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TRANSPORTATION RESEARCH FORUM

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TRANSPORTATION RESEARCH FORUM

New Approaches to Yard Planning Using Computer Simulation

by George P. Engelberg and Charles R. Yager***

WHY TRIM WAS DEVELOPED

OVER THE NEXT TEN YEARS, Canadian National will face the requirement to expand or redesign many of its yards in Western Canada in response to major growth and changes in demand for service. Because of the magnitude of the investment anticipated, it is necessary for CN to rigorously evaluate its approach to improving and expanding yards. The objective is not only to expand yards to cope with projected traffic volumes, but to optimize terminal efficiency in the process.

Historically, CN has analyzed operating and design changes using manual simulation. This approach was costly and time-consuming, permitting the examination of only one or two alternatives. Recognizing the need for a better approach to analyzing yard changes, CN, working with Peat, Marwick, Mitchell & Co., embarked on the development of a computerized Terminal Interactive Model (TRIM) to replace the tedious and costly manual simulation approach.

The objective of TRIM is to retain the benefits provided by a manual simulation (applicability to both hump yards and flat yards of any configuration, maintenance of a high degree of accuracy and level of detail, use of skills of experienced yardmasters) while employing the benefits of computer simulation (faster execution, lower labor intensity, greater detail, rapid analysis of simulation results, flexibility of specification). The result is a tool that combines the best of both approaches through an on-line interactive computer model.

TRIM enables CN to evaluate capital investment alternatives in greater detail than was previously possible using manual techniques. Because the time required to evaluate a proposed design modification is drastically reduced, CN is able to look at a broader range of alternatives than was possible before the development of TRIM. That ability will translate into designs more tailored to the demands expected to be placed on the yards. In turn, CN will achieve more effective application of its capital investments, since the minimum investment necessary to meet demand can be more easily identified through extensive analysis of alternatives.

However, the benefits of TRIM go beyond testing alternative designs. CN has always attempted to improve operations in a yard before committing capital to plant modifications. With TRIM, CN is able to simulate more alternative strategies, and expects to be able to postpone major capital investment by judiciously improving yard operations.

Finally, CN anticipates using TRIM to train yardmasters in the best operation of a redesigned or new yard and to help new yardmasters gain experience in the operation of a yard before going out into the field. By directing the simulation of a yard, the yardmaster can gain valuable insights into how the yard functions under varying conditions.

DEVELOPMENT OF THE MODEL

Starting in the Fall of 1979, CN and Peat Marwick began designing the structure of TRIM. Because of the geographic dispersion of the development team, it was necessary to follow a carefully planned sequence of phases to ensure that each member of the team already understood the results of the prior phase and the objective of the subsequent phase. The phases which were followed in the development process included:

- Concept Development;
- Computer Evaluation;
- General Design Specification (including a manual test of the design);
- Detailed Design Specification;
- Program Development;
- Testing and Refinement of Programs.

At each phase, extensive documentation was prepared for review and future reference. This ensured a fully documented model when the development was completed.

This approach also ensured that the rail operations experts were fully involved in the design of the model and

**Canadian National Railways Company, Montreal, Quebec.*

***Peat, Marwick, Mitchell & Co., Washington, D.C.*

kept informed during the programming phase. These people were a critical resource during the testing of the model. Since the model was designed to be used by rail analysts, rather than computer specialists, many suggestions made by the rail operations experts were incorporated into the model. The successful implementation of TRIM is largely attributed to the team spirit generated between the computer scientists charged with the creation of the model and the operations experts who worked with them.

OPTIONAL LEVELS OF DETAIL

Because the objective was to design a model which could be used to study a yard in great detail, TRIM has the ability to handle all major operations that occur in a yard. The study team is free to choose the amount of detail that is appropriate to the objectives of the yard under study. For example, in evaluating a particular yard design, it may be suspected that not enough departure tracks result in frequent congestion in the classification yard as trains are made up. In this case, the very specific track geometry of these areas of the yard would be represented in the model. In other cases, the track geometry could simply be approximated, combining or ignoring certain tracks which were not expected to have any significant impact on yard performance. A second example of optional detail would be crew management and utilization. TRIM can specifically model the detailed work carried out by inspection crews. Too few crews could result in trains waiting for inspection; too many would later show up as low crew utilization. Should these human resources not be a constraint (or of interest) in a particular evaluation, they can be ignored completely. TRIM also allows the time window for yard activities to be adjusted. For many types of simulation, specifying the duration of time of any activity to be a minimum of one minute (or more), results in no significant loss of accuracy.

DETAILS OF TRIM'S OPERATION

TRIM is applied in three distinct phases:

—preprocessing — preparing and validating the input data

—simulation — performing the simulation

—postprocessing — producing and analyzing the results

Figure 1 shows the interrelationships among the phases.

Preprocessing

Input data for the model are collected in the first phase and subsequently validated by TRIM for correctness and consistency. A great deal of effort must go into creating the input files if realistic yard activities are to be produced by the analysts. Up to five input files may be prepared:

TRACKS: This file is mandatory and would likely take an analyst from one to four weeks to prepare depending upon yard size. A large yard may have in the neighborhood of 1,000 track sections. All tracks are assigned a unique name and the legal movements between tracks must be specified. TRIM validates this file when constructing the network, informing the user of errors and inconsistencies.

SWITCHES: Although the user can specifically name the switches that connect tracks, this file would usually be omitted. During a simulation, the analyst would likely never have to concern himself with switch names.

INITIAL POPULATION: This file if optional. If omitted, however, an extra day or two of simulation may have to be performed to reach a stable car population in the yard. The data contained in the file are the yard's locomotives, cars, and crews, including their specific track locations.

CREW SCHEDULE: This file if optional. If included, the model will call crews automatically at the specified times.

INBOUND TRAINS: Although optional, this will usually be a most important file, along with the track configuration. For each train, the file contains the time of arrival, the arrival track, the number and type of locomotives, and the sequence and detailed information for each car. Each element is important. For example, incorrectly specifying the number or type of locomotives would make it difficult to later depart trains due to a lack of power in the yard. Not realistically marshalling cars on inbound trains would significantly change the work required to be done in the yard. Canadian National uses its CANAT (Computer Assisted Network Analysis Tool) forecasting system to generate inbound trains. A realistic workload for up to 10 years in advance can be obtained. This ofrecast is then scrutinized and, if necessary, edited manually to make any changes before being used for TRIM. The value of a

INTERRELATIONSHIP AMONG PHASES

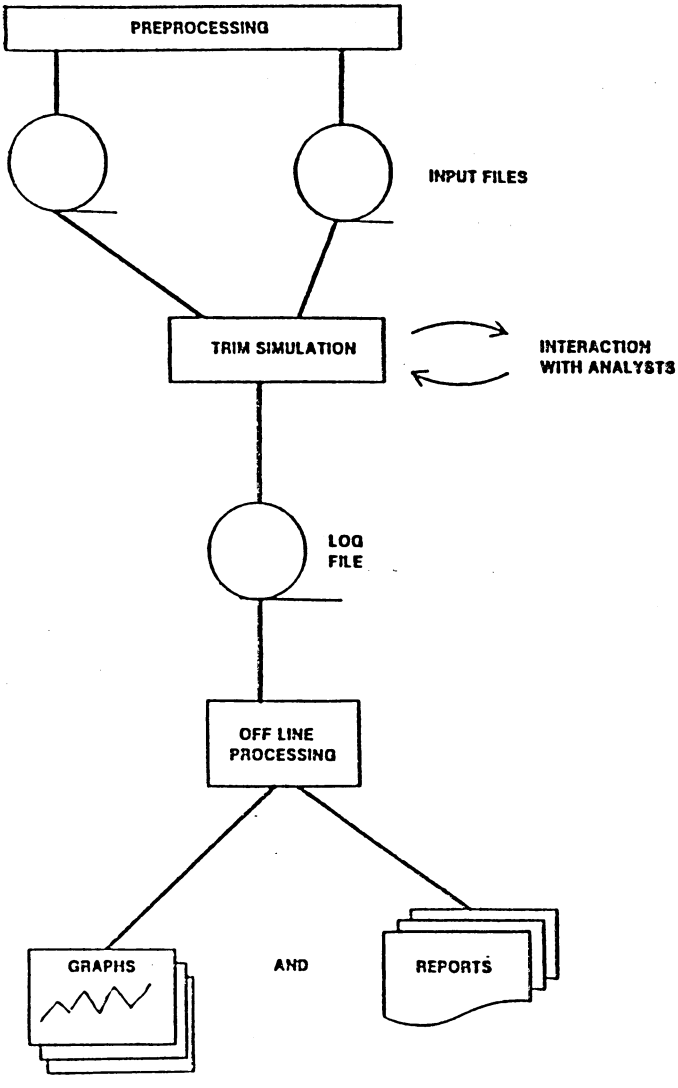

FIGURE 1

computerized forecasting system is apparent when it is considered that up to 15,000 cars can enter a large hump yard over the course of a three day simulation. Numerous shortcuts are possible, however, if the study does not require all the detail to be included.

While not strictly part of the input files or preprocessing, the determination of a realistic train service design for outbound trains is an important activity prior to simulation. This sets the goal for the work to be carried out.

Simulation

TRIM is an "event-based" simulation in that it moves forward through time from one activity to the next. The model examines the work it has to do (based on the commands that have been entered), selects the one that will be completed the soonest, and moves the simulation clock ahead by that amount of time. It then adjusts all yard resources to their new position. As a result, certain resources will have reached their destination, others will have advanced only partially, and still others will remain where they were initially because no specific command was given to move them. Figure 2 illustrates the patterns when only one yardmaster (analyst) is working. More than one yard analyst at a time can participate in the simulation. (TRIM is currently designed to handle up to 10 analysts at a time.) The active resources—locomotives and crews—are assigned to specific yard analysts; yard analysts issue commands to accomplish specific functions. An analyst can issue commands controlling only his own assigned resources. Those resources can be reassigned, if desired. A typical scheme would parallel the sphere of control by a yardmaster in a tower. For example, one analyst may be in control of the receiving yard, another the departure yard, and a third the hump operation. It is by proceeding in this deterministic manner that the plant and operating rationale are evaluated.

The TRIM commands that control the yard operations fall into four main categories:

1) **Movement Commands:** These commands move locomotives (with or without coupled cars) along a route specified by the analyst. As part of the command, the analyst specifies the destination of the move. TRIM automatically can calculate the time required, or the analyst can override this function and specify the time himself. Op-

SIMULATION SEQUENCE

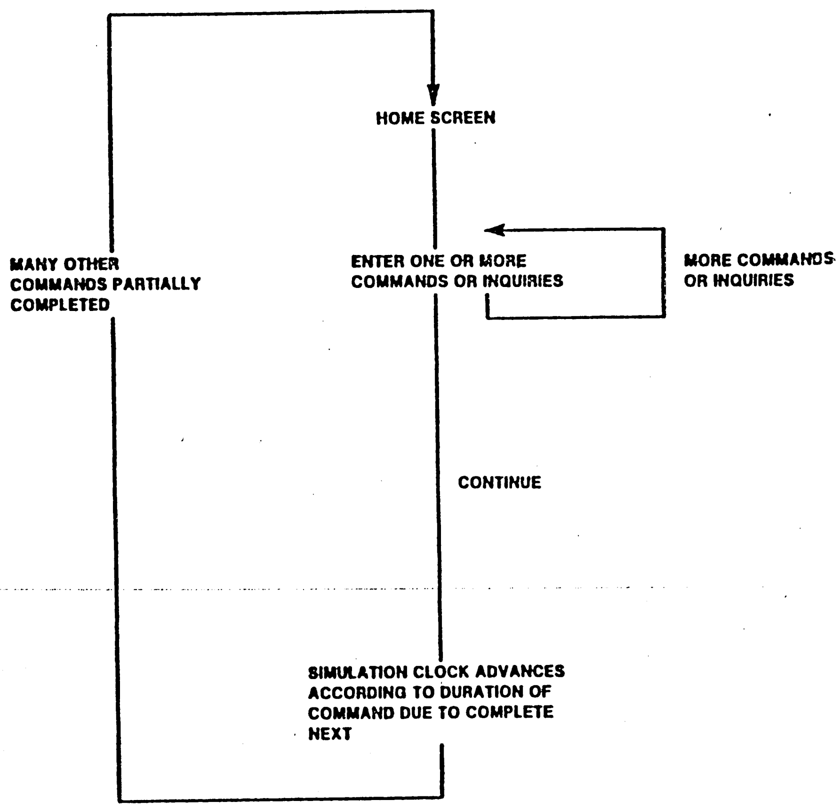

FIGURE 2

tionally, the analyst can kick or set off cars. On a more macroscopic basis, are commands to switch cars or hump a train. To support these latter activities, TRIM maintains switching tables, which are automatically referenced when an analyst prepares a switch list. Of major interest, conflicts in yard are detected and handled. Should a track already be occupied along a route, for example, the system warns the analyst. If so instructed, it will advance the locomotive to the blockage, wait until it clears up, and then resume the balance of the move.

2) **Crew Movement:** These commands affect control of the crew resources. Included is the ability to call or relieve crews, assign them about the yard to tracks or to locomotives, and issue commands for them to inspect trains. The analyst specifies the duration of the above activities.
3) **Coordination Commands:** These commands allow the analyst to control yard environment not specifically associated with movement. Included would be requesting notification when specified yard conditions arise, waiting for specified periods of time, performing switching table maintenance and preparing switch lists, and setting and removing blue flags on tracks.
4) **Inquiries:** Since it is not possible to control yard resources without a detailed knowledge of where they are, a comprehensive inquiry system has been incorporated into TRIM. It is based on CN's computer-based Yard Inventory System (YIS), now in use at many CN hump and flat yards. Car lists for specified tracks can be obtained, for example, which show not only the detailed car data, but also the specific car locations on the track. Other inquiries allow information to be summarized by system destination, advanced consists of trains due in the yard, etc.

As an example of a simulation sequence, suppose two commands are given before the analyst instructs the simulation to continue:

1) assign a crew to a track—travelling time is 5 minutes
2) move a locomotive along a specified three-track route—travelling time is 7 minutes

When the analyst gives the command to continue simulation, the simulation time would move forward 5 minutes. The crew would be located at the new track, and the locomotive would be on an intermediate track between its origin and destination.

In a large simulation, numerous commands could be only partially complete after the clock had advanced and the control has returned to the analyst. When control has returned, the analyst would be presented with a "home screen" (Figure 3). The home screen would inform him what the new simulation time was, describe what activity had just been completed, and provide a list of all other pending activities and their expected completion times. It would also indicate the current location and status of his crews and locomotives, and the resources which were capable of performing further work. Based on the home screen, the analyst could:

- instruct the simulation to continue, choosing not to enter more commands;
- request a formatted screen so a new command can be entered; and/or
- perform inquiries into more detailed yard status so as to assist him in determining what commands to enter.

Figure 4 illustrates a screen an analyst has filled out to specify a sample "move" command. Since most commands follow a fill-in-the-blank approach, they relieve the analyst from memorizing complex computer commands. The move command also offers the analyst a choice of how to specify the move. For example, he can specify the locomotive consist or the track the cars are on. In this case, the consist was specified. Fields directly underneath each other represent a choice. Furthermore, certain fields are optional, and these are indicated by parentheses. If time were not specified, the simulation would calculate it based upon total distance to travel plus certain default track speeds. Spotting cars can also be explicitly specified, or else the system chooses the default, spotting them clear of the switch foul point. In the "next command" field, the analyst can name another command screen he wants next, continue the simulation, or a number of other actions. TRIM performs numerous validation checks before a command is actually accepted into the queue for processing. Resource names must be correct and actually be free; routes must not be blocked and so on. Appropriate errors and warnings are issued.

An important feature built into TRIM

HOME SCREEN

```
                                   HOME             SIMULATION TIME 02/04:08:00
                                                                         *TOP*

 YOUR FOLLOWING ACTIVITIES HAVE COMPLETED:
 MOVE CARS 16 WITH YARD1 ROUTE WL.C WL.A

 YOUR NEXT SCHEDULED ACTIVITIES & COMPLETION TIMES ARE:
 02/04:15:33  DEPT TRAIN 788 ROUTE E1 EDEP

 YOUR CONSIST STATUS:
      CONSIST     TRACK    STATUS  CARS        CONSIST    TRACK    STATUS  CARS
       788        M1.I        A     98          855       ENG4       W       0
       404        ENG9        W      0          561       ENG5       W       0
       567        ENG5        W      0          YARD1     WL.A       W      16

 YOUR CREW STATUS:
            CREW       MEN    CONSIST     TRACK       TYPE    STATUS   WARN
            788         4     788         M1.I        ROAD      A
            [illegible] 3                 EC11        SWIT      W
            WEST1       3     YARD1       WL.A        SWIT      W
            855         4     855         ENG4        ROAD      W
                                                                       *BOTTOM*

                   SCROLL NEXT/PREV     OR NEXT COMMAND       COMMAND  MOVE
```

FIGURE 3

COMMAND TO MOVE CARS

```
                                   MOVE             SIMULATION TIME 02/04:02:00

          MOVE  16   CARS                          WITH CONSIST  YARD1
                TRACK  .                              ON TRACK  ........

                                TO TRACK  WL.A

  ( VIA TRACKS  WL.B      .  ........  .  ........  .  ........  .  ........  .
                ........  .  ........  .  ........  .  ........  .  ........ .)

                              ( RESERVE ROUTE  .  )

  (SETOFF  ...  CARS ( RETURN  .  ) )          (SPOT .... FEET FROM EAST )
  (  KICK  ...  CARS ( RETURN  .  ) )          (      .... FEET FROM WEST )
                (AT TRACK  ........ )          (      COUPLE  .           )
                                               (    CLEAR EAST  .         )
                                               (    CLEAR WEST  .         )
                                   HR    MIN    SEC
                         ( TIME:   ..  :  ..  :  ..  )
                      HR     MIN     SEC
          (DELAY BY  ..  :  ..  :  ..   (REASON  ................ ))

                                                    NEXT COMMAND  HOME
```

FIGURE 4

is the ability to take "checkpoints" of yard status at a particular point in time. If done on a regular basis, work already accomplished will not be lost in the event of computer malfunction, power failures, etc. Checkpoints also allow different yard operating strategies to be evaluated from a common base condition. For example, if the yard status at 1400 hours is deemed unsatisfactory, it is possible to continue simulation from an earlier checkpoint and operate the yard under a different strategy.

One of the outstanding features of TRIM is that it is designed to be used by railroad personnel. A knowledge of computers and scientific modelling is not required. The system converses with the analyst entirely in railroad terms. A familiarization period of a few weeks is required for the analyst to become comfortable in use of the model and aware of its numerous features. In performing the simulation, the analyst or analysts simultaneously play more than one role. Part of their function is to be a yardmaster, determining the overall strategy of operating their portion of the yard. In addition, they are also switching foremen and inspection crew foremen as they direct the more detailed functions of the yard.

Postprocessor

As the simulation proceeds, TRIM performs extensive data logging. The purpose is to reconstruct what transpired during the simulation. Therefore, each car movement onto and off each track is logged, along with the corresponding detailed locomotive and crew movement. The log tapes are then processed through a comprehensive reporting system, separate from TRIM itself. It is not necessary to wait until a simulation has concluded—analysis reports can be produced at any time. If different strategies have been followed from a common base checkpoint condition, the data from either path can be selected for the postprocessing. The log file captures virtually all the yard activity that transpired and is independent of any specific report. By further splitting the log file into subfiles, however, almost any report type can be developed. At this time, the following reports are available:

Report 1—Track population—graphical
Report 2—R&D Occupancy—graphical
Report 3—Lead Occupancy—graphical
Report 4—System Destination Population—graphical
Report 5—Track Put Thru
Report 6—Put Thru by Car Type
Report 7—Crew Utilization (Switching or Inspection)
Report 8—Locomotive Utilization (Switching or Inspection)
Report 9—Conflict and Delay

Each individual report allows the analyst a large degree of flexibility. The analyst can choose to extract and consolidate only those operations in which he is interested. For example, the analyst may specify a time window to use for reporting results so that the activities performed in generating an initial population do not distort the overall statistics. Track population can be examined on an individual track basis, or specified tracks may be grouped together to form an aggregate population. Individual reports are tailored to an analyst's requirements by preparation of a "control" table which governs the selection and consolidation of the associated reporting program.

Two report types are illustrated. Figure 5 shows a graphical report of Track Population. It may be noted that the population is further broken down into its constituent system destination groups. A control table is used to produce the graph, permitting a wide variety of selection and grouping criteria. Figure 6 shows a report on locomotive utilization, indicating how much time was spent in various working and idle categories, plus total miles travelled in the yard.

COMPUTER CONSIDERATIONS

After extensive evaluation of the alternatives available, CN determined that a PRIME 550 system was the most effective computer for its purposes. TRIM is currently running on the following computer configuration:

—PRIME 550 CPU
—1¼ megabytes of main memory
—1 300 megabyte disk drive
—1 tape drive
—1 300 line per minute printer
—4 terminals
—communication capability to CN's mainframe computers

A graphics terminal will be acquired in the near future to provide a 'bird's-eye view' of yard status.

In designing the TRIM applications software, certain important features were considered:

1) All commands are entered via CRT terminals in a fill-in-the-blanks mode.
2) The model handles a variable number of analysts, who can attach to and leave the simulation as desired.
3) TRIM was designed so that it is not permanently tied to one computer system. For example, TRIM could in a relatively straightforward manner, be changed to run on an IBM mainframe computer.

EXPERIENCES WITH THE MODEL

The first yard to undergo simulation with TRIM was Kamloops Yard, a me-

TRACK POPULATION GRAPH

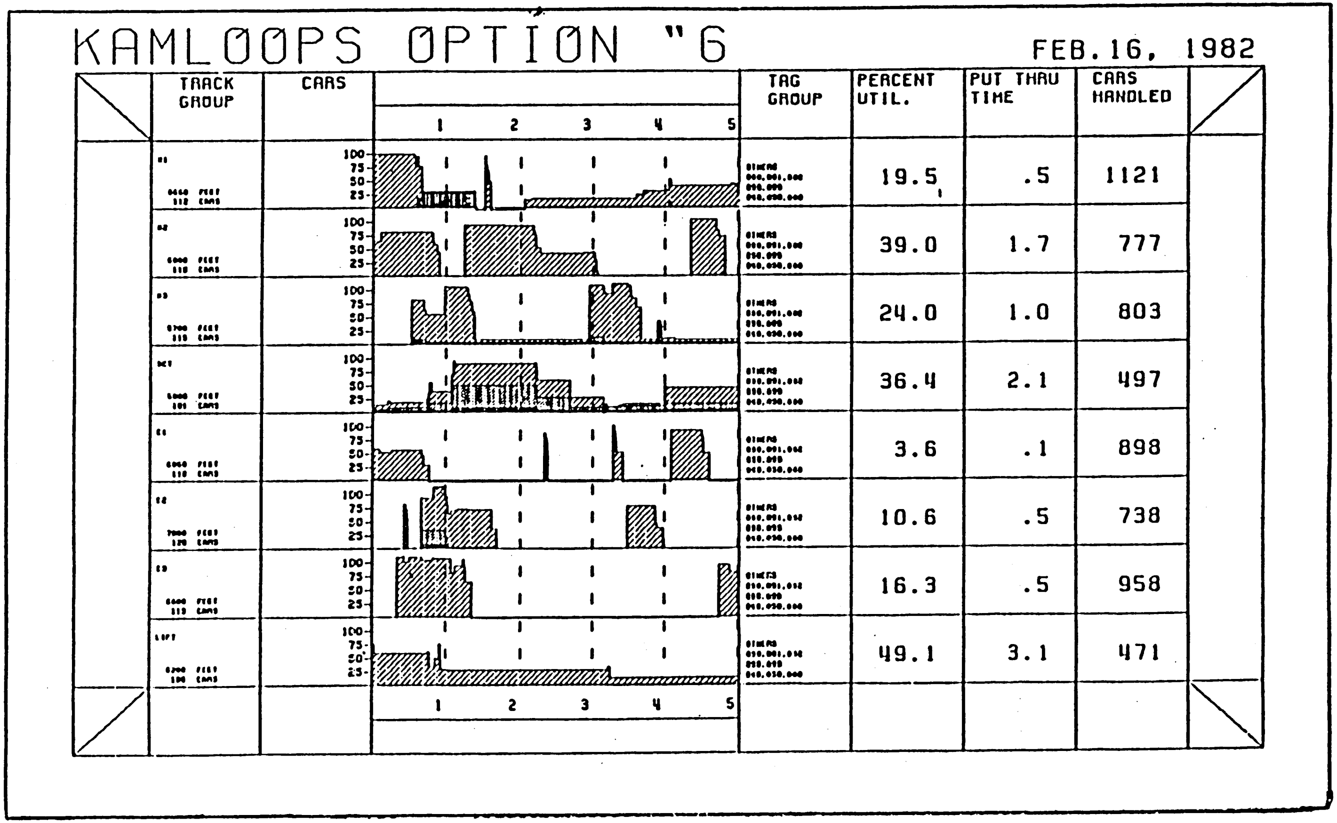

FIGURE 5

LOCOMOTIVE UTILIZATION REPORT

DATE : 02/18/82 SWITCH LOCOMOTIVE REPORT - 8A PAGE 1
TIME : 17:31:55

KAMLOOPS YARD ALTERNATIVE 6

START TIME : 01/00
END TIME : 02/04

CONSIST	SHIFT	CREW	CONS MILES LOADED	CONS HOURS WORKING	CARS HANDLED	CONS HRS IDLE	CONS HOURS BLOCKED	CONS MILES LITE	CONS HOURS LITE	# CARS AVE.	# CARS PEAK
201	01/00:00 01/07:59	201	3.4	0.2		0.8	0.0	0.0	0.0	11.0	77
YARD1	01/00:00 01/07:59	WEST1 WEST2	36.3	2.6		4.0	0.2	42.8	0.8	2.2	48
YARD2	01/00:00 01/07:59	EAST1 309	28.9	2.7		2.7	1.7	28.4	1.3	4.7	77
318	01/00:00 01/07:59	318	3.5	0.3		0.6	0.0	1.7	0.0	8.?	55
314	01/00:00 01/07:59	314	28.0	0.4		1.1	0.0	9.4	0.0	20.1	112
793	01/00:00 01/07:59	793	3.2	0.2		0.1	0.0	0.0	0.0	68.7	87
413	01/00:00 01/07:59	413	8.0	0.4		0.8	0.0	0.0	0.0	23.2	93
304	01/00:00 01/07:59	304	7.4	0.4		1.1	0.1	1.7	0.1	19.8	91
YARD3	01/00:00 01/07:59	CITY1	33.5	1.3		5.2	0.1	14.9	0.6	4.5	108
8791	01/00:00 01/07:59	8791	1.9	0.1		0.0	0.0	0.0	0.0	85.2	99
855	01/00:00 01/07:59	855	1.6	0.1		0.8	0.0	1.0	0.2	11.8	91
779	01/00:00 01/07:59	779	3.7	0.3		0.1	0.0	0.0	0.0	74.7	95
799	01/00:00 01/07:59	797	3.3	0.2		0.2	0.0	0.0	0.0	54.6	95

FIGURE 6

dium size flat yard in British Columbia. In one particular alternative, there were six receiving and departure tracks, 14 tracks in the classification yard, and a surge yard with 6 tracks. The total number of track segments, including connecting tracks and crossovers, was well over 200. The goal of the simulation was to evaluate several yard expansion designs to handle projected 1990 traffic volumes—requiring approximately 4500 car-handlings daily. The strategy employed was to use one yardmaster experienced in Kamloops operations, plus two yard analysts, who actually used the CRT screens to translate the yardmaster's general directives into more specific yard commands. One analyst tended to handle most of the locomotive and car movement commands while the other handled crew assignments and inspections.

Several key lessons were learned from this simulation:

- Each analyst should have about two or three weeks of training with TRIM before participating in a full scale simulation. Although each individual TRIM command is straightforward, the training period is necessary because of the number of commands available and their options, and the requirement to be able to develop a good overall feel for the current yard status.

- The simulation team will require about a week of working together before the teamwork relationship fully evolves. The team members will develop their own sharing of responsibilities, methods, and short-cuts to perform an efficient and well-coordinated simulation.
- The amount of detail included in the simulation must be traded-off with the time available to complete the study. In the case of Kamloops, certain track sections were consolidated (tracks going up a switching ladder, for example) to simplify route specification. Certain crew-related activities were simplified as well, since yard design, not yard operation, was the main goal of the analysis.
- The time window for activities should be specified to be at least two or three minutes. Setting the value too small can frequently cause the simulation time jumps to be only several seconds. It is more efficient to force the simulation to handle all activities up to the longer time-window mark. In this case, some resources would remain unnecessarily idle until the end of the window, when new commands could be entered. Little accuracy is lost with this scheme, however, and the increased opportunity for analyst coordination is a major benefit. This would be especially important in the simulation of larger yards with more than two analysts at terminals.
- The simulation rate achieved for Kamloops was approximately five hours of yard simulation during each working day of the simulation team, or about one full yard day each week of simulating. The various graphical and tabular reports were available on an overnight basis. It is expected that this rate can be increased as the analysts gain more experience with TRIM. A larger flat yard would likely take somewhat longer to simulate because of the requirement for additional yard analysts. It is difficult to estimate the simulation rate for a hump yard, since its size and complexity are mitigated by the requirement for much less switching.

FUTURE ENHANCEMENTS

It is anticipated that numerous additional capabilities will be added to TRIM over the years. The most important ones will be those which automatically handle certain basic decisions, removing these burdens from the analyst. One example is the inclusion of standards into the model. Based on locomotive dynamics, number of cars, and total length, the time for a move could be automatically determined. Similarly, the time to switch a set of cars could be determined from the sequence of system destinations in a switch list. Eventually, certain sequences of commands could be generated automatically. For example, a train could be automatically made up for departure, or trains automatically switched in sequence.

Based on the experiences CN has had to date, plus the enhancements which are planned, CN anticipates that TRIM will be a major tool for its own yard analyses for many years to come.