CHAPTER 6

RESULTS AND DISCUSSION

This chapter attempts to conduct a performance analysis and sensitivity analysis on the proposed models and their methodologies in order to check their efficiencies in the RL context. Sensitive analysis is used to find the impact of various issues on the performance of the proposed models and their methodologies in the RL context.

This chapter is organized as follows. Section 6.1 details to the performance analysis conducted on the proposed models and methodologies. The sensitivity analysis conducted on the proposed models and methodologies detailed in Section 6.2. Section 6.3 summarizes the chapter along with observations.

6.1 PERFORMANCE ANALYSIS

The robustness of the proposed models has been tested by conducting a series of computational experiments on Intel(R) Core(TM)2 Duo Processor (3.00 GB RAM, T6400 @2.00 GHz Frequency and 32-bit Windows-Vista Home Basic OS) using different case settings. LINGO Version 8.0 has been used to obtain the results of these experiments. Performance comparison between different models is carried out by using the obtained results on the basis of different aspects which are described as follows.
6.1.1 Basis of Solution Methodology

This section details the performance comparison between the proposed models for solving the CRAB-SP on the basis of solution methodology which is shown in Figure 6.1.

![Graph showing performance comparison](image)

**Figure 6.1 Performance comparison based on solution methodology**

The results obtained by solving the CRAB-SP with the use of the decomposed methodology (CRAB-SP)[DM] and with the use of the integrated methodology (CRAB-SP)[IM] are shown in Fig 6.1. It is evident from Fig 6.1 that the total cost is increased in most of the problem instances if it is not solved in an integrated manner i.e. an integrated methodology results in reduced costs.

6.1.2 Basis of Lower Bounds

This section details the comparison of lower bounds which are obtained by relaxing the location-routing constraints on the proposed model for solving the CRAB-SP and the CRAB-MP with the use of the integrated methodology.
Table 6.1 Performance comparison of lower bounds for CRAB-SP

<table>
<thead>
<tr>
<th>No</th>
<th>Case instance</th>
<th>Lower bound</th>
<th>Final Solution</th>
<th>Lower bound gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50-8</td>
<td>99356.4</td>
<td>106120.8</td>
<td>6.81%</td>
</tr>
<tr>
<td>2</td>
<td>55-6</td>
<td>95290.3</td>
<td>101346.6</td>
<td>6.35%</td>
</tr>
<tr>
<td>3</td>
<td>60-6</td>
<td>103829.7</td>
<td>111234</td>
<td>7.13%</td>
</tr>
<tr>
<td>4</td>
<td>65-6</td>
<td>110394.35</td>
<td>118601.1</td>
<td>7.43%</td>
</tr>
<tr>
<td>5</td>
<td>70-6</td>
<td>120049.45</td>
<td>130077.5</td>
<td>8.35%</td>
</tr>
</tbody>
</table>

From Table 6.1 and Table 6.2, it is clearly evident that the lower bounds are closely related to the problem size. The result reveals that larger problem size will increase the lower bound gap which is owing to the presence of high computational complexity in solving them.

Table 6.2 Performance comparison of lower bounds for CRAB-MP

<table>
<thead>
<tr>
<th>No</th>
<th>Case instance</th>
<th>Lower bound</th>
<th>Final Solution</th>
<th>Lower bound gap</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50-8</td>
<td>118667.7</td>
<td>127083.5</td>
<td>7.09%</td>
</tr>
<tr>
<td>2</td>
<td>55-6</td>
<td>112892.8</td>
<td>120449</td>
<td>6.67%</td>
</tr>
<tr>
<td>3</td>
<td>60-6</td>
<td>117833.3</td>
<td>126734</td>
<td>7.55%</td>
</tr>
<tr>
<td>4</td>
<td>65-6</td>
<td>122728.7</td>
<td>132592</td>
<td>8.03%</td>
</tr>
<tr>
<td>5</td>
<td>70-6</td>
<td>130388.5</td>
<td>141607.5</td>
<td>8.60%</td>
</tr>
</tbody>
</table>

While analyzing the results based on problem complexity, it has been found that the lower bound gaps obtained for the CRAB-MP is higher than the one obtained for the CRAB-SP. The cause behind this increased lower bound gap is the presence of the large problem complexity in solving the CRAB-MP as compared to the CRAB-SP.
6.2 SENSITIVITY ANALYSIS

To further examine the sensitivity of the proposed model to various problem scenarios, the what-if analysis is conducted by relaxing some of the model constraints (e.g., balancing or clustering constraints) and changing the model parameter (e.g., varying the degree of product quality levels). The following sub-sections discuss the details of this sensitivity analysis.

6.2.1 The Impact of Balanced Allocation on the Model Output

To assess the impact of the balanced allocation on the CRAB-SP and the CRAB-MP, the model experiments were carried out by removing the balancing constraints. The results obtained by solving the CRAB-SP with and without the use of balancing constraints (CRAUB-SP) are shown in Fig 6.2. The integrated methodology was used to solve both the CRAB-SP and the CRAB-MP.

![Graph](image_url)

**Figure 6.2 Impact of balanced allocation on CRAB-SP**
Fig 6.3 shows the results obtained by solving the proposed model for the CRAB-MP with and without the use of the balancing constraints (CRAUB-MP).

![Figure 6.3 Impact of balanced allocation on CRAB-MP](image)

Figure 6.3 Impact of balanced allocation on CRAB-MP

It is evident from Figure 6.2 and Figure 6.3, that the total cost tends to increase in a majority of the case instances as the balancing constraint is removed. That is to say, a balanced allocation leads to cost reduction. In addition, balanced allocation tends to increase the utilization rate of the CRC, thereby reducing the workload disparity among the workers of CRC and reducing the operating (overhead) costs.

6.2.2 The Impact of Clustering on the Model Output

To examine the impact of clustering on the proposed model for solving the CRAB-SP and the CRAB-MP, the clustering constraints were removed and the model without clustering constraints is referred to as “CRABWC-SP” and “CRABWC-MP.”
Figure 6.4 Impact of clustering on CRAB-SP

Figure 6.5 Impact of clustering on CRAB-MP

The integrated methodology was used to solve both the CRAB-SP and the CRAB-MP. Based on the observation of the model experiments with and without the clustering constraints as shown in Figure 6.4 and Figure 6.5, it has been found that the performance of CRAB-SP and CRAB-MP are better than that of CRABWC-SP and CRABWC-MP. This result indicates that clustering ultimately reduces the total cost. The rationale is that clustering helps to identify the true population centres of customers and thus helps to
create the effective customer zones weighed by the number of customer populations. In other words, the clustering procedure is useful for finding the locations of the ICPs convenient (in proximity) to their customers. The convenient location of the ICPs can lower the transportation cost between the customer location and the ICP site.

6.2.3 The Impact of Product Quality Levels on the Model Output

Finally, the effect of the degree of the product quality levels on the CRAB-MP model is examined. For experimental purposes, two and three different product quality levels were considered and they are referred here as CRAB2-SP and CRAB3-SP in the single product RL environment and as CRAB2-MP and CRAB3-MP in the multi product RL environment. As shown in Figure 6.6 and Figure 6.7, it is found that the greater the degree of product quality levels, the higher the total cost in most of the problem instances. That is to say, if a firm wants to reduce the total cost, it needs to reduce the extent of variances in product quality levels. The possible explanation may be that the processing of varying degrees of product quality levels requires more time to sort returned products and multiple setups to process them for reuse and recycling. Thus, if a firm wants to reduce the processing cost, the number of quality levels of returned products should be reduced.

![Figure 6.6 The impact of product quality levels on CRAB-SP](image-url)
Also, if a firm wants to reduce the price paid to the collecting agents, there should be more product quality levels put in place.

![Figure 6.7 The impact of product quality levels on CRAB-MP](image)

6.3 SUMMARY

This chapter details the performance analysis conducted on the proposed model and methodology for solving CRAB-SP and CRAB-MP. From the performance analysis, it is clear that the integrated methodology performs better than the decomposed methodology in solving both the single product and the multi product RL network design problems. The rationale behind this improved performance is the restriction of loss of information while solving the problem in an integrated manner. Analysis using lower bounds reveals that the location-routing constraint plays a major role in reducing the computational effort involved in the problem solving.

This chapter also addresses the drawn observations by conducting sensitivity analysis on the proposed models for solving CRAB-SP and CRAB-MP. This analysis has been carried out by relaxing certain constraints such as clustering, balanced allocation and by changing some index of a model.
parameter such as the number of product quality levels on the proposed models. The purpose for the sensitivity analysis is to analyse the impact of the various issues on the proposed models.

From the results of the sensitivity analysis, it has been observed that the incorporation of clustering in the model improves the performance. The rationale behind this is the increased awareness of the importance of clustering in both the reverse logistics networks and in the location routing problem. The consideration of balanced allocation in the model also has a major impact, since it reduces the workload disparity and the idle time of workers as well as increases the utilization rate of the facilities. Also the number of product quality levels affects the performance of the model. It has been found that more product quality levels increases the total cost, since the higher product quality levels increase the segregation cost, the set up cost and the processing cost.