Helicopter Routing in the Norwegian Offshore Oil Industry: Including Safety Concerns for Passenger Transport

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Introduction

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In the Gulf of Mexico region, close to 3 million passengers on 600 helicopters traveled in 2008 (data from about 15 operators in the Gulf of Mexico region).
Helicopter transportation represents one of the major risks for offshore employees. (Vinnem et al. 2006. Major hazard risk indicators for monitoring of trends in the Norwegian offshore petroleum sector. Reliability Engineering and System Safety 91:778-791.)
In UK offshore oil industry, 8 fatal accidents happened in passenger transportation from 1976 to 2006, which resulted in 95 fatalities. (UK Offshore Public Transport Helicopter Safety Record 1976-2002, 1977-2006.)

- 5 of them in the take-off/landing phases
- Registered data on OGP(The International Association of Oil & Gas producers) offshore accidents relevant for the study show that 28 offshore accidents happened from 2000 to 2005.
- 22 accidents are take-off/landing accidents
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Optimizing Safety of Passenger Transportation with Helicopter

- For the purpose of this study, accidents were divided into three categories, i.e. take-off/landing accident, cruise accident, and others.

- Based on the accident categorization stated above, we suggested to look at the safety of helicopter transportation in terms of expected number of fatalities on operational planning level.
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Based on the accident categorization stated above, we suggested to look at the safety of helicopter transportation in terms of expected number of fatalities on operational planning level.
The expected number fatalities \((NF_1)\) due to take-off/landing accidents

\[
NF_1 = PTL \times f_1 \times (Pr)_1. \tag{1}
\]

\((PTL=\text{person take-off/landings}, f_1 \text{ is the take-off/landing accident frequency}, (Pr)_1 \text{ is the probability of death of an individual passenger involved in an accident})\)

The expected number fatalities \((NF_2)\) from such cruise accidents

\[
NF_2 = PFH \times f_2 \times (Pr)_2. \tag{2}
\]

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The expected number fatalities ($NF_1$) due to take-off/landing accidents

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($PFH=$person flight hours, $f_2$ is the cruise accident frequency, $(Pr)_2$ is the probability of death of an individual passenger involved in an accident)
The total expected number of fatalities \((TENF)\) is the sum of fatalities from these two types of accidents

\[
TENF = NF_1 + NF_2 = PTL \times f_1 \times (Pr)_1 + PFH \times f_2 \times (Pr)_2. \tag{3}
\]
The PTL from this flight stage is 10, since 10 passengers are involved in the take-off/landing process. The corresponding PFH is 5.0 (\(= 10 \times 0.5\)).
Optimizing Safety of Passenger Transportation with Helicopter

Mathematical model

Computational Experiments

Conclusion and Discussion

PTL = 0 + 3 + 5 = 8
PFH = 0 * 0.2 + 3 * 0.2 + 5 * 0.2 = 1.6
Flying hours = 0.2 + 0.2 + 0.2 = 0.6

PTL = 0 + 2 + 5 = 7
PFH = 0 * 0.2 + 2 * 0.2 + 5 * 0.2 = 1.4
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PTL = (0 + 3) + (0 + 2) = 5
PFH = (0 * 0.2 + 3 * 0.2) + (0 * 0.2 + 2 * 0.2) = 1.0
Flying hours = (0.2 + 0.2) + (0.2 + 0.2) = 0.8
**Introduction**

Optimizing Safety of Passenger Transportation with Helicopter

**Mathematical model**

**Computational Experiments**

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Mathematical model

\[
\min f_1(Pr)_1 \sum_{i \in V} \sum_{j \in V} l_{ij} + f_2(Pr)_2 \sum_{i \in V} \sum_{j \in V} t_{ij}l_{ij}. \tag{4}
\]

Theorem

In the case of unlimited number of helicopters, serving each platform directly is always better than any other service modes in terms of the expected number of fatalities in an Euclidean space.
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In the case of unlimited number of helicopters, serving each platform directly is always better than any other service modes in terms of the expected number of fatalities in an Euclidean space.
Theorem 1 shows that hub-and-spoke configuration is the best way of flying helicopter in terms of the minimum total expected number of fatalities.

It indicates that if we fly a trip with more than one stop, we will increase the total expected number of fatalities ($TENF$).

On the other hand, in a hub-and-spoke solution with heliport as the hub, the cost in terms of the total flying hours will be at its maximum.
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Computational Experiments

- The mathematical model is coded in AMPL and the helicopter routing problem is finally solved with CPLEX 9.0 solver.
- We generated two sets of instances based on the geographical data of the platforms at two offshore operation regions in the Norwegian Sea (A instances) and the North Sea (B instances).
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The fleet is assumed to be homogeneous and each of them can accommodate 19 passengers; each helicopter is operated by two pilots.

Delivery and pickup demands are generated employing the same mechanism for generating random demands in Dethloff (2001) (*Vehicle routing and reverse logistics: the vehicle routing problem with simultaneous delivery and pick-up. OR Spektrum 23:*79-96).*
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In order to compare the solutions, we conducted three runs with different objective functions for every instance.

- First, the objective is to minimize the total travel time (5)

\[
\min \sum_{i \in V} \sum_{j \in V} t_{ij} x_{ij}. \quad (5)
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- Second, the total expected number of fatalities (TENF) i.e. (4) is used as the objective function.
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- Second, the total expected number of fatalities (TENF) i.e. (4) is used as the objective function.
Third, the TENF will also contributed by the crew of two pilots who fly helicopter, so the term (6) is added to the objective function (4), in which \( V_1 \) denotes the node set consisting of the depot node, and the customer nodes with positive demand – either pickup or delivery and the parameter \( c \) denotes the onboard crew size.

\[
f_1(Pr)_1 \sum_{i \in V_1} c + f_2(Pr)_2 c \sum_{i \in V} \sum_{j \in V} t_{ij}x_{ij}. \tag{6}
\]
Illustrative example

**Table 1:** Delivery and pickup demand data for the selected instance

<table>
<thead>
<tr>
<th>i</th>
<th>NJA</th>
<th>DRU</th>
<th>WAL</th>
<th>SCA</th>
<th>ASA</th>
<th>ASB</th>
<th>ASC</th>
<th>TRS</th>
<th>HEI</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>$d_i$</td>
<td>8</td>
<td>0</td>
<td>13</td>
<td>14</td>
<td>14</td>
<td>6</td>
<td>7</td>
<td>11</td>
<td>1</td>
<td>74</td>
</tr>
<tr>
<td>$p_i$</td>
<td>8</td>
<td>0</td>
<td>15</td>
<td>8</td>
<td>14</td>
<td>4</td>
<td>8</td>
<td>9</td>
<td>1</td>
<td>67</td>
</tr>
</tbody>
</table>

**Table 2:** Computational results for the selected instance

<table>
<thead>
<tr>
<th>TENF</th>
<th>flying hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>$TT$</td>
<td>$234.17 \times 10^{-6}$</td>
</tr>
<tr>
<td>$TENF$</td>
<td>$226.45 \times 10^{-6}$</td>
</tr>
<tr>
<td>$TENFc$</td>
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<td>8.55</td>
</tr>
<tr>
<td>( TENF )</td>
<td>226.45 \times 10^{-6}</td>
<td>9.28</td>
</tr>
<tr>
<td>( TENFc )</td>
<td>226.95 \times 10^{-6} (26.64 \times 10^{-6})</td>
<td>8.69</td>
</tr>
</tbody>
</table>
**FIGURE 2**: The shortest solution in terms of the minimum total flying hours of a particular A instance
**Figure 3:** The safest solution in terms of the minimum expected number of fatalities of a particular A instance.
FIGURE 4: The safest solution in terms of the minimum expected number of fatalities when the contribution from onboard crew is included of a particular A instance.
General results

- In A instances, an reduction in the expected number of fatalities can reach up to 13.95%, while the travel time correspondingly increases by 53.28% if we compare two extreme solutions, i.e. the cost minimization solution and the safety maximization solution.

- The reduction of $TENF$ is 17.41% and the travel time increases by 53.01% in B instances.
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**FIGURE 5:** Number of extra helicopters vs. total expected number of fatalities of TENF solution of A instances
**Figure 6:** Number of extra helicopters vs. total expected number of fatalities of TENF solution of B instances
### Table 3: Results on two sets of real cases

<table>
<thead>
<tr>
<th>Instances</th>
<th>Objective</th>
<th>$TENF \times 10^6$</th>
<th>Flying hours</th>
<th>CPU seconds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sola 1-05</td>
<td>TT</td>
<td>699.93</td>
<td>14.78</td>
<td>46.05</td>
</tr>
<tr>
<td></td>
<td>TENF</td>
<td>672.62</td>
<td>15.57</td>
<td>48.23</td>
</tr>
<tr>
<td>Sola 1-10</td>
<td>TT</td>
<td>946.42</td>
<td>28.02</td>
<td>32.90</td>
</tr>
<tr>
<td></td>
<td>TENF</td>
<td>925.61</td>
<td>28.97</td>
<td>32.91</td>
</tr>
<tr>
<td>Sola 1-15</td>
<td>TT</td>
<td>1079.54</td>
<td>36.91</td>
<td>26.68</td>
</tr>
<tr>
<td></td>
<td>TENF</td>
<td>1032.33</td>
<td>37.86</td>
<td>25.52</td>
</tr>
<tr>
<td>Flesland 1-05</td>
<td>TT</td>
<td>585.19</td>
<td>9.82</td>
<td>43.64</td>
</tr>
<tr>
<td></td>
<td>TENF</td>
<td>556.37</td>
<td>10.65</td>
<td>52.34</td>
</tr>
<tr>
<td>Flesland 1-10</td>
<td>TT</td>
<td>746.39</td>
<td>16.68</td>
<td>30.96</td>
</tr>
<tr>
<td></td>
<td>TENF</td>
<td>726.03</td>
<td>17.54</td>
<td>38.68</td>
</tr>
<tr>
<td>Flesland 1-15</td>
<td>TT</td>
<td>853.47</td>
<td>24.36</td>
<td>24.31</td>
</tr>
<tr>
<td></td>
<td>TENF</td>
<td>823.05</td>
<td>25.00</td>
<td>25.21</td>
</tr>
</tbody>
</table>
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- The problem of routing helicopter fleet serving offshore platforms to pickup and deliver offshore workers is studied.
- The mathematical model with safety-based objective is proposed to model the helicopter routing problems in order to plan routes for the fleet in a safer manner.
- The suggested procedure is able to provide the decision-makers with a set of solutions from which they can choose the best trade-off between travel time and transportation safety.
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Thank you and questions!