclusively HL and LL platform systems. Even cars recently built for such mixed platform systems have the traditional powered sliding HL door, steps, and manual trap entranceway first used almost a century ago (on the Long Island Rail Road and a subsidiary of the New Haven Railroad (White, 1978)). But there now exist designs that incorporate and the ability to open and close all doors at both LL and HL platforms (discussed in Morlok, 2001), providing an entranceway that is as secure as those on all HL-RC and LL-RC cars. These new designs should be evaluated, and used if they are technically and economically sound. And if not, work is clearly warranted on developing a secure entranceway for these mixed platform systems.

It should be noted that the problem of trains stopping at station platforms at many different levels is not exclusive to the U.S. One commuter line in Canada has the same problem, and Dejeammes (2000) describes an even larger number of platform heights in Europe, with many of the same problems that beset U.S. systems. This is further exacerbated by variations in car floor heights even within the same national rail system. And some Asian systems use the traditional entranceway as well. Thus solutions to the problems of mixed platform systems could find application throughout the world.

The mean employee injury rate is highest on systems with HL platforms—either exclusively or mixed with LL platforms (ML), and both of these rates are statistically significantly higher than the rate for LL platforms. As mentioned earlier, many U.S. systems have a policy of replacing LL platforms with HL ones as funds and circumstances permit, with a view toward having only HL platforms at some time in the future. These data suggest that this will result in increases in employee injuries. An investigation into the reasons for the high employee injury rates with HL platforms should be undertaken. Ways may be found to reduce the number of these injuries. If not, the high employee injury rate associated with HL platforms is a factor that should be considered in any plans to introduce them.

LL platforms exclusively offer an excellent alternative to HL or ML platforms from the standpoint of overall injury rates. LL platforms are widely used for many reasons (including low cost, compatibility with freight service, and ease of lengthening to accommodate longer trains), and if they are used exclusively on a system or line, they permit the use of cars in current manufacture with remotely controlled doors. This results in the lowest mean boarding and alighting injury rate for employees and the second lowest mean rate for passengers.

Finally, it is clear that substantial variations in boarding and alighting injuries result from the designs of the station platforms and of the car entranceway. Systems with HL or LL platforms exclusively, and the secure entranceway (RC) that is now virtually universally used with such designs, provide relatively high overall levels of safety (as measured by the sum of passenger and employee injuries). However, systems with the traditional insecure entranceway (MO), used with a combination of the same types of platforms, leads to a much higher injury rate. Since both platform type and entranceway type are design features that can be changed as systems are modernized with rebuilt station facilities and new cars, attention should be paid in making these choices to the impacts on passenger and employee injuries.

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