the principal effect on operations of changing from a two- to a three-ship-a-week schedule would be that the maximum requirements for container storage would increase by 25 percent. The case study also revealed that, under either schedule,

1. Containers arriving by truck would spend approximately 2 days in the terminal, whereas containers off-loaded from the ship would spend approximately 1 day;
2. More than 10 percent of the containers would be delayed, on average, 10 min because of waiting for a yard hostler; more yard hostlers might be required during peak periods when the ships are in the terminal;
3. Truck delays at the entry gate would be minimal, but almost half of the departing trucks would be delayed at the exit gate; consequently, providing more gates may be appropriate.
4. The maintenance facilities appear to be more than adequate to service the traffic; and
5. The time to load and unload a ship would be approximately 18 hr.

This case study demonstrates only one type of parametric study that can be performed by using TANDEM. The purpose is to illustrate the type and quality of data produced from the TANDEM computer model. In a full-scale analysis effort, all parameters of the terminal would be varied to develop the optimum terminal operating characteristics. For example, the following terminal characteristics would be varied: the number of gates; the number of yard hostlers; the rate, volume, and mix of arriving containers by truck; the size of ships; the arrival schedule of ships (assumed to be equally spaced during the week); and the layout of the terminal.

CONCLUSION

A computer simulation model such as TANDEM offers the terminal designer the opportunity to plan, design, or modify container terminals with less risk and more confidence. Specifically, the designer can use the model to develop the optimum system design and then to test the response of the design to various traffic levels and operational scenarios. Because the cost of capital is high, and because the terminal design can affect the profitability of the operating company for decades, terminals must be planned and designed by using the latest available techniques.

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Simulation of Railway Piggyback Terminals

LOUIS DUBÉ

The computer model described in this paper simulates trailer handlings in railway top-lift piggyback terminals. It allows a fast and accurate evaluation of operating trade-offs by quantifying the use of tracks, storage areas, cranes, and tractors. The input comprises key physical characteristics, machine schedules, and train and trailer arrivals and departures according to specified distributions. Output tables describe the machine time spent in loading, unloading, traveling, or idling, and they also describe an hourly distribution of cars on each track and trailers in storage. Time-distance charts of machine positions on each track give a detailed log of operations performed for each trailer. The simulation has been used to evaluate modifications to existing terminals and for the design of proposed terminals. It has general applicability to a wide variety of terminal configurations, equipment types and speeds, and traffic volumes. It is written in Simscript II.5 and requires 400-600 K of core and 1-5 sec/simulated day to execute, depending on the size of traffic.

A computer simulation model of operations in a railway piggyback terminal, where trailers are lifted on and off railcars, is presented. Such terminals provide the link between the long-distance haul of trailers on railway cars and the delivery of those trailers by road to customers.

The following points are covered in this paper:

1. Objectives of simulation,
2. Events simulated,
3. Events not simulated,
4. Inputs required,
5. Outputs generated,
6. Technical considerations, and
7. Applications for (a) modification of an existing terminal, and (b) design of a proposed terminal.

OBJECTIVES OF SIMULATION

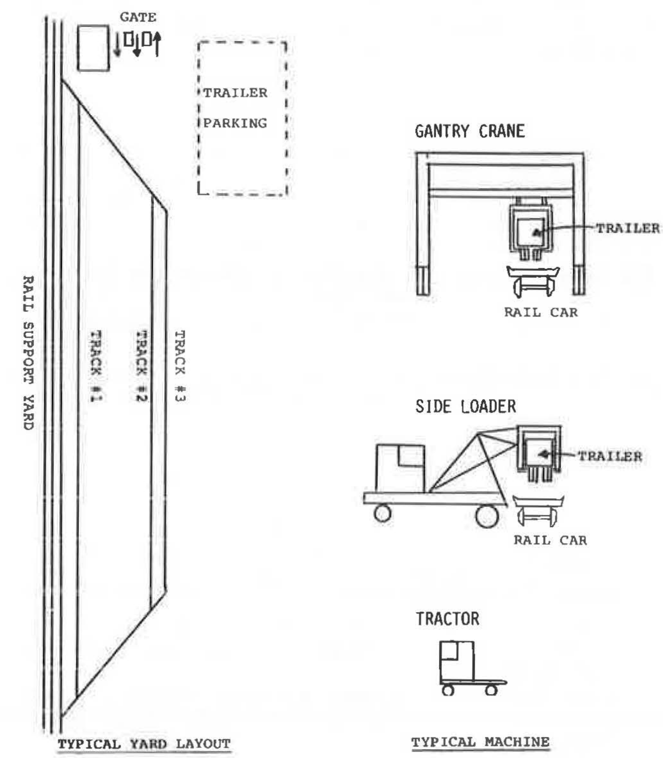
Simulations of operations have always been a powerful tool in designing intermodal terminals. They allow a systematic evaluation of various designs under different traffic levels and operating conditions. Two major difficulties have held back the full use of simulations: (a) the high level of detail required to model reality adequately, and (b) the long time spent in performing simulations manually and recording pertinent information for further analysis.

The computer simulation described here attempts to overcome these difficulties. It includes the most relevant features of a piggyback terminal, simulates its activities in detail, and produces reports on its performance, thus allowing many alternatives to be analyzed quickly. It may be used to evaluate changes in loading tracks, handling equipment, traffic volumes, and train schedules.

EVENTS SIMULATED

In a piggyback terminal, trailers change modes of transportation from road to rail and vice versa.

Figure 1. Physical elements of typical intermodal terminal.



The elements of a typical terminal (shown in Figure 1) are:

1. The gate, where trailers enter or exit the terminal by the road;
2. Rail tracks, where trailers are loaded or unloaded on or off the railcars;
3. Trailer parking, where trailers are stored until railcars are ready to be loaded or (for unloaded traffic) until a tractor picks them up for delivery;
4. Lifting equipment, which lifts trailers on or off railcars from or to the trackside; and
5. Tractors, which pull trailers between parking and trackside.

The events simulated modify the status of the rail tracks, gate, and trailer parking. Status is expressed as the number of trailers at the above locations over time.

Events may be externally generated according to a train schedule or gate arrival distribution for train arrivals on the tracks (loaded with trailers) or trailer arrivals at the gate (individually by road), or they may be internally driven, i.e., unloading of trailers from the car (after train arrival) or loading of trailers onto the car (after gate arrival).

The sequence of events simulated for arriving trains is as follows:

1. Arriving train selects the best track: It must be free of cars, accept the largest number of cars from the train, and waste the least space on the track. If the whole train or part of the train cannot be placed on the tracks, the remaining cars are considered to be on storage tracks until a track is free.
2. Cranes unload trailers off railcars: As soon as the train arrives, unloading may start, provided that a lifting machine is available for unloading on that track. If more than one machine are free, the nearest one will be dispatched. Unloading will tend to be performed sequentially along the track, where the machine moves to the closest (and adjacent) trailer on the track.
3. Yard tractors bring trailers to parking area: Trailers may stay at trackside until an outside tractor picks them up for delivery or until the trackside must be freed for loading trailers; unloaded trailers are then brought by yard tractors to a parking area in the yard. Trailers depart from the yard according to a given probability distribution.

The sequence of events simulated for departing trains is as follows:

1. Trailer arrives by road at the gate: It is processed there according to a given service time. It then proceeds to a section of a track reserved for one of the final destinations of the train it will be loaded on. If the track is not yet ready to accept trailers, the arriving trailer proceeds to the parking area.
2. Yard tractors bring trailers to trackside: When the track is made ready to receive trailers, tractors will start to bring trailers in the parking area for that train to sections of track allocated for each destination.
3. Cranes load trailers on railcars: When empty railcars have been placed on the track, a crane will load trailers at trackside onto the adjacent railcar. The crane will move to the closest trailer to load on that track or any other track. This may result in substantial (and unavoidable) traveling if the track is blocked into a number of destinations and trailers arrive randomly at the gate for each destination.
4. Trains depart according to schedule: When the train must leave, trailers that have not yet been loaded on it remain on the ground. They will be brought to the parking area by yard tractors and remain there until the next train for that destination is placed on the tracks.

EVENTS NOT SIMULATED

Two types of events, railcar availability and trailer and railcar sizes, were not included in the simulation. They were considered too complex to simulate because they required too much detailed input and affected terminal operations in unpredictable or insignificant ways.

1. Railcar availability: In the simulation, it is assumed that empty railcars are always available in sufficient number to load all of the expected trailers. This is not necessarily the case in real life; there may be a lack of railcars, and some trailers would then remain on the ground. Simulating railcar availability requires that the whole fleet of cars across the country be simulated, which is outside the scope of this model.
2. Trailer and railcar sizes: Trailers come in different lengths (26, 40, and 45 ft long), as do railcars (holding a 40-ft and a 45-ft trailer, or two 26-ft trailers, and so on). The simulation does not match trailers to railcars by sizes. It matches them only by destination. Taking sizes into account would require that they all be input individually and that the transportation yard itself be modeled. Instead, an average trailer and car length are used to determine the number of trailers that can be loaded on a given track.

INPUTS REQUIRED

A brief description of the input may give an appreciation of the level of detail that is incorporated in the model. An example of such input is shown in Figures 2-5. The input detail is as follows:

1. Simulation parameters--day and time simulation starts and ends, percentage change in volume over stated traffic, average time to find a trailer in the storage area, average time between removing cars on the track and placing other cars, average car (and trailer) length, average distance between tracks, trailer-to-gate processing time, number of gates, and time between last trailer arrival and train departure;
2. Track--track number and length, distance from track position no. 1 to trailer parking, and other track numbers that share the same roadway;
3. Tractor--travel speed (in miles per hour), coupling and uncoupling time to trailer (in seconds), detailed schedule of working hours or downtime, and particular assignments to specific track or train;
4. Lifting equipment--type (gantry straddling track or side-loader), travel speed (in miles per hour), loading and unloading time cycles (in seconds), time to change tracks (for gantry cranes), detailed schedule of working hours or downtime, and particular assignments to specific track or train (if any);
5. Trains--train name, arrival or departure time, number of trailers on train, specific track (if any) it should be assigned to, time at which arriving trailers should be left at trackside, time before departure at which trailers may be brought

Figure 2. Input example–run parameters and track.

```
DAY AND TIME SIMULATION STARTS :  MON   0   0

SIMULATED TIME :   1.00 DAYS

% CHANGE IN VOLUME OVER STATED TRAFFIC :   0.   (EG. 5 FOR 5%)
         CHANGE CAN BE NEGATIVE (I.E. DECREASE IN VOLUME)
         EG.  -5.5  FOR A DECREASE OF 5.5%

TRACTOR TIME IN STORAGE :   1.0 MINUTES
         TRACTOR TIME INCLUDES THE TIME REQUIRED TO FIND THE
         DESIRED TRAILER OR TO FIND AN EMPTY SPOT TO PARK THE
         TRAILER, ANY INTERFERENCE BETWEEN TRACTORS IN STORAGE,
         THE PARKING AND PLACING TIMES EXCLUDING THE
         COUPLING/UNCOUPLING.

AVERAGE TIME FOR SWITCHING :   30. MINUTES

AVERAGE CAR LENGTH :   50.0 FEET

PAD WITH :   100.0 FEET

GATE PROCESSING TIME :   2.0 MINUTES

NUMBER OF GATES :   1

TIME BETWEEN CUT OFF AND PULL :   15.0 MINUTES

                        TRACK INFORMATION

  FIELD DEFINITION :
        TRACK   :    INTEGER REPRESENTING THE TRACK NUMBER
    PAD LENGTH  :    INTEGER REPRESENTING PAD LENGTH (FEET)
       ACCESS   :      DESCRIBES TRACK ACCESS AS FOLLOWS
                       1 - ONE END ONLY
                       2 - TWO ENDS
     DISTANCE   :      DISTANCE IN FEET BETWEEN BEGINNING OF TRACK
                       AND STORAGE AREA.
  CONNNECTION   :      OTHER TRACK CONNECTED TO BY SHARED ROADWAY
                       (ENTER 0 IF NOT CONNECTED)

TRACK      PAD LENGTH      ACCESS      DISTANCE      CONNECTION

  1           3000            2          500.0            1

END OF TRACK INFORMATION
```

Figure 3. Input example–machine definition.

```
                         TRACTOR DEFINITION

  FIELD DEFINITION :
              TRACTOR I.D.  :  UP TO 8 CHARACTER UNIQUE TRACTOR
                               IDENTIFICATION
              TRAVEL SPEED  :  REAL NUMBER REPRESENTING TRAVELLING
                               SPEED IN MPH OF TRACTOR IN YARD
COUPLING/UNCOUPLING TIME    :  REAL NUMBER REPRESENTING EITHER
                               COUPLING/UNCOUPLING TIME OF A
                               TRACTOR TO A TRAILER IN SECONDS.

                   TRAVEL SPEED      COUPLING/UNCOUPLING TIME
TRACTOR I.D.          (MPH)                 (SECONDS)

 TRACTOR 1             15.0                    60

END OF TRACTOR DEFINITION

                     HEAVY EQUIPMENT DEFINITION

  FIELD DEFINITION :
      EQUIPMENT I.D.   :  UP TO 8 CHARACTER UNIQUE EQUIPMENT
                          IDENTIFICATION
        TRAVEL SPEED   :  REAL NUMBER REPRESENTING TRAVELLING
                          SPEED OF EQUIPMENT IN YARD
           LOAD TIME   :  INTEGER REPRESENTING ONE FULL CYCLE
                          TIME FOR LOADING OPERATIONS
         UNLOAD TIME   :  INTEGER REPRESENTING ONE FULL CYCLE
                          TIME FOR UNLOADING OPERATIONS
  CHANGE TRACKS TIME   :  TIME REQUIRED BY MACHINE TO CHANGE PADS
                          (MINUTES)
                TYPE   :  MACHINE CAN BE OF ONE OF TWO TYPES,
                          CRANES OR FRONT LOADERS
                          (USE CRANE OR LOADER KEYWORDS)

                                                      CHANGE
              TRAVEL SPEED  LOAD TIME   UNLOAD TIME  TRACK TIME
EQUIP. I.D.      (MPH)      (SECONDS)   (SECONDS)    (MINUTES)    TYPE

CRANE-1           6.0          136          115           1        CRANE

END OF HEAVY EQUIPMENT DEFINITION

MACHINE I.D.      TIME FROM        TIME TO

 CRANE-1          MON 1 18 0       MON 1 22 00
 TRACTOR1         MON 1 18 0       MON 1 22 00

                                         SELECTED AREA
MACHINE I.D.        TIME         TRACKS      TRAINS      POSITIONS

 CRANE-1          MON 1 18 0      ANY          ANY          ANY

END OF MACHINE ASSIGNMENTS
```

Figure 4. Input example–distributions and inbound train.

```
                          TRAILER DISTRIBUTIONS

GENERAL DISTRIBUTION OF TYPE 1 (ALWAYS NEEDED)

    FIELD DEFINITION :
        HOURS FROM TRAIN TIME :  NUMBER OF HOURS BEFORE TRAIN
                                 DEPARTURE TIME
             FRACTION TRAILERS : FRACTION OF TRAILERS ARRIVING OR
                                 LEAVING DURING GIVEN HOUR.
                                 APPLIED TO NUMBER OF TRAILERS IN
                                 BLOCK.

DISTRIBUTION NUMBER :  1

HOURS FROM TRAIN TIME          FRACTION TRAILERS

          1                           .10
          2                           .10
          3                           .20
          4                           .30
          5                           .30

END OF GENERAL DISTRIBUTION

                 INBOUND SCHEDULE (STARTING ON A MONDAY)

    FIELD DEFINITIONS :
        ARRIVAL TIME :  OF THE FORMAT MON 1 08 25
               TRAIN :  INTEGER NUMBER REPRESENTING ARRIVING TRAINS
        NO. OF UNITS :  INTEGER NUMBER REPRESENTING THE NUMBER OF
                        TRAILERS OR CONTAINERS ON THE ARRIVING
                        TRAIN
      TRACKSIDE TIME :  A REAL NUMBER REPRESENTING THE TIME, IN
                        HOURS THE TRAILERS WILL BE LEFT ALONG THE
                        SIDE OF THE TRACK TO BE PICKED UP DIRECTLY
                        BY THE CUSTOMERS.
         WORK OFFSET :  TIME (MINUTES) TO WAIT BEFORE STARTING WORK
                        ON TRAIN
                DIST :  DISTRIBUTION SELECTION FOR TRAIN
           TRACK NO. :  REPRESENTS THE SELECTED TRACK NUMBERS
                        ASSIGNED TO THE ARRIVING TRAIN CAN BE OF
                        THE FOLLOWING FORMATS :  01
                                            (02 46 47)
                                               ANY

                          NO.    TRACKSIDE    WORK
ARRIVAL TIME   TRAIN   TRAILERS    TIME      OFFSET   DIST   TRACK NO.

MON 2 10 30     201       37       5.00        0.      2       ANY
END OF SCHEDULED INBOUND TRAINS
```

Figure 5. Input example—outbound train schedule.

```
OUTBOUND SCHEDULE (STARTING ON A MONDAY)

FIELD DEFINITION :
          PULL TIME :  OF THE FORMAT MON 1 19 30
              TRAIN :  INTEGER NUMBER REPRESENTING DEPARTING
                       TRAIN
            (BLOCK) :  DESTINATION BLOCK NUMBER
       NO. OF UNITS :  INTEGER NUMBER REPRESENTING THE TOTAL
                       NUMBER OF TRAILERS OR CONTAINERS ON THE
                       DEPARTING TRAIN
            (UNITS) :  INTEGER NUMBER REPRESENTING THE NUMBER OF
                       UNITS ON EACH DESTINATION BLOCK
         CAR PLACED :  OF THE FORMAT MON 1 17 30
                       REPRESENTS THE TIME AT WHICH EMPTY CARS
                       ARE PLACED ON THE TRACK
     TRACKSIDE TIME :  REAL NUMBER REPRESENTING THE NUMBER OF
                       HOURS BEFORE DEPARTURE THE UNITS WILL BE
                       BROUGHT DIRECTLY BESIDE TRACK
               DIST :  DISTRIBUTION SELECTION FOR TRAIN
          TRACK NO. :  REPRESENTS THE SELECTED TRACK NUMBER(S)
                       ASSIGNED TO THE DEPARTING TRAIN CAN BE OF
                       THE FOLLOWING FORMATS :    01
                                               (02 46 47)
                                                  ANY
```

PULL TIME	TRAIN/ BLOCK	NUMBER OF UNITS/PLACES (UNITS/PLACES)		TIME CAR PLACED	TRACKSIDE TIME	WORK OFFSET	DIST	TRACK NO.
MON 1 22 0	100	60	60	MON 1 18 0	4.00	0.	1	ANY
	BLOCK 1	15	UNITS					
	BLOCK 2	15	UNITS					
	BLOCK 3	15	UNITS					
	BLOCK 4	15	UNITS					

END OF SCHEDULED OUTBOUND TRAIN

Figure 6. Output example—gate report.

MAXIMUM TIME AT GATE 7 MINUTES
MEAN TIME AT GATE 2.6 MINUTES
PROCESSING TIME 2.0 MINUTES

QUEUE LENGTH	PERCENTAGE OF TIME	TIME AT GATE (MINUTES)	NUMBER OF TRAILERS
0	.978	0 <= T < 1	0
1	.018	1 <= T < 2	0
2	.002	2 <= T < 3	40
3	.001	3 <= T < 4	9
4	0.	4 <= T < 5	9
5	0.	5 <= T < 6	0
6	0.	6 <= T < 7	1
7	0.	7 <= T < 8	1
8	0.	8 <= T < 9	0
9	0.	9 <= T < 10	0
10	0.	9 <= T < 10	0
		10 <= T < 11	0
		11 <= T < 12	0
		12 <= T < 13	0
		13 <= T < 14	0

Figure 7. Output example—other reports.

INTERMODAL TERMINAL - CRANE SIMULATION

CRANE	DAY	MINUTES LOAD	UNLOAD	IDLE	TRAVEL	TOTAL	PERCENT LOAD	UNLOAD	IDLE	TRAVEL
CRANE-1	0	135	0	47	58	240	56.	0.	20.	24.
ALL	0	135	0	47	58	240	56.	0.	20.	24.

TRAILERS ARRIVAL AND DEPARTURE BY RAIL

DAY : MON

	TIME HHMM	TRAIN	TRAILERS IN	TRAILERS OUT	TOTAL	REMAINING TRAILERS
	2200	100	0	60	60	0
DAY TOTAL			0	60	60	0
GRAND TOTALS			0	60	60	0

SWITCH LISTING FOR SIMULATION

START	END	TASK	TRAIN	TRACK
MON 18 0	MON 18 0	PLACING	100	1
MON 22 0	MON 22 15	REMOVING	100	1

directly to trackside by customer, time at which empty cars are placed, time at which loading or unloading may be started on that train, and number of destination blocks and number of trailers for each block; and

6. Trailers--trailer-arrival-to-gate probability distribution (expressed as a percentage of total trailers or exact number of trailers arriving randomly within an hour at any given hour of day or hour before train departure), trailer-departure-from-gate probability distribution (expressed in the same manner as arrivals), and any other number of probability distributions (they are referred to by number).

OUTPUTS GENERATED

Outputs summarize the various key statistics that help to evaluate different plant and operating methods (see Figures 6 and 7). Some outputs are also available that, on demand, give a detailed log of each event in the simulation. A description of the main outputs is given below:

1. Echo of input data;
2. Distribution of actual gate arrivals and departures by hour of day;
3. Trailer queues at the gate;
4. Trailer arrivals and departures by rail;
5. Hourly distribution of cars on each track;
6. Number of trailers in storage by hour of day;
7. Crane and tractor use by hour of day;
8. Machine time spent in loading, unloading, traveling, and idling;
9. Time-distance chart of machine position on track with operation performed; and
10. Track status at given hour that shows empty track, empty cars, loaded cars, and trailers by trackside by position.

TECHNICAL CONSIDERATIONS

The simulation is written in Simscript II.5, a computer language designed specifically for discrete-event simulations. It requires from 400 to 600 K of core and 1 to 5 sec/simulated day to execute, depending on the number of trains simulated. The cost per average run ranges from $10 to $20.

The reports process a log file created by the simulation. They require various compilers, e.g., COBOL, FORTRAN, and Data Analyzer.

APPLICATIONS

Two types of applications are discussed in this section--one on existing terminals and the other on proposed terminals that use results of a parametric analysis of key physical elements in a terminal.

Railway intermodal terminals are supported by a rail yard, where trains arrive and depart and where cars are sorted by destination. This simulation does not model any of these car classification operations. The actual configuration of the rail support yard may restrict the design of the intermodal terminal where trailers are loaded on railcars.

Modifications of Existing Terminals

This simulation has been applied to determine what modifications would be required if Canadian National Railway's (CN Rail) Toronto intermodal terminal were to handle 8 additional trains per day of 40 trailers each. This represents an increase of 80,000 trailers/year in and out of that terminal, or 100 percent.

The number of trailer lifts would double as compared with the current number. This does not mean that the terminal would have to expand to twice its current size to handle the extra traffic. It now has slack capacity, with two train arrivals in the morning and one in the evening and three train departures in the evening. The additional traffic is expected to be evenly distributed during the day, filling up the morning and early afternoon slack, but putting a strain on the fairly busy evening operations.

The question to resolve, then, is how many more tracks or machines would be required to handle this additional traffic. The length of additional tracks is fixed at about 2,500 ft because of existing trackage length. The type of machine is also practically fixed to ensure compatibility with gantry cranes currently used.

The terminal now operates two gantry cranes on three tracks. Most of the time only one crane is necessary. The second crane is used mainly as a backup.

Current plant and machines can easily handle the additional traffic during night and morning shifts. However, the table below shows that, during the evening shift, three cranes are required; two cranes cannot load all the traffic (note that the statistic for trailers remaining shows that the cranes did not have enough time to load those trailers before departure):

Item	Plant: Three Tracks and Two Cranes	Plant: Three Tracks and Three Cranes
Time spent (%)		
Loading	55	35
Unloading	20	15
Idling	9	45
Traveling	16	5
Trailers remaining	15	0

As can be seen, travel time decreases, when using three cranes, from 16 to 5 percent. Each crane may be assigned to just one track; no traveling from track to track need occur.

Three cranes on three tracks are thus considered the minimum operating plant to handle the extra traffic. One more track and crane may be recommended in the final design to provide slack capacity for railcar switching and crane breakdowns.

Design of Proposed Terminals

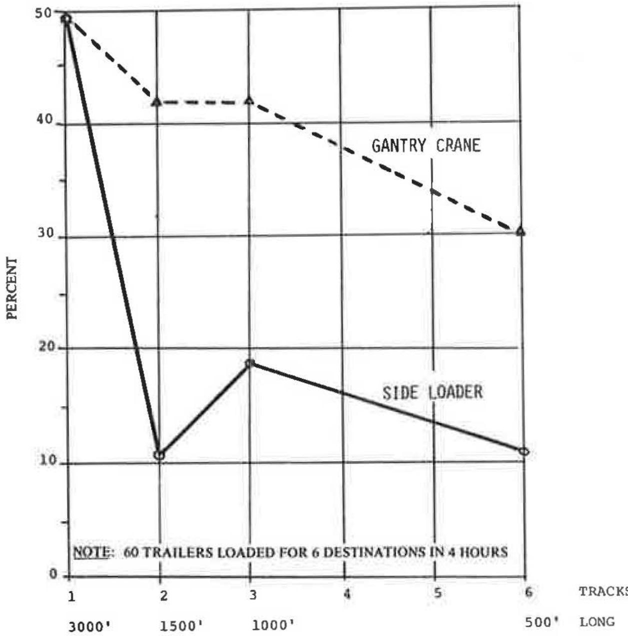
Proposed terminals do not have as many space or equipment constraints as does the extension to existing terminals. Track length and number, and machine type or number, may be allowed to vary more freely. The basic input to this model can be changed easily to test many different situations.

As an example, the simulation was used to test machine travel time as a percentage of loading time, given different track number, length, destination per track, and level of traffic.

Figure 8 shows the results of simulating the loading of 60 trailers for 6 destinations in 4 hr by using 1, 2, 3, or 6 tracks of, respectively, 3,000, 1,500, 1,000, or 500 ft each. Total track length in all cases is 3,000 ft. Each destination has 10 trailers that use up to 500 ft of track.

Two types of lifting equipment are being tested: the gantry crane that straddles a track and the side-lift that moves freely on one side of the track. The main difference between the two machines is that the gantry crane must travel to either end of the track it is straddling to change track, whereas the side-lift may move directly to an adjacent track without having to run to the end of the track. Therefore, use of the side-lift results in less traveling time.

Figure 8. Travel time for different track lengths.



Trailers arrive randomly at the tracks as 10, 20, 20, 20, and 30 percent of total trailers (60) at 1 to 5 hr before train departure for each destination. Thus, 3 hr before departure, 12 trailers will arrive, with 2 (on average) for each destination. The lifting equipment must load them as they arrive in their proper block.

Traveling between destination blocks is inevitable. The machine cannot wait for all trailers for one destination to arrive, because such an event will happen for all destinations separately shortly before train departure. As trailers arrive, the machine loads all adjacent trailers (for one destination), travels past empty rail cars, and loads the next series of adjacent trailers (which have already arrived for another specific destination).

Given those conditions, Figure 8 shows how both types of machines travel less needlessly as the number of tracks increases. Improvements are relatively slow for the gantry crane (50 to 30 percent for 1 to 6 tracks). They are more dramatic for the side-loader at two tracks (50 to 10 percent for 1 to 2 tracks) but do not improve further for a large number of tracks. They even worsen for 3 tracks (18 percent), which is understandable, as track 1 and 2, but not track 3, share the same roadway. An even number of tracks thus reduces traveling time as compared to an odd number.

Figure 9 shows how traveling time is sensitive to the number of destinations per track; e.g., loading 60 trailers in 4 hr on only 1 track for 6, 4, 3, 2, and 1 destinations. Traveling time as a percentage of loading time goes from 50 to 5 percent for runs of 6 to 1 destinations on 1 track. Ideally, at one destination per track, traveling time should be zero. This is not the case because some trailers (30 percent) arrive 1 hr before loading starts. They are stored in the parking area and brought to trackside when the lifting equipment is ready. Space is reserved at the beginning of the track for those trailers that arrived early. The lifting equipment must travel between trailers brought to

Figure 9. Travel time for different destination blocks.

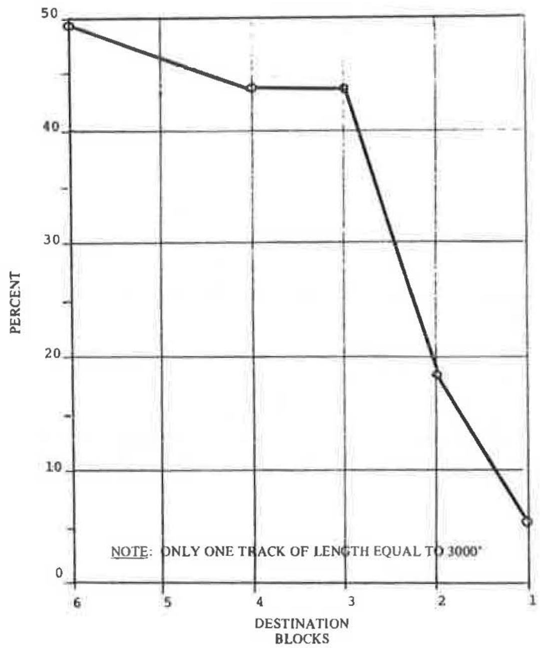
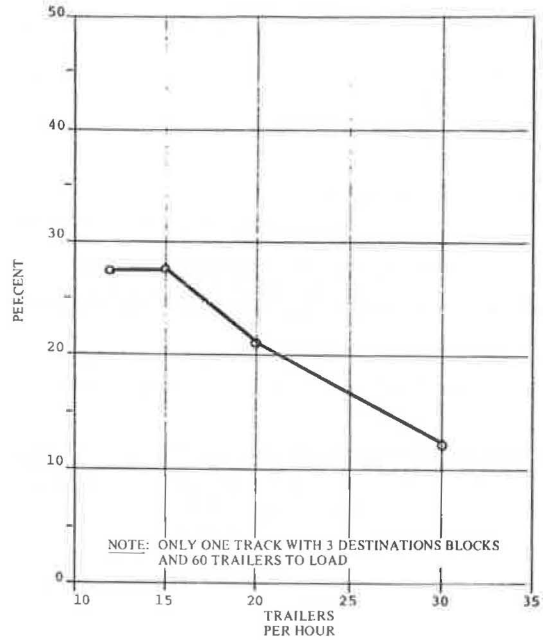


Figure 10. Travel time for different traffic levels.



trackside by the tractors and those arriving directly from the gate.

Because it is assumed that gantry cranes and side-loaders lift and travel at the same speed, there is no difference between those two types of equipment when loading on one track.

It is concluded from this example that it is best to have the least number of destinations for the traffic. That, however, is not a factor that can normally be changed at the terminal level because it is a traffic characteristic.

Figure 10 shows that lifting equipment travel time goes down as the number of trailers per hour goes up. This is to be expected, because the number of adjacent trailers is likely to be higher for any destination if the frequency of arrivals is greater.

This test was done with 60 trailers going to 3 different destinations to be loaded on 1 single track. Trailer arrivals were equal in each hour within each run and varied from 12 to 30 trailers/hr for different runs.

Not all trailers were loaded for frequencies of 20 and 30 trailers/hr. There was not enough time to load all of them before train departure. This implies that, for a given traffic pattern, there is a time to start loading before train departure that will minimize traveling time and at the same time be long enough to load all trailers. Lifting equipment utilization would then be maximized.

CONCLUSIONS

This parametric analysis shows how this model can be used to optimize track length and number and machine utilization. In any concrete applications for a proposed terminal, current and forecasted trains would have to be simulated under different scenarios. Particular traffic patterns would affect the results of this parametric analysis.

The model is limited to the analysis of plant and operating conditions of an intermodal terminal. It may be used to evaluate changes in operations quantitatively. It shows how well-used tracks and machines perform under different situations. But it does not perform an economic analysis on the size of the plant or the number or types of machines. That step comes after the operating analysis.