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Abstract

The Floating Production Storage and Offloading (FPSO) concept is a ship shaped production platform frequently used on the Norwegian Continental Shelf (NCS). One of the main advantages of a FPSO is that the produced oil can be stored in the cargo tanks and offloaded to shuttle tankers by tandem offloading. Tandem offloading means that a loading hose from the stern of the FPSO is connected to the bow of the shuttle tanker. The shuttle tankers will then transport the oil to an oil terminal at shore or directly to the market.

Tandem offloading is a safety critical and weather sensitive operation. Adverse weather conditions such as wave heights, polar lows, sea ice, etc., influences the offloading operation considerably. The shuttle tankers will normally be allowed to start the operation, if the significant wave height is below 4,5m and stop if the wave height increases to above 5,5m. A small storage capacity on the FPSO could lead to multiple offloading operations resulting in low regularity for the shuttle tanker operation and transportation. The storage capacity on the FPSO should allow for a full load for the shuttle tanker and also have some margin in order to include uncertainties in the offloading and transportation chain. Typical shuttle tankers have capacities in the range of 550.000 – 850.000 barrels.

The oil companies have long experience with tandem loading on the NCS. However, offshore field developments are now moving further north into the Barents Sea and we are in sub-arctic area. The Goliat and Johan Castberg projects are example on such developments. These new areas have challenges related to sub-arctic climate and weather conditions. There is also a long transportation route, if the oil should be transported directly to the market in Europe. A fleet of dedicated purpose built shuttle tankers may be needed for a field development in this area.

The cost related to offloading and transportation of oil is significant and the following three main questions need to be addressed;

1. How large should be the FPSO storage capacity in order to secure sufficient offloading regularity?
2. How many shuttle tankers are needed and what should be the capacity in order to ensure sufficient regularity of the transportation?

3. How significant wave height, sea ice & polar lows influence the FPSO storage capacity?

For commercial, safety and efficiency reasons, these three questions need to be considered in early phase of the design. The optimal answer depends on many parameters;

- Oil production profile for the FPSO
- Actual weather condition and weather limitations criteria
- Connecting and disconnecting time
- Pump capacity for the oil transfer
- Sailing route and distance to the market
- Regularity requirements
- Shuttle tankers capacity
- Cost for FPSO storage

Using Johan Castberg oil production rate, typical shuttle tanker capacities, wave limitation criteria, time taken by shuttle tankers to travel on 1.5m thick sea ice and 48 hours duration polar lows in the vicinity of FPSO, this dissertation intend to optimize the storage capacity for the FPSO.

It is assumed that produced oil from Johan Castberg field is transported using shuttle tankers to Murmansk oil terminal located in Russia. The reason for assuming a specific field and oil terminal is to gather input parameters, such as production rate, hindcast data, maritime distance in ice infested waters etc. The case study is performed with shuttle tanker capacity of 850,000 bbls. Otherwise, the adopted concept in this dissertation will be general i.e., to serve the wide variety of situations and geographical locations.

In conclusion, the entire exercise undergone in this dissertation is presented as a model, in a “User friendly” Excel spread sheet format for future use.

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Dedicated to my late sister, Nandhini

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DEFINITIONS

The following terms and acronyms / abbreviations are used throughout this dissertation and are defined here for clarity.

Bbl	Barrel
Bow	Bow is the front of the ship.
CAPEX	Capital expenditure
Double acting ship (DAS)	It is a type of icebreaking ship designed to run ahead in open water and thin ice, but turn around and proceed astern (backwards) in heavy ice conditions.
DNV	Det Norske veritas
DP	Dynamic positioning
FEED	Front-end engineering design
FPSO	Floating production storage and offloading
Hrs	Hours
km	Kilometer
knot	The knot is unit of speed equal to 1.852 km/hr
NORSOK	Norsk Sokkels Konkuranseposisjon
NOK	Norwegian kroner
USD	United states dollar
NPV	Net present value
Port	Port is the left side of the ship
Shuttle tanker, ST	A shuttle tanker is a ship designed for oil transport from an off-shore oil field as an alternative to constructing oil pipelines.
Significant Wave Height (Hs) in ‘m’	It is defined as the mean wave height (trough to crest) of the highest third of the waves ($H_{1/3}$)

Starboard	Starboard is the right side of the ship
Stern	Stern is the back of the ship.
Tandem offloading	Tandem offloading means that a loading hose from the stern of the FPSO is connected to the bow of the shuttle tanker.
ST	Shuttle tanker
F_c	Estimated FPSO Capacity in ‘bbls’
ST_c	Shuttle tanker capacity in ‘bbls’
P_R	Production Rate of oil in ‘bbls’
O_R	Offloading Rate (8000 m3/hr)
$T_{FPSO-max}$	Maximum time FPSO can produce without offloading
S1	Service speed of Shuttle tanker in open water
S2	Service speed of Shuttle tanker / DAS in ice infested water
D1	Maritime distance in open water, between offshore field and Oil terminal
D2	Maritime distance in ice infested water, between offshore field and Oil terminal
T1	Time taken to connect shuttle tanker and FPSO in ‘hrs’
T2 or T_{ST-min}	Minimum Time taken to fill the Shuttle tanker (full parcel) in ‘hrs’
T3	Time taken to disconnect shuttle tanker from FPSO in ‘hrs’
T4	Time taken by ST to travel from offshore field to oil terminal in ‘hrs’
T5	Time taken to connect ST with Oil terminal in ‘hrs’
T6	Time taken for offloading at oil terminal in ‘hrs’
T7	Time taken to disconnect ST from Oil terminal in ‘hrs’
T8	Time taken by ST to travel from Oil terminal to Offshore field in ‘hrs’
T_{ST-RT}	Time taken for ST Round Trip Operation Cycle in ‘hrs’
$T_{FPSO-ST\ min}$	Minimum time required for FPSO to deliver full parcel to shuttle tanker in ‘hrs’
T_{ST-W}	Waiting Time for ST in the field in ‘hrs’
N	Number of ST Required

SF, SF_1, SF_2, SF_3	Safety factor
T_{BS}	Buffer storage time duration in ‘hrs’. i.e., Time interval between $T_{FPSO\text{-}max}$ & $T_{FPSO\text{-}ST\ min}$
$FPSO_{BS}$	FPSO buffer storage capacity in ‘bbls’

1. INTRODUCTION

This chapter covers the background, motivation, objectives, and summary of this dissertation. It starts with a brief introduction to the floating, production, storage and offloading (FPSO) concept and an outline of tandem offloading operations between FPSO and shuttle tanker.

1.1 Background

Around the world, offshore production of hydrocarbons is moving into deeper and even more remote locations such as Barent sea in Arctic regions. Particularly for remote or deep water locations, FPSO – Shuttle tanker combination is essential for cost effective oil production, storage, offloading and transportation. The FPSO concept is based on a combination of traditional ship building technology and platform design. The following definition with respect to FPSO is found in the NORSOK Standard (Haibo Chen, 2003):

> FPSO - Ship Shaped Floating Production, Storage and Offloading Unit
>
> A floating unit can be relocated, but is generally located on the same location for a prolonged period of time. Inspections and maintenance are carried out on location. The Floating Production, Storage and Offloading unit normally consists of a ship shaped hull, with an internal or external turret, and production equipment on the deck. The unit is also equipped for crude oil storage. The crude may be transported to shore by shuttle tankers via an offloading arrangement.

With an increasing number of FPSOs in use, the number of shuttle tankers performing crude oil offloading from these FPSOs is increasing.

A shuttle tanker is a specialized ship designed to transport oil from offshore oil fields to onshore refineries. Shuttle tankers are often used as an alternative to pipeline in harsh climates, remote locations or deep water. Shuttle tankers operate independently in all water and weather conditions. Shuttle tankers are equipped with bow and stern thrusters as well as dynamic positioning to keep the tanker on location.

Shuttle tankers were initially used in the North Sea in the 1970s. Since then the value of using a shuttle tanker instead of pipelines has increased worldwide. The reason being, crude oil from various sources is commingled in a pipeline, but oil offloaded into a shuttle tanker will not be commingled with oil from other producers. Also, Shuttle tankers offer the flexibility of loading oil and transporting it to any destination as opposed to pipelines, which are fixed to one receiving terminal.

FPSOs offload the oil directly to shuttle tanker, to transport the oil to an oil terminal at shore or directly to the market. This direct offloading operation is carried out generally via a tandem configuration (shown schematically in Figure 1-1). Tandem offloading is a safety critical and weather sensitive operation.

Tandem offloading means that a loading hose from the stern of the FPSO is connected to the bow of the shuttle tanker. According to Haibo Chen (2003), during tandem offloading, shuttle tanker is positioned at some distance, e.g. 80 m, behind the FPSO. The two vessels are physically connected by a mooring hawser and a loading hose through which cargo is offloaded. The tanker may position itself by Dynamic positioning (DP) mode or taut hawser mode. The DP tankers have greater uptime in harsh environments and therefore are widely applied in the North Sea.

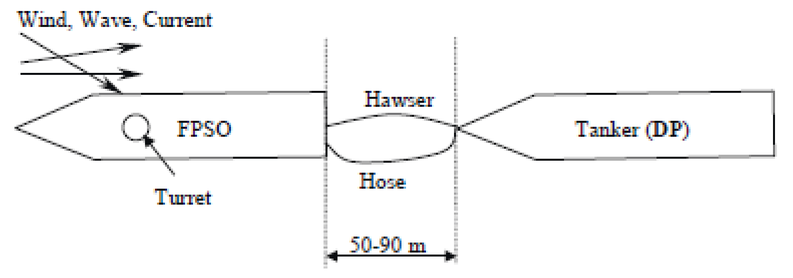


Figure 1-1: FPSO and DP shuttle tanker in tandem offloading operation

Figure.1-2, shows the offloading of stored oil from a floating production storage and offloading (FPSO) unit to a shuttle tanker (Steven and Satish, 2009).

Figure 1-2 : Offloading of a FPSO by shuttle tanker and tugs

According to Haibo Chen (2003), FPSO and DP shuttle tanker tandem offloading operation in principle can be summarized into the following five operational phases, from the point of view of the tanker.

1. Approach: Tanker approaches FPSO stern and stops at a required or specified distance.
2. Connection: Messenger line, hawser and loading hose are connected.
3. Loading: Oil is transferred from FPSO to tanker.
4. Disconnection: Manifold is flushed; loading hose and hawser are disconnected.
5. Departure: Tanker reverses away from FPSO stern while sending back hawser messenger line, and finally sails away from the field.

The tandem offloading operation is a frequent, yet complex and difficult marine operation. It may range from every 3 to 5 days, depending on the production rate, storage capacity of FPSO, and shuttle tanker size. The duration of the operation is based on Shuttle tanker size and oil transfer rate. Meanwhile, a suitable environmental condition is required. FPSO may weathervane (rotate according to the weather) around its turret, located either internally or externally and it may also have significant low frequency motions in the horizontal plane (surge, sway and yaw) due to waves and wind in harsh environments. In order to stay connected for loading and at the same time maintain a separation distance, e.g. 50-90 m behind FPSO stern, the DP shuttle tanker has to position itself according to the FPSO position.

1.2 Motivation

Considering offloading operations in an early stage of the design, increases the safety and reliability of hydrocarbon transfer. Offloading operations have large impact on the design and operation of FPSO. This is because of the possible weather downtime of the offloading operation which affects the overall economic performance of the FPSO.

Front-end engineering design (FEED) is necessary for any new project. This need to be carried out to the necessary extent before the development of specifications, the invitation to tender package, and, in general, the bidding phase.

This dissertation ease the multidisciplinary activities by bringing together the contribution of various engineering disciplines as a model that can be used in the early design phase. This all-inclusive model reduces discontinuities among multidiscipline during the FEED stage.

This dissertation presents a new optimization approach for the determination of storage capacity of FPSO. The concept and associated formulas conceived by the author in this dissertation is unique in all aspects.

1.3 Objectives

The overall objective of this thesis is to develop a model that can be used in the early design phase to answer the 3 main questions described below.

1. How large should be the FPSO storage capacity, in order to secure sufficient offloading regularity?
2. How many shuttle tankers are needed and what should be the capacity, in order to ensure sufficient regularity of the transportation?
3. How significant wave height, sea ice & polar lows, influence the FPSO storage capacity?

For commercial, safety and efficiency reasons, these three questions shall be considered early phase of the design. The optimal answer depends on many parameters;

- Oil production profile for the FPSO
- Actual weather condition and weather limitations criteria
- Connecting and disconnecting time
- Pump capacity for the oil transfer
- Sailing route and distance to marked
- Regularity requirements
- Shuttle tanker capacity
- Cost for FPSO storage

By controlling the above mentioned parameters efficiently, will ensure offloading regularity and secures better economics from the supply chain.

1.4 Summary

It is assumed that produced oil from Johan castberg field (located in Barent Sea) is transported using shuttle tankers to Murmansk oil terminal. The reason for assuming a specific field and oil terminals is to gather input parameters, such as production rate, maritime distance in ice infested waters etc., Otherwise, the adopted methodology in this report will be general i.e., to serve the wide variety of situations and geographical locations.

Using Johan castberg oil production rate (Audun Kjeldsen, 2013), typical shuttle tanker capacities, wave limitation criteria, time taken by shuttle tankers to travel on 1.5m thick sea ice and 48 hour duration polar lows in the vicinity of FPSO, this dissertation intend to optimize the storage capacity for the FPSO.

Adverse weather conditions such as higher significant wave heights, polar lows, sea ice, etc., influences the offshore offloading operation considerably. This necessitates evaluating the offloading and transportation regularity during the different time of the year.
A small storage capacity on the FPSO could result in low regularity for the shuttle tanker operation and transportation. The storage capacity on the FPSO should allow for a full load

for the shuttle tanker and also have some margin in order to include uncertainties in the offloading and transportation chain.

According to Norsk Olje & gass, Lesson #20777 – hull capacity,

> *"Recommended FPSO storage capacity to be 30% more than shuttle tanker capacity."*
>
> i,e., FPSO storage capacity = 1,3 * Shuttle tanker capacity.

However, safety factor - 1,3 may not be sufficient to ensure continuous FPSO production in situations such as shuttle tanker arrival delay and awaiting favorable weather conditions for offloading operation. Therefore, the factor should be increased to curtail loss / deferred production, due to full FPSO storage.

Increase in FPSO storage, increases FPSO CAPEX cost. The optimum storage capacity of FPSO can be found by performing cost – benefit analysis. By calculating Net present value for the investment, we can conclude whether the investment proposal is viable option or not.

Sensitivity of key parameters is discussed in the respective chapters. In conclusion, the entire exercise undergone through this thesis is presented as a model, in a "User friendly" Excel spread sheet format for future use.

2. ARCTIC ASPECTS

The potential wealth of natural resources in the Arctic and the loss of sea ice due to climate change are resulting in increased exploration and production activity in the region. As this activity moves further offshore and into remoter areas, the operational and environmental risks associated with this opportunity are enormous.

Barents Sea is not uniform with respect to ice and metocean conditions. DNV dissected Barents Sea into 8 sub areas. Our area of interest, Norwegian Sea (II) is the south-western part of Barents Sea. This sub area is generally ice free. Refer Figure.2-1 (Ove Tobias Gudmestad, 2013) for more information.

Barents Sea is not uniform with respect to ice and metocean conditions

MANAGING RISK DNV

Sub-areas with uniform ice conditions

(modified from to AARI):

- I) Spitsbergen
- II) Norwegian
- III) Franz Josef Land
- IV) Northeast Barents Sea
- V) Novozemelsky
- VI) Kola
- VII) Pechora
- VIII) White Sea

Sub-area II is generally ice free.

Sub-areas I, III, IV, VII and VIII usually have ice every winter.

Sub-areas V and VI are in-between

Barents Sea = Coastline Tromsø – Ostrov Island (Kara Gate), West coast of Novaya Zemlya, northern tip of NZ to north of Franz Josef Land, shelf break to NW of Spitsbergen, shelf break toTromsø

Coastal areas are included due to terminals, harbors, yards and future onshore related plants, e.g. for LNG

Figure 2-1 : Sub-areas of Barents Sea - DNV dissection

2.1 Field description

The Johan Castberg project comprises the Statoil-operated discoveries Skrugard, Havis and Drivis located in PL 532. According to “Statoil”, the proven volumes in Johan Castberg are estimated to be 400-600 million barrels of oil.

The Johan Castberg development is seen as the second offshore oil development in the Barents Sea. (Goliat being the first oil development, and Snøhvit being a subsea gas development)

Operator is in the process of finalizing the offshore development solution, either Semi-submersible or FPSO. These floating units are considerably larger than any floating production units constructed so far, on the Norwegian continental shelf.

The field is located in blocks 7219/9 and 7220/4, 5, 7, about 100 km north of the Snøhvit field in the Barents Sea, 150 km from Goliat and nearly 240 km from Melkøya. The water depth is 360-390 meters. Skrugard and Havis are located 7km apart.

The location of the field in a sub-arctic area with possibilities of sea drift ice, large snowfalls and low temperatures gives specific design requirements to be met beyond standard requirements for the North or Norwegian Sea. The production parameter (Audun Kjeldsen, 2013) for Johan Castberg field is given in Table 2-1.

Table 2-1 : Johan Castberg field production parameter

Type of Floating production unit	Ship shaped FPSO
Oil Production rate	190000 bbl/day (or) 7862 bbls/hr

3. ENVIRONMENTAL CHALLENGES

Oil transportation in the Barents Sea poses many challenges to the field operators. There are number of challenges more specific to the Barents Sea, in addition to usual challenges associated with offshore oil transportation. Some of the challenges are higher wave height, sea ice, polar lows, atmospheric & spray icing, long periods of low visibility, remoteness, winterization, etc. Of these challenges, this dissertation considers only the influence of significant wave height, sea ice and polar lows on the shuttle tanker operation, which in turn affects the storage capacity of FPSO.

3.1 Significant wave height, Hs

Offloading can normally be effected in a number of ways; the most important is the wave limitation criteria. Tandem offloading is a safety critical and weather sensitive operation. The shuttle tankers will normally be allowed to start the operation if the significant wave height is below 4,5m and stop, if the wave height increases to above 5,5m.

3.2 Presence of sea ice

The presence of sea ice is one of the most obvious challenges for offshore transportation operation. According to Alain, GustoMSC, Remco van der List (2013), challenges related to sea ice presence are:

- High loads on the FPSO & shuttle tankers and their station keeping systems. When ice moves along the long side of the ship, high ice forces act on the ship.
- Damage to operational equipment such as thrusters, riser string and subsea equipment.
- Restricted maneuverability, requiring ice classed double acting shuttle tankers or ice breaker assistance for transits.
- Availability and suitability of escape, evacuation and rescue means.

3.3 Polar low pressure

Polar lows are scale cyclones that form near the ice edge or coast, where very cold air flows from ice or land surfaces over open water, which is warm relative to the air temperature (Sigurd R Jacobsen. 2012). The cold air warms, rises, the pressure falls, a circulation evolves and, depending on other supportive factors such as cooling aloft, the polar low deepens or weakens. Polar lows are very difficult to forecast. We have lack of in situ data, because there are only few weather stations in Polar Regions. The polar lows occur in the season from autumn to winter with a frequency of 2 to 4 per month. Polar lows are potential threat to all activity in the Barents Sea, due to their unpredictable nature. Polar lows develop in a short space of time and have a short lifespan. Polar lows have durations of 6 to 48 hours. Polar low is accompanied by heavy snowfall. The combination of wind, snow and sea spray can increase the danger of icing on vessels, affecting their stability.

4. NORSOK REQUIREMENTS

Offloading operations have a large safety impact, because by definition they involve operation of two heavy structures in close proximity. The safety of personnel and the offshore structure, plus the possible environmental impact is of greater concern for regulating authorities as well as the industry itself. The NORSOK standards are developed by the Norwegian petroleum industry to ensure adequate safety, value adding and cost effectiveness for petroleum industry developments and operations.

4.1 Classification of Barents Sea license area

Norsok N-003 classifies Barents Sea license area of the Norwegian continental shelf as shown in Figure 4-1. Johan Castberg field is located on the border lines of B1 & C zones between Hammerfest and Bjørnøya islands.

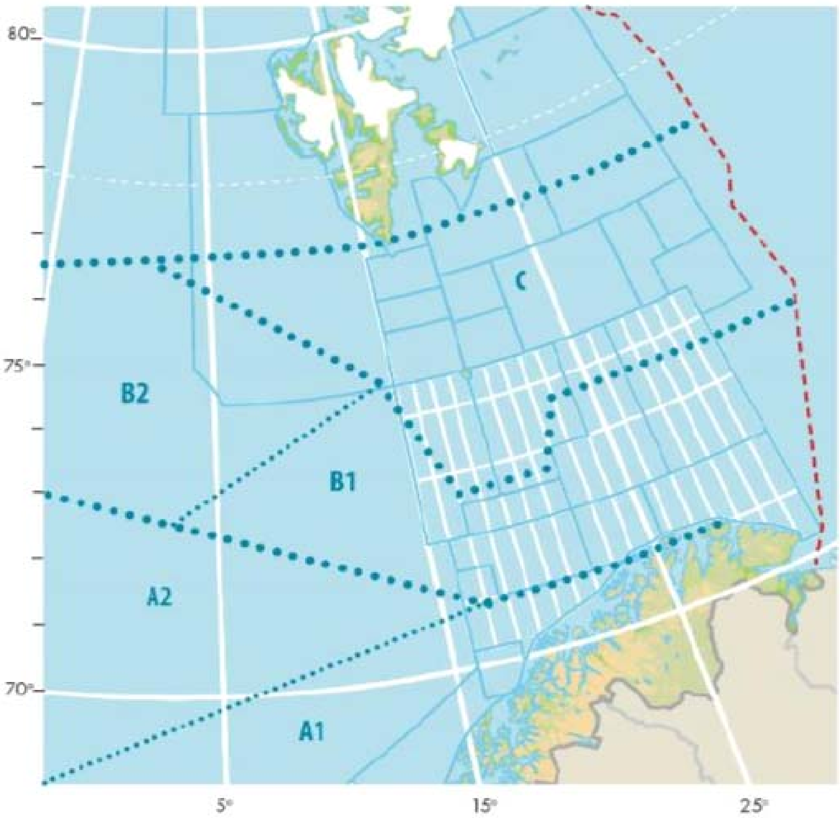


Figure 4-1 : Classification of oil and gas license Barents Sea. Reference Norsok N-003

4.2 Metocean actions

Metocean data describes the physical environment of a location. A good knowledge of metocean conditions is essential for the safe, efficient design and operation of offshore installations. The metocean environment at Johan Castberg field is relatively severe, with a frequent occurrence of high waves, possibility of sea ice and polar lows.

4.2.1 Sea ice & Polar low

According to Norsok N-003, Metocean conditions for zones B1 & C, "Sea ice will occur with annual probability of exceedance 10^{-4}" & "Polar lows may occur". At the same time, Norsok suggest that for planning of operations, the monthly extreme ice limit with annual probability of exceedance of 10^{-2} may be used. Figure 4-2 presents the occurrence of first year ice with annual probability of exceedance of 10^{-2} in the Barents Sea, as given in Norsok N-003.

According to Norsok N-003, "All operations planned in regions with potential for sea ice shall establish an ice management system. The objective of ice management system shall be to reduce the ice risk either by reducing the likelihood of ice-structure interaction or reducing the severity of the interaction." The use of double acting shuttle tankers for oil transportation is a classic example of severity reduction.

4.2.2 Significant wave height, Hs

According to study published by Jim and W. Erick (2014), huge areas of ice-free water are leading to massive waves in the Arctic Ocean. Massive waves are not only possible because of Arctic sea ice melting, but they also have the power to cause sea ice melt themselves. Even though the observation is based on Beaufort Sea, the report concluded that it is applicable to the rest of the Arctic Ocean. It also states that "*Future scenarios for reduced seasonal ice cover in the Arctic suggest that larger waves are to be expected and that swells will be more common. Although the actual wave effects will of course be site specific and complex, our scaling is a starting point in understanding the rapidly changing wave climate in the Arctic Ocean and the likely expanding future role of waves in the Arctic system.*"

The sea states in the non-ice periods are represented by significant wave height. According to Norsok-N003, Significant wave height will occur with annual probability of exceedance of

10^{-2}. Figure 4-3 presents significant wave height and related time period with annual probability of exceedance of 10-2 for sea states of 3hr duration, as given in Norsok N-003.

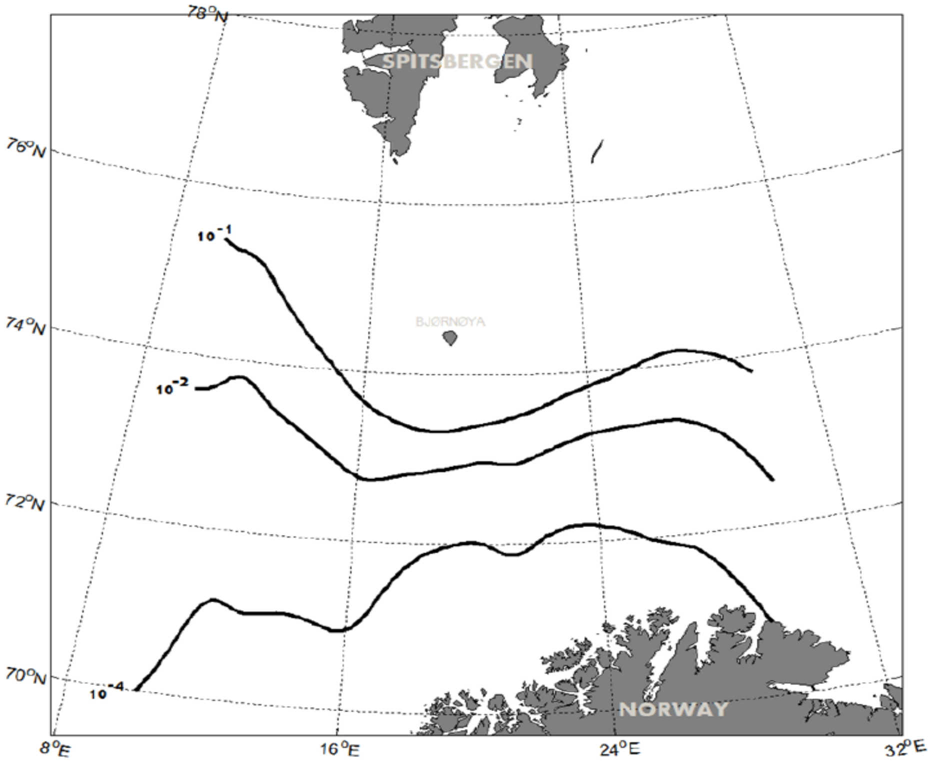


Figure 4-2 : Limits of sea ice extent in the western Barents Sea with annual probability of exceedance of 10^{-1}, 10^{-2} and 10^{-4}. The values given only apply to Norwegian continental shelf.

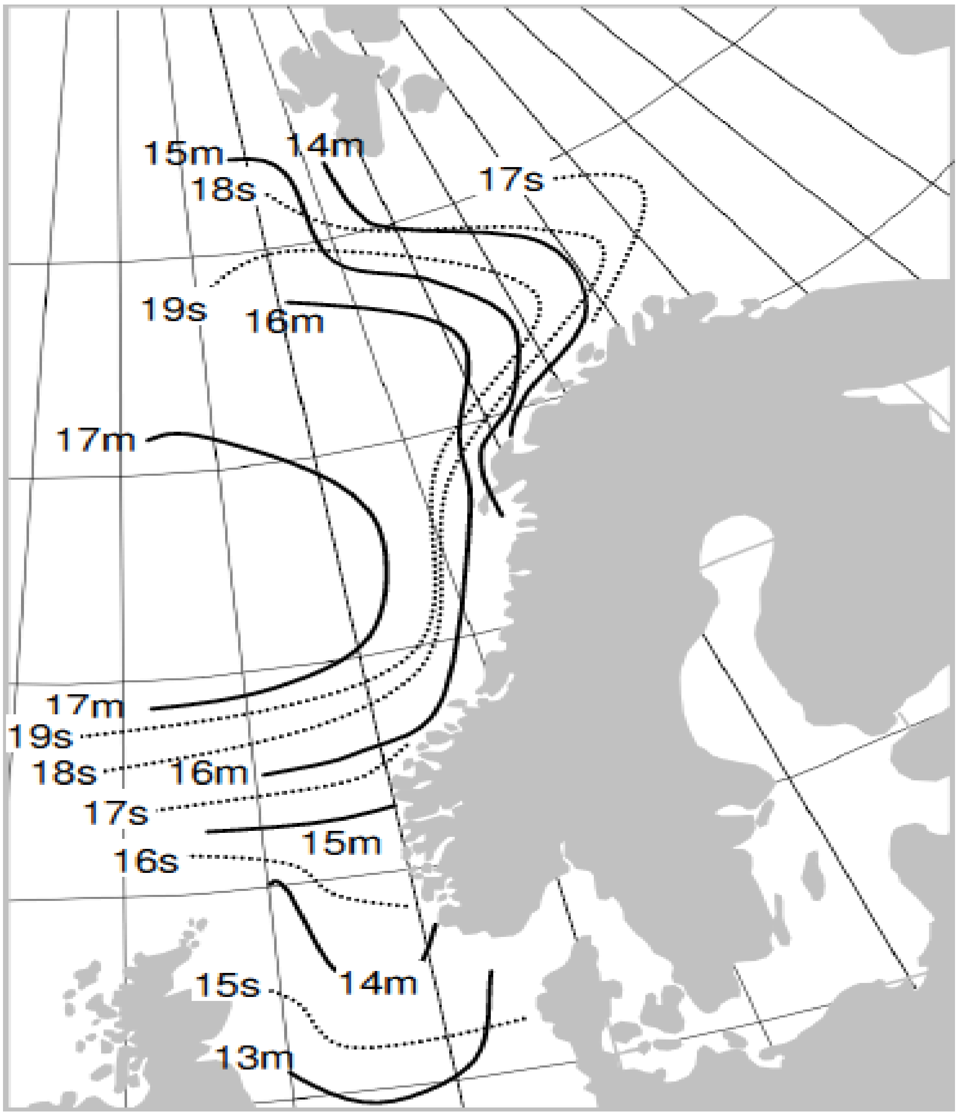


Figure 4-3 : Significant wave height Hs and related maximum peak period Tp with annual probability of exceedance of 10^{-2} for sea states of 3h duration. ISO-curves for wave heights are indicated with solid lines while wave period lines are dotted.

5. OFFLOADING OPERATION

The operation of deep water offshore oil fields entails transferring oil that accumulates in FPSO to onshore oil terminals. A fleet of shuttle tankers are deployed for transferring oil from large oil fields, giving rise to the challenge of scheduling these shuttle tankers to meet the operational constraints, while minimizing waiting time on field, costs and economic losses. For large FPSO's, a fleet of shuttle tanker is required and scheduling of shuttle tanker among terminal and FPSO's should be optimized.

According to Eduardo, Agustinho and Fernando (2012), calculating FPSO storage capacity can be treated as a business case. The daily flow rates, production downtimes, minimum FPSO storage volumes, minimum volume to be offloaded from the FPSO's, the amount of oil left in a FPSO ready for offloading, Shuttle tanker capacity, ST scheduling optimization are some of the constraints that affect the business case. Controlling these constraints efficiently will ensure offloading regularity and secures better economics from this supply chain.

5.1 Strategy

The optimization (of storage capacity of FPSO) process involves the following steps.

- Main design parameters in the offloading and transportation process.
- Assumptions
- Limitations.
- Calculate Minimum time required to fill the shuttle tanker.
- Calculate ST round trip operation cycle time.
- Calculate minimum time required for FPSO to deliver full parcel to ST.
- Calculate waiting time for ST in the field.
- Calculate optimum ST fleet size.

5.2 Main design parameters in the offloading and transportation process

Table 5-1 presents the parameters of the Oil field production scenario, FPSO, Shuttle tankers and onshore terminals.

Table 5-1 : Main design parameters

S. No	Abbreviation	Description	Formula	Units
1	F_c	Estimated FPSO Capacity		bbls
2	ST_c	Shuttle tanker capacity		bbls
3	P_R	Production Rate of oil		bbls/hr
4	O_R	Offloading Rate		bbls/hr
5	$T_{FPSO\text{-}max}$	Maximum time FPSO can produce without offloading	F_c/P_R	hrs
6	S1	Service speed of Shuttle tanker in open water		knots
7	S2	Service speed of Shuttle tanker in ice infested water		knots
8	D1	Maritime distance in open water, between offshore field and Oil terminal		km
9	D2	Maritime distance in ice infested water, between offshore field and Oil terminal		km
10	T1	Time taken to connect shuttle tanker and Fpso		hrs
11	T2 or $T_{ST\text{-}min}$	Minimum Time taken to fill the Shuttle tanker (full parcel)	ST_c / O_R	hrs
12	T3	Time taken to disconnect shuttle tanker from Fpso		hrs
13	T4	Time taken by ST to travel from offshore field to oil terminal	(D1/S1)+(D2/S2)	hrs
14	T5	Time taken to connect ST with Oil terminal		hrs
15	T6	Time taken for offloading at oil terminal	ST_c / O_R	hrs
16	T7	Time taken to disconnect ST from Oil terminal		hrs
17	T8	Time taken by ST to travel from Oil terminal to Offshore field	(D1/S1)+(D2/S2)	hrs
18	$T_{ST\text{-}RT}$	Time taken for ST Round Trip Operation Cycle	T=T1+T2+T3+T4+T5+T6+T7+T8	hrs
19	$T_{FPSO\text{-}ST\ min}$	Minimum time required for FPSO to deliver full parcel to shuttle tanker	$=ST_C*((1/PR)-(1/OR))$	hrs
20	$T_{ST\text{-}W}$	Waiting Time for ST in the field.	$T_{ST-W}=\left[\left(\frac{ST_C}{P_R}*N\right)-\left(T_{\text{ST-RT}}\right)\right]$	hrs
21	N	Number of ST Required	$N=\frac{\left[(72+T_{ST-RT})*P_R\right]}{ST_C}$	no.

5.3 Assumptions

Assumptions and limitations affect the inferences we can draw from this dissertation. Hence, parameters are intricately spelled out to help readers understand the boundaries of this dissertation.

Table 5-2 : Assumptions

S. No	Abbreviation	Design / Calculated parameter	Assumption	Units
1	ST_c		850,000	bbls
2	P_R	7862 Refer Table 2-1		bbls/hr
3	O_R	50314 (Norsk Olje & gass, Lesson #20782 – Offloading Rate - 8000 m^3/hr)		bbls/hr
4	S1		12	knots
5	S2		3 (in 1.5 m thk ice)	knots
6	T1		3 (Conservative)	hrs
7	T3		3 (Conservative)	hrs
8	T5		3 (Conservative)	hrs
9	T6		Time taken for offloading cargo from ST at oil terminal (T6) = Time taken to fill the ST (T2)	hrs
10	T7		3 (Conservative)	Hrs
11	During peak winter months from December to March, DAS tankers are used in ice infested waters.			
12	Both shuttle tanker and FPSO offloading stations are sufficiently winterized.			
13	Both FPSO & DAS tankers are designed to operate in 1.5m thick ice.			

Table 5-3 : Maritime distance from offshore Oil field to Oil terminal

From / To	Murmansk	
	Open water	Ice infested water
Units	Km	Km
Maritime distance between Johan Castberg field and oil terminal during winter months	300	335 (assumption)
	Total Distance = 635 km (Maritime distance)	

5.4 Limitations

The following limitations, but not limited to, in this dissertation cannot be reasonably dismissed and can affect the Round trip operation cycle of shuttle tankers.

- Time taken for Flushing of Shuttle tankers after offshore loading operation.
- Time taken for Striping / flushing of shuttle tankers after discharging cargo at oil terminal.
- Time taken for fueling (bunker) operation.
- Minimum draft requirements of FPSO & Shuttle tankers.
- Maximum filling requirements for Shuttle tankers.

5.5 Calculate Minimum time required to fill the shuttle tanker

Cargo oil would be offloaded to the shuttle tanker using the FPSO's main cargo pumps. Excluding weather downtime, the minimum time required to fill shuttle tanker is determined using,

- Shuttle tanker capacity.
- Offloading rate of FPSO main cargo pumps.

$$\text{T2} = T_{ST-\min} = \left[\frac{STc}{O_R}\right] \text{ in 'hrs'----------------------(5.1)}$$

5.6 Calculate ST Round Trip Operation Cycle time

Shuttle tanker makes regular round trips between a producing field and an onshore terminal or oil refinery. Round trip time of the shuttle tanker is the sum of the following components,

$T_{ST\text{-}RT} = \{$(T1) Time taken to connect shuttle tanker and FPSO +

(T2) Minimum Time taken to fill the Shuttle tanker (full parcel) +

(T3) Time taken to disconnect shuttle tanker from FPSO +

(T4) Time taken by ST to travel from offshore field to oil terminal +

(T5) Time taken to connect ST with Oil terminal +

(T6) Time taken for offloading at oil terminal +

(T7) Time taken to disconnect ST from Oil terminal +

(T8) Time taken by ST to travel from Oil terminal to offshore field}

$$T_{ST\text{-}RT} = \{T1+T2+T3+T4+T5+T6+T7+T8\} \text{ in 'hrs'---------(5.2)}$$

5.7 Calculate Minimum time required for FPSO to deliver full parcel to ST

A major constraint on FPSO operation is to recognize the balancing demands of achieving optimal plant throughput and allowing timely off-take before the storage on the FPSO is full and production has to be curtailed. Offloading can normally be effected in a number of ways and the most appropriate is the prevailing sea and weather conditions. To reduce the uncertainties associated with sea and weather conditions, offloading operation should be initiated as soon as FPSO is ready to deliver full parcel to ST.

The minimum time required ($T_{FPSO-ST\min}$) for FPSO to deliver full parcel to shuttle tanker can be found by equating,

{[Required Minimum filled in Volume of FPSO to start offloading] +
[Volume of Production during offloading period]} = {ST capacity}

$$\left[(T_{FPSO-ST\min} * P_R) + \left(P_R * \frac{ST_C}{O_R} \right) \right] = ST_C$$

$$\left[T_{FPSO-ST\min} * P_R \right] = STc - \left[P_R * \frac{ST_C}{O_R} \right]$$

$$T_{FPSO-ST\min} = \left[\frac{STc}{P_R} \right] - \left[\frac{ST_C}{O_R} \right]$$

$$T_{FPSO-ST\min} = STc \left[\frac{1}{P_R} - \frac{1}{O_R} \right] \text{ in 'hrs'-----(5.3)}$$

5.8 Calculate waiting time for shuttle tankers in the field

The goal is to solve the scheduling problem and find a feasible schedule that minimizes the combination of inventory holding, underproduction, and transportation costs in an acceptable computational time respecting all the constraints.

The ST waiting time ($T_{ST\text{-}W}$) in the field can be computed by equating,

{Shuttle Tanker waiting time in the field} =

{[Time taken to produce oil for ST capacity * No. of shuttle tankers] -
[Time taken for ST Round Trip Operation Cycle]}

$$T_{ST-W} = \left[\left(\frac{ST_C}{P_R} * N\right) - \left(T_{\text{ST-RT}}\right)\right] \text{ in 'hrs'----------(5.4)}$$

Where, N is the number of ST. For the assumed shuttle tanker capacity, given rate of production and Time taken for ST round trip operation, N can be varied to get the optimal waiting time in the field.

5.9 Calculate optimum Shuttle tanker fleet size

Working out an adequate shuttle vessel requirement is very important as it involves cost and time in a big way. The number and type of shuttle vessel is determined by:

- Rate of production.
- Distance from port of discharge
- Speed of shuttle tankers.
- Shuttle tanker capacity.

Today industrial practice is to allow 3 days (72 hours) Shuttle tanker waiting time in the field. Substituting shuttle tanker waiting time of 3 days in Eqn. (5.4) and rearranging the equation, the number of shuttle tankers required is given by,

$$N = \frac{\left[(72 + T_{ST-RT}) * P_R\right]}{ST_C} \text{ ------------------ (5.5)}$$

6. WAVE LIMITATION CRITERIA

Offloading can normally be effected in a number of ways and the most appropriate is the prevailing sea and weather conditions. For marine operations such as offshore offloading, the time history of weather conditions and duration of weather events are the key parameters. As discussed in DNV-RP-H103, “Recommended practice for modelling and analysis of marine operations”, Weather criteria and availability analysis shall include identified environmental parameters critical for an operation and provide duration of the events for exceeding and not exceeding the threshold limits of these parameters.

Wave data for new fields must often be obtained by measurements, hindcasting, or from comparable situations. This chapter describes the metocean data for Johan Castberg field required for the development of FPSO design.

6.1 Hind cast data

Marine operations need reliable metocean information. The site-specific metocean conditions at a particular location have a great influence on operability of FPSO. The parameters describing the environmental conditions shall be based on observations from or in the vicinity of the relevant location and on general knowledge about the environmental conditions in the area. According to Norsok N-003, Chapter 6.1.1, Environmental conditions, “If wave observations at the preferred locations are limited, measured data can be replaced by hind cast predictions. Hind casting can be used to extend measured time series, or to interpolate to places where measured data have not been collected.” Using hind cast data (From January’1947 to December’2014) for Johan Castberg field, significant wave heights durations that do not allow offloading operations were analyzed and presented in forthcoming sections.

6.2 Wave limitation criteria for offloading operation

Tandem offloading is a safety critical and weather sensitive operation. In the field, Shuttle tankers wait for favorable weather window to start the offloading operation.

Wave limitation criteria for offloading operation include,

- If the average wave height in the area is below 4.5 m, offloading operation is initiated.
- If wave heights increase above 5.5m offloading operation is aborted and postponed until wave heights decrease below 4.5m

Applying wave limitation criteria on hindcast data, we can establish duration of wave heights that does not allow offloading operation for any month or any year. As an example, Figure 6-1 & 6-2 presents the significant wave height for Jan'2013 & for the year 2013 respectively. The registration in these figures shows that there are wave heights above 4,5m where offloading operations cannot be initiated. From figure 6-2, we can also infer that such events occur frequently in the winter months (October to March) than in the summer months (April to September).

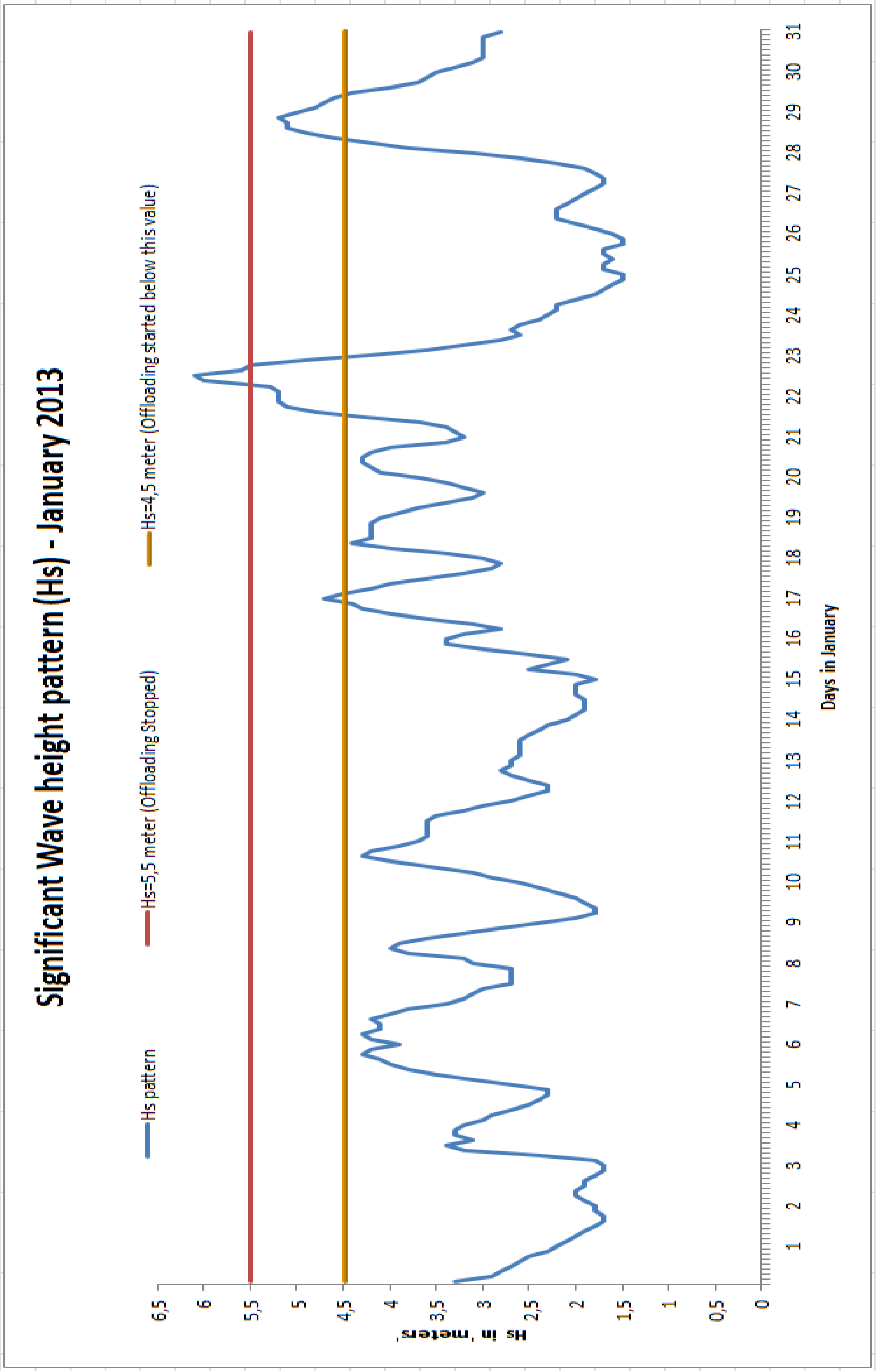


Figure 6-1 : Significant wave height pattern (Hs) - January 2013

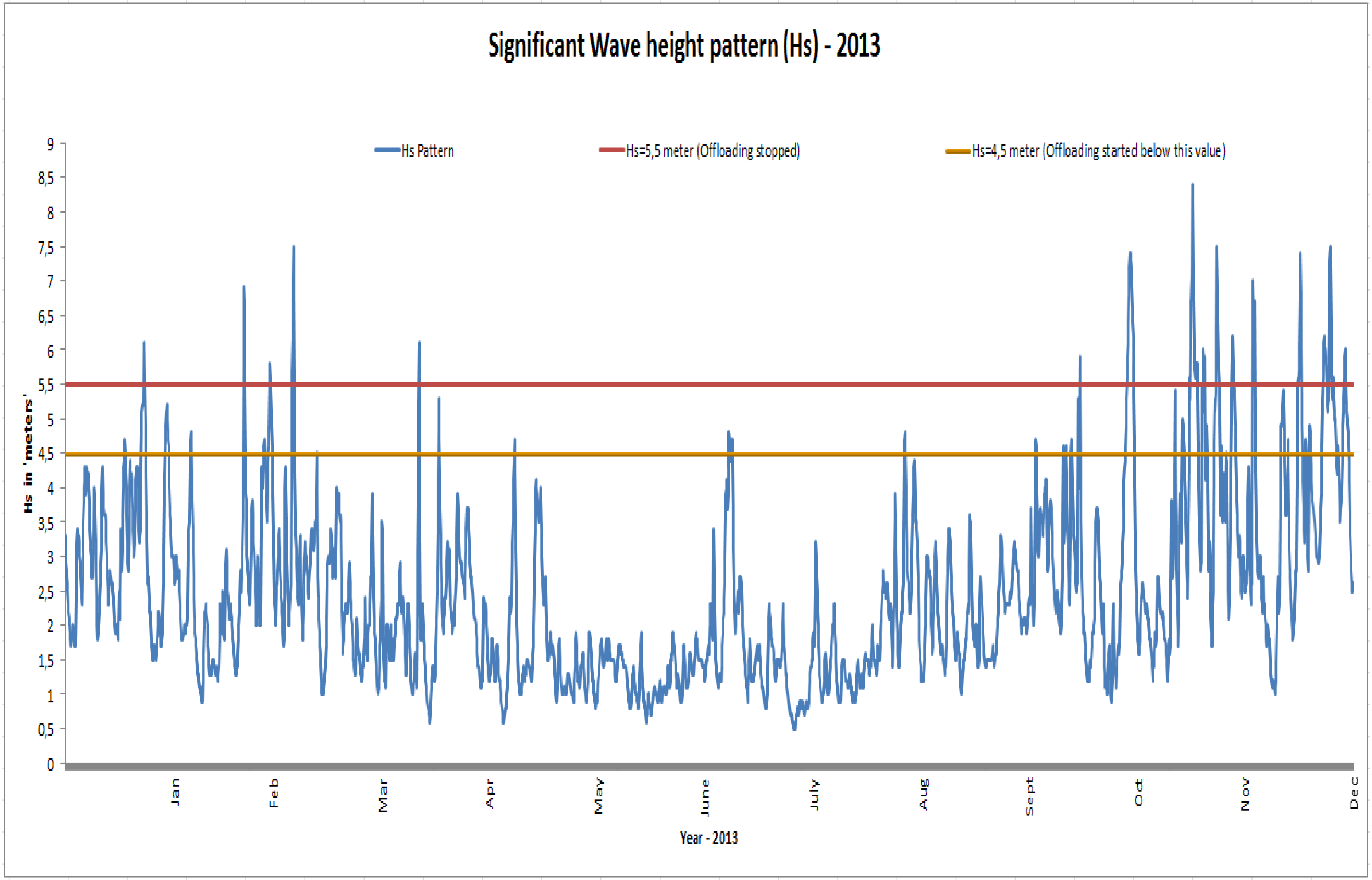
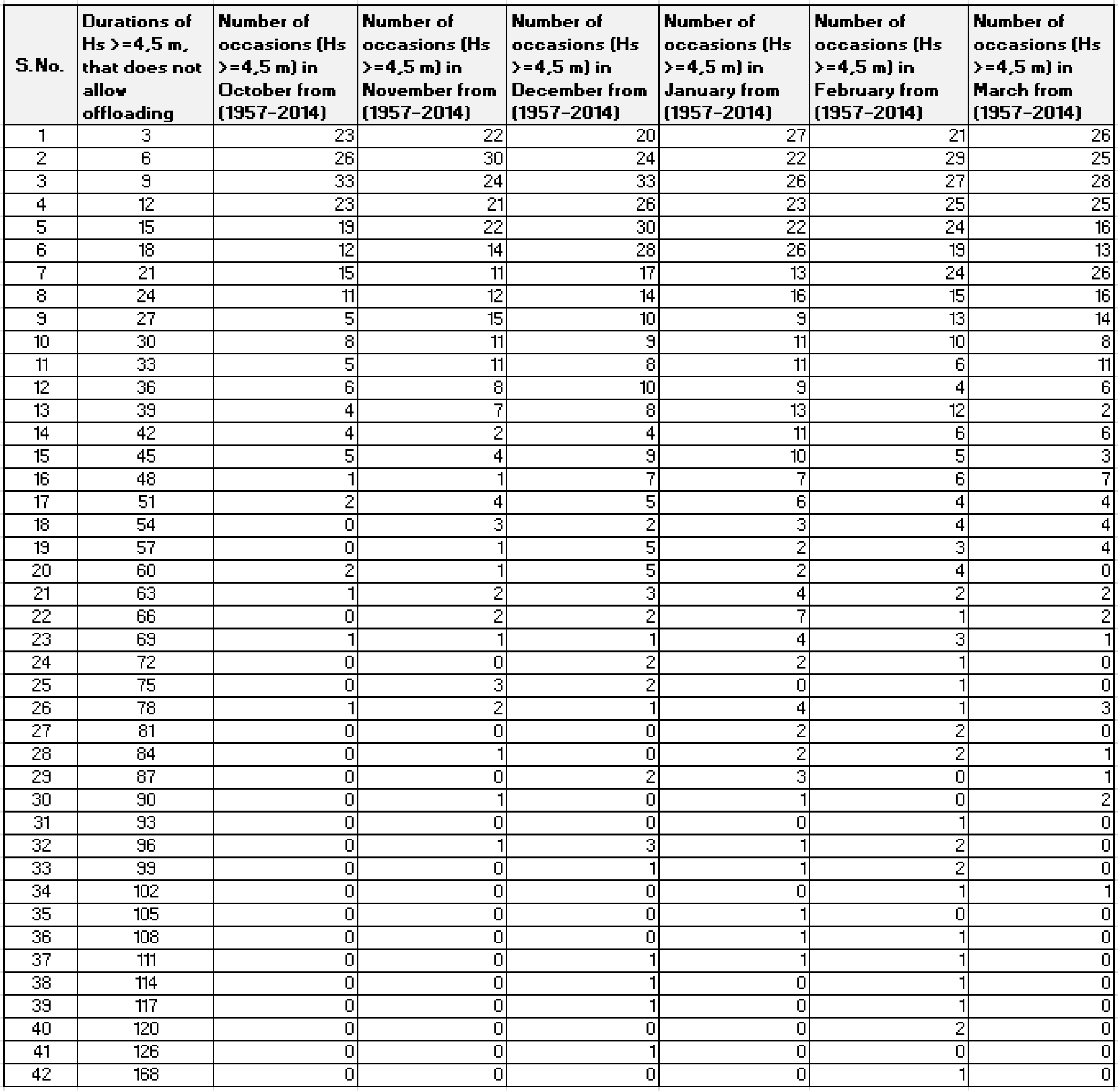


Figure 6-2 : Significant wave height pattern (Hs) -

6.2.1 Frequency of durations (of Hs>=4,5m) in winter months (1957 -2014)

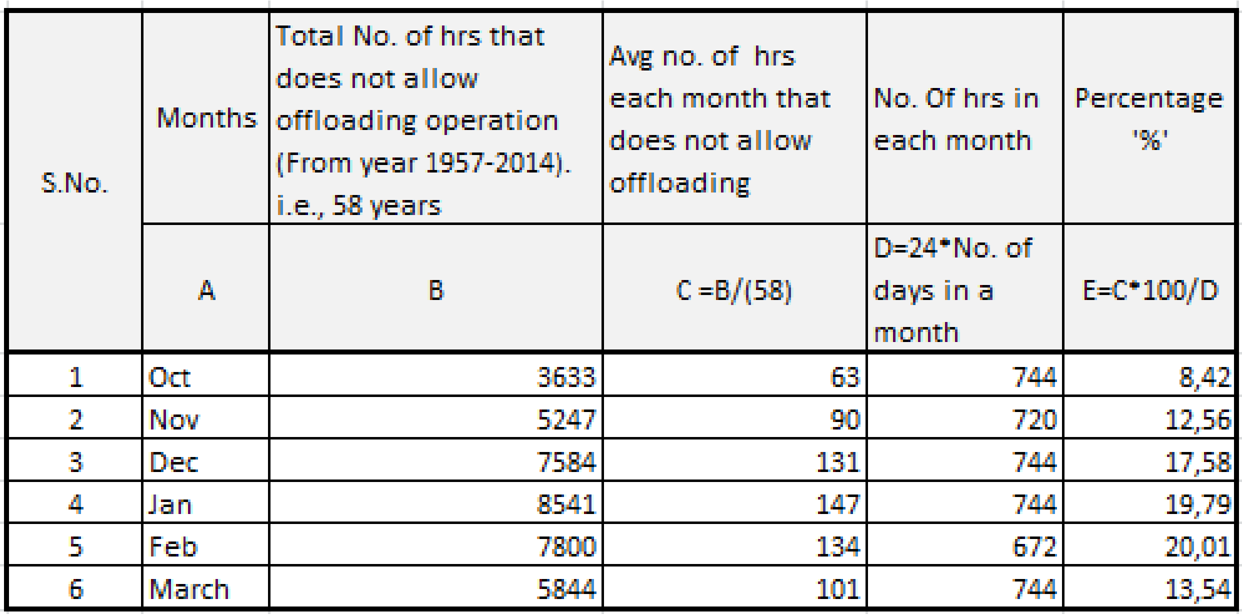
Using hindcast data, the frequency of durations (of Hs>=4,5m) for the winter months were compiled and presented in Table 6-1. Tabulation data indicate that shorter duration sea states are more frequent and vice versa. Even though the compiled data for a particular month, say January, is not a continuous linear pattern, but the trend suggest so.

Table 6-1: Frequency of durations (Hs>=4,5m) in winter months (1957 – 2014)



S.No.	Durations of Hs >=4,5 m, that does not allow offloading	Number of occasions (Hs >=4,5 m) in October from (1957-2014)	Number of occasions (Hs >=4,5 m) in November from (1957-2014)	Number of occasions (Hs >=4,5 m) in December from (1957-2014)	Number of occasions (Hs >=4,5 m) in January from (1957-2014)	Number of occasions (Hs >=4,5 m) in February from (1957-2014)	Number of occasions (Hs >=4,5 m) in March from (1957-2014)
1	3	23	22	20	27	21	26
2	6	26	30	24	22	29	25
3	9	33	24	33	26	27	28
4	12	23	21	26	23	25	25
5	15	19	22	30	22	24	16
6	18	12	14	28	26	19	13
7	21	15	11	17	13	24	26
8	24	11	12	14	16	15	16
9	27	5	15	10	9	13	14
10	30	8	11	9	11	10	8
11	33	5	11	8	11	6	11
12	36	6	8	10	9	4	6
13	39	4	7	8	13	12	2
14	42	4	2	4	11	6	6
15	45	5	4	9	10	5	3
16	48	1	1	7	7	6	7
17	51	2	4	5	6	4	4
18	54	0	3	2	3	4	4
19	57	0	1	5	2	3	4
20	60	2	1	5	2	4	0
21	63	1	2	3	4	2	2
22	66	0	2	2	7	1	2
23	69	1	1	1	4	3	1
24	72	0	0	2	2	1	0
25	75	0	3	2	0	1	0
26	78	1	2	1	4	1	3
27	81	0	0	0	2	2	0
28	84	0	1	0	2	2	1
29	87	0	0	2	3	0	1
30	90	0	1	0	1	0	2
31	93	0	0	0	0	1	0
32	96	0	1	3	1	2	0
33	99	0	0	1	1	2	0
34	102	0	0	0	0	1	1
35	105	0	0	0	1	0	0
36	108	0	0	0	1	1	0
37	111	0	0	1	1	1	0
38	114	0	0	1	0	1	0
39	117	0	0	1	0	1	0
40	120	0	0	0	0	2	0
41	126	0	0	1	0	0	0
42	168	0	0	0	0	1	0

Table 6-2: Durations affecting offloading operation



S.No.	Months	Total No. of hrs that does not allow offloading operation (From year 1957-2014). i.e., 58 years	Avg no. of hrs each month that does not allow offloading	No. Of hrs in each month	Percentage '%'
	A	B	C =B/(58)	D=24*No. of days in a month	E=C*100/D
1	Oct	3633	63	744	8,42
2	Nov	5247	90	720	12,56
3	Dec	7584	131	744	17,58
4	Jan	8541	147	744	19,79
5	Feb	7800	134	672	20,01
6	March	5844	101	744	13,54

Using data sets from Table 6-1, Table 6-2 presents the durations (in terms of percentage) in each of the winter months that affect offloading operation. Column B in Table 6-2 is computed as given below. From Table 6-1, we know that 3hr duration (Hs>4,5m) has occurred 23 times in October. Total 3hr duration is 69 hrs (23*3). Next, 6hr duration (Hs>4,5m) has occurred 26 times in October. Total 6hr duration is 156 hrs (26*6). In a similar manner, we can compute for other durations and summate the results to get 3633 hrs. The procedure is repeated for remaining winter months. In Table 6-2, formulas used for computation are presented in respective column headings.

Column C gives the average number of hours in a particular month that does not allow offloading operation. Computing data in Column C with number of hours in each month (Column D), we can find percentage of time offloading operation will be affected. The details in Table 6-2 are presented pictorially in Figure 6-3 for better understanding.

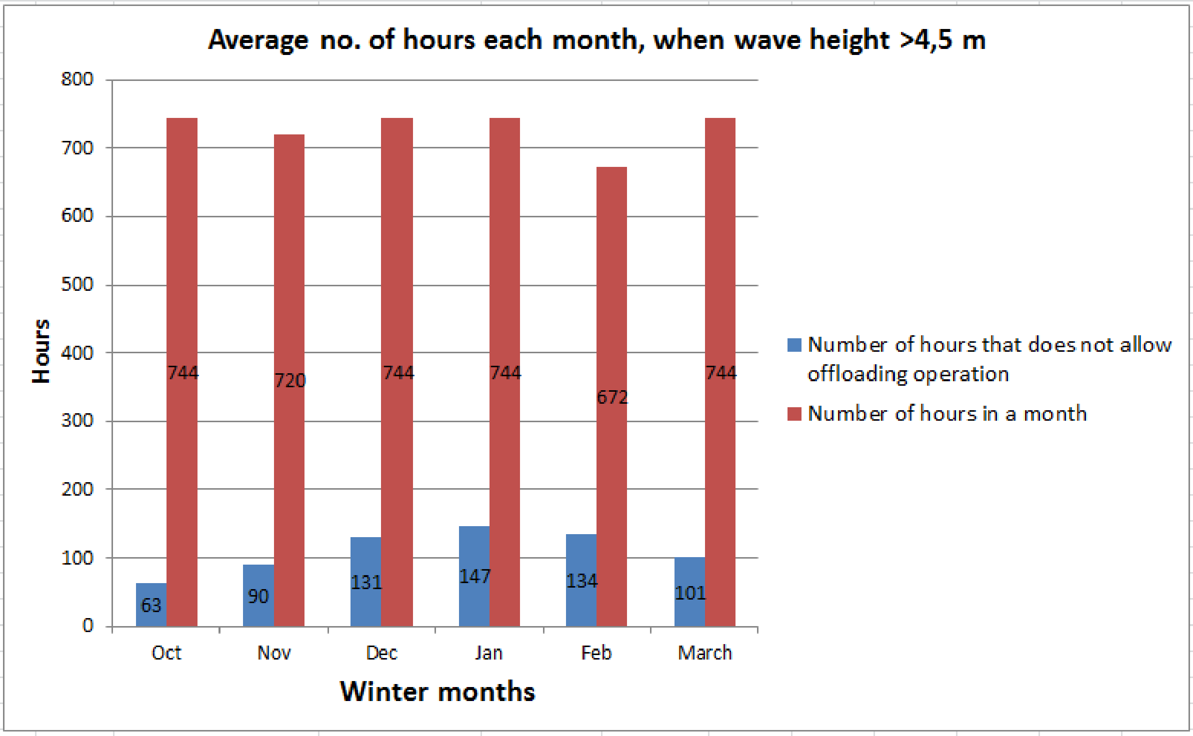


Figure 6-3 : Average no. of hours each month when wave height >=4,5m

7. SHUTTLE TANKER FLEET SIZE

Working out an adequate shuttle vessel requirement is very important as it involves cost and time in a big way. Among the large number of natural conditions characterizing the arctic seas, two of the main ones directly influencing shuttle tanker fleet size are sea ice & open water, and polar low.

7.1 Number of Shuttle tankers

The parameters & formulas discussed in Chapter 5 are presented as a case study in Annexure 1. Annexure 1 gives a complete overview of the concept conceived in this dissertation. From Annexure 1, the key parameters that affect the Shuttle tanker fleet size are reproduced in Table 7-1 for ready reference.

Table 7-1: Parameters affecting ST fleet size

<table>
<tr><th colspan="7">Annexure -1, Case study - Optimal Storage capacity of FPSO</th></tr>
<tr><th colspan="7">Oil delivery from Johan castberg field to Murmansk</th></tr>
<tr><th>S.No.</th><th>Abbrn</th><th>Description</th><th>FPSO$_1$</th><th>FPSO$_2$</th><th>FPSO$_3$</th><th>Units</th></tr>
<tr><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>3</td><td>STc</td><td>Shuttle tanker capacity</td><td>850000</td><td>850000</td><td>850000</td><td>bbls</td></tr>
<tr><td>4</td><td>P_R</td><td>Production Rate (Johan castberg production - 30000 Sm3/sd)</td><td>7862</td><td>7862</td><td>7862</td><td>bbls/hr</td></tr>
<tr><td>19</td><td>T_{ST-RT}</td><td>Time taken for ST Round Trip Operation Cycle T=T1+T2+T3+T4+T5+T6+T7+T8</td><td>193</td><td>193</td><td>193</td><td>hrs</td></tr>
<tr><td>23</td><td>N Required</td><td>Calculating number of shuttle tankers assuming 3 days (72 hrs) waiting time in the field. $N=[(72+T_{ST-RT})*P_R]/ST_C$</td><td>2,45</td><td>2,45</td><td>2,45</td><td>no.</td></tr>
</table>

The following shows equation number 5 in Chapter 5.

$$N = \frac{\left[(72 + T_{ST-RT}) * P_R\right]}{ST_C} \text{--------------------} \ (5.5)$$

The required number of shuttle tanker for a field is primarily a function of the FPSO production rate, shuttle tanker capacity and ST round trip operation cycle time. Assuming that STc and P_R are constant parameters in Eqn. (5.5), we can infer that 'N' is directly proportional to the sum of Shuttle tanker round trip cycle time, $T_{ST\text{-}RT}$ and shuttle tanker waiting time of 3 days (72 hours). Eqn. (5.2) shows that $T_{ST\text{-}RT}$ is a function of time for 8 different marine operations in the supply chain process.

$$T_{ST\text{-}RT} = \{T1+T2+T3+T4+T5+T6+T7+T8\} \text{ in 'hrs' ------------ } (5.2)$$

7.2 Influence of sea ice and open water on ST fleet size

In Eqn. (5.2), parameters such as T1, T2, T3, T5, T6, and T7 are standard marine operations involving shuttle tankers either with FPSO or with oil terminal. During ideal environmental conditions for marine operation, the time taken to perform these operations is constant. Then we are left with T4 & T8 in Eqn. (5.2), the shuttle tanker travelling time between offshore field and oil terminal. Let us see how the presence of sea ice influences shuttle tanker traveling time T4 & T8.

The maximum service speed of DAS (S2) in 1.5 meter thick ice is 3 knots. The service speed of shuttle tankers (S1) in open waters varies between 10 and 20 knots depending on sea conditions. Let us assume average service speed during the voyage to be 12 knots. We can evaluate the impact of sea ice with the help of two case studies. Case 1 deals with shuttle tanker voyage that encounters both Open & Ice infested water. Case 2 deals with shuttle tanker voyage that encounters only open water conditions. To understand the impact of sea ice, we have to evaluate the time difference between these two voyages as shown in Table- 7-2.

Table 7-2: Shuttle tanker travel time on open & ice infested waters

Description	**Case 1 (Open + Ice infested water)**	**Case 2 (Open Water)**
Time taken by shuttle tanker to travel in open water.	$Tx = \frac{D1}{S1}$	$Tz = \frac{D}{S1}$,where D=D1+D2
Time taken by shuttle tanker to travel in ice infested water.	$T_y = \frac{D2}{S2}$	Not Applicable
Total Time taken from Offshore oil field to Oil terminal	$T_{\text{case-1}} = Tx + Ty$	$T_{\text{case-2}} = Tz$
Time difference between Case 1 & Case 2	$T_{case2-case1} = D2 * \left(\frac{S1-S2}{S1*S2}\right)$ in 'hrs'---- (7.1)	

If we assume that S1=12 knots and S2= 3 knots (Mikko Niini and Sergey Kaganov, Robert D Tustin, 2007) are constant parameters in Eqn. (7.1), then D2 will be the only variable parameter. As D2 increases, shuttle tanker travelling time in ice infested water increases resulting in increase of shuttle tanker round trip cycle ($T_{ST\text{-}RT}$). Since,'$T_{ST\text{-}RT}$' is directly proportional to 'N'; we need more shuttle tankers in the supply chain in ice infested waters. The equation below shows proportionality between different parameters.

$$D2 \ \alpha \ (T4 \ \& \ T8) \ \alpha \ (T_{ST\text{-}RT}) \ \alpha \ N \text{ -------- } (7.2)$$

7.3 Influence of Polar low over ST fleet size

Polar lows can be difficult to detect using conventional weather reports and are hazardous to shipping operations. Polar lows have durations of 6 to 48 hours. The combination of wind, snow and sea spray can increase the danger of icing on vessels, affecting their stability. In Barents sea, Polar low occurs in the season from autumn to winter with a frequency of 2 to 4 per month. i.e., maximum of 24 polar lows in a year.

Eqn. (5.2) shows that $T_{ST\text{-}RT}$ is a function of time for 8 different marine operations in the supply chain process. During polar low situations, it is unsafe to perform these marine operations. Hence, extreme caution is advisable for shuttle tanker operations.

In Eqn. (5.5), Shuttle tanker waiting time of 72 hours is based on current industrial practice and bore no relationship to polar low durations. However, 72 hour waiting time can be seen here as a contingency reserve to pass off 48 hour polar low. Such advocacies reduce the shuttle tanker waiting time from 72 hours to 24 hours. If the operator wishes not to consider contingency reserve to pass off 48 hour polar low, one should replace 72 hours with 120 hours in Eqn. (5.5). This may result in an additional shuttle tanker.

The probability of polar low enroute the shuttle tanker voyage is uncertain. Therefore, it is the prerogative of the operator to decide whether to use 72 hour waiting time as a contingency reserve to pass off 48 hour polar low or not.

Polar lows and weather cells can be detected by weather radars mounted on shuttle tankers. A route will be chosen around the polar low or stop navigation and wait for weather.

8. OPTIMUM STORAGE CAPACITY OF FPSO

This chapter covers the activities of FPSO storage tank and offloading facility. It also emphasizes key parameters that affect the FPSO storage capacity.

The factors affecting the storage capacity include the following (Jeom & Anil 2007):

- Rate of production
- Shuttle tanker capacity
- Shuttle tanker round trip operation time cycle
- Weather criteria and window availability for offshore offloading
- Offloading system efficiency and other characteristics
- Buffer storage capacity requirements

The simplest way to select the storage capacity is to determine the most frequent large export parcel size and then add spare capacity to deal with events such as shuttle tanker arrival delay and awaiting the favorable weather conditions for offloading.

According to Norsk Olje & gass, Lesson #20777 – hull capacity,

> *"Small storage capacity on FPSO results in multiple loading operations. FPSO storage capacity should allow for full load for shuttle tanker. Recommended FPSO storage capacity to be 30% more than shuttle tanker capacity."*

i,e., FPSO storage capacity, F_c = 1,3 * Shuttle tanker capacity.

However, safety factor of 1, 3 may not be sufficient to ensure continuous FPSO production in situations such as shuttle tanker arrival delay and unfavorable weather conditions for offloading operation. Hence, the safety factor should be increased to curtail loss / deferred production due to full FPSO storage. It raises the question "By how much? This involves estimating buffer storage time $T_{BS,}$ which determines the magnitude of safety factor.

The process of optimizing the storage capacity of FPSO necessitates addressing the following concerns.

1. ***What is T_{BS} and how it influences $FPSO_c$ & FPSO operating efficiency?***
2. ***Understanding the loading and offloading pattern of the FPSO-ST combination***
3. ***How environmental conditions influence T_{BS}?***

8.1 Buffer storage time, T_{BS}

Minimum time required by FPSO to deliver full parcel to shuttle tanker is given by $T_{FPSO-Stmin.}$ i.e., offloading operation should be initiated. The maximum time duration FPSO can produce without offloading operation is given by $T_{FPSO-max.}$ The difference between these time intervals gives us buffer storage time duration, T_{BS}. FPSO buffer storage capacity, $FPSO_{BS}$ is the product of T_{BS} & $P_{R.}$

$$T_{BS} = T_{FPSO-MAX} - T_{FPSO-ST} \text{ ----------------------- } (8.1)$$

$$FPSO_{BS} = T_{BS} * P_R \text{ ------------------------------- } (8.2)$$

The parameters & formulas discussed in Chapter 5 are presented as a case study for ST capacity of 850,000 bbls in Annexure-1 and 700,000 bbls in Annexure-2. Annexure-1 & Annexure-2 gives a complete overview of the concept conceived in this dissertation.

From here on, we consider data from Annexure 1 (ST capacity – 850,000 bbls) for detailed analysis. Nevertheless, we refer data from Annexure-2 (ST capacity – 700,000 bbls) for crucial discussions.

From Annexure-1, the key parameters that affect the storage capacity of FPSO are reproduced in Table 8-1 for ready reference.

Table 8-1 : Parameters affecting optimal storage capacity of FPSO for ST capacity – 850,000 bbls

S.No.	Abbreviation	Description	$FPSO_1$ (SF_1)	$FPSO_2$ (SF_2)	$FPSO_3$ (SF_3)	Units
1	$FPSO_c$	FPSO capacity	1105000	1204960	1305005	bbls
2	SF_1, SF_2, SF_3	Safety factor	1,3	1,4176	1,5353	
3	STc	Shuttle tanker capacity	850000	850000	850000	bbls
4	P_R	Production Rate (Johan castberg production - 30000 Sm3/sd)	7862	7862	7862	bbls/hr
5	O_R	Offloading Rate (8000 m3/hr)	50314	50314	50314	bbls/hr
6	$T_{FPSO\text{-}max}$	Maximum time FPSO can produce without offloading operation, F_C/P_R	141	153	166	hrs
21	$T_{FPSO\text{-}ST\ min}$	Minimum time required for FPSO to deliver full parcel to shuttle tanker, =STC*((1/PR)-(1/OR))	91	91	91	hrs
25	Estimated $T_{BS,}$ (Assumed for this case study)	Increasing the T_{BS} value reduces the consequences of wave limiting criteria on FPSO storage. T_{BS} mainly reduces the frequency of stoppage of FPSO due to full storage.	48	48	48	hrs
26	Maximum duration of Polar low		48	48	48	hrs
27	Calculated, T_{BS}	Buffer storage time duration. i.e., Time interval between TFPSO-max & TFPSO-ST min. $T_{BS} = T_{FPSO\text{-}max} - T_{FPSO\text{-}ST}$	49	62	75	hrs
28	$FPSO_{BS}$	FPSO buffer storage capacity, $T_{BS} * P_R$	387820	487780	587825	bbls

In Table 8-1, Three FPSO sizes are considered for analysis, namely $FPSO_1$, $FPSO_2$ & $FPSO_3$ with buffer storage time T_{BS1}, T_{BS2} & T_{BS3} and safety factors SF_1, SF_2 & SF_3 respectively. The only difference between these FPSO's is their buffer storage time T_{BS} & safety factor SF.

- Base case $FPSO_1$ = Max. of $[(1{,}3 * ST); (T_{FPSO\text{-}STmin} + 48\ hrs) * P_R);$
  $((T_{FPSO\text{-}STmin} + \text{Estimated } T_{BS}) * P_R)]$ --- (8.3)

- $FPSO_2$ = Max. of $[(1{,}4176 * ST); (T_{FPSO\text{-}STmin} + 48\ hrs) * P_R);$
  $((T_{FPSO\text{-}STmin} + \text{Estimated } T_{BS}) * P_R)]$ --- (8.4)

- $FPSO_3$ = Max. of [(1,5353 * ST); ($T_{FPSO\text{-}STmin}$ + 48 hrs) * P_R);
  (($T_{FPSO\text{-}STmin}$ + Estimated T_{BS}) * P_R)] --- (8.5)

- Base case, Norsk Olje & gass recommended Safety factor,

$$SF_1 = 1{,}3 \text{ --------------------------------------- } (8.6)$$

- Safety factor, $SF_2 = \left(\dfrac{ST_c * SF_1 + 100{,}000}{ST_c} \right) = 1{,}4176$ --------------- (8.7)

- Safety factor, $SF_3 = \left(\dfrac{ST_c * SF_1 + 200{,}000}{ST_c} \right) = 1{,}5353$ --------------- (8.8)

8.1.1 Relationship among T_{BS}, $T_{FPSO\text{-}max}$, ST_c and SF

Minimum time required by FPSO to deliver full parcel to shuttle tanker is given by $T_{FPSO\text{-}Stmin.}$ i.e., offloading operation should be initiated. The maximum time duration FPSO can produce without offloading operation is given by $T_{FPSO\text{-}max.}$ The difference between these time intervals gives us buffer storage time duration, $T_{BS.}$

The buffer storage time T_{BS1} (for $FPSO_1$) can be found by equating,

{FPSO capacity} = {[Required Minimum filled in Volume of FPSO to start offloading] +
[Buffer time storage capacity]}

$$FPSO_c = (T_{FPSO-ST\min} * P_R) + T_{BS} * P_R \text{ --------------------------------- } (8.9)$$

Since, $FPSO_c = T_{FPSO-\max} * P_R$, Eqn. (8.9) becomes

$$T_{FPSO-\max} * P_R = (T_{FPSO-ST\min} * P_R) + T_{BS} * P_R$$

$$T_{FPSO-\max} = T_{FPSO-ST\min} + T_{BS}$$

$$T_{BS} = T_{FPSO-\max} - T_{FPSO-ST\min} \text{ in 'bbls'-------------------- } (8.10)$$

$$T_{BS} = \frac{ST_c * SF}{P_R} - ST_c * (\frac{1}{P_R} - \frac{1}{O_R}) \text{ in 'bbls'}$$

$$T_{BS} = \frac{ST_c}{P_R} * (SF - 1) + \left(\frac{1}{O_R} \right) \text{ in 'bbls'------------------- (8.11)}$$

In Eqn. (8.11), If P_R & O_R are fixed parameters for a given FPSO, and then T_{BS} is directly proportional to ST_c & SF.

8.1.2 Reflection

The following shows Eqn. (8.10).

$$T_{BS} = T_{FPSO-\max} - T_{FPSO-ST\min} \text{ in 'bbls'-------------------------- (8.10)}$$

From Eqn. (8.10), Since $T_{FPSO-STmin}$ is constant for a particular ST capacity; we can affirm that T_{BS} is directly proportional to FPSO maximum storage time, $T_{FPSO-max}$. Figure 8-1 shows that, as T_{BS} increases, $T_{FPSO-max}$ increases resulting in increasing FPSO storage volume and vice versa. By increasing $T_{BS,}$ we can maximizes uptime and avoid financial loss caused by associated loss of production due to unfavorable weather conditions for offloading operation.

T_{BS} α $T_{FPSO-max}$ α FPSO Storage Volume α FPSO Operating efficiency

Figure 8-1 : Proportionality among FPSO storage parameters

Selecting an appropriate T_{BS} is an economic tradeoff between increased capex of hull size versus increase in FPSO operating efficiency. Therefore, it is field operator's prerogative to decide on T_{BS} based on cost benefit analysis. Cost benefit analysis takes into account hull size, export system capacity, production life cycles, and related costs. In Chapter 9, the cost benefit analysis of T_{BS} is discussed in detail.

8.2 Loading / offloading pattern of the FPSO-Shuttle combination

This section outlines the activities of FPSO storage tank & offloading facility, i.e., receiving produced oil from the processing facilities and discharging the final product to the shuttle tankers. Both receiving and discharging events happen simultaneously. While the processed product loading (P_R) is a continuous process, export (O_R) may be performed within relatively short time duration.

Using parameters in Table 8-1, loading and offloading pattern for $FPSO_1$, $FPSO_2$ & $FPSO_3$ is graphically shown in Figure 8-2, Figure 8-3 and Figure 8-4 respectively.

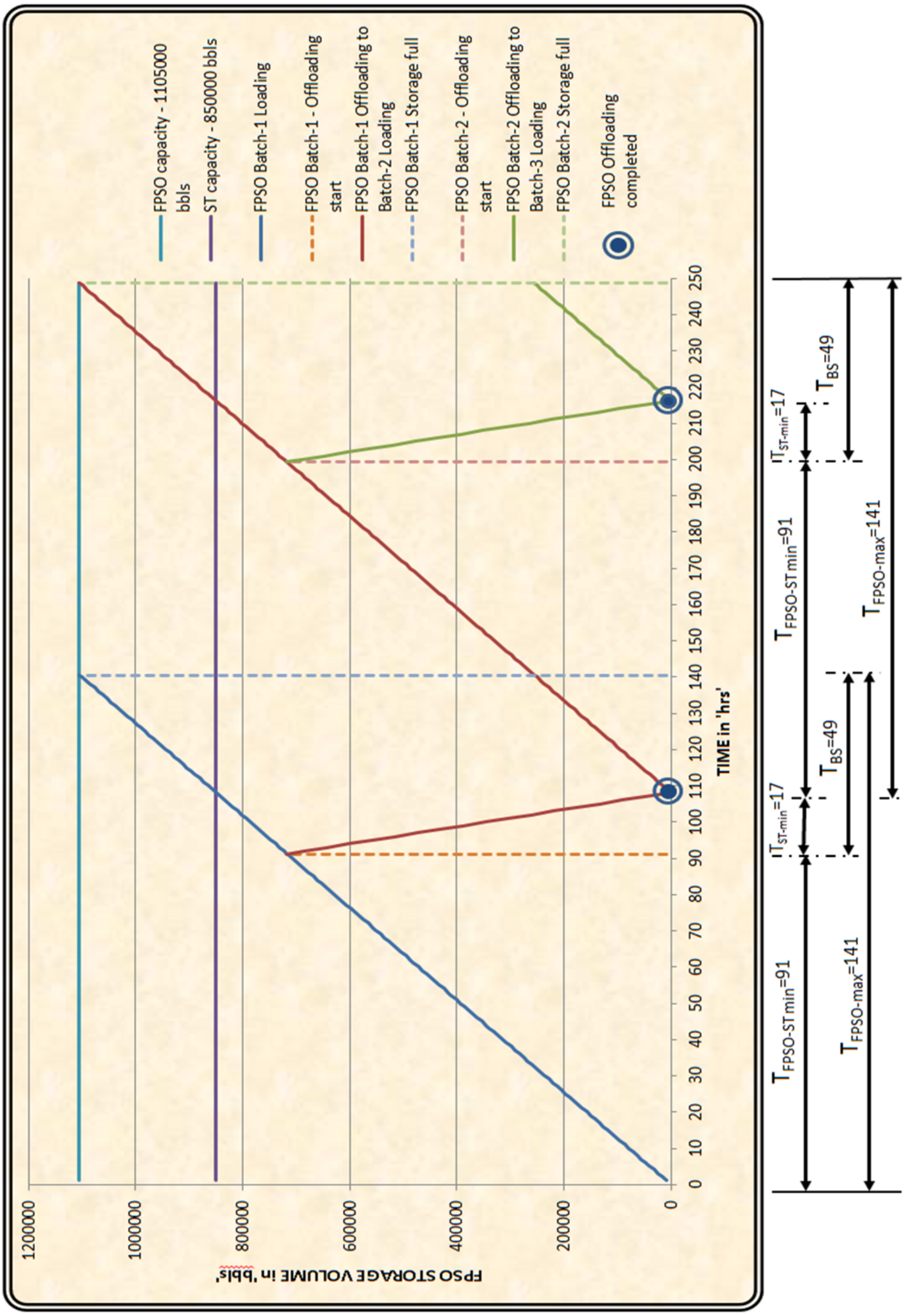


Figure 8-2 : Loading and offloading pattern for $FPSO_1$

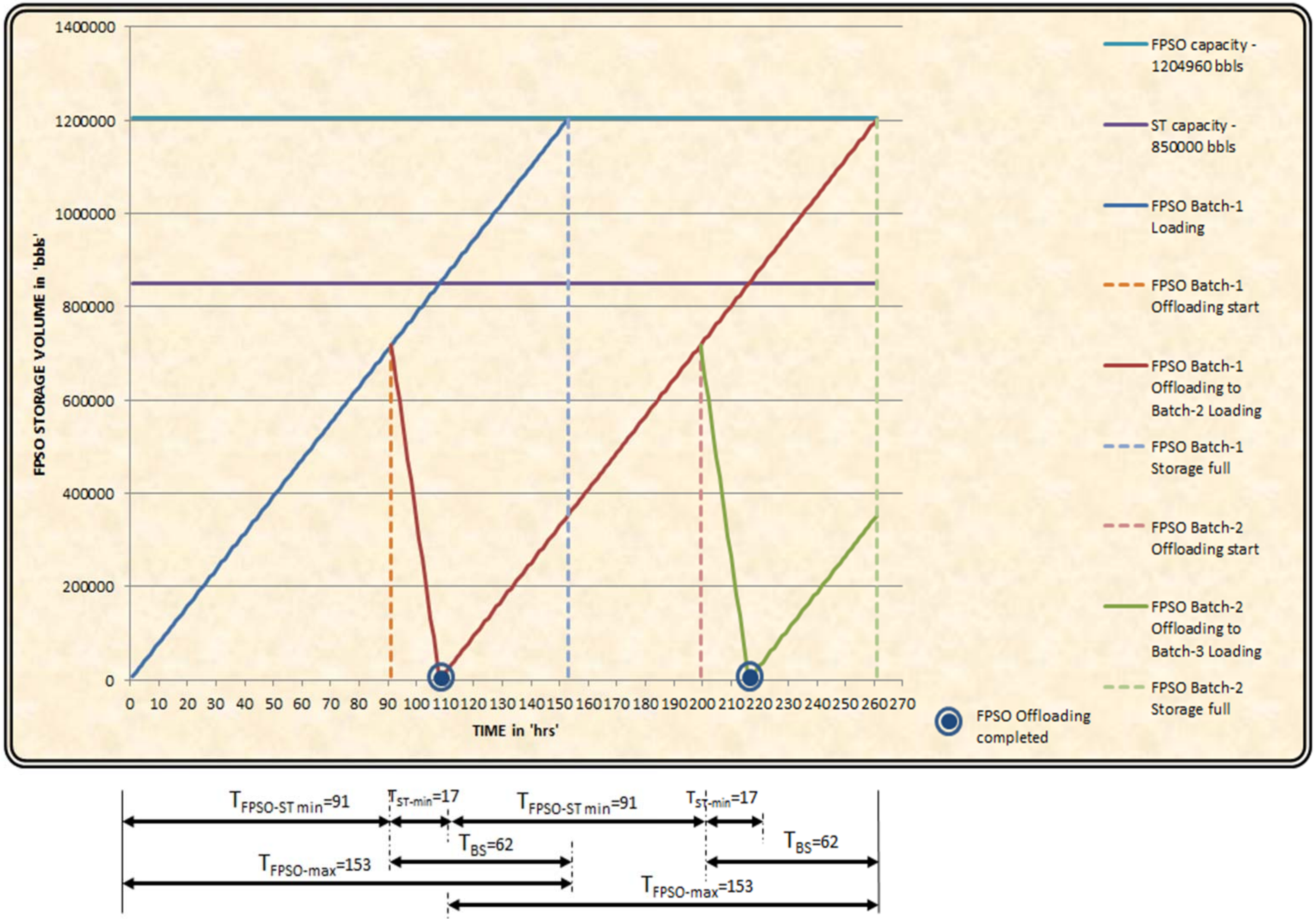


Figure 8-3 : Loading and offloading pattern for $FPSO_2$

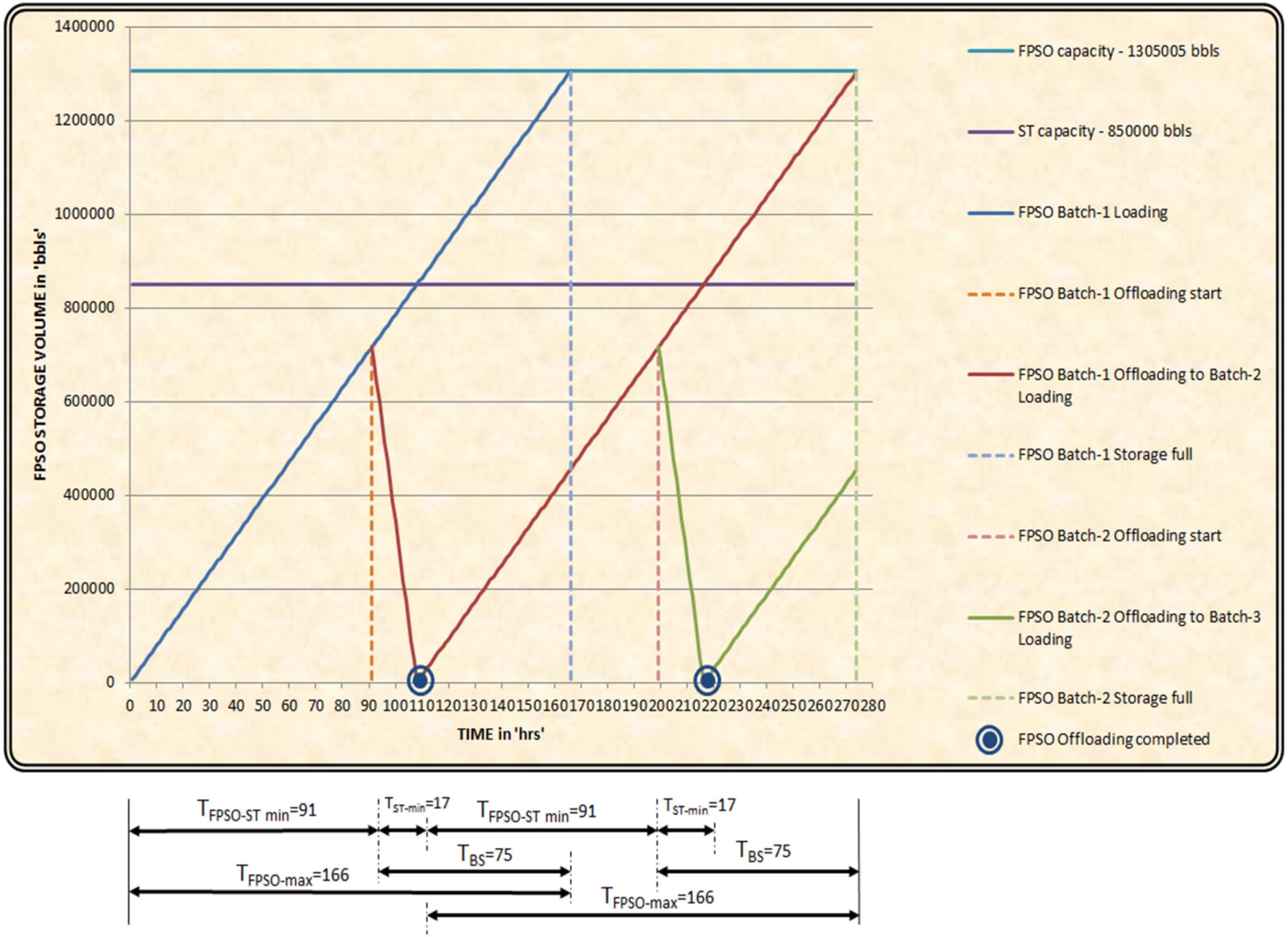


Figure 8-4 : Loading and offloading pattern for FPSO$_3$

8.3 Influence of Environmental conditions over T_{BS}

As indicated in Section 8.1, the simplest way to select the FPSO storage capacity is to determine the Shuttle tanker size and then add spare capacity to deal with events such as shuttle tanker arrival delay and unfavorable environmental conditions for offloading. Some of the unfavorable environmental conditions include significant wave height, sea ice and polar lows. . Buffer storage time, T_{BS} plays a key role in dealing with these unfavorable environmental conditions.

8.3.1 Influence of Significant wave height over T_{BS}

Let us consider a probable situation; FPSO is ready to deliver full parcel to shuttle tanker, at $T_{FPSO\text{-}Stmin}$, but a 54 hour duration Hs>=4,5 m has developed. Offloading operations can be initiated only after 54 hours. During this period, FPSO will continue production and shuttle tanker will wait for favorable weather to perform offloading operation. For FPSO to continue production without stoppage, T_{BS} should be greater than 54 hrs. An appropriate T_{BS} reduces the frequency of stoppage of FPSO due to full storage.

The influence of 54 hour duration Hs>=4,5 m over $FPSO_1$, $FPSO_2$ & $FPSO_3$ is presented in Table 8-2 & Table 8-3 for ST capacity 850,000 bbls & 700,000 bbls respectively. We can observe that only $FPSO_1$ has to stop production if 850,000 bbls ST is used. In contrast, both $FPSO_1$ & $FPSO_2$ have to stop production if 700,000 bbls ST is used. This is because T_{BS} is a function of ST capacity. Reference is invited to Section 8.1.1, Eqn. (8.11), we noted that as ST capacity increases, T_{BS} increases and vice versa.

Table 8-2 : Wave height vs T_{BS} for ST capacity – 850,000 bbls

FPSO	Calculated buffer storage time duration, T_{BS} in 'hrs'	Probable situation, Duration of Hs>=4,5 m in 'hrs'	Consequence
$FPSO_1$	49	54	$FPSO_1$ production stopped due to full storage.
$FPSO_2$	62	54	$FPSO_2$ will continue production
$FPSO_3$	75	54	$FPSO_3$ will continue production

Table 8-3 : Wave height vs T_{BS} for ST capacity – 700,000 bbls

FPSO	Calculated buffer storage time duration, T_{BS} in 'hrs'	Probable situation, Duration of Hs>=4,5 m in 'hrs'	Consequence
$FPSO_1$	48	54	$FPSO_1$ production stopped due to full storage.
$FPSO_2$	53	54	$FPSO_2$ production stopped due to full storage.
$FPSO_3$	66	54	$FPSO_3$ will continue production

Let us assume that $FPSO_1$, $FPSO_2$ & $FPSO_3$ are producing and transporting hydrocarbons from Johan Castberg field. Using hind cast data (From January'1947 to December'2014) for Johan Castberg field, the frequency of durations (of Hs>=4,5m) for the winter months were compiled and presented in Table 6-1. By summing up the frequencies of durations that are greater than T_{BS} values for $FPSO_1$, $FPSO_2$ & $FPSO_3$, we can calculate the number of times these FPSO's could have stopped production. Analysis is presented in Table 8-4.

Table 8-4 : FPSO operating efficiency

FPSO	**Safety factor**	**Buffer storage time duration, T_{BS} in 'hrs'**	**Number of times "Durations of Hs>=4.5 m is greater than T_{BS}" in 'nos.'**	**Remarks**
$FPSO_1$	1,3	49	180	From 1947 to 2014, $FPSO_1$ could have stopped production on 180 occasions due to full storage.
$FPSO_2$	1,4176	62	110	From 1947 to 2014, $FPSO_2$ could have stopped production on 110 occasions due to full storage. It is 70 occasions fewer than $FPSO_1$.
$FPSO_3$	1,5353	75	60	From 1947 to 2014, $FPSO_3$ could have stopped production on 60 occasions due to full storage. It is 120 occasions fewer than $FPSO_1$.

From Table 8-4, we can infer that selecting an appropriate T_{BS} can maximize uptime and avoid financial loss caused by associated loss of production due to unfavorable weather conditions for offloading operation. The arguments in this section are formulated as an equation for optimizing the FPSO storage.

$$\textbf{Optimal FPSO storage} = \textbf{Max of } [(SF * \text{Shuttle tanker capacity}); ((T_{FPSO\text{-}STmin} + \text{Estimated } T_{BS}) * \text{Production rate})]. \text{---------} (8.12)$$

8.3.2 Influence of sea ice over T_{BS}

The Norwegian meteorological institute monitors and forecast the ocean weather and climate for the seas surrounding Norway. Ocean weather means sea level, sea ice, waves, ocean currents, etc. From met.no, one can gather sufficient information about the presence of sea ice in a particular area. Sea ice can delay shuttle tanker arrival time, which in turn may affect offloading regularity resulting in full FPSO and production has to be curtailed. Since sea ice is predictable, it is important to find a feasible shuttle tanker schedule that minimizes delays and maximizes offloading regularity. By solving the scheduling problem, one can conclude that presence of sea ice does not directly influence the storage capacity of FPSO.

8.3.3 Influence of polar lows over T_{BS}

One of the unfavorable weather conditions for offloading is polar lows. Polar lows develop in a short space of time and have a short lifespan. Polar lows have durations of 6 to 48 hours. During this period, we cannot perform offloading operation.

Let us consider a probable situation; FPSO is ready to deliver full parcel to shuttle tanker, at $T_{FPSO\text{-}Stmin}$, but a 48 hour duration polar low is developed. Offloading operations can be initiated only after 48 hours. During this period, FPSO will continue production and ST will wait for favorable weather to perform offloading operation. For FPSO to continue production without stoppage, T_{BS} should be greater than 48 hrs. The influence of 48 hour duration polar low over $FPSO_1$, $FPSO_2$ & $FPSO_3$ is presented in Table 8-5.

Table 8-5: Polar low vs T_{BS} for ST capacity - 850,000 bbls

Description	Buffer storage time duration, T_{BS} in 'hrs'	Polar low duration in 'hrs'	Consequence
$FPSO_1$	49	48	$FPSO_1$ could continue production
$FPSO_2$	62	48	$FPSO_2$ could continue production
$FPSO_3$	75	48	$FPSO_3$ could continue production

The arguments in this section are formulated as an equation for optimizing estimating the FPSO storage.

Optimal FPSO storage = Max of

[(SF * Shuttle tanker capacity);

(($T_{FPSO\text{-}STmin}$ + 48 hrs) * Production rate)] ------ (8.13)

8.4 Optimal storage capacity of FPSO

This dissertation conceives only the influence of significant wave height, sea ice and polar lows on the shuttle tanker operation, which in turn affects the storage capacity of FPSO. The Eqn. (8.12) & Eqn. (8.13) are conjoined to form Eqn. (8.14) that gives us the optimal storage capacity of FPSO.

Optimal FPSO storage = Maximum of

[(SF * Shuttle tanker capacity);

(($T_{FPSO\text{-}STmin}$ + 48 hrs) * Production rate);

(($T_{FPSO\text{-}STmin}$ + Estimated T_{BS}) * Production rate)]. ---------------- (8.14)

9. COST- BENEFIT ANALYSIS

The governing objective for the implementation of any project in today's oil and gas industry is to make the projects more cost efficient in order to maximize the Net Present Value (NPV) of the investments. This chapter covers the cost analysis of three FPSO's, namely $FPSO_1$, $FPSO_2$ & $FPSO_3$ with buffer storage time T_{BS1}, T_{BS2} & T_{BS3} respectively.

9.1 Background

This dissertation intends to optimize the FPSO storage capacity. The FPSO storage capacity should be sufficient to minimize production downtime due to weather preventing shutter tanker connection. In chapter 8, we concluded that selecting an appropriate T_{BS} can maximize production uptime and avoid financial loss caused by the associated loss of production due to unfavorable weather conditions for offloading operation.

Selecting an appropriate T_{BS} is an economic tradeoff between increased capex of hull size versus increase in FPSO operating efficiency. T_{BS} is finalized based on cost benefit analysis. Cost benefit analysis takes into account hull size, export system capacity, production life cycles, and related costs.

This chapter aims at achieving the cost analysis of three FPSO's, namely $FPSO_1$, $FPSO_2$ & $FPSO_3$ with buffer storage time T_{BS1}, T_{BS2} & T_{BS3} respectively. The only difference between these FPSO's is their buffer storage time $T_{BS.}$

Cost of downtime for a project is based on the production profile given in the plan for development and operation.

9.2 Oil field Production profile

A typical "field life" is of the order of 20 years, but there are large differences. A small oil field may be produced in only 5 years, while a large gas field may have a life of more than 50 years. An illustration of the production volume per year is referred to as the production profile. The production life of an oil field can be divided into three different phases as shown in Figure 9-1 (Oilfield decline rates).

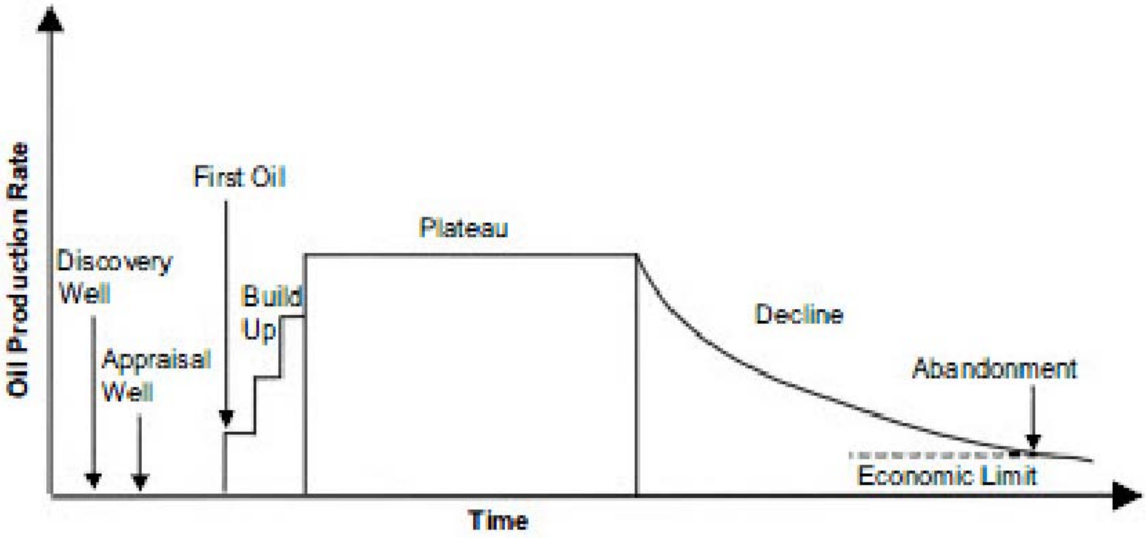


Figure 9-1: Production life of an oil field

9.2.1 Production build-up

The objective during this phase is to fill installed production capacity as fast as possible. Once the investment is made, concentration is on the cash flow. In fact, this means that irrespective of oil price trends, the objective is almost always to maximize production early in the producing life of a field.

9.2.2 Plateau production

Plateau production starts when available production capacity has been filled. The total well potential is 10 to 20% higher than the production capacity. Reservoir management activities are now shifted to the process engineers, and the objective is to de-bottle neck the producing facilities, thus increasing the capacity. In this phase, the capacity utilization is at maximum, and any value chain upset (shutdown or breakdown of production) will automatically lead to loss / deferred production. Value chain monitoring and maintenance are regarded as important factors in securing an optimal cash flow.

9.2.3 Production decline

A new phase in reservoir management starts when the production starts declining. In this phase, field shifts from being process restricted to be well potential restricted. The efforts to keep production as high as possible have to be intensified.

9.3 Assumptions & data

- Field life cycle – 10 years.
- FPSO life span – 10 years. After 10 years, it will not have any salvage value.
- Production start – Year 2016. End of production – Year 2025
- ST capacity – 850,000 bbls
- $FPSO_1$, $FPSO_2$, and $FPSO_3$ are considered for analysis. (Refer Table 8-1 for data)
    - Base case $FPSO_1$ = Max. of [(1,3 * ST); ($T_{FPSO\text{-}STmin}$ + 48 hrs) * P_R); (($T_{FPSO\text{-}STmin}$ + Estimated T_{BS}) * P_R)]
    - $FPSO_2$ = Max. of [(1,4176 * ST); ($T_{FPSO\text{-}STmin}$ + 48 hrs) * P_R); (($T_{FPSO\text{-}STmin}$ + Estimated T_{BS}) * P_R)]
    - $FPSO_3$ = Max. of [(1,5353 * ST); ($T_{FPSO\text{-}STmin}$ + 48 hrs) * P_R); (($T_{FPSO\text{-}STmin}$ + Estimated T_{BS}) * P_R)]
- Delta cost for 100,000 bbl storage capacity on the FPSO is around 200 mill NOK.
- Delta cost for 200,000 bbl storage capacity on the FPSO is around 400 mill NOK.
- From Eqn. (8.14), we can infer the following.
    - Sea ice does not influence storage capacity of FPSO
    - Polar low duration is 48 hrs. Base case $FPSO_1$'s T_{BS}=49 hrs, which is greater than polar low duration. We can conclude that polar low does not influence FPSO storage capacity.
    - Wave limitation criteria affect the FPSO storage capacity.
- Wave limitation criteria for offloading operation are applied on hindcast data of Johan Castberg field to get production downtime durations for a period of 10 years from year 2003 to year 2013. Let us utilize these production downtime durations to evaluate production downtime of $FPSO_1$, $FPSO_2$ & $FPSO_3$ for a period of 10 years from year 2016 to year 2025.

- The discount rate is assumed to be 8% (rate of interest).
- The shuttle tankers are normally leased and the day rate is around 100 000 USD/day (764,635 Nok/day). The fuel cost will come in addition but it is not included in economical evaluation of the delta cost.
- Crude oil price per barrel – 60$ (458 Nok).
- Other technical & commercial implications due to delta storage capacity on FPSO are not considered.

9.4 NPV Analysis

Net present value method, also known as discounted cash flow method, is a capital budgeting technique that takes into account the time value of money. NPV is the difference between the present value of cash inflows and the present value of cash outflows that occur as a result of undertaking an investment project. It may be positive, zero or negative. The summary of the concept explained so far is given below:

- Present value of cash inflow > Present value of cash outflow
  Positive NPV
  Project is acceptable

- Present value of cash inflow = Present value of cash outflow
  Zero NPV
  Project is acceptable

- Present value of cash inflow < Present value of cash outflow
  Negative NPV
  Project is not acceptable

Investments in assets are usually made with the intention to generate revenue in future. The net present value method is used here to evaluate investment on additional FPSO buffer storage tank capacity T_{BS}, which is supposed to generate cash inflow.

9.5 Case study

Let us assume a field life of 10 years with the following phases.

1. Plateau production phase (Year 1 – 5). This means that we achieve plateau production from day one. Production build up phase is neglected.
2. Production decline phase (Year 6 – 10).

On such fields, the plateau production is reached as soon as the field starts to produce. During the plateau production phase, unfavorable weather conditions for offloading operation leads to loss / deferred production. The loss / deferred production can result in substantially decreased revenue over the life of the project, as well as less oil.

The assumptions and data discussed in Section 9.3 are presented in Annexure - 3 & Annexure - 4. Annexure-3 & 4 gives a complete overview of the commercial concept conceived in this Chapter. Financial loss incurred due to FPSO stoppage & shuttle tanker waiting time for $FPSO_1$ and $FPSO_2$ is presented in Annexure-3 whereas for $FPSO_1$ & $FPSO_3$ is presented in Annexure-4. The formulas used for calculation are presented in respective column headings.

9.5.1 Loss of production

Within the limits of this dissertation, Loss of production shall be defined as the shortfall of actual production due to full FPSO storage capacity. In other words, loss of production is the fact of no longer having hydrocarbons in the reservoir for future production. i.e., production lost during plateau production phase cannot be recovered in the production decline phase.

From Annexure-3 & Annexure-4, 10 years cash inflow data for $FPSO_2$ & $FPSO_3$ is reproduced in Table 9-1and NPV calculation is performed. $FPSO_1$ is used as a base case. By using $FPSO_2$ or $FPSO_3$, instead of $FPSO_{1,}$ losses can be curtailed. NPV is positive for both the cases. i.e., cash inflow is greater than cash outflow. We can infer that investments in FPSO buffer storage tank capacity, T_{BS} can maximize production uptime and generate revenue in future. Also we can observe that increasing buffer storage time from T_{BS1} to T_{BS2} and further to T_{BS3} will increase the Net Present Value (NPV) of the investments respectively.

Table 9-1: NPV Analysis - Loss of Production case

S.No.	Year	Case1: Cash inflow by changing from FPSO$_1$ to FPSO$_2$, i.e., increase in TBS, in 'Million Nok' Q = H-L	Case2: Cash inflow by changing from FPSO$_1$ to FPSO$_3$, i.e., increase in TBS, in 'Million Nok' R = H-P	Unit
1	Year 1	72,41	117,24	mill Nok
2	Year 2	106,90	113,79	mill Nok
3	Year 3	93,10	93,10	mill Nok
4	Year 4	331,03	520,69	mill Nok
5	Year 5	179,31	282,76	mill Nok
6	Year 6	206,90	324,14	mill Nok
7	Year 7	62,07	106,90	mill Nok
8	Year 8	179,31	358,62	mill Nok
9	Year 9	172,41	265,52	mill Nok
10	Year 10	134,48	206,90	mill Nok
	NPV			
	Rate of Interest	8 %	8 %	
	Capital Expenditure	-200	-400	mill Nok
	Net Present Value (NPV)	kr 749,98	kr 1 059,47	mill Nok

However this is not a realistic case for an oil reach field. For an oil reach field, the production lost during plateau production phase is recoverable in the production decline phase. Hence, for evaluating an oil field, deferred production case is preferred to loss of production case.

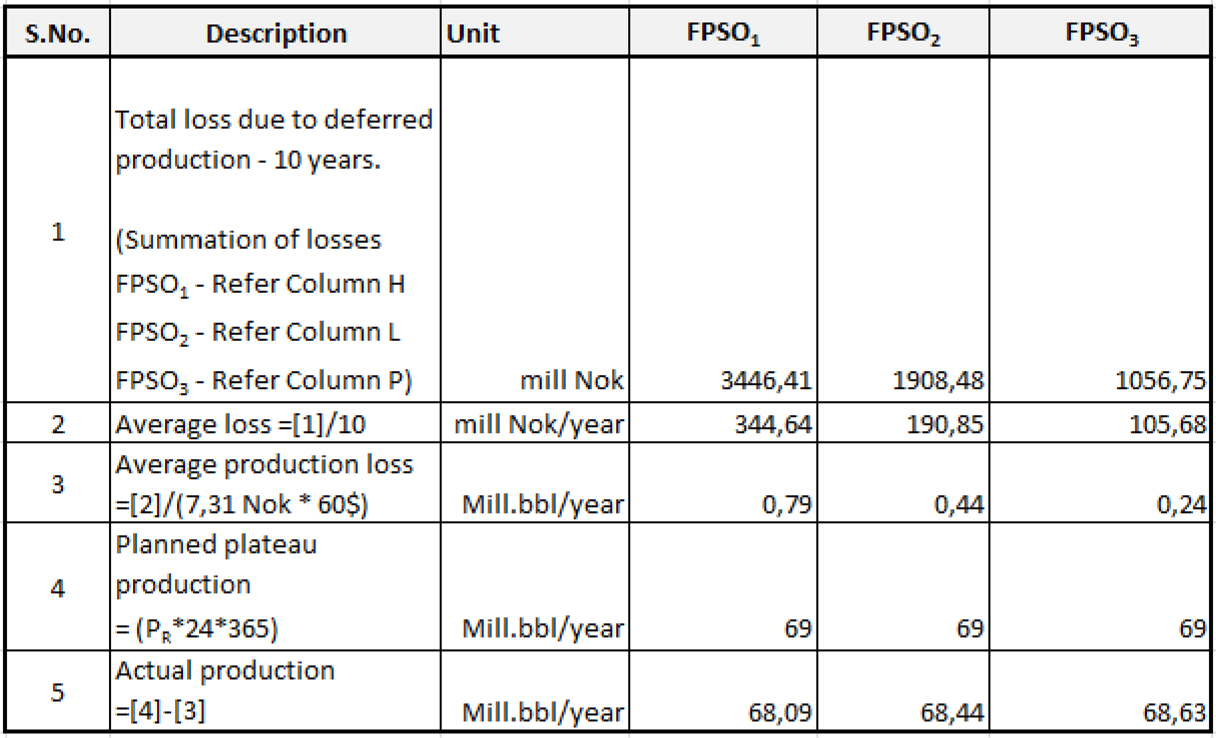
9.5.2 Deferred production

Within the limits of this dissertation, deferred production shall be defined as the postponement of production due to full FPSO storage capacity. In other words, deferred production is the fact of having hydrocarbons in the reservoir for future production. i.e., production deferred during plateau production phase can be recovered in the production decline phase.

In chapter 8, we concluded that selecting an appropriate T_{BS} can maximize production uptime and reduce financial loss caused by the associated loss of production due to unfavorable weather conditions for offloading operation. Financial loss incurred due to FPSO stoppage & shuttle tanker waiting time for FPSO$_1$ and FPSO$_2$ is presented in Annexure-3 whereas for

$FPSO_1$ & $FPSO_3$ is presented in Annexure-4. Using this data, financial & production loss incurred for each year is computed and results are presented in Table 9-2. We can see from Table 9-2 that average production loss decreases as we move from $FPSO_1$ to $FPSO_2$ and further to $FPSO_3$. Average production loss and T_{BS} are inversely proportional.

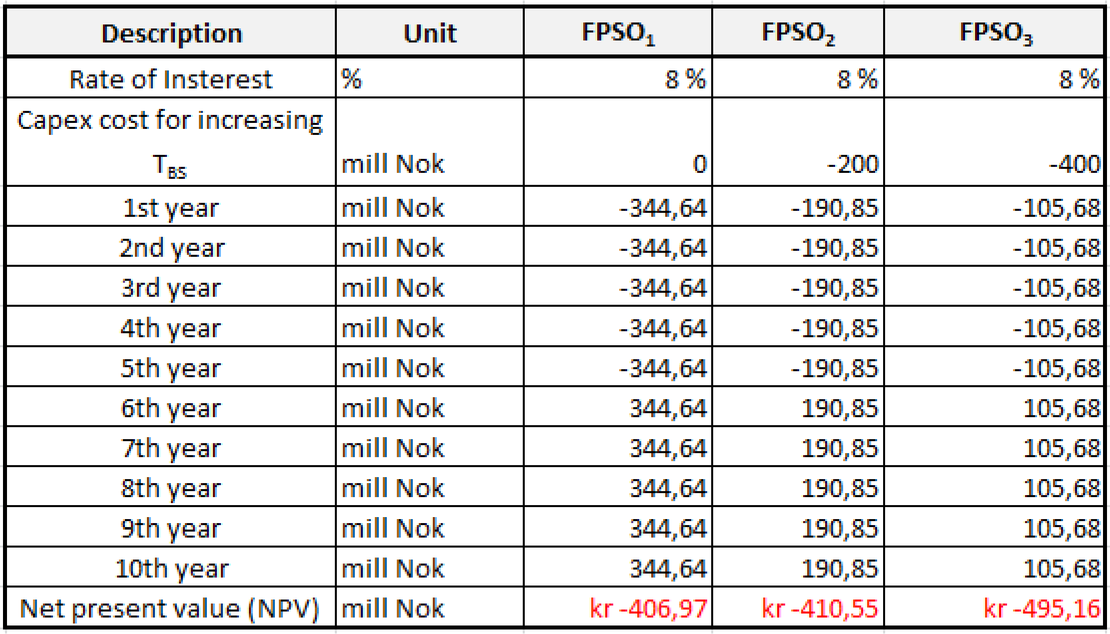
Table 9-2: Financial & Production loss incurred during Plateau production phase



S.No.	Description	Unit	$FPSO_1$	$FPSO_2$	$FPSO_3$
1	Total loss due to deferred production - 10 years. (Summation of losses $FPSO_1$ - Refer Column H $FPSO_2$ - Refer Column L $FPSO_3$ - Refer Column P)	mill Nok	3446,41	1908,48	1056,75
2	Average loss =[1]/10	mill Nok/year	344,64	190,85	105,68
3	Average production loss =[2]/(7,31 Nok * 60$)	Mill.bbl/year	0,79	0,44	0,24
4	Planned plateau production = (P_R*24*365)	Mill.bbl/year	69	69	69
5	Actual production =[4]-[3]	Mill.bbl/year	68,09	68,44	68,63

Nevertheless, one cannot conclude that increasing T_{BS} will reduce financial loss without performing NPV calculation. In the beginning of this section, we mentioned that production deferred during plateau production phase can be recovered in the production decline phase. Average loss each year due to deferred production can be regarded as cash outflow for year 1 - 5 in NPV calculations. In the production decline phase, due to the recovery of deferred hydrocarbons, the computed average loss can be perceived as average gain each year. This average gain each year can be regarded as cash inflow for year 6 – 10 in NPV calculations. Table 9-3, presents NPV analysis for deferred production case.

Table 9-3: NPV Analysis - Deferred production case



Description	Unit	$FPSO_1$	$FPSO_2$	$FPSO_3$
Rate of Insterest	%	8 %	8 %	8 %
Capex cost for increasing T_{BS}	mill Nok	0	-200	-400
1st year	mill Nok	-344,64	-190,85	-105,68
2nd year	mill Nok	-344,64	-190,85	-105,68
3rd year	mill Nok	-344,64	-190,85	-105,68
4th year	mill Nok	-344,64	-190,85	-105,68
5th year	mill Nok	-344,64	-190,85	-105,68
6th year	mill Nok	344,64	190,85	105,68
7th year	mill Nok	344,64	190,85	105,68
8th year	mill Nok	344,64	190,85	105,68
9th year	mill Nok	344,64	190,85	105,68
10th year	mill Nok	344,64	190,85	105,68
Net present value (NPV)	mill Nok	kr -406,97	kr -410,55	kr -495,16

We can observe that NPV is negative for all the 3 FPSO's. Increasing buffer storage time from T_{BS1} to T_{BS2} and further to T_{BS3} is not yielding a positive NPV for the investments. We can infer that investments in FPSO buffer storage tank capacity, T_{BS} can maximize production uptime but not necessarily maximize the NPV of the investments.

The governing objective for the implementation of any project in today's oil and gas industry is to make the projects more cost efficient in order to maximize the Net Present Value (NPV) of the investments. Considering this objective, it is prudent to conclude that $FPSO_1$ is best positioned to actively compete with $FPSO_2$ & $FPSO_3$.

This is the most realistic comparison among FPSO's capacities for an oil reach field. Hence, for evaluating an oil field, deferred production case is preferred to loss of production case.

10. CONCLUSION

The objective of this dissertation is to ensure offloading regularity by selecting an optimal FPSO storage capacity. The primary factor affecting offloading regularity is the prevailing environmental conditions such as waves, polar low, sea ice, etc., but by maximizing T_{BS}, the effect of unfavorable weather conditions can be considerably reduced. Incorporating Norsk Olje & gas recommendation, polar low durations, and wave limitation criteria, optimal storage capacity of FPSO is given in Eqn. (8.14),

Optimal FPSO storage capacity = Maximum of
[(SF * Shuttle tanker capacity);
(($T_{FPSO\text{-}STmin}$ + 48 hrs) * Production rate);
(($T_{FPSO\text{-}STmin}$ + Estimated T_{BS}) * Production rate)]. --- (8.14)

The framework of the above equation is contingent on the happening of unfavorable weather conditions at $T_{FPSO\text{-}Stmin}$. Such a situation articulates the worst case scenario for offloading operation. This situation calls for an appropriate $T_{BS.}$ Both offloading regularity and FPSO operating efficiency will improve if we increase the buffer storage time T_{BS}. Selecting an appropriate T_{BS} is an economic tradeoff between increased capex of hull size versus increase in FPSO operating efficiency. Based on cost benefit analysis, field operator can estimate the appropriate $T_{BS.}$

Three FPSO sizes are considered for analysis, namely $FPSO_1$, $FPSO_2$ & $FPSO_3$ with buffer storage time T_{BS1}, T_{BS2} & T_{BS3} and safety factors SF_1, SF_2 & SF_3 respectively.

Unfavorable weather conditions for offloading operation leads to loss / deferred production. The loss / deferred production can result in substantially decreased revenue over the life of the project, as well as less oil. The NPV method is used to evaluate investments on different FPSO sizes for loss / deferred production cases. It was concluded in Section 9.5.2 that deferred production case offers the most realistic comparison among FPSO's capacities.

One cannot conclude that increasing T_{BS} will reduce financial loss without performing NPV calculation. From NPV analysis, we inferred that increasing buffer storage time from T_{BS1} to T_{BS2} and further to T_{BS3} is not yielding a positive NPV for the investments. Investments in FPSO buffer storage tank capacity can maximize production uptime but not necessarily maximize the NPV of the investments.

The governing objective for the implementation of any project in today's oil and gas industry is to make the projects more cost efficient in order to maximize the Net Present Value (NPV) of the investments. Considering this objective, for the given parameters and assumptions, it is prudent to conclude that $FPSO_1$ is the optimum choice. $FPSO_1$ is best positioned to actively compete with $FPSO_2$ & $FPSO_3$.

Table 10-1 compiles some of the key assumptions, outcomes & discussion points that are set forth in this dissertation.

Table 10-1: Key Outcomes & discussion points

Description	**$FPSO_1$**	**$FPSO_2$**	**$FPSO_3$**
Key facts & assumptions			
FPSO Size in 'bbls'	$FPSO_1$= Max. of [(1,3 * ST); ($T_{FPSO-STmin}$ + 48 hrs) * P_R); (($T_{FPSO-STmin}$ + Estimated T_{BS}) * P_R)]	$FPSO_2$= Max. of [(1,4176 * ST); ($T_{FPSO-STmin}$ + 48 hrs) * P_R); (($T_{FPSO-STmin}$ + Estimated T_{BS}) * P_R)]	$FPSO_3$= Max. of [(1,5353 * ST); ($T_{FPSO-STmin}$ + 48 hrs) * P_R); (($T_{FPSO-STmin}$ + Estimated T_{BS}) * P_R)]
ST Size in 'bbls'	850,000	850,000	850,000
Safety facto, SF	1,3	1,4176	1,5353
Production rate, P_R in 'bbls/hr'	7862	7862	7862
Offloading rate, O_R in 'bbls/hr'	50314	50314	50314
Estimated T_{BS} (Assumed for this case study) in 'hrs'	48	48	48

Description	**$FPSO_1$**	**$FPSO_2$**	**$FPSO_3$**
Max. duration of polar low in 'hrs'	48	48	48
Key outcomes			
Calculated T_{BS} in 'hrs'	49	62	75
Offloading regularity: Influence of wave limitation criteria over Offloading regularity of FPSO (for period 2003-2013):- Number of occasions FPSO has to stop production due to full storage.	39	28	14
Increase in FPSO operating efficiency	Nil	$\frac{39-28}{39} = 38\%$	$\frac{39-14}{39} = 64\%$
Polar low: Influence of 48 hr duration polar low over offloading regularity	T_{BS}>48 hrs. Hence, offloading regularity is not affected.	T_{BS}>48 hrs. Hence, offloading regularity is not affected.	T_{BS}>48 hrs. Hence, offloading regularity is not affected.
Sea Ice: Influence of sea ice over offloading regularity	Sea ice delays shuttle tanker arrival time. Since sea ice is predictable, by proper scheduling of ST, we can ensure that offloading regularity is not affected.		
Shuttle tanker fleet size			
N - Number of shuttle tankers assuming 3 days (72 hrs) waiting time in the field. 'N' is a function of ST capacity, ST round trip cycle time & Production rate. 'N' is independent of FPSO size.	2.45	2.45	2.45

Description	**FPSO$_1$**	**FPSO$_2$**	**FPSO$_3$**
Hence, we require same number of ST for different FPSO's.			
NPV Analysis for deferred production case			
Additional investment	Nil	200 mill Nok	400 mill Nok
NPV in 'mill Nok'	-406,97	-410,55	-495,16
Conclusion			
For the given parameters and assumptions, it is prudent to conclude that FPSO$_1$ is the optimum choice. FPSO$_1$ best positioned to actively compete with FPSO$_2$ & FPSO$_3$.			

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12. APPENDIX

APPENDIX – 1 – Case Study for Shuttle tanker capacity – 850,000 bbls

APPENDIX – 2 – Case Study for Shuttle tanker capacity – 700,000 bbls

APPENDIX – 3 – NPV Analysis: $FPSO_1$ & $FPSO_2$

APPENDIX – 4 – NPV Analysis: $FPSO_1$ & $FPSO_3$

APPENDIX – 5 – Hindcast data – Johan Castberg field – Year 2013 – Winter months

Annexure - 1

Case study - Optimal Storage capacity of FPSO

Shuttle tanker capacity - 850,000 bbls

Transportation of hydrocarbon from from Johan castberg field to Murmansk Oil terminal

S.No.	Abbreviation	Description	$FPSO_1$	$FPSO_2$	$FPSO_3$	Units
1	F_c	FPSO capacity	1105000	1205000	1305000	bbls
2	F	Factor of Safety	1,3	1,418	1,5353	
3	STc	Shuttle tanker capacity	850000	850000	850000	bbls
4	P_R	Production Rate (Johan castberg production - 30000 Sm3/sd)	7862	7862	7862	bbls/hr
5	O_R	Offloading Rate (8000 m3/hr)	50314	50314	50314	bbls/hr
6	$T_{FPSO\text{-}max}$	Maximum time FPSO can produce without offloading operation	141	153	166	hrs
7	S1	Service speed of Shuttle tanker in open water	12	12	12	knots
8	S2	Service speed of Shuttle tanker in ice infested water	3	3	3	knots
9	D1	Maritime distance in open water, between offshore field and Oil terminal	300	300	300	km
10	D2	Maritime distance in ice infested water, between offshore field and Oil terminal	335	335	335	km
11	T1	Time taken to connect shuttle tanker to FPSO	3	3	3	hrs
12	T2	Minimum Time taken to fill the Shuttle tanker (full parcel) (STc / OR)	17	17	17	hrs
13	T3	Time taken to disconnect shuttle tanker from Fpso	3	3	3	hrs
14	T4	Time taken by ST to travel from offshore field to oil terminal	74	74	74	hrs
15	T5	Time taken to connect ST with Oil terminal	3	3	3	hrs
16	T6	Time taken for offloading at oil terminal	17	17	17	hrs
17	T7	Time taken to disconnect ST from Oil terminal	3	3	3	hrs
18	T8	Time taken by ST to travel from Oil terminal to Offshore field	74	74	74	hrs
19	$T_{ST\text{-}RT}$	Time taken for ST Round Trip Operation Cycle T=T1+T2+T3+T4+T5+T6+T7+T8	193	193	193	hrs
	Calculating Waiting time and Shuttle tanker fleet size					
20	N assumed	Number of ST Required - assumed to calculate waiting time for shuttle tankers in the field.	3	3	3	

Annexure - 1

Case study - Optimal Storage capacity of FPSO

Shuttle tanker capacity - 850,000 bbls

Transportation of hydrocarbon from from Johan castberg field to Murmansk Oil terminal

S.No.	Abbreviation	Description	$FPSO_1$	$FPSO_2$	$FPSO_3$	Units
21	$T_{FPSO-ST\ min}$	Minimum time required for FPSO to deliver full parcel to shuttle tanker, =STC*((1/PR)-(1/OR))	91	91	91	hrs
22	T_{ST-W}	Waiting Time for ST in the field, $T_{ST-W}=(ST_{C*}N/P_R)-(T_{ST-RT}))$. If this value is minus, then it means that FPSO is waiting for shuttle tanker to arrive	130,97	130,97	130,97	hrs
23	N Required	Calculating number of shuttle tankers assuming 3 days (72 hrs) waiting time in the field. $N=[(72+T_{ST-RT})*P_R]/ST_C$	2,45	2,45	2,45	no.
24	Number of Shuttle tanker trips in a year. (This value depends on shuttle tanker capacity)		81	81	81	no.
	Weather criteria and window availability analysis					
25	Estimated T_{BS}	Increasing the T_{BS} value reduces the consequences of wave limiting criteria on FPSO storage. T_{BS} mainly reduces the frequency of stoppage of FPSO due to full storage.	48	48	48	hrs
26	Maximum duration of polar low		48	48	48	hrs
27	Calculated T_{BS}	Buffer storage time duration. i.e., Time interval between TFPSO-max & TFPSO-ST min. $T_{BS} = T_{FPSO-max} - T_{FPSO-ST}$	49	62	75	hrs
28	$FPSO_{BS}$	FPSO buffer storage capacity	387820	487820	587820	bbls

🟨 Input fields are highlighted in Yellow

Annexure - 2

Case study - Optimal Storage capacity of FPSO

Shuttle tanker capacity - 700,000 bbls

Transportation of hydrocarbon from from Johan castberg field to Murmansk Oil terminal

S.No.	Abbreviation	Description	$FPSO_1$	$FPSO_2$	$FPSO_3$	Units
1	F_c	FPSO capacity	967995	1010000	1110000	bbls
2	F	Factor of Safety	1,3	1,443	1,5857	
3	STc	Shuttle tanker capacity	700000	700000	700000	bbls
4	P_R	Production Rate (Johan castberg production - 30000 Sm3/sd)	7862	7862	7862	bbls/hr
5	O_R	Offloading Rate (8000 m3/hr)	50314	50314	50314	bbls/hr
6	$T_{FPSO\text{-}max}$	Maximum time FPSO can produce without offloading operation	123	128	141	hrs
7	S1	Service speed of Shuttle tanker in open water	12	12	12	knots
8	S2	Service speed of Shuttle tanker in ice infested water	3	3	3	knots
9	D1	Maritime distance in open water, between offshore field and Oil terminal	300	300	300	km
10	D2	Maritime distance in ice infested water, between offshore field and Oil terminal	335	335	335	km
11	T1	Time taken to connect shuttle tanker to FPSO	3	3	3	hrs
12	T2	Minimum Time taken to fill the Shuttle tanker (full parcel) (STc / OR)	14	14	14	hrs
13	T3	Time taken to disconnect shuttle tanker from Fpso	3	3	3	hrs
14	T4	Time taken by ST to travel from offshore field to oil terminal	74	74	74	hrs
15	T5	Time taken to connect ST with Oil terminal	3	3	3	hrs
16	T6	Time taken for offloading at oil terminal	14	14	14	hrs
17	T7	Time taken to disconnect ST from Oil terminal	3	3	3	hrs
18	T8	Time taken by ST to travel from Oil terminal to Offshore field	74	74	74	hrs
19	$T_{ST\text{-}RT}$	Time taken for ST Round Trip Operation Cycle T=T1+T2+T3+T4+T5+T6+T7+T8	187	187	187	hrs
	Calculating Waiting time and Shuttle tanker fleet size					
20	N assumed	Number of ST Required - assumed to calculate waiting time for shuttle tankers in the field.	3	3	3	

Annexure - 2

S.No.	Abbreviation	Description	$FPSO_1$	$FPSO_2$	$FPSO_3$	Units
Case study - Optimal Storage capacity of FPSO						
Shuttle tanker capacity - 700,000 bbls						
Transportation of hydrocarbon from from Johan castberg field to Murmansk Oil terminal						
21	$T_{FPSO-ST\ min}$	Minimum time required for FPSO to deliver full parcel to shuttle tanker, =STC*((1/PR)-(1/OR))	75	75	75	hrs
22	T_{ST-W}	Waiting Time for ST in the field, $T_{ST-W}=(ST_{C*}N/P_R)-(T_{ST-RT}))$. If this value is minus, then it means that FPSO is waiting for shuttle tanker to arrive	79,69	79,69	79,69	hrs
23	N Required	Calculating number of shuttle tankers assuming 3 days (72 hrs) waiting time in the field. $N=[(72+T_{ST-RT})*P_R]/ST_C$	2,91	2,91	2,91	no.
24	Number of Shuttle tanker trips in a year. (This value depends on shuttle tanker capacity)		98	98	98	no.
	Weather criteria and window availability analysis					
25	Estimated T_{BS}	Increasing the T_{BS} value reduces the consequences of wave limiting criteria on FPSO storage. T_{BS} mainly reduces the frequency of stoppage of FPSO due to full storage.	48	48	48	hrs
26	Maximum duration of polar low		48	48	48	hrs
27	Calculated T_{BS}	Buffer storage time duration. i.e., Time interval between TFPSO-max & TFPSO-ST min. $T_{BS} = T_{FPSO-max} - T_{FPSO-ST}$	48	53	66	hrs
28	$FPSO_{BS}$	FPSO buffer storage capacity	377376	419381	519381	bbls

🟨 Input fields are highlighted in Yellow

Annexure -3

NPV Analysis : $FPSO_1$ and $FPSO_2$

			Shuttle tanker cost			$FPSO_1$ (SF = 1,3), (T_{BS}=49 hrs), (T1=3 hrs FPSO-ST connecting time), (Cost per bbl -60$) (Production Rate -7862 bbl/hr) (1$=7,31 Nok)				$FPSO_2$ (SF = 1,4176), (T_{BS}=62 hrs), (T1=3 hrs FPSO-ST connecting time), (Cost per bbl -60$) (Production Rate -7862 bbl/hr) (1$=7,31 Nok)				Case1: Cash inflow by changing from $FPSO_1$ to $FPSO_2$, i.e., increase in $T_{BS,}$ in 'Million Nok' Q = H-L
S.No.	**year**	**Wave limitation criteria "Durations of Hs>=4.5 m" in 'hrs' (A)**	ST additional waiting time in 'days' B=(A/24)	ST leasing cost - 100000 'USD / day' (C)	ST additional cost in 'USD' D=(B*C)	No. Of hours FPSO has to stop prod. In 'hrs' E=(A-49+3)	Deferred FPSO prod. cost due to stoppage in '$' F=E*7862*60	Total loss in 'Million Nok' G=D+F	Total loss in 'Million Nok' (each year) (H)	No. Of hours FPSO has to stop prod. In 'hrs' I=(A-62+3)	Deferred FPSO prod. cost due to stoppage in '$' J=I*7862*60	Total loss in 'Million Nok' K=D+J	Total loss in 'Million Nok' (each year) (L)	
1	2003	75	3,13	100000	312500	29	13679880	102,28	131,52	16	7547520	57,46	59,10	72,41
2	2003	54	2,25	100000	225000	8	3773760	29,23			0	1,64		
3	2004	60	2,50	100000	250000	14	6604080	50,10	119,00	1	471720	5,28	12,10	106,90
4	2004	60	2,50	100000	250000	14	6604080	50,10		1	471720	5,28		
5	2004	51	2,13	100000	212500	5	2358600	18,79			0	1,55		
6	2005	54	2,25	100000	225000	8	3773760	29,23	98,13		0	1,64	5,03	93,10
7	2005	57	2,38	100000	237500	11	5188920	39,67			0	1,74		
8	2005	54	2,25	100000	225000	8	3773760	29,23			0	1,64		
9	2006	78	3,25	100000	325000	32	15095040	112,72	588,68	19	8962680	67,89	257,64	331,03
10	2006	51	2,13	100000	212500	5	2358600	18,79			0	1,55		
11	2006	69	2,88	100000	287500	23	10849560	81,41		10	4717200	36,58		
12	2006	81	3,38	100000	337500	35	16510200	123,16		22	10377840	78,33		
13	2006	66	2,75	100000	275000	20	9434400	70,98		7	3302040	26,15		
14	2006	60	2,50	100000	250000	14	6604080	50,10		1	471720	5,28		
15	2006	63	2,63	100000	262500	17	8019240	60,54		4	1886880	15,71		
16	2006	66	2,75	100000	275000	20	9434400	70,98		7	3302040	26,15		
17	2007	78	3,25	100000	325000	32	15095040	112,72	354,88	19	8962680	67,89	175,57	179,31
18	2007	51	2,13	100000	212500	5	2358600	18,79			0	1,55		
19	2007	84	3,50	100000	350000	38	17925360	133,59		25	11793000	88,77		
20	2007	54	2,25	100000	225000	8	3773760	29,23			0	1,64		
21	2007	63	2,63	100000	262500	17	8019240	60,54		4	1886880	15,71		
22	2008	63	2,63	100000	262500	17	8019240	60,54	647,09	4	1886880	15,71	440,20	206,90
23	2008	117	4,88	100000	487500	71	33492120	248,39		58	27359760	203,56		
24	2008	54	2,25	100000	225000	8	3773760	29,23			0	1,64		
25	2008	63	2,63	100000	262500	17	8019240	60,54		4	1886880	15,71		
26	2008	117	4,88	100000	487500	71	33492120	248,39		58	27359760	203,56		
27	2010	51	2,13	100000	212500	5	2358600	18,79	131,52		0	1,55	69,45	62,07
28	2010	78	3,25	100000	325000	32	15095040	112,72		19	8962680	67,89		
29	2011	120	5,00	100000	500000	74	34907280	258,83	743,10	61	28774920	214,00	563,79	179,31
30	2011	96	4,00	100000	400000	50	23586000	175,34		37	17453640	130,51		
31	2011	84	3,50	100000	350000	38	17925360	133,59		25	11793000	88,77		
32	2011	96	4,00	100000	400000	50	23586000	175,34		37	17453640	130,51		
33	2012	87	3,63	100000	362500	41	19340520	144,03	325,65	28	13208160	99,20	153,23	172,41
34	2012	60	2,50	100000	250000	14	6604080	50,10		1	471720	5,28		
35	2012	72	3,00	100000	300000	26	12264720	91,85		13	6132360	47,02		
36	2012	57	2,38	100000	237500	11	5188920	39,67			0	1,74		

Annexure -3

NPV Analysis : FPSO$_1$ and FPSO$_2$

S.No.	year	**Wave limitation criteria “Durations of Hs>=4.5 m" in 'hrs' (A)**	Shuttle tanker cost			FPSO$_1$ (SF = 1,3), (T_{BS}=49 hrs), (T1=3 hrs FPSO-ST connecting time), (Cost per bbl -60\$) (Production Rate -7862 bbl/hr) (1\$=7,31 Nok)				FPSO$_2$ (SF = 1,4176), (T_{BS}=62 hrs), (T1=3 hrs FPSO-ST connecting time), (Cost per bbl -60\$) (Production Rate -7862 bbl/hr) (1\$=7,31 Nok)				Case1: Cash inflow by changing from FPSO$_1$ to FPSO$_2$, i.e., increase in $T_{BS,}$ in 'Million Nok' Q = H-L
			ST additional waiting time in 'days' B=(A/24)	ST leasing cost - 100000 'USD / day' (C)	ST additional cost in 'USD' D=(B*C)	No. Of hours FPSO has to stop prod. In 'hrs' E=(A-49+3)	Deferred FPSO prod. cost due to stoppage in '\$' F=E*7862*60	Total loss in 'Million Nok' G=D+F	Total loss in 'Million Nok' (each year) (H)	No. Of hours FPSO has to stop prod. In 'hrs' I=(A-62+3)	Deferred FPSO prod. cost due to stoppage in '\$' J=I*7862*60	Total loss in 'Million Nok' K=D+J	Total loss in 'Million Nok' (each year) (L)	
37	2013	63	2,63	100000	262500	17	8019240	60,54	306,85	4	1886880	15,71	172,37	134,48
38	2013	63	2,63	100000	262500	17	8019240	60,54		4	1886880	15,71		
39	2013	99	4,13	100000	412500	53	25001160	185,77		40	18868800	140,95		
								Total loss due to deferred production - 10 years, in 'mill Nok'	**3446,41**			**Total loss due to deferred production - 10 years, in 'mill Nok'**	**1908,48**	

Annexure - 4

NPV Analysis : FPSO$_1$ and FPSO$_3$

S.No.	year	Wave limitation criteria “Durations of Hs>=4.5 m" in 'hrs' (A)	Shuttle tanker cost			FPSO$_1$ (SF = 1,3), (T$_{BS}$=49 hrs), (T1=3 hrs FPSO-ST connecting time), (Cost per bbl -60$) (Production Rate -7862 bbl/hr) (1$=7,31 Nok)				FPSO$_3$ (SF = 1,5353), (T$_{BS}$=75 hrs), (T1=3 hrs FPSO-ST connecting time), (Cost per bbl -60$) (Production Rate -7862 bbl/hr) (1$=7,31 Nok)				Case2: Cash inflow by changing from FPSO$_1$ to FPSO$_3$, i.e., increase in T$_{BS,}$ in 'Million Nok' R = H-P
			ST additional waiting time in 'days' B=(A/24)	ST leasing cost - 100000 'USD / day' (C)	ST additional cost in 'USD' D=(B*C)	No. Of hours FPSO has to stop prod. In 'hrs' E=(A-49+3)	Deferred FPSO prod. cost due to stoppage in '$' F=E*7862*60	Total loss in 'Million Nok' G=D+F	Total loss in 'Million Nok' (each year) (H)	No. Of hours FPSO has to stop prod. In 'hrs' M=(A-75+3)	Deferred FPSO prod. cost due to stoppage in '$' N=M*7862*60	Total loss in 'Million Nok' O=D+N	Total loss in 'Million Nok' (each year) (P)	
1	2003	75	3,13	100000	312500	29	13679880	102,28		3	1415160	12,63		
2	2003	54	2,25	100000	225000	8	3773760	29,23	131,52		0	1,64	14,27	117,24
3	2004	60	2,50	100000	250000	14	6604080	50,10			0	1,83		
4	2004	60	2,50	100000	250000	14	6604080	50,10			0	1,83		
5	2004	51	2,13	100000	212500	5	2358600	18,79	119,00		0	1,55	5,21	113,79
6	2005	54	2,25	100000	225000	8	3773760	29,23			0	1,64		
7	2005	57	2,38	100000	237500	11	5188920	39,67			0	1,74		
8	2005	54	2,25	100000	225000	8	3773760	29,23	98,13		0	1,64	5,03	93,10
9	2006	78	3,25	100000	325000	32	15095040	112,72		6	2830320	23,07		
10	2006	51	2,13	100000	212500	5	2358600	18,79			0	1,55		
11	2006	69	2,88	100000	287500	23	10849560	81,41			0	2,10		
12	2006	81	3,38	100000	337500	35	16510200	123,16		9	4245480	33,50		
13	2006	66	2,75	100000	275000	20	9434400	70,98			0	2,01		
14	2006	60	2,50	100000	250000	14	6604080	50,10			0	1,83		
15	2006	63	2,63	100000	262500	17	8019240	60,54			0	1,92		
16	2006	66	2,75	100000	275000	20	9434400	70,98	588,68		0	2,01	67,99	520,69
17	2007	78	3,25	100000	325000	32	15095040	112,72		6	2830320	23,07		
18	2007	51	2,13	100000	212500	5	2358600	18,79			0	1,55		
19	2007	84	3,50	100000	350000	38	17925360	133,59		12	5660640	43,94		
20	2007	54	2,25	100000	225000	8	3773760	29,23			0	1,64		
21	2007	63	2,63	100000	262500	17	8019240	60,54	354,88		0	1,92	72,12	282,76
22	2008	63	2,63	100000	262500	17	8019240	60,54			0	1,92		
23	2008	117	4,88	100000	487500	71	33492120	248,39		45	21227400	158,74		
24	2008	54	2,25	100000	225000	8	3773760	29,23			0	1,64		
25	2008	63	2,63	100000	262500	17	8019240	60,54			0	1,92		
26	2008	117	4,88	100000	487500	71	33492120	248,39	647,09	45	21227400	158,74	322,95	324,14
27	2010	51	2,13	100000	212500	5	2358600	18,79			0	1,55		
28	2010	78	3,25	100000	325000	32	15095040	112,72	131,52	6	2830320	23,07	24,62	106,90
29	2011	120	5,00	100000	500000	74	34907280	258,83		48	22642560	169,17		
30	2011	96	4,00	100000	400000	50	23586000	175,34		24	11321280	85,68		
31	2011	84	3,50	100000	350000	38	17925360	133,59		12	5660640	43,94		
32	2011	96	4,00	100000	400000	50	23586000	175,34	743,10	24	11321280	85,68	384,48	358,62
33	2012	87	3,63	100000	362500	41	19340520	144,03		15	7075800	54,37		
34	2012	60	2,50	100000	250000	14	6604080	50,10			0	1,83		
35	2012	72	3,00	100000	300000	26	12264720	91,85			0	2,19		
36	2012	57	2,38	100000	237500	11	5188920	39,67	325,65		0	1,74	60,13	265,52
37	2013	63	2,63	100000	262500	17	8019240	60,54			0	1,92		

Annexure - 4

NPV Analysis : FPSO$_1$ and FPSO$_3$

S.No.	**year**	**Wave limitation criteria "Durations of Hs>=4.5 m" in 'hrs' (A)**	Shuttle tanker cost			FPSO$_1$ (SF = 1,3), (T_{BS}=49 hrs), (T1=3 hrs FPSO-ST connecting time), (Cost per bbl -60$) (Production Rate -7862 bbl/hr) (1$=7,31 Nok)				FPSO$_3$ (SF = 1,5353), (T_{BS}=75 hrs), (T1=3 hrs FPSO-ST connecting time), (Cost per bbl -60$) (Production Rate -7862 bbl/hr) (1$=7,31 Nok)				Case2: Cash inflow by changing from FPSO$_1$ to FPSO$_3$, i.e., increase in $T_{BS,}$ in 'Million Nok' R = H-P
			ST additional waiting time in 'days' B=(A/24)	ST leasing cost - 100000 'USD / day' (C)	ST additional cost in 'USD' D=(B*C)	No. Of hours FPSO has to stop prod. In 'hrs' E=(A-49+3)	Deferred FPSO prod. cost due to stoppage in '$' F=E*7862*60	Total loss in 'Million Nok' G=D+F	Total loss in 'Million Nok' (each year) (H)	No. Of hours FPSO has to stop prod. In 'hrs' M=(A-75+3)	Deferred FPSO prod. cost due to stoppage in '$' N=M*7862*60	Total loss in 'Million Nok' O=D+N	Total loss in 'Million Nok' (each year) (P)	
38	2013	63	2,63	100000	262500	17	8019240	60,54			0	1,92		
39	2013	99	4,13	100000	412500	53	25001160	185,77	306,85	27	12736440	96,12	99,96	206,90
								Total loss due to deferred production - 10 years, in 'mill Nok'	**3446,41**			**Total loss due to deferred production - 10 years, in 'mill Nok'**	**1056,75**	

Annexure - 5

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
January	1	3,3	
January	1	2,9	
January	1	2,8	
January	1	2,7	
January	1	2,6	
January	1	2,5	
January	1	2,3	
January	1	2,2	
January	2	2,1	
January	2	2	
January	2	1,9	
January	2	1,8	
January	2	1,7	
January	2	1,7	
January	2	1,8	
January	2	1,8	
January	3	1,9	
January	3	2	
January	3	2	
January	3	1,9	
January	3	1,9	
January	3	1,8	
January	3	1,7	
January	3	1,7	
January	4	1,8	
January	4	2,4	
January	4	3,2	
January	4	3,4	
January	4	3,1	
January	4	3,3	
January	4	3,3	
January	4	3,2	
January	5	3	
January	5	2,9	
January	5	2,7	
January	5	2,5	
January	5	2,4	
January	5	2,3	
January	5	2,3	
January	5	2,7	
January	6	3,1	
January	6	3,5	
January	6	3,8	
January	6	4	
January	6	4,1	
January	6	4,3	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
January	6	4,2	
January	6	3,9	
January	7	4,2	
January	7	4,3	
January	7	4,1	
January	7	4,1	
January	7	4,2	
January	7	4	
January	7	3,8	
January	7	3,4	
January	8	3,2	
January	8	3,1	
January	8	3	
January	8	2,7	
January	8	2,7	
January	8	2,7	
January	8	2,7	
January	8	3,1	
January	9	3,2	
January	9	3,8	
January	9	4	
January	9	3,9	
January	9	3,6	
January	9	3,2	
January	9	2,8	
January	9	2,4	
January	10	2	
January	10	1,8	
January	10	1,8	
January	10	1,9	
January	10	2	
January	10	2,2	
January	10	2,4	
January	10	2,6	
January	11	2,9	
January	11	3,1	
January	11	3,6	
January	11	4	
January	11	4,3	
January	11	4,2	
January	11	3,9	
January	11	3,7	
January	12	3,6	
January	12	3,6	
January	12	3,6	
January	12	3,6	
January	12	3,5	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
January	12	3,2	
January	12	3	
January	12	2,7	
January	13	2,5	
January	13	2,3	
January	13	2,3	
January	13	2,5	
January	13	2,7	
January	13	2,8	
January	13	2,7	
January	13	2,7	
January	14	2,6	
January	14	2,6	
January	14	2,6	
January	14	2,6	
January	14	2,5	
January	14	2,4	
January	14	2,3	
January	14	2,1	
January	15	2	
January	15	1,9	
January	15	1,9	
January	15	1,9	
January	15	2	
January	15	2	
January	15	2	
January	15	1,8	
January	16	2	
January	16	2,5	
January	16	2,3	
January	16	2,1	
January	16	2,5	
January	16	3	
January	16	3,4	
January	16	3,4	
January	17	3,2	
January	17	2,8	
January	17	3,1	
January	17	3,6	
January	17	4	
January	17	4,3	
January	17	4,4	
January	17	4,7	
January	18	4,5	6
January	18	4,2	
January	18	4	
January	18	3,6	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
January	18	3,2	
January	18	2,9	
January	18	2,8	
January	18	3	
January	19	3,4	
January	19	4	
January	19	4,4	
January	19	4,2	
January	19	4,2	
January	19	4,2	
January	19	4,2	
January	19	4,1	
January	20	3,9	
January	20	3,7	
January	20	3,4	
January	20	3,1	
January	20	3	
January	20	3,2	
January	20	3,4	
January	20	3,7	
January	21	4,1	
January	21	4,2	
January	21	4,3	
January	21	4,3	
January	21	4,2	
January	21	4	
January	21	3,4	
January	21	3,2	
January	22	3,3	
January	22	3,4	
January	22	3,7	
January	22	4,3	
January	22	4,8	
January	22	5,1	
January	22	5,2	
January	22	5,2	
January	23	5,2	
January	23	5,3	
January	23	6	
January	23	6,1	
January	23	5,6	
January	23	5,5	
January	23	4,9	33
January	23	4,2	
January	24	3,6	
January	24	3,2	
January	24	2,8	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
January	24	2,6	
January	24	2,7	
January	24	2,6	
January	24	2,4	
January	24	2,3	
January	25	2,2	
January	25	2,2	
January	25	2	
January	25	1,8	
January	25	1,7	
January	25	1,6	
January	25	1,5	
January	25	1,5	
January	26	1,7	
January	26	1,7	
January	26	1,6	
January	26	1,7	
January	26	1,7	
January	26	1,5	
January	26	1,5	
January	26	1,6	
January	27	1,8	
January	27	2	
January	27	2,2	
January	27	2,2	
January	27	2,2	
January	27	2,1	
January	27	2	
January	27	1,9	
January	28	1,8	
January	28	1,7	
January	28	1,7	
January	28	1,8	
January	28	1,9	
January	28	2,2	
January	28	2,6	
January	28	3,1	
January	29	3,8	
January	29	4,2	
January	29	4,6	
January	29	4,9	
January	29	5,1	
January	29	5,1	
January	29	5,2	
January	29	5	
January	30	4,8	
January	30	4,7	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
January	30	4,6	27
January	30	4,4	
January	30	4	
January	30	3,7	
January	30	3,6	
January	30	3,5	
January	31	3,3	
January	31	3,1	
January	31	3	
January	31	3	
January	31	3	
January	31	3	
January	31	3	
January	31	2,8	
February	1	2,6	
February	1	2,7	
February	1	3	
February	1	3	
February	1	2,9	
February	1	2,8	
February	1	2,7	
February	1	2,7	
February	2	2,7	
February	2	2,8	
February	2	2,7	
February	2	2,5	
February	2	2,3	
February	2	2,1	
February	2	1,9	
February	2	1,8	
February	3	1,8	
February	3	1,8	
February	3	1,8	
February	3	1,8	
February	3	1,9	
February	3	1,9	
February	3	2	
February	3	1,9	
February	4	1,9	
February	4	2	
February	4	2	
February	4	2	
February	4	2,1	
February	4	2,4	
February	4	3	
February	4	3,4	
February	5	3,4	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
February	5	3,5	
February	5	3,6	
February	5	4,3	
February	5	4,7	
February	5	4,8	
February	5	4,6	9
February	5	4,2	
February	6	3,8	
February	6	3,4	
February	6	3,1	
February	6	2,7	
February	6	2,4	
February	6	2,1	
February	6	1,9	
February	6	1,8	
February	7	1,7	
February	7	1,6	
February	7	1,5	
February	7	1,4	
February	7	1,3	
February	7	1,3	
February	7	1,2	
February	7	1,2	
February	8	1,1	
February	8	1,1	
February	8	1,1	
February	8	1	
February	8	1	
February	8	0,9	
February	8	0,9	
February	8	0,9	
February	9	1,2	
February	9	1,6	
February	9	2	
February	9	2,2	
February	9	2,1	
February	9	2,2	
February	9	2,3	
February	9	2,2	
February	10	2,1	
February	10	2,1	
February	10	2	
February	10	1,8	
February	10	1,7	
February	10	1,6	
February	10	1,4	
February	10	1,3	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
February	11	1,4	
February	11	1,3	
February	11	1,3	
February	11	1,3	
February	11	1,4	
February	11	1,4	
February	11	1,5	
February	11	1,5	
February	12	1,4	
February	12	1,4	
February	12	1,4	
February	12	1,3	
February	12	1,3	
February	12	1,4	
February	12	1,4	
February	12	1,3	
February	13	1,3	
February	13	1,3	
February	13	1,2	
February	13	1,3	
February	13	1,4	
February	13	1,4	
February	13	1,8	
February	13	2,3	
February	14	2,2	
February	14	1,9	
February	14	1,9	
February	14	2	
February	14	2,3	
February	14	2,5	
February	14	2,2	
February	14	1,9	
February	15	1,8	
February	15	2	
February	15	2,5	
February	15	2,9	
February	15	3,1	
February	15	3,1	
February	15	2,9	
February	15	2,7	
February	16	2,5	
February	16	2,4	
February	16	2,3	
February	16	2,2	
February	16	2,1	
February	16	2,1	
February	16	2,2	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
February	16	2,3	
February	17	2,2	
February	17	2,1	
February	17	2	
February	17	1,9	
February	17	1,8	
February	17	1,7	
February	17	1,6	
February	17	1,5	
February	18	1,4	
February	18	1,4	
February	18	1,3	
February	18	1,3	
February	18	1,4	
February	18	1,4	
February	18	1,4	
February	18	1,6	
February	19	1,8	
February	19	2	
February	19	2,2	
February	19	2,4	
February	19	2,8	
February	19	2,8	
February	19	2,6	
February	19	2,5	
February	20	2,7	
February	20	3,1	
February	20	3,6	
February	20	4,5	
February	20	5,8	
February	20	6,9	
February	20	6,7	
February	20	5,4	
February	21	4,5	18
February	21	3,9	
February	21	3,8	
February	21	3,3	
February	21	3	
February	21	2,9	
February	21	2,8	
February	21	2,7	
February	22	2,5	
February	22	2,4	
February	22	2,3	
February	22	2,7	
February	22	2,7	
February	22	3,1	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
February	22	3,7	
February	22	3,8	
February	23	3,8	
February	23	3,6	
February	23	3,2	
February	23	3,1	
February	23	3,1	
February	23	2,8	
February	23	2,5	
February	23	2,3	
February	24	2	
February	24	2	
February	24	2	
February	24	2,5	
February	24	2,9	
February	24	3	
February	24	2,4	
February	24	2,3	
February	25	2,1	
February	25	2	
February	25	2	
February	25	2,3	
February	25	3,4	
February	25	4,3	
February	25	4,2	
February	25	4	
February	26	4,3	
February	26	4,6	
February	26	4,7	
February	26	4,7	
February	26	4,5	12
February	26	4,4	
February	26	4,2	
February	26	3,9	
February	27	3,7	
February	27	3,5	
February	27	3,5	
February	27	3,9	
February	27	4,4	
February	27	4,6	
February	27	4,8	
February	27	5,5	
February	28	5,8	
February	28	5,6	
February	28	5,4	
February	28	5,1	
February	28	4,9	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
February	28	4,6	27
February	28	3,9	
February	28	3,4	
March	1	3	
March	1	2,5	
March	1	2,3	
March	1	2,2	
March	1	2	
March	1	2,1	
March	1	2,5	
March	1	2,6	
March	2	2,6	
March	2	2,8	
March	2	3	
March	2	3,3	
March	2	3,4	
March	2	3,3	
March	2	3,1	
March	2	2,8	
March	3	2,6	
March	3	2,4	
March	3	2,3	
March	3	2,2	
March	3	2,1	
March	3	1,9	
March	3	1,7	
March	3	1,7	
March	4	1,8	
March	4	2,6	
March	4	4	
March	4	4,3	
March	4	4	
March	4	3,5	
March	4	2,9	
March	4	2,6	
March	5	2,5	
March	5	2,3	
March	5	2	
March	5	2	
March	5	2,2	
March	5	2,4	
March	5	2,5	
March	5	2,6	
March	6	2,8	
March	6	4,1	
March	6	5,7	
March	6	6,2	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
March	6	7,1	
March	6	7,5	
March	6	6,7	
March	6	5,6	
March	7	4,8	21
March	7	4,2	
March	7	3,6	
March	7	3,3	
March	7	3,1	
March	7	2,9	
March	7	2,6	
March	7	2,4	
March	8	2,3	
March	8	2,3	
March	8	2,4	
March	8	3	
March	8	3,3	
March	8	3	
March	8	2,5	
March	8	2,3	
March	9	2	
March	9	1,8	
March	9	1,8	
March	9	2	
March	9	2,2	
March	9	2,6	
March	9	3	
March	9	3,2	
March	10	3,2	
March	10	3	
March	10	3	
March	10	3	
March	10	2,8	
March	10	2,7	
March	10	2,5	
March	10	2,4	
March	11	2,6	
March	11	2,8	
March	11	2,8	
March	11	2,9	
March	11	3,1	
March	11	3,4	
March	11	3,3	
March	11	3,4	
March	12	3,3	
March	12	3,2	
March	12	3,1	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
March	12	3,2	
March	12	3,2	
March	12	3,2	
March	12	3,5	
March	12	3,5	
March	13	3,5	
March	13	4	
March	13	4,5	3
March	13	3,9	
March	13	3,1	
March	13	2,7	
March	13	2,4	
March	13	2,1	
March	14	1,9	
March	14	1,7	
March	14	1,6	
March	14	1,4	
March	14	1,2	
March	14	1	
March	14	1	
March	14	1	
March	15	1	
March	15	1	
March	15	1,1	
March	15	1,2	
March	15	1,3	
March	15	1,4	
March	15	1,5	
March	15	1,7	
March	16	2,1	
March	16	2,6	
March	16	2,9	
March	16	3	
March	16	3	
March	16	2,9	
March	16	2,9	
March	16	2,9	
March	17	2,9	
March	17	3,1	
March	17	3,4	
March	17	3,3	
March	17	3,2	
March	17	3	
March	17	2,7	
March	17	2,8	
March	18	3	
March	18	3,1	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
March	18	3,1	
March	18	3	
March	18	2,7	
March	18	3,1	
March	18	3,7	
March	18	4	
March	19	3,8	
March	19	3,7	
March	19	3,7	
March	19	3,9	
March	19	3,9	
March	19	3,6	
March	19	3,5	
March	19	3,6	
March	20	3,5	
March	20	3,2	
March	20	2,7	
March	20	2,2	
March	20	1,8	
March	20	1,6	
March	20	1,7	
March	20	1,8	
March	21	2	
March	21	2,1	
March	21	2,2	
March	21	2,2	
March	21	2,3	
March	21	2,3	
March	21	2,2	
March	21	2,2	
March	22	2,2	
March	22	2,4	
March	22	2,6	
March	22	2,9	
March	22	2,8	
March	22	2,6	
March	22	2,4	
March	22	2,3	
March	23	2,1	
March	23	2	
March	23	2	
March	23	1,9	
March	23	1,7	
March	23	1,5	
March	23	1,5	
March	23	1,4	
March	24	1,3	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
March	24	1,3	
March	24	1,3	
March	24	1,4	
March	24	1,9	
March	24	2,1	
March	24	1,9	
March	24	1,7	
March	25	1,6	
March	25	1,6	
March	25	1,6	
March	25	1,5	
March	25	1,4	
March	25	1,3	
March	25	1,3	
March	25	1,2	
March	26	1,3	
March	26	1,4	
March	26	1,4	
March	26	1,4	
March	26	1,6	
March	26	1,8	
March	26	1,6	
March	26	2,2	
March	27	2,4	
March	27	1,9	
March	27	1,8	
March	27	1,7	
March	27	1,5	
March	27	1,5	
March	27	1,9	
March	27	2	
March	28	2	
March	28	2	
March	28	2,3	
March	28	2,6	
March	28	2,7	
March	28	2,6	
March	28	2,6	
March	28	3,2	
March	29	3,9	
March	29	3,3	
March	29	2,7	
March	29	2,4	
March	29	2,1	
March	29	1,9	
March	29	1,8	
March	29	1,6	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
March	30	1,4	
March	30	1,3	
March	30	1,1	
March	30	1,1	
March	30	1	
March	30	1	
March	30	1,1	
March	30	1,2	
March	31	1,4	
March	31	1,7	
March	31	1,8	
March	31	2,1	
March	31	2,4	
March	31	2,5	
March	31	3,5	
March	31	3,4	
October	1	2,4	
October	1	2,3	
October	1	2,3	
October	1	2,8	
October	1	3,7	
October	1	3,6	
October	1	3	
October	1	2,6	
October	2	2,3	
October	2	2,2	
October	2	2	
October	2	2	
October	2	2,3	
October	2	2,9	
October	2	3,8	
October	2	4,7	
October	3	4,6	6
October	3	3,9	
October	3	3,5	
October	3	3,2	
October	3	3,1	
October	3	3	
October	3	3	
October	3	3,3	
October	4	3,6	
October	4	3,7	
October	4	3,7	
October	4	3,6	
October	4	3,5	
October	4	3,5	
October	4	3,5	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
October	4	3,3	
October	5	3,4	
October	5	3,6	
October	5	3,9	
October	5	3,9	
October	5	4	
October	5	4	
October	5	4,1	
October	5	4,1	
October	6	4	
October	6	3,7	
October	6	3,1	
October	6	2,8	
October	6	2,9	
October	6	3,4	
October	6	3,6	
October	6	3,7	
October	7	3,8	
October	7	3,8	
October	7	3,7	
October	7	3,6	
October	7	3,3	
October	7	3	
October	7	2,8	
October	7	2,7	
October	8	2,5	
October	8	2,4	
October	8	2,3	
October	8	2,3	
October	8	2,2	
October	8	2,2	
October	8	2,3	
October	8	2,5	
October	9	2,5	
October	9	2,5	
October	9	2,4	
October	9	2,3	
October	9	2,1	
October	9	2	
October	9	2	
October	9	2	
October	10	1,9	
October	10	2	
October	10	2,3	
October	10	2,7	
October	10	3,5	
October	10	4,6	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
October	10	4,5	6
October	10	3,7	
October	11	3,2	
October	11	3,4	
October	11	4,2	
October	11	4,5	
October	11	4,6	6
October	11	4,4	
October	11	4,2	
October	11	3,8	
October	12	3,4	
October	12	2,9	
October	12	2,6	
October	12	2,4	
October	12	2,3	
October	12	2,4	
October	12	3,3	
October	12	4,5	
October	13	4,7	
October	13	4,5	9
October	13	4,1	
October	13	3,9	
October	13	3,5	
October	13	3,3	
October	13	3,2	
October	13	3,1	
October	14	2,9	
October	14	2,8	
October	14	2,6	
October	14	2,5	
October	14	2,6	
October	14	2,6	
October	14	3,7	
October	14	5,3	
October	15	4,5	6
October	15	4	
October	15	4,7	
October	15	5,9	
October	15	5,3	9
October	15	4,4	
October	15	3,5	
October	15	3	
October	16	2,7	
October	16	2,3	
October	16	2,2	
October	16	2,1	
October	16	1,9	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
October	16	1,9	
October	16	1,9	
October	16	1,7	
October	17	1,6	
October	17	1,5	
October	17	1,4	
October	17	1,3	
October	17	1,2	
October	17	1,2	
October	17	1,2	
October	17	1,2	
October	18	1,2	
October	18	1,4	
October	18	1,5	
October	18	1,5	
October	18	1,4	
October	18	1,5	
October	18	1,7	
October	18	1,9	
October	19	1,9	
October	19	1,9	
October	19	1,9	
October	19	2	
October	19	2,1	
October	19	2,1	
October	19	2,9	
October	19	3,4	
October	20	3,5	
October	20	3,6	
October	20	3,7	
October	20	3,7	
October	20	3,6	
October	20	3,5	
October	20	3,2	
October	20	2,9	
October	21	2,7	
October	21	2,6	
October	21	2,4	
October	21	2,2	
October	21	2,1	
October	21	1,9	
October	21	1,9	
October	21	2,3	
October	22	2,1	
October	22	1,7	
October	22	1,4	
October	22	1,3	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
October	22	1,2	
October	22	1,1	
October	22	1,1	
October	22	1,1	
October	23	1,1	
October	23	1	
October	23	1	
October	23	1,3	
October	23	1,5	
October	23	1,6	
October	23	1,7	
October	23	1,5	
October	24	1,2	
October	24	1	
October	24	0,9	
October	24	1	
October	24	1,2	
October	24	1,7	
October	24	2,3	
October	24	2	
October	25	1,6	
October	25	1,5	
October	25	1,4	
October	25	1,3	
October	25	1,3	
October	25	1,2	
October	25	1,1	
October	25	1,3	
October	26	1,5	
October	26	1,7	
October	26	1,7	
October	26	1,7	
October	26	1,6	
October	26	1,7	
October	26	1,8	
October	26	2,3	
October	27	2,6	
October	27	2,7	
October	27	2,8	
October	27	2,9	
October	27	3,2	
October	27	3,4	
October	27	3,7	
October	27	4,1	
October	28	4,3	
October	28	4,3	
October	28	4,4	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
October	28	4,6	
October	28	4,9	
October	28	5,3	
October	28	5,6	
October	28	5,9	
October	29	6,1	
October	29	6,4	
October	29	6,8	
October	29	7,2	
October	29	7,4	
October	29	7,4	
October	29	7,4	
October	29	7,3	
October	30	7,2	
October	30	6,9	
October	30	6,6	
October	30	6,4	
October	30	6,2	
October	30	5,8	
October	30	5,3	
October	30	4,7	63
October	31	4	
October	31	3,3	
October	31	2,8	
October	31	2,5	
October	31	2,2	
October	31	2	
October	31	1,8	
October	31	1,7	
November	1	1,6	
November	1	1,6	
November	1	1,7	
November	1	1,8	
November	1	2	
November	1	2,3	
November	1	2,4	
November	1	2,5	
November	2	2,6	
November	2	2,6	
November	2	2,6	
November	2	2,6	
November	2	2,5	
November	2	2,4	
November	2	2,3	
November	2	2,3	
November	3	2,2	
November	3	2,2	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
November	3	2,3	
November	3	2,3	
November	3	2,2	
November	3	2,1	
November	3	2,1	
November	3	2	
November	4	1,9	
November	4	1,8	
November	4	1,8	
November	4	1,7	
November	4	1,6	
November	4	1,6	
November	4	1,5	
November	4	1,4	
November	5	1,2	
November	5	1,3	
November	5	1,4	
November	5	1,4	
November	5	1,6	
November	5	1,8	
November	5	1,9	
November	5	1,9	
November	6	1,7	
November	6	1,8	
November	6	2,2	
November	6	2,5	
November	6	2,7	
November	6	2,7	
November	6	2,6	
November	6	2,4	
November	7	2,3	
November	7	2,2	
November	7	2,2	
November	7	2,2	
November	7	2,2	
November	7	2,1	
November	7	2,1	
November	7	2,2	
November	8	2,1	
November	8	2	
November	8	1,9	
November	8	1,8	
November	8	1,8	
November	8	1,8	
November	8	1,7	
November	8	1,6	
November	9	1,5	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
November	9	1,4	
November	9	1,2	
November	9	1,3	
November	9	1,5	
November	9	1,7	
November	9	1,8	
November	9	1,6	
November	10	1,7	
November	10	2,7	
November	10	3,5	
November	10	3,8	
November	10	3,4	
November	10	2,9	
November	10	2,7	
November	10	3,1	
November	11	3,1	
November	11	3,3	
November	11	4,2	
November	11	5,4	3
November	11	4,4	
November	11	3,5	
November	11	2,8	
November	11	2,4	
November	12	2,2	
November	12	1,9	
November	12	1,7	
November	12	2	
November	12	3,4	
November	12	3,9	
November	12	3,7	
November	12	3,5	
November	13	3,3	
November	13	3,2	
November	13	3,4	
November	13	4,1	
November	13	4,9	
November	13	5	
November	13	4,9	
November	13	4,7	
November	14	4,5	15
November	14	4,1	
November	14	3,8	
November	14	3,5	
November	14	3,2	
November	14	2,9	
November	14	2,6	
November	14	2,4	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
November	15	2,8	
November	15	3,5	
November	15	4,3	
November	15	5,6	
November	15	5,5	
November	15	5,3	
November	15	6,1	
November	15	6,2	
November	16	6,7	
November	16	7,1	
November	16	7	
November	16	8,4	
November	16	8,1	
November	16	7,2	
November	16	6,7	
November	16	6,1	
November	17	5,7	
November	17	5,6	
November	17	5,8	
November	17	5,8	
November	17	5,8	
November	17	5,8	
November	17	5,3	
November	17	4,6	63
November	18	4	
November	18	3,5	
November	18	3,2	
November	18	2,9	
November	18	2,8	
November	18	3,1	
November	18	2,9	
November	18	3	
November	19	4,9	
November	19	5,5	
November	19	5,4	
November	19	6	
November	19	5,8	
November	19	5,1	
November	19	5,2	
November	19	5,9	24
November	20	4,4	
November	20	4,1	
November	20	4,7	
November	20	4,9	
November	20	4,5	9
November	20	4	
November	20	3,3	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
November	20	2,8	
November	21	2,8	
November	21	3,2	
November	21	3	
November	21	2,5	
November	21	2,1	
November	21	1,9	
November	21	1,7	
November	21	1,7	
November	22	2,3	
November	22	2,5	
November	22	3,2	
November	22	4,1	
November	22	4,7	
November	22	5,3	
November	22	5,1	
November	22	5,4	
November	23	6,2	
November	23	7,5	
November	23	7,4	
November	23	6,9	
November	23	6,4	
November	23	5,9	
November	23	5,7	
November	23	5,5	
November	24	5	39
November	24	4,2	
November	24	3,6	
November	24	3,8	
November	24	4,6	3
November	24	4	
November	24	3,5	
November	24	4,1	
November	25	4,2	
November	25	4,1	
November	25	3,8	
November	25	3,6	
November	25	3,5	
November	25	3,8	
November	25	4,5	3
November	25	4,3	
November	26	4,4	
November	26	3,9	
November	26	2,9	
November	26	2,5	
November	26	2,2	
November	26	2,1	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
November	26	2,3	
November	26	2,4	
November	27	2,8	
November	27	3,3	
November	27	4,3	
November	27	5	
November	27	5,4	
November	27	5,9	
November	27	6,2	
November	27	5,8	
November	28	5,5	
November	28	5,4	
November	28	5,3	
November	28	4,9	
November	28	4,5	30
November	28	4,1	
November	28	3,8	
November	28	3,6	
November	29	3,4	
November	29	3,1	
November	29	3	
November	29	3,1	
November	29	3,3	
November	29	3,3	
November	29	3,2	
November	29	2,9	
November	30	2,7	
November	30	2,5	
November	30	2,4	
November	30	2,7	
November	30	3	
November	30	3	
November	30	3	
November	30	2,8	
December	1	2,6	
December	1	2,5	
December	1	2,5	
December	1	2,7	
December	1	2,8	
December	1	2,6	
December	1	3	
December	1	3,8	
December	2	4,2	
December	2	4,3	
December	2	3,9	
December	2	3,4	
December	2	3	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
December	2	2,7	
December	2	2,5	
December	2	2,3	
December	3	2,7	
December	3	2,6	
December	3	3,9	
December	3	6,3	
December	3	7	
December	3	6,4	
December	3	5,7	
December	3	6,3	
December	4	6,7	
December	4	5,1	21
December	4	4,2	
December	4	3,6	
December	4	3,2	
December	4	2,9	
December	4	2,8	
December	4	2,7	
December	5	2,7	
December	5	2,9	
December	5	3	
December	5	3	
December	5	3	
December	5	2,8	
December	5	2,6	
December	5	2,4	
December	6	2,3	
December	6	2,2	
December	6	2,7	
December	6	2,6	
December	6	2,3	
December	6	2,2	
December	6	2,3	
December	6	2,1	
December	7	2	
December	7	1,8	
December	7	1,7	
December	7	1,7	
December	7	1,9	
December	7	2	
December	7	1,9	
December	7	1,8	
December	8	1,8	
December	8	1,8	
December	8	1,7	
December	8	1,5	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
December	8	1,3	
December	8	1,2	
December	8	1,2	
December	8	1,1	
December	9	1,2	
December	9	1,2	
December	9	1,1	
December	9	1,1	
December	9	1,1	
December	9	1	
December	9	1,1	
December	9	1,2	
December	10	1,5	
December	10	2	
December	10	2,5	
December	10	2,7	
December	10	2,7	
December	10	2,5	
December	10	2,3	
December	10	2,2	
December	11	2,3	
December	11	2,4	
December	11	3,7	
December	11	4,9	
December	11	4,9	
December	11	4,9	
December	11	5	
December	11	5,2	
December	12	5,4	
December	12	5,2	
December	12	4,8	24
December	12	4,4	
December	12	3,9	
December	12	3,6	
December	12	3,6	
December	12	3,9	
December	13	4	
December	13	4	
December	13	4,4	
December	13	4,7	3
December	13	4,3	
December	13	3,7	
December	13	3,1	
December	13	2,8	
December	14	2,7	
December	14	2,5	
December	14	2,4	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
December	14	2,2	
December	14	2,1	
December	14	1,9	
December	14	1,8	
December	14	1,9	
December	15	2	
December	15	2,1	
December	15	2,3	
December	15	2,6	
December	15	2,8	
December	15	2,8	
December	15	3,1	
December	15	4,1	
December	16	4,9	
December	16	5,5	
December	16	5,6	
December	16	5,5	
December	16	5,7	
December	16	6	
December	16	6,8	
December	16	7,4	
December	17	6,8	
December	17	6	
December	17	5,3	
December	17	4,9	
December	17	4,5	39
December	17	4,1	
December	17	3,7	
December	17	3,4	
December	18	3,2	
December	18	3,7	
December	18	4,7	
December	18	4,7	
December	18	4,5	9
December	18	4,2	
December	18	3,7	
December	18	3,3	
December	19	3	
December	19	2,8	
December	19	3,2	
December	19	4,3	
December	19	4,9	
December	19	4,8	
December	19	4,5	9
December	19	4,3	
December	20	4,1	
December	20	3,9	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
December	20	3,8	
December	20	3,7	
December	20	3,7	
December	20	3,6	
December	20	3,6	
December	20	3,5	
December	21	3,5	
December	21	3,3	
December	21	3,2	
December	21	3	
December	21	3	
December	21	3	
December	21	3	
December	21	3	
December	22	2,9	
December	22	2,9	
December	22	3	
December	22	3,1	
December	22	3,4	
December	22	3,7	
December	22	3,9	
December	22	4,6	
December	23	5,1	
December	23	5,3	
December	23	5,6	
December	23	6,1	
December	23	6,2	
December	23	6	
December	23	5,9	
December	23	6	
December	24	5,9	
December	24	5,9	
December	24	5,8	
December	24	5,4	
December	24	5,2	
December	24	5,1	
December	24	5,2	
December	24	5,3	
December	25	5,6	
December	25	6,4	
December	25	7,3	
December	25	7,5	
December	25	7,2	
December	25	6,4	
December	25	5,6	
December	25	5,3	
December	26	5,6	

Hindcast data - Johan Castberg field - Year 2013 (Winter months)

Month	Days in a month	Wave height (in 'm') recorded for sea states of every 3 hrs.	Applying wave limitation criteria, Duration of wave>=4,5m in 'hrs'
December	26	5,6	
December	26	5,3	
December	26	5,1	
December	26	5	
December	26	5	
December	26	4,9	
December	26	4,6	99
December	27	4,4	
December	27	4,3	
December	27	4,2	
December	27	4,2	
December	27	4,5	
December	27	4,6	6
December	27	4,4	
December	27	4,1	
December	28	3,7	
December	28	3,5	
December	28	3,7	
December	28	3,7	
December	28	3,8	
December	28	4	
December	28	4,4	
December	28	4,9	
December	29	5,1	
December	29	5,3	
December	29	5,6	
December	29	5,9	
December	29	6	
December	29	5,9	
December	29	5,5	
December	29	5,2	
December	30	5,1	
December	30	5	
December	30	4,9	
December	30	4,8	
December	30	4,6	42
December	30	4,4	
December	30	4,1	
December	30	3,6	
December	31	3,3	
December	31	3	
December	31	2,8	
December	31	2,6	
December	31	2,5	
December	31	2,5	
December	31	2,6	
December	31	2,6	