A Definitive Approach to Engineering Improved Refrigerated Trailer Vans and Containers

Philip L. Breakiron

MANY refrigerated trailer vans and containers in use today are giving unsatisfactory and unreliable service in transporting shipments of perishable agricultural and food products. Consequently, many millions of tons of these products each year are transported to both domestic and foreign markets under less than ideal environmental conditions. Indeed, some shipments are transported under conditions that almost appear to be calculated to promote product losses rather than prevent them.

Because time is an important element in the deterioration and spoilage of perishables, losses are greater in long distance shipments to both domestic and overseas markets than on hauls of a few hundred miles (Hinds 1970a). Such unfavorable environmental conditions during transport as the lack of uniformly optimum temperatures throughout the cargo, too little or too much moisture, harmful concentrations of certain gases exhaled by the products, and unsecured cargo result in substantial losses from physical damage, spoilage, deterioration of product quality, and reduced shelf life. Accurate assessment of the costs of such losses is almost impossible, but they are known to total several hundred million dollars each year for fresh fruits and vegetables, meats, frozen foods, fish and sea foods, and many other products.

Finding satisfactory solutions to the problem of reducing these losses is of critical importance to our economic well-being since their costs are reflected in both higher costs for the products to consumers and lower returns to producers. Also, since losses of all types are especially high in long distance shipments to overseas markets, the success of U.S. producers of many perishable products in exploiting the rapidly growing and discriminating foreign market for the products hinges upon finding ways of reducing such losses to acceptable minimums (Hinds 1970b).

The Agricultural Research Service has worked for more than 30 years to find better, lower cost ways of transporting perishable foods to market. Included in this program is research to improve shipping containers, loading and related handling methods, and transport and refrigeration equipment. The work is done in the laboratory and the physical distribution system for the products, and involves stationary tests and shipping experiments to both domestic and overseas markets to evaluate different techniques and equipment. The results of this research have shown that, although there are a number of causes of loss and damage during transport, a major contributing factor is the deficiency of the refrigerated transport equipment (Hinds and Chace 1962, Anthony 1970). This research also suggested that because of the interrelationship between the many different variables in the shipping and handling of the products, the most productive approach to improving the refrigerated transport equipment would be one which considered the total transport and physical distribution environment in which it is used.

CONVENTIONAL EQUIPMENT

It appears obvious that the basic cause for the failure of refrigerated trailer vans and containers to more fully meet the environmental needs of the products transported in them is the way the equipment was developed. The present trailers and van containers evolved over a period of about 50 years from more primitive predecessor vehicles. This development process was one continuous modification which has undeniably resulted in greatly improved equipment compared with that in use two or three decades ago. However, in this development process little or no functional engineering was possible because the two types of equipment were not considered and treated as a single unit.

There are a number of reasons for the refrigerated trailer and van containers not being conceived and treated as single functioning units. First, because of the way the equipment evolved, the van bodies have been and still are built by one group of manufacturers, the truck trailer builders, and the refrigeration units by another group. Practically all refrigerated vans and containers have traditionally been custom-built to very general specifications supplied by the purchaser. More often than not, the purchasers have no specific data upon which to base their specifications. They, therefore, usually choose from among several different types of insulated vans available from the manufacturers and order that the van be equipped with one of several types of mechanical refrigeration units. Thus, the two types of equipment are combined with little or no consideration of how they will function as integrated units.

The second reason for failure to treat refrigerated trailers and van containers as single units has been a dearth of information about what actually happens in the cooling process in many different types of equipment. Because of this deficiency in data, there have never been any commercial specifications or standards for refrigerated vehicles in the United States. However, such standards are being prepared for van containers by the MH-5 Committee of the American National Standards Institute.

Another cause for the refrigerated vehicle not being considered as a single functioning entity has been the lack of suitable methods of obtaining reliable performance measures for the van and its refrigeration unit. Although a method of rating thermal effectiveness of the van body was developed some years ago in research by the USDA and the National Bureau of Standards, the method has not been widely used. The method also is suitable for rating empty vans only. A suitable method of obtaining reliable performance data for loaded refrigerated vans and containers has been lacking.

FACTORS CONSIDERED FOR NEW DESIGN

We became convinced that substantial improvements in the suitability and

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The author is: PHILIP L. BREAKIRON, Chief, Transportation and Packaging Research Lab., Northeastern Region, ARS, USDA, Beltsville, Md.

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performance of refrigerated trailer vans and containers could be had only by functionally engineering the equipment to do the job for which it is intended more efficiently and at lower overall costs. It was evident that functional engineering of the equipment required defining in detail the functions it was expected to perform and the parameters of its operation under different environments.

In the planning of such a definitive approach to this problem it soon became apparent there were a myriad of factors to be considered and that they could be classified in several different ways. The problem was further complicated by the interrelationship among many of these factors. We also knew that we would have to allow our idealism to be properly tempered by the realities of the situation. This meant, for example, that while we might define certain transport environments for a number of commodities as being desirable, we also had to define the operating and managerial environments in which the refrigerated transport equipment was and would continue to be operated. This latter step was necessary if we were to assess properly the feasibility of specific functional engineering approaches to meeting the environmental needs of the products to be transported.

It also was recognized that to obtain the greatest benefits, we would have to consider both long range and short range problems and give the proper weight to each in developing the best solutions. Both experimentation and experience had already demonstrated that with some slight modifications, and, in some instances only ingenuity, the equipment could be used for more than one purpose with substantial savings in distribution costs for some products. Recognition of this phenomenon further suggested that we should also take into consideration the direction in which the total physical distribution system for agricultural and food products was evolving.

If we were to be realistic about the prospects of attaining the goals we might set for the improvements we were seeking, we had to recognize that there are good reasons why they could not all be achieved in a short period of time. One specific cause would be the huge capital investment in the equipment already in service which could not be written off in a short period. Acceptance of this limitation on the schedule for achieving the goals of the work made it necessary that, in addition to functionally engineering completely new equipment, we should also try to develop innovations that would raise the performance levels of the present types of refrigerated vans which will likely be with us for many years to come.

Once we had decided on the overall definitive approach, the remaining steps were comparatively simple. All we had to do was to delineate the appropriate sub-areas and identify, define, and assess the effects of the various factors in each sub-area. First among these definitive sub-areas was the optimum environment for the perishable products during transport and related handling. Fortunately, the requirements for most commodities had already been established by previous research. These included optimum temperature ranges, relative humidities, atmospheric composition, and, in some instances, the tolerances of the products for pressure and other physical forces related to packaging, loading, handling, and transport. We also were in pretty good shape in this area because our previous research had shown to what extent these conditions did or did not exist during transport. What we did lack, however, was complete information on why these optimum conditions were not obtainable with the present refrigerated equipment. Fortunately, we did have enough data to enable us to postulate with fairly good accuracy most of the causes which we could not establish by empirical measures.

The second area we had to consider in developing our definitive approach was the operating environments in which the equipment was to be used. Three decades ago this phase of our problem would have been far less complicated since we would have had to consider operation in highway environment only. Two decades ago we would have had to allow for operation in highway and rail piggyback environments. Today, however, we have to consider the distinct possibility that any refrigerated van container may move by the highway, rail, marine, or air modes and that they may frequently move by two or three modes in completing a single journey. Each of these transport modes provided a different environment in which the equipment was to be operated—environments that would place different demands upon it, subject it to different hazards, and create a host of engineering and operating problems not encountered with equipment used in a single mode. This facet of the problem was also complicated by the use of different operating and handling procedures by different carriers within the same transport mode.

When we first began our work in this area some 9 years ago, lack of standardization of van containers and related equipment posed a real problem. Since that time, however, considerable progress has been made in developing design specifications and standards of performance for the van bodies. Standards for refrigerated van containers are now in preparation. We have participated in, kept abreast of, and contributed to this work done through the MH-5 Committee of the American National Standards Institute. We have, in addition, participated in the work of the Inland Transport Committee of the Economic Commission for Europe (ECE) on development of standards for refrigerated transport vehicles.

Also given important consideration in developing our approach was the managerial environment in which the equipment was to be used. To give proper weight to this important area required taking into account a broad range of factors. Some of these factors would primarily interest and involve people in top managements of the carriers, equipment lessors, and other firms, while others would be of primary concern to operating personnel, and still others to shippers and loaders of the equipment.

We know, for example, that favorable physical and cost performance were needed in improved equipment. The physical performance would be of primary interest to the operating departments. Cost performance would, of course, be more important to higher levels of management in several different departments of firms owning or using the equipment. Cost performance would be strongly affected by the rate of utilization of the equipment, which in turn might be determined by the degree of versatility built into the equipment. This consideration, however, posed the question of how much versatility could feasibly be built into general purpose vans and where the break-even point in the cost-benefit picture might be in different operating environments. We know that the answers to such questions would likely be very elusive because of the many different arrangements under which the van equipment is purchased, leased, and used.

One of the major problems constantly present in the managerial environment is that of human failure or error. Therefore, management of a system will be enhanced by use of any equipment which reduces the incidence of human failure. Recognition of this situation, therefore, led us to set as one of our goals development of equipment features that will reduce the number of operating situations where human failure could occur. This goal could be achieved in part by improved instrumentation and monitoring of the operation of the equipment. Automation of the control and operation of the refrigeration system also would help solve some of the problems of human failure. Yet another approach that suggested itself was to engineer into the equipment certain features that would force the users to take certain necessary steps in the proper sequence in order to be able to use the equipment at all.

The final step in the definitive approach was that of identifying and defining our limited objectives. We had at the outset of our project defined our overall goal as the development of improved refrigerated trailer vans and containers. In the first steps of our definitive approach we identified the needs of the system, the various factors that had to be considered in meeting those needs and the limitations that might be imposed on the alternative steps that could be taken in that direction. This process enabled us to identify several important and desirable limited objectives and assess the feasibility of attaining them. For example, defining the operating environments of the refrigerated vans and giving proper weight of the effect of the managerial environments suggested that we could make a major contribution to improving the transportation of perishables in the short run if we could develop practical and inexpensive innovations to upgrade the performance of the present refrigerated equipment. These same steps also indicated that a refrigerated van that would meet the needs of all perishable products in all environments was not likely to be attainable. However, this approach did suggest that the chances of our making a real contribution to improving the transport of perishables would be enhanced if we first concentrated our work on developing innovations which could be used in both new and existing equipment. Also suggested by this approach were the advantages to be gained in a number of situations by having some features of the equipment serve two or more purposes.

Completion of this step in our definitive approach to the project brought us to the point where we could more easily and realistically prepare a work plan and schedule for attaining the objectives set for our research. Identification and description of our objectives, the needs of the perishable transport system, and the many factors to be considered in meeting those needs have, we believe, enabled us to do a better job of planning and enhanced the prospects of our reaching most of our goals.

EXAMPLES OF APPLICATION

One of the most important outcomes of our application of the definitive approach to obtain improvement in refrigerated trailer vans and containers has been our work to develop what we have chosen to call a multi-purpose van container. This research was an attempt to come up with a design for a more versatile refrigerated container that would lend itself to a wider range of products, both perishable and nonperishable, and, therefore, have a higher rate of utilization than the conventional refrigerated containers. Also set as a goal for the new van container was the capability of doing this job more efficiently and at lower cost than the equipment now in use.

Our next step in this work was to set down the features we thought the container should have. We then tried to find out if they were practical. An engineering feasibility study was done for us which assessed the feasibility of different engineering approaches and also produced design specifications and bills of materials for a prototype. In subsequent work, also done under contract, tests were made on a lateral air circulation in a 10-ft long test module. Under a third research contract, we obtained an experimental van, consisting of a rebuilt trailer van, containing as many of the features of the original concept as possible.

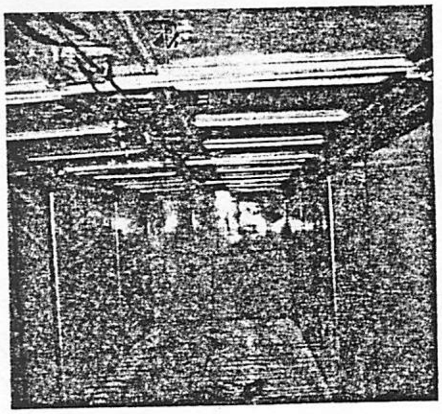

FIG. 1 Interior of 40-ft long experimental multipurpose van. Cables attached to middle of ceiling are bundles of thermocouple wires installed to monitor temperatures at different locations in the van.

The experimental van, which is not regarded as a prototype, (Figs. 1 and 2) was used for a series of thermal efficiency and other tests. The purpose of these tests was to further check out the air circulation, the refrigeration and humidity control systems, and to test the validity of some engineering assumptions that were made in designing the van.

FEATURES OF THE MULTI–PURPOSE VAN CONTAINER

Probably the most distinguishing feature of the multi-purpose van is its air circulation system. Instead of having the longitudinal air circulation of conventional refrigerated trailers and van containers, the multi-purpose van has a lateral air circulation system (Goddard 1968). The evaporator coils are mounted on the surface of the true ceiling in two rows, extending the length of the van body instead of up at the front

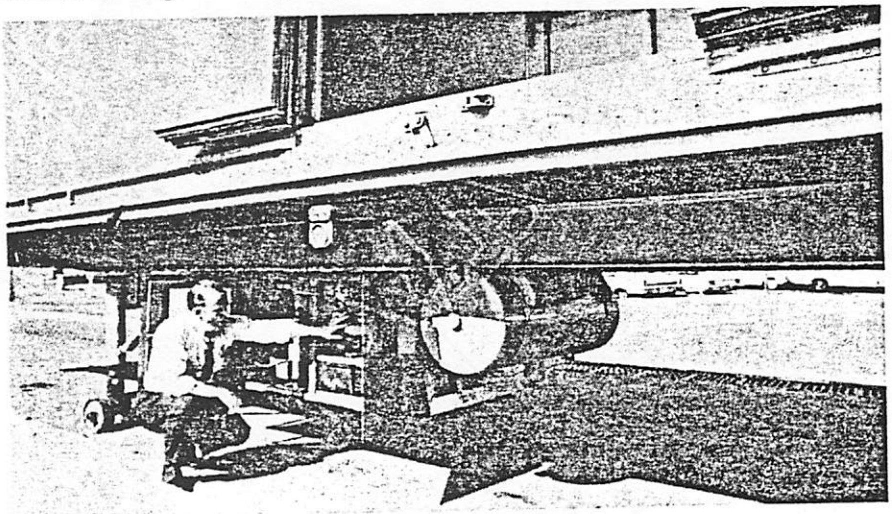

FIG. 2 Experimental van container on chassis. Engineer, William F. Goddard, Jr., points to control panel on diesel-electric generator that supplies power for refrigeration compressor and air blowers.

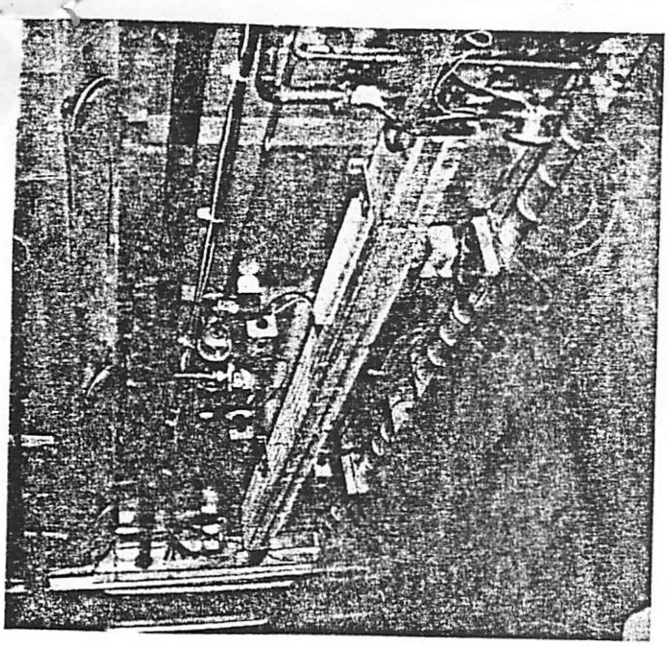

FIG. 3 Ceiling panel at one side of van lowered to expose evaporator coils immediately to right of center and squirrel-cage, tangential-type air blowers at extreme right.

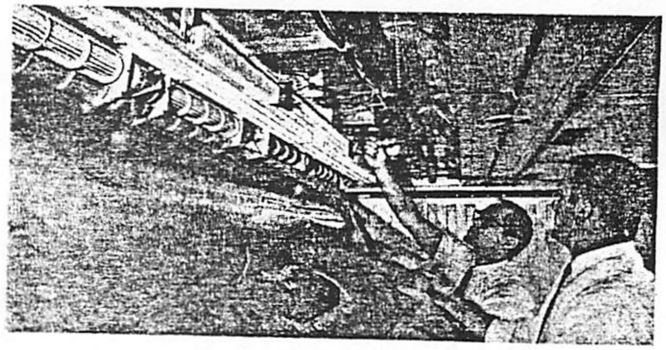

FIG. 4 Ceiling panel is lowered to expose squirrel-cage-type tangential air blowers at far left, evaporator coils immediately in front of blowers and refrigerant piping and valves in center of exposed area.

as in conventional refrigerated vans (Figs. 3 and 4). In the cooling cycle, the air is drawn across the coils by squirrel-cage type tangential blowers and is blown down the sidewall air plenums to the floor of the cargo area. In loads of commodities such as fruits and vegetables and fresh meat with residual heat in the cargo, the air is pulled upward through the load and into openings in the ceiling panel. This completes the cooling cycle. For cargos such as frozen foods, which need only perimeter cooling to remove the heat entering the van body before it can reach the cargo, the blowers on only one side of the van are operated. This allows the cooled air to circulate peripherally around and under the load.

To prevent excessive dehydration of certain products, the circulating air is rehumidified by use of condensate from periodic defrosting of the evaporator coils. Special entrance and exit ducts allow the outside air to be drawn into the van, circulating through the cargo area and exhausted. This feature also allows the use of outside air for cooling the cargo when its temperature is low enough. With the use of timing devices to activate periodically the entrance and exit hatches to the air ducts, this feature could be used periodically to purge the interior atmosphere in the van of harmful accumulations of certain injurious gases (Goddard 1969). Heat can also be added to the circulating air as required to prevent product freezing.

The lateral air circulation system allows the van interior to be compartmentized by the use of lightweight, insulated, removable partitions (Fig. 5). This feature makes it possible to carry products at different temperatures in each 10-ft long compartment. Each compartment has its own solid-state thermostat to control the temperature in it.

In the lateral air circulation system the distribution of cooled or warmed air is more uniform since most of it moves only about one-third as far in completing its cycle as in the lengthwise circulation pattern in conventional vans. More positive and more uniform control of product temperatures are, therefore, obtainable than with the latter air distribution system. Greater coil surface area and lower air-to-coil-surface temperature differentials should reduce icing of the evaporator coils, freezing of some products and excessive dehydration of others.

Since each 10-ft long section of the cargo area of the van has two sections of evaporator coils and two air blowers, each section has its own built-in safety factor. Should one coil or blower fail, the other will continue to operate. Such features are not present in conventional refrigerated vans which have one coil and usually only one fan for the whole van.

The van also is equipped with steel tracks on the sidewalls adjacent to the ceiling panels to allow for the use of rolling sectional meat racks for carriage of carcass meats. When the van is not used for this purpose, the racks can be removed, thereby effecting a considerable savings in tare weight.

Built-in adjustable platens on the inside surface of the rear doors allows the take-up of slack at this critical point between the rear face of the last stack of the load and the doors. The load can thus be secured to help prevent both lateral and rearward shifting of the cargo. This feature should make it unnecessary for the shipper to use any dunnage at this point to secure the load.

OTHER APPLICATIONS

In keeping with the plan developed for our research under the definitive approach to the problem, work also is un-

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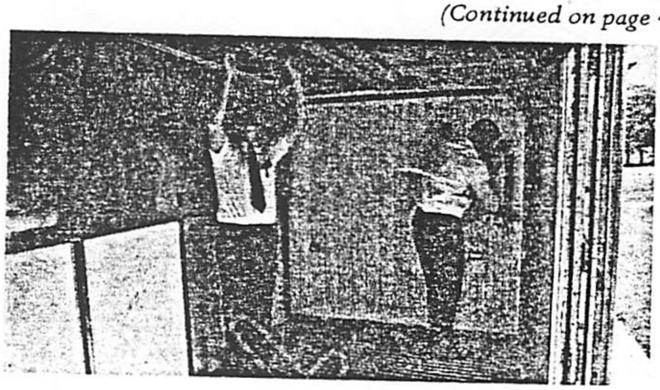

FIG. 5 Part of interior of experimental van showing light-weight removable insulated partition for compartmentizing van in place. Man at rear examines hand pump used to inflate sealing gaskets around edges of partition.

Refrigerated Trailer Vans

(Continued from page 41)

derway in several areas to develop methods of adapting some of the more important features of the multi-purpose van container to conventional refrigerated trailer vans and containers. If this work is successful, it should provide an inexpensive means of upgrading the performance of many thousands of such vans already in service. Included in this work is the development of a low cost method of converting the air circulation systems from the conventional longitudinal pattern to the lateral pattern. We also are beginning work to develop and adapt improved cargo securing equipment to conventional vans and containers. Such devices will be especially designed for refrigerated vans and become integral parts of the van's equipment. In the planning stage at this time is still other research to develop monitoring and control of refrigeration systems on trailers and van containers from a remote point such as the bridge or engine room of a containership or the cab of a truck tractor on the highway.

These are only a few of the many things that can be done to improve the performance of refrigerated trailers and containers. Much more remains to be done. The work is sometimes difficult and frustrating, but it is always a challenging and rewarding task.

References

1 Anthony, Joseph P., Jr. 1970. Exploratory cooling tests with 40-ft refrigerated trailer and container vans. ARS 52-48, 11 p.

2 Goddard, William F., Jr. 1968. The multi-purpose van container—a progress report. Paper presented at the 27th Annual Convention of the Truck Trailer Manufacturers Association, Hot Springs.

3 Goddard, William F., Jr. 1969. Air conditioned transport (carriage) for agricultural commodities. Modern Refrigeration and Air Conditioning Magazine, Croydon, Surrey, Great Britian, January.

4 Hinds, Russell H., Jr. 1970a. Observations on refrigerated van container service to Europe. Transportation in Seventies Conference paper.

5 Hinds, Russell H., Jr. 1970b. Transporting fresh fruits and vegetables overseas. ARS 52-39, 34 p.

6 Hinds, Russell H., Jr., and William G. Chace, Jr. 1962. Piggyback transportation of Florida citrus fruit, problems, methods, equipment. AMS 482, USDA, 21 p.