Table 1: Pipes data for Malard City

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Pipe number | Hazen Williams coefficient | Pipe length (m) | Pipe number | Hazen Williams coefficient | Pipe length (m) | Pipe number | Hazen Williams coefficient | Pipe length (m) |
| 1 | 100 | 438.2 | 35 | 100 | 856.0 | 69 | 100 | 348.3 |
| 2 | 140 | 735.0 | 36 | 100 | 534.1 | 70 | 140 | 253.7 |
| 3 | 100 | 476.2 | 37 | 100 | 545.0 | 71 | 140 | 186.5 |
| 4 | 100 | 946.9 | 38 | 100 | 505.7 | 72 | 140 | 240.6 |
| 5 | 140 | 525.5 | 39 | 100 | 557.2 | 73 | 140 | 398.6 |
| 6 | 100 | 241.0 | 40 | 100 | 650.7 | 74 | 140 | 85.9 |
| 7 | 100 | 37.0 | 41 | 100 | 459.0 | 75 | 140 | 138.1 |
| 8 | 100 | 413.9 | 42 | 100 | 265.1 | 76 | 100 | 44.2 |
| 9 | 100 | 695.7 | 43 | 140 | 283.8 | 77 | 100 | 298.7 |
| 10 | 140 | 736.0 | 44 | 100 | 234.9 | 78 | 100 | 874.3 |
| 11 | 100 | 492.4 | 45 | 140 | 221.5 | 79 | 140 | 58.4 |
| 12 | 100 | 161.2 | 46 | 140 | 247.5 | 80 | 140 | 60.7 |
| 13 | 100 | 391.5 | 47 | 140 | 519.3 | 81 | 140 | 348.6 |
| 14 | 100 | 630.7 | 48 | 100 | 723.8 | 82 | 140 | 383.2 |
| 15 | 100 | 382.5 | 49 | 100 | 90.0 | 83 | 140 | 294.4 |
| 16 | 100 | 529.2 | 50 | 100 | 214.0 | 84 | 140 | 355.1 |
| 17 | 100 | 956.8 | 51 | 100 | 435.2 | 85 | 140 | 306.6 |
| 18 | 100 | 665.4 | 52 | 100 | 745.2 | 86 | 140 | 198.5 |
| 19 | 100 | 1133.5 | 53 | 100 | 827.6 | 87 | 140 | 442.1 |
| 20 | 100 | 173.7 | 54 | 100 | 625.7 | 88 | 100 | 1505.3 |
| 21 | 100 | 504.6 | 55 | 100 | 625.3 | 89 | 100 | 126.0 |
| 22 | 100 | 636.6 | 56 | 140 | 599.0 | 90 | 140 | 488.2 |
| 23 | 100 | 806.2 | 57 | 140 | 684.9 | 91 | 140 | 32.8 |
| 24 | 100 | 163.5 | 58 | 100 | 614.5 | 92 | 140 | 73.9 |
| 25 | 100 | 343.4 | 59 | 100 | 635.5 | 93 | 140 | 111.8 |
| 26 | 100 | 427.0 | 60 | 120 | 168.3 | 94 | 140 | 423.1 |
| 27 | 140 | 767.2 | 61 | 100 | 69.2 | 95 | 140 | 563.8 |
| 28 | 100 | 643.8 | 62 | 100 | 553.3 | 96 | 140 | 989.5 |
| 29 | 100 | 770.8 | 63 | 140 | 454.2 | 97 | 140 | 161.0 |
| 30 | 140 | 802.3 | 64 | 140 | 39.5 | 98 | 140 | 616.1 |
| 31 | 100 | 398.5 | 65 | 100 | 254.2 | 99 | 140 | 275.7 |
| 32 | 100 | 752.5 | 66 | 100 | 1390.3 | 100 | 140 | 378.2 |
| 33 | 100 | 601.0 | 67 | 100 | 473.2 | 101 | 140 | 145.8 |
| 34 | 100 | 404.8 | 68 | 100 | 1143.9 | 102 | 140 | 104.5 |

Table 2: Nodal requirements for Malard city

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Node number | Peak Demand (L/s) | Level (m) | Node number | Peak Demand (L/s) | Level (m) | Node number | Peak Demand (L/s) | Level (m) |
| 9 | 7.5 | 1200 | 34 | 53.4 | 1198 | 59 | 1.6 | 1165 |
| 10 | 12.4 | 1202 | 35 | 31.3 | 1198 | 60 | 0.3 | 1165 |
| 11 | 16.9 | 1203 | 36 | 6.8 | 1197 | 61 | 1.4 | 1162 |
| 12 | 24.1 | 1205 | 37 | 28.3 | 1203 | 62 | 2.3 | 1163 |
| 13 | 12.4 | 1203 | 38 | 22.0 | 1204 | 63 | 3.5 | 1164 |
| 14 | 24.2 | 1203 | 39 | 16.6 | 1201 | 64 | 0.9 | 1165 |
| 15 | 52.2 | 1199 | 40 | 34.9 | 1195 | 65 | 3.8 | 1165 |
| 16 | 37.3 | 1195 | 41 | 15.6 | 1188 | 66 | 17.3 | 1165 |
| 17 | 5.1 | 1194 | 42 | 21.2 | 1190 | 67 | 8.1 | 1162 |
| 18 | 8.2 | 1189 | 43 | 11.8 | 1187 | 68 | 5.4 | 1159 |
| 19 | 3.2 | 1190 | 44 | 5.5 | 1185 | 69 | 6.9 | 1156 |
| 20 | 4.5 | 1194 | 45 | 1.6 | 1179 | 70 | 6.3 | 1154 |
| 21 | 0.5 | 1195 | 46 | 1.3 | 1185 | 71 | 3.0 | 1153 |
| 22 | 1.3 | 1194 | 47 | 17.1 | 1185 | 72 | 0.0 | 1155 |
| 23 | 11.1 | 1183 | 48 | 12.2 | 1190 | 73 | 3.6 | 1144 |
| 24 | 11.2 | 1174 | 49 | 8.9 | 1198 | 74 | 0.7 | 1143 |
| 25 | 7.4 | 1167 | 50 | 20.7 | 1183 | 75 | 3.7 | 1143 |
| 26 | 12.9 | 1169 | 51 | 6.4 | 1178 | 76 | 0.2 | 1142 |
| 27 | 4.3 | 1170 | 52 | 5.3 | 1179 | 77 | 4.2 | 1142 |
| 28 | 12.0 | 1175 | 53 | 2.0 | 1182 | 78 | 10.0 | 1146 |
| 29 | 10.3 | 1179 | 54 | 0.9 | 1179 | 79 | 0.9 | 1146 |
| 30 | 7.9 | 1177 | 55 | 9.5 | 1168 | 80 | 4.0 | 1154 |
| 31 | 24.9 | 1182 | 56 | 1.9 | 1166 | 81 | 6.4 | 1158 |
| 32 | 38.3 | 1189 | 57 | 3.6 | 1167 | 82 | 1.6 | 1161 |
| 33 | 24.9 | 1190 | 58 | 4.6 | 1166 |  |  |  |

Table 3: Commercially available pipe sizes and costs for Malard city

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Diameter (mm) | Cost (Iranian Rial/m) | Diameter (mm) | Cost (Iranian Rial/m) | Diameter (mm) | Cost (Iranian Rial/m) |
| 110 | 443,300 | 300 | 2,504,700 | 700 | 13,341,000 |
| 160 | 750,200 | 400 | 4,681,000 | 800 | 17,461,000 |
| 200 | 1,190,400 | 500 | 7,254,000 | 900 | 21,141,000 |
| 250 | 1,835,200 | 600 | 10,501,000 |  |  |

## Optimization and results of Malard City

In the current research, the SA-VNS has implemented for the Malard City network 15 times. The results of the best solution are shown in Tables 35, and 36. Furthermore, minimum, average, and maximum pressure heads achieved were 20.06, 37.641 and 59.24 respectively. The results show that the pressure heads have appropriate standard values (especially in terms of average). Furthermore, Figure 16 shows that the relationship between total cost and the number of objective function evaluations for Malard City. Finally, it is worth noting that the total cost of the current network was about 214 billion (Iranian Rial) which is significant compared to the optimized total cost about 36.6 billion (Iranian Rial). A comparison between the pressure head of the current network and the optimized network and its polynomial fitting is shown in Figure 17. As illustrated in the figure, average pressure head in the whole network is decreased, which leads to the life improvement of the pipes. Furthermore, 21 nodes had pressure head higher than 60 (m) while the pressure head in all nodes in the optimized network was less than 60 (m).

Table 4: Results of Malard city (Pipes)

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Pipe ID | Diameter (mm) | Discharge (L/s) | Velocity (m/s) | Pipe ID | Diameter (mm) | Discharge (L/s) | Velocity (m/s) | Pipe ID | Diameter (mm) | Discharge (L/s) | Velocity (m/s) |
| 2 | 160 | 20.18 | 1.00 | 36 | 160 | 20.57 | 1.02 | 71 | 110 | 4.68 | 0.49 |
| 3 | 250 | 96.11 | 1.96 | 37 | 160 | 13.61 | 0.68 | 72 | 110 | 9.24 | 0.97 |
| 4 | 200 | 39.55 | 1.26 | 38 | 200 | 19.76 | 0.63 | 73 | 200 | 7.23 | 0.23 |
| 5 | 110 | 12.64 | 1.33 | 39 | 160 | 17.45 | 0.87 | 74 | 160 | 5.84 | 0.29 |
| 6 | 160 | 11.36 | 0.56 | 40 | 250 | 30.00 | 0.61 | 75 | 110 | 3.49 | 0.37 |
| 8 | 160 | 22.10 | 1.10 | 41 | 110 | 6.17 | 0.65 | 76 | 160 | 18.09 | 0.90 |
| 9 | 110 | 12.21 | 1.28 | 42 | 110 | 0.91 | 0.10 | 77 | 110 | 7.07 | 0.74 |
| 10 | 160 | 39.65 | 1.97 | 43 | 200 | 3.39 | 0.11 | 79 | 200 | 104.57 | 3.33 |
| 11 | 160 | 15.49 | 0.77 | 44 | 160 | 5.44 | 0.27 | 80 | 200 | 43.42 | 1.38 |
| 12 | 160 | 3.06 | 0.15 | 45 | 110 | 3.10 | 0.33 | 81 | 160 | 17.31 | 0.86 |
| 13 | 160 | 29.80 | 1.48 | 46 | 110 | 14.85 | 1.56 | 82 | 110 | 22.28 | 2.34 |
| 14 | 200 | 26.58 | 0.85 | 47 | 160 | 18.96 | 0.94 | 83 | 110 | 19.33 | 2.03 |
| 15 | 110 | 8.78 | 0.92 | 48 | 200 | 47.33 | 1.51 | 84 | 160 | 46.25 | 2.30 |
| 16 | 110 | 12.40 | 1.30 | 50 | 200 | 43.15 | 1.37 | 85 | 200 | 39.31 | 1.25 |
| 17 | 110 | 3.59 | 0.38 | 51 | 200 | 32.44 | 1.03 | 86 | 200 | 15.15 | 0.48 |
| 18 | 110 | 7.45 | 0.78 | 52 | 200 | 20.21 | 0.64 | 87 | 110 | 0.00 | 0.00 |
| 19 | 160 | 15.07 | 0.75 | 53 | 160 | 11.33 | 0.56 | 88 | 160 | 12.18 | 0.61 |
| 20 | 200 | 28.02 | 0.89 | 54 | 160 | 12.71 | 0.63 | 89 | 110 | 8.56 | 0.90 |
| 21 | 160 | 32.27 | 1.61 | 55 | 160 | 12.73 | 0.63 | 90 | 110 | 7.89 | 0.83 |
| 22 | 110 | 12.57 | 1.32 | 56 | 110 | 9.44 | 0.99 | 91 | 110 | 3.72 | 0.39 |
| 23 | 110 | 2.25 | 0.24 | 57 | 160 | 17.93 | 0.89 | 92 | 110 | 13.37 | 1.41 |
| 24 | 200 | 86.84 | 2.76 | 58 | 160 | 6.40 | 0.32 | 93 | 160 | 13.56 | 0.67 |
| 26 | 200 | 64.12 | 2.04 | 59 | 160 | 17.13 | 0.85 | 94 | 200 | 10.01 | 0.32 |
| 27 | 200 | 23.05 | 0.73 | 60 | 200 | 26.95 | 0.86 | 95 | 160 | 27.78 | 1.38 |
| 28 | 160 | 16.19 | 0.81 | 62 | 200 | 51.43 | 1.64 | 96 | 200 | 28.68 | 0.91 |
| 29 | 160 | 14.78 | 0.73 | 63 | 160 | 46.35 | 2.31 | 97 | 200 | 17.91 | 0.57 |
| 30 | 160 | 8.51 | 0.42 | 65 | 200 | 99.37 | 3.16 | 98 | 110 | 14.73 | 1.55 |
| 31 | 200 | 1.14 | 0.04 | 66 | 110 | 7.88 | 0.83 | 99 | 160 | 53.46 | 2.66 |
| 32 | 110 | 4.98 | 0.52 | 67 | 160 | 9.43 | 0.47 | 100 | 160 | 60.25 | 3.00 |
| 33 | 160 | 25.72 | 1.28 | 68 | 110 | 3.35 | 0.35 | 101 | 110 | 5.16 | 0.54 |
| 34 | 110 | 5.46 | 0.57 | 69 | 200 | 0.88 | 0.03 | 102 | 200 | 32.34 | 1.03 |
| 35 | 250 | 57.65 | 1.17 | 70 | 200 | 1.06 | 0.03 |  |  |  |  |
| Min velocity: **0.03** Average velocity: 1**.006** Max velocity: **3.33** | | | | | | | | | | | |

Table 4: Results of Malard city (Nodes)

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Node ID | Consumption (L/s) | |  | Pressure head (m) | Node ID | Consumption (L/s) | Pressure head (m) | Node ID | Consumption (L/s) | Pressure head (m) |
| 1 | -140.89 | |  | 0.00 | 29 | 10.31 | 28.14 | 57 | 3.61 | 50.64 |
| 2 | -11.27 | |  | 0.00 | 30 | 7.91 | 58.54 | 58 | 4.56 | 52.12 |
| 3 | -174.02 | |  | 0.00 | 31 | 24.88 | 39.43 | 59 | 1.62 | 55.29 |
| 4 | -109.71 | |  | 0.00 | 32 | 38.35 | 27.49 | 60 | 0.29 | 55.70 |
| 5 | -107.57 | |  | 0.00 | 33 | 24.85 | 27.50 | 61 | 1.40 | 58.16 |
| 6 | -158.87 | |  | 0.00 | 34 | 53.41 | 22.52 | 62 | 2.34 | 57.11 |
| 7 | -130.02 | |  | 0.00 | 35 | 31.32 | 34.68 | 63 | 3.49 | 55.90 |
| 8 | -17.54 | |  | 8.00 | 36 | 6.78 | 34.88 | 64 | 0.90 | 53.14 |
| 9 | 7.55 | |  | 49.91 | 37 | 28.30 | 42.81 | 65 | 3.84 | 52.62 |
| 10 | 12.39 | |  | 52.45 | 38 | 22.02 | 28.72 | 66 | 17.31 | 51.00 |
| 11 | 16.92 | |  | 40.22 | 39 | 16.55 | 28.32 | 67 | 8.10 | 37.98 |
| 12 | 24.06 | |  | 25.43 | 40 | 34.88 | 31.26 | 68 | 5.42 | 30.56 |
| 13 | 12.43 | |  | 23.95 | 41 | 15.63 | 41.33 | 69 | 6.94 | 23.37 |
| 14 | 24.21 | |  | 23.90 | 42 | 21.25 | 36.47 | 70 | 6.25 | 23.17 |
| 15 | 52.19 | |  | 20.06 | 43 | 11.75 | 34.10 | 71 | 2.98 | 23.93 |
| 16 | 37.30 | |  | 21.49 | 44 | 5.54 | 35.83 | 72 | 0.00 | 21.93 |
| 17 | 5.15 | |  | 33.34 | 45 | 1.55 | 59.24 | 73 | 3.62 | 26.12 |
| 18 | 8.19 | |  | 32.48 | 46 | 1.27 | 54.57 | 74 | 0.67 | 25.28 |
| 19 | 3.22 | |  | 35.56 | 47 | 17.09 | 57.97 | 75 | 3.72 | 21.95 |
| 20 | 4.51 | |  | 40.85 | 48 | 12.23 | 45.50 | 76 | 0.19 | 24.32 |
| 21 | 0.53 | |  | 45.49 | 49 | 8.89 | 34.60 | 77 | 4.20 | 24.65 |
| 22 | 1.28 | |  | 47.44 | 50 | 20.74 | 36.38 | 78 | 10.01 | 20.41 |
| 23 | 11.06 | |  | 23.14 | 51 | 6.39 | 46.29 | 79 | 0.90 | 26.95 |
| 24 | 11.22 | |  | 29.35 | 52 | 5.26 | 41.63 | 80 | 3.96 | 22.90 |
| 25 | 7.45 | |  | 28.84 | 53 | 2.05 | 38.60 | 81 | 6.39 | 32.08 |
| 26 | 12.95 | |  | 41.96 | 54 | 0.95 | 41.57 | 82 | 1.63 | 39.43 |
| 27 | 4.25 | |  | 42.19 | 55 | 9.54 | 49.64 |  |  |  |
| 28 | 12.00 | |  | 51.06 | 56 | 1.94 | 51.64 |  |  |  |
|  | | Min pressure: **20.06** Average pressure: **37.641** Max pressure: **59.24** | | | | | | | | |