Case Study

Analysis and simulation of a distribution system for flowers

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Received August 1982
Revised November 1982
Communicated by J.P.C. Kleijnen

One of the largest flower auctions in the world is located in the Netherlands. Because of an expected expansion of the auction, the capacity of its distribution system was investigated. Discrete event simulation was applied to study the complex system. The simulation results show that the present system cannot handle the expected expansion. However, the analysis also shows ways for improving the system’s efficiency, thereby enlarging its capacity.

1. Introduction

The C.C.W.S. (Coöperatieve Centrale West-Bergen Sierteelprodukteneveiling; Flower Auction Westland–Holland) in Honselersdijk, The Netherlands, is one of the world’s largest flower auctions. In 1980 its turnover amounted to approximately 700 million Dutch guilders (1 guilder = US$ 0.35). About 1700 million cut flowers were sold to approximately 1400 individual merchants. These merchants exported about 75% of the flowers to countries all over the world. Inside the auction building there is a distribution system that is used to distribute the flowers over a maximum of 600 merchants that can be present each day. This distribution system was the topic of our study.

The first part of our paper describes the distribution system. Next a discrete-event simulation model of the system is presented. This model is validated by confronting the simulation results with real data. The simulation model has been used in a series of experiments to investigate the capacity and efficiency of the system.

This investigation was performed within the framework of a Master of Science thesis at the Twente University of Technology, Department of Mechanical Engineering, Enschede, The Netherlands (see Jansen [2]). In this practical study it is shown how certain simplifications can be made in order to obtain a manageable simulation model, and how simulation can be used to analyze and design very complex systems.

2. The distribution system

The growers of flowers bring their products to the auction building, packed in carton boxes and loaded onto aluminium carts. These carts are used for the transportation of flowers within the auction building. After selling the flowers by so-called Dutch auction, they are distributed to the carts of the merchants that bought them. Figure 1 shows the layout of the distribution system.

There are four auction clocks (1–4) at which the flowers are sold. The load of a cart is generally split up into a number of lots for different merchants. The merchants are located in five areas, the so-called streets (7–11). The input of the distribution system is generated at the auction clocks, and the output consists of carts with lots that are sorted per merchant and enter the proper streets. Carts that are split up into more than one lot are
called multi-transaction carts. These carts are transported to buffers A and B (5 and 6), where they await further processing.

So-called distributors take care of the actual distribution of individual transactions. A distributor may take a cart from either one of the buffers A and B. He handles one multi-transaction cart at a time. After taking a cart from either buffer, the distributor checks which merchants are to receive lots from this cart. Then he starts a trip through the distribution area (13). In this area so-called merchant carts (14) are lined up. Each merchant has a number and for every number there is a cart located at a specific spot in the distribution area. While crossing the area the distributor loads the lots of the multi-transaction cart onto the proper merchants' cart. As a result the distributor's multi-transaction cart is emptied. When reaching the opposite side of the distribution area, the distributor leaves the empty cart behind. It will be used to fill up empty spots in the distribution area that arise when full merchant carts are removed. The distributor takes a new multi-transaction cart from the buffer he has reached now and repeats the process, now crossing the distribution area in opposite direction.

Full merchant carts are removed from the distribution area, mainly by means of the in-floor closed loop conveyor (12). The carts are hooked on to this conveyor which pulls them to the entrances of the five streets. Auction personnel takes care of the removal of carts from the conveyor at the entrances of the proper streets. In the part of the distribution area on the side of the auction clocks (13a) there are carts lined up mainly for merchants located in street 5 (11). Carts from this part of the area are not hooked on to the conveyor because the conveyor rotates in the 'wrong' direction. Therefore, these carts cross the conveyor and are transported to street 5 by electrically driven tractors. Transportation via the conveyor would not only lead to very long transit times for these carts, but would also commit a large part of the capacity of the conveyor.

It should be noted that some carts are distributed in a slightly different manner. If the largest transaction on a multi-transaction cart consists of at least ten boxes of flowers, the following rule applies. The largest transaction is not loaded on to a merchant cart, but instead it is left on the original cart. After distribution of all smaller transactions the cart is hooked on to the conveyor in order to transport it to the appropriate street. These are the so-called rest-transaction carts which form a substantial part of the output from the distribution system.

Carts with a load that is sold to one dealer only, the so-called single-transaction carts, do not need
to be distributed. They are simply transported to the entrance of street 1 (7) by electrically driven tractors. There, the single-transaction carts are either transported to street 1 or hooked on the conveyor to transport them to one of the other streets.

Every day about 3500 carts are processed in approximately 6 hours time. An average of 100 distributors are handling transactions for about 475 merchants that are present.

3. The simulation model

The simulation model is shown schematically in Fig. 2.

The model simulates the progress of individual transactions through the system. It contains a number of simplifications of reality. The main reasons for these simplifications are:

- Manageability of the model in terms of required computer time per simulation experiment and effort needed to introduce modifications of the system.

![Fig. 2. The simulation model.](image-url)
The correctness of the model, which would become questionable if more detail is incorporated because of uncertainties in those details themselves.

In this section the most important simplifications are discussed and justified.

The transit time needed to transport multi-transaction carts from the auctionclocks to buffers A and B has been omitted. In reality, this transit time is about 1 to 2 minutes. Because the average waiting time of carts in the buffers is about 30 minutes, we decided to ignore this transit time.

A second simplification concerns the distribution of multi-transaction carts over the buffers A and B. In reality carts from clock 1 are always sent to buffer A and carts from clock 4 always go to buffer B. For the two remaining auctionclocks, however, the distribution rule is more or less random. One tries to keep the states of both buffers reasonably equal but in practice large differences in buffer states occur frequently. In the model these differences are kept very small through strict obedience of distribution rules. This simplification seems permitted because the total number of carts buffered, in both buffers together, is more important than the individual buffer states.

A third simplification concerns the activities of a distributor. In reality a distributor performs a number of operations during a trip through the distribution area. In the model the distributor performs all the operations for one multi-transaction cart at one moment in time, at the end of a trip. This implies a somewhat disadvantageous representation of the real system because the model full merchant carts are created a little later than in reality. Since the average distribution time per cart is about 12 minutes, whereas the average waiting time in buffers A and B is about 30 minutes, and because there are about 100 distributors active at the same time, this simplification seems permitted.

A fourth simplification concerns the degree of utilization of merchant carts. In reality the utilization of the volume of these carts varies because lots might not fit onto a partly filled cart and transactions are not split up. In the model all collection carts removed from the distribution area are utilized for exactly 77% of their maximum capacity because transactions are split. These 77% equal the average degree of utilization of merchant carts in practice. Because of the large number of carts that is processed, this simplification seems permitted.

The last simplification concerns the modelling of the closed loop conveyor. In reality carts can be hooked on to the conveyor at any point along its circumference. In the model, however, there are only four hooking-on-points. Again this implies a somewhat disadvantageous representation of the system because it is possible that in the model empty spots on the conveyor are utilized a little later than in reality. Because no significant waiting times occurred at the hooking-on-points, this simplification seems permitted.

The model is translated into a computer program, using the simulation package SOLE—Simulation Of Logistics Elements (Rooda [3])—which is an extension of DEMOS—Discrete Event Modelling On SIMULA (Birtwistle [1]). The model simulates a six hour day of auction in about 2.5 minutes of CPU time on the DEC-10 computer system of the Twente University of Technology. The input consists of the data of approximately 18 000 transactions a day plus some data concerning the volumes of different kinds of boxes, locations of merchants in the distribution area and locations of merchants in each of the five streets.

4. Validation of the model

The model has been validated by comparing its output to the real system’s output on two completely different days. Table 1 shows the results of this exercise.

There are some small differences in the data that specifies the inflow of carts from the auctionclocks. These differences were inevitable since this input data was collected manually. Because the results of the model agree very well with the reality of both days (no formal tests performed) it is assumed that the model will also correctly simulate alternative situations.

5. System capacity

The capacity of the system depends on the bottlenecks. These are:
- Buffers A and B, which have limited capacity;
- Section 5 of the closed loop conveyor, from the
Table 1

<table>
<thead>
<tr>
<th>Validation</th>
<th>Day 1</th>
<th>Day 2</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>Reality</td>
<td>Simulation</td>
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<td>Time (hours)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clocks active</td>
<td>4:41</td>
<td>4:44</td>
</tr>
<tr>
<td>Distribution active</td>
<td>5:30</td>
<td>5:43</td>
</tr>
<tr>
<td>Conveyor working</td>
<td>6:00</td>
<td>6:09</td>
</tr>
<tr>
<td>Number of carts sold</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Multi-transaction</td>
<td>2430</td>
<td>2260</td>
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<tr>
<td>Single-transaction</td>
<td>170</td>
<td>210</td>
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<tr>
<td>Total</td>
<td>2600</td>
<td>2470</td>
</tr>
<tr>
<td>Buffer states approx. (carts)</td>
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<td></td>
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<tr>
<td>Average buffer A</td>
<td>110</td>
<td>150</td>
</tr>
<tr>
<td>Average buffer B</td>
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<td>150</td>
</tr>
<tr>
<td>Maximum buffer A</td>
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<td>280</td>
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<tr>
<td>Maximum buffer B</td>
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<td>300</td>
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<tr>
<td>Maximum A + B</td>
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<td>580</td>
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<tr>
<td>Conveyor usage approx. (%)</td>
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<td></td>
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<tr>
<td>Section 1</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Section 3</td>
<td>40</td>
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<td>Section 5</td>
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<td>Section 7</td>
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<td>20</td>
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<tr>
<td>Section 8</td>
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<td>0</td>
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<tr>
<td>Waiting-time carts (min.)</td>
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<td></td>
</tr>
<tr>
<td>In buffer A</td>
<td>–</td>
<td>44</td>
</tr>
<tr>
<td>(average)</td>
<td>–</td>
<td>45</td>
</tr>
<tr>
<td>In buffer B</td>
<td></td>
<td></td>
</tr>
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</table>

- The number of distributors, that is limited to prevent distributors getting into each other's way.

First the influence of the storage capacity of buffers A and B is studied. Simulation experiments show that it is possible to significantly reduce the average number of carts in these buffers by attuning the number of active distributors to the time dependent pattern of the in-flow of carts into the buffers. Figure 3 shows an example of this. The resulting buffer states are shown for the original, and for an alternative pattern of active labour supply. The alternative requires the same number of man-hours for the distribution of transactions as the original did. However, due to the fact that the alternative contains a labour supply pattern that matches better with the in-flow of carts to process, the resulting maximum number of carts buffered is only 60% of the original one. Similar experiments showed that such reductions of buffer states are, in general, possible. Therefore, it is concluded that this bottleneck is not necessarily critical.

Next, the capacity of section 5 of the closed loop conveyor is studied. In addition to single-transaction carts for street 5, carts for both street 3 and 4 pass this section. Therefore, this section always has the highest utilization degree. In the following analysis of the capacity of section 5 it is...
assumed that the number of distributors is not restricted. Later on the result will be corrected for this third bottleneck. A series of simulation experiments was performed to investigate section 5's capacity. In each of these experiments there was a constant number of distributors active during the entire day. The resulting utilization degree of section 5 was recorded. The number of distributors, and thus the rate of carts to be transported via the conveyor, was increased with every new experiment. The result is a relation between the number of distributors and the utilization degree, see Fig. 4. For small numbers of distributors the relation is linear; for higher rates of distribution the marginal effect is decreasing. In the latter case problems with the output of carts from the distribution area arise. There is an increase of the waiting time of carts at the hooking-on points, although these waiting times remain relatively small. The point where the marginal output becomes decreasing indicates the capacity of section 5. For the two different days this occurs at about 160 and 230 distributors respectively.

The difference in the number of active distributors that generate the maximum output from the distribution area can be explained by the so-called splitting factor (s) that represents the average number of transactions per multi-transaction cart. A low splitting factor results in a small number of transactions per cart. This shortens the distribution time per cart. Also, because the transactions are relatively large, a large number of rest-transaction carts is generated in the distribution area.

Rest-transaction carts have a relatively low degree of utilization and therefore the total number of carts to be transported to the streets is large. Consequently a small number of distributors will produce the maximum output when the splitting factor is low. This was the case for day 2, with a splitting factor of 5.6. For day 1, when the splitting factor was 7.5, similar reasoning explains the large number of distributors that can be activated before the maximum output is reached.

Although the maximum number of active distributors depends on the splitting factor, the maximum output of carts from the distribution area was approximately 15 carts per minute for both days. From this result, still ignoring the limitation on the number of distributors, a final result can be obtained for the maximum number of auction-clocks that the system can handle. This result is a function of the splitting factor as shown in Fig. 5. Effects of the splitting factor on the number of rest-transaction carts, auction speed in terms of the rate at which carts are sold, and other factors are incorporated. The result shows that at low splitting factors the system can handle only a few auction-clocks. The causes are the high auction speed and the large number of rest-transaction carts that is generated in the distribution area, resulting in a relatively large number of carts to be transported to the merchants.

The result of Fig. 5 should be corrected for the

![Fig. 4. Utilization degree of section 5 versus number of distributors.](image)

![Fig. 5. Maximum number of clocks versus splitting factor.](image)
third bottleneck, the maximum number of distributors that can be activated while avoiding obstructions in the distribution area. This number cannot be specified with great accuracy. However, practice showed that the maximum is about 150 to 170 distributors. Clearly, this restraints the maximum input into the distribution area. Figure 6 shows the input per distributor as a function of the splitting factor. For low splitting factors the input is high as a result of the simple distribution process (only a few transactions per cart).

By combining the results presented in Figs. 5 and 6 the final result is obtained for the maximum number of auctionclocks that can be allowed. This result is shown in Fig. 7. In periods with a low splitting factor of about 5 transactions per multi-transaction cart, it is useless to generate more selling capacity than there is at present, namely four auctionclocks. An increase in this number will lead to unacceptable buffer states, obstructions in the distribution area or an output from the distribution area that cannot be handled by the conveyor. For periods with a high splitting factor, say about 7, only one extra clock is useful. Although the system could handle more clocks, the capacity is then limited by the maximum number of distributors (about 150).

Of special importance is the conclusion for periods with a low splitting factor. These are often the busiest periods for the auction. The supply of carts to sell is very large and in order to process the total input within a limited time-span this seems to call for extra auctionclocks; however, the analysis shows this 'solution' will not work.

6. Efficient system utilization

In the previous section it was concluded that the capacity of the system is insufficient to cope with an expected expansion of the auction. Therefore, alternatives with respect to the efficiency of the system have been investigated. In this section two such alternatives are discussed. It will be shown that efficiency can indeed be improved.

The first alternative concerns increasing the average load of rest-transaction carts leaving the distribution area. This would reduce the utilization degree of the closed loop conveyor. At present the rest-transaction carts are created if the largest transaction on a multi-transaction cart consists of at least 10 boxes of flowers (see Section 2). Because of the large variation in the sizes of boxes this practice leads to low degrees of utilization of the rest-transaction carts. For instance, 10 of the largest boxes will fill up half a cart, but there are also boxes so small that 10 pieces use only one tenth of a cart's volume. An alternative is to
introduce the rule that rest-transaction carts must be utilized for at least 50%. Experiments showed that this would reduce the number of rest-transaction carts with 45% to 50%. Consequently, the number of collection-carts increases with 10% to 15%. The total number of carts generated in the distribution area is reduced with approximately 10%, whereas the increase in the number of manhours in the distribution process is about 5%. Significant reductions of the utilization degree of the conveyor result. Section 5 remains the bottleneck but its utilization degree drops with about 25%. Thus the system’s capacity is enlarged significantly.

The second alternative changes the transit direction of the closed loop conveyor from clock-wise to counter-clock-wise. This implies a major modification of the system. Its purpose is to prevent the large flow of carts bound for street 5 that is presently transported via the section of the conveyor on the side of streets 1 to 4. By changing the transit direction the utilization of that section is reduced considerably. As a result the utilization degree of the section on the side of the auction-clocks increases. The results of the experiments performed for this case show a much more efficient use of the conveyor. This is expressed by the so-called passing-by percentage, that represents the percentage of the total number of carts arriving at the entrance of a street while not destined for that street and therefore passing by the entrance. Theoretically the passing-by percentage should be zero. At present the average over the five streets is about 63%. The change in the transit direction of the conveyor resulted in a reduction of this percentage to 45%-50%. Again it is concluded that significant improvement of the system’s efficiency can be realized.

7. Conclusion

Discrete-event simulation enabled a comprehensive analysis of the distribution system. The capacity of the system proved to be insufficient to cope with an expected expansion of the flower auction. The system should be modified in order to realize sufficient capacity in the future. The system’s efficiency can be improved, thereby enlarging the capacity. This analysis offered directions for modifications of which some have already been implemented, e.g. attuning of the supply of active distributors in the distribution phase and imposing a better rule for creation of rest-transaction carts.

References