A computer simulation model of train operations in CTC territory

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CENTRALIZED TRAFFIC CONTROL (CTC) is a system which controls the movement of trains. One train dispatcher, located at a central point, can manipulate the position of track switches and the indication of track signals through the use of a series of push buttons. It is the position of the track switches and the signal indications which govern the progress of the trains through the CTC system. A schematic of a section of single track with a siding and a section of double track is shown in Exhibit I. The CTC Simulation is a model of the train movements through a CTC system.

The design of the computer program commenced in 1961, and up to its latest application was still being fine-tuned. The simulation was programmed for an IBM 7080 computer in Autocoder language with one Fortran subroutine. The running time varies with the number of trains and the length of territory being simulated. The computer running time to produce the attached output was approximately twenty minutes.

The input to this program is comprised of three types:

1. Track Profile Record—for a section of track up to one mile in length, this record contains the resistance due to grade and curvature (in lbs./tons) in each direction and the track speed limit for freight and passenger trains in each direction,
2. Signal Block Record—contains the mileage of the signal at the beginning of the signal block, the length of the signal block, the mileage of spur tracks, and a code describing the type of the signal block,
3. Train Data Records—(a) contains the number of diesel locomotives, the dispatching priority code, the departure mileage and time, the arrival
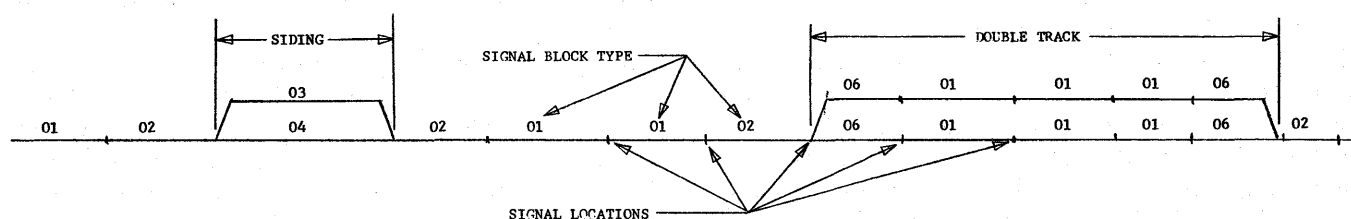
A SIGNAL BLOCK is the section of track between two signals

Exhibit I

TRAIN 1   SIDING A   SIDING B   TRAIN 2
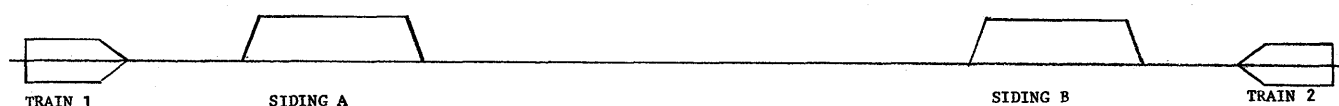
Delay to TRAIN 1 if meet takes place at siding A = 15 minutes

Delay to TRAIN 2 if meet takes place at siding B = 18 minutes

Exhibit II

mileage, the gross weight of the train, the horse-power, and the schedule or standard running time of the train over the territory being simulated,
                            (b) contains the scheduled, or work stop, delay information, such as mileage and duration of the delay, any change in the consist of the train (adding or deleting cars and diesel locomotives), and whether the delay is clearing or non-clearing.

The inputs for the Track Profile and the Signal Block Records are obtained from Engineering drawings. The input for the Train Data Records is obtained from dispatcher train sheets, existing train schedules, and Transportation planning personnel.

Appendix I contains the generalized logic diagram of the simulation. After the Track Profile and Signal Block Records have been edited and stored in the computer memory, a reservoir of the first sixteen trains, in chronological order, is created. Throughout the simulation, this reservoir of trains is scanned, and the train with the lowest clock time is selected and progressed through the system to its next event or decision point. As the trains move through the system, the information describing each train is actually moved from signal block to signal block in the computer memory. The simulator treats each signal location as a decision or event point, where the relative position of each train can be evaluated in order to determine whether they should stop, proceed, slow down, or enter a siding.

If the selected train is originating, or returning from a clearing work stop, the simulator must decide whether to allow the train to enter the system. In real life, a train dispatcher must scan the track in the vicinity of the train to determine if the track is clear before deciding whether to permit the train to enter the system. This is precisely what the simulator does. If the track is clear, the simulator places the train in the signal block and calculates the time it will take the train to move to the next signal location. This time is then added to the train clock time and the train returned to the reservoir. If the track is not clear, the train is not placed in the signal block. One minute is added to the train clock time before the train is returned to the reservoir.

When the selected train is one that has arrived at its terminating point, a statistical record is created for that train and the train is removed from the system. The signals for that signal block are reset to clear. A new train is then added to the reservoir.

When the selected train is one that has arrived at a scheduled or work stop delay point, the duration of the train's delay is added to the train clock time. A work stop may be of two types—clearing and non-clearing. A clearing work stop is one in which the train leaves the CTC system, whereas a non-clearing work stop is one in which the train remains in the CTC system. Therefore, if the train has a clearing work stop, the simulator removes the train from the CTC system, cancels all meets and passes for that train, resets to clear the signals for the signal block the train is in, and returns the train to the reservoir. If the train has a non-clearing work stop, the simulator returns the train to the reservoir.

Before moving a train to the end of a signal block, the
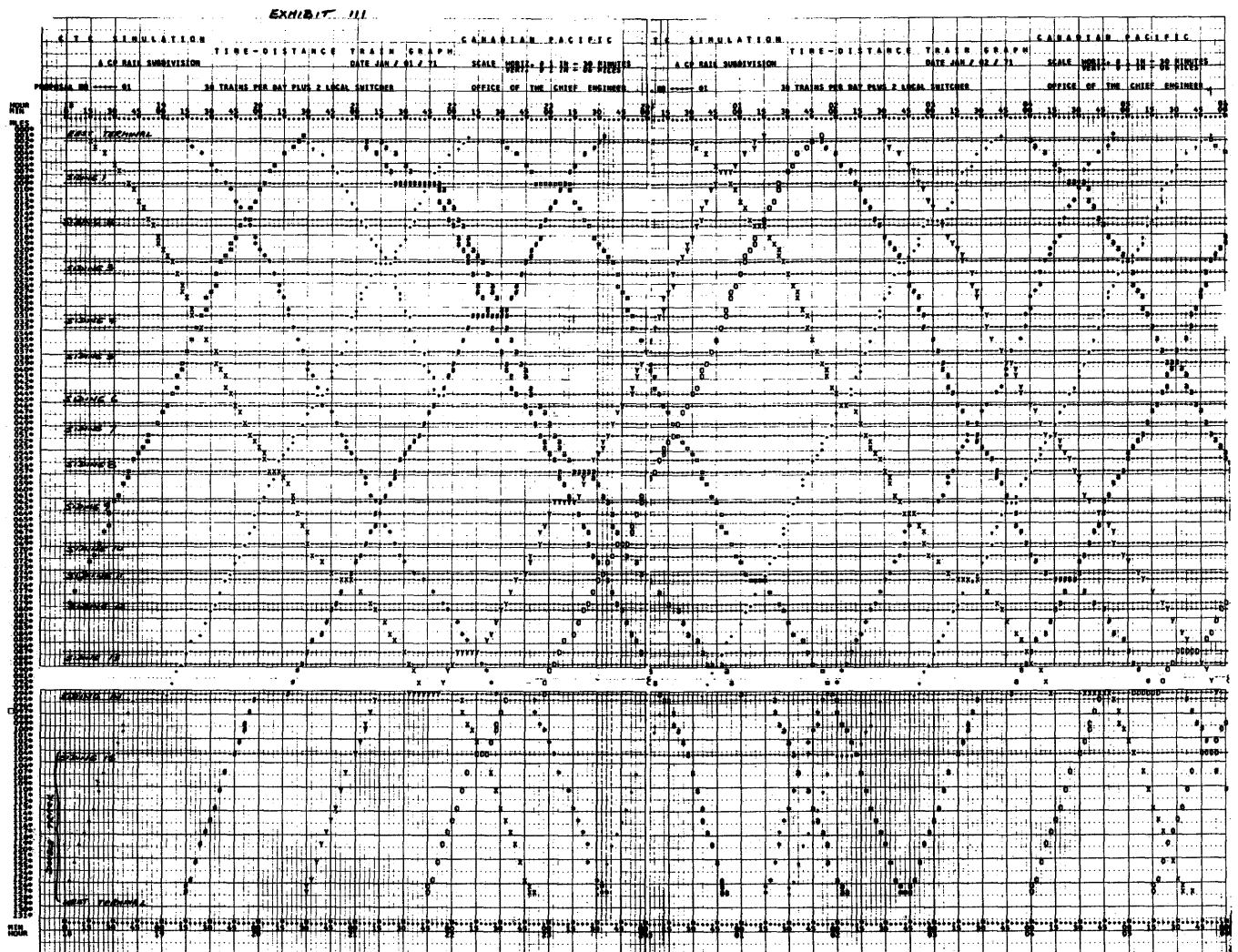
Exhibit III

simulator must first determine if the train terminates in this signal block or has a work stop in the signal block. If either of the above is the case, the time for the train to move to the terminating or work stop point from its present location is calculated. Otherwise, the time for the train to move to the next signal location from its present location is calculated. Appendix II is the logic diagram for the routine which calculates the train running time over a specified distance. The dynamic characteristics of the train are developed by the Newtonian force equation $F = MA$, where F, the net force available for acceleration, and M, the mass of the train, are known and A, the acceleration, is calculated. The net force is the algebraic sum of the forces acting on the train, that is, the 'pulling' force or 'tractive effort' of the diesel locomotives minus the 'retarding' forces or the train resistance due to grade, curvature, flange and bearing friction, and still air resistance. The train is progressed in small increments of distance of between 100 and 260 feet until the train has travelled the required distance. The times for the train to move over all the small distance increments are summed and added to the train clock time. The train is then returned to the reservoir.

When the train has reached the end of a signal block, and hence, is about to enter the next signal block, the simulator must first evaluate the position of the train relative to other trains in the vicinity of this train. All

EXHIBIT IVa

2

* C T C   S I M U L A T I C N   C A N A C I A N   P A C I F I C

S T A T I S T I C A L   R E P C R T

A CF RAIL SUBDIVISION   PERIOD JAN 1 TO JAN 3 , 1971

PRCPCSAL AC ----- 01   38 TRAINS PER CAY PLUS 2 LCCAL SWITCHER   OFFICE OF THE CHIEF ENGINEER

I PERFORMANCE SUMMARY OF INDIVICUAL TRAINS

TRAIN NO SPB	TYP	CLS	NC CF CSLS	DEPARTURE TIME DY HR MIN	POWER IN H/P	NC OF CARS	TONS	ELAPSEC TIME RUN CC HR MIN	RUN O1 HR MIN	TIME SAVED HR MIN	WK STP HR MIN	CNFLCT HR MIN	TOTAL HR MIN	NO OF CNFLCT	AVG SPD
1C10 o	F	E	08	01 16 30	24000	114	04695	4 3C	3 57	33	15	02	17	2	31.8
1C91 ,	F	I	04	01 20 30	06800	100	036CC	1 3C	1 25	05			1	1	30.3
2C02 .	F	E	08	01 18 00	24000	114	04695	4 3C	4 10	20	15	14	29	5	30.1
1C11 X	F	C	06	01 18 15	18000	114	15990	4 45	4 37	08	15	15	30	4	27.2
2C04 #	F	E	08	01 19 15	24000	114	04695	4 3C	4 10	12	15	22	37	5	29.2
1C13 *	F	C	06	01 19 15	18000	114	1599C	4 45	4 22	23	15		15	4	28.8
1C01 0	P	A	03	01 21 05	05000	012	01200	3 4C	3 47	07-	02	26	28	4	33.2
2FE2 Y	F	F	08	01 20 30	24000	114	04695	4 3C	4 45	15-	15	47	1 02	5	26.4
2FE4 C	F	F	08	01 21 45	24000	114	04695	4 3C	4 05	25	15	10	25	5	30.8
1C15 a	F	C	06	01 21 15	18000	114	1599C	4 45	4 52	07-	15	31	46	5	25.8
1Eb3 o	F	F	02	01 22 30	06000	079	02365	4 3C	4 13	17		28	28	5	29.8
20C6 .	F	E	08	01 23 30	24000	114	04695	4 3C	4 11	19	15	13	28	5	30.0
2C02 *	P	A	03	02 01 15	05000	012	01200	3 4C	3 37	03	11	04	15	4	34.7
1G01 X	F	D	06	02 00 30	18000	114	15990	4 45	5 08	23-	15	46	1 01	5	24.5
2C08 .	F	E	08	02 01 30	24000	114	04695	4 3C	4 20	10	15	23	38	5	29.0
1C17 #	F	C	06	02 01 30	18000	114	1599C	4 45	4 54	09-	15	32	47	5	25.6
2C1C 8	F	E	08	02 02 45	24000	114	04695	4 3C	3 56	34	15		15	5	31.9
1G03 Y	F	D	04	02 02 30	12000	114	10452	4 45	4 34	11	15	14	29	5	27.5
1F03 #	F	D	06	02 04 00	18000	114	15990	4 45	4 37	08	15	15	30	5	27.2
2FE6 C	F	F	08	02 04 00	24000	114	04695	4 3C	4 57	27-	15	1 00	1 15	5	25.4
2GE2 0	F	F	08	02 05 15	24000	114	04695	4 3C	4 10	20	15	14	29	5	30.1
2C01 0	F	C	06	02 05 40	18000	114	1599C	4 45	4 58	13-	15	37	52	5	25.3
1F05 X	F	D	06	02 06 40	18000	114	15990	4 45	4 23	22	15	02	17	4	28.7
2C12 .	F	E	08	02 06 30	24000	114	04695	4 3C	4 35	05-	15	37	52	5	27.4
2C90 Y	F	I	04	02 09 15	06800	1C0	0635C	1 3C	2 01	31-		09	09	3	21.3
2902 *	F	B	06	02 07 45	18000	114	07725	4 15	4 20	05-	15	15	30	6	29.0
2966 #	F	B	03	02 08 15	09000	114	0715C	4 0C	4 28	28-	15	20	35	6	28.1
2GE4 ,	F	F	06	02 09 00	18000	114	04305	4 3C	4 45	15-	15	48	1 03	5	26.4
2948 C	F	B	06	02 11 00	18000	114	07725	4 15	4 05	10	15		15	5	30.8
2C03 8	F	C	06	02 09 30	18000	114	1599C	4 45	5 35	50-	15	1 13	1 28	6	22.5
2C05 8	F	C	06	02 10 20	18000	114	15990	4 45	5 00	15-	15	37	52	7	25.1
2C14 o	F	E	08	02 11 30	24000	114	04695	4 3C	4 17	13	15	21	36	6	29.3
2C07 0	F	C	06	02 11 20	18000	114	1599C	4 45	4 39	06	15	18	33	5	27.0
2E82 X	F	F	02	02 13 15	06000	1C8	0309C	4 3C	4 20	10		25	25	5	29.0
2C09 .	F	C	06	02 13 00	18000	114	1599C	4 45	5 08	23-	15	44	59	6	24.5
2E01 *	F	F	03	02 13 40	09000	114	04507	4 3C	4 37	07-		36	36	5	27.2
2LU2 #	F	B	06	02 14 15	18000	085	1C095	4 15	4 44	29-	15	31	46	6	26.5
2C16 V	F	E	08	02 15 15	24000	114	04695	4 3C	4 12	18	15	15	30	5	29.9
2901 ,	F	B	03	02 14 50	09000	114	0715C	4 0C	4 48	48-	15	39	54	5	26.2
2018 8	F	E	08	02 16 30	24000	114	04695	4 3C	4 16	14	15	20	35	4	29.4

PROPCSAL AC ----- 01   38 TRAINS PER DAY PLUS 2 LOCAL SWITCHER   OFFICE OF THE CHIEF ENGINEER

I PERFORMANCE SUMMARY OF INDIVIDUAL TRAINS

TRAIN AC SPB	TYP	CLS	NC CF CSLS	DEPARTURE TIME DY HR MIN	PCWER IN H/P	NO OF CARS	TONS	ELAPSEC TIME RUN CC HR MIN	RUN O1 HR MIN	TIME SAVED HR MIN	WK STP HR MIN	CNFLCT HR MIN	TOTAL HR MIN	NO OF CNFLCT	AVG SPD
2F01 8	F	D	06	02 16 50	18000	114	1599C	4 45	4 22	23	15		15	5	28.8
2C02 C	F	E	08	02 18 00	24000	114	04695	4 3C	4 09	21	15	12	27	6	30.3
2C9I X	F	I	04	02 20 30	06800	1C0	036CC	1 3C	1 42	12-		16	16	2	25.2
2C11 0	F	C	06	02 18 15	18000	114	1599C	4 45	4 37	08	15	15	30	6	27.2
2C04 .	F	E	08	02 19 15	24000	114	04695	4 3C	4 14	16	15	18	33	6	29.7
2C13 0	F	C	06	02 19 15	18000	114	1599C	4 45	4 46	01-	15	25	40	4	26.4
2C01 #	P	A	03	02 21 05	05000	012	0120C	3 4C	3 21	19	02		02	5	37.5
3F02 *	F	F	08	02 20 30	24000	114	04695	4 3C	4 45	15-	15	48	1 03	5	26.4
2C15 ,	F	C	06	02 21 15	18000	114	1599C	4 45	4 29	16	15	08	23	4	28.0
3FE4 Y	F	F	08	02 21 45	24000	114	04695	4 3C	4 57	27-	15	1 00	1 15	6	25.4
28H3 8	F	F	02	02 22 30	06000	079	02365	4 3C	4 31	01-		44	44	5	27.8
3CC6 3	F	E	08	02 23 30	24000	114	04695	4 3C	4 06	24	15	10	25	5	30.6
3C02 C	P	A	03	03 01 15	05000	012	0120C	3 4C	3 52	12-	18	14	32	5	32.5
2G0I C	F	D	06	03 00 30	18000	114	1599C	4 45	5 08	23-	15	45	1 00	6	24.5
3C08 .	F	E	08	03 01 30	24000	114	04695	4 3C	4 12	18	15	15	30	4	29.9
2C17 0	F	C	06	03 01 30	18000	114	1599C	4 45	4 54	09-	15	32	47	5	25.6
3C1C *	F	E	08	03 02 45	24000	114	04695	4 3C	3 59	31	15	02	17	4	31.5
2G83 X	F	D	04	03 02 30	12000	114	10452	4 45	4 54	09-	15	37	52	5	25.6
3FE6 ,	F	F	08	03 04 00	24000	114	04695	4 3C	4 11	19	15	16	31	2	30.0
2F03 #	F	D	06	03 04 00	18000	114	1599C	4 45	4 2C	25	15		15	4	29.0
6C/ 57	AVRGES		06		18088	1C5	08584	4 3C	4 28	02	13	23	37	4.9	28.4

AVERAGE DELAY PER TRAIN PER CCNFLICT IS ---- 4.77 MINUTES

EXHIBIT IVb

C T C   S I M U L A T I O N   CANADIAN   PACIFIC

S T A T I S T I C A L   R E P O R T

A CP RAIL SUBDIVISION   PERIOC JAN 1 TO JAN 3 , 1971

PROPOSAL NC ----- 01   38 TRAINS PER DAY PLUS 2 LOCAL SWITCHER   OFFICE OF THE CHIEF ENGINEER

II PERFORMANCE SUMMARY, AVERAGED BY CLASSIFICATION

CLASS OF TRAIN	DESCRIPTION	NO OF TRNS	POWER IN H/P	NO OF CARS	TONS	ELAPSED TIME RUN OC HR MIN	RUN 01 HR MIN	TIME SAVED HR MIN	DELAY TIME WK STP HR MIN	CNFLCT HR MIN	TOTAL HR MIN	NO OF CNFLCT	AVG SPD	AVG DLY PER CNFLCT
A	FAST PASSENGER, EXP.	004	05000	012	01200	3 40	3 39	01	08	11	19	5	34.5	2.4
B	FAST FREIGHT	005	14400	108	07969	4 05	4 29	20-	15	21	36	6	28.1	3.8
C	PIGGYBACK	013	18000	114	15590	4 45	4 50	05-	15	28	43	5	26.1	5.6
D	THROUGH FREIGHT	008	16500	114	14606	4 45	4 41	04	15	20	35	5	27.0	4.1
E	RCC PASSENGER	015	24000	114	04695	4 30	4 11	19	15	15	30	5	30.0	3.2
F	LOW PRIORITY FREIGHT	012	17750	108	04125	4 30	4 31	01-	10	36	46	5	27.9	7.5
G	LOCAL PASSENGER													
H	WORK TRNS,WORK GANGS													
I	SHORT RUN TRAINS	003	06800	100	04517	1 30	1 43	13-		08	08	2	25.6	4.2
J	EXPERIMENTAL TRAINS													

Exhibit IVb

the possible types of signal blocks are shown in Exhibit I and are described below:

1. 01—intermediate signal block,
2. 02—approach signal block to a siding or to double track,
3. 03—siding signal block,
4. 04—mainline signal block adjacent to a siding signal block,
5. 06—first signal block on double track.

If the train is about to move from one intermediate block (01) to another intermediate block (01), or from an approach block (02) to an intermediate block (01), or from the first block of double track (06) to an intermediate block on double track (01) the simulator checks to see if this next signal block is occupied by another train. If this next signal block is occupied by another train, the signal will be set to prevent the train from entering the next signal block. If the next signal block is unoccupied, the second next signal block ahead is checked. If it is occupied, the signal will be set to restrict the train to enter the signal block at a speed of 30 m.p.h. If the second next signal block ahead is unoccupied, the signal will be clear, and the train can enter the signal block at speed limit.

If the train is about to move from an intermediate block (01) to an approach block (02), the simulator scans the track up to and including the first signal block ahead of the next siding. If another train going in the same direction is detected, the simulator determines whether this other train should be passed, and, if so, at which siding the pass should be executed. Signals and switches are set accordingly. Otherwise, the simulator scans the track up to the third siding ahead to detect if there is another train coming in the opposite direction. If so, the siding at which a meet must take place is determined, as well as which train will go into the siding. In determining at which siding meets will take place, the simulator always attempts to minimize the delay. However, the decision as to which siding will be used could be modified according to:

1. the location and duration of any work stops that either train may have,
2. the amount of delay time that either train has accumulated prior to this meet,
3. the relative priorities of the two trains.

Exhibit II is a hypothetical example of how the siding for a meet is chosen. If the two trains are of equal priority and neither has work stops nor has accumu-

EXHIBIT IVc   2

C T C S I M U L A T I O N								C A N A D I A N P A C I F I C	

S T A T I S T I C A L   R E P O R T

A CP RAIL SUBDIVISION   PERIOD JAN 1 TO JAN 3, 1971

PROPOSAL NO ----- 01   38 TRAINS PER DAY PLUS 2 LOCAL SWITCHER   OFFICE OF THE CHIEF ENGINEER

III PERFORMANCE SUMMARY BY SIDINGS

LOCATION	TYPE	MILEAGE	LENGTH	WK STP HR MIN	CNFLCT HR MIN	TOTAL HR MIN	NO OF CONFLICTS	AVERAGE DELAY PER CONFLICT
EAST TERMINAL	TRMNL	.00	1.51		1 31	1 31		
SIDING 1	SDP/P	7.17	1.75		3 31	3 31	18	11.7
SIDING 2	SDP/P	14.52	1.75		1 34	1 34	14	6.7
SIDING 3	SDP/P	22.47	1.87		1 05	1 09	8	8.6
SIDING 4	SDP/P	31.18	1.42		1 02	1 02	9	6.9
SIDING 5	SDP/P	37.00	1.70		53	53	13	4.1
SIDING 6	SDP/P	44.21	1.75	04	40	44	7	5.7
SIDING 7	SDP/P	48.86	1.91		36	36	7	5.1
SIDING 8	SDP/P	55.32	1.70		1 11	1 11	11	6.5
SIDING 9	SDP/P	62.14	1.85	29	59	1 28	11	5.4
SIDING 10	SDP/P	69.04	1.75		34	34	6	5.7
SIDING 11	SDP/P	73.63	1.68		1 32	1 32	12	7.7
SIDING 12	SDP/P	78.74	1.75		58	58	10	5.8
SIDING 13	SDP/P	86.82	1.76		2 03	2 03	11	11.2
SIDING 14	SDP/P	93.55	1.77	12 15	3 20	15 35	1	200.0
SIDING 15	SDP/P	103.79	2.91		47	47		
AVERAGES FOR 15 SIDINGS				51	1 23	2 14	9.2	9.1

Exhibit IVc

lated delay in excess of thirty minutes, then the meet would take place at siding A. However, if train 1 had accumulated more than thirty minutes delay, then the meet would take place at siding B.

If the train is about to move from an intermediate block (01) to the last block of double track (06), the simulator scans each signal block ahead up to the next siding. If a train is detected coming in the opposite direction, the signal at the end of the 06 signal block is set to prevent the train from entering the approach block (02). Otherwise, the train is given clear signals.

If the train is about to move from an approach block (02) into a siding block (03), the signal is set to reduce the train speed to 15 m.p.h. If the train has a meet or a pass at this siding and if the other train is already at the siding, the meet or pass is cancelled.

If the train is about to move from an approach block (02) into a main line block adjacent to a siding block (04) and if the train does not have a meet or pass at this siding, the train is given a clear signal. Otherwise, the signal is set to restrict the train speed to 30 m.p.h. If the other train is already at the siding, the meet or pass is cancelled.

If the train is about to move from an approach block (02) into the first block of double track (06), and has a meet set up in the (06) block, the meet is cancelled.

If the train is about to move from a siding block (03), or from the main line block adjacent to a siding block

(04), or from the last block of double track (06) into an approach block (02), the simulator checks whether the train has a meet or pass in this block. If so, and if the other train is not yet at the siding, or on the double track, the signal is set to prevent the train from entering the next block. Otherwise the meet or pass is cancelled. Then the simulator scans the track ahead up to the next siding. If a train is detected coming in the opposite direction, the signal is set to prevent the train from entering the next signal block. Otherwise, the train is given a clear signal.

The simulator has now evaluated the position of the train relative to other trains and has set the signal for the next signal block accordingly. If the signal indication is set to prevent the train from entering the next signal block, one minute is added to the train clock time and the train is returned to the reservoir without being moved into the next signal block. Otherwise, the time for the train to move into the next signal block is calculated and added to the train clock time. The train is then moved into the next signal block and returned to the reservoir. The simulator processes each train in the above manner until all trains have reached their terminating point.

The simulator produces three types of output:

1. a time-distance graph,
2. statistical reports,

EXHIBIT Va   **3**

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C T C   S I M U L A T I O N          INTERVALS  OF  FREE - TIME

   JUN  2 1971
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MILEAGE FROM TO	INTERVAL FROM TO	DURATN HR MIN	INTERVAL FROM TO	DURATN HR MIN	INTERVAL FROM TO	DURATN HR MIN	INTERVAL FROM TO	DURATN HR MIN	INTERVAL FROM TO	DURATN HR MIN	INTERVAL FROM TO	DURATN HR MIN	INTERVAL FROM TO	DURATN HR MIN

EAST TERMINAL

1.51- 2.93	* 2332-0030	0 58	* 0036-0108	0 32	* 0114-0131	0 17	* 0155-0230	0 35	* 0235-0400	1 25	* 0406-0447	0 41	*
	* 0451-0541	0 50	* 0556-0640	0 44	* 0646-0717	0 31	* 0723-0814	0 51	* 0826-0927	1 01	* 0933-1019	0 46	*
	* 1025-1105	0 40	* 1111-1149	0 38	* 1155-1345	1 50	* 1351-1451	1 00	* 1510-1539	0 29	* 1546-1550	0 04	*
	* 1555-1650	0 55	* 1656-1815	1 19	* 1821-1857	0 36	* 1904-1915	0 11	* 1921-2020	0 59	* 2027-2031	0 04	*
	* 2050-2105	0 15	* 2108-2115	0 07	* 2123-2220	0 57	* 2226-2230	0 04	* 2235-2332	0 57	*		
2.93- 4.34	* 2328-0033	1 05	* 0044-0102	0 18	* 0110-0137	0 27	* 0145-0153	0 08	* 0204-0233	0 29	* 0243-0403	1 20	*
	* 0414-0441	0 27	* 0447-0537	0 50	* 0544-0553	0 09	* 0604-0643	0 39	* 0654-0712	0 18	* 0719-0809	0 50	*
	* 0817-0825	0 08	* 0835-0921	0 46	* 0929-1013	0 44	* 1021-1059	0 38	* 1108-1143	0 35	* 1151-1348	1 57	*
	* 1359-1452	0 53	* 1500-1508	0 08	* 1518-1534	0 16	* 1541-1553	0 12	* 1603-1653	0 50	* 1704-1818	1 14	*
	* 1829-1852	0 23	* 1900-1918	0 18	* 1929-2015	0 46	* 2022-2032	0 10	* 2040-2048	0 08	* 2058-2107	0 09	*
	* 2114-2118	0 04	* 2129-2214	0 45	* 2222-2233	0 11	* 2240-2326	0 46	*				
4.34- 5.75	* 2325-0039	1 14	* 0046-0056	0 10	* 0107-0132	0 25	* 0142-0159	0 17	* 0209-0238	0 29	* 0249-0409	1 20	*
	* 0419-0436	0 17	* 0442-0531	0 49	* 0542-0559	0 17	* 0609-0649	0 40	* 0656-0706	0 10	* 0716-0803	0 47	*
	* 0814-0830	0 16	* 0840-0915	0 35	* 0926-1007	0 41	* 1018-1054	0 36	* 1104-1138	0 34	* 1148-1354	2 06	*
	* 1404-1446	0 42	* 1457-1513	0 16	* 1523-1528	0 05	* 1539-1558	0 19	* 1608-1659	0 51	* 1709-1824	1 15	*
	* 1834-1846	0 12	* 1857-1924	0 27	* 1934-2009	0 35	* 2020-2027	0 07	* 2037-2053	0 16	* 2104-2113	0 09	*
	* 2119-2124	0 05	* 2134-2209	0 35	* 2219-2238	0 19	* 2248-2321	0 33	*				
5.75- 7.17	* 2319-0044	1 25	* 0101-0129	0 28	* 0137-0204	0 27	* 0212-0244	0 32	* 0251-0414	1 23	* 0422-0434	0 12	*
	* 0437-0528	0 51	* 0533-0604	0 31	* 0612-0641	0 29	* 0711-0800	0 49	* 0808-0836	0 28	* 0841-0912	0 31	*
	* 0920-1004	0 44	* 1012-1050	0 38	* 1058-1134	0 36	* 1142-1359	2 17	* 1407-1443	0 36	* 1451-1514	0 23	*
	* 1533-1604	0 31	* 1610-1704	0 54	* 1712-1829	1 17	* 1837-1843	0 06	* 1851-1929	0 38	* 1937-2006	0 29	*
	* 2014-2024	0 10	* 2030-2059	0 29	* 2106-2118	0 12	* 2122-2129	0 07	* 2137-2205	0 28	* 2213-2244	0 31	*
	* 2249-2317	0 28	*											
7.17- 8.92 S	* 2253-0045	1 52	* 0051-0419	3 28	* 0426-0659	2 33	* 0706-1510	8 04	* 1516-1834	3 18	*		
SIDING 1														
7.17- 8.92 M	* 2314-0049	1 35	* 0056-0125	0 29	* 0131-0209	0 38	* 0216-0248	0 32	* 0255-0431	1 36	* 0434-0525	0 51	*
SIDING 1	* 0530-0609	0 39	* 0616-0637	0 21	* 0642-0757	1 15	* 0802-0839	0 37	* 0845-0909	0 24	* 0915-1001	0 46	*
	* 1007-1047	0 40	* 1053-1131	0 38	* 1136-1404	2 28	* 1411-1440	0 29	* 1445-1522	0 37	* 1528-1607	0 39	*
	* 1614-1709	0 55	* 1716-1840	1 24	* 1845-1934	0 49	* 1941-2003	0 22	* 2008-2020	0 12	* 2026-2103	0 37	*
	* 2109-2121	0 12	* 2124-2134	0 10	* 2141-2202	0 21	* 2208-2247	0 39	* 2253-2314	0 21	*		
8.92- 10.32	* 2316-0042	1 26	* 0047-0053	0 06	* 0059-0123	0 24	* 0127-0213	0 46	* 0219-0252	0 33	* 0258-0424	1 26	*
	* 0437-0522	0 45	* 0527-0613	0 46	* 0619-0635	0 16	* 0639-0704	0 25	* 0709-0754	0 45	* 0759-0842	0 43	*
	* 0848-0906	0 18	* 0911-0958	0 47	* 1003-1043	0 40	* 1049-1128	0 39	* 1133-1408	2 35	* 1414-1437	0 23	*
	* 1442-1508	0 26	* 1513-1525	0 12	* 1531-1611	0 40	* 1617-1713	0 56	* 1719-1837	1 18	* 1847-1938	0 51	*
	* 1944-2000	0 16	* 2005-2018	0 13	* 2022-2107	0 45	* 2112-2124	0 12	* 2126-2138	0 12	* 2144-2200	0 16	*
	* 2204-2250	0 46	* 2256-2312	0 16	*									
10.32- 11.72	* 2319-0040	1 21	* 0044-0056	0 12	* 0101-0120	0 19	* 0125-0216	0 51	* 0221-0255	0 34	* 0300-0426	1 26	*
	* 0429-0435	0 06	* 0440-0520	0 40	* 0524-0616	0 52	* 0622-0632	0 10	* 0637-0706	0 29	* 0712-0752	0 40	*
	* 0756-0845	0 49	* 0850-0902	0 12	* 0909-0956	0 47	* 1000-1037	0 37	* 1048-1125	0 37	* 1131-1411	2 40	*
	* 1416-1434	0 18	* 1440-1506	0 26	* 1510-1528	0 18	* 1533-1614	0 41	* 1619-1716	0 57	* 1721-1833	1 12	*
	* 1840-1845	0 05	* 1850-1941	0 51	* 1946-1953	0 12	* 2002-2015	0 13	* 2020-2110	0 50	* 2115-2126	0 11	*
	* 2129-2141	0 12	* 2146-2157	0 11	* 2202-2253	0 51	* 2258-2309	0 11	*				

Exhibit Va

3. reports listing and summarizing the intervals that each signal block is unoccupied.

Exhibits III, IV, and V are samples of these outputs.

On the time-distance graph, time is represented on the horizontal axis, and distance on the vertical axis. The sidings are represented as the horizontal lines on the graph. The trace of the train is indicated as it traverses the territory, showing the location of any work stops, meets and passes that the train had en route. A similar graph is produced by the CTC system, which makes the simulation graph easily understood by operating personnel in the evaluation of the simulation output.

The statistical reports are comprised of three tables.

The first (Exhibit IVa) tabulates the performance of each individual train in terms of its elapsed running time, which is compared to the standard or scheduled running time, the amount of delay due to work stops, meets, and passes, the number of conflicts (meets and passes), and the average speed. These results are then averaged to give general performance indicators for the simulation. The second table (Exhibit IVb) gives the same general information as the first table, but averaged for various classes of trains. This report is useful in determining the performance of each class of train. The third table (Exhibit IVc) summarizes the performance of each siding in terms of the delay due to work stops and conflicts, the number of conflicts at each siding, and the average delay per conflict. This report is very useful when evaluating alternative siding configurations.

The third type of output is the report listing and

CTC SIMULATION SUMMARY OF FREE - TIME INTERVALS

JUN 2 1971

MILEAGE FROM TO	TOTAL FREE TIME HR MIN	NUMBER OF INTERVALS	LESS THAN 1 HR NO HR MIN	1-1.5 HRS NO HR MIN	1.5-2 HRS NO HR MIN	2-2.5 HRS NO HR MIN	2.5-3 HRS NO HR MIN	3-3.5 HRS NO HR MIN	3.5-4 HRS NO HR MIN	4 HRS AND OVER NO HR MIN
EAST TERMINAL										
1.51- 2.93	20 16	29	24 13 41	4 4 45	1 1 50	*** ** **	*** ** **	*** ** **	*** ** **	*** ** **
2.93- 4.34	19 01	34	30 13 25	3 3 39	1 1 57	*** ** **	*** ** **	*** ** **	*** ** **	*** ** **
4.34- 5.75	18 29	34	30 12 34	3 3 49	*** ** **	1 2 06	*** ** **	*** ** **	*** ** **	*** ** **
5.75- 7.17	19 40	31	27 13 18	3 4 05	*** ** **	1 2 17	*** ** **	*** ** **	*** ** **	*** ** **
7.17- 8.92 S SIDING 1	19 15	5	*** ** **	*** ** **	1 1 52	*** ** **	1 2 33	2 6 46	*** ** **	1 8 04
7.17- 8.92 M SIDING 1	21 16	29	24 12 58	2 2 39	2 3 11	1 2 28	*** ** **	*** ** **	*** ** **	*** ** **
8.92- 10.32	21 02	32	28 14 17	3 4 10	*** ** **	*** ** **	1 2 35	*** ** **	*** ** **	*** ** **
10.32- 11.72	21 01	34	30 14 22	3 3 59	*** ** **	*** ** **	1 2 40	*** ** **	*** ** **	*** ** **
11.72- 13.12	20 59	34	30 14 30	3 3 43	*** ** **	*** ** **	1 2 46	*** ** **	*** ** **	*** ** **
13.12- 14.52	20 31	29	22 11 08	6 6 31	*** ** **	*** ** **	1 2 52	*** ** **	*** ** **	*** ** **
14.52- 16.27 S SIDING 2	25 15	9	2 0 52	2 2 25	*** ** **	1 2 20	*** ** **	*** ** **	*** ** **	4 19 38
14.52- 16.27 M SIDING 2	21 23	25	17 10 12	7 8 07	*** ** **	*** ** **	*** ** **	1 3 04	*** ** **	*** ** **
16.27- 17.51	20 38	30	24 12 13	5 5 21	*** ** **	*** ** **	*** ** **	1 3 04	*** ** **	*** ** **
17.51- 18.75	21 00	34	30 14 41	3 3 15	*** ** **	*** ** **	*** ** **	1 3 04	*** ** **	*** ** **
18.75- 19.99	20 58	34	31 15 39	2 2 15	*** ** **	*** ** **	*** ** **	1 3 04	*** ** **	*** ** **
19.99- 21.23	21 08	34	31 15 50	2 2 14	*** ** **	*** ** **	*** ** **	1 3 04	*** ** **	*** ** **
21.23- 22.47	20 32	30	27 15 16	2 2 11	*** ** **	*** ** **	*** ** **	1 3 05	*** ** **	*** ** **
22.47- 24.34 S SIDING 3	23 47	5	*** ** **	*** ** **	*** ** **	*** ** **	2 5 14	*** ** **	1 3 53	2 14 40
22.47- 24.34 M SIDING 3	21 44	30	26 15 21	3 3 21	*** ** **	*** ** **	*** ** **	1 3 02	*** ** **	*** ** **
24.34- 25.71	22 19	34	30 15 57	3 3 17	*** ** **	*** ** **	*** ** **	1 3 05	*** ** **	*** ** **
25.71- 27.07	22 23	35	31 15 58	3 3 19	*** ** **	*** ** **	*** ** **	1 3 06	*** ** **	*** ** **
27.07- 28.44	22 09	35	31 15 46	3 3 18	*** ** **	*** ** **	*** ** **	1 3 05	*** ** **	*** ** **

Exhibit Vb

summarizing the intervals of time that each signal block is unoccupied. These reports are used to estimate the amount of track maintenance that could be performed with various train densities and schedules.

Initially, the simulation was used mainly to evaluate various siding configurations for proposed CTC installations. More recently, the simulation was used extensively to determine the effects of large increases in the density of trains through an existing CTC system, and. what effects capital improvements would have. The time-distance graph was very useful in helping operating personnel visualize the projected train operations up to ten years in the future.

In terms of future requirements for simulation models of this type, computer aided dispatching and dispatcher training simulation models are only two of the possibilities. In both these cases, visual display systems will play a key role.

(01-01) (02-01) (06-01)

Is next signal block occupied → no → Is second next signal block occupied → no → Clear signal for train

yes ↓ Set signal to prevent train from entering next signal block

yes ↓ Set signal to restrict train to 30 m.p.h.

Return

(01-02)

Scan the track ahead up to the first signal block after the first siding

Is there another train going in the same direction → yes → Determine whether trains should pass and if so where. Set signals accordingly

no ↓ Scan the track up to the third siding ahead

Is there another train coming in the opposite direction → yes → Determine where trains will meet and which train will go into the siding → Set signals accordingly

no ↓ Will train be going into the first siding → yes → Set signal to reduce train speed to 30 m.p.h.

no ↓ Return

(01-06)

Scan track up to the first siding

Is there another train coming in the opposite direction → yes → Set signals to stop train at end of double track

no ↓ Return

Read in input, edit, and store in computer memory

Select train with lowest clock time

Is train originating → yes → Is track clear for train to enter system → no → Add one minute to train clock time

yes ↓ Place train in the appropriate signal block

no ↓ Is train returning from a clearing work stop → yes

no ↓ Has train arrived at its terminating point → yes → Prepare train statistics. Remove train from system → Reset signals

no ↓ Has train arrived at a work stop point → yes → Add duration of work stop delay to train clock time → Is work stop clearing or nonclearing

clearing → Cancel all meets and passes for the train. Remove train from system → Reset signals

no ↓ Does train terminate in this signal block → yes → Calculate time for train to move to terminating point → Add time to train clock time

no ↓ Does train have a work stop in this signal block → yes → Calculate time for train to move to work stop point

no ↓ Is train at the end of a signal block → no → Calculate time for train to move to the end of signal block

Reset signals

Evaluate position of train relative to other trains

(01-01) (01-02) (01-06) (02-01) (02-03) (02-04) (02-06) (03-02) (04-02) (06-01) (06-02)

Can train move into next signal block → no → Add one minute to train clock time

yes ↓ Calculate time for train to move into next signal block → Add time to train clock time → Set signals

S= Train speed
T= Time
X= Distance train is to move

W= tons / cars & diesels
T= 0

(A)

Tractive effort= 3080*horse power / S
DX= .05

Is S greater than 10 m.p.h.   yes   no

Tractive effort= 420*horse power
DX= .02

$\dfrac{T.E.}{tons} - (G+.6+\dfrac{60}{W}+.04*S+\dfrac{.07*S^2}{W})$
A= ——————————————————————— / 0.6

Type of train   frt.   psgr

$\dfrac{T.E.}{tons} - (G+13+\dfrac{116}{W}+3*S+\dfrac{.0346*S^2}{W})$
A= ——————————————————————— / 0.6

Is S greater than the speed limit   yes

Is A greater than -45 mph /min   no

DX= $\dfrac{\text{speed limit}^2 - S^2}{120 \; A}$

yes

A= -45 mph/min

no

Is A negative

Is S less than speed limit   no   no

DT= $\dfrac{DX*60}{S}$
DS= 0

yes   yes

DT= $\dfrac{-S+(S^2+120*A*DX)^{1/2}}{A}$

DS= A*DT

T= T+ DT
S= S+ DS
X= X-DX

Is X=0   no   (A)

yes

Return

Appendix II

(02-03)

Does train have a meet or pass in the siding — yes → Is the other train waiting for this train — yes → Cancel the meet or pass

no ↓ / no ↓

Set signal to reduce train speed to 15 m.p.h.

Return

(02-04)

Does train have a meet or pass in this block — yes → Is the other train waiting for this train — yes → Cancel the meet or pass

no ↓ / no ↓

Clear signal for train

Set signal to reduce train speed to 30 m.p.h.

Return

(02-06)

Does train have a meet on double track — yes → Cancel the meet

no ↓

Return

(03-02) (04-02) (06-02)

Does train have a meet or pass in the siding — no

yes ↓

Set signals to prevent train from entering the next signal block ← no — Is the other train in the siding

yes ↓

Cancel the meet or pass

Scan the track up to the next siding

Is there another train coming in the opposite direction — yes

no ↓

Clear signal for train

Return