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Final Report—Phase II (Part B)

SORTING AND TRAIN FORMATION SCHEMES FOR EFFICIENT OPERATION OF A HUMP YARD

By: M. W. SIDDIQEE

Prepared for:

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ABSTRACT

This report covers the work done during the development of efficient schemes of car sorting and train formation in a hump yard. Various schemes were studied with particular reference to the expected hump yard activity in the proposed West Colton Yard. Some fundamental schemes as well as several practical examples are described in the report. Using these fundamental schemes and the examples as a guide, suitable detailed schemes can be developed for each yard with a view to minimizing the total effort either on a system-wide basis or on a purely local basis.

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I INTRODUCTION

A. General

In a railroad humpyard, each incoming train typically contains randomly distributed cars destined for various geographical zones. In the humpyard, all cars destined for the same zones are required to be grouped together to form a batch. Some of the batches are later coupled together to form new outbound trains. Other batches may form single-batch trains. If there are as many sorting tracks (in sufficient length) available as the number of desired batches, then each batch can be assigned a separate track so that cars belonging to a certain batch are directed to the respective track during the humping process. In this case each car is obviously required to be humped only once and there is no difficulty in sorting the batches. However, as is frequently the case, if the number of sorting tracks available is less than the number of desired batches to be formed, then the process of batch separation and formation will in general be an involved operation, particularly if the number of sorting tracks is significantly less than the number of batches to be sorted. It is this situation that creates the basic sorting and track assignment problem. Other factors such as train arrival schedules, train departure schedules, delays in arrivals, tracks being partially filled, and the need of some batches to be in a particular sequence are related aspects of the problem.

In the present humpyard operations, the yard master does not receive the information about the composition of the incoming trains sufficiently in advance to be able to plan a specific strategy of sorting and batch formations that best matches the particular requirements for each day. He has to rely generally on his experience and intuition to assign sorting tracks to various cars of the incoming train during the humping process. The yard masters have developed a keen sense of yard operations and are generally capable of performing sorting and train formation processes in a satisfactory manner. However, in view of the expected introduction of modern data-processing and communication equipment in various yards, information about the incoming trains will be available sufficiently in advance, and could be used to plan efficient schemes of sorting. Furthermore, with continually increasing railroad activity, resulting in more cars handled per day in each hump yard, it seems desirable to investigate potential systematic approaches for sorting cars and forming the desired outgoing trains in order to avoid delays, excessive rehumpings, and unnecessary engine operations.

With the advance information about the incoming trains, several alternative schemes of sorting and batch formation can be developed. Depending on the existing and expected yard conditions and also on other factors--i.e., priority of some outgoing trains over others, etc.--the yard master may then choose one scheme or the other and plan a track assignment schedule ahead of time. This will result in an expedient and efficient operation of the yard.

B. Statement of the Problem

In its basic form, the sorting and track assignment problem can be stated as follows: With the constraint that the number of sorting tracks available is significantly less than the number of batches to be sorted and formed, find some feasible schemes, most appropriate in some sense, of sorting and forming the desired batches arranged in a desired sequence, given the advance information about the number, length, and destination of the cars in the incoming trains.

The purpose of this report is to present some basic approaches to the batch sorting problem, which can be utilized to develop suitable sorting and train formation schemes for various yard conditions. Some fundamental schemes of sorting and batch formation are presented in Section III. Several examples of developing various detailed schemes using the fundamental approaches are presented in Section IV. The utility of such schemes and methods of practical implementation are also discussed.

C. Acknowledgment

We wish to acknowledge the guidance and suggestions received from Messrs. W. V. Williamson, B. Flohr, and David King in formulating the problem and familiarizing us with several practical aspects of the hump yard operation.

II SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

A. Summary of Findings and Conclusions

The process of sorting and batch formation in various hump yards of Southern Pacific is currently done on a local basis with procedures based on past experience. The yard masters in each yard do not receive the specific information needed for humping until shortly before the train actually arrives. Thus, they do not have sufficient time to plan in advance a systematic sorting scheme. As the total system-wide information-processing and communication capability of the TOPS computer system becomes available to yard masters, the potential is created for more efficient sorting procedures. This report investigates several such procedures that would permit more batches to be sorted on fewer tracks with a minimum of rehumping. The increased throughput rates of 6 to 8 cars per minute achieved through the yard design and control studies make it feasible to consider humping schemes that utilize rehumping but reduce the number of tracks required (and hence capital investment) in relation to the number of blocks being sorted. Conversely, a given number of tracks can be used to sort more blocks and to arrange the blocks in desired order. This could be used in certain special cases to reduce switching at later points in the system or to simplify the delivery of batches.

This concept could be extended to consider the potential savings to be gained by investigating methods in which, in selected cases, the effort required for sorting and train formation is distributed among various yards on a system-wide basis and by employing systematic schemes of sorting and train formation. It might prove to be more efficient to do some preliminary sorting in one yard and the rest of sorting in another, depending upon the capabilities of each yard.

A study of a few hump yards and the typical requirements of batch sortings in these yards, as well as the consist data provided to us, indicates that the average number of batches in outgoing trains is typically 2 or 3. The maximum number of batches in the outgoing trains is 6 or 7. The highest ratio between the total batches to be sorted and the total number of tracks expected to be available appears to be 2:1--i.e., typically 20 to 30 batches would be sorted on 10 to 15 tracks. Under these circumstances either basic scheme 1 or basic scheme 2, or a combination of the two, is considered the most suitable approach to develop detailed sorting schemes. The triangular scheme, which has advantages when there are fewer but very long tracks and where the number of batches to be sorted is considerably more than available tracks, does not appear to be of any particular advantage for the yard conditions existing in the Southern Pacific yards. Furthermore, in the triangle scheme, most of the cars have to be humped three times.

B. Recommendations

Recommendations are as follows:

(1) Using the projected traffic studies for West Colton, investigate to see if an increase in the number and ordering of the batches in the outbound trains (particularly for local Los Angeles delivery) would improve overall system efficiency. If an affirmative answer is obtained, study the practical application of the basic sorting methods presented here to determine specific benefits and costs.

(2) Conduct a system-wide study of the sorting and train formation process. Such a study would take into account the following factors:

   (a) Number of total sorting tracks available in each yard involved in the sorting process

   (b) Time table for the availability of the required communication and data-processing facilities in each yard

(c) The present system requirements of sorting and train formation.

Such a study would establish an overall picture of the train sorting activity and could be used to efficiently distribute the sorting and train formation activity on a system-wide basis. The study could result in an overall reduction of effort to achieve present system sorting requirements or could more effectively use the present yards to sort the cars to permit faster and more efficient delivery.

(3) Develop suitable computer programs for sorting schemes. Several suitable sorting schemes, covering a large range of yard conditions, should be developed and be made available as a quick reference tool for the yard master. Knowing the details of the incoming trains, the yard master can feed the data to the computer and get a quick analysis of the implications of employing one or the other scheme and then choose the scheme that best suits the existing yard conditions, and, if necessary, take any necessary step that might improve the yard operation.

III SOME FUNDAMENTAL SORTING AND TRAIN FORMATION SCHEMES

A. General

A few introductory remarks and definitions will be helpful in understanding the schemes to be described.

The process in which the cars of each incoming train are humped for the first time will be referred to as "primary humping." Let the outbound train to be formed be called Trains A, B, C, D, E, etc. Each of these trains may consist of some batches required to be in a certain sequence. Let these batches be designated by corresponding script--i.e., train A consists of Batches A_1, A_2, A_3, ..., B consists of B_1, B_2, etc. in the indicated sequence. The length of each batch can be expressed by the number of cars in each batch. In the incoming trains, cars belonging to various batches will in general be distributed randomly. All cars belonging to Batch A_i will be denoted by a_i--i.e., a_i represents cars that belongs to Batch A_1, etc. When lower-case letters with subscript numbers appear in parentheses, it means that all these cars are randomly mixed--e.g., (a_1, a_2, ..., b_1, b_2, ...) means that in this group Cars a_1, a_2, b_1, b_2, etc., are randomly mixed.

With the above definitions and explanations in mind, we now present a few basic schemes of sorting and batch forming.

B. Basic Scheme No. 1--Initial Grouping According to Subscript

According to this scheme, cars having the same subscript designation are grouped together during primary humping--e.g., a_1, b_1, c_1, ..., are grouped together and assigned one track; a_2, b_2, c_2, ..., are assigned to another, and so on. Thus, after primary humping the yard will appear as in Figure 1.

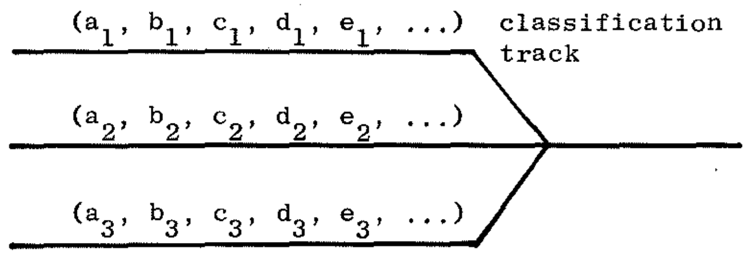

Figure 1 Primary Grouping According to Basic Scheme 1

After the primary humping is completed, the tracks are pulled back in a proper sequence so that the group having the lowest subscript precedes the group with the next lower and so on, as shown below in Figure 2. Alternatively, the cars can be rehumped track-by-track in proper sequence if extra tracks are available to receive the rehumped cars.

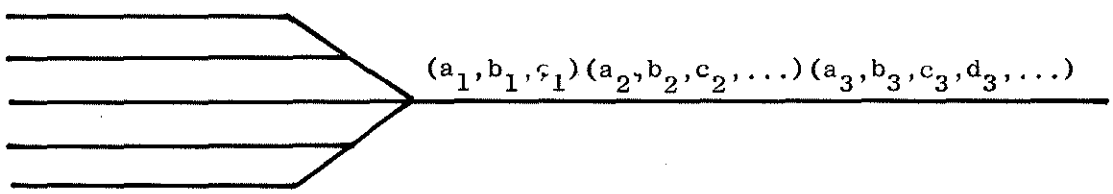

Figure 2 Arrangement of Groups for Second Humping in Basic Scheme 1

When the cars are rehumped now, a_1 can be put on one track, b_1 on another, and so on. The a_2 cars are put behind the a_1 cars on Track 1, the b_2 cars behind the b_1 cars on Track 2 and so on. Similarly with a_3, b_3, ... When all cars are rehumped, the batches are separated and are in proper sequence.

This scheme has the property that cars are humped only two times and the batches are put in proper sequence during the second humping. All trains are formed simultaneously. However, under certain conditions of track limitations, some modification of this scheme might be necessary, as will be elaborated with the help of some examples in later sections.

C. Basic Scheme No. 2--Initial Grouping According to Outbound Trains

According to this scheme, the cars of outbound trains are combined in a few groups during the primary humping--e.g., cars of trains A, B, C in one group, D, E, F in another group, etc.--and cars belonging to each group are assigned a common track during primary humping. Thus, if there are outbound trains A, B, C, D, E, and F, etc. to be formed, each with batches A_1, A_2, B_1, B_2, etc., the cars belonging to Train A and B (i.e., all cars a_1, a_2, ..., b_1, b_2...) can be put on one track. Similarly, all cars c_1, c_2, c_3..., d_1, d_2, d_3 can be put on another, etc., as shown in Figure 3.

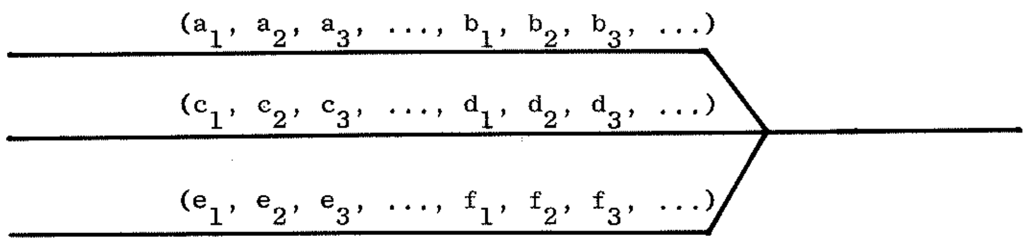

Figure 3 Primary Grouping According to Basic Scheme 2

Each track can then be rehumped and each batch put on a separate track as shown in Figure 4.

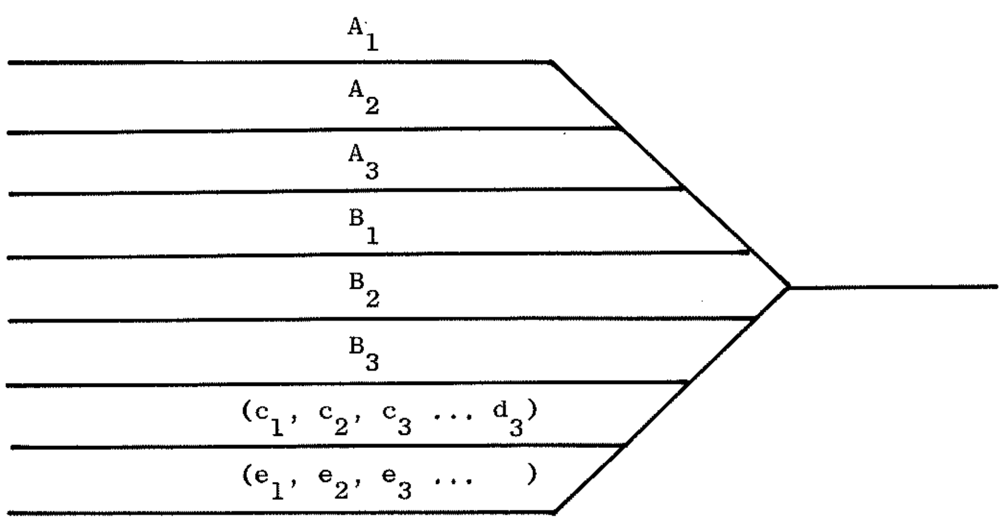

Figure 4 Arrangement After First Track is Rehumped in Basic Scheme 2

This approach might be useful when the total number of batches in the combined group is of a small order--i.e., 4 or 5. This combination has the property that trains can be formed one after another in a prearranged order. For example, referring to Figure 4, either Train A or Train B can be pulled out first by coupling respective batches.

D. Basic Scheme No. 3--Triangular Scheme

One scheme of batch sorting employed frequently in some of the European humpyards is the so-called "triangular" scheme. According to this scheme, the car subscript numbers are arranged in the following way:

1	3	5	8
2	6	9	
4	10		
7			

During primary humping, all cars having the subscript 1, 3, 5, 8 (the first horizontal set of numbers) are assigned the same track; 2, 6, 9 (the second horizontal set of numbers) are assigned another track, and so on. The first track is now pulled back and rehumped. The cars with subscript 1 are directed to as many separate tracks as there are batches with subscript 1--e.g., a_1 cars to one track, b_1 cars to another, c_1 to a third, etc. Cars of subscript 3 are directed on Track 2, behind the (2, 6, 9...) group. Cars with subscript 5 are directed toward Track 3, etc. The second track is now pulled back and cars with subscript 2 are directed to respective tracks behind cars with subscript 1--e.g., a_2 behind a_1, b_2 behind b_1, etc.

This scheme appears to be suitable under certain special circumstances in which the number of tracks is small but in which the tracks are quite long and where the total number of batches in various trains is fairly large. For example, with this scheme, 3 trains, one having 6 batches, the other having 5 batches, and the third having 3 batches (i.e., in total, 14 batches) can be formed using only three tracks (provided these are long enough) in the following way:

Let the train with 6 batches be called A, with batches A_1, A_2,...A_6.

Let the train with 5 batches be called B, with batches B_2, B_3,...B_6.

Let the train with 3 batches be called C, with batches C_4, C_5,...C_6.

Note that the first batch of train B is labeled B_2 and not B_1. Similarily, in train C, the first batch is labeled C_4 instead of C_1. The advantage of relabeling the first batches in this manner is that no further sorting tracks are needed during second and third humpings. These numbers--i.e., 1, 2, and 4, which are used for the first batches of various trains--are the numbers that appear in the first column of the triangular scheme.

During primary humping all cars having subscript 1, 3, 5, are collected on one track. This will include all cars (a_1, a_3, a_5, b_3, b_5, c_5) all mixed up. All cars having subscript 2, 6 are collected on a second track; i.e., a_2, a_6, b_2, b_6, c_6. Cars having subscript 4 are collected on the third track. Thus only three tracks are needed. The tracks appear as in Figure 5.

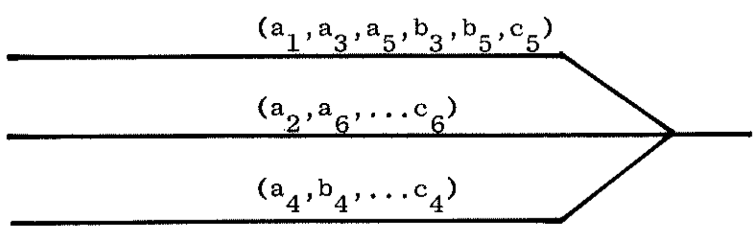

Figure 5 Cars After Primary Humping According to Basic Scheme 3 (Triangular Scheme)

In the second phase of humping track 1 is pulled back and rehumped. Cars a_1 can be re-collected on Track 1. The (a_3, b_3) cars are collected on Track 2 behind existing cars. The (a_5, b_5, c_5) cars are collected on the third track behind existing cars. The yard appears as in Figure 6.

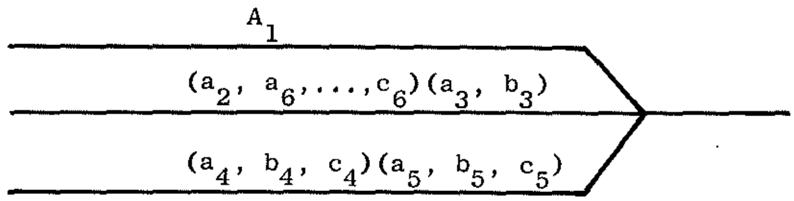

Figure 6 Arrangement After Second Humping of Track 1, according to Basic Scheme 3

The second track is now pulled back and rehumped. The a_2 cars are collected behind A_1 batch on Track 1, the b_2 cars are collected on Track 2, and the a_6, b_6 and c_6 cars are collected on the third track behind existing cars. The a_3 cars are collected behind the a_2 on Track 1, and b_3 behind b_2 on Track 2. The yard appears as in Figure 7.

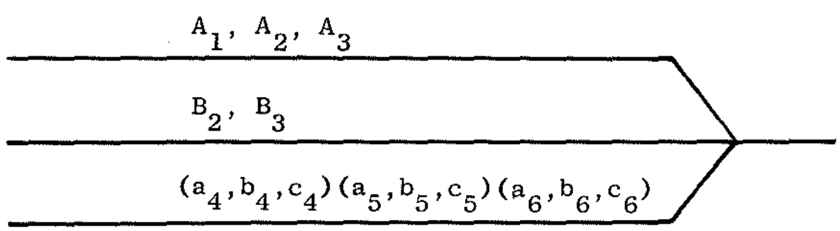

Figure 7 Arrangement After Second Humping of Track 2, according to Basic Scheme 3

The third track is now pulled back and rehumped. The a_4 cars are collected behind the a_3 on Track 1, the b_4 cars behind B_3 on Track 2, and the c_4 on Track 3. Then the a_5 cars are collected on Track 1, the b_5 on Track 2, the c_5 on Track 3; then the a_6 on 1, b_6 on 2, and c_6 on 3. The three trains are now completely formed, with the batches in proper sequence as shown in Figure 8.

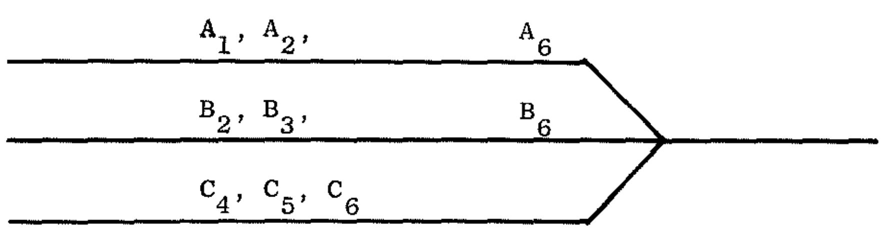

Figure 8 Arrangement After Second Humping of Track 3, according to Basic Scheme 3

This scheme can be extended by properly filling further numbers in the triangular formation. For example, numbers up to 15 will be arranged as follows according to triangular schemes:

1	3	5	8	12
2	6	9	13	
4	10	14		
7	15			
11				

With 5 tracks available (note that 5 is also the number of rows in the table above) 5 trains can be formed in which one train can have up to 15 batches, the second may have as many as 14, the third may have 12, the fourth may have 9 batches, and the fifth may have 5 batches (total batches 15 + 14 + 12 + 9 + 5 = 55). The train batches can be numbered as follows:

$$A_1, A_2, \ldots, A_{15}$$

$$B_2, B_3, \ldots, B_{15}$$

$$C_4, \ldots, C_{15}$$

$$D_7, \ldots, D_{15}$$

$$E_{11}, \ldots, E_{15}$$

The grouping during primary and secondary humpings will be similar to that described in the example above.

The above-mentioned train schemes of sorting and grouping have been described mainly to serve as basic tools for developing detailed sorting and batch forming processes. For any particular yard, a combination of one or more of such schemes will have to be evolved depending upon the yard design, operating conditions, and desired goals. In Section IV we present several examples based on some consist data provided to us by Messrs. Williamson and Bruce Flohr. Several schemes are presented and the properties of each scheme are also discussed. The purpose of these examples is to further elaborate the previously discussed techniques that a yard master might find useful in developing his own scheme depending upon the working condition in his yard.

IV SOME PRACTICAL EXAMPLES

A. General

We now present several examples to further elaborate various ideas presented in the previous sections. These examples can be divided into two categories. In the first category the examples are based on the assumption that the number of available sorting tracks may be small when the primary humping commences, but further tracks become available as the operation progresses--e.g., some formed trains might leave. The examples in the second category are based on the assumption that the number of tracks during the entire humping process remains fixed. Thus various typical situations that may arise in actual humpyard operation have been considered. The examples were selected with reference to the consist data provided by M/S Williamson and Bruce Flohr. However, the schemes presented are essentially independent of any particular consist data, and with suitable modifications will be found applicable under other operating conditions as well.

B. Brief Description of the Consist Data and Some Yard Operating Constraints

The consist data provided to us contain an assumed typical schedule of trains arriving at W. Colton during an afternoon. According to this data, the following 8 trains arrive in the following sequence at W. Colton:

Train ID	Train Name
1A/BSM	"First Advanced Blue Streak Merchandise" From Pine Bluff, Arkansas, to W. Colton
TXN	"Texan" From Houston to W. Colton
1GS	"First Gold Streak" From Chicago to W. Colton via Rock Island R.R.
2GS	"Second Gold Streak" From Kansas City to W. Colton via Rock Island R.R.
2A/BSM	"Second Advanced Blue Streak Merchandise" From Pine Bluff, Arkansas, to W. Colton
1BSM	"Blue Streak Merchandise" From St. Louis, Missouri, to Los Angeles with Set Out at W. Colton
MTS	"Missouri Pacific, Texas Pacific, Southern Pacific" From TPRR at El Paso to W. Colton
2 BSM	"Second Blue Streak Merchandise" From Pine Bluff, Arkansas to W. Colton

Cars of all these inbound trains are required to be sorted and regrouped to form 9 west-bound outgoing trains. The total number of cars in the incoming 8 trains to be included in the new outbound trains is of the order of 400 to 500. For convenience, the outgoing trains will be denoted by A, B, C, ..., H, I. These trains are required to consist of cars destined for various cities in a certain sequence as indicated below. Each outbound train will typically consist of 60 to 100 cars.

Outgoing Train	Consists of Cars Destined for
A	Kalamath Falls, Ogden, Sparks, Marysville, Roseville, N.W.P. (cars can be randomly grouped in 1 batch)
B	Stockton, Fresno, Bakersfield, Mojave (4 batches)
C	Portland, Eugene, Medford (3 batches)) Two Trains
D	Portland, Eugene, Medford (3 batches))
E	San Luis Obispo, Los Angeles A yard, Los Angeles Bull Ring (3 batches)
F	Oakland, Warm Springs, Milpitas (3 batches)
G	San Francisco, San Jose (2 batches)
H	City of Industry (to consist of 2 batches)
I	Los Angeles Shops (1 batch)

The sorting track length has been assumed to be about 3000ft.--i.e., a total of 60 cars can be accommodated on each track assuming an average car length of 50 ft. If the total number of cars in a departing train is more than 60, it will have to be formed in 2 or 3 sections on 2 or 3 tracks. These 2 or 3 sections can be regarded as fictitious trains. Thus it can be assumed that the maximum number of cars in outgoing trains on each track is 60. It is also assumed that for the purpose of rehumping, as many as 180 cars can be pulled back by the engine--i.e., 3 sorting tracks can be made empty simultaneously. This fact has been mentioned because some of the schemes to be presented are based on this possibility. The objective of the various schemes in general is to achieve the sorting and formation of outbound trains without excessive engine effort or rehumping. Various schemes will have various implications and the decision to use one or the other scheme will depend upon the yard master who has an "on-the-spot" knowledge of the yard conditions and is in a better position to select the proper scheme.

C. Examples of Train Formation Schemes with Limited Initial Track Availability

For convenience, the batches of the desired outgoing trains will be indicated with corresponding subscripts instead of city names--i.e., in Train B, the 4 batches for Stockton, Fresno, Bakersfield, and Mojave will be indicated by B_1, B_2, B_3, and B_4, respectively. Thus the following 9 outgoing trains have to be formed:

A with 1 batch: A (cars of the 6 indicated cities are not required to be in any order.

B with 4 batches: B_1, B_2, B_3, B_4

C with 3 batches: C_1, C_2, C_3

D with 3 batches: D_1, D_2, D_3

E with 3 batches: E_1, E_2, E_3

F with 2 batches: F_1, F_2

G with 2 batches: G_1, G_2

H with 2 batches: H_1, H_2

I with 1 batch: I

We now present some schemes to form these desired trains for various conditions. A preliminary analysis indicated that a minimum of 5 tracks is almost absolutely necessary initially to keep the number of engine operations and car humpings within any reasonable limits. One of these tracks could be assigned to Train A; another could be assigned to Train 1 so that these two trains are formed already after the first humping. The other tracks are required to perform one or another scheme of sorting the cars of incoming trains.

All the following schemes are based on the possibility of up to 180 cars being pulled back on receiving track for rehumping. If this is not possible or not desirable, the schemes can still be used provided 2 extra empty tracks are available.

1. Scheme No. 1

This scheme is based on the assumption that initially only 5 tracks are available. According to this scheme all the trains B, C, D, E, F, G, H, are formed simultaneously, and are complete in about 4 hours after the last arriving train has been primary-humped.*

Initial Assignment:

Assign Track 1 for A, and Track 2 for I.
Assign Track 3 for cars having subscript 1--i.e., b_1, b_c, d_1, e_1, f_1, g_1, h_1 or 4 (i.e., b_4). Call this Group 1.
Assign Track 4 for cars having subscript 2--i.e., b_2, c_2, f_2, g_2, etc. Call this Group 2.
Assign Track 5 for cars having subscript 3--i.e., b_3, c_3, etc. Call this Group 3.

It is assumed that by the time any or all the tracks 3, 4, or 5 are filled, extra tracks will become available so that each group can be extended on other tracks. Thus, after all the incoming trains have been humped once, the yard may typically appear as in Figure 9.

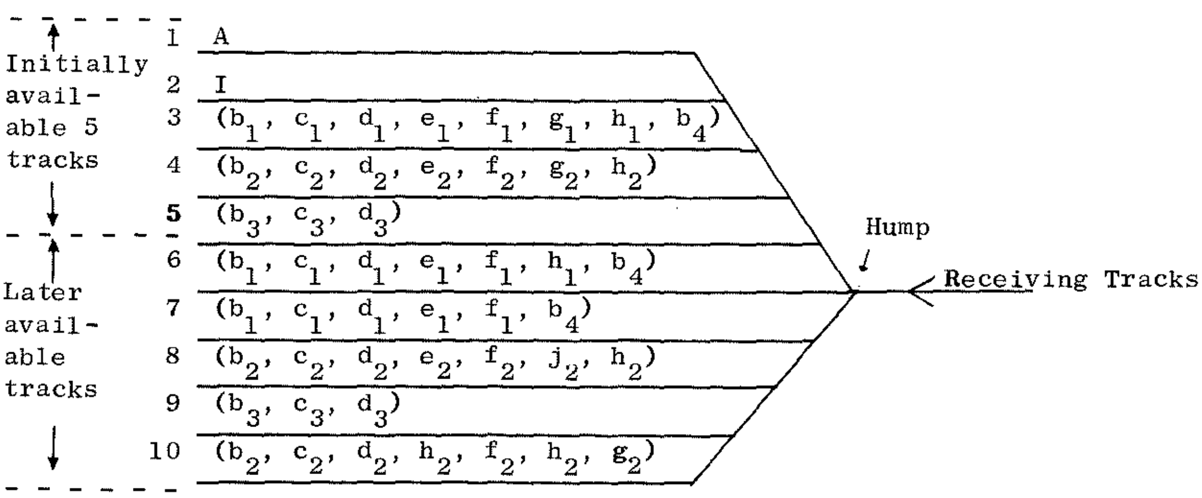

Figure 9 Arrangement of Cars After Primary Humping, According to Scheme 1

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* Approximation based on a shunting and humping speed of 5 cars per minute.

Note that the groups 1--i.e., (b_1, c_1, ... b_4) etc.--may occupy more than one track but that they are still separated from other groups--i.e., from Groups (b_2, c_2, ...) or (b_3, c_3, ...).

Assuming now that Trains A and I can depart and make Tracks 1 and 2 free, and assuming that three more empty tracks, 12, 13, and 14, are available by now, the second phase of sorting and forming can proceed as follows.

The first time around, pull out 3 tracks and rehump and then either pull 3 or 2 tracks or 1 track in such a way that all cars of Group 1 are rehumped first, all cars of Group 2 are rehumped after Group 1, and all cars of Group 3 are rehumped last. This will always be possible irrespective of the number of cars in each group. For example, considering the distribution given above, there are four tracks containing cars of the first group. Pull out cars from Tracks 3, 6, and 7. This leaves these tracks empty. Tracks 1 and 2 are already empty. Adding to this the three empty tracks, 12, 13, and 14, we have, in total, 8 empty tracks. The yard appears as in Figure 10.

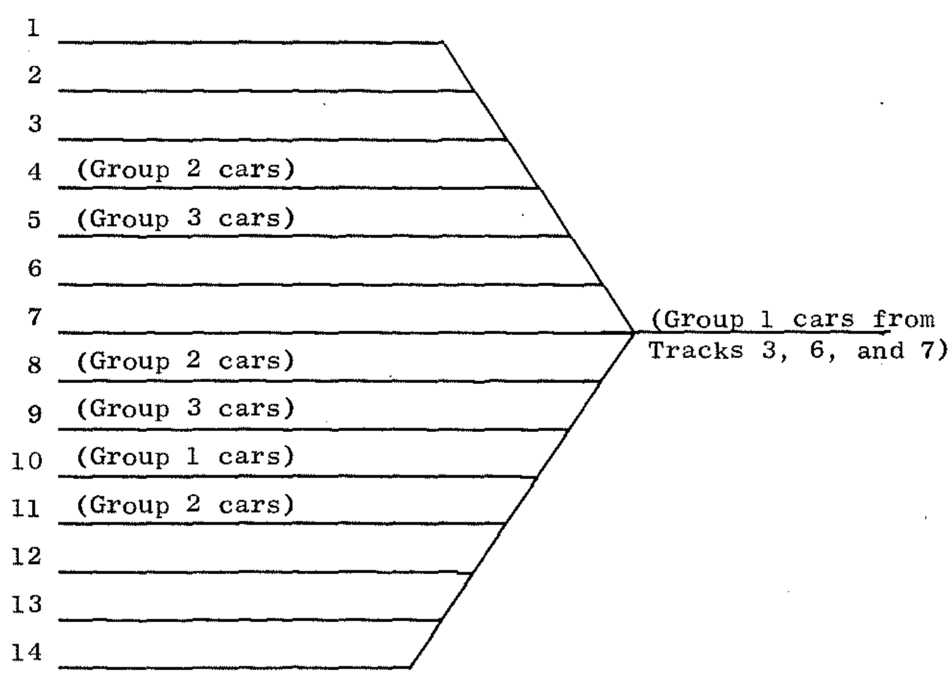

Figure 10 Scheme 1 - Arrangement of Cars After Group 1 Cars are Pulled Back

Rehump the cars. Put

B_1 on Track 1

B_4 on Track 2

C_1 on Track 3

D_1 on Track 6

E_1 on Track 7

F_1 on Track 12

G_1 on Track 13

H_1 on Track 14.

Now pull cars from Tracks 4, 8, and 10 on the receiving track. The yard appears as in Figure 11.

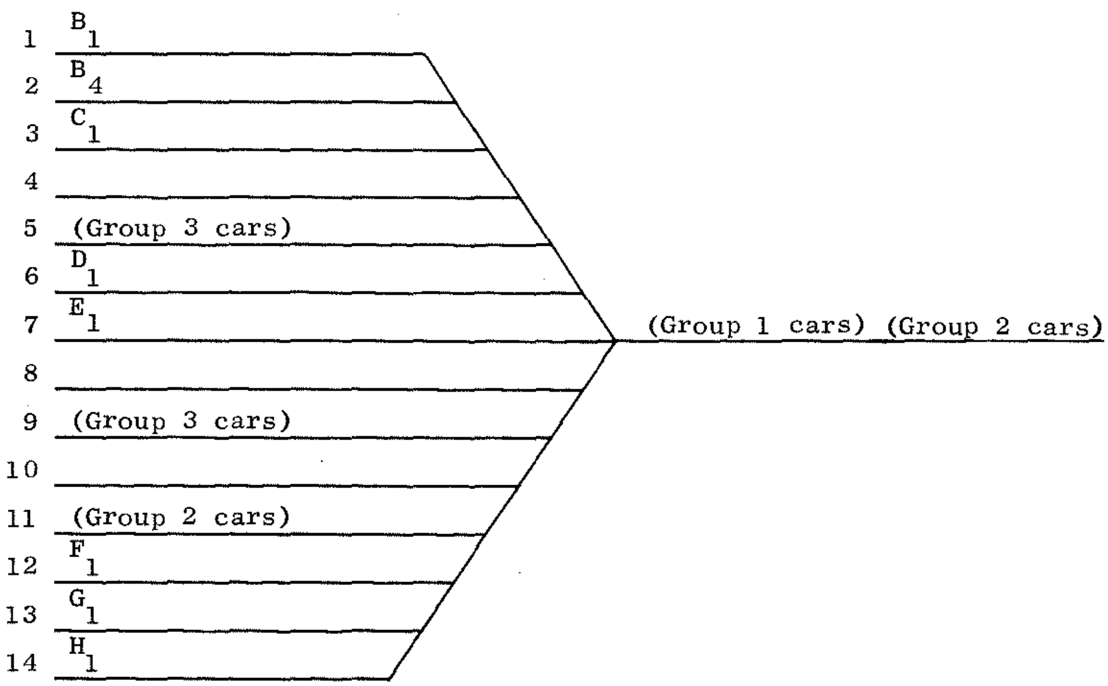

Figure 11 Scheme 1 - Arrangement of Cars After Rehumping of Tracks 3, 6, and 7 and pulling back 4, 8 and 10.

Rehump, put B_1 on 1, B_4 on 2, C_1 on 3, D_1 on 6, E_1 on 7, F_1 on 12, G_1 on 12, and H_1 on 14. Then put B_2 on 1 behind B_1, C_2 behind C_1, and so on.

Now pull cars from Tracks 11, 9, and 5 so that Group 2 cars precede Group 3 cars. Rehump, putting the B_3, C_3, etc. behind B_2, C_2 on the respective tracks. The train will be formed after this last humping. Train B is formed in two parts on Tracks 1 and 2. C is formed on 3, D on 6, E on 7, F on 12, G on 13, and H on 14.

2. <u>Scheme No. 2</u>

This scheme is based on the assumption that initially 6 tracks are available. Whereas in Scheme 1 the 7 trains, B, C, ..., H, are formed simultaneously, the scheme to be described now offers the possibility of forming trains C, D, E first in about 1-1/2* hours after the completion of primary humping. Trains B, F, G, H can then be formed in another 2-1/2 hours. Alternatively trains B, F, G, H can be formed first in about 2-1/2 hours, and C, D, E later in the next 1-1/2 hours. Furthermore, trains C, D, E are each formed in two parts--i.e., (C_1 + C_2) and C_3, (D_1 + D_2) and D_3, etc.--as will be clarified below.

<u>Initial Assignment</u>:

Track 1 for A

Track 2 for I

Track 3 for (c_1, d_1, e_1, c_3, d_3, c_3). Call this Group 1.

Track 4 for (c_2, d_2, e_2). Call this Group 2.

Track 5 for (b_1, f_1, g_1, h_1, b_3). Call this Group 3.

Track 6 for (b_2, f_2, g_2, h_2, b_4). Call this Group 4.

As in the case of Scheme 1, it is assumed that if any group fills the track, additional tracks will have become available by then so that the group can be extended. At the end of primary humping of all cars, the yard may typically appear as in Figure 12.

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* Based on an average shunting and humping speed of 5 cars per minute.

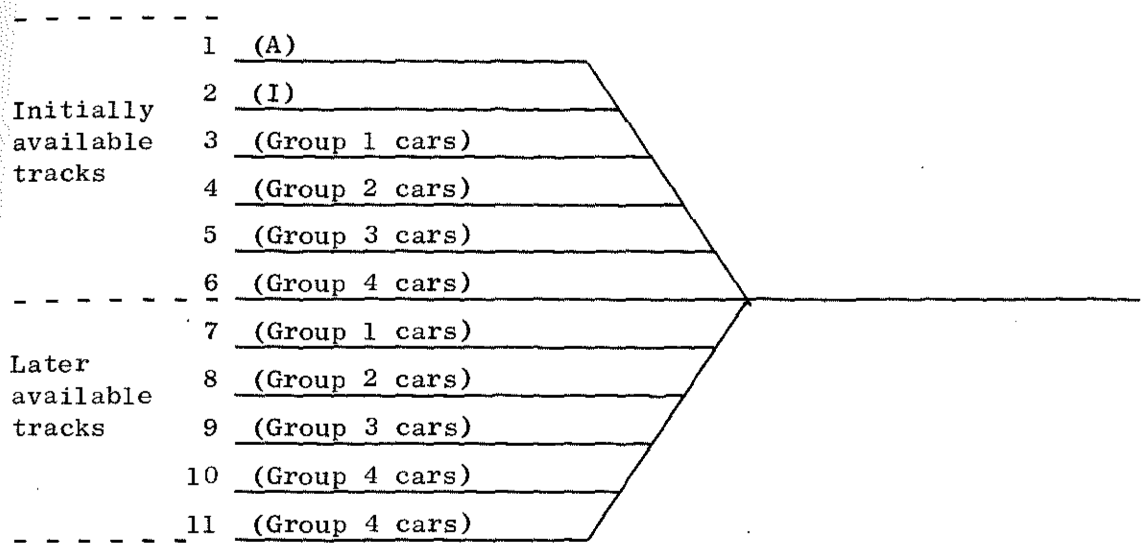

Figure 12 Arrangement of Cars After Primary Humping According to Scheme 2

Now let trains A and I depart so that Tracks 1 and 2 become free.

Case 1: If E, C, D have to be formed first, then pull the 180 cars of Groups 1 and 2 from Tracks 3, 4, 7, and 8 on the receiving track in such a way that all cars of Group 1 precede the cars of Group 2. The yard will appear as in Figure 13.

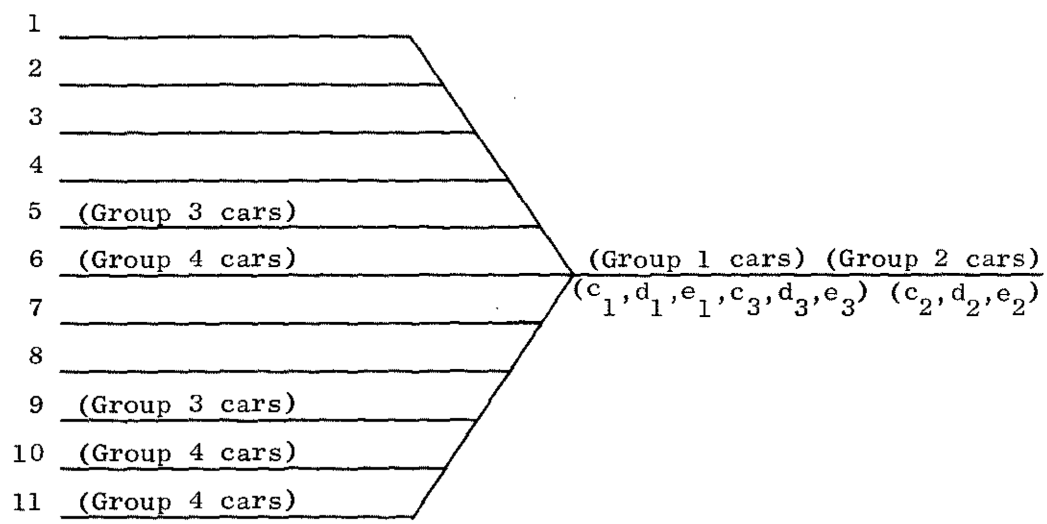

Figure 13 Scheme 2 - Arrangement of Cars When Group 1 and Group 2 Cars are Pulled Back

Rehump. Put c_1 on 1, c_3 on 2, d_1 on 3, d_3 on 4, e_1 on 7, e_3 on 8. Then put c_2 on 1, d_2 on 3, e_2 on 7.

The yard will appear as in Figure 14.

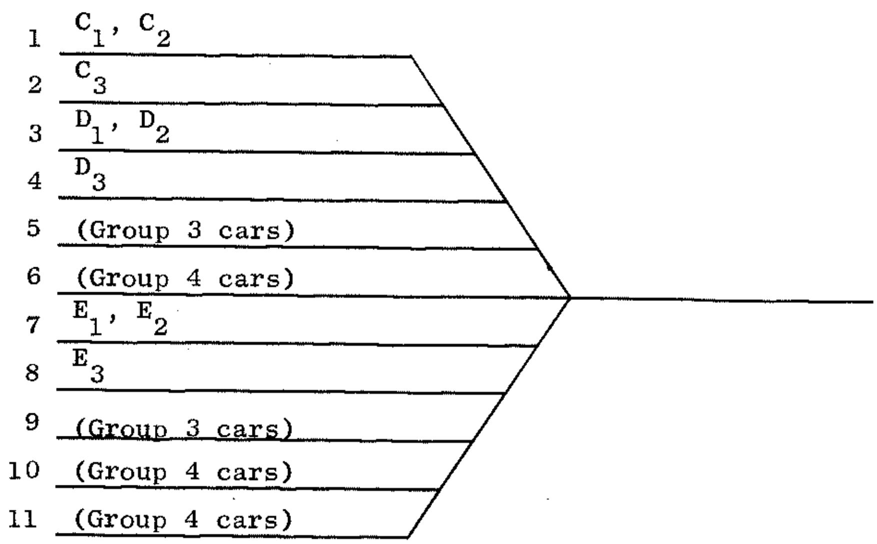

Figure 14 Scheme 2 - Arrangement of Cars After Rehumping of Group 1 and Group 2 Cars

Now let C depart so Tracks 1 and 2 become free again. Pull back cars of Group 3 and 4 from three tracks, and later from the remaining two tracks, and rehump in such a sequence that all cars of Group 3 are rehumped first and then cars of Group 4 are rehumped. This will always be possible. For example, in case of above distribution, Tracks 10, 9, and 5 should be pulled back first so that cars of Track 10 are behind cars of 9 and 5. The yard will appear as in Figure 15.

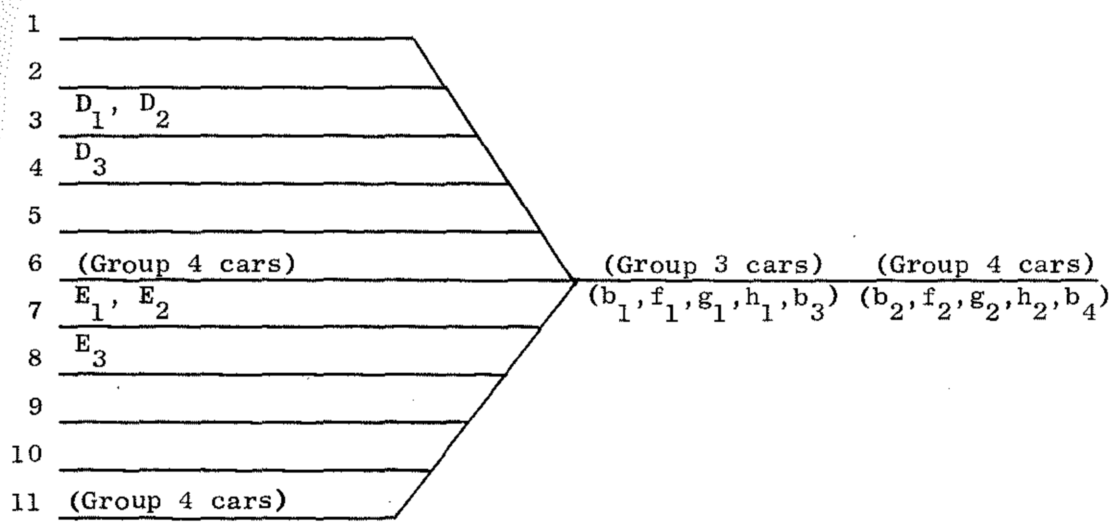

Figure 15 Scheme 2 - Arrangement of Cars After Group 3 and Group 4 Cars are Pulled Back

Rehump: Put b_1 on 1, b_3 on 2, f_1 on 5, g_1 on 9, h_1 on 10; Then put b_2 on 1, b_4 on 2, f_2 on 5, g_2 on 9, h_2 on 10

Pull back the rest of the two tracks containing only cars of Group 4, and rehump, putting B_2 on 1, B_4 on 2, F_2 on 5, G_2 on 9, and H_2 on 10. The yard will appear as in Figure 16. The trains are ready to depart.

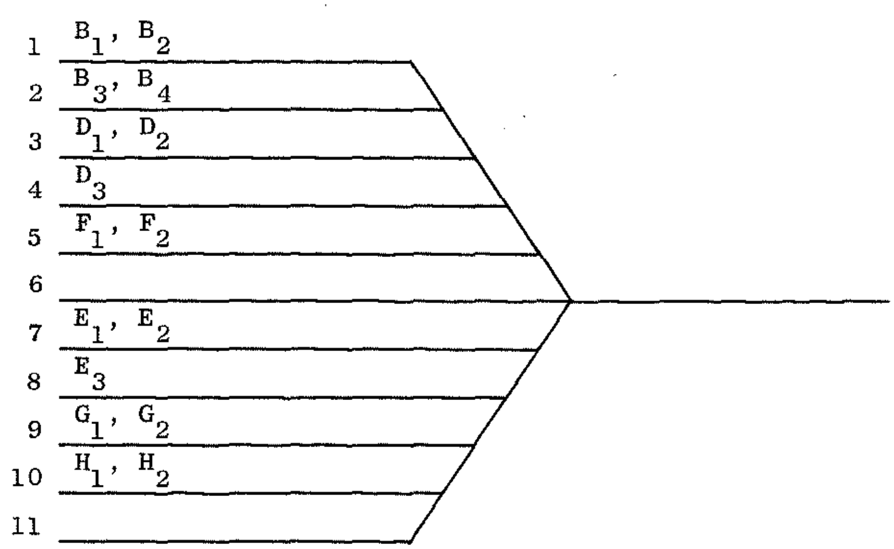

Figure 16 Scheme 2 - Arrangement of Cars After Rehumping of Group 3 and Group 4 Cars

Case 2: If B, F, G, H have to be formed first, the procedure is similar to that explained above. The two tracks, 1 and 2, and the three tracks emptied by pulling the cars of Group 3 and 4 can be used to form the trains as above. It will be noticed that after the formation of Trains B, F, G, H, two tracks will become available so that Trains C, D, and E can be formed without any need of Trains B, F, G, H departing first.

3. Scheme No. 3

Both Schemes 1 and 2 were essentially based on grouping according to subscripts. The scheme to be described below is based on grouping according to outbound trains. Assuming that initially 6 tracks are available, the initial grouping can be arranged in the following manner also:

Track 1 -- For A

Track 2 -- For I

Track 3 -- Cars of Trains C and F--
i.e. $(c_1, c_2, c_3, f_1, f_2)$

Track 4 -- Cars of Trains D and G--
i.e. $(d_1, d_2, d_3, g_1, g_2)$

Track 5 -- Cars of Train E and H--
i.e. $(e_1, e_2, e_3, h_1, h_2)$

Track 6 -- Cars B, i.e. (b_1, b_2, b_3, b_4).

The yard will typically appear as in Figure 17 after completion of primary humping.

Note: The grouping for Tracks 3, 4, or 5 is flexible. The main idea is to combine any one train of three batches with any train of two batches so that in each group there are 5 batches. Thus, $(c_1, c_2, c_3, g_1, g_2)$ and $(d_1, d_2, d_3, f_1, f_2)$ will be equally acceptable.

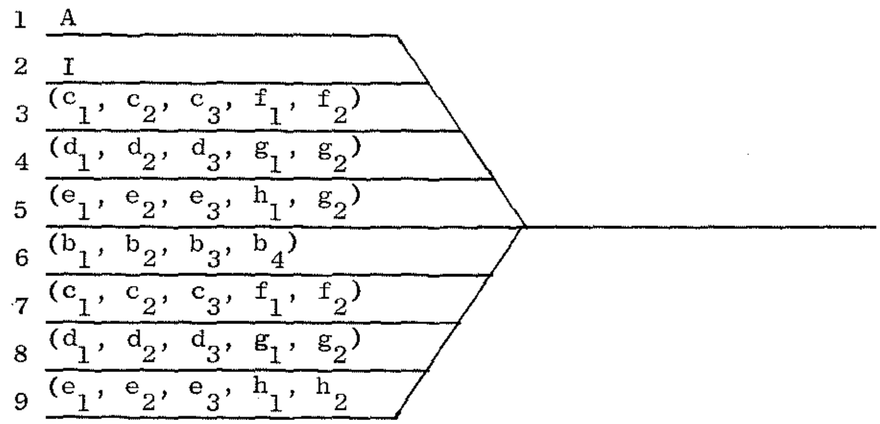

Figure 17 Arrangement of Cars After Primary Humping According to Scheme 3

Assume that A and I depart so Tracks 1 and 2 become free. Now depending upon which trains are to be formed first, 3 suitable tracks can be pulled back on the receiving track. This leaves 5 tracks empty. It will be observed that on each track, the number of batches is only 5 (except Track 6 when it is 4). With the assumed grouping mentioned above it is possible to separate the batches of trains in various sequences. A typical operation of rehumping will be as follows, assuming Train B has to depart first, after which C and F should depart. Pull the tracks 6, 3, and 7 on receiving track so the yard appears as in Figure 18.

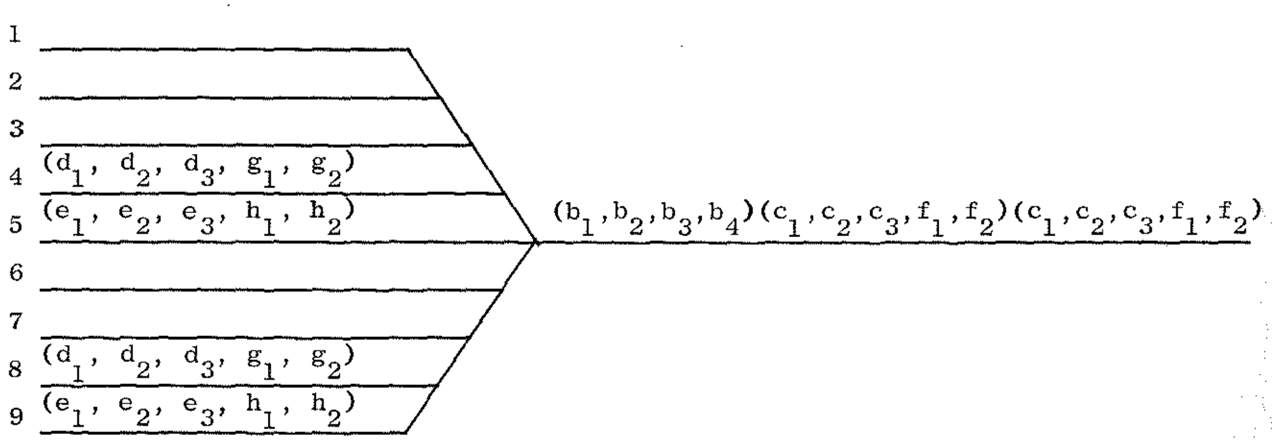

Figure 18 Scheme 3 - Arrangement of Cars After Tracks 6, 3, and 7 are Pulled Back

Rehump till the group (b_1, b_2, b_3, and b_4) is finished. Put b_1 on 1, b_2 on 2, b_3 on 3, and b_4 on 6. Stop rehumping if necessary.* Let Train B depart, so that Tracks 1, 2, 3, and 6 become free again. Resume humping; put

c_1 on 1
c_2 on 2
c_3 on 3
f_1 on 6
f_2 on 7 .

Let Trains C and F depart. Pull Tracks 4 and 8 out and rehump. Put

d_1 on 1
d_2 on 2
d_3 on 3
g_1 on 6
g_2 on 7 .

Lastly, pull Tracks 5 and 9 and sort out the batches of Trains E and H. This scheme has the advantage that trains can be formed in various sequences. However, according to this scheme, each batch is formed on a separate track so that the batches belonging to the same outbound train have to be coupled together after these are sorted.

Note: While the engine on the departing side is pulling the batches already formed, the engine on the humping side can simultaneously pull the remaining tracks to be rehumped. Thus there will be no undue waste of time.

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* Stopping of rehumping will usually not be necessary since C_1 can be put behind B_1, C_2 behind B_2, C_3 behind B_3, F_1 behind B_4, and F_5 on Track 7. However, if during this process any track is filled completely--i.e., if $B_1 + C_2 > 60$ or $B_4 + F_1 > 60$, etc., then the humping may have to be stopped temporarily so that the respective batch of B is cleared first.

D. Implementation of Various Schemes for Train Formation with Limited Initial Track Availability

Three example schemes of train formation with limited initial track availability were described above. The purpose of the present subsection is to outline the methodology and sequence of logical steps that the yard master will have to take to decide which scheme to choose and how to implement it. Let us first briefly summarize what each scheme achieves and what the basic track requirements are:

(1) Scheme 1. Initially 5 tracks are available.

(a) Initial Track Assignment

Cars of Train A are collected in one group--Track 1

Cars of Train I are collected in one group--Track 2

Cars having subscripts 1 and 4 are collected in one group--Track 3

Cars having subscript 2 are collected in one group--Track 4

Cars having subscript 3 are collected in one group--Track 5.

(b) Performance Feature

All trains B, C, ..., H, are formed simultaneously with batches in proper sequence for trains that are 60 or less car lengths long. For trains that are more than 60 car lengths long, the train has to be subdivided and formed as two fictitious trains on two tracks.

(2) Scheme 2. Initially 6 tracks are available.

(a) Initial Track Assignment

Cars of Train A are collected in one group--Track 1

Cars of Train I are collected in one group--Track 2

(c_1, d_1, e_1, c_3, d_3, e_3) are collected in one group--Track 3

(c_2, d_2, e_2) are collected in one group--Track 4

(b_1, f_1, g_1, h_1, b_3) are collected in one group--Track 5

(b_2, f_2, h_2, b_4) are collected in one group--Track 6

(b) Performance Feature

Either Trains C, D, E can be formed first and then B, F, G, H, or B, F, G, H first and C, D, E later.

Trains B, C, D and E are formed in two parts on two different tracks.

(3) Scheme 3. Initially 6 tracks are available.

(a) Initial Track Assignment

Cars of Train A are collected in one group--Track 1
Cars of Train I are collected in one group--Track 2
Cars of Train C and F in one group--Track 3
Cars of Trains D and G in one group--Track 4
Cars of Trains E and H in one group--Track 5
Cars of Train B in one group--Track 6

(b) Performance Features

Trains can be formed in various sequences--e.g., C and F first, then D and G, and then E and H and B, etc.

Each batch is formed on a separate track.

Knowing the composition and sequence of arriving trains, the yard master may calculate beforehand (with the help of a computer, or even by hand calculations) the required number and length of tracks for each of the schemes (including possible variations in each scheme) as various incoming trains arrive. He then has a complete picture of what he can do and what he can achieve if he used one or the other schemes, and he can choose the scheme that he finds most appropriate under the existing yard conditions. The calculations and the results can be conveniently put in a systematic tabular form for each scheme. An example will now be considered to elaborate these points.

E. An Example of Implementation of a Scheme

Let the 8 incoming trains contain the cars belonging to various batches as indicated in Table I. These numbers have been selected rather randomly. The total number of cars in each incoming train to be included

Table I

ASSUMED NUMBER OF CARS BELONGING TO VARIOUS BATCHES IN THE INCOMING TRAINS

Departing Train	Batches	Number of Cars Belonging to Various Batches in Arriving Trains								
		1A/BSM	TXN	1GS	2GS	2A/BSM	1BSM	MTS	2BSM	Total
A	A	10	15	2	-	14	5	-	6	52
I	I	10	12	2	-	20	10	3	7	64
B	B_1	5	3	10	7	-	2	4	-	31
	B_2	2	5	5	8	-	3	5	-	28
	B_3	3	4	7	-	3	10	3	6	36
	B_4	5	2	1	4	-	12	-	7	31
C	C_1	4	-	5	-	5	-	10	-	24
	C_2	2	-	3	-	3	11	10	5	34
	C_3	3	6	7	-	2	-	3	5	26
D	D_1	7	3	2	3	-	3	5	4	27
	D_2	8	2	4	-	7	-	6	6	33
	D_3	5	4	-	10	2	3	7	5	36
E	E_1	10	4	-	3	3	4	2	3	29
	E_2	3	2	-	4	-	5	8	2	24
	E_3	8	1	4	-	5	-	1	10	29
F	F_1	2	2	-	5	6	-	2	11	28
	F_2	2	3	-	6	2	2	3	-	18
G	G_1	3	4	3	-	3	-	3	2	18
	G_2	4	2	-	3	2	5	-	3	19
H	H_1	4	-	2	-	3	-	5	-	14
	H_2	2	-	-	7	8	2	-	2	21

in the departing trains has been chosen to be varying between 50 and 125, which is typically the case.

The necessary advance calculations relating to various schemes are shown in Tables II, III, and IV.

1. Analysis of Table II

A study of this table indicates the following facts:

(1) If there are 5 completely empty tracks initially, the cars of the Train 1A/BSM and TXN can be distributed according to the desired grouping, without any track being filled.

(2) When IGS arrives, an additional track is necessary to extend Group 3.

(3) When 2GS arrives, one more additional track is necessary to extend Group 4.

(4) When 2A/BSM arrives, two more additional tracks are necessary to extend Group 5 and Group 3.

(5) When 1BSM arrives, one more additional track is necessary to extend Group 4 further.

(6) No additional tracks are needed when MTS arrives.

(7) When 2BSM arrives, three more additional tracks are required to extend Groups 5, 3, and 2.

If the additional track becomes available as required, then the yard will appear as in Figure 19 after the primary humping of all trains.

Note: Group 1 = cars of Train A

Group 2 = cars of Train I

Group 3 = $(b_1, c_1, d_1, e_1, f_1, g_1, h_1, b_4)$

Group 4 = $(b_2, c_2, d_2, e_2, f_2, g_2, h_2)$

Group 5 = (b_3, c_3, d_3, e_3)

Table II

CALCULATIONS FOR SCHEME 1

Incoming Train I/D	Lengths of Various Groups After Arrival of Each Train									
	Group 1 A Cars		Group 2 I Cars		Group 3 (B_1, C_1, D_1, E_1, F_1, G_1, H_1, B_4)		Group 4 (B_2, C_2, D_2, E_2, E_2, F_2, G_2, H_2)		Group 5 (B_3, C_3, D_3)	
	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard
1A/BSM	10	10	10	10	40	40	23	23	19	19
TXN	15	25	12	22	18	58	14	37	15	34
IGS	2	27	2	24	23	81	12	49	18	42
2GS	--	27	--	24	22	103	28	77	10	52
2A/BSM	14	41	20	44	20	123	26	103	12	64
1BSM	5	46	10	54	21	144	28	131	13	77
MTS	--	46	3	57	31	175	18	149	26	103
2BSM	6	52	7	64	20	195	18	167	26	129

Table III

CALCULATIONS FOR SCHEME 2

Incoming Train I/D	Length of Various Groups After Arrival of Each Train											
	Group 1 A Cars		Group 2 I Cars		Group 3 (C_1,D_1,E_1,C_3,D_3,E_3)		Group 4 (C_2,D_2,E_2)		Group 5 (B_1,B_3,F_1,G_1,H_1)		Group 6 (B_2,B_4,F_2,G_2,H_2)	
	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard
1A/BSM	10	10	10	10	37	37	13	13	17	17	15	15
TXN	15	25	12	22	18	55	4	17	13	30	12	27
IGS	2	27	2	24	18	73	7	24	22	42	16	39
2GS	-	27	-	24	16	89	4	28	12	54	28	67
2A/BSM	14	41	20	44	17	106	10	38	15	69	12	79
1BSM	5	46	10	54	10	116	16	64	12	81	24	103
MTS	-	46	3	57	28	144	24	78	17	98	8	111
2BSM	6	52	7	64	27	171	13	91	19	117	12	123

Table IV

CALCULATIONS FOR SCHEME 3

Incoming Train I/D	Length of Various Groups After Arrival of Each Train											
	Group 1 A Cars		Group 2 I Cars		Group 3 $(C_1, C_2, C_3, F_1, F_2)$		Group 4 $(D_1, D_2, D_3, G_1, G_2)$		Group 5 $(E_1, E_2, E_3, H_1, H_2)$		Group 6 (B_1, B_2, B_3, B_4)	
	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard	No. of Cars in Train	Total Cars in Yard
1A/BSM	10	10	10	10	13	13	27	27	27	27	15	15
TXN	15	25	12	22	11	24	15	42	7	24	14	29
IGS	2	27	2	24	15	39	9	51	6	40	23	52
2GS	-	27	-	24	11	50	16	67	14	54	19	71
2A/BSM	14	41	20	44	13	63	14	81	19	73	3	74
1BSM	5	46	10	54	13	76	11	92	11	84	27	101
MTS	-	46	3	57	28	104	21	113	16	100	12	113
2BSM	6	52	7	64	21	125	20	133	17	117	13	126

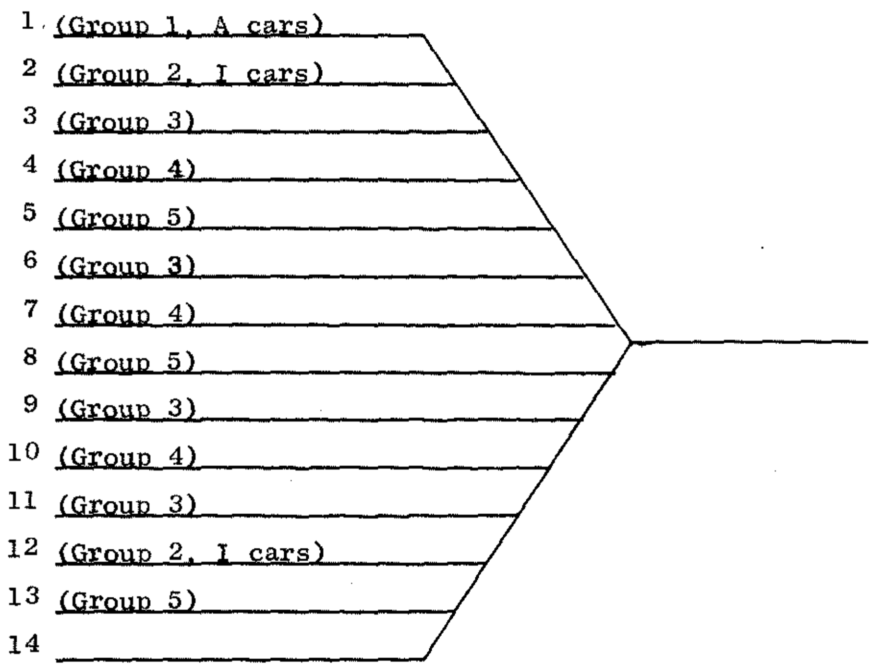


Figure 19 Arrangement of Cars After Primary Humping According to Scheme 1, for the Example Problem

Now if A and I depart, making Tracks 1, 2, and 12 empty, and, in addition, Track 14 is also available, then rehumping can be taken up as follows: Pull Tracks 3, 6, 9, and 11 back. There are 195 cars altogether that can be pulled back. The yard appears as in Figure 20.

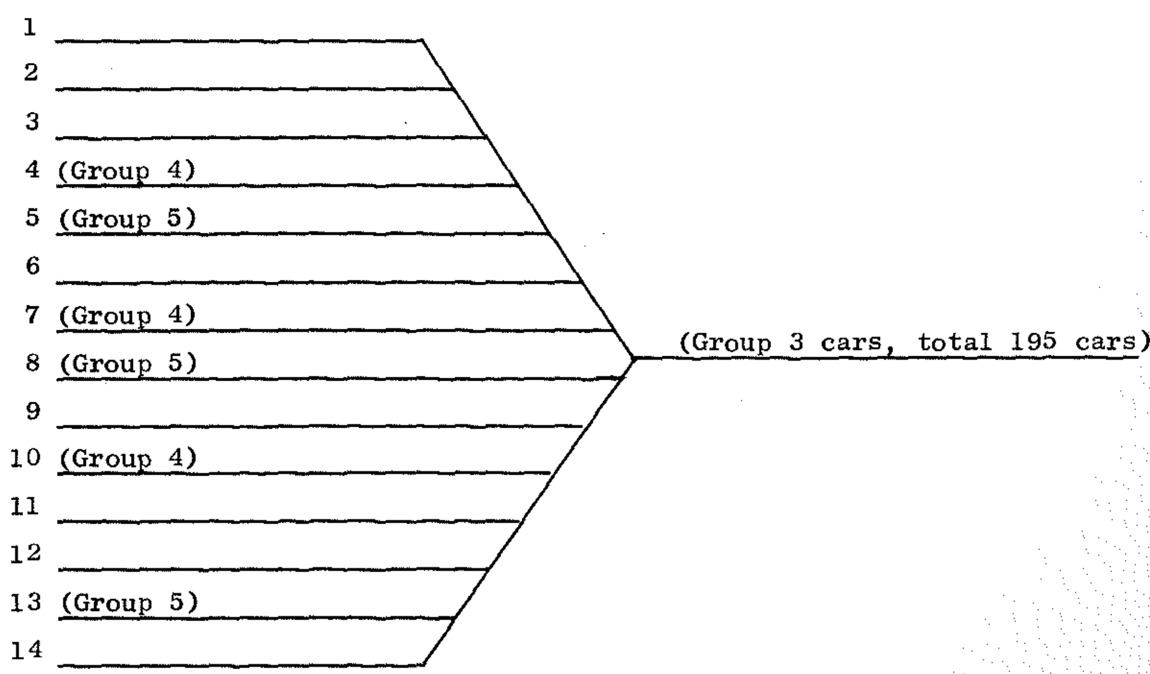


Figure 20 Scheme 1 for Example Problem. Arrangement of the Cars When Tracks 3, 6, 9, and 11 are Pulled Back

There are 8 empty tracks. Therefore, B_1, B_4, C_1, D_1, E_1, F_1, G_1, and H_1 can be put separately on one of these tracks. The yard appears as in Figure 21.

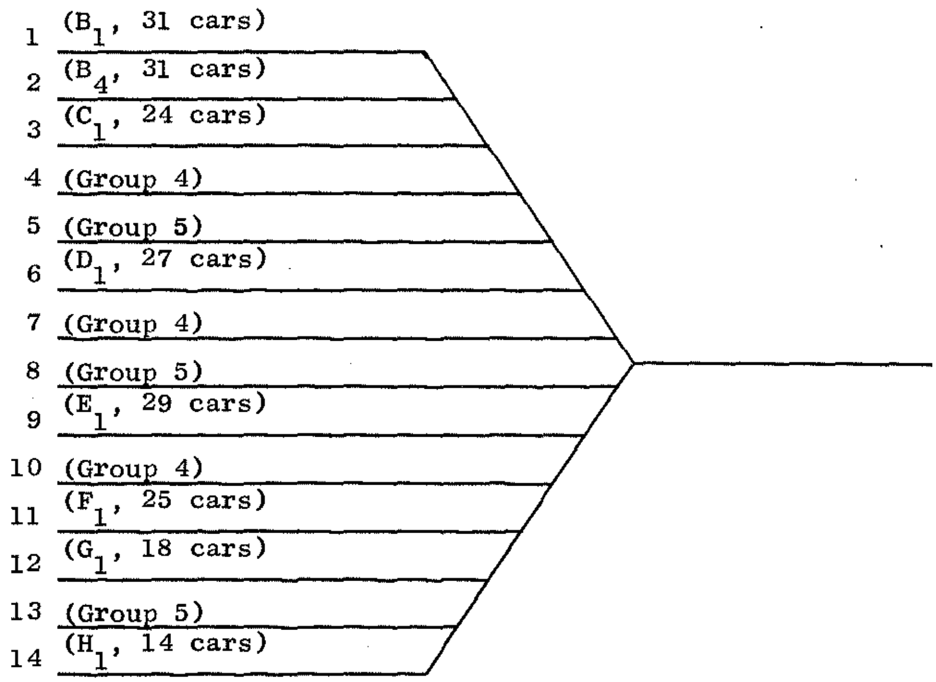


Figure 21 Scheme 1 for Example Problem. Arrangement of the Cars When Tracks 3, 6, 9 and 11 are Rehumped

Pull Group 4 cars from Tracks 4, 7, and 10 back and rehump.

Put B_2 behind B_1 on 1
C_2 behind C_1 on 3
D_2 behind D_1 on 6
E_2 behind E_1 on 9
F_2 behind F_1 on 11
G_2 behind G_1 on 12
H_2 behind H_1 on 14. The yard appears as in Figure 22.

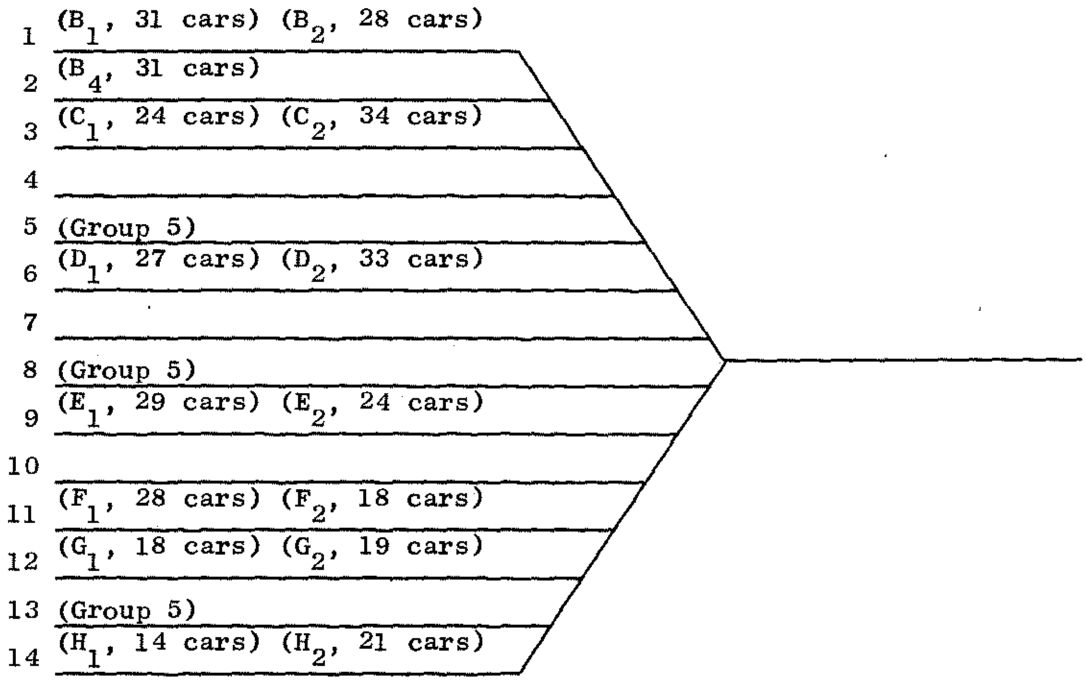


Figure 22 Scheme 1 for Example Problem. Arrangement of Cars When Tracks 4, 7, and 10 are Rehumped

Group 5 cars can now be pulled back and rehumped.

B_3 can be put on Track 4 or behind B_4 if sequence is not important.

C_3 can be put on Track 5

D_3 can be put on Track 7.

At this stage the batches of all departing trains have been separated and are located such that any of the trains B, C, D, ... H can depart. In some cases--e.g., Train B--batches (B_1 and B_2) have to be coupled together on departing tracks with B_3 and B_4 which are located on other tracks.

A similar study and calculations can be made for Schemes 2 and 3. The calculations of these schemes are shown in Tables III and IV, respectively.

2. Analysis of Table III

A study of Table III for Scheme 2 indicates the following:

(1) The initially available 6 tracks can absorb cars of trains 1A/BSM and TXN.

(2) Track 7 is needed to extend Group 3 when IGS arrives.

(3) Track 8 is needed to extend Group 6 when 2GS arrives.

(4) Track 9 is needed to extend Group 5 when 2A/BSM arrives

(5) No additional track is needed when 1BSM arrives

(6) Tracks 10 and 11 are needed to extend Group 3 and Group 4 when MTS arrives

(7) Track 12 (only to accommodate 4 cars) is needed to extend Group 2 when 2BSM arrives.

It is seen that if the 4 cars of Group 2 (I train) could be sluffed somewhere conveniently, only 11 tracks are ultimately needed to accommodate the cars of all incoming trains according to grouping of Scheme 2. The yard appears as in Figure 23.

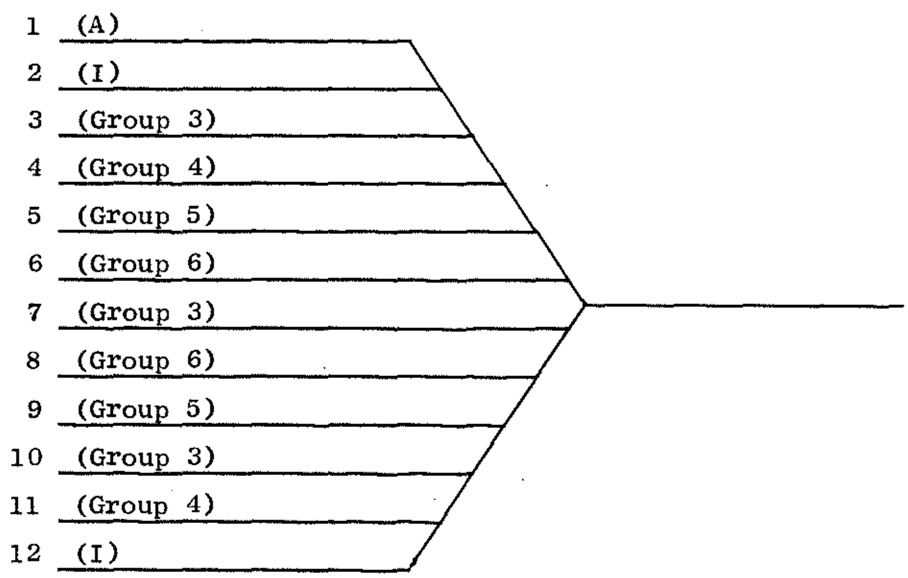


Figure 23 Arrangement of Cars After Primary Humping According to Scheme 2, for the Example Problem

<u>Note</u>: Group 3 = (c_1, d_1, e_1, c_3, d_3, e_3); Group 4 = (c_2, d_2, e_2); Group 5 = (b_1, f_1, g_1, h_1, b_3); Group 6 = (b_2, f_2, g_2, h_2, b_2).

If A and I depart, Tracks 1 and 2 become free. There are two alternatives now. If Train E, C, and D should be formed first, then pull Tracks 11, 10, 7, and 3 back (total 202 cars) so the yard appears as in Figure 24.

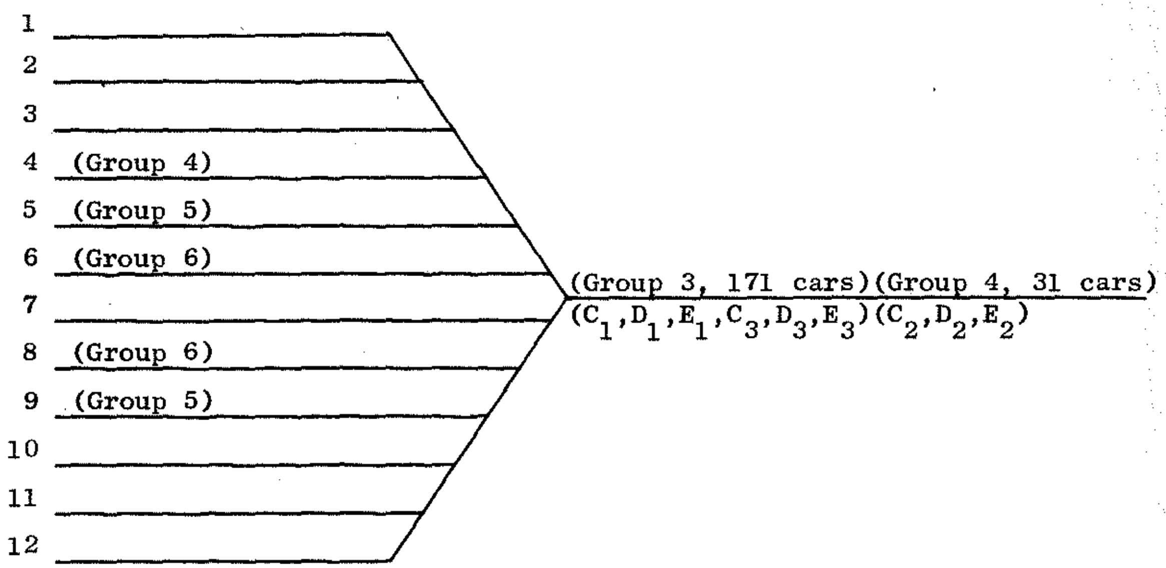


Figure 24 Scheme 2, Example Problem. Arrangement of Cars When Tracks 11, 10, 7 and 3 are Pulled Back

Rehump groups 3 and 4 so that

C_1 goes to 1, C_3 to 2
D_1 goes to 3, D_3 to 7
E_1 goes to 10, E_3 to 11
C_2 goes to 1, D_2 to 3, E_2 to 10.

Pull Track 4 back and rehump and put C_2, D_2, and E_2 behind C_1, D_1, and E_1 on respective tracks. The yard appears as in Figure 25. Trains C, D, and E now depart. Simultaneously, Tracks 6, 5, and 9 can be pulled back so that Tracks 4, 5, 6, 9, and 12 are free. Rehump and put B_1 on 4, B_3 on 5, F_1 on 6, G_1 on 9, and H_1 on 12. Then B_2 on 4, F_2 behind F_1, G_2 behind G_1, and H_2 and H_1. Track 8 can now be rehumped and B_2, etc., can be put behind respective batches. After this, Trains B, F, G, and H can depart.

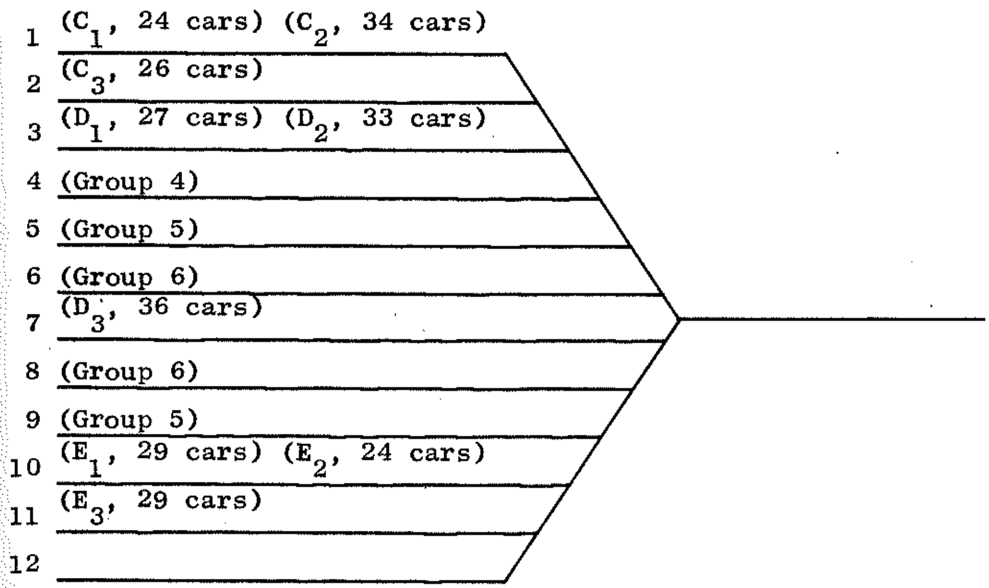


Figure 25 Scheme 2, Example Problem. Arrangement of Cars When Track 4 is Rehumped.

3. Analysis of Table IV

A study of Table IV, for Scheme 3, indicates that:

(1) The initially available 6 tracks can absorb cars of trains 1A/BSM, TXN, and IGS.

(2) Tracks 7 and 8 are needed to extend Groups 4 and 6 when 2GS arrives.

(3) Tracks 9 and 10 are needed to extend Groups 3 and 5 when 2A/BSM arrives.

(4) No further additional tracks are required when 1BSM and MTS arrive.

(5) When 2BSM arrives and is primary-humped, the total number of cars in Group 2 will be 64--i.e., only 4 cars more than 1 track length can absorb. The total number of cars in Group 4 is 133--i.e., 13 cars more than 2 tracks can absorb--and the total number of cars in Group 6 is 126--i.e., only 6 cars more than 2 tracks can absorb. If 4 additional tracks are not available to keep these small groups separated, these could possibly be sluffed

on one additional track and then resorted later. This decision will depend on the yard master depending upon the yard conditions.

Assuming that only one additional track is available to sluff the small number of additional cars of Groups 2, 3, 4, and 6, the yard will appear as in Figure 26.

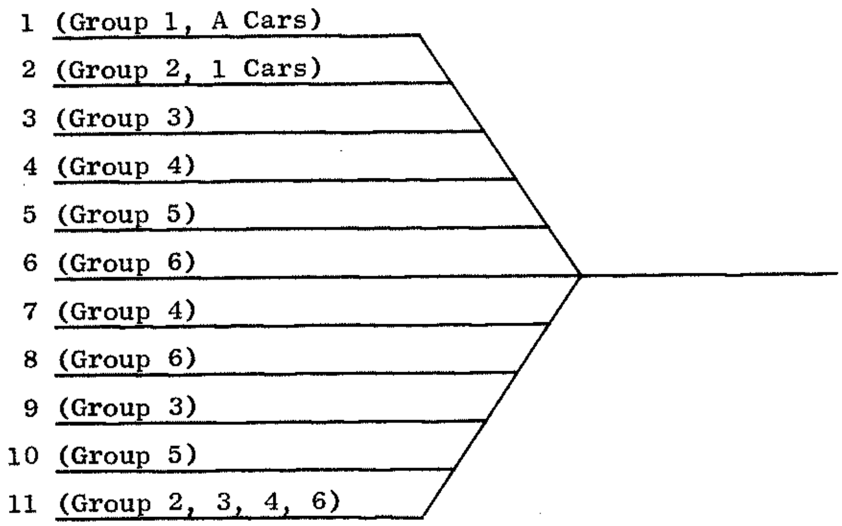


Figure 26 Arrangement of Cars After Primary Humping According to Scheme 3, for Example Problem

<u>Note</u>: Group 3 = (c_1, c_2, c_3, f_1, f_2); Group 4 = (d_1, d_2, d_3, g_1, g_2); Group 5 = (e_1, e_2, e_3, h_1, h_2); Group 6 = (b_1, b_2, b_3, b_4).

Let A and I depart so Tracks 1 and 2 become empty. Pull Tracks 3, 4, and 9 back, so that when rehumped, all cars of Group 3 are humped first and then cars of Group 4 are humped. Put

C_1 on Track 1
C_2 on Track 2
C_3 on Track 3
F_1 on Track 4
F_2 on Track 9

and stop humping at Group 4 cars. Let Trains C and F depart. Resume humping of Group 4; put

D_1 on 1
D_2 on 2
D_3 on 3
G_1 on 4
G_2 on 9.

Pull the rest of Group 4 from Track 7 and rehump, completing the batches D_1, D_2, etc. Similarly, Group 5 cars can be pulled back from Tracks 5 and 10 and so on. The mixture of Group 2, 3, 4, and 6 on Track 11 can either be rehumped separately or included in the next day's trains. If necessary, the yard master may try some variations in Scheme 3 by combining the batches in different groups. There are 6 possible variations in this scheme which can all be analyzed easily, and then the one that seems most appropriate could be selected. The six variations are tabulated below for convenience.

	I	II	III	IV	V	VI
Group 3	C + F	C + F	C + G	C + G	C + H	C + H
Group 4	D + G	D + H	D + F	D + H	D + F	D + F
Group 5	E + H	E + G	E + H	E + F	E + G	E + F

The variation I was analyzed above in detail. Groups 1, 2, and 6 remain the same in all these variations.

4. Summary of Yard Master's Sequence of Steps

(1) Receives the composition of incoming trains.

(2) Generates Table A giving the number of cars belonging to each batch in each train.

(3) Generates Tables II, III, and IV and any variation of these to visualize and analyze what and how each scheme would function for the given number of cars in each batch.

(4) Checks track availabilities at various stages--i.e., when various trains arrive.

(5) Selects the scheme that fits best in the existing and expected yard conditions and takes necessary steps to create favorable conditions when possible.

F. Examples of Train Formation Schemes with Fixed Number of Tracks

Let us consider Table I in the previous subsection giving the advance information about the number of cars belonging to various batches, and present some examples of sorting the batches assuming that all the sorting tracks are available from the very beginning. The total number of cars in all the nine trains to be formed, according to the last column, is 622. Since each track can accommodate 60 cars, the minimum number of tracks, just to physically accommodate the 622 cars without any regard to grouping or sorting, is 10 full tracks and 1 track with empty space for 22 cars. However, in order that some grouping and sorting may be possible, some extra empty tracks will definitely be required. As an extreme case, we will first consider the case with only 1 extra empty track (i.e., a total of 12 tracks) available. It will be shown that by using suitable combinations of groups during primary humping, the desired trains can be formed without any excessive engine effort.

1. Case 1--Scheme When Only 12 Tracks are Available

A study of the batch sizes in the last column of Table I indicated easily the following facts:

(1) Trains A, F, G, and H are all less than 60 car lengths long.

(2) Trains B, C, D, E all consist of more than 60 cars and will have to be formed in at least two sections--e.g., (B_1 and B_2) and (B_3 and B_4); (C_1 and C_2) and C_3; etc. The corresponding two sections can be coupled later.

(3) Train I contains 64 cars. The 4 cars above the maximum limit of 60 cars can be sluffed on a separate siding during the primary humping, or if some extra length is available on the track the train can be formed with 64

cars. Similarly, any small number (e.g., 4 or 5 cars) of cars in a group that cannot be accommodated on the respective track can be sluffed on a common sluff track during the primary humping. These sluffed cars can later be coupled to respective trains or made a part of next day's trains if permissible.

Keeping these facts in mind, a suitable scheme is as follows. The scheme is based on groupings according to subscript numbers.

An initial assignment could be as follows. Assign one track, say No. 1, for A, another, No. 2, for I. This leaves 10 tracks for other cars. Use one of these (third) as a sluff track. The other 9 tracks are assigned as follows:

Track 4 for the group (F_1, G_1, H_1) -- There are 60 cars.
Track 5 for the group (F_2, G_2, H_2) -- There are 58 cars (i.e., < 60)
Track 6 for the group (C_1, E_1) -- There are 53 cars (i.e., < 60).
Track 7 for the group (C_2, E_2) -- There are 58 cars (i.e., < 60).
Track 8 for the group (C_3, E_3) -- There are 55 cars (i.e., < 60).
Track 9 for the group (B_1, D_1) -- There are 58 cars (i.e., < 60).
Track 10 for the group (B_2, D_2) -- There are 61 cars, divert 1.
Track 11 for the group (B_4, D_3) -- There are 67 cars, divert 7 B_4 cars on sluff track
Track 12 for the group (B_3) -- There are 36 cars (i.e., < 60).

After the primary humping according to this grouping, the yard appears as in Figure 27. At this stage, there are several alternatives--e.g.:

Pull Tracks 9 and 10 together back so that (b_1, d_1) group precedes the (b_2, d_2) group and rehump. Put

B_1 on 9
D_1 on 10.

Then put B_2 on 9 behind B_1
D_2 on 10 behind D_1.

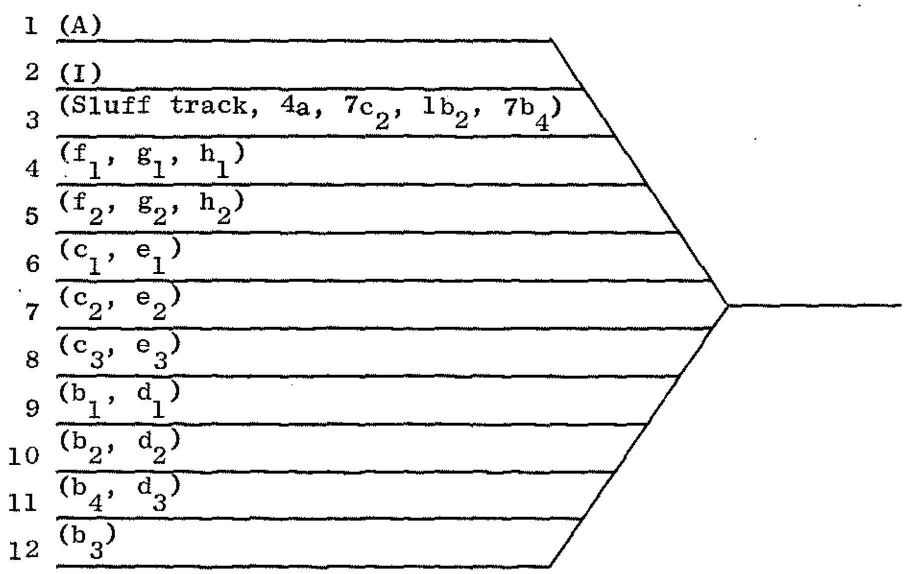


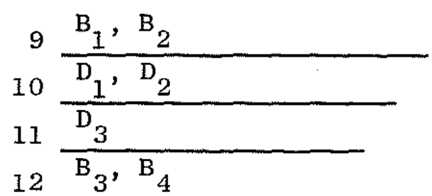
Figure 27 Arrangement of Cars After Primary Humping With Initially 12 Tracks Available for the Example Problem

Pull Track 11 back and rehump. Put

B_4 on 12 behind B_3

D_3 on 11.

The batches of Trains B and D are now properly arranged on Tracks 9, 10, 11, and 12 as follows:



By a slight modification B_3, B_4 could have been formed on the 10th track--i.e., close to Track 9.

If now either Trains A or I or B or D can depart, 2 or 3 extra empty tracks will become available and sorting of the rest of the group will not be any complicated process. For example, suppose Trains A and I depart, making Tracks 1 and 2 empty.

Track 4 can now be pulled back and rehumped. Put

F_1 on 1

G_1 on 2

H_1 on 4.

Then rehump Track 5. Put

F_2 on 1 behind F_1

G_2 on 2 behind G_1

H_2 on 4 behind H_1.

Trains F, G, and H are now ready to depart. A similar process can be followed to form Trains C and E.

2. Case 2--Schemes When 15 Tracks are Available

Considering now a more relaxed yard condition and using the same data as in the above example, there are several possible alternatives. One of these is as follows:

Assign one individual track to each of the following batches:

Batch No:	A,	I,	B_1,	B_2,	B_3,	B_4,	D_1,	D_2,	D_3
Track No:	1	2	3	4	5	6	7	8	9

Assign Track 10 to f_1, g_1, h_1 (Total 60 cars)

Track 11 to f_2, g_2, h_2 (Total 58 cars)

Track 12 to c_1, e_1 (Total 53 cars)

Track 13 to c_2, e_2 (Total 58 cars)

Track 14 to c_3, e_3 (Total 55 cars)

The trains A, I, B, and D can depart in any sequence by coupling the respective batches. Note that the batches belonging to these trains were sorted already during the primary humping. Thus the number of cars to be rehumped is considerably reduced. If now any one track can be made empty--e.g., if Train A or I or B or D can depart, then the following rehumping schedule can be adopted. Assume that Track 1 becomes empty.

Pull the cars on Track 13 back and rehump. Put

C_1 on Track 1

E_1 on Track 13

Pull the cars on Track 14 and rehump. Put

C_2 on Track 1 behind C_1

E_2 on Track 13 behind E_1.

Pull the cars on Track 15 back and rehump. Put

C_3 on Track 1 behind C_2

E_3 on Track 13 behind E_2.

Train C and E are now formed. Tracks 14 and 15 are empty.

Pull Track 10 and rehump. Put

F_1 on Track 10

G_1 on Track 14

H_1 on Track 15.

Pull Track 11 and rehump. Put

F_2 on Track 10 behind F_1

G_2 on Track 14 behind G_1

H_2 on Track 15 behind H_1.

Trains F, G, and H are also formed.

A study of both Case 1 and Case 2 indicates the fact that the greater the number of sorting tracks available, the more easy and flexible the sorting schemes, requiring considerably less rehumpings. Thus, if there were 21 tracks available, then each batch could have been assigned a separate track and no rehumpings would have been necessary.

3. Case 3--Example of a Composite Scheme

Let us assume that Train A in the above noted examples is to consist of 6 batches, A_1, A_2, ..., A_6. With reference to Table I, let the number of cars in each of the batches be:

$$A_1 = 5, A_2 = 10, A_3 = 15, A_4 = 5, A_5 = 5, A_6 = 12$$

so that $A_1 + A_2 + \dots + A_6 = 52$ cars (i.e., the same as the total number of A cars in the batch). Let the data for other batches be the same as in Table I.

Considering now again the extreme case when only 12 tracks are available, it can easily be seen that the scheme described under Case 1 cannot be used per se since Train A now consist of 6 batches which have to be in proper sequence. A possible scheme composed of Basic Schemes 1 and 3 is presented below:

Let 1 track each be assigned initially to the following groups as in Case 1:

Group:	(I);	(f_1, g_1, h_1);	(f_2, g_2, h_2);	(c_1, e_1);	(c_2, e_2);	(e_3, e_3)
Track No:	1	2	3	4	5	6

Trains F, G, H, C, and E can easily be formed using the same rehumping process as described in Case 1. The cars of the other three trains, A, B, and D, could be initially distributed on the remaining 6 tracks in the following manner, which is partly based on the triangular scheme:

(b_1, b_3) on Track 7
(b_2, b_4) on Track 8
(d_1, d_3) on Track 9
(d_2) on Track 10
(a_1, a_3, a_5) on Track 11
(a_2, a_4, a_6) on Track 12.

Note that the grouping of subscripts corresponds roughly to the rows of the triangular scheme. With this initial grouping, the rehumping can be done as follows:

Pull Tracks 8 and 7 so that (b_1, b_3) precedes the (b_2, b_4) group (looking from bowl track side) and rehump. Put

b_1 on Track 7
b_3 on Track 8
b_2 on Track 7 behind B_1
b_4 on Track 8 behind B_3

Train B is now formed on two tracks in two sections. Train D can similarly be formed by pulling (d_1, d_3) and rehumping. D_1 can be put back on Track 9 and D_3 behind D_2 on Track 10. All trains except A have been formed now without the need of any extra tracks. Assuming now that at least one of the 8 trains has departed in the meantime, Train A can easily be formed as follows:

Assume D train has left, making Track 10 and 9 empty.

Pull Tracks 11 and 12 in proper sequence--i.e., (a_1, a_3, a_5) preceding (a_2, a_4, a_6) group and rehump. Put

a_1 on Track 10
a_3 on Track 11
a_5 on Track 12.

Then put a_2 on Track 10 behind A_1
a_4 on Track 11 behind A_3
a_6 on Track 12 behind A_5.

Train A is formed in 3 sections which can be easily coupled together.

G. Concluding Remarks

Several examples were presented above to indicate how various systematic schemes can be developed to efficiently sort the batches and form the trains. In view of the large variations in the track availabilities, number of cars in various batches, etc., no general, universally applicable scheme is possible. However, one or the other suggested schemes or a combination of schemes that are all based on systematic combination rules should almost always be applicable.

Simple computer programs for various schemes can easily be written based on typical yard operating conditions and covering a large set of possible variations. With the advance information available about the incoming cars, various combinations of schemes can quickly be tested and analyzed beforehand and a decision can be made about the sorting and train formation strategy. If necessary and possible, the yard master may even take suitable steps to create favorable conditions.