Analysis and Comparison of Rail and Road Intermodal Freight Terminals that Employ Different Handling Techniques

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The purpose of this paper is to determine the possible advantages for rail and road intermodal freight terminals of eight different handling techniques by comparing them with transfer by gantry crane. Design concepts were drawn up for each technique for three typical terminal sizes that were designed for the forecast volume of intermodal freight in West Germany in 1990. Functional capability and cost were the bases for comparison. The terminals were also viewed within the context of the West German transport system as a whole. Although all of the techniques studied were found to cope with the peak-hour work load, there are major differences in terms of capital outlay and functional properties. The costs of terminals with handling techniques that involve little or no vertical movement are significantly higher than the others. None of the new techniques offers any advantages over the gantry crane. The unit handling costs in large terminals are not lower than those of medium-sized terminals. The handling costs in terminals are inferior to the total cost of inland intermodal freight transport. Based on capacity assumptions made for the typical terminals considered in this study, the optimum number of terminals for West Germany is 50 in terms of the total cost of the intermodal freight transport system.

Intermodal freight transport varies markedly from one country to the next. This is due, among other things, to differing statutory regulations, distances that have to be covered, and admissible dimensions and weights. These differences are particularly pronounced between the United States and Europe. Thus, only limited transfer of experience and know-how is possible.

A welcome exception is the international standardization of shipping container sizes, which has led to the establishment of uniform container handling techniques throughout the world. For inland freight traffic, however, transport units are still being used for which there are, at most, only national standards. [It suffices here to mention the swap bodies widely used in West Germany and the trailers-on-flatcars (TOFCs) used in the United States.] Terminals in the United States have to perform different tasks than do terminals in West Germany and are accordingly designed and equipped differently.

Despite the differences from country to country, the publication of major findings in one country can be useful to other countries. This is the case for the study of intermodal transport in West Germany carried out over the past few years by the Krupp Research Institute for the Federal Minister for Transport (1). The original aim of this study was to establish whether handling techniques that deviate from the conventional use of gantry cranes offered any advantages. The study was not restricted to freight terminals but covered the entire West German intermodal transport system, including rail transport and road haulage to and from the terminals. This was necessary because an isolated study of handling techniques or terminals could have produced misleading results.

Studies of various handling and transportation techniques for inland intermodal freight have also been undertaken in other countries, e.g., the United States (2,3) and the United Kingdom (4). It was not possible to include their results in this paper because both their objectives and terms of reference were different. The procedure employed in and the results gained from this study are, however, worthy of note because they are in part unique and in part generally applicable. They could thus provide food for thought in other countries.

HANDLING TECHNIQUES STUDIED

In all, nine handling techniques were included in the study. Eight of them were either selected from previous studies as being promising or were put forward at the beginning of the study (in 1978). The ninth technique, which furnished the basis for comparison, was transfer by rail-mounted gantry cranes such as that applied by Deutsche Bundesbahn in its freight terminals.

The handling techniques studied can be divided into three main groups. Classified into the first group are those techniques in which handling involves pronounced vertical movement of the load units. One example is transfer by gantry crane. This group is therefore designated vertical handling. The four members of this group are as follows:

1. System DB: In this system, gantry cranes straddle the tracks, road-vehicle lanes, and storage areas (see Figure 1). Transfer is by spreader for containers or grabpler arms for swap bodies or semitrailers. (Note that system DB is used as the basis for comparison with the other systems.)

2. System DA: This is a rail-mounted gantry crane (see Figure 2). It differs from system DB in that it features an L-shaped lifting attachment that is capable of operating under overhead wires. However, this imposes restrictions on the layout of the terminal.

3. System AC: This system is for loading and unloading rail vehicles by using a special-purpose gantry crane that can operate underneath overhead wires (see Figure 3). It can handle intermediate storage of load units, and there is an additional rail-mounted gantry crane for subsequent loading onto road vehicles and also into storage.

4. System SF: This system is similar to system AC; the difference being that the gantry crane can serve a very large storage area so that the load units do not need to be stacked (see Figure 4).

The second group comprises the three following handling techniques, which entail little or no vertical movement and in which horizontal movement is predominant. This group is therefore called horizontal handling. One example of this technique—although it was not included in this study because of its impracticability in Europe (insufficient loading gauge)—is the transport of TOFCs with road vehicles driving onto and off of rail vehicles. The horizontal handling systems are described below:

1. System R: Vehicles and ramps are fitted with powered roller conveyors (Figure 5) for the simultaneous transfer of all load units to the neighboring lane. In addition, the gantry crane serves the
Figure 1. System DB handling technique.

Figure 2. System DA handling technique.

Figure 3. System AC handling technique.

Figure 4. System SF handling technique.

Figure 5. System R handling technique.

Figure 6. System H handling technique.

Figure 7. System W handling technique.

storage yard and is used for transfers to road vehicles.

2. System H: This system includes rail-mounted transfer equipment that picks up the load units from the neighboring track by lifting from below and subsequently loads onto road vehicles in the neighboring lane or vice versa (see Figure 6). To facilitate pickups, load units are in a raised position.

3. System W: The load units are swap bodies, which are unloaded from the road vehicle and positioned above the track so that the rail vehicle can move underneath and take the load (see Figure 7).

The third group is made up of two techniques that cannot be classified as clearly belonging to either of the other two groups:

1. System SH: This is a combination of handling equipment and high bay racks for the load units (see Figure 8).

2. System LS: This system is similar to system H, with the difference being that the transfer equipment grabs the load units at the top and can also put them down at ground level (see Figure 9).

TERMINAL ASSUMPTIONS

A comparison can only be objective if underlying conditions are uniform. Toward this end, the tasks and capacities of typical terminals were exactly defined in this study. The terminals were designed to accommodate the various techniques, and it was assumed that all the terminals would have to be built from scratch. The comparison was then made on the basis of a functional and a cost analysis.

In line with conditions prevailing in West Germany, three capacity classes for terminals were entered. These were defined as the number of load units that arrive at the terminal monthly by rail vehicles. On the basis of the forecast (5) that by 1990 a total of 23 million tonnes of goods will be transported by combined modes, 500, 3,000, and 10,000 load units per month were set as the capacities of the small, medium, and large terminals, respectively (sizes A, B, and C). Daily density,
peak-hour and peak-day work load, and the respective volumes of freight carried by container or swap body and semitrailers were projected for 1990 on the basis of data from current terminals.

Freight terminals, particularly those of high capacity, require a lot of space and involve considerable expense. As Figure 10 shows for the large system DB terminal, seven gantry cranes are required over two groups of track. Efficient use of equipment will keep costs, and possibly the amount of equipment needed, low.

SIMULATION USED FOR COMPARISONS

To examine efficiency and to determine the space and equipment requirements, the peak hour is usually considered. By determining equipment capacity use during the peak hour, a good reference value is obtained. Although this enables major errors in dimensioning to be recognized, the realistic examination of terminal concepts is only possible by computational simulation. A complex simulation program was therefore developed to look into all operations within the terminal, and this has proved an effective tool for analysis. Its structure and some of the results achieved are mentioned here because of their general importance.

A total of 12 origin-to-destination connections are possible in transfer operations between rail and road as well as storage and intermediate storage means in a freight terminal. Some of the events in these connections run parallel, but load units, times, routes, handling equipment, and priorities may differ considerably.

The various functions of the terminal are simulated in several quasi-parallel processes via event control. These functions include the physically active items (such as handling equipment, trains, and road vehicles) as well as administrative tasks (such as management of vehicles in the parking area or of containers in the intermediate storage yard awaiting transfer to the main storage yard) that have to be carried out independently of physical events. The necessary linking of the individual modular processes is effected by a central control unit.

The results furnished by the simulation program include the following items:

1. Specific time values (such as load unit transit times, road vehicle turnaround times, train stopping times, and handling equipment cycle times),
2. Load capacity utilization (e.g., handling equipment, and duty factor of in-terminal vehicles and various terminal areas), and
3. Sensitivity of the complex to changes in priorities, allocations, sequences, loading, and equipment breakdowns.

RESULTS OF SIMULATIONS

Functional analysis on the basis of equipment use in the peak hour and by simulation showed that all 27 concepts (9 handling techniques for each of the 3 terminal sizes) are able to perform the tasks set. Because of the characteristics of the individual techniques, there are major differences in the capacity use of the equipment in the peak hour. For example, Figure 11 shows that the gantry cranes in system DB are used to a large extent in all three terminal sizes. Although the equipment in system SF
is in some cases badly underused, the equipment in
system R is overloaded. The amount of equipment
needed to cope with the work load differed consider­
ably. As will be demonstrated, this has a major
bearing on costs and capital spending. Unfortu­
nately, only a few examples from the wide range of
realistic results of the simulation calculations can
be cited here.

Figures 12 and 13 represent the daily density
diagrams of the handling jobs that employ systems DB
and AC measured at half-hourly intervals in a size B
terminal. Comparisons of the target and actual
density curves show that both terminals satisfy the
requirements. The fact that the target and actual
lines are at times out of synchronization stems from
bringing forward scheduled handling jobs. The
higher volume of work in Figure 13 reflects the ex-
tra yard movements caused by the separation of the
container storage yard from the intermediate storage
yard and by the use of different equipment to serve
these yards.

Better insight into the performance and potential
of the terminals is afforded by comparing terminal
transit times. In the case of trucks, the transit
time is identical with the turnaround time, i.e.,
the time spent in the terminal. Figure 14 shows a
few examples for the mean turnaround times of the
road vehicles and the transit time of the direct­
transfer load units (rail and road and road and
rail). Note here that terminal size B, which em­

dploys the LS technique, and terminal size C, which
employs the AC technique, compare favorably with the
others.

The selection of the correct operating strategy
has a major influence on terminal operating productiv­
ity. Figure 15 shows the simulation results for the truck
turnaround times in the size B terminal for three
different working sequences in accordance with three
priorities: P1, P2, and P3. Although system AC re­
mains virtually unaffected by the changes in working
sequence, the turnaround times in system DB show a
steady drop as the working sequence changes from P1
to P2 to P3. In system LS, however, strategy P2
brings a substantial deterioration on P1 and strat­
egy P3 brings a slight improvement.

Figure 12. Daily density diagram of handling jobs for system DB, terminal size B.

Figure 13. Daily density diagram of handling jobs for system AC, terminal size B.

Figure 14. Turnaround times of road vehicles and direct-transfer load units.

Figure 15. Changes in truck turnaround times that reflect changes in operating strategies.
The costs of simulation depend greatly on the specific circumstances of the terminal to be simulated. However, they are much less than, for example, the cost of a gantry crane that could be saved by optimizing terminal operations with the aid of simulation.

**Terminal Costs**

Given adequate functional capability, profitability plays a decisive role in the comparative assessment of alternative terminal concepts. Everything else being equal, this is determined by the costs incurred. These in turn largely depend on investment expenditure. For all 27 terminal concepts, capital expenditure was therefore determined on the basis that all would have to be set up from scratch, including land, building, plant, and equipment. The total cost was then calculated by adding depreciation, interest payments, operating costs (utilities, repairs, maintenance, and so on), personnel costs (management, loading and unloading, supervision, operation of equipment), and miscellaneous costs (e.g., shunting). (Note that the figures given in the following graphs reflect prices and interest rates for 1978.)

Figure 16 compares the annual costs of the individual techniques for the medium-sized terminal. Costs for plant and equipment in terminals of the horizontal handling group are pushed up by the fact that the vehicles, load units, or both require extra features (e.g., roller conveyors, supporting blocks) that are proportionally allocated to the investment cost for the terminal.

It is also noticeable that, for some techniques, equipment costs are far higher than land and building costs, whereas for other techniques the latter predominate.

Terminal sizes A and C exhibit the same ratio. It can be seen that the horizontal handling group involves, in part, substantially higher costs than the two other groups, which are roughly of the same order of magnitude.

It can prove very interesting to determine specific terminal costs, i.e., the annual costs that refer to the load units arriving at the terminal by rail. Figure 17 shows the specific terminal costs for the three groups as a function of monthly arrivals by rail. The poor position of the horizontal handling group is noticeable, but much more important is the finding that, from about 3,000 arrivals/month and more, specific terminal costs (unit costs) stop decreasing. This means that bigger terminals can no longer by advocated on grounds of cost. This finding is to be welcomed, at least in West Germany with its high population density, because proposals for the construction of large terminals are encountering ever-increasing difficulties.

**Cost-Benefit Analysis**

As a final assessment of the alternative terminal concepts, a cost-benefit analysis was undertaken. To determine the benefit, a number of criteria relating to efficiency, reliability, and flexibility were defined and weighted according to their relative significance. The alternative concepts were given points according to how well they fulfilled these criteria. These were set against the cost ratio. Figure 18 shows that, for the size B terminal, a strange situation applies whereby system DB (the basis of comparison) provides the highest benefits and also involves the lowest costs. This finding also applies for the two other terminal sizes.

**Network Examination**

Viewing the terminal in isolation (i.e., separate
from the transport system as a whole) can lead to wrong conclusions. Such errors are liable to occur when, for example, the basis of comparison—the three terminal sizes as defined—are out of line with future circumstances. To avoid such an error, the terminal study was followed by an examination of the transport system as a whole. The rail network that connects the terminals, optimizes rail transport, and connects the road links for forwarders and consignees with the terminals was studied. The total costs for several alternatives, which differ in the number of terminals, were determined. The details of this study cannot be dealt with here, but some of the significant and interesting findings are highlighted.

The annual cost of running the entire intermodal freight transport system is made up of the costs for road haulage (including operational service), for the terminal itself, and for rail transport. The cost for the terminal demands only 10 to 15 percent of the total costs against the cost of rail transport, which takes up by far the higher share. For a small number of terminals, the same is true of road haulage. Although the level of costs for rail transport increases with the number of terminals, road haulage costs rise inversely to the number of terminals. There is thus an optimum number of terminals at which the annual cost of West Germany's intermodal freight transport system, based on the assumptions made for this study, is at its lowest.

CONCLUSIONS

As revealed by the cost-benefit analysis (Figure 18), none of the alternative handling techniques examined offers advantages over the base technique practiced by Deutsche Bundesbahn, and some are much less favorable.

The optimum number of terminals at which the annual costs of the transport system studied is at its lowest was determined to be approximately 50.

Although the terminal costs are inferior to the total costs of transport, the overall optimum was determined for comparing handling technique DB with techniques H and R (both horizontal). As can be seen from Figure 19, the technique employed has no significant bearing on the optimal number of terminals. By contrast, the total costs for systems H and R rise substantially as a result of the higher terminal costs.

The final check was to determine whether the terminal sizes used in the comparison reflect real circumstances. For the optimum rail network with 50 terminals, the work load of the individual terminals was calculated. Figure 20 shows the results, including the situation as it was in 1976 (46 terminals). It is clear that the capacities selected for the typical terminals match very well the work loads expected for 1990. The graph also shows that capacity of the current terminals will have to be substantially increased to cope with future volumes of goods.

REFERENCES