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Computer Methods in Blocking and Train Operations Strategies

Waheed Siddiquee and Donato A. D'Esopo, Stanford Research Institute, Menlo Park, California

This paper presents a set of computer-aided methods for developing blocking and train operations strategies for railroad networks. These methods are iterative processes in which complex, judgmental decisions are made by experienced railroad operators and extensive, repetitive calculations are performed by a computer. By using these methods, railroad operators can compare the consequences of various blocking and train operations strategies in terms of such measures as car switching, yard loading, block size, car-kilometers, ton kilometers, train-kilometers, and the like, which are calculated by the computer; operators can then develop efficient blocking and train operations strategies.

The blocking and train operations strategies currently used by various railroad companies have taken years of professional experience, judgment, and knowledge to develop. However, because of mergers, railroad networks have become increasingly extended and complex, and network conditions and demand patterns have been changing continuously. Blocking strategies thus tend to lag behind the real-world situation by even a year or two and create a need to be constantly reviewed and revised.

One outstanding example of such a need occurred recently when Congress charged the U.S. Railway Association (USRA) with the responsibility of developing a systemwide operating and management plan for the rail operations of the Consolidated Rail Corporation (Conrail). A key element of USRA's approach to this problem was to develop detailed schemes for blocking railroad cars and forming trains, as well as for routing and scheduling these trains within the network both on rail lines and through the yards.

To get some idea of the magnitude of the problem, consider the following statistics about the Conrail network. It has about 32 200 km (20 000 miles) of track, part of which is double; it handles approximately 40 000 cars per day, including both loaded and empty cars; and it has 500 to 600 distinct origins and destinations (actually many more when considered in detail). With such a

large network and so much activity, it is obviously exceedingly difficult and laborious to analyze and develop blocking and train operations strategies purely manually.

On the other hand, the interrelations among the demand patterns, the car blocking, the train routing, and the constraints on rail tracks and yards are inherently so complex that the logic of forming blocks and trains cannot realistically be stated in sufficiently concrete steps for purely automatic generation of blocking and train operations strategies. Consequently, USRA needed a method by which complex judgmental decisions could be made by experienced railroad operators but the extensive and tedious calculations would be performed by a computer.

The resulting method, the subject of this paper, was developed by a team of researchers from USRA and Stanford Research Institute (SRI) and was used extensively in developing both the preliminary and the final plans for the Conrail system. However, because the method and the computer programs described in this paper are so general, they have also successfully been used to analyze and develop suitable blocking and train operations strategies for other railroad networks.

STATEMENT OF THE PROBLEM

In its basic form, our blocking and train operation problem can be stated as follows: Given a railroad network in terms of the origin-destination (O-D) nodes (yards) and the connecting links (tracks) and given the O-D demand data on railroad cars, we wanted to develop an efficient blocking and operations strategy for the movement of railroad cars.

Unfortunately, no single criterion of efficiency can be realistically defined for comparing various alternatives. However, operators used the following typical attributes of blocking and train operations strategies

to compare various alternatives:

1. Total number of car handlings the system has;
2. Number of times cars are switched before reaching their destinations;
3. Number of cars that are switched at various nodes;
4. Number and sizes of the blocks that are made at various yards;
5. Total train-kilometers, car-kilometers, train hours, car hours, and ton kilometers there are on a per day basis; and
6. Number of trains per day, cars per day, tons per day there are on various links.

By studying such measures as those noted above, experienced operators can develop an efficient blocking and train operations strategy after a few iterations. It is, of course, possible to translate the above attributes into a common set of units, for instance, delays or costs. However, defining suitable equivalent delays or costs for various attributes is quite a difficult task and may even be misleading, because certain attributes cannot realistically be treated on an equivalent basis. We therefore calculated the various measures individually and used them as a set of criteria for comparing various alternatives.

METHODOLOGY

For a given network and O-D data, there are two approaches for developing blocking and train operations strategies: (a) the blocking strategies are developed for all nodes simultaneously, and the resulting blocks are then combined to form trains; (b) the blocking strategies are first developed for the extremity nodes, which generally do not have any transit traffic, and then trains from these nodes are designed to carry the developed blocks to the various destination nodes. Blocking strategies are then developed for the set of nodes next to the extremity nodes.

The blocking strategies for this second set account for any cars sent to these nodes from the extremity nodes for further movement. Trains are then developed from this next set of nodes to carry the designed blocks to the respective destination nodes. This process of developing blocks and then trains at a small set of nodes at each stage is continued until all the cars have been moved to their destinations.

The advantage of the first approach is that a significant amount of information related to system car handlings, block sizes, and yard loadings becomes available during the first stage. The second stage then provides the information related to train-kilometers, ton kilometers, and the like (although our program was based on the mile). In the second approach this information becomes available in partial steps, and the whole process has to be completed before systemwide data can be established.

In view of the advantage mentioned above and the ease with which the process can be computerized, the first approach was selected by the SRI-USRA team to develop the strategies. Figure 1 indicates the overall logic and interrelationship of the blocking strategy analysis and development process. Figure 2 indicates the overall logic and interrelationship of the train operations analysis and development process. The following steps are associated with the development of blocking and train operations strategies. (It should be noted here that all the calculations were carried out in customary, rather than metric units; these have not, then, been converted, but metric equivalents have been noted where applicable.)

1. A suitable representation of the railroad network was prepared. For example, to develop the preliminary system plans, the bankrupt railroad network in the Northeast and Midwest was represented by 147 nodes, 23 junction points, and 246 links. Later, a more detailed representation with 494 nodes and 650 links was developed to conduct more detailed analyses and to develop the final system plan.

2. An O-D table giving average daily traffic between pairs was prepared.

3. The designer manually prepared a preliminary blocking strategy, based on experience and on study of the network and the O-D table, for each node. In a later version of the program, a preliminary blocking strategy, based on some heuristic rules, was generated automatically. Specifying the blocking strategy for each node includes (a) the destinations of various blocks to be made at the node and (b) the destinations of other groups of cars to be included in each block. For example, the designer may specify that at node 1 he or she wishes to make a block destined for node 53, containing cars for nodes 53, 54, 74, and 89; another block destined for node 87, containing cars for destination nodes 87, 90, 91, and so forth. All destinations are to be accounted for. Note that the designer need only specify the destination of the nodes included in each block. The actual number of cars in each block is automatically calculated by a program based on the O-D table, as discussed below. The details of the exact format for specifying blocking strategy are explained elsewhere (1, 2).

4. The specified blocking strategies for all the nodes are put into the blocking strategy analysis program, which uses the specified strategies along with the O-D file stored in the computer. The program is designed to calculate the number of cars in each block by adding not only all cars originating at the node for the destinations included in the block but also all the cars sent to the node by other nodes through the specified strategy. The specifications of blocking strategies for each node in combination with the O-D table uniquely determine several operating characteristics through simple mathematical relationships, such as number of car switchings at each node, number of cars switched how many times, block sizes made at each node, and total system switchings. These data are used to analyze the proposed blocking strategy. The program also generates and stores a block file in the computer to be used with train formation and a road statistics analysis program. The designer can modify the blocking strategy by using an editing program and can rerun the program many times to accomplish a satisfactory strategy.

5. After a few iterations, when the blocking strategy has been refined to the satisfaction of the designer (the yard loadings are satisfactory; the number of car switchings is acceptable; and the block sizes are satisfactory), he or she manually combines various blocks generated by the proposed blocking strategy into trains and specifies a route for each train. The designer may also specify the departure time of each train. The formats for specifying these data are included in our other papers (1, 2).

6. These manually generated routing and departure time data are then applied to the train formation and road statistics generation program. Specification of the train composition (blocks in each train) and routing in combination with network details (link length in miles or travel times) uniquely determines several operational characteristics through simple mathematical relationships, for example train-miles, car-miles, ton miles, and trains per link. These operational characteristics are used to analyze the proposed train formation and routing strategies. The designer can modify the composition, routing,

and scheduling of trains and can rerun the program many times to accomplish a satisfactory set of trains.

Completion of the above steps results in a set of blocking tables and trains for each yard that is realistic because it has been defined by experienced designers and is efficient because the various performance attributes calculated by the computer have been used by the designers to select the strategies. In a related effort, a detailed yard simulation program (1, 3) was also developed and used to study the yard operations in finer detail; this ensured that the loadings imposed on various yards as a result of the selected blocking strategies were feasible.

EXAMPLES OF PROGRAM OUTPUTS

As indicated earlier, the computer programs associated with blocking and train operations strategies calculate several performance attributes for these strategies spec-

ified by the designer. Examples of several outputs are presented for content and format, and those discussed under car handling and blocks and block sizes below are produced by the blocking analysis program; those discussed under block routing and train and link statistics are produced by the train analysis program.

Systemwide Car-Handling Output

Systemwide car-handling output gives the total number of cars switched and how many times. It also gives the total number of system switchings and the total number of switchings in all intermediate yards. These systemwide figures are very helpful in comparing blocking strategies quickly on a systemwide basis. A sample output is shown in Figure 3.

According to this figure 6774 cars were handled once (either once at the origin or once at the destination); 13 176 cars were handled twice (once at the origin and once at the destination); 13 752 cars were handled three

Figure 1. Blocking strategy analysis and development process.

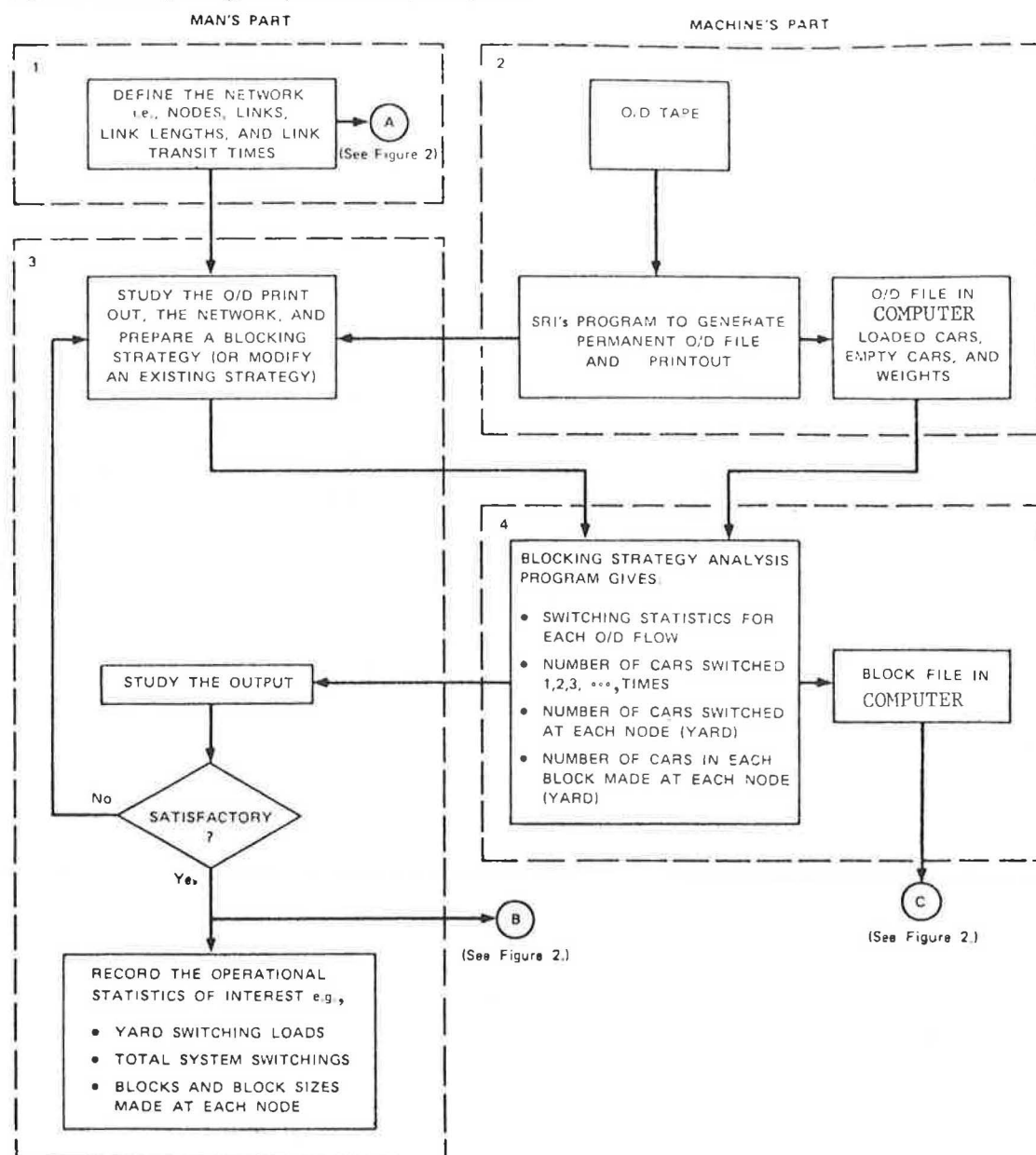
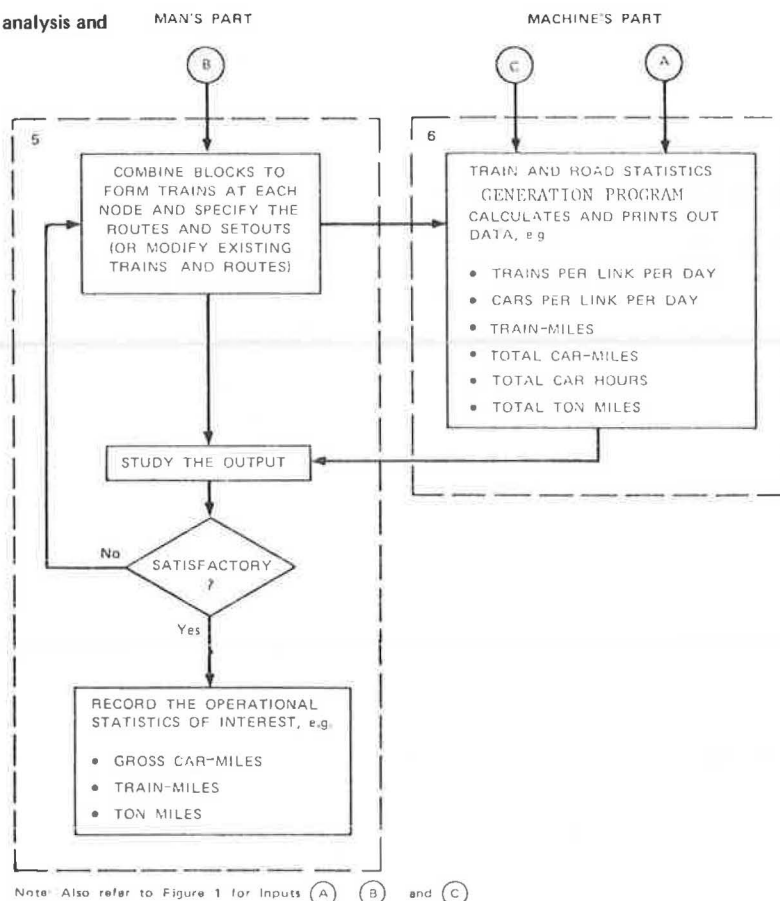


Figure 2. Train and road statistics analysis and development process.



times (once at the origin, once at an intermediate yard, and once at the destination), and so on. The total handlings, 90 576, is the sum of $6774 + 2(13\ 176) + 3(13\ 752) + 4(3730) + 5(250) + 6(4)$. The total excess handlings, 21 978, is the sum of $13\ 752 + 2(3730) + 3(250) + 4(4)$ and gives the total number of intermediate yard car handlings not including the handlings at the origin or destination.

Individual Flow-Handling Output

This output gives the number of times cars are handled (switched) before reaching a destination from various origins. The program is designed to print any selected data specified by the designer. Figure 4 shows a portion of the flow-handling output associated with destination nodes 32, 33, 34, 35, 36, and 37. It is assumed that cars are handled once at the origin node, once at the destination node, and once at each intermediate node (yard). Thus, considering the flows associated with destination node 35 (Grandview), all cars from node 3 destined for node 35 are handled once at node 3, once at intermediate node 34, and once at destination node 35. The numbers (Figure 4) in the columns give the products of the numbers of cars times the number of handlings. The 21 cars from nodes 3 to 35 are handled three times; therefore, the number of car handlings from this flow is 63, as indicated. Similar remarks apply to other flows.

From this output, the designer can spot flows that are handled too many times. For example, referring again to Figure 4, the flows from node 58 to node 35 are switched at three intermediate nodes, at nodes 57, 49, and 34, before reaching node 35. The designer may wish to improve his or her strategy by checking the blocking

strategies for nodes 34, 49, and 57.

If the designer does not want a switching count at certain yards (in case the block is being delivered to an interchange yard to be switched by other railroads), he or she may specify the node numbers of all such yards as inputs to the program. The program will not count switchings at all these specified yards. Exact details of this feature are explained in the user's manual for network analysis computer programs (2).

Yard-Loadings Output

This output gives the number of cars handled at each yard as a result of the prepared blocking strategy. Displayed are the numbers of inbound cars, outbound cars, local cars, and cars in transit, and the total number of cars switched at every yard. A breakdown of loaded and empty cars is also indicated, as well as the weight in tons. A sample output showing the loadings for some selected yards is given in Figure 5.

Blocks and Block Sizes Output

This output is one of the most useful. It gives a list of all the blocks made at each node, together with the number of loaded and empty cars and total weights. A sample output showing blocks made at nodes 1 through 5 is given in Figure 6. This output gives the designer a complete picture of block sizes, contents, and weights for each node resulting from his or her proposed strategy. Some blocks may be found to contain too many or too few cars. If so, the designer can then revise his or her strategy on the basis of this information and rerun the program until satisfactory block sizes have been formed.

Block-Routing Review Outputs

These outputs are intended basically to help the designer find out if the complete movement of each block has been specified correctly (for instance, if some blocks were

overlooked or some were set out but not picked up). Because of the large number of blocks involved, say, around 2000 blocks in the network under consideration, and the hundreds of trains to be specified, it almost always happens, particularly in the first go round, that

Figure 3. Sample output of systemwide car handling.

CAR HANDLINGS FOR STRATEGY CONRAIL 2A-85 12 FEB 75						
TOTAL CARS HANDLED 1,2,3 TIMES	6774	13176	13752	3730	250	4
TOTAL HANDLINGS =	90576					
TOTAL EXCESS HANDLINGS =	21978					

Figure 4. Sample output of flow handling.

FLOW HANDLINGS FOR STRATEGY CONRAIL 2A-85 12 FEB 75						75/05/08, 10,10,12.	
DESTINATION	ORIGIN	LOADS	EMPTY	CARS	CARS*HANDLINGS	---INTERMEDIATE TANKS---	
32 DAYTON	32 DAYTON	1	15	16	16		
33 SPRINGFIELD	30 SHARONVILLE	29	54	83	166		
	33 SPRINGFIELD	0	3	3	3		
34 BUCKEYE	34 BUCKEYE	0	5	5	5		
35 GRANDVIEW	3 EXERMONT	10	11	21	63	34	
	12 CHICAGO	38	8	46	134	34	
	14 COLHOUR	5	17	22	44		
	30 SHARONVILLE	22	18	40	80		
	35 GRANDVIEW	53	28	81	81		
	39 STANLEY	4	34	38	76		
	50 FAIRLANE	1	25	26	52		
	58 GATEWAY	5	0	5	25	57	49 34
	61 ASHTABULA	1	14	15	45	51	
	62 ERIE	1	11	12	48	60	51

Figure 5. Sample output of yard loadings.

YARD LOADING FOR STRATEGY CONRAIL 2A-85 12 FEB 75										75/05/08, 10,10,12.														
-----INBOUND-----					-----OUTBOUND-----					-----LOCAL-----					-----TRANSIT-----					-----TOTAL-----				
		LOAD	EMPTY CARS	TONS			LOAD	EMPTY CARS	TONS			LOAD	EMPTY CARS	TONS			LOAD	EMPTY CARS	TONS			LOAD	EMPTY CARS	TONS
1	ROSEFLAKE	285	112	397	24475	134	93	227	15009	3	9	12	581	165	124	289	18969	587	338	925	59034			
4	PARIS	21	64	85	4115	35	19	54	4011	2	17	19	648	65	115	180	9689	123	215	338	18703			
5	TERREHAUTE	35	58	93	5220	6	51	107	6023	1	20	21	722	7	1	8	624	49	130	229	12594			
10	AVON	53	150	203	9036	89	74	163	8730	1	5	6	232	1362	1135	2497	134052	1505	1364	2869	157050			
11	HAWTHORNE	172	230	402	23385	177	255	432	20673	27	207	234	9462	89	67	156	9399	465	759	1224	63419			
12	CHICAGO	167	196	363	22722	1529	662	2191	142310	3	85	88	2832	90	62	152	13244	1789	1605	2744	181128			
13	CHICAGO59	189	268	457	24028	99	130	229	10979	0	56	56	1680	1	3	4	214	289	457	746	36901			
14	COLHOUR	159	117	276	16616	151	153	304	19293	0	82	82	2464	0	0	0	0	310	352	662	78381			
16	ELKHART	108	45	203	12924	86	181	267	11661	1	22	23	756	1160	1297	2457	126822	1355	1545	2950	152163			
19	LOGANSPOUT	63	62	125	7815	46	74	120	7029	3	32	35	1168	28	6	34	2805	140	174	314	18617			
20	MARION	53	47	150	8881	128	44	172	8659	2	12	14	560	48	81	89	5284	231	194	425	23384			
21	ANDERSON	73	57	130	8488	69	59	128	6274	4	5	9	604	5	4	9	659	151	125	276	18025			
23	PALAMAZOO	72	53	125	8605	75	65	140	6691	1	20	21	684	37	26	63	3617	185	164	349	19597			
25	JACKSON	119	64	183	10358	66	96	162	7442	2	50	52	1633	81	127	204	10208	268	337	605	29641			
27	FT. WAYNE	80	81	161	9090	87	77	164	10338	8	56	64	2368	0	1	1	30	175	215	390	21826			

Figure 6. Sample output of blocks and block sizes.

BLOCKS AT EACH ORIGIN FOR STRATEGY CONRAIL 2A-85 12 FEB 75						75/05/08, 10,10,12.	
ORIGIN	DESTINATION	CARS	TONS	LOADS	EMPTY		
1 ROSFLAKE	1 ROSFLAKE	409	25061	288	121		
	2 MADISON	4	138	0	4		
	3 EXERMONT	5	206	1	4		
	4 PARIS	13	615	4	9		
	5 TERREHAUTE	38	2481	17	21		
	10 AVON	50	2820	24	26		
	11 HAWTHORNE	82	3511	21	61		
	12 CHICAGO	51	5783	41	10		
	16 ELKHART	40	2403	20	20		
	34 BUCKEYE	19	1054	7	12		
	39 STANLEY	16	691	9	7		
	51 CLEVELAND	10	428	4	4		
	66 CONWAY	80	5142	54	26		
	98 ALLENTOWN	44	3325	41	3		
	124 DEWITT	36	3589	30	6		
	130 KELKIRK	27	1781	25	2		
2 MADISON	1 ROSFLAKE	155	8195	66	89		
	2 MADISON	319	12184	74	245		
	10 AVON	65	2662	14	51		
	34 BUCKEYE	35	1668	10	25		
	39 STANLEY	45	1587	5	40		
	66 CONWAY	31	1709	18	13		

Figure 7. Sample output of block routing review.

Block Origin	Block Destination	Number Loaded Cars	Number Empty Cars	Tons	Trains in Which Block Was Carried
1	2	0	4	138	BT2(2)
1	3	1	4	206	BT1(1)
1	16	20	20	2403	BC1(9) 21 BA3(32)
.
.
4	7	2	1	239	-----
4	10	34	17	3777	BB7(16)
.
.
6	58	10	20	1622	AC7(92)51-----
.
.

Transfer Node

Dashes in this column indicate no block movement at all

Dashes in this and other columns on the right-hand side indicate partial movement

Figure 8. Sample output of beginning portion of train statistics.

TRAIN COUNT	TRAIN MILES	CAN MILES			TON MILES	TRAIN HOURS			CAN HOURS	T
		L	E	T		L	E	T		
BT1	1	0	0	0	0	1.25	66.25	90.00	156.25	
BT2	1	0	0	0	0	1.25	25.00	24.75	49.75	
BB2	1	224	13440	12768	26208	6.67	400.00	380.00	780.00	
BB3	1	224	12674	21539	34213	7.42	377.92	667.00	1044.92	
BT1	1	482	94164	5444	104608	31.75	3153.83	171.67	3325.50	
BA1	1	310	16975	4766	20741	14.58	1108.92	610.33	1719.25	
BB1	1	236	4456	14396	14352	7.42	155.75	452.42	608.17	
BB4	1	236	10010	10670	20680	8.42	380.92	405.25	786.17	
BC1	1	454	20029	36057	56086	15.83	663.75	1207.58	1871.33	
BC2	1	417	21684	33777	55461	15.25	777.50	1204.75	1982.25	
BU1	1	589	45942	10602	56544	17.42	1347.50	322.50	1770.00	
BD2	1	584	46768	24243	74011	16.67	1486.25	741.25	2227.50	
BE1	1	953	46363	3588	44951	30.42	1487.06	115.25	1602.33	
BB5	1	90	410	7318	8228	11.00	111.00	893.00	1004.00	
BB6	1	90	4770	1080	8650	11.00	583.00	132.00	715.00	
BB7	1	146	4932	3867	13799	7.75	488.25	222.83	711.08	
BB8	1	146	4493	5917	15310	7.75	530.92	241.25	772.17	
AB1	1	310	8506	11840	20346	16.08	414.25	614.17	1028.42	
AB50	1	152	5676	5552	11228	11.42	415.17	404.50	819.67	
BB9	1	224	1753	5141	6894	7.42	53.83	164.83	218.67	
BB10	1	131	16113	1572	17685	10.08	1240.25	121.00	1361.25	
BB11	1	131	1048	16637	17685	10.08	80.67	1280.58	1361.25	
BB12	2	234	17433	14870	30303	13.33	943.33	733.33	1726.67	
BB13	2	234	14274	14054	29133	13.33	813.33	646.67	1660.00	
BB14	3	672	55328	16128	71456	14.25	1584.92	462.00	2046.92	
BB15	2	448	13808	40768	54656	14.83	454.83	1349.83	1809.67	
BB16	5	1120	76304	40544	116928	33.33	2273.33	1204.67	3488.00	
BT3	2	24	1246	1548	2784	2.00	103.00	129.00	232.00	
BT4	2	24	1546	2520	4056	2.00	124.00	210.00	338.00	
BA2	1	167	14918	10832	30750	14.50	1680.50	910.17	2590.67	
AB2	1	179	14355	5286	14641	15.50	1185.50	434.50	1620.00	
BA3	1	167	9432	7285	16717	8.92	499.50	341.25	840.75	
BA4	1	119	5503	2659	8162	6.17	284.67	150.33	435.00	
AB3	1	119	4410	3417	7827	6.17	241.17	170.33	411.50	
BA5	1	244	15243	4234	19527	11.92	730.50	190.17	920.67	
AB4	1	221	7538	6089	13627	11.25	373.33	295.42	668.75	
BC3	1	119	4699	2756	6455	5.50	166.17	128.17	294.33	
CB1	1	119	2500	5670	8170	5.50	125.00	262.50	387.50	
BC4	2	350	4386	25891	35277	16.17	434.67	1196.42	1631.08	
BB50	1	77	453	1704	2657	3.00	35.00	60.00	95.00	
BC5	1	187	13263	8240	21553	9.08	645.33	402.92	1048.25	
BE2	1	727	47882	15057	62939	25.42	1657.67	531.67	2189.33	
BC40	1	158	6122	6132	12254	6.75	278.25	274.50	552.75	
BF3	1	296	15045	18629	33674	9.67	487.67	603.33	1091.00	
BC6	1	292	4589	8549	18138	11.42	341.25	315.75	657.00	
CB2	1	142	5271	1526	4747	5.67	226.92	79.17	306.08	
BD3	1	365	13505	8030	21535	11.25	416.25	247.50	663.75	
AT1	1	0	0	0	0	2.50	19.00	143.00	162.00	
AT2	1	0	0	0	0	2.50	58.50	104.50	163.00	
AA1	1	22	1034	1034	4068	3.50	140.00	124.50	264.50	
AA2	1	22	1188	902	4090	3.00	136.00	61.00	197.00	
AB5	2	334	4352	34569	43921	28.00	784.00	2898.00	3682.00	
AA3	2	174	14740	7221	24011	11.00	888.00	431.50	1321.50	
AA4	1	87	3415	4263	8178	3.00	135.00	147.00	282.00	

Figure 9. Sample output of beginning portion of link statistics.

LINKS																				
LINK	MILES	THAINS	L	CARS	E	T	ALL	THAIN	MILES	CAR	MILES	E	T	THOURS	CAR	HOIRS	F	T		
14 = 15	22	21	1413	409	1822	126773	462	31086	8998	40084	21.00	1413.00	409.00	1822.00	1413.00	409.00	1822.00			
15 = 14	22	14	1710	1078	1898	86493	396	16940	23716	40656	18.00	1710.00	1078.00	1898.00	1710.00	1078.00	1898.00			
15 = 16	65	21	1427	458	1895	128547	1365	27770	122525	42.00	2854.00	916.00	2854.00	916.00	2854.00	916.00	2854.00			
16 = 15	65	14	808	1684	1892	93201	1170	52520	70460	122980	36.00	1616.00	2168.00	1784.00	1616.00	2168.00	1784.00			
16 = 169	42	17	1217	392	1555	107469	714	51114	16464	67576	19.83	1419.83	457.33	1877.17	1419.83	457.33	1877.17			
169 = 16	42	15	715	843	1556	79442	630	40030	35406	65436	17.50	834.17	981.50	1817.67	834.17	981.50	1817.67			
26 = 169	51	16	722	852	1574	80301	816	36822	43452	80274	25.33	1143.17	1349.00	2492.17	1143.17	1349.00	2492.17			
169 = 26	51	18	1224	349	1628	108787	918	62674	20349	83028	28.50	1945.92	631.75	2577.67	1945.92	631.75	2577.67			
26 = 40	42	18	1234	408	1647	108194	756	52038	17136	69174	24.00	1652.00	544.00	2196.00	1652.00	544.00	2196.00			
40 = 26	42	16	720	856	1576	80657	672	30240	35952	66192	21.33	960.00	1141.33	2161.33	960.00	1141.33	2161.33			
40 = 50	70	21	1576	434	2010	132410	1470	110320	30380	140700	42.00	3152.00	468.00	4020.00	3152.00	468.00	4020.00			
50 = 40	70	20	814	1116	1935	95848	1400	57330	76120	135450	40.00	1638.00	2232.00	1870.00	1638.00	2232.00	1870.00			
50 = 51	34	22	1596	531	2127	135647	748	54204	18054	72318	22.00	1596.00	531.00	2127.00	1596.00	531.00	2127.00			
51 = 50	34	21	867	1124	1991	101467	714	29478	38216	67694	21.00	867.00	1124.00	1991.00	867.00	1124.00	1991.00			
51 = 60	29	18	1187	294	1486	104663	522	34423	8671	43094	22.50	1483.75	371.75	1857.50	1483.75	371.75	1857.50			
60 = 51	29	17	517	441	1506	66630	497	14993	28739	43732	21.25	646.25	1234.75	1845.00	646.25	1234.75	1845.00			
60 = 61	26	18	1153	324	1477	100671	468	29978	8424	38402	13.50	864.75	243.00	1107.75	864.75	243.00	1107.75			
61 = 60	26	17	537	978	1515	71058	442	13962	25428	39390	12.75	402.75	731.50	1136.25	402.75	731.50	1136.25			
61 = 62	42	19	1306	364	1670	121168	798	54852	15288	70140	22.17	1523.67	424.67	1948.33	1523.67	424.67	1948.33			
62 = 61	42	19	623	1101	1724	81328	798	26166	45242	72408	22.17	724.83	1284.50	2011.33	724.83	1284.50	2011.33			
62 = 81	80	19	1271	348	1614	116052	1520	101680	27840	129520	41.17	2753.83	754.00	3507.83	2753.83	754.00	3507.83			
81 = 62	80	19	604	1041	1650	79417	1520	48720	83280	132000	41.17	1319.50	2254.50	3575.00	1319.50	2254.50	3575.00			
81 = 82	8	24	1346	442	1838	125477	192	10768	3936	14704	12.00	673.00	244.00	919.00	14704	12.00	673.00	244.00		
82 = 81	8	24	665	1149	1804	86402	192	5320	9112	14432	12.00	332.50	569.50	902.00	5320	12.00	332.50	569.50		
1 = 160	147	11	583	500	1083	66472	1617	85701	73500	159201	43.08	2283.42	1958.33	4241.75	159201	43.08	2283.42	1958.33		
160 = 1	147	12	707	503	1210	62518	1764	103929	73941	177870	47.00	2769.00	1970.68	4739.17	177870	47.00	2769.00	1970.68		
5 = 160	18	12	712	535	1247	63877	216	12816	4630	22446	8.00	474.67	354.67	831.33	474.67	354.67	831.33			
160 = 5	18	11	583	500	1083	66472	1616	10494	4000	19494	7.33	388.67	331.33	722.00	19494	7.33	388.67	331.33		
5 = 10	59	12	697	524	1220	77274	708	41123	31211	72334	22.00	1277.83	960.83	2247.67	72334	22.00	1277.83	960.83		
10 = 5	59	13	713	604	1382	71531	767	45607	35931	81538	23.83	1417.17	1114.50	2533.67	81538	23.83	1417.17	1114.50		
10 = 21	46	19	486	732	1714	105538	874	45356	33672	79028	38.00	1972.00	1464.00	3436.00	79028	38.00	1972.00	1464.00		
21 = 10	46	18	872	847	1714	88020	828	40112	38962	79074	36.00	1744.00	1694.00	3438.00	79074	36.00	1744.00	1694.00		
21 = 170	49	16	851	659	1510	91017	784	41694	32291	73990	21.33	1134.67	878.67	2013.33	73990	21.33	1134.67	878.67		
170 = 21	49	15	763	775	1538	74260	735	37387	37975	75362	20.00	1017.33	1033.33	2050.67	37975	20.00	1017.33	1033.33		
170 = 172	57	6	341	216	557	35105	342	19437	12312	31749	14.00	795.67	504.00	1299.67	31749	14.00	795.67	504.00		
172 = 170	57	6	254	255	554	30702	342	14763	16815	31578	14.00	604.33	680.33	1284.67	31578	14.00	604.33	680.33		
34 = 172	41	7	291	355	646	35277	287	11931	14555	26486	11.67	485.00	591.67	1076.67	26486	11.67	485.00	591.67		
172 = 34	41	7	372	242	614	38248	287	15252	9922	25174	11.67	620.00	403.33	1023.33	25174	11.67	620.00	403.33		
34 = 67	61	8	443	241	684	45032	488	27023	14701	41724	14.00	775.25	421.75	1197.00	41724	14.00	775.25	421.75		
67 = 34	61	7	367	442	804	49096	427	22387	26962	49349	12.25	642.25	771.50	1415.75	49349	12.25	642.25	771.50		
67 = 68	90	8	435	241	676	44235	720	39150	21690	60840	20.00	1087.50	602.50	1690.00	60840	20.00	1087.50	602.50		
68 = 67	90	7	363	430	793	48451	630	32670	38700	71370	17.50	907.50	1075.00	1982.50	71370	17.50	907.50	1075.00		
65 = 68	34	7	235	474	704	36045	238	7990	16116	24106	4.17	274.17	554.00	827.17	24106	4.17	274.17	554.00		
68 = 65	34	6	339	227	566	39885	204	11526	7718	19244	7.00	395.50	264.00	660.33	19244	7.00	395.50	264.00		
65 = 66	11	6	367	237	604	43008	66	4017	2607	6644	3.50	214.00	134.25	352.33	6644	3.50	214.00	134.25		
66 = 65	11	6	256	346	602	34097	66	2816	3806	6622	3.50	149.33	201.83	351.17	6622	3.50	149.33	201.83		
38 = 170	58	10	415	521	936	44083	580	24070	30218	54268	18.33	760.63	955.17	1716.00	54268	18.33	760.63	955.17		
170 = 38	58	10	576	311	887	57432	580	33408	18038	51446	18.33	1056.63	576.17	1626.17	51446	18.33	1056.63	576.17		
38 = 49	49	9	580	252	832	57605	441	28420	12348	40768	13.50	870.00	378.00	1248.00	40768	13.50	870.00	378.00		
49 = 38	49	11	381	634	1015	44976	539	18669	31066	49735	16.50	571.50	951.00	1522.50	49735	16.50	571.50	951.00		
49 = 51	75	8	447	180	627	45266	600	33525	13500	47025	16.00	894.00	364.00	1254.00	47025	16.00	894.00	364.00		
51 = 49	75	8	245	546	781	32180	600	18375	40200	58575	16.00	490.00	1072.00	1562.00	58575	16.00	490.00	1072.00		
34 = 49	66	3	213	64	277	21597	148	14058	4224	18282	5.75	408.25	122.47	530.72	18282	5.75	408.25	122.47		

some blocks are overlooked, set out but not picked up, or assigned to more than one train simultaneously. The program checks each block in the blocking table, follows its movement in accordance with the specified trains and their routes, and flags whenever there is an incomplete journey of a block or a block has been assigned to more than one train. Figure 7 shows a sample of this output.

Train and Link Statistics Outputs

The specification of blocks for various trains, together with routing of the trains—in combination with link tables, link lengths, and link transit times—uniquely defines many statistics associated with trains and links: train-miles, car-miles, ton miles, train hours, car hours, trains per link per day, cars per link, and car-miles per link. The program has been designed to calculate several of these values, which are printed in two sets of tables. The first set is arranged with reference to trains and the second with reference to links. Figure 8 shows a portion of the output with reference to trains. The symbols L, E, and T under the headings of cars or car-miles refer to loaded, empty, and total cars. Figure 9 shows the beginning portion of the output, referring to each link.

USEFULNESS OF THE METHOD

The method and computer programs discussed in this paper can be used for the following purposes:

1. Development of efficient blocking strategies so

that systemwide and individual car handlings are not excessive;

2. Appropriate distribution of the switching load at various system yards so that each yard's share in the switching load is consistent with its capabilities; and

3. Development of suitable train compositions and routings so that link loadings are not excessive.

In addition to the above purposes, the method could, for example, be used to study overall system effects of closing yards, downgrading or upgrading mainlines, and opening yards. It is also possible to test the systemwide effects of major changes in operating philosophy on yard and mainlines, such as the effects of short and long trains.

AREAS FOR FURTHER RESEARCH

The methods and the computer programs in their present forms are valuable for analyzing and developing systemwide operating plans, but there is room for modification and improvement. Under an extended research contract, SRI is currently adding a feature to trace the movement of selected traffic flows from origin to destination in terms of time spent in waiting in the origin yard, in transit on road, in intermediate yards for switching, and in waiting to be set out and picked up, until arrival at the destination. This will give the designer additional information regarding the individual and systemwide travel times of various cars. These data will also be helpful in comparing various blocking and train formation strategies in terms of car hours and delivery times.

Some other possible improvements in the present program are as follows:

1. Developing an improved automatic blocking strategy process;
2. Developing a technique to combine blocks and form trains automatically;
3. Developing a cost model to compare various strategies on a cost basis; and
4. Converting the whole system to time sharing with interacting blocking strategy and train editing capabilities.

The above is only a partial list, and several other features have been suggested during the course of the project. We hope that the present programs can eventually be augmented, by incorporating all the significant features, so that a highly efficient and useful tool will be available for railroad operators.

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U.S. Railway Association, whose support and permission to present and publish the paper are gratefully acknowledged. However, the contents of this paper reflect our views, and we alone are responsible for the facts and accuracy of the information presented. The contents do not necessarily reflect the official views or the policy of the U.S. Railway Association.

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Inventory Model of the Railroad Empty-Car Distribution Process

Craig E. Philip, Freight Car Utilization Program, Association of American Railroads

Joseph M. Sussman, Department of Civil Engineering, Massachusetts Institute of Technology

Techniques to improve freight-car fleet use are of considerable interest to the railroad industry. One potentially high improvement area is the disposition of empty cars within the network. This paper reports the first results of inventory control applied to one aspect of the process, namely the sizing of empty-car inventories at points in the network. First we evaluate existing techniques for distributing empty cars on a rail network. These techniques deal primarily with optimizing empty-car movements from areas of surplus to areas of deficit. To account for variations in supply and demand, we designed a discrete event simulation model that can determine optimum inventory level, for a single terminal area, as a function of (a) daily supply variations, (b) daily demand variations, and (c) cost of holding a car in a terminal awaiting loading compared to cost of having no car available to satisfy shipper demand. A first attempt to use the model to evaluate the performance of an actual railroad terminal area indicates that excessive inventories are maintained in surplus terminal areas. The applicability of the model to a real railroad operating situation is also demonstrated.

Empty-car distribution is an unavoidable problem for most railroads, because demand and supply are typically unbalanced in any given region. Thus, surpluses and deficits at terminal areas are inevitable, and some mechanism must be employed to move cars from points where they are not needed to points where they are.

Shippers feel the impact of the distribution mechanism directly. Car availability will largely be determined by the ability of the railroad to efficiently move cars from surplus to deficit areas.

This recurring need to manage and monitor car movement has come to dominate current empty-car distribu-

tion processes. The techniques used to allocate cars usually employ standard static optimization methods and thus rely on the hypothesis that levels of supply and demand will not vary significantly. Variations, however, do exist, and one of them is periodic shortages caused by railroads unreliably routing cars from surplus to deficit areas.

Some empty-car distribution practices have evolved to cope with this problem; individual terminal distributors, for example, often maintain an inventory of empty cars to protect against the uncertainties of supply and demand. Still, since distribution mechanisms seldom consider inventory levels, no strategy for determining appropriate inventory levels has yet been proposed, and costs to the railroad incurred by wasted car days or lost loads due to shortage can be directly related to these levels.

This report evaluates the theoretical implications and tests the methodology of one strategy for determining inventory level in a railroad operating environment. The proposed strategy grew naturally from our reexamination of the empty-car distribution process from the perspective of the local or terminal decision maker. Several theoretical solutions to the empty-car distribution problem, such as existing network models that determine flow rules, are contrasted with a theoretical construct of the need for empty-car inventories.

A discrete event simulation model of empty-car