Spare Part Transportation Management in the High North

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ABSTRACT

The demanding physical conditions of the Arctic, the remote location, and the uncertainty regarding the travel time can increase the challenges related to the transportation of spare parts in the region. Thus, designing and implementing an appropriate path for the transportation of spare parts for the region's oil and gas industry is a major problem. In this paper we develop the concept of spare part transportation block diagrams (STBD) for possible transportation routes. In this method, each transportation tool (e.g. truck, railway, etc.) is modeled by a block, and then a transportation route can be formed by a series of these blocks. Furthermore, the concept of the transportation network is used to calculate the mean time for transportation for each route. The application of the model is demonstrated by a case study of the transportation of spare parts for the Goliat Oil and Gas Field in the Barents Sea, Norway.

Keywords: Spare part, Transportation, Block diagram, Deliverability, Arctic

1. INTRODUCTION

Currently, oil and gas exploration and production is moving to the High North, the Arctic region. This unfamiliar operational environment of the Arctic poses new challenges for the industry (Gudmestad et al., 2007, Barabadi et al., 2009, Gudmestad and Strass, 1994, Kayrbekova et al., 2011). Due to the severe and complex operational conditions in the Arctic, the consequences of a failure relating to human, safety and/or environment can be much higher than in other areas. Moreover, in an industry with a high level of investment, such as offshore oil and gas, the costs of the production losses due to failure and downtime are substantial, which can affect business performance (Gao et al., 2010).

Maintenance activity can act as a barrier to reduce the risk related to failures. Preventive maintenance, as an active barrier, can reduce the probability of failure, and corrective maintenance, being a passive barrier, can reduce the consequence of failures. Hence, it is very important to have an effective maintenance strategy from the early design stage and to keep it updated based on experience gained during the operation phase (Gao et al., 2010, Gao et al., 2007). Product support and spare part planning are important prerequisites for an effective maintenance program. They can have a significant economic impact, by helping to maintain the reliability of the system, by reducing the downtime, and by facilitating the maintenance process.

In spare part planning it is very important to predict the transportation time of the spare parts precisely (Barabadi, 2012, Barabadi et al., 2012). This helps to avoid down-time and stockouts caused by the unavailability of spare parts. Moreover, it helps to ensure that the right spare part and resources are in the right place at the right time, in the hands of the right person. Hence, it is essential to develop a spare part transportation management plan for better prediction of travel time and probabilistic estimation of delivery time. In this case the quickest and most economical possible delivery of the requested spare parts must be ensured (Ghodrati, 2006).

The Arctic is characterized by extreme cold, varying forms and amounts of sea ice, seasonal darkness, high winds, polar lows, and extended periods of heavy fog, all of which can affect the transportation time of spare parts (Gudmestad et al., 2007, Barabadi et al., 2009, Gudmestad and Strass, 1994, Kayrbekova et al., 2011, Gao et al., 2010, Hasle et al., 2009). Moreover, the long-distance location of manufacturers and providers of industrial services and skilled man-power, insufficient infrastructure together with the remote geographical location are some of the most important factors that must be considered during the spare part planning. Hence, a spare part transportation management plan, intending to meet company/market requirements, by considering the effect of the operational conditions of the Arctic, is essential.

The aim of this paper is to introduce the concept of the spare part transportation block diagram (STBD) for possible transportation routes and mode of transportation to facilitate the spare part planning and execution process. The model also helps users to estimate the mean time to delivery of spare parts, and also to estimate the probability of having the requested spare part on-site within the planned time, considering the operational conditions. The rest of the paper is organized as follows: Section 2 introduces the STBD concepts. Section 3 presents a description of the case study and the application of the STBD model. Section 4 provides the conclusion.

2. SPARE PART TRANSPORTATION MODEL, STBD

In order to establish effective transportation management, all possible transportation routes need to be identified and then, for each route, the time and cost of the transportation need to be calculated. To achieve this aim, the concept of spare part transportation block diagrams (STBD) is developed in this paper. The initial idea for the model comes from the reliability block diagram, which is used in reliability engineering in order to calculate the reliability of the system (Barabadi et al., 2009).

An STBD is a success-oriented network describing the functions of a transportation system. Specifically, each STBD model consists of an input point (starting point), an output point (ending point), and a set of blocks. Each block represents a transportation mode, like air-cargo, that functions correctly (Steffanusen, 2012). The block diagram shows how blocks (modes of transportation) are connected together and is used to facilitate understanding of the complete array of modes of transportation by breaking them down into the most dominant modes (air, land, and water) (Steffanusen, 2012). An STBD is easy to read and understand for the designer and manager, who design and make decisions on system configuration.

An STBD is used to measure how probable it is to have the spare part on-site, within the planned delivery time. The time to deliverability of the network is determined by - calculating the deliverability of blocks and considering the relationship between the different blocks. An

STBD for the proposed plan, is time-dependent because of uncertainty regarding the travel time. Time-dependent analysis looks at the deliverability of spare parts as a function of time to delivery *(TTD)* and operational conditions. Spare part deliverability in a given network and specific mode of transportation, is a probability that the spare part will be delivered, under a given condition, within an intended delivery time.

The spare part deliverability of each mode can be quantified using common probability distribution, such as Weibull distributions, or a covariate model like the proportional hazard model (Kumar and Westberg, 1997). In the common probability distributions the only variable is the time to delivery *(TTD),* but the covariate model can be used to model the effect of operational conditions such as snow on the spare part deliverability. In other words, in covariate models the spare part deliverability will be a function of the time and influence factor. If continuous random variable, *T*, is the time to delivery of the spare part: $T \geq 0$, then the spare part deliverability, $D(t)$, using the common probability distribution can be expressed as:

$$D(t) = Pr[T \leq t] \quad (1)$$

where, t is the random delivery time, $D(t) \geq 0$, $D(0) = 0$, and $lim_{t\to\infty} D(t) = 1$

For a given value of t, $D(t)$ is the probability that the time to delivery (*TTD*) is less than or equal to t. The spare part deliverability, $D(t)$, defined for all real $t \in (0, +\infty)$ can also be expressed mathematically as:

$$D(t) = \int_0^t f(s)ds \quad (2)$$

where, s is a dummy integration variable and t is a random delivery time. Conversely, the probability density function, $f(t)$, of the continuous random variable T, can be expressed as:

$$f(t) = -\frac{d(D(t))}{dt} \quad (3)$$

For two numbers, a and b with $a \leq b$, the probability that T takes on a value in the interval $[a,b]$ is given by:

$$P(a \leq T \leq b) = \int_a^b f(t)dt, \qquad f(t) \geq 0 \ \forall t \text{, and } \int_0^\infty f(t)dt = 1 \quad (4)$$

In addition, mean time to delivery (*MTTD*), which is a measure of the speed of a given mode of transportation, can be calculated by:

$$MTTD(t) = \int_0^\infty tf(t)dt \quad (5)$$

To calculate the deliverability of the network or STBD after calculating the spare part deliverability of each mode, the relationship between them needs to be modeled. In general, the main types of configurations used in constructing STBD are series, parallel and combined configurations. These models are discussed below briefly.

2.1. Series Transportation Network

A network can have modes network-wise in series, when the delay or cancellation of any one or more modes results in the delay or cancellation of the entire network (Fig. 1). Note that, below, modes 1, 2,… mode (n) could be any type of mode of transport such as truck-cargo, air-cargo, etc.

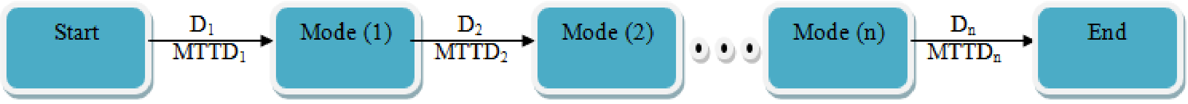

Figure 1. Series spare part transportation network

Since all of the units in the series need to succeed for a successful mission, the deliverability of the network is the probability that all n modes in the series succeed. The deliverability of series transportation network ($D_{stn}(t)$) is then given by:

$$D_{stn}(t) = \prod_{i=1}^{n} D_i(t) \tag{6}$$

where, $D_i(t)$ ($i = 1$ to n) is the probability of deliverability for each mode.

2.2. Parallel Transportation Network

A network can also have modes network-wise in parallel (redundancy), when only the delay/cancellation of all the modes in the network results in the delay/cancellation of the overall network (Fig. 2). It must be considered that when there is a parallel configuration, different routes can be selected for transportation. However, these routes do not have the same weight in the decision making process. In order to show this concept, the probability of selecting one mode, P_i from the available mode's needs to be defined, where $0 \leq P_i \leq 1$ and $\sum_{i=1}^{n} P_i = 1$, where n is the total number of alternatives (mode of transport). Considering this definition, the deliverability of the parallel transportation network (D_{ptn}) (assuming independence) is then given by:

$$D_{ptn}(t) = 1 - \prod_{i=1}^{n}(1 - P_i(t)D_i(t)) \tag{7}$$

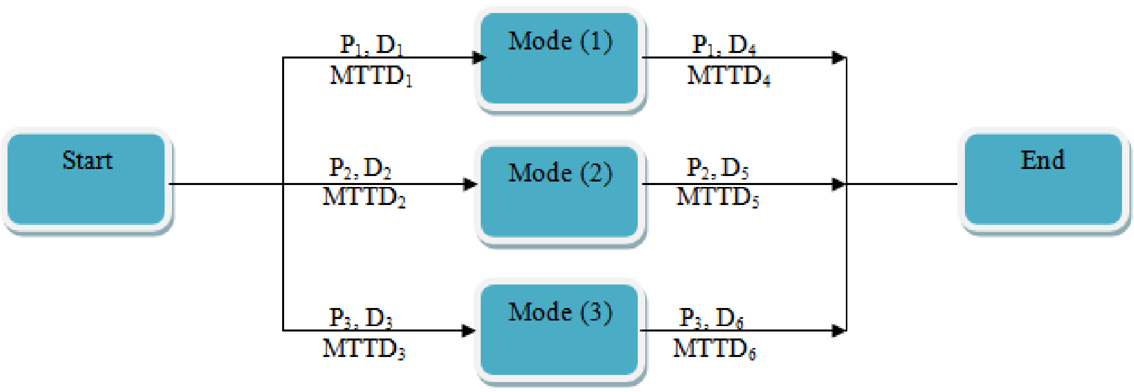

Figure 2. Parallel spare part transportation network

It must be taken into consideration that there are many factors which may have an effect on P_i such as the cost or the reliability of the transportation mode.

2.3. Combined Transportation Network

The Combined Transportation Network is a combination of series and parallel transportation networks (Fig. 3). The deliverability of the combined network is calculated by simplifying or breaking the network down into a series and parallel network. The application of this model is shown by a case study in Section 3.

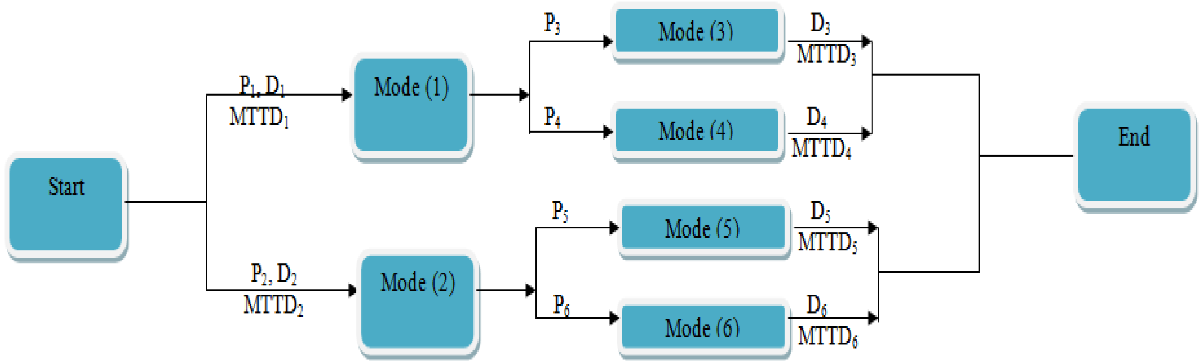

Figure 3. Combined spare part transportation network

3. CASE STUDY: GOLIAT PRODUCTION FACILITY PROJECT, NORWAY

The Goliat FPSO (Floating, Production, Storage and Off-loading) field is the first oil field development project in the Barents Sea. The field is situated off Norway's northern tip, about 85 kilometers northwest of Hammerfest, in the Barents region. In this section the concept of the spare part transportation block diagram (STBD) will be illustrated for transporting spare parts from the southwestern part of Norway to Goliat FPSO.

3.1. Case Description

For the Goliat FPSO development project, the operator plans to get logistic support from an onshore warehouse located at the Polarbasen, Hammerfest, in the north of Norway and from a manufacturer and supplier's warehouse located at Dusavika, Stavanger, in the southwest of Norway. Polarbasen, Hammerfest, is the main hub for oil and gas (O& G) related activities in the Barents Sea, and is considered as a hub for operator/ owner spare part warehouses. Dusavika, Stavanger, is considered as a hub for spare part manufacturers and suppliers.

The concept of STDB is applied to estimate the mean time to delivery of the spare part from Dusavika to Goliat FPSO via Polarbasen. In addition, spare part deliverability and overall network spare part deliverability are estimated. Air-cargo, ship-cargo, and truck-cargo, are used to transport the spare part from Dusavika to Polarbasen. Helicopter and ship-cargo are used to transport the spare part from Polarbasen to Goliat FPSO. Figure 4 shows the STBD for Goliat FPSO.

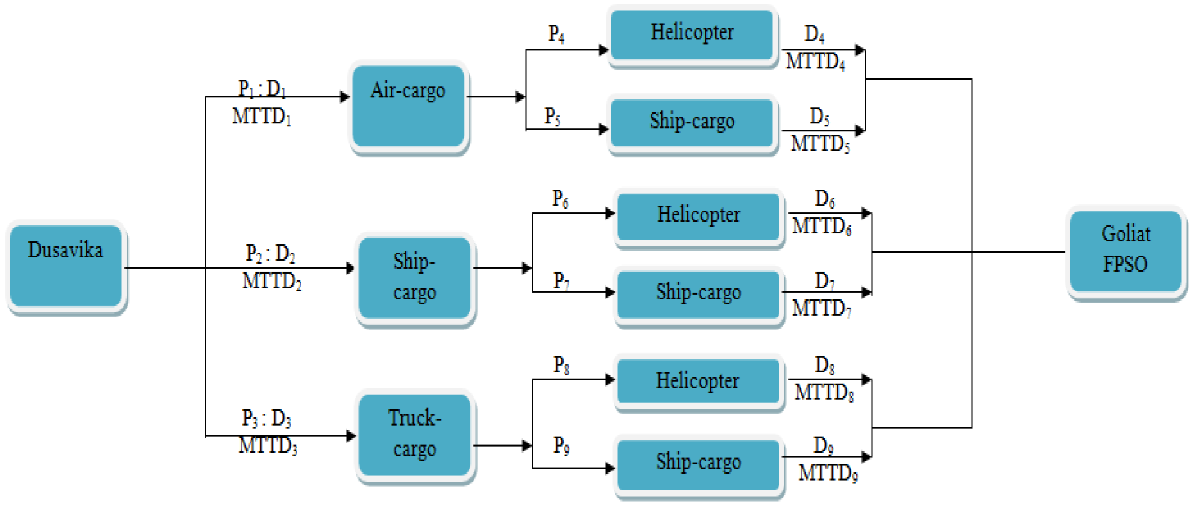

Figure 4. STBD for Goliat FPSO

3.2. Data Collection

The transportation data used in this study have been collected using different sources such as meetings and discussions with shipping agents, email requests, and telephone conversations. Some of the companies which have been requested and provided the transportation data are including Johs. Sundfør AS, Nor Lines AS, SAS Cargo, and other freight forwarding companies, ship broker, and liner agencies. Transportation times, distance between two transits, and average allowable speed are part of the collected data. In this paper, in order to verify datas from logistic companies, we compare the collected datas with Statens vegvesen route planner. Statens vegvesen route planner is a route planner developed by the Norwegian Public Roads Administration. For example, data from SAS Cargo, when spare part delivery starts from Dusavika (from the manufacturer/supplier's warehouse) at 09:50 (in the morning), it will take approximately 35 min by truck-cargo to the airport and the spare part must be delivered at least 30 min before takeoff, for processing at the airport terminal. Then, if the air-cargo takeoff is at 10:55 (in the morning) – from Stavanger airport, the latest delivery in Polarbasen is at 18:18 (in the evening). From Polarbasen to Goliat FPSO it will take from half an hour to four hours. Therefore, the total approximated travel time for air-cargo is 8 to 13 hours. Table 1 shows a summary of the collected data.

Table 1. Transport mode, distance, and travel time

Transport Mode	Dusavika - Polarbasen		Polarbasen - Goliat FPSO		Total Time (T_T) (hrs)
	Distance (D_1)	Time (T_1) (hrs)	Distance (D_2)	Time (T_2) (hrs)	$T_1 + T_2$
Air-cargo	-	8.0 – 11.5	-	0.5 – 1.5	8.5 – 13.0
Ship-cargo	930 nm	85.0 – 95.0	46 nm	4.5 – 8.0	90.0 – 103.0
Truck-cargo	2392 km	35.0 – 45.0	-	-	35.0 – 45.0

For each transport mode, time to delivery data are collected and estimated for both winter and summer seasons, in order to analyze the effect of operational conditions. In other words, the travel time data are classified into two different groups, winter and summer data, based on the operational conditions. Thereafter, for each group, the analysis has been carried out separately. Table 2 shows an example of *TTD* data for ship-cargo.

Table 2. Examples of *TTD*

Dusavika - Polarbase		Polarbase - Goliat FPSO	
Summer	Winter	Summer	Winter
TTD (hr)	*TTD* (hr)	*TTD* (hr)	*TTD* (hr)
87.0	95.0	5.5	6.5
88.5	100.0	5.5	9.5
88.0	94.5	6.0	8.0
90.0	93.0	6.0	11.0
91.0	95.5	5.5	8.0
90.0	99.0	6.0	8.0
89.0	93.0	5.5	7.0

3.3. Data Analysis

As previously mentioned, in order to consider the effect of operational conditions on the spare part deliverability function, the data have been categorized into - two groups. Moreover, in order to obtain the spare part transportation deliverability, the common distributions have been used and STBD are employed to obtain the network deliverability. The following assumptions have been made, for the data analysis: (1) the weight and size of the spare part are within an acceptable range. Hence, air-cargo, the ship-cargo, and truck-cargo can be used to transport the spare part. (2) The total planned delivery time equals 100 hours (from Dusavika to Polarbase and then to Goliat FPSO).

3.3.1. Spare Part Deliverability Function

In order to find the spare part deliverability function using the common groups in the first stage, some distributions such as normal, log-normal or Weibull need to be nominated for the data. In the next stage using some goodness of fit test, best fit distribution for the data can be found. Then the distribution parameter needs to be calculated using available methods such as maximum likelihood (MLE) methods (Kumar et al., 2000). In this paper, Weibull ++7 distribution wizard is used as a tool to estimate the best fit distribution for the given data (ReliaSoft, 2007). Then, by implementing the best fit distribution for the given data using MLE, mean time to delivery *(MTTD)* are estimated.

Table 3. Summary of data analysis for different transportation blocks

Transport Mode		Best-fit	$MTTD_1$ (hrs) Dusavika – Polarbasen	Transport Mode	$MTTD_2$ (hrs) Polarbasen – Goliat FPSO	$MTTD_T$ (hrs) $MTTD_1 + MTTD_2$
Air-cargo	Summer	Log-logistic	8.70	Helicopter	1.30	10.00
				Ship-cargo	5.80	14.50
	Winter	G-Gamma	10.00	Helicopter	2.10	12.10
				Ship-cargo	8.20	18.20
Ship-cargo	Summer	3P-Weibull	90.30	Helicopter	1.30	91.60
				Ship-cargo	5.80	96.10
	Winter	3P-Weibull	94.10	Helicopter	2.10	96.20
				Ship-cargo	8.20	102.30
Truck-cargo	Summer	3P-Weibull	45.60	Helicopter	1.30	46.90
				Ship-cargo	5.80	51.40
	Winter	Exponential	55.80	Helicopter	2.10	57.90
				Ship-cargo	8.20	64.00

As Table 3 shows, the minimum total *MTTD* is about 10 hours in summer time. However, in the Barents region, during the summer season there is a heavy fog condition which sometimes halts helicopter operation. Thus, in such conditions, the only alternative to transport the spare part from Polarbasen to Goliat FPSO will be ship-cargo, which will increase the minimum *MTTD* by around 4.5 hours, and in this case the latest delivery will be after around 14.5 hours.

However, according to our assumption the total planned delivery time from Dusavika to Goliat FPSO via Polarbasen is 100 hours. In addition, the probability of using air-cargo to transport the spare part from Dusavika to Polarbasen might not be 1. Thus, it is feasible to consider the other alternatives such as truck-cargo and ship-cargo in order to reduce the cost of transportation. Table 4 shows the probability of the requested spare part arriving at Polarbasen from Dusavika at the end of different time intervals.

Table 4. Deliverability of each block from Dusavika to Polarbasen

Interval Time (hrs)	Air-cargo	Ship-cargo	Truck-cargo
	D(t)	*D(t)*	*D(t)*
0	0.00	0.00	0.00
10	0.85	0.00	0.00
20	0.99	0.00	0.00
30	1.00	0.00	0.00
40	1.00	0.00	0.06
50	1.00	0.00	0.84
60	1.00	0.00	0.99
70	1.00	0.00	0.99
80	1.00	0.00	1.00
90	1.00	0.47	1.00
100	1.00	1.00	1.00

For example, within 90 hours we have 47.00% probability of having the requested spare part at Polarbasen, if we use a ship-cargo to transport the spare part from Dusavika. Once the spare part is delivered at Polarbasen then helicopter and ship-cargo can be used to transport the spare part to Golait FPSO. Table 5 summarizes spare part deliverability from Polarbasen to Goliat FPSO.

Table 5. Deliverability of each block from Polarbasen to Goliat FPSO

Interval Time (hrs)	Helicopter	Ship-cargo
	D(t)	*D(t)*
0	0.00	0.00
1	0.47	0.00
2	0.85	0.00
3	0.97	0.00
4	0.99	0.00
5	0.99	0.09
6	0.99	0.62
7	1.00	0.96
8	1.00	0.99
9	1.00	1.00
10	1.00	1.00

3.3.2. Network Spare Part Deliverability

As mentioned, in this case study the spare part must first be transported to Polarbasen from Dusavika, then to Goliat FPSO. The maximum *MTTD* from Dusavika to Polarbasen is around 95 hours, and from Polarbasen to Goliat FPSO is around 8 hours. Hence, in order to calculate the deliverability of the system, in the first stage the deliverability of the spare part to Polarbasen from Dusavika within 90 hours, $D_{N1}(t=90hr)$ and the spare part deliverability to Goliat FPSO from Polarbasen within 10 hours, $D_{N2}(t=10hr)$ are estimated. Moreover, after calculating the deliverability of the spare part from Dusavika to Polarbasen and Polarbasen to Goliat, considering the series configuration, the deliverability of the network can be calculated as:

$$D_N(t) = D_{N1}(t).D_{N2}(t) \tag{8}$$

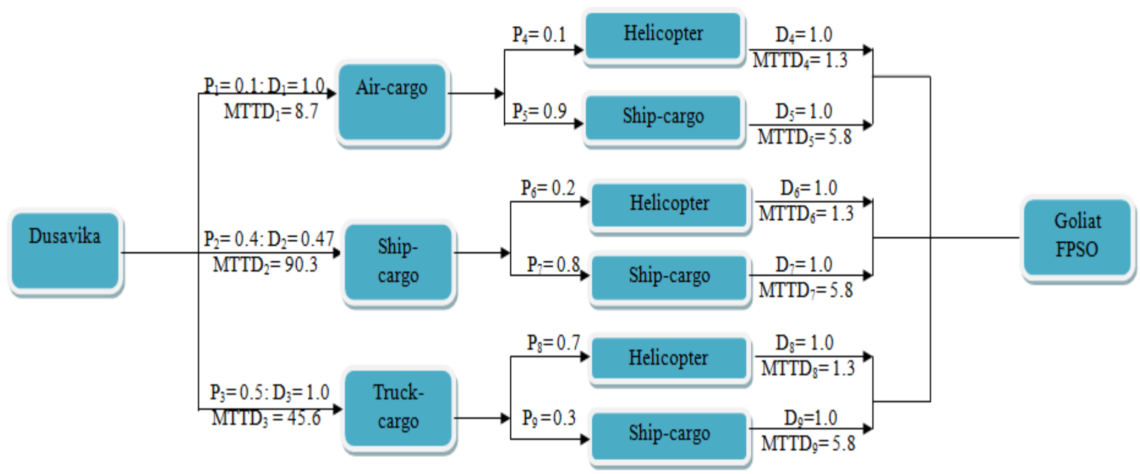

Figure 5. STBD for the Goliat FPSO in summer season

Figure 5 shows the STBD for the case study in the summer; the probability of selecting one mode, P_i and the spare part deliverability (D_i) within the *MTTD* are shown in this figure. Table 6 shows the result of deliverability analysis for the network in summer and winter.

Table 6. Network spare part deliverability in summer and winter season's

Season of Transport	Dusavika - Polarbasen				Polarbasen - Goliat FPSO				Network Delivera-bility
	Mode of Transport	D_{N1}			Mode of Transport	D_{N2}			
		P_i	D_i	$D_{N1}(t=90hr)$ $=P_i . D_i$		P_i	D_i	$D_{N2}(t=10hr)$ $=P_i . D_i$	$D_N = D_{N1}.D_{N2}$
Summer	Air-cargo	0.1	1.00	0.10	Helicopter	0.1	1.00	0.10	0.01
					Ship-cargo	0.9	1.00	0.90	0.09
Winter	Air-cargo	0.1	1.00	0.10	Helicopter	0.1	1.00	0.10	0.01
					Ship-cargo	0.9	0.80	0.72	0.07
Summer	Ship-cargo	0.4	0.47	0.19	Helicopter	0.7	1.00	0.70	0.13
					Ship-cargo	0.3	1.00	0.30	0.06
Winter	Ship-cargo	0.4	0.18	0.07	Helicopter	0.7	1.00	0.70	0.05
					Ship-cargo	0.3	0.80	0.24	0.02
Summer	Truck-cargo	0.5	1.00	0.50	Helicopter	0.2	1.00	0.20	0.10
					Ship-cargo	0.8	1.00	0.80	0.40
Winter	Truck-cargo	0.5	1.00	0.50	Helicopter	0.2	1.00	0.20	0.10
					Ship-cargo	0.8	0.80	0.64	0.32

The result of the analysis shows that the most suitable way of transporting the spare parts is using truck-cargo from Dusavika to Polarbasen and ship-cargo from Polarbasen to Goliat FPSO. Moreover, for the summer season, there is a 40% probability of having the spare part at Goliat FPSO within 100 hours, if we use truck-cargo from Dusavika to Polarbasen and ship-cargo from Polarbasen to Goliat FPSO. However, for the winter season, this probability decreased to 32%. This shows that during the winter season the operational conditions of the Arctic region have a significant effect on spare part transportation.

4. CONCLUSION

The results obtained from data analysis showed that the spare part transportation block diagrams (STBD) can be used as tools to analyze different means of transportation connected network-wise considering the operational conditions. STBD can help the user to investigate the appropriate path for the spare part transportation, from manufacturer to on-site or from operator/owner's warehouse to on-site. In addition, STBD is helpful in supporting the user to estimate the probability of having the requested spare part on-site, within the planned delivery time. In the case study, comparing the network deliverability of the summer and winter seasons shows that there are approximately 20% extended delay's during the winter season due to the operational conditions. Hence, any decision about the transportation of spare parts in the Arctic region must consider the effects of the operational conditions of the region.

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