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A Q-GERT MODEL FOR FACILITIES SIZING FOR A PLANNED PRODUCT DISTRIBUTION NETWORK

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A newly designed chemical plant will require distribution facilities to transport the products to the consumers. A Q-GERT model of the distribution network was developed and used in determining the least-cost physical facilities required to meet the system performance objectives. The emphasis of the paper is on the development and operation of the model, and its use as a tool for determining the storage tank capacities, rail car fleet size, and loading rack capacities needed for the new plant.

1. PROBLEM DESCRIPTION

Union Carbide Corporation has designed a plant to produce large quantities of two liquid commodity products. The location of the plant dictates the use of rail traffic as the primary method of product distribution, and business considerations require a highly reliable distribution system. The Strategic and Facilities Planning department has determined that the products should be distributed to five widespread and diverse consumers. The physical facilities required at the production site are storage tanks and a tank car fleet for each product grade, a tank car loading rack, and a marshalling yard. New storage and unloading rack facilities are also required at two of the consumer locations. In addition, product receiving and storage facilities at two other consuming locations may require upgrading to be capable of handling the new product flows.

Two alternative shipping operations are being considered--trainload shipments and conventional shipments. In a trainload shipment operation a large number of tank cars are assembled and shipped as a unit, bypassing the railroad classification yards in transit. In a conventional shipment operation a few cars are shipped each day, and they must be processed through the classification yards. Because of the more direct routing, trainloads have a shorter expected travel time, and consequently require fewer cars in the fleet. However, trainloads require larger storage and rack facilities at the plant and consumer locations.

Each consumer may be served by either type of shipping operation. Because of the different characteristics regarding travel time, and frequency and quantity of shipments, the choice of shipping operation has a direct impact on the size of the physical facilities required.

The objectives of the product distribution project are to design the physical facilities to:

1. minimize the frequency and duration of product stockouts at the consumer locations,
2. minimize the number of shutdowns of the production unit due to inadequate storage or tank car fleet capacity, and
3. accomplish the first two objectives with the least investment cost.

2. SOLUTION TECHNIQUE

Working in conjunction with the Distribution Project Team, a Q-GERT model of the proposed distribution network was developed. The purpose of the model was to aid in the design of new facilities and to evaluate the ability of existing facilities to handle the expected product flows. Past experiences with dynamic systems have shown simulation to be the best evaluative technique for facility size and design problems. Q-GERT was chosen as the simulation language since it ensured a short model development time. Moreover, the distribution system was easily described in Q-GERT network form, which proved to be an invaluable tool for explaining model operation to the project team. Also, the statistics collection and network tracing features of Q-GERT simplified the task of model validation.

3. SYSTEM AND MODEL OPERATION

The following describes both the physical system and the model, and points out any special modelling considerations taken. A schematic diagram of the distribution network is shown in Figure 1.

Each day's production is stored temporarily in a make tank for quality analysis. If the product meets Product A specifications, the content of the tank is transferred to the Product A tank. If it fails to meet these specifications, the product is transferred directly to the Product B tank or is recycled if storage is not available. The production unit is modeled as a distribution of the daily production quantity which takes into account seasonality, scheduled and unscheduled shutdowns, and production cutbacks. Each simulated day a pick is made from this distribution to obtain the amount produced. While the physical system has a limited number of make tanks, the model assumes an infinite supply. Statistics are collected on the frequency and the duration when the number of simulated full make tanks exceeds the actual number available. These statistics represent the percent of time that the production unit is shut down due to high inventory conditions.

The dashed lines on the Product A and Product B tanks in Figure 1 represent inventory trigger points. When the level of the Product A tank reaches its upper trigger point, material is transferred to the Product B tank to protect the production unit from a high inventory shutdown. To protect the sales of Product A, the lower trigger point of the Product A tank causes the transfer to the Product B tank to be curtailed. Only sales of Product A can cause the tank level to drop below this trigger point. The trigger point on the Product B tank is a sales protection trigger for type B product. Whenever Product B inventory drops to the trigger level, a transfer of material from the Product A tank occurs.

Following these product tanks, there are separate sub-networks for each product grade. For simplicity, only one stream will be described since the two are essentially identical.

Each empty tank car arriving at the plant is matched with an equivalent volume of product, and it awaits the availability of a spot at the loading rack. The loading rack is common to each stream, with eight spots serving either product and eight spots which serve only Product B. The loading rack operates two six-hour shifts per day, seven days a week with a constant loading time. After loading, the full cars are placed in the marshalling yard to await an order.

Separate orders are generated for each of the five consumers. The frequency and quantity of orders are dependent upon the destination and the shipping mode. Destinations served by trainload shipments have an order for another full train generated upon arrival of an empty train from that destination. Trainload order quantities are fixed and constant for a given destination. Consumers served by conventional shipments have orders generated on a periodic interval (usually once each day), with the order quantity being a random variable and dependent upon the destination's demand.

Receipt of an order for full cars causes the appropriate number of full cars to be assembled into a train. There is a constant delay to account for interfacing with the railroad. Travel time to and from the destination is variable and seasonal. Travel time is determined by a process generator whose parameters are keyed to simulated time and change from season to season.

Full cars arriving at the consuming destination are loaded after sufficient rack space and storage space are available. The product is transferred to the consumer's feed tank, for later use by the consumer. The model represents the consumer as a distribution of periodic use, taking into account variability, seasonality, and scheduled shutdowns.

The unloaded cars are held in a marshalling yard until they are assembled into a train for their return journey to the plant. Trainload shipments return only when all of the cars are empty, but for conventional shipments all empty cars in the marshalling yard are returned each day.

Periodically, returning empty cars are routed to a maintenance facility for preventive maintenance. The model places a proportion of the returning cars into either minor (1 day) or major (2 months) maintenance. After maintenance is complete, the repaired cars join the empty car pool to await reuse.

4. MODEL VALIDATION

The choice of Q-GERT as the simulation language greatly simplified the validation procedure. Statistics were collected on each process generator to ensure that the random variables generated were conforming to the desired distribution. However, the most significant aid to model validation was the nodal and event tracing option in Q-GERT. The trace output was used to check the flow of transactions through the network to ensure that the events and activities conformed to the real-world system operation. The trace output was examined thoroughly by representatives of the Distribution Project Team to confirm the face validity of the model.

5. ANALYSIS AND RESULTS

Four scenarios were developed and evaluated jointly with the Distribution Project Team. Each scenario consisted of a different combination of shipping operation modes to the five consumers as shown in Table 1. A series of experiments were conducted using the model to determine the storage and loading rack capacities, and the tank car fleet size required to meet the project objectives for each scenario.

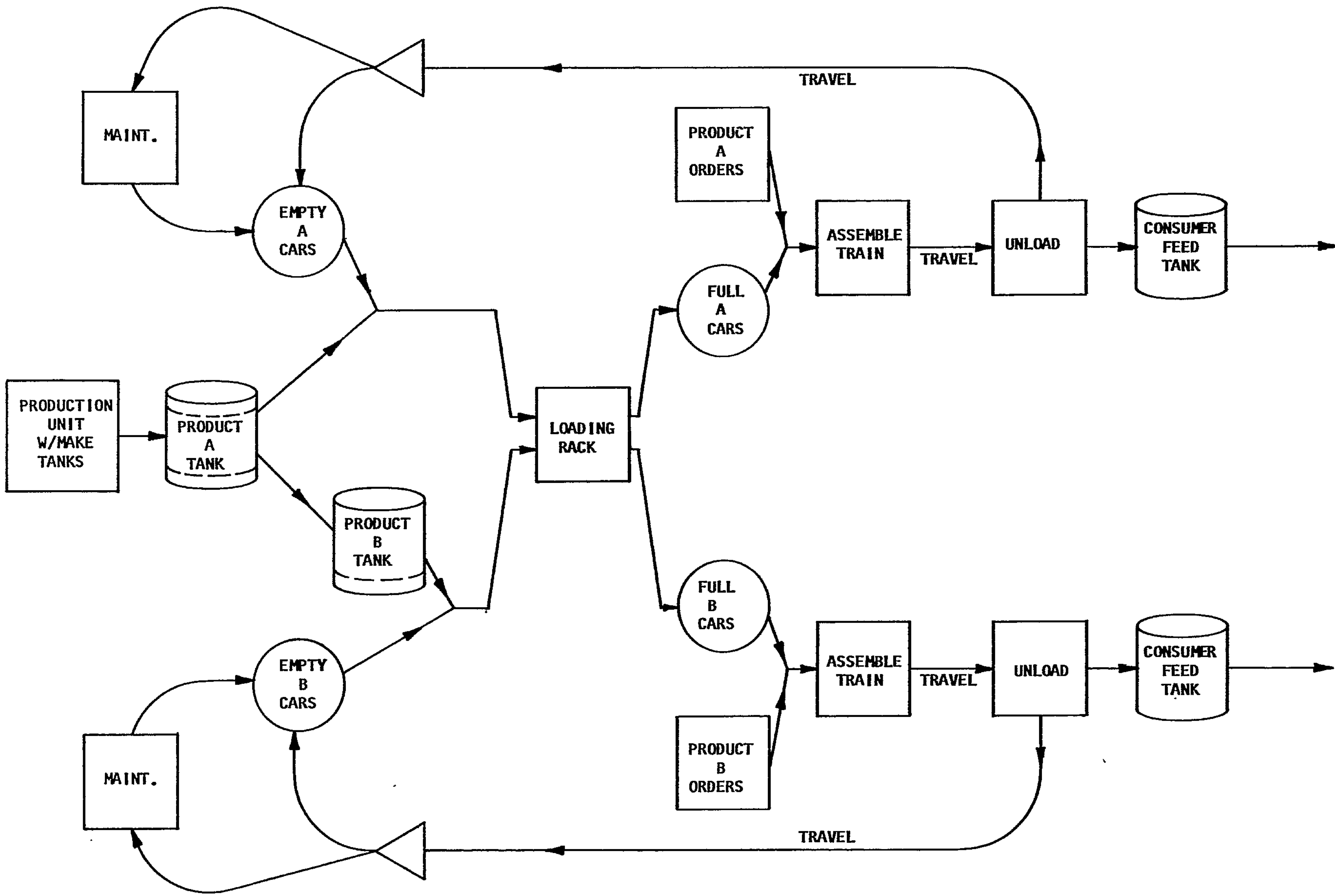

FIGURE 1. SCHEMATIC DIAGRAM OF DISTRIBUTION NETWORK

Table 1: Scenario Descriptions

	Scenario A		Scenario B		Scenario C		Scenario D	
Consumer	Product Received	Shipping Mode	Product Received	Shipping Mode	Product Received	Shipping Mode	Product Received	Shipping Mode
1	B	Unit	B	Unit	B	Unit	B	Conv
2	B	Unit	B	Conv	B	Conv	B	Conv
3	B	Conv	B	Conv	B	Conv	B	Conv
4	A	Unit	A	Unit	A	Conv	A	Conv
5	A	Conv	A	Unit	A	Conv	A	Conv

The primary measures of effectiveness were 1) the ability of the distribution network to deliver product to the consumers, and 2) the frequency and duration of production unit shutdowns due to high inventory. Additional measures were the statistics collected on rack utilization, the number of surplus cars, the required marshalling yard capacity, and the delays at the consumers' unloading facilities. These statistics allowed for the fine tuning of the facilities design to the minimum requirements to meet project objectives.

6. BENEFITS

The Distribution Project Team determined the investment and operating costs required for each scenario from the facilities requirements obtained with the aid of the model. This evaluation of the scenarios greatly simplified the selection of the least-cost design. The model was cited by the project team as a contribution to the reduction of the project distribution facilities investment by 30 percent, while maintaining a high degree of distribution system reliability. This reduction in investment for the distribution portion of the project was a significant share of a total plant cost reduction of 20 percent, which was critical to obtaining approval for the final phases of design and construction.

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