The Application of Floyd-Warshall Algorithm in Solving Shortest Path Problem for Fire Evacuation System at High Rise Building (Case Study at eL Royale Hotel Bandung)

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Abstract
Wildfires can happen anytime and anywhere, for example in high rise building. In attempt to control the wildfires, evacuation routes is one of the most important aspects that each building developer should consider. Evacuation is an action of moving peoples from the danger zone or the area that affected by it to a safety zone with the intention of safety. When we’re facing the wildfires situation in a building, the evacuation procedure focused on the best attempt to finding the shortest route in order to minimize time travel to get out from the building to the safety zone as quickly as possible. Evacuation planning in high rise building is totally different compared to evacuation planning in open ground. Main components such as rooms, lobbies, corridors, stairs, alleys, etc. can determine the evacuation planning to completely success or fail. This research will discuss about the application of Floyd-Warshall Algorithm in finding the solution of shortest path problem in wildfires evacuation system at eL Royale Hotel Bandung as object of this research.

Keywords: Wildfires, Evacuation, Shortest Path Problem, Floyd-Warshall Algorithm.

1. Introduction
Wildfire is an incident where unwanted fire occurs or fire that placed in a wrong area. It happens because of three reasons; by fuel, by oxygen, and by heat sources. Wildfire can happen in anywhere and anytime. For example, it can happen on hotel. Hotel is one example of high rise buildings that has a chance where wildfire can be happen. Quoted from Decree of Indonesian Minister of Public Works number 11/KPTS/2000, hotel is classified as building that has a chance of wildfire in section seven. Thus, hotel building does not have higher risk of wildfires. However, it doesn’t mean that wildfire won’t happen in the hotel building. So, the existence of fire protection equipment such as sprinkler, hydrant, smoke alarm, and fire extinguisher cannot be ruled out in every hotel.

Evacuation is an action of moving people from the affected area to the save zone which is far from the affected area. The purpose of it is to making sure that those people are saved. When wildfire happens in high rise building, the evacuation procedures are focused on searching the shortest route in order to minimize time travel from the danger area to the safer zone. Planning the evacuation in high rise building is different from planning evacuation from open ground. There are several aspects that we should pay attention to it. Those aspects are rooms, lobbies, stairs, corridors, and many more.
There are some algorithms that can be used to solving the shortest path problem, such as Dijkstra Algorithm, Bellman-Ford Algorithm, and Floyd-Warshall Algorithm. Floyd-Warshall Algorithm is one of the easiest algorithms to use because of its simplicity to find the shortest route from every pair-points in the system (All-pairs Shortest Path) and it’s very effective to find the optimal route.

This research will be discussed about the solution of the problem when finding the shortest route in case of wildfire incident in eL Royale Hotel Bandung. This problem solved by using Floyd-Warshall algorithm.

2. Description of Problem

To finding the solution from shortest path problem of fire evacuation system at eL Royale Hotel Bandung, we’re using Floyd-Warshall Algorithm as our calculation method because of its simplicity. Based from the data we’ve got from eL Royale Hotel Bandung, there are 224 guest rooms, which is spread from floor 2 until 15, 2 emergency exits, and 1 assembly point. Then, we draw a graph to represent guest rooms, corridors, stairs that everyone can access.

This system will include greater number of nodes and lines. To facilitate the calculation, we’re gonna calculate the system from floor to floor, not the whole system. Based from the data, there are 255 nodes that builds the system, consists of 224 guest rooms, 28 emergency stair entries, 2 emergency stair exits, and 1 assembly point. As for the recap for the number of nodes in fire evacuation system in every floor can be seen in Table 2.1 below.

<table>
<thead>
<tr>
<th>Floor</th>
<th>Guest Rooms</th>
<th>Entries</th>
<th>Exits</th>
<th>Assembly Point</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>11</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>12</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>13</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>14</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>15</td>
<td>16</td>
<td>2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>224</td>
<td>28</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

There are some assumptions we’re using to this research, such as:

1) The method we’re using is Floyd-Warshall Algorithm.
2) The calculation only applies in Tower C of eL Royale Hotel Bandung.
3) There are 224 guest rooms which is spread from floor 2 until floor 15.
4) There are 2 emergency stairs that can be accessed from every floors.
5) There are only one assembly point in this system, which is located in ground floor.
6) We’re assumed that if one guest already choosing one emergency stairs from the floor he/she stayed, he/she can’t moved to another stairs in next floor.
7) During the evacuation, lift is shutting off.
8) Individual parameters such as running speed, physical ability, gender, psychological condition, etc. has no effect into calculation.
9) We’re using Borland C++ 5.02 version as calculating software to make the calculation easier.
3. Analysis of Calculation using Floyd-Warshall Algorithm

To finding the solution of shortest path problem in fire evacuation system at eL Royale Hotel Bandung using Floyd-Warshall Algorithm, we must start by forming a graph based on layout map we already got. For example, we using floor number 2 as a sample. Based on the layout, the graph of fire evacuation system at floor 2 eL Royale Hotel Bandung can be seen in Figure 3.1 below.

![Graph of Floor 2 eL Royale Hotel Bandung](image)

Figure 1 Graph of Floor 2 eL Royale Hotel Bandung

Based on that picture, there is some nodes that symbolized as a circles with three different colors. Red circles means hotel rooms, blue circles means access from/to fire emergency exits, and green circles means assembly point.

Using Figure 3.1, and some data that we got from Engineering Department, we obtained adjacency matrices W and Z as described below:

$$W_0 = \begin{bmatrix}
    & v_1 & v_2 & v_3 & \ldots & v_{18} & v_{253} & v_{254} & v_{255} \\
v_1 & 0 & 3.1 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_3 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_4 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_5 & 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0 \\
v_6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_9 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{10} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{11} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{12} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{13} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{14} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{15} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{16} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{17} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{18} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{253} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{254} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{255} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\end{bmatrix}$$

$$Z_0 = \begin{bmatrix}
    & v_1 & v_2 & v_3 & \ldots & v_{18} & v_{253} & v_{254} & v_{255} \\
v_1 & 0 & 3.1 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_3 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_4 & 0 & 2 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_5 & 0 & 0 & 3 & 0 & 0 & 0 & 0 & 0 \\
v_6 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_7 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_9 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{10} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{11} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{12} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{13} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{14} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{15} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{16} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{17} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{18} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{253} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{254} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
v_{255} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
\end{bmatrix}$$

where $v_1, v_2, v_3, \ldots, v_{18}, v_{253}, v_{254}, v_{255}$ are nodes that forming fire evacuation system at floor 2.
Adjacency matrices $W$ is used to find the shortest distance from every node pairs, while matrices $Z$ is used to find the path from the shortest distance from every node pairs that we’ve already obtained in matrices $W$.

For example, $W_0$ is an adjacency matrices from a random directed and weighted graph, $W^*$ is an new adjacency matrices with $w_{i,j}$ is a value from edge that connecting node $i$ and node $j$. Floyd-Warshall Algorithm for finding the shortest path can be described below:

1) Pick $W = W_0$
2) For $k = 1, 2, ..., n$
   For $i = 1, 2, ..., n$
   For $j = 1, 2, ..., n$, do :
   a. if $w_{i,j} > w_{i,k} + w_{k,j}$, then choose $w^*_{i,j} = w_{i,k} + w_{k,j}$.
   b. if $w_{i,j} \leq w_{i,k} + w_{k,j}$, then choose $w^*_{i,j} = w_{i,j}$.
3) Pick $W^* = W$

Floyd-Warshall Algorithm can be used for finding the shortest route only, but not describe its path. For finding the path that connected two random nodes using Floyd-Warshall Algorithm, we must added matrices $Z$ that described as:

Inizialiation $z_{i,j} = \left\{ \begin{array}{ll}
     j, & \text{if } w_{i,j} \neq \infty \\
     0, & \text{if } w_{i,j} = \infty \text{ or } i = j
\end{array} \right.$

In every iteration, for every value changes of elements $w_{i,j}$ in adjacency matrices $W$, we must changed the value $z_{i,j}$ in matrices $Z$ with $z_{i,k}$.

Based on that, updated version of Floyd-Warshall Algorithm (1) using matrices $Z$ (2) is described below:

1) Pick $W = W_0$, $Z = Z_0$
2) For $k = 1, 2, ..., n$
   For $i = 1, 2, ..., n$
   For $j = 1, 2, ..., n$, do :
   a. if $w_{i,j} > w_{i,k} + w_{k,j}$, then choose $w^*_{i,j} = w_{i,k} + w_{k,j}$ and $z^*_{i,j} = z_{i,k}$
   b. if $w_{i,j} \leq w_{i,k} + w_{k,j}$, then choose $w^*_{i,j} = w_{i,j}$ and $z^*_{i,j} = z_{i,j}$
3) Pick $W^* = W$, $Z^* = Z$

The method and solution of finding the shortest path problem using Floyd-Warshall Algorithm in floor 2 can be seen below.

**Iteration $k = 1$**

For every elements in adjacency matrices $W$ will be checked whether $w_{i,j} > w_{i,k} + w_{k,j}$, with :

$i = 1, 2, 3, ..., 18, 253, 254, 255$,
$j = 1, 2, 3, ..., 18, 253, 254, 255$, and
$k = 1, 2, 3, ..., 18, 253, 254, 255$

If yes, then choose $w^*_{i,j} = w_{[i,k]} + w_{[k,j]}$ and $z^*_{i,j} = z_{[i,k]}$.

$i = 1, j = 1$

$w_{[1,1]} = 0$, meanwhile $w_{[1,1]} + w_{[1,1]} = 0 + 0 = 0$. So choose $w^*_{[1,1]} = 0$ and $z^*_{[1,1]} = 0$.

$i = 1, j = 2$

$w_{[1,2]} = \infty$, meanwhile $w_{[1,1]} + w_{[1,2]} = 0 + \infty = \infty$. So choose $w^*_{[1,2]} = \infty$ and $z^*_{[i,j]} = 0$.

$i = 1, j = 3$

$w_{[1,3]} = 3.1$, meanwhile $w_{[1,1]} + w_{[1,3]} = 0 + 3.1 = 3.1$. So choose $w^*_{[1,3]} = 3.1$ and $z^*_{[i,j]} = 3$.

Repeat those steps above until $i = 255$ and $j = 255$ so we can obtained an updated version of matrices $W$ and $Z$ as follows:

Based on that matrices, we can see some values are changes, that is in $w_{[3,17]}$ and $w_{[17,3]}$. That means we’ve found the new shortest route from $v_3$ to $v_{17}$ and vice versa, that is going through $v_1$. By that, the newest shortest route from $v_3$ to $v_{17}$ are $v_3 \rightarrow v_1 \rightarrow v_{17}$.
Repeat those steps until \( k = 255 \), so we can obtained final adjacency matrices \( W^* \) and \( Z^* \) from the calculation using Floyd-Warshall Algorithm that shows the results of shortest distance of every node pairs and it’s path. In full, the matrices \( W^* \) and \( Z^* \) can be seen below.

| \( v_1 \) | 0 | 11.8 | 3.1 | 14.9 | 6.2 | 18 | 9.3 | 21.1 | 12.4 | 24.2 | 15.5 | 18.6 | 21.7 | 24.8 | 27.9 | 31.2 | 18.8 | 47.9 | 28.5 |
| \( v_2 \) | 11.8 | 0 | 14.9 | 3.1 | 18.6 | 21.1 | 9.3 | 24.2 | 12.4 | 27.3 | 30.4 | 33.5 | 31.1 | 27.9 | 24.8 | 9.8 | 32.1 | 21.9 | 43.9 |
| \( v_3 \) | 3.1 | 14.9 | 0 | 18.6 | 21.1 | 30.4 | 6.2 | 24.2 | 12.4 | 27.3 | 30.4 | 33.5 | 31.1 | 27.9 | 24.8 | 9.8 | 32.1 | 21.9 | 43.9 |
| \( v_4 \) | 14.9 | 3.1 | 18.6 | 0 | 21.1 | 30.4 | 6.2 | 24.2 | 12.4 | 27.3 | 30.4 | 33.5 | 31.1 | 27.9 | 24.8 | 9.8 | 32.1 | 21.9 | 43.9 |
| \( v_5 \) | 6.2 | 18.6 | 3.1 | 21.1 | 0 | 30.4 | 6.2 | 24.2 | 12.4 | 27.3 | 30.4 | 33.5 | 31.1 | 27.9 | 24.8 | 9.8 | 32.1 | 21.9 | 43.9 |
| \( v_6 \) | 12.4 | 21.1 | 30.4 | 6.2 | 24.2 | 0 | 30.4 | 33.5 | 31.1 | 27.9 | 24.8 | 9.8 | 32.1 | 21.9 | 43.9 | 31.6 |
| \( v_7 \) | 28.5 | 26.9 | 31.6 | 30.4 | 34.7 | 33.1 | 37.8 | 36.2 | 40.9 | 39.3 | 44 | 42.4 | 45.5 | 46.6 | 45.4 | 47.3 | 44.3 | 49.1 | 34.6 |

Based on matrices \( W^* \) dan \( Z^* \) above, we obtained the shortest distance from every rooms in floor 2 into assembly point with it’s path. For example, if we are in the room number 240 \( (v_4) \), the shortest distance from room 240 into assembly point \( (v_{255}) \), the shortest distance from room 240 into assembly point is 28.5 meters. Meanwhile, the route we must follow are:

\[ v_1 \rightarrow v_{17} \rightarrow v_{253} \rightarrow v_{255} \]

Based on the calculation above, we obtained the solution of finding the shortest path problem in fire evacuation system at floor 2 eL Royale Bandung as described in Figure 3.2 below.

![Figure 3.2](image-url)
Based on picture above, we can conclude that for every guests that stay in rooms number 240 until 255, they must use fire exit number 1 or red tracks, meanwhile guests in rooms number 257 and 259 must use fire exit number 2 or blue tracks, in case of wildfire happens.

Using the same method, we can also find the solution of shortest path problem in fire evacuation system at floor 3 until floor 15. The fire evacuation system based on the shortest route for floor 3 until floor 15 can be seen in Figure 3.3 below.

**Figure 3** Fire Evacuation System Based on Solutions of Finding Shortest Path Problem at Floor 3-15 eL Royale Hotel Bandung

4. **Results Analysis**

Based from the calculation results from section 3, we’ve got the solution of shortest path problem in fire evacuation system at every floor from eL Royale Hotel Bandung using *Floyd-Warshall* Algorithm. As for the summary of emergency stairs choice of every rooms in eL Royale Hotel Bandung based on calculation using *Floyd-Warshall* Algorithm can be seen in Table 2 below.
Table 2 summary of emergency stairs choice of every rooms in eL Royale Hotel Bandung based on calculation using \textit{Floyd-Warshall} Algorithm

<table>
<thead>
<tr>
<th>Floor</th>
<th>Guest Rooms that must used Emergency Stair 1 (Red)</th>
<th>Guest Rooms that must used Emergency Stair 2 (Blue)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>240, 241, 242, 243, 244, 245, 246, 247, 248, 249, 250, 251, 253, 255</td>
<td>257, 259</td>
</tr>
<tr>
<td>4</td>
<td>440, 441, 442, 443, 444, 445, 446, 447, 448, 449, 450, 451, 453, 455</td>
<td>457, 459</td>
</tr>
<tr>
<td>5</td>
<td>540, 541, 542, 543, 544, 545, 546, 547, 548, 549, 550, 551, 553, 555</td>
<td>557, 559</td>
</tr>
<tr>
<td>6</td>
<td>640, 641, 642, 643, 644, 645, 646, 647, 648, 649, 650, 651, 653, 655</td>
<td>657, 659</td>
</tr>
<tr>
<td>7</td>
<td>740, 741, 742, 743, 744, 745, 746, 747, 748, 749, 750, 751, 753, 755</td>
<td>757, 759</td>
</tr>
<tr>
<td>8</td>
<td>840, 841, 842, 843, 844, 845, 846, 847, 848, 849, 850, 851, 853, 855</td>
<td>857, 859</td>
</tr>
<tr>
<td>9</td>
<td>940, 941, 942, 943, 944, 945, 946, 947, 948, 949, 950, 951, 953, 955</td>
<td>957, 959</td>
</tr>
<tr>
<td>10</td>
<td>1040, 1041, 1042, 1043, 1044, 1045, 1046, 1047, 1048, 1049, 1050, 1051, 1053, 1055</td>
<td>1057, 1059</td>
</tr>
<tr>
<td>11</td>
<td>1140, 1141, 1142, 1143, 1144, 1145, 1146, 1147, 1148, 1149, 1150, 1151, 1153, 1155</td>
<td>1157, 1159</td>
</tr>
<tr>
<td>12</td>
<td>1240, 1241, 1242, 1243, 1244, 1245, 1246, 1247, 1248, 1249, 1250, 1251, 1253, 1255</td>
<td>1257, 1259</td>
</tr>
<tr>
<td>13</td>
<td>1340, 1341, 1342, 1343, 1344, 1345, 1346, 1347, 1348, 1349, 1350, 1351, 1353, 1355</td>
<td>1357, 1359</td>
</tr>
<tr>
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<td>1440, 1441, 1442, 1443, 1444, 1445, 1446, 1447, 1448, 1449, 1450, 1451, 1453, 1455</td>
<td>1457, 1459</td>
</tr>
<tr>
<td>15</td>
<td>1540, 1541, 1542, 1543, 1544, 1545, 1546, 1547, 1548, 1549, 1550, 1551, 1553, 1555</td>
<td>1557, 1559</td>
</tr>
<tr>
<td>Total</td>
<td>196</td>
<td>28</td>
</tr>
</tbody>
</table>


5. Conclusion

Based from the summary in section 4, we can draw several conclusions, that is:

a. \textit{Floyd-Warshall} Algorithm can be used to find the solution of shortest path problem in fire evacuation system at eL Royale Hotel Bandung with the final results of calculation are a system of fire evacuation with the shortest route possible from every rooms there into assembly point.


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References


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