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Research Results Digest 74

TRAIN DOOR SYSTEMS ANALYSIS

This digest is the final report for TCRP Project J-6, Task 62, "Field Door Survey Project." Appendixes to this digest are available as *TCRP Web-Only Document 28.* This digest is based on research conducted by Transportation Systems Design, Inc.

Failures of train doors are the biggest single cause of delay and disruption of rail transit service; therefore, in-depth study and analysis of train door problems can lead to significant increases in the reliability of transit service. This digest describes (1) the development of a relational database for data on the causes and conditions of train door failures and (2) some preliminary analyses of the data.

SUMMARY

The American Public Transportation Association (APTA) Rolling Stock Equipment Technical Forum (RSETF) developed the Train Door Project, whose goal is to help transit managers resolve door equipment problems that adversely affect rail transit reliability and service. The primary output from this work has been the creation of an on-line questionnaire and database detailing door failure causes and conditions.

The Train Door team consisted of volunteer participants from transit agencies, railcar manufacturers, door equipment manufacturers, and consulting companies. The project received strong support and participation from chief executives and staff at five leading U.S. transit agencies: San Francisco Bay Area Rapid Transit District (BART), the Chicago Transit Authority (CTA), New York City Transit (NYCT), The Port Authority Trans-Hudson (PATH), and the Washington Metropolitan Area Transit Authority (WMATA). Others have expressed interest in participating.

The Train Door project plan consisted of six steps: (1) identify door population, (2) define segment of study, (3) define field investigation strategy, (4) manage collected information, (5) formulate problem-solving actions, and (6) communicate findings to transit community.

For steps 1, 2, and 3, the Train Door team created a four-part questionnaire covering railcar fleets, door equipment, operations, and maintenance for the five participating transit agencies. Part I of the questionnaire covers railcar fleets in service, including car classes in service, number of cars per class, years of service for each class, average speed, annual miles of operation, minimum and maximum consist length, and operating and maintenance responses to door incidents. Part II covers door equipment and component technical specifications for each car class, including covered locations, types, manufacturers, models, and original/retrofit condition for major electrical, electronic, mechanical,

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and switch components. Part III includes train operations, rules governing delays and reliability calculations, and operating procedures. Part IV covers door maintenance issues and practices for major door components.

Following collection, review, and public presentation of data from the first questionnaire, the Train Door team identified seven common door failures and conditions that affect all the surveyed transit agencies: (1) door fails to open or close when commanded from the operator location; (2) door status interlock failures; (3) incorrect door opening; (4) incorrect door operation (operation/wayside error: wrong side opening or open when not berthed): (5) obstruction detection failures/drags; (6) freewheeling door panel; and (7) door fails to completely close and lock and/or to indicate closed and locked.

The Train Door team then created a second questionnaire about component causes of the seven common door failures. For each failure, the questionnaire lists generic door system components that could cause the identified door failure. In addition to requesting information on component causes, the questionnaire asks for solutions to these common problems, including maintenance procedure changes, operational changes, and/or equipment design changes.

The resulting data from both questionnaires includes answers to 34 groups of questions, with 191 data items covering 21 railcar classes. The data, collected in 2004, were unique, in depth, and of great value. To permit processing and broad use of the data, the Train Door team built a web-accessible, MySQL database that provides a permanent location for the data, provides tools to enable access, ensures responses are in the expected format, is easily scaled to accept input from more transit agencies, and does not require clerical processing for new transit agency data to be entered. The website, to be installed at www.traindoors.com, is implemented in proven commercial and open-source software, including MySQL, Linux, Apache, PHP, Smarty, and XHMTL. (The sponsors have delayed public release of the traindoors.com website and database, while they resolve issues concerning access to the Train Door data.)

The MySQL database consists of 29 tables, structured to parallel the questionnaire data. The website lets users download selected tables into Excel or other file management applications.

The website allows the user to display or export results from the Train Door database; enter new or modified data for a transit agency, in response to the two questionnaires; participate in a discussion forum; access resources including technical papers about train door technology and database documentation; and get contact information for the website and database.

The first results obtained from analysis of the information in the Train Door database suggest improvement areas and directions for further research and analysis. Figure 1 shows the distribution of types of door failures by car class. Further analysis is needed to understand how to reduce the number of door incidents, and why a failure type is quite significant at one transit agency or in one car class but less significant in another.

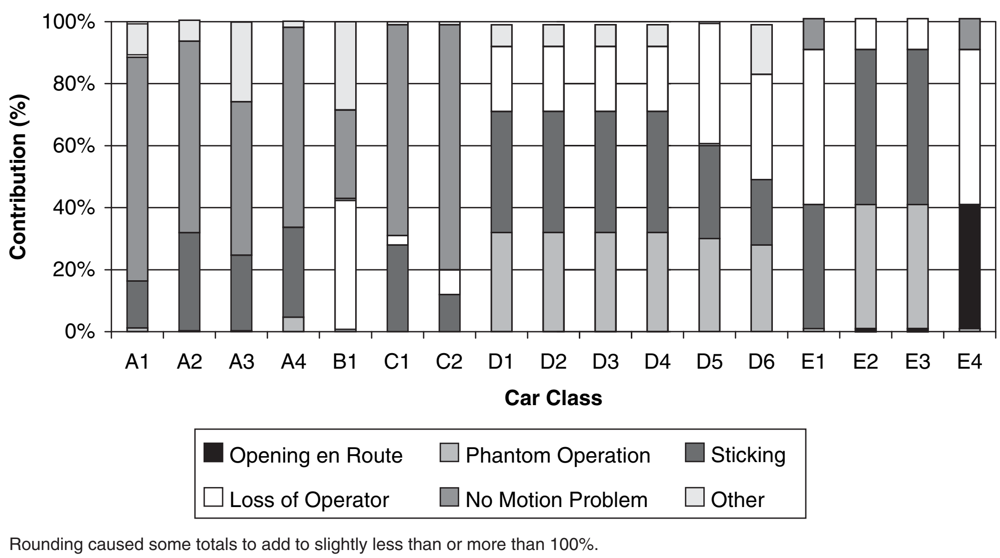


Figure 1 Door failures by type.

Other initial results showed the following:

- Improved door switch reliability could have a big positive impact on door and transit service.
- Certain car classes account for a disproportionate share of door failures, and a focused effort to address those car classes could have a big positive impact on service.
- Winter weather correlates with increased door problems, and reliability improvement efforts related to weather should focus there.
- Improved maintenance tools, techniques, training, and design provisions in support of maintenance could have a big positive impact on service.

Users should be aware that the data in the Train Door database come from only five transit agencies. The possibility exists that the sample of data, while covering a great breadth of topics and detailed technical information, may not be deep enough to provide conclusive evidence of a trend or possibility. Accordingly, the Train Door database at this stage should be considered one tool, but not the last word, in analyzing train door conditions and failures.

Next steps for the Train Door database and traindoors.com are to determine how to handle sensitive data such as manufacturer details; to use the on-line questionnaire to guide collection of data in uniform format; to expand the database to cover maintenance and other performance aspects; to solicit and encourage participation from other transit agencies; and to continue to expand the data analysis to understand the trends shown in the data and investigate problems and possible solutions within and among car classes and transit agencies.

Next steps for the transit industry are to evaluate value and utility of traindoors.com and determine whether the concept should be extended to collect similar or expanded data on other equipment reliability and performance characteristics.

1 INTRODUCTION

Starting in 2002, the APTA RSETF assessed rolling stock problems that rail transit professionals considered critical to their operations with the intent to develop a project to help transit managers resolve one set of those problems.

Transit industry managers from heavy rail, commuter, and light rail transit agencies identified critical problems involving railcar body structures, doors, propulsion and dynamic braking, air braking, trucks and suspension, wheels and axles, heating ventilating and air conditioning, couplers and draft gears, communications, lighting, and train control. Door system failures stood out because transit managers identified them as having the greatest negative impact on railcar reliability and transit service, particularly on heavy rail rapid transit systems. As a result, the RSETF selected train door system failures as the recommended project focus.

This digest reports on the results of the RSETF Train Door Project and its accomplishments to date.

2 DEVELOPMENT PROCESS

2.1 Five Participating Transit Agencies

The RSETF proposed to focus on train doors in a meeting with the CEOs of leading U.S. rail transit systems at the 2003 APTA Rail Transit Conference. The chief executives endorsed and supported the proposal, and they committed key technical and project staff to support and help implement the Train Door Project. As a result of this high-level support, the RSETF Train Door Project team had enthusiastic participation and cooperation from the transit agencies and their technical and operating staff and from door manufacturers, railcar builders, and transit industry consultants.

To control the project scope, the team selected five heavy rail transit agencies as the first group for analysis and action: BART, CTA, NYCT, PATH, and WMATA. These agencies were chosen because of their readiness to participate in the project and because they collectively operate a wide range of railcars, door equipment, and service levels in diverse regions and climates. The team understood that the pilot assessment would entail a learning curve, and the limited volunteer resources of the Train Door team were matched to the limited initial data sample provided by the five transit agencies.

2.2 Project Plan

The Train Door Project plan consisted of the following steps:

1. Identify door population: equipment suppliers, users, and car fleets
2. Define segment of study: door system components, technology, and life cycle phases to be investigated
3. Define field investigation strategy: create a questionnaire, perform interviews, and document findings

4. Manage collected information: create a database and analyze data
5. Formulate problem-solving actions: investigate problems, plan corrective actions, and document lessons learned
6. Communicate findings to transit community

An overview of the process is provided in Appendix D.

2.3 First Questionnaire: Fleets, Equipment, Operations, and Maintenance

The Train Door team created a questionnaire that addressed four general information categories related to doors: railcar fleets, door equipment, operations, and maintenance.

2.3.1 Part I: Fleet Survey

Part I of the questionnaire covers the particulars of railcar fleets in service at each of the five participating transit agencies:

- The car classes in service
- Number of cars per class
- Years of service for each class
- Average speed
- Annual miles of operation
- Minimum and maximum consist length

Questions also cover the operating and maintenance responses to door incidents. To provide a visual perspective of door opening and door operator locations, the questionnaire requests a door schematic for each car class, showing plan and elevation views of the car, side door openings (two, three, or four), and door operator locations (under-seat, wall pocket, or overhead).

The five participating transit agencies operate a total of 32 car classes. Responses were provided for 21 of the car classes.

2.3.2 Part II: Door Equipment Survey

Part II covers door equipment and component technical specifications for each car class. The survey covers locations, types, manufacturers, models, and original/retrofit condition for each of the following:

- Door operators and master door controllers, relays, cams, and micro switches
- Wiring
- Mechanical linkages
- Door panels, sensitive edges, hangers, threshold plates, and bottom door-panel guides
- Microprocessor/electronics equipment (at door level and at car level)
- Inter-car communications, train line wiring, electric couplers, and electric portions

2.3.3 Part III: Operations

Part III covers train operations, applicable rules, and standard operating procedures, including the following:

- The definition and calculation of train delays
- Railcar performance reliability
- Basis for calculating mean distance between failures (MDBF) or mean time between failures (MTBF)

This part studies the distribution of door failures in each car class. The questions on operational failures experienced, factors affecting satisfactory operations and reliability, and incidents leading to passenger injuries are rated on a percentile basis for each, totaling 100%.

2.3.4 Part IV: Maintenance

Part IV covers door maintenance issues and practices for major door components: master door controllers, door operators, mechanical linkages, door panels, door-panel sensitive edges, door hangers, micro switches, relays, microprocessors, electronics equipment, wiring, threshold plates and door guides, and coupler electric portions and pins. Questions cover the following:

- Repair reporting method
- Preventive maintenance (PM) intervals
- Average time spent on door equipment during each PM
- Percentage that in-car system components contribute to door incidents
- Most common types of failure associated with each door component
- Percentage that trainline components contribute to door incidents
- Details and elements of any car body/door component interfacing problems that contribute to incidents

2.4 Getting Industry Data

In early 2004, the Train Door team began collecting data. With the full support of the transit agency CEOs, a volunteer group visited each of the transit agencies and conducted interviews to complete the questionnaires, working closely with the key transit agency staff in operations, door maintenance, and engineering with door responsibilities.

The tool used for data collection was a word processor–generated questionnaire, and the format for data collection was entry into the word processor file of the questionnaire, or hand-entry onto a printed copy of the questionnaire.

With the data in hand, the Train Door team began to review and assess the data, and develop first results. The data showed the current state of door system equipment at the selected transit agencies and pointed to problem areas related to specific equipment.

During the analysis, the Train Door team realized that the paper format was limited as a medium to hold, distribute, manage, and analyze the data and concluded a better tool was needed to enable thorough analysis of the data. Such a tool would help the team understand specific door problem causes, pinpoint critical areas where operational mishaps and equipment failures adversely affect door system performance, and learn how some problems were corrected.

2.5 Communicating with the Industry

At the June 2004 APTA Rail Transit Conference, the Train Door team presented "Hold That Door," a technical session on its work to date and its plans to move forward to the transit industry. The session covered the project purpose, goals, the five participating transit agencies, and the project plan. The panelists represented a transit operator, car manufacturer, door system manufacturer, and industry consultant.

The session accomplished three things:

- Garnered interest within the industry. There was a lively question and answer period after presentations were completed. Executives from several heavy rail, light rail, and commuter rail transit agencies expressed an interest in becoming involved in the Train Door Project.
- Developed the future focus for the project. The question and answer session provided the Train Door team with ideas about door problems and areas where future focus was required.
- Initiated the involvement of TCRP. Following the session, the RSETF and the Train Door team developed the work plan for TCRP Project J-6, Task 62, "Field Door Survey Project," which enabled the project to develop a database for the collected train door information.

2.6 Second Questionnaire: Common Door Failures and Component Causes

Following review of data from the first questionnaire and the "Hold That Door" session, the Train Door team identified a set of seven common door failures and conditions that affect all the surveyed transit agencies and contribute to delays and other door problems. The team realized that further information was needed to expand the understanding of the causes of these door failures. As a result, the team created a second questionnaire. The second questionnaire asks about the component causes of the following seven common door failures:

- **Door fails to open or close when commanded from the operator location.** The questionnaire provides 14 choices for items causing the failure, of which 11 are door components.
- **Door status interlock failures.** This serious in-service failure is particularly troubling because door status interlocks are designed to protect train passengers against other hazardous door open failures or conditions. Because interlock functions are sensitive to operating practices and driver actions, operator error was included as a possible cause.
- **Incorrect door opening.** This door system failure is safety related and potentially dangerous. In this case, a single door opens without command because of a failure in the door operator mechanism. This is a safety problem, since one of the most important safety functions of train doors is to stay closed and locked except when it is safe to open. As with interlock failures, preventive designs to address incorrect door openings have also gradually increased the complexity of door systems and possibly reduced reliability.
- **Incorrect door operation (operation/wayside error: wrong side opening or open when not berthed).** In this case, all doors on one side of the train open on the wrong side or when the train is not safely stopped at a platform. This condition generally relates to operator, train-level, or wayside error. For passenger safety, doors must open on the correct side at each station, which poses real design and operational

challenges. Human factors, wayside control variations, and track and platform configurations constantly test both the operator's ability and the equipment's provisions to open the correct doors.

- **Obstruction detection failures/drags.** The second most important safety function of train doors is to prevent the train from moving with an object stuck in the doors. The mechanisms and procedures to achieve this sometimes conflict with consistently keeping doors closed and locked when the train is moving. Multiple schemes and processes have been deployed to reduce the possibility of moving a train with a person caught in the doors. The performance and reliability of these systems is the main focus of this question.
- **Freewheeling door panel.** A door panel that fails to respond to commands must be manually placed in the closed and locked position and mechanically locked out. Normally associated with mechanical linkage failures or loss of power, this type of failure has begun to re-emerge. The team's collective experiences have identified recent occurrences of this failure not caused by the traditional failure mode. The introduction of microprocessor- and software-controlled door systems has increased the occurrence of this failure. Latent software defects and control logic failures in the advanced control systems have been increasingly reported as the root cause of this type of failure.
- **Door fails to completely close and lock and/or to indicate closed and locked.** This failure is by far the most numerous and most frustrating of the seven common door failures. Measures that prevent unsafe train operations significantly add to the quantity and complexity of door system equipment. Increased part counts and complexity provide more opportunities for causing this failure. Along with increased system complexity comes increased time to identify root causes and carry out corrective repairs. This failure impacts both the operation of doors and the reliable operation of the rail system as a whole.

For each of the seven door failures, the questionnaire lists generic door system components that can cause or contribute to the identified door failure. Many components can contribute to more than one of the seven common door failures. In addition to the causes, the questionnaire asks for solutions to these seven common failures, including maintenance procedure changes, operational changes, and/or equipment design changes.

Associating the information from the second questionnaire on seven common door failures with the first questionnaire information on railcar fleets, door equipment, operations, and maintenance was expected to yield new insights into relationships among failures and the components and conditions that combine to create them.

3 THE DATABASE TOOL: TRAINDOORS.COM

The five participating transit agencies gave strong support and extensive responses to the two questionnaires. The resulting data include answers to 34 groups of questions in the categories of railcar fleets, door equipment, train and door operations, maintenance, and common door failures. There are 191 data items covering 21 car classes. Paper copies of the results fill a 3-inch notebook. Clearly, there is a lot to learn from the experience of these five leading transit agencies.

The collected information was unique, in depth, and of great value, but also presented a challenge to the Train Door team regarding how to use the information and make it useful to the broader transit community. The team decided a database would give immediate and continuing results.

TCRP Project J-6, Task 62, "Field Door Survey Project," enabled the team to develop and implement a database for the Train Door Project information. The resulting database

- Provides a permanent location to record the collected data;
- Provides tools to enable access to and analysis of the recorded data;
- Is easily accessible to the world community of transit professionals;
- Ensures that responses to questions are in the expected format, so that answers to a single question from several transit agencies can be directly compared;
- Is easily scaled to accept added input from new transit agencies as well as updates from the original transit agencies; and
- Does not require clerical processing of data to be added for new transit agencies.

The selected structure for the Train Door database is MySQL, an industry-standard structured query language (SQL) relational database, hosted on a web server and accessed via website clients. The host website, to be installed at www.traindoors.com, is implemented in broadly accepted, proven, commercial and open-source software:

- MySQL, the industry-standard SQL relational database system
- Linux, the reliable open-source operating system similar to Unix
- Apache, the mature open-source web server
- PHP, the broadly used open-source programming language, to interconnect on-line, web based forms to a web-based server and a database manager
- Smarty, an open-source PHP templating engine
- XHMTL/CSS, the standard markup language for web pages and browser-viewable information

The MySQL database currently consists of 32 tables. Of these, 28 tables hold 191 data items for each of the 21 car classes. Each car class adds an additional 112 pieces of data to the database for that transit agency. Three other tables contain invariant data (constants) and one holds computed data. There are about 2,750 pieces of data in the database collected for the five transit agencies.

A user can retrieve data for a selected question or topic. The data are presented in the same format as the survey form, for the selected transit agency or car class, or for all transit agencies and all car classes.

To aid users who want to explore data relationships within the collected data, the website lets users download selected tables as a Microsoft® Excel file, which can be ported to Microsoft® Access, FileMaker®, or other commonly used desktop file management systems. To make user processing easier, the database tables are not normalized or structured to minimize redundant data entry; the contents are formatted for display as numbers, dates, etc.; and foreign keys are not used as is typical with normalized data tables. Appendix A describes the database design approach and provides technical information on data tables, contents, and formats. Appendix B provides design information on the traindoors.com website.

This open-source, web-based approach chosen for traindoors.com allows continuing extension, enhancement, and maintenance of the database and the website without expensive and proprietary software development tools. Making database access via a website enabled several other important benefits: on-line entry of new data using an interactive questionnaire, a technical forum bulletin board service, and a technical library are all easy to include and useful for the transit community.

The team considered other approaches such as an Access database on a standalone PC. However, these approaches did not offer the same advantages for enabling broad access to data across the transit industry and entailed levels of technical complication for end users that were at cross-purposes to the Train Door team's intentions.

4 TRAINDOORS.COM AND THE TRAIN DOOR PROJECT DATABASE

4.1 Using traindoors.com

The Train Door Project database will be hosted at www.traindoors.com. As of the publication of this digest, the sponsors have delayed public release of the traindoors.com website and database, while they work to resolve issues concerning access to the Train Door data. For the same reasons, data in the following figures—such as transit agency names, car classes, door equipment manufacturer names, and part numbers—have been substituted with alphanumeric identifiers. This substitution enables understanding of the scope and potential value of the database, but does not publicly distribute comparison data and the whole database.

The traindoors.com home page is shown in Figure 2. The navigation tabs provide the following choices:

- **Home:** The page shown in Figure 2.
- **See Results:** These pages allow the display or export of results from the Train Door database.
- **Take Survey:** These pages enable new or modified data for a transit agency to be entered in response to the two questionnaires.
- **Discussion Forum:** These pages are a set of linked topic discussions covering train doors and the website.
- **Resources:** This page links to technical papers about train door technology and provides technical documentation for the Train Door database.
- **About:** This page gives contact information for the website and database.

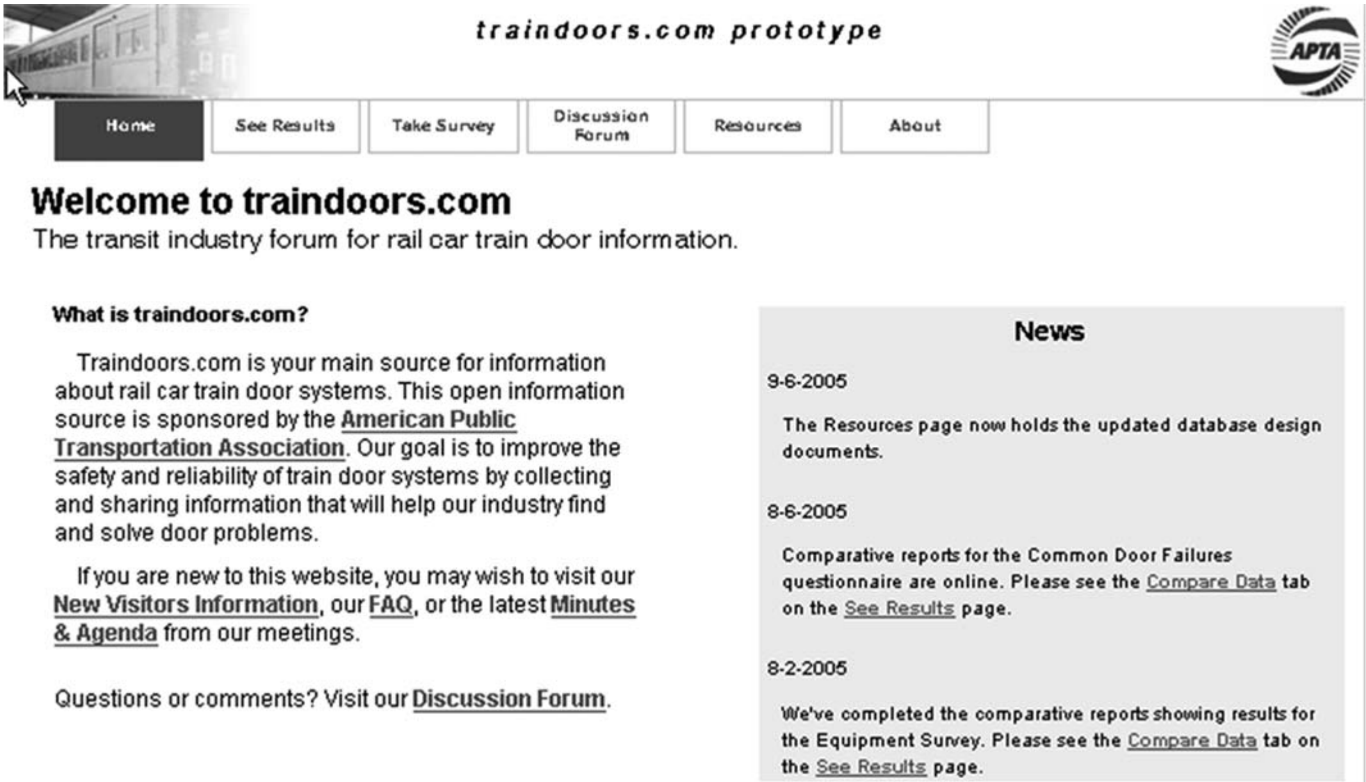


Figure 2 traindoors.com home page.

4.2 Getting Train Door Data

To get data from the Train Door database, a user chooses the See Results tab on the home page, shown in Figure 3.

From here, the user can select from three tabs:

- **One At A Time.** This tab displays selected or complete results for a single transit agency. Here a user can examine complete survey results by transit agency and use the data to look at the details of the selected transit agency's replies to questions on door failures, failure causes for each type of failure, narrative descriptions and definitions such as door MTBF, failure rate and impact, the presentation of operational data, details of door components and equipment, and fleet descriptions within a transit agency. Figure 3 shows the page for choosing these outputs.
- **Compare Data.** This tab displays selected results for equivalent items across *all* transit agencies. For example, asking for a display of causal environmental factors as indicated by each transit agency will display the responses for the selected variable by all transit agencies in table form. For a question about door equipment, the table will give the responses for each car class at each transit agency.
- **Export Data to Excel.** This tab provides data tables for further off-line analysis and processing by the user. The user can import the data into a relational database and make combinational queries, bring the data into a spreadsheet and plot distribution histograms, or undertake any analysis which uses the base data.

Figure 4 shows typical data output from the Compare Data tab, a comparison of train door sensitive-edge equipment. The output shows, for each car class, the type of door sensitive-edge equipment, its basic configuration, and its retrofit status. Appendix C shows examples of other types of output.

The capability to export data to Excel for off-line analysis is an important one. The volume and detail of data invite explorations of relationships among equipment, operations, failures, climate, region, and other differences. The Train Door team did not consider limiting or presetting the combinations that could be analyzed to be practical or desirable. Accordingly, the Export Data to Excel tab allows an interested user direct access to the primary data.

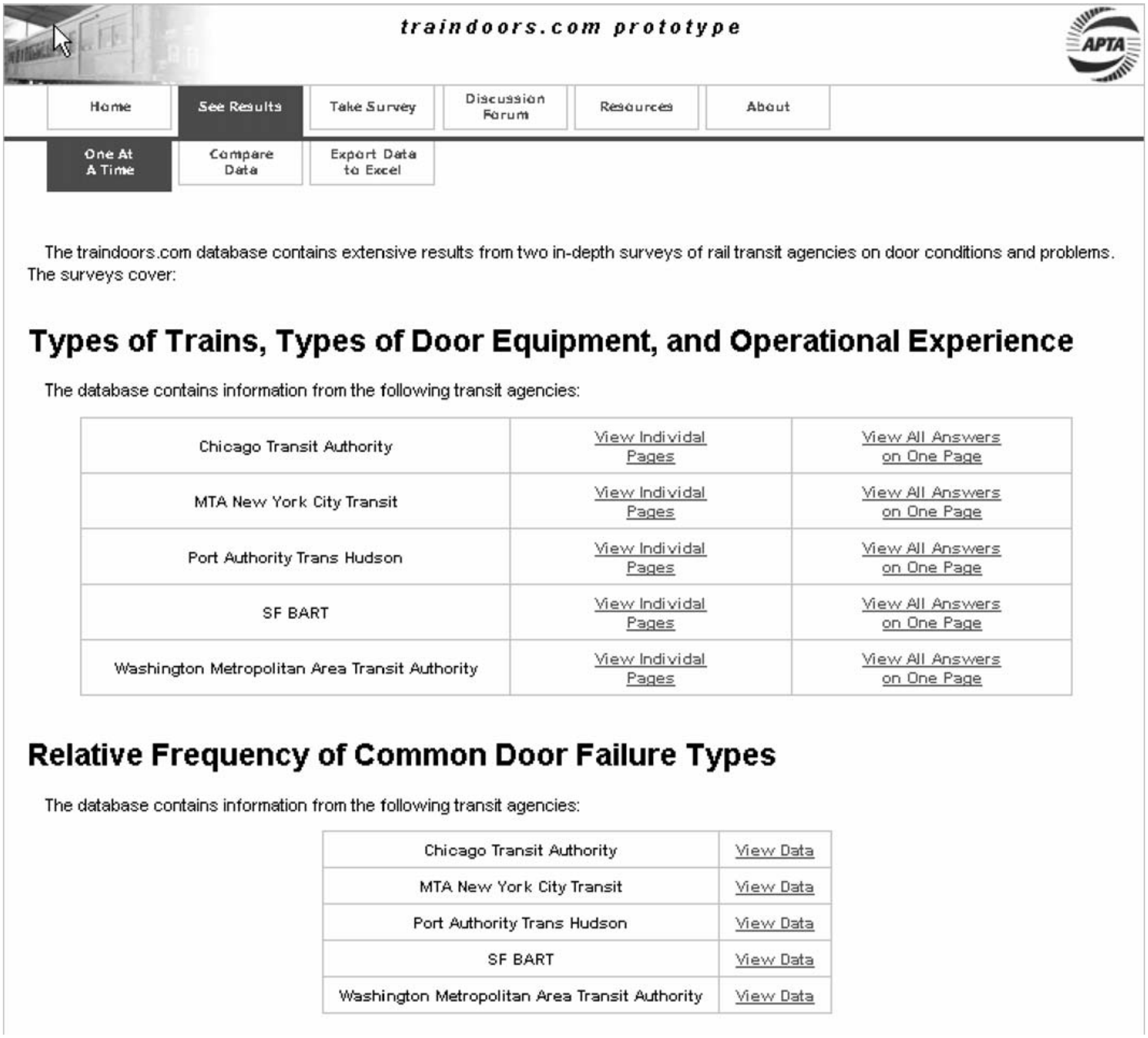


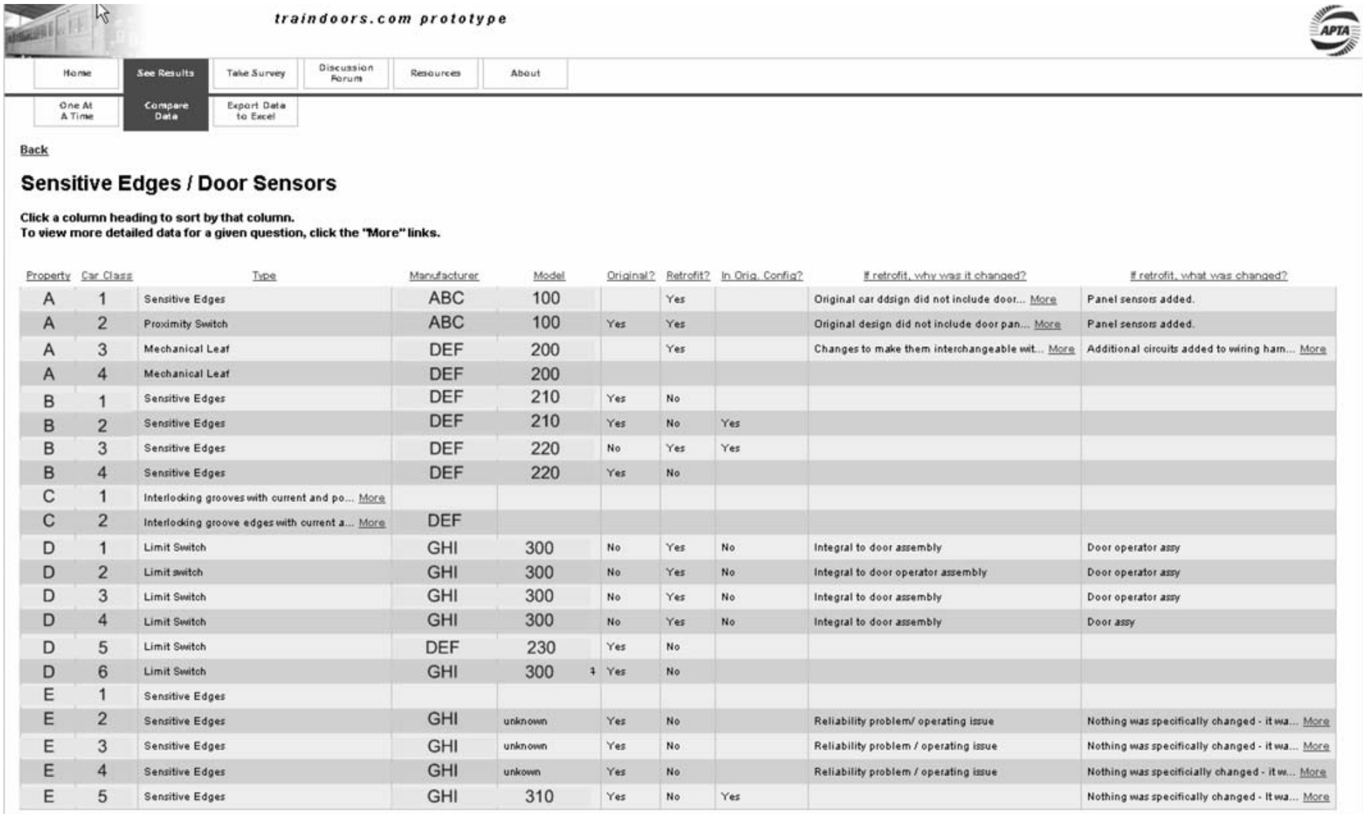
Figure 3 traindoors.com 'see results' page.

For the user who wants to probe deeper into the Train Door database or to view it in a different form, the traindoors.com site permits the user to download selected tables from a drop-down list into an Excel file. This file or files can be used for manipulation as a spreadsheet or flat file for sorting, graphing etc., or in turn be exported to Access or other database applications for the conditional extraction of data. Appendix A provides the complete structure of the MySQL database tables, as well as introductory material describing the database structure.

4.3 Entering New Data

The Train Door team plans to expand the Train Door database by including more transit agencies. Therefore, the traindoors.com website allows easy entry of a new railcar class or an entire new transit agency and all its railcar classes.

The Take Survey tab on the home page brings the user to a log-in screen, shown in Appendix C. Once a new user has an account established by the traindoors.com administrator, the user can access the survey forms on line. Figure 5 shows a typical entry form.


traindoors.com prototype

Home | See Results | Take Survey | Discussion Forum | Resources | About

One At A Time | Compare Data | Export Data to Excel

Back

Sensitive Edges / Door Sensors

Click a column heading to sort by that column.
To view more detailed data for a given question, click the "More" links.

Property	Car Class	Type	Manufacturer	Model	Original?	Retrofit?	In Orig. Config?	If retrofit, why was it changed?	If retrofit, what was changed?
A	1	Sensitive Edges	ABC	100		Yes		Original car ddsign did not include door... More	Panel sensors added.
A	2	Proximity Switch	ABC	100	Yes	Yes		Original design did not include door pan... More	Panel sensors added.
A	3	Mechanical Leaf	DEF	200		Yes		Changes to make them interchangeable wit... More	Additional circuits added to wiring harn... More
A	4	Mechanical Leaf	DEF	200					
B	1	Sensitive Edges	DEF	210	Yes	No			
B	2	Sensitive Edges	DEF	210	Yes	No	Yes		
B	3	Sensitive Edges	DEF	220	No	Yes	Yes		
B	4	Sensitive Edges	DEF	220	Yes	No			
C	1	Interlocking grooves with current and po... More							
C	2	Interlocking groove edges with current a... More	DEF						
D	1	Limit Switch	GHI	300	No	Yes	No	Integral to door assembly	Door operator assy
D	2	Limit switch	GHI	300	No	Yes	No	Integral to door operator assembly	Door operator assy
D	3	Limit Switch	GHI	300	No	Yes	No	Integral to door assembly	Door operator assy
D	4	Limit Switch	GHI	300	No	Yes	No	Integral to door assembly	Door assy
D	5	Limit Switch	DEF	230	Yes	No			
D	6	Limit Switch	GHI	300	Yes	No			
E	1	Sensitive Edges							
E	2	Sensitive Edges	GHI	unknown	Yes	No		Reliability problem/ operating issue	Nothing was specifically changed - it wa... More
E	3	Sensitive Edges	GHI	unknown	Yes	No		Reliability problem / operating issue	Nothing was specifically changed - it wa... More
E	4	Sensitive Edges	GHI	unkown	Yes	No		Reliability problem / operating issue	Nothing was specificially changed - it w... More
E	5	Sensitive Edges	GHI	310	Yes	No	Yes		Nothing was specifically changed - It wa... More

Figure 4 Sensitive-edge comparison results.

The on-line data entry form has several key advantages:

- The questionnaire is readily available at all times.
- There is no added work for a clerk to translate the answers from one form to another.
- Each entry is pre-formatted, so each new data set will be in a data format compatible with all the other data.

5 FIRST RESULTS

Preliminary analysis of the data collected with the two questionnaires suggests failure areas requiring improvement and directions for future research and analysis.

5.1 Component Causes of Common Door Failures

Figure 6 compiles the frequency of component causes of the seven common door failures studied in the second questionnaire. The chart shows the distribution of tallies of component causes for all of the seven common door failures, weighted by the frequency with which the response was given, for all transit agencies, for all car classes, and for all types of door failures. For each of the seven door failures, the questionnaire asks the transit agency to rank the relative frequency with which each of fourteen possible causal component items contributed to the door failure. Causal component items reported as having frequency '1,' least often, were not tallied in the totals for Figure 6.

The seven causal components—switch/sensor, interlock, local door controller, threshold/bottom guide, door push button, door operator motor, and unlock mechanism—account for 55% of the total door failure incidents reported by the five transit agencies. The components causing the other 45% of the reported door failure incidents are trainline, car network, electric coupler, door panel, short or open circuit, design problem requiring modification, and other.

Figure 6 shows that switches/sensors were the causal component in 12% of the common door failures. Door push buttons were the causal component in 6% of the common door failures. Because switches/sensors and door push buttons are switch-type de-

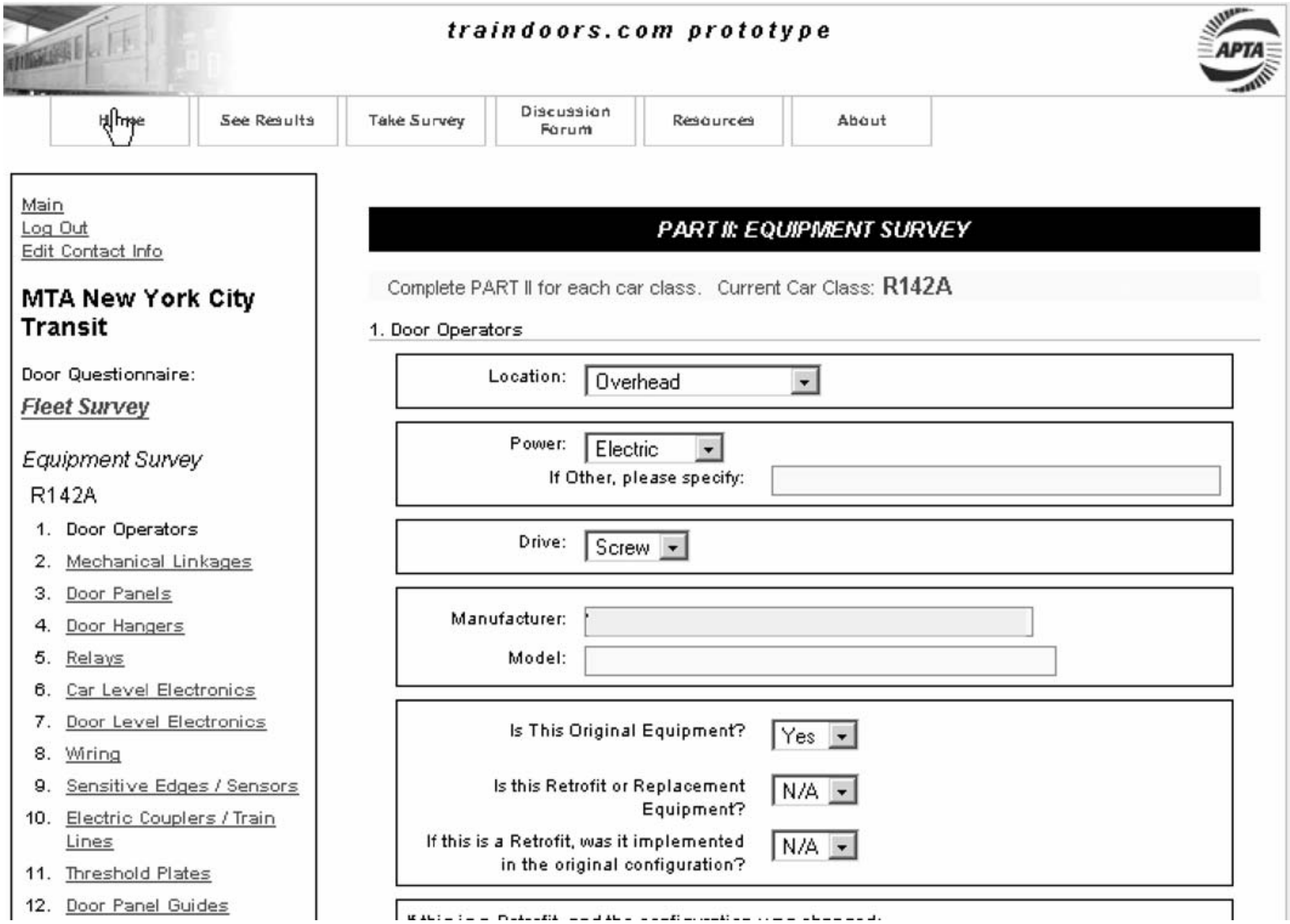


Figure 5 Train Door questionnaire data entry form.

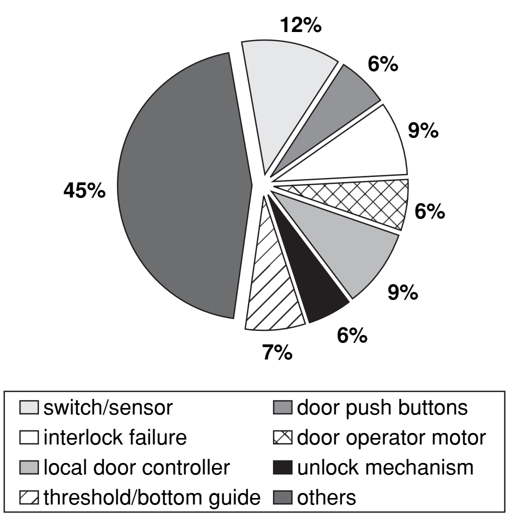


Figure 6 Distribution of reported causes.

vices, Figure 6 shows that switches of some sort were identified as the causal component in 18% of all reported door system failures. The figure suggests that a focused effort to improve door switch reliability could have a big positive impact on door and transit service.

5.2 Door Failures by Railcar Class

In the first questionnaire, question 4 in Part II, Operations, deals with train delays caused by doors, reported by car class. Other parts of the questionnaire divide delays into three levels: Level 1, where the train operator clears the door fault (e.g., by re-cycling door open/door close command); Level 2, where the train operator reports to central control for assistance (i.e., a service delay is reported); and Level 3, where the train is removed from service and passengers disembarked (i.e., a significant delay). However, this question 4 includes any of the delay levels.

The collected data, shown in Figure 7, show great variation in the impact of doors, depending on the railcar and transit agency. The figure suggests that a focused effort to address failures of doors on certain railcar classes at transit agencies B, C, D, and E could have a big positive impact on service.

5.3 Door Problems by Season

In the first questionnaire, question 6 in Part II, Operations, deals with train delay variation by season. The collected data, shown in Figure 8, show variations in the impact of door problems by season among transit agencies. Some variations seem correlated to weather and some do not.

For example, transit agency 'A' in a moderate climate has the least variation in weather, and the least reported weather effects. The other transit agencies are in four-season climates and show some sign of seasonal effects. The figure suggests that winter effects are the most consistent and, therefore, implies that a design effort concerning weather effects and door reliability should start with those possible winter effects.

5.4 Types of Door Failures

In the first questionnaire, question 7 in Part II, Operations, deals with train delay by type of door failure. The collected data, shown in Figure 9, show a substantial variation by agency and car class.

Door opening en route is a substantial hazard, as it exposes riders to the risk of falling out of a moving train. Phantom operation occurs when doors open or close under safe conditions but without driver command. Sticking doors do not fully open or fully close and require driver intervention. Loss of operator means that the door cannot operate at all and must be taken out of service.

The 'A,' 'B,' and 'C' transit agencies have many failures because of no motion indications, while the other transit agencies show few incidents of this type. All transit agencies and car classes report substantial problems with sticking, except the car class 'B1' at transit agency 'B.' Phantom operation is a problem in some cars but not in others.

The variations in these data suggest that further analysis will be useful to understand why a failure type is significant at one transit agency or in one car class but not significant in another.

5.5 Factors Affecting Satisfactory Operations and Reliability

In the first questionnaire, question 8 in Part II, Operations, deals with factors affecting satisfactory operations and reliability, including maintenance, passengers, design, environment, and employee actions. The collected data, shown in Figure 10, show a substantial variation in effects.

Maintenance affects door operations for every reporting car class, and at transit agency 'E' it is the principal effect. Passenger use is a consistent cause of door incidents, as is to be expected. Most of the "other" cases indicate no trouble was found during maintenance, which often indicates an intermittent

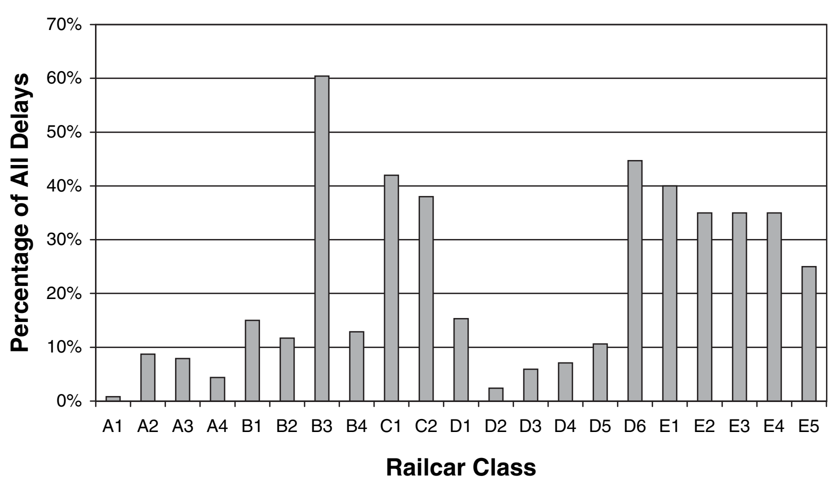


Figure 7 Train delays due to doors.

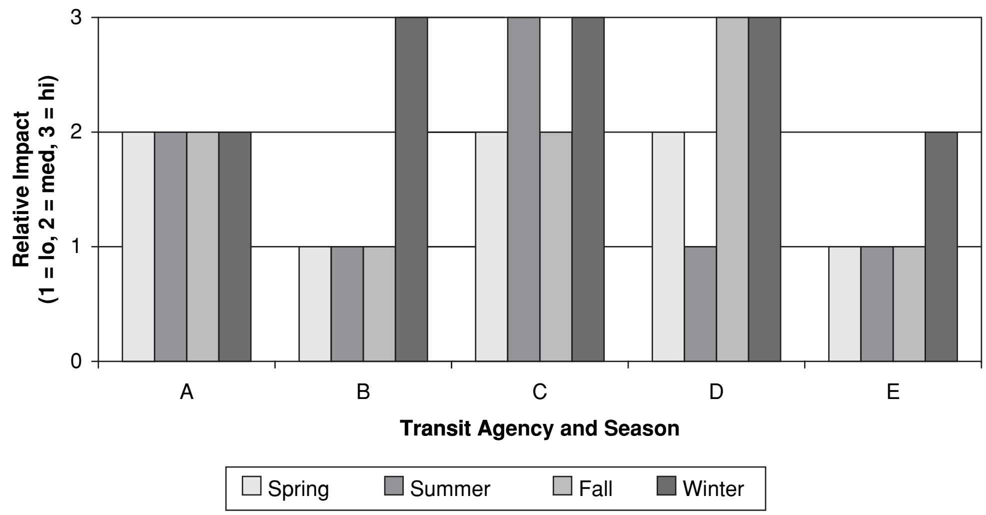


Figure 8 Door problems by season.

design condition. Environment and design are small to medium factors.

The data suggest that improved maintenance tools, techniques, training, and design provisions in support of maintenance could have a big positive impact on service.

6 THE PATH FORWARD

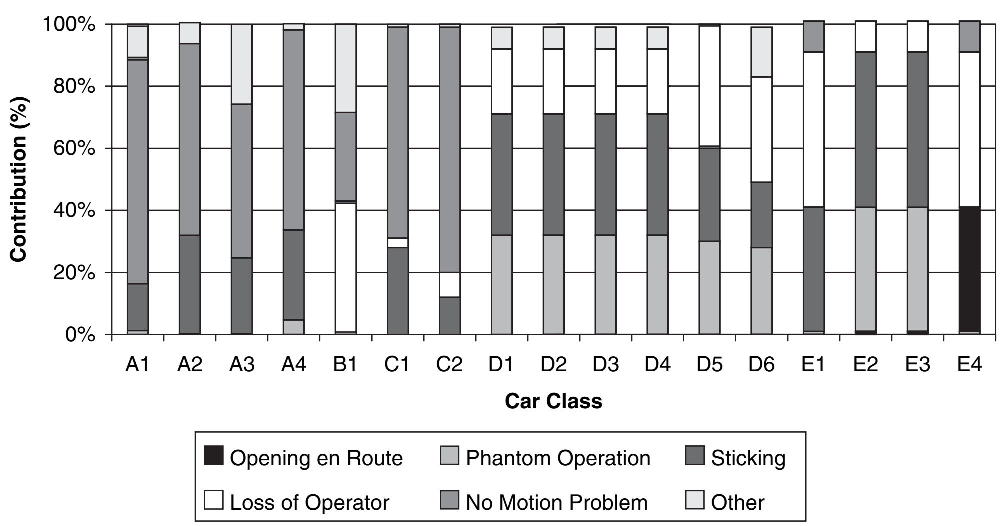
To the best of the team's knowledge, the collection of data presented on traindoors.com is unique in the transit world. Nowhere else is it possible to access detailed, usable, timely data on a rail transit vehicle subsystem from leading transit agencies.

Such data are important to a specialized community. While the transit equipment engineering community is barely known in the broad world, its work has a big impact on rail transit reliability and safety and on the daily commuting experience of millions of people, every day.

6.1 Recommendations and Next Steps

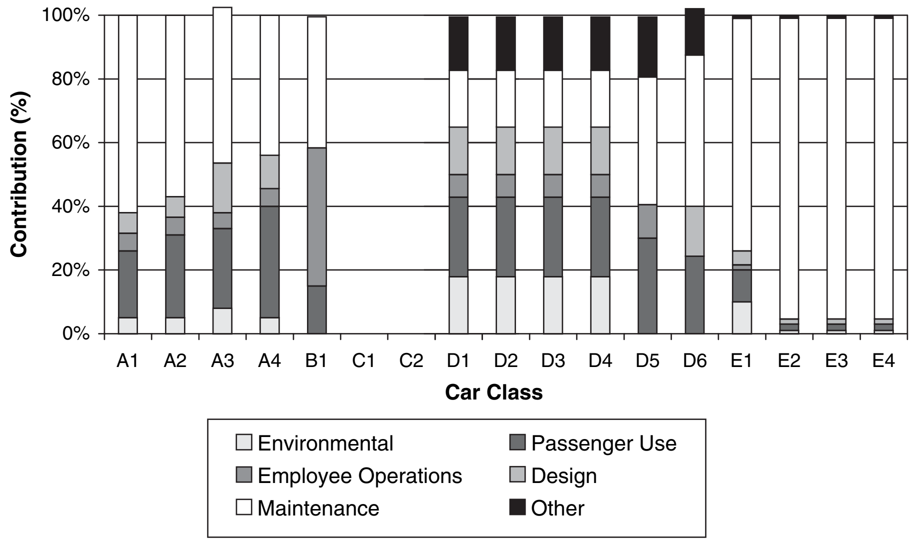
6.1.1 Next Steps for traindoors.com

- Determine how to handle sensitive data such as manufacturer details.
- Use the on-line questionnaire to guide collection of data in uniform format.



Rounding caused some totals to add to slightly less than or more than 100%.

Figure 9 Door failures by type.



Rounding caused some totals to add to slightly more than 100%.

Figure 10 Factors affecting satisfactory operations and reliability.

- Expand the database to cover maintenance and other performance aspects.
- Solicit and encourage participation from other transit agencies.
- Continue and expand the data analysis. Address key questions such as
  - "What should I change in the specifications for my next door equipment procurement?"
  - "I'm having door switch and sensor problems. Anyone else have this problem?"

6.1.2 Next Steps for the Transit Industry

- Evaluate value and utility of traindoors.com.
- Determine whether the concept should be extended to collect similar or expanded data on other equipment reliability and performance characteristics.

6.2 Cautionary Note

Users should be aware that, although there is a plethora of information in the Train Door database, it comes from only five transit agencies. The possibility exists that the sample of data, while covering a great number of topics and including a substantial amount of detailed technical information, may not be deep enough to provide conclusive evidence of a trend or possibility. Accordingly, the Train Door database at this stage should be considered one tool, but not the last word, in analyzing train door conditions and failures.

6.3 Conclusions

The general conclusions from the team's collection effort to date have confirmed to the team the following:

- The steps reported here to collect, manage, and report on train door data are effective in collecting transit industry information that can provide important and useful results.
- The common door failures questionnaire provides a valuable source of data to focus on specific door system components.
- The data reported by the transit agencies point to problems caused by switches, sensors, and push buttons.

7 ACKNOWLEDGMENTS

The generous and energetic contributions of scores of supporters and participants are recognized and appreciated.

Thanks to the APTA RSETF, whose ranks produced many volunteers and contributors to this project. The team membership grew to include 30 participants, including rail car manufacturers Alstom Transport and Kawasaki Rail Car; door equipment manufacturer Faiveley Rail Corporation; engineering consulting firms Booz•Allen & Hamilton, LTK Engineering, Interfleet Technologies, Transportation Systems Design, and Turner Engineering Company; and transit agencies BART, CTA, Delaware Area Port Authority (DRPA), NYCT, PATH, and WMATA.

Thanks to TCRP and to the National Academies, whose encouragement has been vital to performing the research, maintaining the momentum, and enabling the development and building of traindoors.com.

Grateful acknowledgement to the pivotal contributions and hard work of the staff and CEOs of the five transit agency participants: BART, CTA, NYCT, PATH, and WMATA. Their data are valuable to the community, and it, collectively, can yield valuable benefits for the transit agencies and the riding public.

Special thanks to the working group for TCRP Project J-6, Task 62, for their dedication to this project, in particular Paul Messina, MTA New York City Transit; Christopher Pacher, LTK Engineering Services; and Harry Burt, LB Transportation Consultants. Also for their dedication to this project, special thanks to Connie Hwang, Aleph Associates, and David Turner, Turner Engineering Company.

Finally, gratitude and fond remembrances to Tom Sullivan, whose skills, enthusiasm, technological grasp, courage, and gentle leadership were so important to starting, guiding, and executing the work reported here.

APPENDIXES

Appendixes are posted on the TRB website as *TCRP Web-Only Document 28* (www4.trb.org/trb/onlinepubs.nsf/).

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