Risks in DP Shuttle Tanker Offloading Operations

Dr Haibo Chen
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Main Contributors (1999 – 2013)

Dr. Haibo Chen  
Scandpower Inc., Lloyd’s Register  
Beijing, China

Prof. Torgeir Moan  
CeSOS, Dept. of Marine Technology  
NTNU, Trondheim, Norway

Dr. Sverre Haver, Mr. Harald Kleppestø  
Mr. Kjell Larsen  
Statoil, Norway

Dr. Jan Erik Vinnem  
Preventor AS, Stavanger

Capt. Helge Samuelsen  
Mr. Arve Lerstad  
Ship Modelling and Simulation Centre  
Trondheim, Norway

Mr. Kåre Breivik  
Sevan Marine  
Arendal, Norway

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What are offloading concepts: late 1970s - Present

- Indirect offloading:
  - A small offloading platform
  - Submerged offloading systems such as OLS, SAL, STL

- Direct offloading:
  - Tandem/alongside from ship-shaped units (weather vane), typical 80 m distance
  - Normally with hawser and hose connections
What are risks: Collision and Oil Spill

• DP shuttle tanker position loss

• Towards installation: Collision risk
  – DP shuttle tanker collision had occurred on Emerald FSU, Gryphon FPSO, Captain FPSO, Schiehallion FPSO, Norne FPSO, Njord FSU and several loading platforms in the past 15 years in the North Sea.
  – The highest shuttle tanker speed at contact had reached 2.4 knots.
  – The impact energy involved in these collision ranges from a few MJ to around 100 MJ. In one of the collision incident flare tower supporting structure located on the stern of FPSO suffered damage.

• Away from installation: Hose rupture and oil spill risk
Has oil spill happened before?

- On the 20th August 1980: One fatality on the bow of a shuttle tanker performing offloading. The hose was ruptured after hawser breakage and timely shutdown of crude offloading was not achieved. The crude oil pumped to the shuttle tanker bow area and caught fire. (station-keeping problems)

- On the 12th December 2007: Statfjord A loading buoy A rupture in the hose resulted in around 4,400 m³ of crude oil being pumped into the sea. (hose integrity problems)

- Practical frequency model between DP shuttle tanker and FPSO

\[ P(\text{collision}) = P(\text{drive-off}) \times P(\text{Failure of recovery} \mid \text{drive-off}) \]

- \(P(\text{drive-off})\): Frequency of shuttle tanker drive-off forward which has the potential to cause collision.

- \(P(\text{Failure of recovery} \mid \text{drive-off})\): Failure probability of recovery initiated from shuttle tanker, given a shuttle tanker drive-off forward.

- Identify vulnerable situations for drive-off: surging and yawing

- Recognize human recovery element and investigate how to improve

Drive-off Forward: Causes and Frequency

• DP2 shuttle tanker generic drive-off forward frequency is around 0.02 to 0.05 per year (assume 24 hours operation, 1 offloading per week)
  – Incidents information from 1980s to 2009. Estimated DP shuttle tanker offloading hours based on industrial statistical sources.
  – Assumptions related to DP2 vs. DP1 shuttle tankers

• Main causes
  – Controllable pitch propeller, e.g. failure in pitch control, or feedback
  – Position reference systems, e.g. common mode failure of DARPS
  – Sensors, e.g. failure of one wind sensor, hawser tension sensor, or draught sensor
  – DP software, e.g. software error, hidden bugs
  – Human operators, e.g. human errors by DP operator
Vulnerable Situation: Relative Motions in Offloading

- Tanker is vulnerable to drive-off when relative motions between FPSO and tanker is excessive.

**Surging**

**Yawing**

\[ H_s = 5.5 \text{ m loading} / 4.5 \text{ m connection} \]

- **Objectives:**
  - Predict how likely excessive surging and yawing will happen.
  - Identify effective measures to reduce these occurrences.

- **Simulation work in cooperation with Statoil and Marintek**
  - SIMO time-domain simulation of FPSO and tanker
  - Vessel and environmental data provided by Statoil
  - Validation by full scale motion measurements on FPSO and tanker

- **Recommendations**:
  - FPSO should minimize surge motion, and tanker should avoid following a moving target on FPSO stern for positioning.
  - Operational coordination on FPSO and tanker for mean heading.
  - FPSO should minimize yaw motion.

The modelling work was summarized in Journal of Offshore Mechanics and Arctic Engineering, August 2004, Vo.126, 235-242.
DP Operator Recovery Actions

(1) FPSO Stern → Tanker Bow

(2) FPSO Stern → Tanker Bow

(3) FPSO Stern → Tanker Bow
   - Primary
   - Secondary
To stop tanker within a short separation distance in drive-off scenario, recovery has to be initiated very early.

**Big tanker mass vs. Short distance**

<table>
<thead>
<tr>
<th>Separation Distance (m)</th>
<th>50</th>
<th>80</th>
<th>150</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time window for recovery (s)</td>
<td>37</td>
<td>53</td>
<td>81</td>
</tr>
</tbody>
</table>

How much time is needed by a human operator?
Modelling of Operator Intervention

Drive-off Initiation

First Abnormal Signal

Decision time: Ta-Td

Execution time: Td-T1

Time

DECISION

State Evaluation

Task Formulation

INFORMATION

Observation

Detection

EXECUTION

Muscle Command

Action

Action Initiation

Reference: Wickens’ model & Step-ladder model for human information processing stages

A member of the Lloyd’s Register Group
Investigate Operator Action Time

• Incidents indicated that the action initiation time range from one to two minutes.

• Expert judgment by Simulator instructor
  – Simulator training with experienced tanker DP operators
  – An average 29 s in INFORMATION stage and 56 s in DECISION & EXECUTION stages, and in total 85 s for action initiation

<table>
<thead>
<tr>
<th>Time (sec)</th>
<th>Information Stage</th>
<th>Decision and Execution Stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. out of 100 times Training</td>
<td>10 20 20 50</td>
<td>0 20 30 50</td>
</tr>
<tr>
<td>Probability</td>
<td>0.1 0.2 0.2 0.5</td>
<td>0.0 0.2 0.3 0.5</td>
</tr>
</tbody>
</table>
DP Operator Questionnaire Survey in 2002

- 10 captains and 7 DP officers
- 16 Feedbacks of time estimation, 1093 tandem offloadings experience behind.
- Questionnaire formulated based on human action model

- DP operator reaction time to drive-off in simulator
- Human action vs. probability curve fitted, representing best available knowledge.

DP Operator Reaction Time in Drive-off Scenario (2003-2006, 66 simulator observations)
Direct Offloading Development (2007 – 2013)

• Shuttle tanker offloading operations from fixed or geostationary floating offshore installations in the North Sea.
• Offloading from Kristin Platform, 2007, 12-days
• Offloading from geostationary Sevan FPSOs in the Hummingbird/Chestnut fields in the North Sea
• Offloading from Sevan FPSO in the Goliat field in the Barents Sea (2015)
What’s new in direct offloading?

- Separation distance 250 m
- Weathervane with inherent safe heading philosophy
  - Heading pivot point
  - Min. 150 m no entry zone
- No hawser between installation and shuttle tanker

Illustration drawing: The size and distance are not to scale.
Risks in Offloading: Collision and Oil Spill

- DP shuttle tanker position loss!
- Towards installation = Collision risk
- Away from installation = Hose rupture and oil spill risk

The 29th, 30th Int. Conference on Ocean, Offshore and Arctic Engineering (OMAE):
- OMAE2010-21185 for collision risk analysis
- OMAE2011-50344 for oil spill risk analysis

Illustration drawing: The size and distance are not to scale.
Drive-off with Potential for Collision

Illustration drawing: The size and distance are not to scale.
Inherent Operational Safety Barriers

- Shuttle tanker positioning strategy = less than 1 hour drive-off collision risk exposure time vs. 20 hours.

- 250 m distance = Time window for recovery action by tanker DP operator is 3 minutes vs. 1 minute.

**DP Operator Reaction Time in Drive-off Scenario**

(2003-2006, 66 simulator observations)
Collision Frequency: Direct vs. Tandem Offloading

- The collision frequency in the direct offloading ($6.43 \cdot 10^{-5}$ per year) is much lower than the equivalent tandem offloading from FPSO ($1.62 \cdot 10^{-2}$ per year).

**Premises:**
- Offloading once per week, 24 hours operational time.
Summary

• Collision frequency model with “human element” into equation.
  – Study of failure prone situation of drive-off: relative motions
  – Investigate human action time under emergency situations

• Simulator observation of human action and timing

• Direct offloading from geostationary FPSO/installation: from concept to real operation.
References

For more information, please contact:

Dr. Haibo Chen
Managing Director
Scandpower Asia Operations

T +86 138-0132-0200
E hch@scandpower.com
W www.scandpower.com
    www.lr.org