Supplementary material

MODELING RISKS IN REAL ESTATE DEVELOPMENT PROJECTS: A CASE FOR EGYPT

Mohamed MARZOUK, Ahmed ABOUSHADY

Table S1. Example Boolean matrix representation

<table>
<thead>
<tr>
<th>Gate event ID</th>
<th>Gate type</th>
<th>Basic events</th>
<th>OR (GE)</th>
<th>AND (GE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>A B C D E</td>
<td>TE GE2</td>
<td>GE1 GE3</td>
</tr>
<tr>
<td>TE</td>
<td>OR</td>
<td>0 0 0 0 0</td>
<td>0 0 1</td>
<td>1 1</td>
</tr>
<tr>
<td>GE2</td>
<td>OR</td>
<td>1 0 1 1 0</td>
<td>0 0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>GE1</td>
<td>AND</td>
<td>1 1 0 0 0</td>
<td>0 0 0</td>
<td>0 0</td>
</tr>
<tr>
<td>GE3</td>
<td>AND</td>
<td>1 1 0 0 1</td>
<td>0 0 0</td>
<td>0 0</td>
</tr>
</tbody>
</table>

Table S2. Qualitative fault tree analysis iterations

<table>
<thead>
<tr>
<th>Iteration (methodology steps)</th>
<th>Basic events</th>
<th>OR (GE)</th>
<th>AND (GE)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A B C D E</td>
<td>TE GE2</td>
<td>GE1 GE3</td>
</tr>
<tr>
<td>1</td>
<td>0 0 0 0 0</td>
<td>0 1</td>
<td>0 0</td>
</tr>
<tr>
<td></td>
<td>0 0 0 0 0</td>
<td>0 0</td>
<td>1 0</td>
</tr>
<tr>
<td></td>
<td>0 0 0 0 0</td>
<td>0 0</td>
<td>0 1</td>
</tr>
<tr>
<td>2</td>
<td>0 0 1 1 0</td>
<td>0 0</td>
<td>0 0</td>
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<tr>
<td></td>
<td>0 0 0 0 0</td>
<td>0 0</td>
<td>0 0</td>
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<tr>
<td></td>
<td>0 0 0 0 0</td>
<td>0 0</td>
<td>1 0</td>
</tr>
<tr>
<td></td>
<td>0 0 0 0 0</td>
<td>0 0</td>
<td>0 1</td>
</tr>
<tr>
<td>3</td>
<td>0 0 1 0 0</td>
<td>0 0</td>
<td>0 0</td>
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<tr>
<td></td>
<td>0 0 0 1 0</td>
<td>0 0</td>
<td>0 0</td>
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<tr>
<td></td>
<td>1 1 0 0 0</td>
<td>0 0</td>
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<tr>
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<td>0 0 0 0 0</td>
<td>0 0</td>
<td>0 1</td>
</tr>
<tr>
<td>4</td>
<td>0 0 1 0 0</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td></td>
<td>0 0 0 1 0</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td></td>
<td>1 1 0 0 0</td>
<td>0 0</td>
<td>0 0</td>
</tr>
<tr>
<td></td>
<td>1 1 0 0 1</td>
<td>0 0</td>
<td>0 0</td>
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Table S3. Working Boolean matrix of mitigation strategies failure

<table>
<thead>
<tr>
<th>Basic events</th>
<th>Mitigation strategy 1</th>
<th>Mitigation strategy 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR (GE)</td>
<td>AND (GE)</td>
</tr>
<tr>
<td>A</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>GE1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>GE2</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>GE3</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Table S4. Fuzzy probability of failure for mitigation strategies using $\alpha$–cut principle

<table>
<thead>
<tr>
<th>$\alpha$</th>
<th>Mitigation strategy 1</th>
<th>Mitigation strategy 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Lower bound</td>
<td>Upper bound</td>
</tr>
<tr>
<td>0</td>
<td>37</td>
<td>88</td>
</tr>
<tr>
<td>0.05</td>
<td>38</td>
<td>87</td>
</tr>
<tr>
<td>0.1</td>
<td>39</td>
<td>87</td>
</tr>
<tr>
<td>0.15</td>
<td>40</td>
<td>86</td>
</tr>
<tr>
<td>0.2</td>
<td>42</td>
<td>85</td>
</tr>
<tr>
<td>0.25</td>
<td>42</td>
<td>84</td>
</tr>
<tr>
<td>0.3</td>
<td>44</td>
<td>83</td>
</tr>
<tr>
<td>0.35</td>
<td>44</td>
<td>83</td>
</tr>
<tr>
<td>0.4</td>
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<td>82</td>
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<td>47</td>
<td>81</td>
</tr>
<tr>
<td>0.5</td>
<td>48</td>
<td>80</td>
</tr>
<tr>
<td>0.55</td>
<td>49</td>
<td>79</td>
</tr>
<tr>
<td>0.6</td>
<td>50</td>
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<td>53</td>
<td>75</td>
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<tr>
<td>0.8</td>
<td>54</td>
<td>74</td>
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<tr>
<td>0.85</td>
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<td>73</td>
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<tr>
<td>0.9</td>
<td>56</td>
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<tr>
<td>0.95</td>
<td>57</td>
<td>71</td>
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<tr>
<td>1</td>
<td>58</td>
<td>70</td>
</tr>
</tbody>
</table>

Table S5. Fuzzy importance analysis of failure for mitigation strategies

<table>
<thead>
<tr>
<th>Mitigation strategy</th>
<th>Event ID</th>
<th>(TE1)</th>
<th>(TE2)</th>
<th>FIM</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A</td>
<td>64</td>
<td>55</td>
<td>14.06</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>64</td>
<td>65</td>
<td>1.56</td>
<td>4</td>
</tr>
<tr>
<td>2</td>
<td>C</td>
<td>76.5</td>
<td>64</td>
<td>16.34</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>76.5</td>
<td>64</td>
<td>16.34</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>E</td>
<td>76.5</td>
<td>57.5</td>
<td>14.84</td>
<td>2</td>
</tr>
</tbody>
</table>
Table S6. Description of real estate development projects

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Project description</th>
<th>Project price (million EGP)</th>
<th>Project location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Constructing 30 villas and 10 residential buildings</td>
<td>145</td>
<td>6 October City</td>
</tr>
<tr>
<td>2</td>
<td>Constructing 70 residential buildings</td>
<td>350</td>
<td>6 October City</td>
</tr>
<tr>
<td>3</td>
<td>Constructing 30 residential buildings</td>
<td>210</td>
<td>6 October City</td>
</tr>
<tr>
<td>4</td>
<td>Constructing 20 residential buildings</td>
<td>100</td>
<td>6 October City</td>
</tr>
<tr>
<td>5</td>
<td>Construction 50 town houses and 100 residential building</td>
<td>650</td>
<td>El-Sheikh Zayed City</td>
</tr>
<tr>
<td>6</td>
<td>Construction 120 residential buildings</td>
<td>600</td>
<td>6 October City</td>
</tr>
<tr>
<td>7</td>
<td>Construction 35 residential buildings</td>
<td>175</td>
<td>6 October City</td>
</tr>
<tr>
<td>8</td>
<td>Interior and exterior Finishes of 20 residential buildings</td>
<td>25</td>
<td>6 October City</td>
</tr>
<tr>
<td>9</td>
<td>Interior and exterior Finishing of 10 residential buildings</td>
<td>14</td>
<td>6 October City</td>
</tr>
<tr>
<td>10</td>
<td>Interior and exterior Finishing of 15 Villas</td>
<td>13</td>
<td>El-Sheikh Zayed City</td>
</tr>
<tr>
<td>11</td>
<td>Constructing 15 residential buildings</td>
<td>55</td>
<td>6 October City</td>
</tr>
<tr>
<td>12</td>
<td>Interior and exterior finishing of 10 residential buildings</td>
<td>10</td>
<td>El-Sheikh Zayed City</td>
</tr>
<tr>
<td>13</td>
<td>Interior and exterior finishing of five villas</td>
<td>6</td>
<td>El-Sheikh Zayed City</td>
</tr>
<tr>
<td>14</td>
<td>Construction and finishing of one commercial mall and 100 residential apartments</td>
<td>75</td>
<td>6 October City</td>
</tr>
<tr>
<td>15</td>
<td>Constructing 20 villas and 35 residential buildings</td>
<td>210</td>
<td>El-Sheikh Zayed City</td>
</tr>
</tbody>
</table>