REVIEW OF CAPACITY MEASUREMENT
METHODOLOGIES; SIMILARITIES AND DIFFERENCES IN
THE U.S. AND EUROPEAN RAILROADS

Hamed Pouryousef*
PhD Candidate at Rail Transportation Program,
Civil and Environmental Engineering Department, Michigan Tech. University,
1400 Townsend Drive, Houghton, MI 49931
phone: (906)-231-2320
hpouryou@mtu.edu

Pasi Lautala, Ph.D, P.E.
Assistant Professor
Director, Rail Transportation Program,
Michigan Tech Transportation Institute (MTTI), Michigan Tech. University,
1400 Townsend Drive, Houghton, MI 49931
phone: (906)-487-3547
ptlautal@mtu.edu

Thomas White,
Senior Operations Specialist
Transit Safety Management
3604 220th PI SW
Mountlake Terrace WA 98043
phone: 425-771-4289
taw@vtld.net

* Corresponding Author

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ABSTRACT

Most passenger rail services in the United States (U.S.) operate on corridors that are shared with freight traffic, creating more complicated operation practices. As the demand for passenger and freight transportation grows and emphasis is placed on increased speed and on-time performance of passenger services, the available capacity is further consumed. Where higher speed passenger trains are mixed with freight, the increased heterogeneity from expanding speed differential creates further challenges for reliable operations. Based on the experiences in the other parts of the world, the required reliability is typically secured through structured/planned/scheduled operation. As the U.S. continues to develop higher speed passenger service with similar characteristics to those in European shared-use lines, the accuracy of capacity analysis methods becomes more important, and tools applied in Europe may become more applicable to the U.S. conditions as well. This paper presents the fundamental particulars on railway capacity obtained through the literature review. It will provide a brief review of capacity definitions used in both Europe and the U.S., followed by description of differences in the respective rail systems. The paper will also introduce the main methodologies of capacity measurement approaches, and highlights several capacity analysis case studies conducted in the U.S. and Europe.

INTRODUCTION

Typically, the capacity of rail line is defined as the number of trains that can safely pass along a given segment of the line through a period of time and is affected by different system configurations, such as: 1) Track infrastructure, 2) Signaling system, 3) Operations philosophy, and 4) Rolling stock.

The configuration differences between European and the U.S. rail systems may lead to different methodologies, techniques, and tools to evaluate and measure the capacity levels. There are high utilization corridors in Europe where intercity passenger, commuter, freight, and even high speed services operate on shared tracks and where all train movements follow highly structured timetables and schedules. In the U.S. the prevalent operations pattern on current shared corridors is improvised operational philosophy where some trains are assigned their slots in the network on a daily basis. Recently, the U.S. has placed an increasing emphasis to introduce new, or to incrementally increase the speeds of passenger services on selected shared corridors [1] while the slower speed freight rail transportation is also expected to increase [2]. These increases in volumes and operational heterogeneity can be expected to add pressure for higher capacity utilization of the U.S. shared-use corridors. Capacity measurement and analysis approaches, methods and tools play a crucial part in preparing the U.S. network for these changes. The accuracy and applicability of these in the U.S. environment should be carefully evaluated. It would also be beneficial to investigate whether the analysis and operations approaches utilized in Europe would provide any benefits for the U.S. application.

This paper focuses on reviewing the capacity analysis approaches and methodologies in the U.S. and Europe. The paper provides a brief review of different capacity definitions, identifies main differences between the U.S. and European rail systems, reviews the main methodologies of capacity measurement approaches, and highlights several capacity analysis case studies conducted in the U.S. and Europe.

WHAT IS CAPACITY?

Capacity Concept and Definitions

The definition used for rail capacity in the literature varies based on the techniques and objectives of the specific study. For instance, Barkan and Lai defined capacity as "a measure of the ability to move a specific amount of traffic over a defined rail line in the U.S. rail environment with a given set of resources
under a specific service plan, known as level of service (LOS). They listed several infrastructure and operational characteristics which affect capacity levels, such as: length of subdivision, siding length and spacing, intermediate signal spacing, percentage of number of tracks (single, double and multi-tracks), heterogeneity in train types (train length, power-to-weight ratios). [3] In another piece of U.S. literature, Tolliver introduced freight rail capacity as the number of trains per day for typical track configurations depending on several factors, such as track segment length, train speed, signal aspects and signal block length, directional traffic balance, and peaking characteristics. [4] American Railway Engineering and Maintenance-of-way Association (AREMA) offers a simplified approach for line capacity that estimates practical capacity by multiplying theoretical capacity ($C_t$) and dispatching efficiency ($E$) of the line ($C = C_t \times E$). AREMA’s method for calculating theoretical capacity and dispatching efficiency require consideration of various factors, such as number of tracks, the operations rules (single or bi-direction operation), stopping distance between trains (or headway), alignment specifications (grade, curves, sidings, etc.), trains specifications (type of train, length, weight, etc.), maintenance activities requirements, and the signaling and train control systems. [5] In Europe, the most common method for capacity analysis is provided by International Union of Railways (UIC) code 406. According to UIC 406, there is no solid definition of capacity and the railroad infrastructure capacity concerns and expectations vary between different points of view by railroad customers, infrastructure planner, timetable planner, and railroad operators. UIC also emphasizes that the capacity is affected by interdependencies and the interrelationship between the four major elements of railroad as shown in Figure 1. [6]

![FIGURE 1- Capacity balance according to UIC code 406 definition](image)

According to UIC, the "Theoretical Capacity" is the absolute maximum capacity which can be achieved subject to:

- Absolute train-path harmony (the same parameters for majority of trains)
- Minimum headway (shortest possible spacing for all trains)
- Providing best quality of service

UIC also recognizes that it is almost impossible to achieve theoretical capacity in practice. [6]
Besides the UIC literature, research conducted as part of European Commission’s Improve Rail project produced a definition of ultimate capacity that was similar to the UIC’s theoretical capacity definition, but placed higher emphasis on the train schedules and running time. [7]

**Capacity Metrics**

The literature divides the main types of metrics to measure the capacity levels to three groups: throughput (such as number of trains, tons, train-miles), level of service (LOS) (terminal/station dwell, punctuality/reliability factor, and delay), and asset utilization (velocity, infrastructure occupation time or percentage). [8] In 1975, The Federal Railroad Administration (FRA) introduced a parametric approach developed by “Peat, Marwick, Mitchell and Co” to measure capacity in the U.S. rail network based on delay unit (hours per 100 miles per train per day). [4] The European rail operators typically use throughput metrics (number of trains per day or hours) to measure the capacity levels, although punctuality and asset utilization metrics are also applied as secondary units. [7, 9]

**MAIN DIFFERENCES BETWEEN THE U.S. AND EUROPEAN RAIL SYSTEMS**

The U.S. and European rail networks have several similarities, such as operating mixed traffic on shared-use corridors, and using modern signaling and traffic control systems (e.g., developing ETCS in Europe and PTC in the U.S.). On the other hand, significant differences between the U.S. and European networks also exist and they may change the preferred methodologies and the outcomes of capacity analysis. Figure 2 and the following discussion uses the literature review to highlight some of the key differences between infrastructure, signaling, operations and rolling stock in Europe and the U.S.

![Figure 2- The main differences in the U.S. and Europe rail systems](image.png)

**Infrastructure Characteristics**

- **Public vs. Private Ownership of Infrastructure**: The ownership of rail infrastructure is one of the main differences between Europe and the U.S. rail networks. More than 90% of the infrastructure is
owned and managed by private freight railroads in the U.S.; while almost all infrastructures are owned and managed by governments or public agencies in Europe. In addition, operations and infrastructure are vertically separated in Europe while in the U.S., the majority of operations (mainly freight) are handled by the same corporations who own the infrastructure. The ownership and vertical separation have wide impact in the railway system. Perhaps the greatest effect is on the prioritization of operations and accessibility for operating companies, but other aspects, such as operations philosophy, maintenance strategy and practices, signaling and train control systems, rolling stock configuration, and capital investment criteria are also affected. [4, 10]

- **Single vs. Double-Track:** More than 46% of rail corridors in Europe are at least double-track [11, 12], while approximately 80% of the U.S. rail lines are single-track. [2, 4]

- **Directional vs. Bidirectional:** Most of the U.S. double tracks operate in bidirectional fashion and use crossovers along the corridor, while directional operation with intermediate sidings and stations is the common approach in Europe. [4]

- **Distance between Sidings:** The distances between stations and sidings in the European rail network are generally shorter than the U.S. The siding distribution rate throughout the European network (total route mileage per number of stations, including freight and passenger services) is approximately four miles/station in both UK and Germany [12, 13]. In the U.S. the distance between sidings varies greatly and passing sidings on double-track sections are relatively far apart. [10, 14]

- **Siding Length:** Siding/yard tracks in the U.S. are typically longer than the European rail network, but in many cases are still not sufficient for the longest freight trains. [10, 15]

- **Track Conditions:** Typically, railroad structure in the U.S. is designed for higher axle loads, but tighter horizontal curves (shorter radius) and lower maximum speed operations, in comparison to the European rail network. [10, 15]

- **Grade Crossings:** There are approximately 227,000 grade-crossings in operation along the main lines in the U.S. [16, 17], while there are few grade-crossings along main corridors in Europe. High frequency of grade crossings and difficulty of elimination is an operational and safety challenge for increased train speeds. [18]

**Signaling Characteristics**

- **Manual blocking vs. signaling systems:** Manual blocking is absent on main passenger corridors in the U.S. today, but some of the planned passenger corridors are located along such lines. On the other hand, most shared-use corridors in Europe are equipped with one of the common blocking systems. [19]

- **Cab Signaling:** A more significant difference is the extensive use of cab signaling and enforced signal systems (among which are PTC systems such as ETMS) in Europe, while such implementation is limited in the U.S. [10]

**Operation Characteristics**

- **Improvised vs. Structured Operation:** The U.S. operations philosophy is based on the improvised pattern, (no repeatable dispatching plan in-advance) for almost all freight trains, except some intermodal trains. On the passenger side, many Amtrak and commuter train daily operation patterns are also developed without details, anticipating improvised resolution of conflict among the passenger trains, or between passenger and freight trains. In Europe, almost all freight and passenger trains have a regular schedule developed well in advance, known as structured operations. [20]

- **Preponderance Freight vs. Passenger Traffic:** The preponderance of U.S. rail traffic is freight while the preponderance of European rail traffic is passenger rail. [4, 21]

- **Delay vs. Waiting Time:** Delay (deviation of train arrival/departure time from what was predicted/planned) and waiting time (scheduled time spent at stations for passing or meeting another train) are two fundamental concepts in the railroad operations. The waiting time concept is typically used in the European rail operation management due to the structured operations pattern in Europe.
Delay is more used in the U.S. capacity analysis as the main capacity metric, while it is limited in Europe to the events that are not predictable in advance. [20]

- **Punctuality**: The punctuality of trains is quite different in the U.S and Europe. Amtrak's trains are considered on-time if they arrive within 15 minutes of a scheduled timetable for short distance journeys (less than 500 miles) or within 30 minutes for long distance trains (over 500 miles). In 2011, Amtrak trains' punctuality was 77% for long-distance trains, 84% for short-distance trains, and 92% for Acela. According to Amtrak, more than 70% of passenger train delays are caused either by the freight trains performance or infrastructure failure. [22] The passenger trains in Europe have shorter average delay per train. For instance, Network Rail in the UK reported that about 90% of all passenger trains were punctual with arrival time deviation within five minutes from planned timetable (short-distance trains) and 10 minutes (long-distance trains) [23]. In Switzerland, more than 95% of all passenger trains are punctual with an arrival delay of five minutes or less. [24] The punctuality of European freight trains in 2003 was reported to be approximately 70%. [25]

**Rolling Stock Characteristics**

- **Train configuration (length and speed)**: Typically freight trains in the U.S. are longer and heavier than freight trains in Europe. Based on the Association of American Railroads (AAR), the number of cars in the average U.S. freight train varies between 63-164 in West and 57-110 in East, while the typical number in Europe is 25-40. In addition, the average speed of intercity passenger trains in Europe is faster than in the U.S. [2, 10, 15]. Freight trains also typically operate on higher speeds and with less variability in Europe.

- **Diversity of Freight vs. Passenger Trains**: The U.S. rail transportation is more concentrated on the freight trains than Europe, and there is a great diversity between the types, lengths, etc. of freight trains. On the passenger side, Europe has more diverse configurations (such as speed, propulsion, train type, power assignment, HSR services, diesel and electric multi-unit trains) in comparison to the U.S. [2, 19]

While the principles of rail capacity remain the same in all rail networks, the characteristics reviewed above all have an effect on capacity and its utilization. What remains unclear is the effect of these differences in various capacity analysis tools and methodologies used and whether they limit the applicability of the U.S. tools in the European environment and vice versa.

**CAPACITY MEASUREMENT, ANALYTICAL, SIMULATION AND COMBINED APPROACHES**

The literature classifies capacity analysis approaches and methodologies in several different ways. Even though the approaches differ, the input data for most of them is similar and includes infrastructure and rolling stock data, operation rules and signaling features. Abril, et al., classified the capacity methodologies as analytical methods, optimization methods, and simulation methods. [26] Joern Pachl divided the capacity methodologies into two major classes: analytic and simulation. [27] Similar categorization was used in research conducted by Murali on delay estimation technique. [28] Khadem Sameni, and Preston, et al., categorized capacity methods to timetable based and non-timetable based approaches. [8] Finally, research conducted at the University of Illinois, Sogin, Barkan, et al., classified capacity methods as theoretical (analytical), parametric, and simulation methods. [3, 29] The analytical and simulation methods are the most common methods found in the literature. For our review, we have divided methods into three groups; analytical, simulation, and combined. Although the term "combined methodology" is not a commonly used term in the reviewed literature, we added it as new class, because many studies take advantage of both analytical and simulation methods.
Analytical Approach

The analytical approach typically uses several steps of data processing through mathematical equations or algebraic expressions and is often used to determine a solution for the problem (theoretical capacity). [26] The outcomes vary based on the level of complexity of the scenario and may be as simple as the number of trains per day, or include a combination of several performance indicators, such as timetable, track occupancy chart, fuel consumption, speed diagrams, etc. Analytical methods can be conducted with or without specific software. One example of analytical capacity software is SLS PLUS in Germany. SLS PLUS is used in the German rail network (DB Netz AG) for estimating capacity through analytical determination of the performance, asynchronous simulation and manual timetable construction. [30] Figure 3 presents the different methodologies that can be used in the analytical approach and how complexity, such as optimization and timetable compression methods, can be added to provide more detailed results of capacity estimation. In some cases, analytical models are introduced under different names like optimization methods or parametric models, taking advantage of different modeling features, such as probabilistic distribution or timetable optimization. The latter method, timetable optimization, is typically achieved by using specific software, or specific simulation tools. [26, 27]
Timetable compression method is one of the main analytical approaches in Europe to improve the capacity levels, especially for those corridors which have pre-scheduled timetables of all daily trains (structured operation pattern). A majority of techniques and tools for improving the capacity levels in Europe, including the UIC method (leaflet 406), are partly developed based on timetable compression. [6, 9, 31-33] The UIC's method modifies the pre-scheduled timetable and reschedules the trains as close as possible to each other. [26] Figure 4 provides an example of the methodology where a given timetable of trains along a quadruple segment of tracks (Scenario a) is first modified by compressing the timetable (Scenario b) and then further improved by optimizing the order of trains (Scenario c). As demonstrated, the third scenario could provide a higher level of theoretical capacity in comparison to the scenarios a, and b. [9]

![Figure 4](chart layout follows typical European presentation) [9]

**Simulation Approach**

Simulation is an imitation of a system's operation which should be as close as possible to its real-world equivalent. [26] The process of simulation is repeated several times until an acceptable result is achieved by the software (Heuristic approach). The data needed for the simulation are similar to the analytical methods, but typically at a higher level of detail. The simulation practices in rail industry started in the early 1980s by developing models and techniques, such as dynamic programming and branch-and-bound, proposed by Petersen, as well as heuristic methods developed by Welch and Gussow in 1986. Today, the simulation process utilizes computer tools to handle sophisticated computations and the stochastic models in a faster and more efficient way. The commercial railroad simulation software is typically developed based on two major components; 1) Train movement simulation, and 2) Train dispatching simulation. The first component calculates the train speed along the track by using the train resistance formula (like Davis equation) and train traction power. The dispatching simulation component typically emulates (or attempts to emulate) the action of the dispatcher in improvising traffic management, but in some cases, it can be used as part of a traffic management software to help traffic dispatchers to manage and organize the daily trains’ schedules. [20]

According to Pachl, the simulation method can also be divided into asynchronous and synchronous methods. Asynchronous simulation attempts to consider stochastically generated train paths within a timetable, following the scheduling rules and the train priorities. In synchronous simulation, the process of rail operations is followed in real time sequences and the results are expected to be closely aligned with data of real operations. In contrast to asynchronous method, it cannot directly simulate the scheduling, or develop a timetable, unless the simulation results are used by additional computer tools and programs to create a timetable. [27] The outputs of simulation software typically include several parameters such as delay, dwell time, waiting time, elapsed time (all travel time), transit time (time between scheduled stops), trains speed, and fuel consumption of trains. [20, 26]
Simulation Methods: Timetable Based vs. Non-timetable Based

The commercial railroad simulation software can be classified in two major groups; 1) non-timetable based vs. 2) timetable based. The non-timetable based simulations are typically applied in railways that operate based on the improvised operation pattern without initial timetable, such as the majority of the U.S. rail network. In this type of simulation, after loading the input data in the software, the train dispatching simulation process improvises the departure times from the initial station that are included in the input data. The software may encounter a problem to assign all trains and request assistance from the software user to resolve the issue by adjusting the train data, or by modifying the schedule constraints. [8, 20] The rail traffic controller (RTC), developed by Berkeley Simulation Software is the most common software in this category, used extensively by the U.S. rail industry. [8]

The simulation procedure in timetable based software (typically used in Europe) is based on the initial timetable of trains and uses software tools to improve the timetable as much as possible. The UIC's capacity approach would be one of the main theories behind timetable based simulation approach. The simulation process in this methodology begins with creating a timetable for each particular train. In the case of schedule conflict between trains, the user must change the timetable until the feasible schedule is achieved; however, the user interference is not arbitrary as in the improvised method, but it is implemented as part of the simulation process. [20] Common software used in this category are: MultiRail (U.S), RAILSIM (U.S), OpenTrack (Switzerland), SIMONE (Netherlands), RailSys (Germany), DEMIURGE (France), RAILCAP (Belgium), and CMS (UK). [8, 26]

Combined Analytical-Simulation Approach

In the combined approach, simulation tools are used to evaluate and understand the capacity bottlenecks through the corridor, and analytical methods are developed to improve the capacity utilization levels. The process of applying simulation-analytical practices may be repeated by the research team until an acceptable set of outputs and alternatives is found. (Figure 5)

![Simulation results] - Comparing the results - Interpreting
Analytical results - Rearrangement/Modification
Conclusion and Suggestions on Capacity

FIGURE 5 - Basic diagram of combined analytical-simulation approach to evaluate capacity

As an example of combined analytical-simulation approach, the Missouri DOT analyzed the rail capacity on the Union Pacific (UP) line between St. Louis to Kansas City in 2007 to improve the reliability of service for the passenger trains and to reduce the freight train delay. Six different alternatives were generated based on a Theory of Constraints analysis and then compared with each other using the Arena simulation method. Finally, a set of recommendations were proposed with respect to delay reduction and capital investment for each proposed alternative. [34]

In another project, Washington DOT (WSDOT) conducted a master plan in 2006 to provide a detailed operation and capital plan for the Amtrak Cascades intercity passenger rail program. The capacity of the corridor was also evaluated using the combined simulation-analytical approach. First, analytical methods were used to determine the proposed infrastructure. The proposed traffic and infrastructure were simulated with RTC software to test the infrastructure and operational results. After running simulation on RTC software, an analytical method, called Root Cause analysis, was applied to
evaluate the simulation output. The objective of Root Cause analysis method was to re-adjust the simulation outputs to be more accurate, in addition to locating infrastructure bottlenecks which caused the capacity issues and delays. [35]

The Swedish National Rail Administration (Banverket) carried out a research project in 2005 to evaluate the application of the UIC capacity methodology (timetable compression) for the Swedish rail network. Railsys software was used for the simulations and the research team analytically evaluated the capacity consumption, its relationship with time supplements and the traffic simulation punctuality. The research concluded that the time supplements are absolutely necessary for the recovery time. When there is no time supplement, the service punctuality can be significantly degraded by increasing capacity consumption. Banverket also confirmed the validity of the framework and the results of the UIC’s approach in their network and asked their experts and consultants to implement this capacity approach when using different software such as Railsys, Simon, and OpenTrack. [32]

REVIEW OF CAPACITY CASE STUDIES IN THE U.S. AND EUROPE

Several capacity-related case studies (CS) have been conducted in the U.S. and Europe. The research team reviewed more than 40 studies and selected studies (16 of them) that included sufficiently detailed explanation of the used capacity analysis approach and respective results for further review and evaluation. Table 1 and the following discussion summarize the approach, tools, purpose, types of effort and outcomes, and accuracy assessment of these case studies.

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<th>TABLE 1- Review of 16 selected Case Studies (CS) in the U.S. and Europe [2, 3, 8, 9, 20, 24, 28, 31, 32, 34-40]</th>
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Approach: Most case studies used either simulation or combined analytical-simulation approaches. Yet, research conducted by Association of American Railroads (AAR), University of Illinois at Urbana-Champaign (UIUC) and University of Southern California (USC), applied analytical-only methodologies.

Tools and Software: All European case studies used timetable based simulation software while the U.S. case studies relied on other tools like optimization/parametric modeling (applied by UIUC and USC), general simulation software (e.g., Arena) and non-timetable based rail capacity software (RTC).

Purpose of Research: Three different subcategories of research purposes were identified: 1) introducing new methodology for capacity evaluation, 2) evaluating the capacity status of a given corridor as part of a corridor master plan development, and 3) an academic research on different capacity issues. The majority of European case studies (Denmark, Austria, and Switzerland) were conducted by industry to justify and evaluate the UIC's approach (UIC code 406) for capacity methodology while the objectives of the U.S. case studies included all three subcategories.

Type of Outcomes or Solutions: The outcomes and solutions obtained from the U.S. case studies varied from delay analysis and suggested improvements (UIUC by using RTC and USC by using Awesim/Minitab), to rescheduling and recommendations related to current operations (UIUC and White), infrastructure development, and combination of all outcomes mentioned above (typically as part of the master plans). In addition, new tools and parametric models were also evaluated as the final outcome of three U.S. case studies (all by USC). The outcomes of European case studies were not as diverse, as they either approved the application of UIC's capacity methodology to be used on their network, or suggested network rescheduling and operational changes (the timetable compression concept). One of the common conclusions of various case studies was the identification of operational heterogeneity as a major reason of delay, especially in the U.S. rail network with improvised operation pattern.

Accuracy of Simulation Results: Some of the case studies assessed the accuracy of simulation results in comparison to the real practices. Three types of accuracy assessments were conducted:

- **Base Model:** Only the results of basic model were compared with the real data. Several case studies in both the U.S. and Europe regions used this type of assessment.
- **Base and alternative results:** In addition to basic model comparison, the alternative outcomes were compared with the real data. Only the USC case study can be considered in this category.
- **No comparison:** In the final category no specific information or comparison were provided between simulated results and real practices.

As presented in Table 1, majority of the case studies did not address the accuracy of simulation results, either because case study was not constructed based on real operational data, or simulation results were not compared with the real practices as part of research. The case studies that used general simulation software claimed that capacity delays derived from the modeling approach were close to the real operation practices.

CONCLUSIONS AND NEXT STEPS OF RESEARCH

This paper has used a literature review to provide an overview of the capacity definitions in the U.S. and Europe, to discuss the main similarities and differences between their respective rail systems and to introduce different approaches and methodologies for capacity analysis. The review revealed no single definition of rail capacity, but it can rather be interpreted in various ways based on different perspectives and tools and parameters applied. There are several differences between the U.S. and European rail systems that affect the capacity, such as ownership, type and extent of double track network, distance...
between and length of sidings, operation philosophy, punctuality of services, preponderance passenger
traffic, and train configurations, but the effect of these differences on capacity or capacity analysis hasn’t
been evaluated in detail.

The capacity analysis approaches and methodologies can also be classified in several different
ways. The methods were typically divided into analytical and simulation methods, but this paper also
offered an additional “combined” category. The case studies revealed that majority of analysis utilize
simulation approaches, but analytical methods have also been used, either by themselves, or in
combination with simulations. The European rail networks typically take advantage of several
commercial simulation software available in Europe, which have been developed based on the timetable
compression concept, while the U.S. railroads usually apply the non-timetable based simulation, in
addition to the general analytical tools and modeling approaches. The accuracy of the simulation results is
a major concern when conducting the analysis, but the case studies showed limited effort in comparing
the simulation results to the actual conditions, especially after recommended improvements were
implemented.

The literature review and case studies presented in this paper are part of an effort to develop a
foundation for a more in-depth analysis of current capacity analysis tools and methodologies used in the
U.S. and in Europe. As the U.S. continues developing its passenger traffic on shared corridors, the future
operation patterns of shared corridors in the U.S. will likely have closer resemblance to the European
shared-use lines. The objective of the next research steps is to apply both the U.S. and European based
methods on selected U.S. corridors and evaluate the applicability and accuracy of both approaches and
tools in the U.S. environment. An interesting additional research question is whether implementation of
the structured operational approach that is currently prevalent in Europe would provide any benefits for
the shared U.S. corridors and what are the roadblocks or obstructions for its implementation.

REFERENCES:
1. FRA, Vision for High-Speed Rail in America, U. DOT, Editor 2009, Federal Railroad Administration
2. Cambridge Systematics, Inc., National Rail Freight Infrastructure Capacity and Investment Study,
7. State University.
12. IMPROVERAIL, IMPROVED tools for RAILway capacity and access management-Deliverable 6
15. Melody Khadem Sameni, Mark Dingler, John M. Preston, Christopher P.L. Barkan. Profit-
17. TRB.
19. Aalborg University, Denmark
20. White, Thomas, Comparison of U.S. and European Railroads, Lecture notes for CE-4490, 2012,


13. DB-AG, Station Categories 2012 (in German), 2011, DB-AG: Berlin-Germany.


17. DOT, National Transportation Statistics 2011, U.S. Department of Transportation: Washington, DC.


23. Wearden, Graeme, UK Train Times Back on Track, in the Guardian2007: UK.


32. BANVERKET, Application of the UIC Capacity leaflet at Banverket, 2005, Banverket, Swedish National Rail Administration.


34. James S. Noble, Charles Nemmers, Missouri Freight and Passenger Rail Capacity Analysis, 2007, Missouri Department of Transportation (MoDOT): Jefferson City, MO.


