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AN INTRODUCTION TO THE LINE CAPACITY ANALYSIS SYSTEM

Carl D. Van Dyke
Howard A. Rosen
Peter D. Mayewski
ALK Associattes, Inc.
Princeton, NJ 08540

Introduction

The Line Capacity Analysis System (LCAS) is a multi-track dispatching model that can be used to estimate the capacity of railway lines. The model works by simulating the movement of trains, determining where trains should meet and pass each other, and accumulating statistics on train running times and delays. LCAS was developed for a capacity analysis of the Beijing to Shanghai railway corridor, and was instrumental in the success of the analysis. The model is applicable to a wide range of problems encountered by railroads both inside and outside of North America. Typical applications include assessing the impact of changes to train schedules, train performance, track layout and profile, operating rules, and signalling systems.

This paper describes LCAS, the motivations for its design and development, and some of the possible applications for the model. The remainder of the paper consists of 10 sections. Section 2 presents why LCAS was developed, Section 3 describes the overall model design, and Section 4 details the model's data requirements. Sections 5 through 9 describe each of the five sub-systems that make up LCAS, Section 10 presents some of the possible LCAS applications, and Section 11 discusses future development work.

Background

A line capacity analysis of the railway line between Beijing and Shanghai (the Jinghu line) was conducted as a joint effort between the authors, the World Bank, and the Ministry of Railways (MR) of the People's Republic of China. The objectives of this effort included examination of specific methods for increasing the Jinghu line's capacity, customization and delivery of a set of computer models to the MR, and training a group of MR employees in the study techniques and software used in the capacity analysis. The objective of the training was to allow the MR to conduct future studies largely on its own.

The MR set the 1995 capacity objectives in terms of the number of trains to be operated and the freight tonnage to be hauled. Currently, about 35 pairs of passenger trains and about 65 pairs of freight trains operate each day on a typical section of the line. The number of passenger trains will increase to around 50 pairs of trains per day. Freight trains will increase in length from 55 cars/800 meters to 70 cars/1000 meters. Total freight traffic is expected to reach 70 million net-tonne-kilometers per kilometer in the downbound direction (the Beijing to Shanghai direction).

To conduct this study, a line capacity simulation model was required. This type of model takes a description of the track and the trains to be operated, and predicts how the trains would perform.

The impact of changes to the trains and track can then be studied, and the value of various options assessed.

Line capacity models require two basic sets of data. First, a track description that details each section of the rail line including switches, sidings, signals, speed limits, and expected train performance characteristics. Second, a data base that describes the train routings, lengths, weights, critical time points, locations where activities are planned, and the locomotives used.

During the simulation, each train is dispatched according to the requirements laid down by the signalling system, track configuration, and train characteristics. Individual meets and passes are computed, and trains are advanced based on various criteria including the train's priority and the likelihood that a "lock-up" may occur. A lock-up is a situation where no trains can advance because all of the trains mutually block each other.

Outputs of these models include time-distance or string-line diagrams, and summaries of train performance, line occupancy, and train delay.

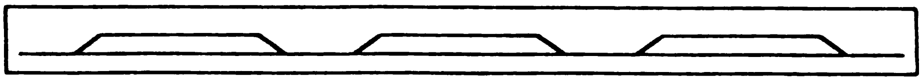


Figure 1: Single Track Layout

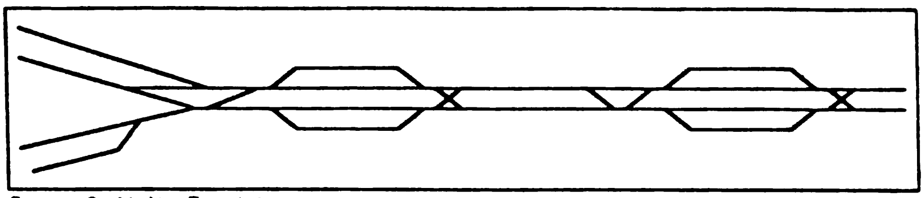


Figure 2: Multi-Track Layout

Line capacity models generally fall into two categories: single and multiple track. Typical layouts of single and multiple track configurations are shown in Figures 1 and 2. Multi-track models are more complex due to the number of routing possibilities and the greater potential for lock-up situations. Most models designed for single track configurations cannot also handle multi-track problems.

The China capacity study required a multi-track model. Typical simulations for China consisted of 150 kilometer double-track line segments with four to six track stations every 5-10 kilometers, and a total of 400 to 600 switches. In addition, separate routes often existed for passenger and freight trains at major cities.

Currently, there are two simulation models in wide use by North American railroads: the single-track Route Capacity Model (RCM) developed by Burlington Northern and Canadian National, and a multi-track model originally developed by Peat, Marwick, Mitchell (PMM model). The RCM is not capable of handling multi-track problems, and the PMM model has a tendency to lock-up when a large number of trains are operated. Neither was suitable for this study.

Research into alternatives to the RCM and PMM models was undertaken. Two primary alternatives were identified. The first was the SCAN model developed by Patrick Harker and Dejan Jovanovic, and the second was the Chessie Line Capacity Simulation Model (C-Model) developed by Edwin Kraft.

The SCAN model attempts to find a close to optimal dispatching plan for a set of trains based on a series of train delay functions. This model represents an exciting development in the area of train dispatching, and holds great promise for developing improved computer-aided dispatching systems. However, the software did not handle multi-track problems of the complexity represented by the Jinghu line.

The C-Model is a full multi-track model that had been used successfully for a number of problems at Chessie and CSX Transportation. The underlying logic of this model was judged as being able to handle complex multi-track problems, but not as complex as the Jinghu line. The C-Model also relied on a great deal of manual intervention to resolve dispatching conflicts.

None of these models, including the user-friendly SCAN model, provided much in the way of editing support for defining the trains and track.

After weighing the available options, it was decided to develop a new line capacity model, using the existing C-Model as a starting point. This effort would be three-fold: (1) improving the dispatching logic to handle the problems presented by the Jinghu line, (2) creation of an integrated, user-friendly, environment for the software that included editors for defining the track and trains, and (3) moving the software from an IBM mainframe to an IBM PC environment.

The remainder of this paper presents the resulting model, known as the Line Capacity Analysis System (LCAS). A general introduction to the design and logic of the model is presented, along with a discussion of some of the reasons for the adopted design.

Overview of Model Structure

The Line Capacity Analysis System consists of five sub-systems: 1) the Line Capacity Train Scheduling System (LC-TSS), 2) the Track Editing System, 3) the LCAS Main Simulation Module, 4) the LCAS Post-Processing System, and 5) the PC-based Train Performance Calculator (pcTpc). Figure 3 presents an overview of how these sub-systems relate to each other. The LC-TSS is used to develop and maintain the train data, as well as generate string-line diagrams. The Track Editing System performs a similar function for the track data. The dispatching simulation is performed by the Main Simulation Module, and the Post-Processing System allows the results of the simulation to be examined. The pcTpc is used to estimate train running times and examine the performance characteristics of individual trains. Both the LC-TSS and pcTpc sub-systems can also be used on a stand-alone basis.

LCAS is designed to run on 80386 or 80486-based IBM PC or compatible computers using version 1.1 or later of the OS/2 operating system. The editing systems, string-line generator, and pcTpc can be used under MS-DOS in a 640k RAM environment, while the Main Simulation Module requires 4 mB of memory and OS/2. The Windows environment became a viable option after the start of model development. The Main Simulation Module is written in MicroSoft FORTRAN 77, which is highly compatible with IBM's VS/FORTRAN. The original C-Model was written in FORTRAN 66.

The editors and other support components are primarily written in Borland's Turbo Pascal. Small parts of the code are written in C, and commercial utility software is used for graphic displays and sorting. Pascal was chosen over C due to the familiarity of the development team and because an in-house library of support code written in Pascal already existed. Borland's product was selected primarily due to the quality of its software development environment. In retrospect, a different compiler should have been used, as Borland's product is not compatible with OS/2, forcing LCAS to use the DOS window of OS/2 (however Borland fully supports Windows).

Data Requirements

The primary data requirements for LCAS consist of a track description and a set of train schedules. These are described below. In addition, there are a number of subsidiary data files to support the model such as equipment descriptions, TPC/track file interface data, and train priority data. These support data will not be described in this paper, but are explained in the LCAS manual.

Track Data

LCAS uses a network based railroad line description. As a result, virtually any track configuration can be described. An example of a station track layout typical of the Jinghu line is provided in Figure 4. The railroad line description consists of the physical relationship of the various tracks (links) and switches (nodes), the attributes of each link and node, and higher level information on yards and segments.

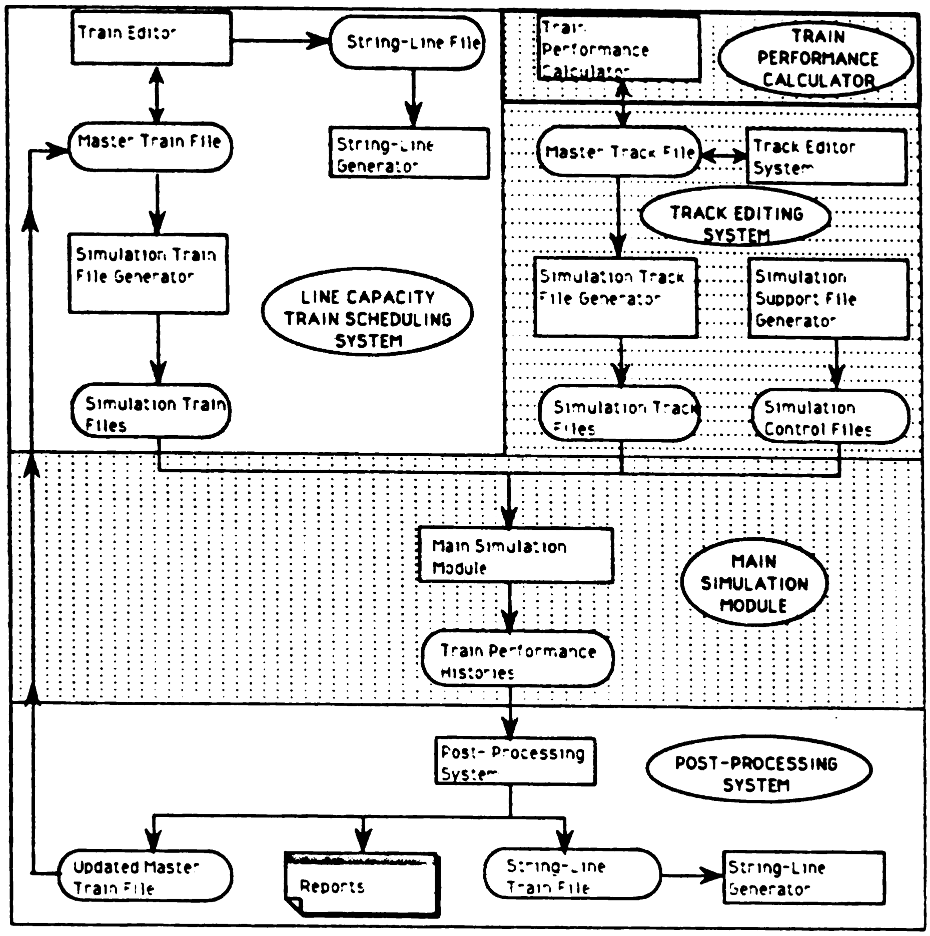


Figure 3 The ALK Line Capacity Analysis System

Switches or Nodes - There are three kinds of nodes used in a LCAS track layout: switches, control points, and diamonds. Switches are the most obvious part of any rail line, and need little explanation. Control points are locations where two track segments join each other. Typically, control points are used to sub-divide long sections of track between switches into smaller components to represent signal blocks. Control points are also used as terminators of stub end tracks, and the beginning and ending points of lines being modelled.

Diamonds are locations where two rail lines cross each other at grade, without a switch being present. Diamonds raise the possibility of interference between trains on two otherwise independent lines. LCAS can model train operations on two independent lines at the same time, and will account for the interference that occurs at the points of interaction such as diamonds.

Each switch or node is assigned a number of attributes including speed limits and hand-thrown switch penalties. Each switch has four movement directions associated with it, with certain attributes defined in terms of these four directions (see Figure 5). The same is also true for diamonds.

Speed Limits: Speed limits can be specified for each possible movement direction across a switch or diamond. They are used to slow a train appropriately when moving through a switch or diamond, and are defined in terms of the movement directions shown in Figure 5. Speed limits do not apply to control points.

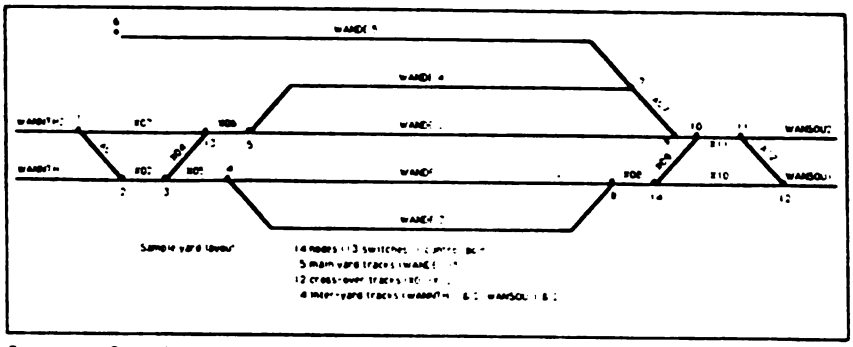


Figure 4 Sample Yard Layout (Wande)

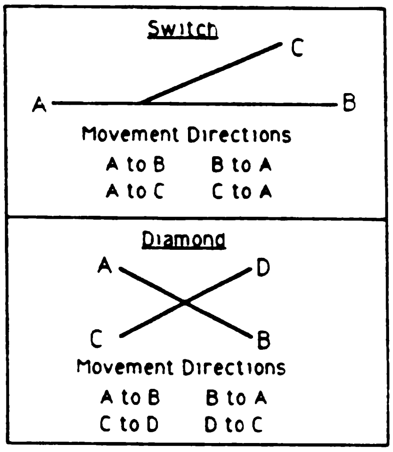


Figure 5 Possible Movement Directions for a Switch or Diamond

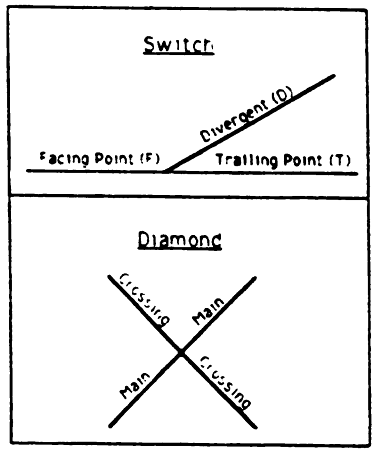


Figure 6 Switch and Diamond Link/Node Relationships

Hand-Thrown Switch Penalties: In certain cases, where switches are thrown by hand, delays are incurred while the train crew throws the switch and re-boards the train. To reflect these delays, time penalties can be defined for each of the four movement directions through a switch. These penalties do not apply to diamonds or control points.

Other Information: Other information can be recorded for each switch. This is intended primarily for use in future versions of LCAS to support generating string-line diagrams and graphic representations of the track files. For example, an X and Y coordinate can be specified for each switch.

Tracks or Links - The tracks or links join the nodes. All links are given a track name and an optional track number. The track name is any six character alpha-numeric string that starts in a letter, and the track number must be between 0 and 99. The combination of the track name and number must be unique.

The links can be categorized into three types: transit, yard, and cross-over. The transit or main-line links are used to go from one location to another, and are typically the tracks found between yards, stations, or sidings. The transit links are often separated by control points which represent the signal breaks. The yard links are the main tracks found in a yard or station, and are generally only those tracks long enough to hold a train. The other yard tracks are considered cross-over links. All of the main yard tracks are usually given the same name. The cross-over links are various short links used to cross-over from one track to another, or that are part of the throat of a yard.

Each link or track has a number of attributes including link length, connectivity information, directionality, running times, speed limits, and segment assignments. The length is expressed in feet or meters, with cross-over links generally given a length of zero. The connectivity information shows which pair of switches or nodes each link joins, and the relationship of each link to the switch (see Figure 6). Directionality allows the desirability of running a train in each direction on a link to be independently specified. Running times are the time it takes a train to traverse each link based on a train's type or power-to-weight ratio. Speed limits specify the maximum speed over each link by train type. Segment assignments are discussed below under the heading "Segment Definitions."

LCAS treats each link as a separate signal block. The model restricts occupancy of a link to only one train, and will not permit a second train to occupy a link until a user specified number of minutes has passed since the tail-end of the previous train has cleared the link (the signal wake).

Yard Definitions - Train routes can be defined as going either to specific links, or to yards. Yards are collections of links where LCAS can choose which specific link (track) a train should use. Yards are defined by specifying a track name, and a set of track numbers with the same name. Thus, it becomes important that the links in each yard be given consistent track names. A sample yard is shown in Figure 4. In this example, the Wande yard could be defined by any combination of tracks WANDE 01 through WANDE 05. In general, a yard definition should exclude tracks that cannot be used to hold or pass trains. Thus, in this example, only tracks 1, 2, 3, and 4 should be made part of the yard. Track 5 should be separate.

Segment Definitions - Segments provide a mechanism for sub-setting the line defined in the track file for simulation purposes. The user can break a large track data base into several separate sections or segments by assigning each link to a specific segment. The software then allows the user to specify a set of segments to be used for a particular simulation run. LCAS will automatically limit the trains to be simulated to those trains that traverse the segments being simulated.

Train Data

A train is defined by a train schedule. Each train schedule contains four types of data: (1) general attributes, (2) routing and times, (3) work activities, and (4) cars and locomotives picked-up and set-off.

General Attributes - The general attributes include the name of the train, the days of the week it operates, the train's general type and priority, the train's performance or running time attributes, and optional randomization data. The performance or running time attribute indicates that either a fixed running time should be used, or one based on the train's power-to-weight ratio. The randomization data allows the origin departure time for the train to vary from day to day in the simulation.

Route and Time Data - The minimum route information for a train is its origin, destination, and an origin departure time. Given an initial starting time, LCAS will estimate all other time points based on the running time data found in the track file, and the meets and passes experienced by the train during the simulation. Additional time points and dwell times can be specified. Arrival times are treated as goals, while dwell times and departure times are treated as fixed events in the train's schedule.

If a time is specified for arrival at the train's destination, LCAS will attempt to keep the train on schedule. The importance of keeping the train on time is determined by the train's priority attributes. If intermediate departure times are specified, LCAS will not depart the train earlier than the time specified. This allows passenger trains to be modelled. LCAS has an optional pacing feature which adjusts each train's speed so that it will not arrive before its next scheduled arrival time. Without pacing, trains always operate at their maximum speed.

If a dwell time is specified by itself, then the train will be held the specified number of minutes at the appropriate location. If both a dwell time and a departure time are specified, the train will depart the later of the simulated arrival time plus the dwell time, or the scheduled departure time. Note that the simulated arrival time is the time that LCAS predicts the train will actually arrive, and is not the same as the scheduled arrival time.

En-route Work Activities - Specific work items can be coded at each location in a train's route. The "clear track" work item causes the train to completely clear the track for the specified period of time. The "unscheduled delay" work item cause the train to be held at location for a specified number of minutes. LCAS's dispatcher has no prior knowledge of the delay. This is used to model mechanical problems. LCAS will track the amount of time each crew works relative to the hours of service rules. Specifying a "crew change" work item will restart the train's crew clock. In addition to the above work items, whenever a dwell time is specified, the train will be held at the specified location for that number of minutes. This is considered a "normal" or "regular" work item.

Traffic and Locomotive Data - The traffic and locomotive data is used to determine the train's length, weight, and power-to-weight ratio. The power-to-weight ratio is used to determine the train's running time based on data in the track file.

Trains can be instructed to set-off or pick-up cars or locomotives at various yards in their routes. Whenever the train consist changes during the simulation, the power-to-weight ratio is recomputed and the train's speed is adjusted.

Cars, locomotives, and crews are considered "resources" that can be optionally tracked by LCAS. When resource tracking is on, the user specifies an initial amount of each resource for each yard, and as resources are added and subtracted from trains the resource counts at the yards are adjusted. The trains can be optionally held at a location if a required resource is not available. This can be used to allow the explicit modelling of a limited number of locomotives in helper service, or crew availability.

The Line Capacity Train Scheduling System

The Line Capacity Train Scheduling System (LC-TSS) is one of the five sub-systems that make up LCAS. It is designed to assist in the maintenance of a set of train schedules, and to provide trains for analysis by the LCAS Main Simulation Module. The most important components of the LC-TSS system are: 1) interactive train editor, 2) report generator, 3) string-line diagram generator, and 4) simulation train file generator. Each of these components is described below. One can also import the trains used by the LC-TSS from other sources.

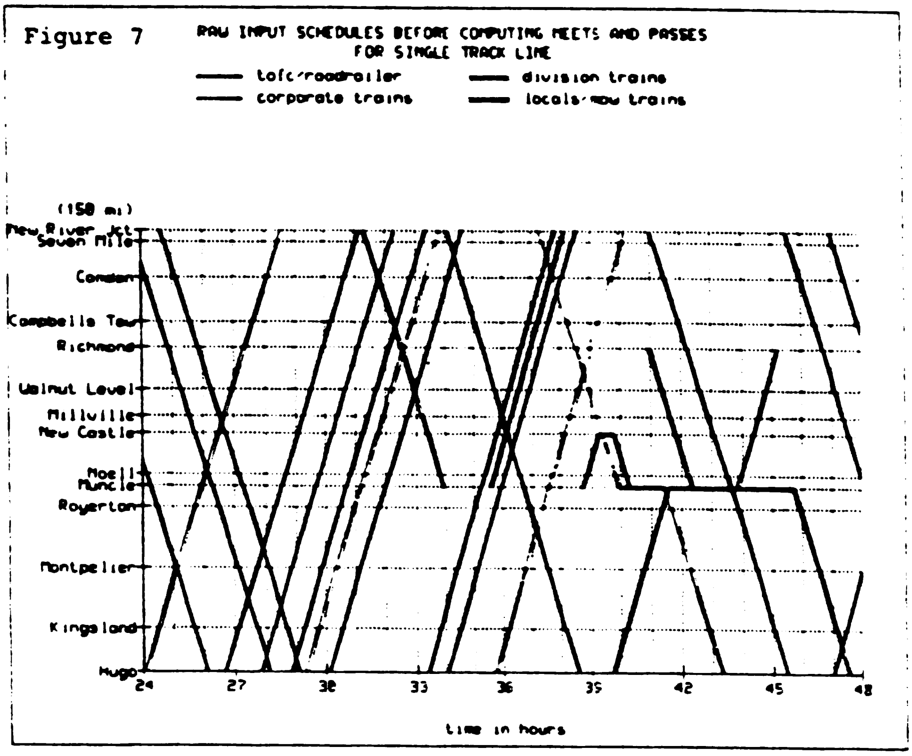
The LC-TSS can be used as a support tool for the LCAS simulation, or as an independent tool to plan and maintain a set of train schedules. While all of the data described in Section 4.2 is required by the LCAS Main Simulation Module, it is not all required to use the software in a schedule planning mode.

Interactive Train Editor - The centerpiece of the LC-TSS is a user friendly, menu-based editor for defining all aspects of the train data. The editor's menus allow the train schedules to be inspected, and various special keys and commands allow the schedules to be modified. In addition, the editor is designed to track the validity of the train names, stations, time points, and other data entered for each train.

One important capability of the editor is its ability to "expand" a train route. The minimum route requirements for a train are an origin, a destination, and at least one time point. Given this limited amount of information, the software is capable of expanding the route to show all of the locations the train will pass through, and to suggest the operating times at each of these locations. The expansion process uses a weighted shortest path algorithm to find the route between each user-specified pair of locations (yards). Times are computed either using interpolation or running times by train type for each link. If the user does not like the resulting route expansion, the user can specify additional intermediate points to further control the expansion process.

Train Report Generator - The train report generator serves two purposes: 1) to document a train schedule data base, and 2) to describe special exceptions. Train schedule documentation reports can be produced at several levels of detail. At the most compressed level, the reports show the basic attributes of the trains, and the starting and ending points. At the intermediate level, the user specified locations in the train's route are reported. At the most detailed level the entire route of the train is output. The exception reports describe trains that are going exceptionally fast or slow, trains that have no traffic data, and trains that have exceptionally long dwell times.

Figure 7



String-line Generator - The LC-TSS can be used to interactively generate string-line or time-distance diagrams. String-line diagrams allow one to graphically examine and understand a set of train schedules. They also allow problems in the schedules to be quickly identified. The combination of the time-distance diagrams and train editing system allows a user to manually create a complete dispatching plan. The LCAS Main Simulation Module, when used in combination with the Post-Processor, is also capable of generating files that can be examined using the string-line software. An example of a pre-simulation string-line diagram is shown in Figure 7.

LCAS Simulation Train File Generator - A special program is provided in the LC-TSS to create the input train file required by the LCAS Main Simulation Module. The simulation file can be limited to a subset of the trains, and/or a subset of the train's routes. Numerous user controlled options are provided to allow the user to adapt a set of train schedules to the user's simulation needs. These include specifying the number of days to be simulated, the starting and ending date of the simulation, and the specific simulation parameters to be associated with each train priority. The user can also control the exact approach that is used to specify the time points and routes of the trains, thus determining the degree to which the simulation is constrained by user specified requirements. Special options, such as "track outage" trains are also supported.

The LCAS Track Editing System

To support the creation and maintenance of the track data, LCAS includes a complete track editing system. The important components of the Track Editing System are: 1) interactive track editor, 2) simulation track file generator, and 3) TPC interface system. Each of these components is described below. In addition, a number of utility and report programs are provided for validating data, generating data base reports, and performing data base management tasks. One can also import the track used by LCAS from other sources.

Interactive Track Editor - A user-friendly, full screen editor is provided that facilitates the maintenance and entry of track and switch data. The editor contains many default options and features that speed the track definition process. For example, the user generally only needs to enter the links. The nodes are automatically created by the editor based on the link data. Only if the user wants to change the default node attributes do they need to be edited. The editor continuously cross-checks the data as it is entered, preventing entry of invalid node and switch data.

Simulation Track File Generator - A special program creates the input track file required by the LCAS Main Simulation Module. This file can be limited to a subset of the full track data base, permitting the user to simulate only selected line segments. The sub-setting process uses the segment assignments described in Section 4.1. In addition, the track file stores many attributes using a letter-based coding scheme. The track file generator replaces these letters with specific user supplied values. This allows the user to test a variety of attribute settings without having to edit the base network definition.

TPC Interface System - As discussed in Section 4.1, each track has a number of running times associated with it. The editor has the ability to set these running times based on a series of user defined defaults. Alternatively, some or all of the running times can be taken from an externally supplied running time file. Generally, this external file is created using the pcTpc Train Performance Calculator program supplied with LCAS. The interface system both exports the data from the track file required by the pcTpc, and imports the resulting running time file.

The PC-based Train Performance Calculator (pcTpc)

The Line Capacity Analysis System includes a train performance calculator, which is used both to support LCAS and to perform stand-alone analyses. A Train Performance Calculator (TPC) model, sometimes also know as a TPS (Train Performance Simulator), simulates the operation of a train over a railway route. The TPC moves a train over a line at the speeds that would be expected for an actual train based on the following factors: 1) the tractive effort available from the locomotive consist; 2) train resistance due to: weight of cars and engines, number of axles, wind, curvature and grade; 3) speed limits over the line; 4) operating rules for the train; and 5) performance limitations of the locomotives. The rules for moving the train are based on the fundamental laws of physics and a number of empirical analyses that have been performed.

As the train is moved over each distance increment, vital train data is calculated by appropriate equations for each incremental step. This data includes:

- distance of train from starting point
- average grade under the train
- tractive effort output of locomotives
- elapsed time from start of train run
- train speed
- fuel consumption
- locomotive throttle notch position

At selected locations along the route of the train this data is stored for generation of various reports.

LCAS requires running times over each link in the track file. Many of these running times can be determined based on default values. However, the mainline tracks require accurate estimates of the running times by type of train. The pcTpc has a special option that allows the running times to be generated in a form that is compatible with the LCAS's Track Editing System. The user can specify a series of different trains in the pcTpc, and import the resulting running times into the LCAS track file.

The pcTpc can also be used to evaluate the overall impact of numerous types of changes on train performance. These include: use of alternate locomotive types; changes to certain operating rules; speed limits; stopping distance rules; changes to train length/weight; changes in the number of locomotives used; and changes in the track profile. Using these analyses, the initial value of various options can be estimated, and the need for further study can be determined.

The LCAS Main Simulation Module

This section presents an overview of how the LCAS simulation works. It is not intended to be highly technical in its nature, or to explain LCAS's logic in detail. First, a number of basic LCAS concepts are described. Then, an explanation of the simulation logic is presented.

Train Priority: Each train is assigned a set of three priority values. Priority One is the overall priority of the train. It is expressed in minutes, and represents how far in advance of the train's current position the train can make claims to track time. The higher the value, the more important the train, with typical values falling between 0 and 30 minutes. Priority Two is the train's tolerance to lateness, also expressed in minutes. If the train is expected to be more than Priority Two minutes late, then the train's overall priority will be increased. Priority Three is used to determine the rate at which the train's priority is increased when it is late.

Holding Positions: A holding position is defined as a location where a train could be held to make a meet or pass. The most common holding positions are a track in a yard, or the track immediately preceding a switch. All tracks defined as being part of a yard are considered holding positions.

Paths: As each train is advanced in the simulation it establishes a path. The path represents the sequence of links and associated occupancy times required by the train to reach its current location.

Track Claims: The key to LCAS's train management is the track claim. A track claim represents the future right of a train to occupy a link or control a switch for a specific time period. A set of track claims is maintained for all trains at all times. This set of claims consists of a series of links and switches, as well as the time period during which the train requires control of the links and switches, such that the train can advance from its current holding position to its next holding position. Secondary claims also exist to prevent lock-ups.

Event Queue: LCAS tags each train with the time when the next decision must be made about that train. These decision points are called "events." The software keeps a time sorted list of events. This list is called the event queue.

Scheduler and Dispatcher: The scheduler is the part of LCAS that actually manages the event queue and determines which train is to be processed next. It also adds new trains to the queue as they become eligible to be operated, and subtracts trains from the queue once they have completed their itineraries. The dispatcher is the component of LCAS that actually decides how to move each train selected by the scheduler. It also determines when the next event for each train will occur, and how to resolve conflicts between trains based on the track claims.

Lock-Ups: The most significant problem faced by any line capacity simulation model is preventing lock-ups. A lock-up is a condition where no train can be moved because the route of every train is blocked by another train. When this condition occurs, the simulation must be terminated prematurely. Because of the importance of preventing lock-up situations, the entire design of the dispatching logic used by LCAS is focused on lock-up prevention. An example of a lock-up condition is shown in Figure 8.

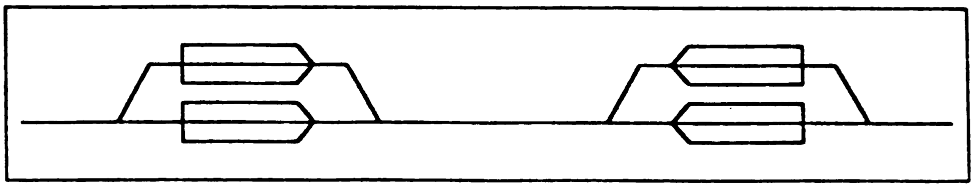


Figure 8 Example of a Lock-Up Condition

How the Simulation Works

The primary tools used by the LCAS Main Simulation Module are the event queue and the track claims. Every currently active train is listed in the event queue, along with any trains scheduled to run in the future. Each train carries with it a set of track claims defining how its next movement is to be made.

The LCAS simulation works by processing the first event in the event queue, until the queue is empty. Processing an event generally consists of advancing the train from its current location to the end point of its current track claims. After processing the event, the next event for the train is inserted into the queue based on an estimated time for that event, except when a train has terminated. In addition, the train's track claims are updated. LCAS then selects and processes the new first event in the queue. The process continues until the queue is empty indicating a completed simulation.

Each train (event) has several attributes associated with it. These include its current location and path to that location, the earliest possible departure time from that location, the estimated time for its next event, and any track claims held by the train. In some cases the train's next event time in the queue reflects a work activity being done by the train at its current location, or the need to adhere to specific time points in the train's schedule.

An attempt is made to keep the current next event for each train always valid. When the train at the top of the queue is processed, all trains that are affected by it are updated. For example, if the current train makes a claim that conflicts with another train, the train with the higher priority gets to keep its claim, and the other train has its claim adjusted. This can cause significant changes to occur in the event queue each time an event is processed.

The establishment and retention of track claims are based on the priority of each train. Trains can have their priorities adjusted for three reasons: conflicts, crew time, and lateness. If a low priority train blocks the movement of a high priority train the low priority train will temporarily be given a higher priority so that it can be moved and clear the way for the high priority train. In the case of crew time, trains that have crews approaching their 12 hour limit will have their priority improved (if this option is enabled), increasing the chance of the train reaching its destination before the crew exceeds its hours of service limit. In addition, trains that are late will also have their priority improved. Priorities are adjusted dynamically based on a set of parameters specified for each individual train.

LCAS uses a modified shortest path routine to determine the link sequences needed for each track claim. The shortest path is used to find the link sequence all of the way to the train's destination. The resulting route is scanned, and the first valid holding position the train reaches after the train is advanced a number of minutes equal to its Priority One value is selected. This holding point then represents the extent of the train's track claims. In general, the next valid holding position will be the holding location in the train route closest to the current location of the train. It should be noted that this path is affected by the paths of other trains, and the track claims of other trains.

While many holding positions may be defined, only "valid" ones will be used to advance a train. To be valid the holding position track must be long enough to hold the entire train, and to prevent lock-ups, there must be at least one clear path from that holding position to the next scheduled point in the train's route.

A number of special factors are taken into account by the LCAS shortest path logic. These include directionality preferences of links, the paths and track claims of other trains, and the legal movement directions through switches. The shortest path finds the weighted least time route, where the primary weights come from the directionality factors and switch related time penalties.

Given the link sequence, the running time for the train is determined. The basic running time is taken from the input link file. This is then modified to reflect stopping and starting the train (if necessary), switch speed limits, and hand thrown switch penalties. LCAS contains a simple TPC model for determining acceleration and deceleration time penalties.

Train pacing can be used to force a train to comply with a particular schedule. When pacing is turned on, trains will be slowed so that they will not arrive at their next scheduled time point early. Trains can also be instructed to not leave locations before a specified amount of dwell time has elapsed or before a specified departure time.

If LCAS finds a problem with a particular train that it cannot resolve, it will annul or cancel the train. When this occurs, a message is issued to the user warning of the problem. LCAS can be asked to create a highly detailed dispatching log, which can be used to trace the full logic used by the model in dispatching the trains.

The LCAS Post-Processing System

The Post-Processing System allows the results of the simulation to be documented, and supports the creation of a post-simulation train file for use by the Line Capacity Train Scheduling System (allowing all of the reports and other capabilities of LC-TSS to be used). Documentation includes a wide variety of reports as well as string-line diagrams. Reports range from detailed train schedule and yard activity reports, to aggregate train hour summaries. A sample string-line diagram is shown in Figure 9, and an example of the train hours report is shown in Figure 10.

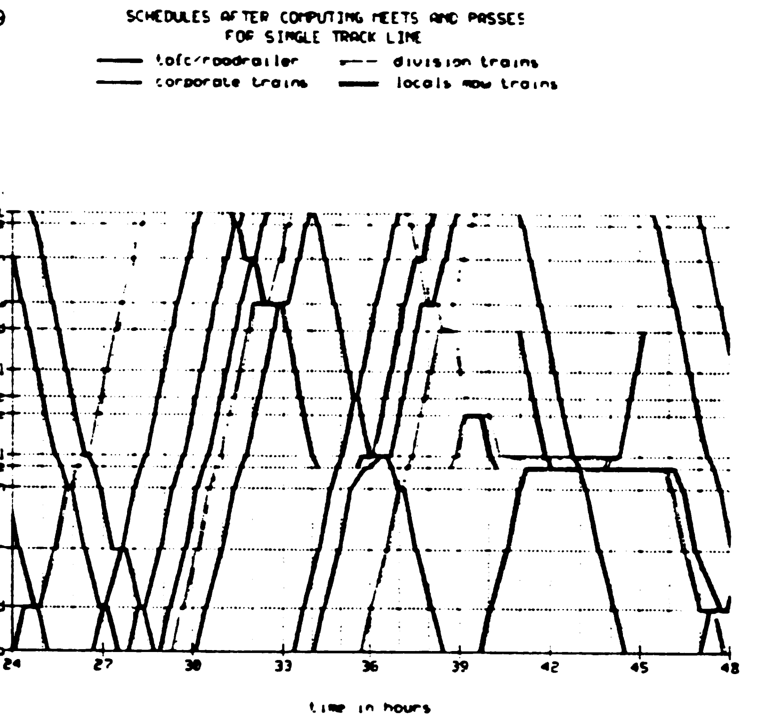
The train hours report shows the total elapsed time each train required to complete its route. The report is sorted or grouped by train type so that the performance of each class of train can be assessed. The string-line diagram shows the exact history of each train, and can be used to inspect the dispatching decisions and refine the LCAS analysis through changes to the inputs. The string-line diagram from the LCAS simulation can also be compared to a string-line diagram of the pre-simulation train schedules (see Figure 7).

Applications of LCAS

LCAS was used for many types of applications as part of the Jinghu line study. These problems had typical problem sizes of 400 to 500 trains over a two day period, 1000 track segments and nodes, of which 400 to 600 were switches. Figure 11 shows a section of a typical time-distance diagram produced by the LCAS simulation for the China project.

Some of the problems LCAS can be used to study include: 1) changes to track configurations, 2) changes to train performance, 3) changes to trains operated, 4) changes to signalling, and 5) impact of track maintenance outages. Each of these is discussed briefly below.

Figure 9



Changes to Track Configurations - One of the most common applications of a line capacity model is to evaluate the impact of changes to the track configuration. Typical changes include: 1) adding a passing siding; 2) adding an additional main-line track; 3) removing a main-line track (single tracking a line); 4) changing junctions, yard throats, and/or how the main-line tracks relate to a yard, including building fly-overs; and 5) reducing grades or curvature. One typically runs two scenarios: one with and one without the relevant changes. The total number of train hours for each scenario is examined, and the value of the change is assessed. Note that the grade and curvature reduction option involves no changes to the track layout. Instead, the running times in the track file are updated to reflect the improved profile.

Changes to Train Performance - A number of factors can affect train performance. These include: 1) use of alternate locomotive types (including electrification), 2) changes in train length or weight, and 3) changes to the equipment attributes such as aerodynamic drag or bearing type. The primary impact of these types of changes is generally on the running times for trains. Thus, these changes are examined through changes to the train consists (which affects the power-to-weight ratios) and updated track running times.

Changes to Trains Operated - Another common application of LCAS is to evaluate the capability of a line to handle more trains or a different mix of trains. In this situation, the track is not changed, but instead the train schedules being simulated are changed. This is then used to establish an assessment of the future impact of running more or different trains. This alternative scenario can then be used as a base case for examining the impact of other types of changes on future train performance.

Changes to Signalling - LCAS reflects a signalling system in three ways. First, the directional preferences for each line reflects the ease with which trains can be run in each direction over each track. Second, the headway between each train is a model parameter, and can be used to reflect the capabilities of the signal system. Finally, the running times used by LCAS in part reflect the limitations of the signalling system. Thus, by changing these three aspects of the LCAS inputs, the impact of changes to the signalling system can be reflected.

LCPP: TRAIN PERFORMACE SUMMARY REPORT

TRAIN SYMBOL	TG	TP	TRAIN ORG	DST	SCHED DEPART	CMODEL DEPART	SCHED DWELL	CMODEL DWELL	SCHED ARRIV	CMODEL ARRIV	LATE/ EARLY
2060-02	3	6	JNX	DZU	32:20	32:20	0:59	2:22	35:25	36:10	- 0:45
A3102/-01	3	6	OSN	JNX	16:00	16:00	0:20	0:55	17:34	18:18	- 0:44
A1022-02	3	5	JNX	DZU	32:50	32:50	0:00	1:15	34:54	35:36	- 0:42
2038-02	3	6	JNX	DZU	26:53	26:53	0:40	2:00	29:43	30:22	- 0:39
551-PJ-01	2	6	PYN	JNN	18:27	18:27	0:35	1:12	20:17	20:53	- 0:36
2034-02	3	6	JNX	DZU	25:55	25:55	0:21	1:24	28:14	28:49	- 0:35
A1032-01	3	5	JNX	DZU	12:50	12:50	0:00	0:59	14:54	15:28	- 0:34
2048-02	3	6	JNX	DZU	29:21	29:21	0:20	1:33	31:51	32:24	- 0:33
A101-02	2	2	DZU	JNN	25:18	25:18	0:05	0:34	26:58	27:30	- 0:32
A1005-02	3	5	DZU	JNX	25:52	25:52	0:00	0:55	27:55	28:26	- 0:31
3174-01	3	6	JNN	DZU	20:20	20:20	4:00	6:56	28:40	29:11	- 0:31
195-02	2	2	DZU	JNN	25:33	25:33	0:22	0:43	27:26	27:54	- 0:28
908-01	3	5	JNX	DZU	12:24	12:24	0:00	1:13	14:41	15:07	- 0:26

Figure 10: Sample Train Hours Report

Impact of Maintenance Track Outages - Maintenance work has two primary impacts on rail networks: temporary or permanent track outages, and temporary or permanent slow orders. Both situations can be directly modelled by LCAS, and the resulting impact on train performance studied.

Future Developments

A number of enhancements to LCAS are being pursued both in terms of the user interface and the software's capabilities.

The largest user-interface change is the development of a graphics-based track editor, which should make the track coding process easier. Once a graphic representation of the track can be created, the next step will be a graphic animation of the dispatching process. Other user interface changes are the possible use of MicroSoft Windows, addition of various reports, editors for the various support files, and general fine tuning of the support programs.

Enhancements to the software's simulation capabilities focus primarily on increasing the accuracy of the simulations. These include: 1) possible use of an in-line TPC for computation of train running times; 2) handling various special cases for train meets, passes and connections; and 3) refinements in the simulation's signalling, crew, fuel, helper, and pacing logic.

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Figure 11 MEETS AND PASSES COMPUTED FOR VERY HIGH DENSITY MULTIPLE TRACK LINE