**Sensitivity Analysis**

To assess the robustness of the results obtained by the GACRFNI algorithm under variations in other parameters, including risk aversion levels, number of scenarios, and capacities, a comprehensive sensitivity analysis has been conducted.

**Table 1** Sensitivity analysis based on number of scenarios, risk aversion levels, and capacities of warehouses and collection centers

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **|S|=400** |  | **Average FF** | | | | | |  | **Average TNOS** | | | | | |  | **Average ENTOW** | | | | | |
|  |  | **Risk aversion levels** | | | | | |  | **Risk aversion levels** | | | | | |  | **Risk aversion levels** | | | | | |
|  |  | **α=0** | **α=0.3** | **α=0.6** | **α=0.8** | **α=0.9** | **α=1** |  | **α=0** | **α=0.3** | **α=0.6** | **α=0.8** | **α=0.9** | **α=1** |  | **α=0** | **α=0.3** | **α=0.6** | **α=0.8** | **α=0.9** | **α=1** |
| **Capacity  Levels** | **HC** | 162024.0 | 328092.0 | 369588.4 | 406870.0 | 412400.2 | 282524.0 | **HC** | 0 | 1 | 1.31 | 1.68 | 1.63 | 0.72 | **HC** | 0 | 2.06 | 2.37 | 2.42 | 2.57 | 1.23 |
| **MC** | 162024.0 | 366521.8 | 404224.2 | 437349.5 | 429493.8 | 329648.9 | **MC** | 0 | 1 | 1.31 | 1.67 | 1.51 | 0.82 | **MC** | 0 | 2.20 | 2.48 | 2.48 | 2.56 | 1.32 |
| **LC** | 162024.0 | 419636.3 | 452607.8 | 485691.6 | 453970.4 | 381812.1 | **LC** | 0 | 1 | 1.32 | 1.71 | 1.33 | 0.84 | **LC** | 0 | 2.33 | 2.55 | 2.54 | 2.48 | 1.40 |
| **|S|=300** |  | **Average FF** | | | | | |  | **Average TNOS** | | | | | |  | **Average ENTOW** | | | | | |
|  |  | **Risk aversion levels** | | | | | |  | **Risk aversion levels** | | | | | |  | **Risk aversion levels** | | | | | |
|  |  | **α=0** | **α=0.3** | **α=0.6** | **α=0.8** | **α=0.9** | **α=1** |  | **α=0** | **α=0.3** | **α=0.6** | **α=0.8** | **α=0.9** | **α=1** |  | **α=0** | **α=0.3** | **α=0.6** | **α=0.8** | **α=0.9** | **α=1** |
| **Capacity  Levels** | **HC** | 159998.3 | 325105.9 | 367775.6 | 401699.8 | 406997.0 | 275820.3 | **HC** | 0 | 1 | 1.33 | 1.67 | 1.62 | 0.70 | **HC** | 0 | 2.04 | 2.36 | 2.37 | 2.52 | 1.17 |
| **MC** | 159998.3 | 363038.5 | 401692.6 | 431937.4 | 423813.7 | 321518.7 | **MC** | 0 | 1 | 1.33 | 1.66 | 1.49 | 0.78 | **MC** | 0 | 2.17 | 2.45 | 2.43 | 2.50 | 1.26 |
| **LC** | 159998.3 | 415260.0 | 449285.7 | 479519.2 | 447817.9 | 373398.2 | **LC** | 0 | 1 | 1.33 | 1.70 | 1.32 | 0.80 | **LC** | 0 | 2.30 | 2.52 | 2.49 | 2.43 | 1.34 |
| **|S|=200** |  | **Average FF** | | | | | |  | **Average TNOS** | | | | | |  | **Average ENTOW** | | | | | |
|  |  | **Risk aversion levels** | | | | | |  | **Risk aversion levels** | | | | | |  | **Risk aversion levels** | | | | | |
|  |  | **α=0** | **α=0.3** | **α=0.6** | **α=0.8** | **α=0.9** | **α=1** |  | **α=0** | **α=0.3** | **α=0.6** | **α=0.8** | **α=0.9** | **α=1** |  | **α=0** | **α=0.3** | **α=0.6** | **α=0.8** | **α=0.9** | **α=1** |
| **Capacity  Levels** | **HC** | 157973.3 | 322579.2 | 366001.6 | 396672.4 | 401796.2 | 268030.3 | **HC** | 0 | 1 | 1.34 | 1.66 | 1.61 | 0.66 | **HC** | 0 | 2.03 | 2.33 | 2.32 | 2.47 | 1.12 |
| **MC** | 157973.3 | 359815.6 | 399443.7 | 426621.7 | 418290.3 | 313448.8 | **MC** | 0 | 1 | 1.34 | 1.65 | 1.48 | 0.75 | **MC** | 0 | 2.16 | 2.43 | 2.39 | 2.45 | 1.21 |
| **LC** | 157973.3 | 411238.8 | 446281.8 | 473627.6 | 441815.3 | 268030.3 | **LC** | 0 | 1 | 1.34 | 1.68 | 1.30 | 0.66 | **LC** | 0 | 2.28 | 2.50 | 2.45 | 2.38 | 1.12 |

**HC:** High Capacity associated with Case 1 – **MC:** Moderate Capacity associated with Case 2 – **LC:** Low Capacity associated with Case 3

Table 1 presents the performance metrics corresponding to changes in these key parameters. The analysis considers three levels associated with the cases (Case-1, Case-2, and Case-3) for both collection center and warehouse capacities. Six levels of risk aversion and three levels for the number of scenarios are also evaluated. The computational results are visualized in Figure 1.

According to the results, all metric values remain nearly identical for different numbers of scenarios, with minimal variation even in average FF values. This indicates that the proposed GACRFNI algorithm consistently delivers high-quality and robust solutions, even when the number of scenarios is set to 200. Therefore, for larger-sized problems, it is recommended to use 200 scenarios for demand and capacity generation under uncertainty to achieve high-quality results within a reasonable computation time.

From the capacity aspect, as shown in Figure 1, the low-capacity level consistently leads to higher overall costs, regardless of the risk aversion level. On the other hand, changes in capacity levels begin to influence average TNOS values at higher risk aversion levels. Interestingly, the impact of capacity level changes is noticeable in average ENTOW values across all levels of risk aversion. Therefore, it can be concluded that making warehouse opening decisions after the realization of uncertainty is a reasonable approach to ensure flexibility and support resilient HSC design under limited capacity.

The most significant changes in all metrics are observed with variations in risk aversion levels. For all metrics, values initially increase as risk aversion levels rise, then start to decrease after reaching a certain level, which is consistent across all metrics. This indicates that identifying the optimal risk aversion level for achieving a resilient HSC design with viability is critically important. As mentioned earlier and confirmed by the sensitivity analysis, the crucial risk aversion level is set at 0.8 for the given problem settings. Beyond this point, a sustainable HSC design that balances resilience and viability cannot be ensured.

metin, ekran görüntüsü, diyagram, tasarım içeren bir resim

Açıklama otomatik olarak oluşturuldu

**Figure 1** Visualization of average FF, TNOS, and ENTOW for sensitivity analysis