Spare Part Transportation Management in High North

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ABSTRACT

The demanding physical conditions of the Arctic, remote location, and uncertainty regarding the travel time can both heighten the challenges related to transportation of spare part in the region. Managing to get the appropriate path for transportation of spare parts for oil and gas industries in the region, is one of the major and demanding tasks. In this paper we develop the concept of transportation block diagrams (TBD) for possible transportation routes and mode of transportation. In this method each transportation tools (e.g. truck, railway, etc.) is modeled by block and then a route of the transportation can be a series of these blocks. Furthermore, the concept of transportation network is used to calculate the mean time to transportation for each route. The application of the model is demonstrated by a case study for transportation of spare part for Goliat Oil and Gas Field in the Barents Sea, Norway.

Keywords: Spare part, Transportation, Block diagram, Deliverability

1. INTRODUCTION

Currently the oil and gas exploration and production is moving to high north, Barents Sea, sub-Arctic circle. This unfamiliar operational environment of the Arctic poses new challenges for the industry. Due to lack of data and experience with Arctic operations, the uncertainty and risks can be higher than in the familiar climate on the North Sea(Kayrbekova 2011), as well as it is expected that system failure could increase significantly. However, much of the data and experience from the 40 years of operations in the North Sea can be used in the operation and maintenance of production facilities in the Barents Sea, but the special Arctic conditions and the location need to be taken into consideration in order to reduce costs and achieve the performance goals(Larsen and Markeset 2007).

Sometimes oil & gas (O& G) industrial companies are faced with machine down-time due to a shortage of required spare parts, and this is because of the manufacturer's/supplier's recommendation for the average number of required spare parts to be kept in stock(Ghodrati 2005). Hence, in smoothing the progress of the advancement and implementation of new O & G fields in the Barents region, Arctic, preeminent spare part transportation management plan have a key role to play in ensuring no stockouts and no extended downtime of the system, due to undeliverability of spare part.

Consequently, to avoid down-time and stockouts caused by the unavailability of spare parts, it is necessary to deliver the spare part at the right time, without incurring any additional cost. The costs involved in long lead times for critical spare parts, for O & G industries, are enormous. In this case the quickest possible delivery of the requested spare parts must be ensured. Short lead times became crucial, and probabilistic estimation of delivery time is undoubtedly important.

Currently, there are a number of transportation management system software's (TMS) in market, for transportation planning and execution solution. Most of TMS software's used real-time optimization engine, adaptive algorithms, automated exception management, and rating engines to handle real time changes, to improve on-time pickup, on-time delivery, and lead time. For example, SAP-SCM, TMS software by SAP AG, uses its integrated plan delivery time function to calculate the planned delivery time. But, implementing transportation management system software's (TMS) is major and demanding task that requires considerable planning and execution.

Hence, the aim of this paper is to introduce the concept of spare part transportation block diagram (TBD) for possible transportation routes and mode of transportation to facilitate spare part planning and execution process. The model also helps users to estimate mean time to delivery, and also to estimate the probability of having the requested spare part onsite with in planned delivery time.

The rest of the paper is organized as follows: Section 2 briefly introduces the proposed spare part transportation management plan for harsh environment. Section 3 presents description of the case study and the application of the proposed plan. Section 4 will summarize the findings, discuss and interpret the results from the case study. Note that the authors assumes the reader of this paper have some knowledge of probability and statistics (basic statistical concepts).

2. PROPOSED SPARE PART TRANSPORTATION MANAGEMENT PLAN

As a rule, oil & gas companies approach the long-term supportability of their production facilities with varying strategies. Traditionally, the support and service of a production facilities has not been strategic, but instead has been viewed as a cost of doing business(PTC 2011). Today, O & G companies have realized that strategic product support practices can provide an ongoing, predictable cost reduction opportunity, often with higher margins(PTC 2011).

In the proposed plan we develop spare part transportation block diagrams for possible transportation routes and mode of transportation. A transportation block diagram (TBD) is a specialized, high-level type of flowchart. Its highly structured form which presents a quick overview of major process steps and key process participants, as well as the relationships and interfaces involved. It is useful tool, both in defining new routes and in improving existing routes. The diagrams are used to understand complete mode of transportation by breaking them down into the most dominant modes of transport (air, land, and water) or blocks, which follows different routes from starting point to ending. Each block performs a particular function and the block diagram shows how they are connected together. No attempt is made to show the components used within a block, only the inputs and outputs are shown.

The diagram consists of a number of blocks based on selected mode of transportation and selected routes. The logic behind this plan is that assigning mode of transportation and associated routes, to transportation block diagram, in order to identify most suitable mode of transportation, to estimate time to delivery, and also to identify the shortest path (in terms of mean time to delivery).

The network, for the proposed plan, is time-dependent because of uncertainty regarding the travel time. Time-dependent analysis looks at deliverability as a function of time. That is, a known time to delivery (TTD) distribution is assigned to each mode of transportation. The time scale in transportation block diagram can assume any quantifiable time measure, such as weeks, days, hours, minutes or seconds.

2.1. Spare part Deliverability, Spare part Deliverability Function and Network Spare part Deliverability

In order to ensure the achievement of the aim of proposed plan - the concept of deliverability, deliverability function, and transportation network deliverability must be introduced. Hence, in this section the concept for finding deliverability in time dependent network, in particular for spare part transportation is introduced.

2.1.1. Spare part Deliverability: 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, with in an intended planned delivery time. In addition, we have mean time to delivery (MTTD), which is a measure of how fast a given mode of transportation is. This means to deliver the spare part with in an intended planned delivery time and by following specific routes.

2.1.2. Spare part Deliverability Function: In order to estimate mean time to delivery and to know the probability of deliverability, from the starting node to end node, we need deliverability function – a function that supports its user to estimate how probable is to have the requested spare part onsite, within planned delivery time. Node, in this paper context, is a location at which spare parts transportation originate, transit or delivered.

If continuous random variable T to be the time to delivery of the spare part; $T \geq 0$, then the ***Spare part deliverability, D(t),*** can be expressed as:

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

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

The ***deliverability function*** provides the probability of deliverability, by time t. mathematically, also can be expressed:

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

Where *f (s),* is probability density function and *t* is continuous random variable. ***Spare part deliverability*** can be specified with an associated time. In other words, we can say that probability of deliverability is 0,85 - for a given planned delivery time. For example, D(t = 38hr) = 85 %, for truck-cargo from starting node to ending node or transit node.

2.1.3. Network Spare part Deliverability

Network spare part deliverability is a measure of how probable is to have the spare part onsite, with in planned delivery time, by utilizing different types of mode of transportation. The network can have modes network-wise in parallel, series and/ or combined. The difference between spare part deliverability and network spare part deliverability is that the first only represent for a given specific mode of transport but the second one is for the overall network, this could be a number of modes connected network-wise. A spare part transportation network is made up of different mode of transport. The TTD distribution (deliverability) of the network can be determined, once distributions (deliverability's) of each mode of transport determined (estimated or approximated). Mode deliverability is quantified using a mathematical model that describes the probability of deliverability (or the probability of success). The "model" is a statistical probability density function *(pdf)* and each mode can be described by different model, for example one of the models can be two-parameter Weibull distribution.

The type of mode of transport and the network configuration in which modes are arranged in the network has a direct effect on the network's deliverability.

- The network's deliverability is derived from the deliverability of the modes.
- Each modes have deliverability's that can change over time (such as winter and summer), as does the network.

The main objective of network deliverability is to estimate the overall deliverability of the network, by analyzing probability of deliverability for each mode, with in intended/ planned time. Spare part transportation block diagrams (TBD), shows how modes are connected. Blocks represent the modes of the network. Lines connect the blocks.

- The structure of these connections affects the deliverability configuration of the network.
- At the very least, a transportation block must include information of time to delivery for each mode (i.e. the deliverability model of the block).

Once the block's (modes) deliverability characteristics are determined, they can then be connected in a network-wise manner to create spare part transportation block diagram (TBD) for the network. Once the TBD of the network is created, it can be analyzed to determine the network deliverability. Types of configurations used in constructing TBD's are discussed below.

a) Series Transportation Network (STN): 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. Note that, below, mode 1, 2, and 3 could be any type of mode of transport, and also we can have n-modes in our series transportation network.

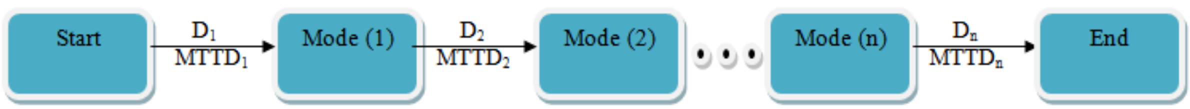

Figure 3. Series Transportation Network (STN)

Description,

- D_1, D_2 ... D_n is probability of deliverability, for each mode, within intended planned delivery time. Note that we can have *n* number of transits, with respective probability of deliverability.

- $MTTD_1$, $MTTD_2$ … $MTTD_n$ is mean time to delivery from one node to the other, for specific mode of transport.

Since all of the units in series need to succeed for a successful mission: The deliverability of the network is the probability that mode 1 succeeds and mode 2 succeeds ..., and all *n* modes in the series succeed. The deliverability of series transportation network (D_{STN}) is then given by:

$D_{STN} = D_1 \times D_2 \times \ldots \times D_n$	(3)

Where, D_i (i = 1 to n) is probability of deliverability for each mode.

b) Parallel Transportation Network (PTN): 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.

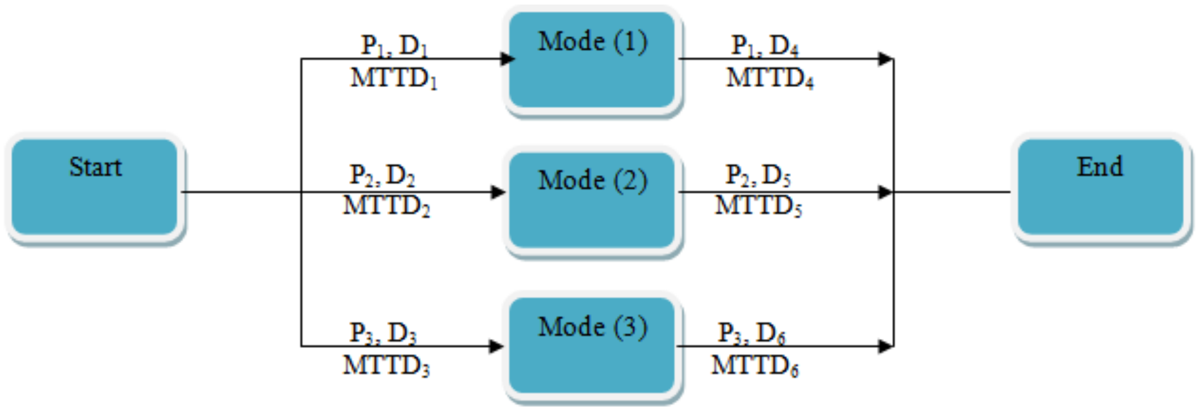

Figure 4. Parallel Transportation Network (PTN)

Description:

- P_1, P_2, and P_3 are probability to select one mode from given options. Consider a network with mode of transport, m_1, $m_2 \ldots m_n$ then $P(m_i)$ is the probability that mode m_i be selected, from the available option. It must be that $0 \leq P(m_i) \leq 1$ for each mode m_i and $\sum P(m_i) = 1$ (the sum of the probabilities is equal to 1).
- D_1, $D_{2\ldots}$ Dn is probability of deliverability (for e.g. for mode 1: D_1 is probability of deliverability from starting node to transit node, but D_4 is from transit to end node. This is because of the difference in distance).
- $MTTD_1$, $MTTD_2$ … $MTTD_n$ is mean time to delivery from one end to the other.

At least one of the modes in parallel must succeed for a successful mission. The probability of undeliverability- is the probability that mode 1 delays/cancelled, and mode 2 delays/cancelled, and ..., and mode n delays/cancelled. The deliverability of parallel transportation network (D_{PTN}) (assuming independence) is then given by:

$D_{PTN} = 1 - [(1 - (P_1{*}D_1)) {*} (1 - (P_2{*}D_2)) {*} \ldots {*} (1 - (P_n{*}D_n))]$	(4)

Where, D_i is probability of deliverability for each mode and P_i is the probability that mode m_i be selected.

c) Combined Transportation Network (CTN): is combination of Series and Parallel transportation networks. The deliverability of the combined network is calculated by simplifying or breaking the network down in to series and parallel network.

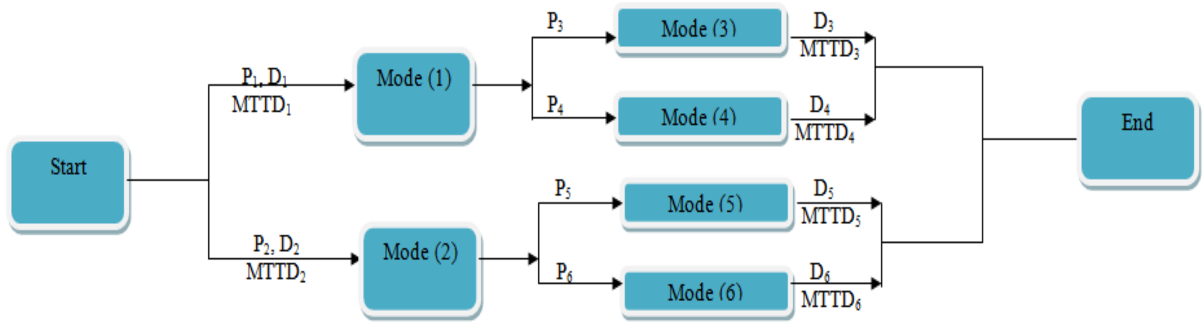

Figure 5. Combined Transportation Network (CTN)

In this section, section 2, the attempt is done to introduce the concept of probability of spare part deliverability, spare part deliverability function, and spare part network deliverability. In the next section, case studies for Goliat project, numerical example is introduced to show calculation steps for combined transportation network deliverability (assuming independence). The above mathematical / probabilistic formulations are the back-bones of the data analysis.

3. CASE STUDY: GOLIAT PROJECT, NORWAY

The Goliat field is the first oil field development project in the Barents Sea. The field is situated off Norway's northern tip about 85 kilometers (53 miles) northwest of Hammerfest, and consists of five blocks with an area totaling 1,010 square kilometers (390 square miles)(Subseaiq 2012).

3.1. Case Description

Goliat FPSO is planned to get logistic support from onshore warehouse located at Polarbase, Hammerfest and also from manufacturer and suppliers warehouse located at Dusavik, Stavanger. Both located in Norway. Polarbase, is the main hub for O& G related activities in the Barents Sea, and is hub for operator/ owner spare part warehouse. Dusavik, Stavanger is considered as hub for spare part manufacturer/ supplier. The spare parts could also be stored onboard considering the criticality of the spare part.

In this section, we will use the results of the proposed plan to estimate mean time to delivery of the spare part from Dusavika to Goliat FPSO via Polarbase, spare part deliverability, and overall network spare part deliverability. Air-cargo, Cargo-ship, and Truck-cargo, are used to transport the spare part from Dusavik to Polarbase; Helicopter and Cargo-ship are used to transport from Polarbase to Goliat FPSO. In addition, we will evaluate different transportation paths to identify appropriate path for spare part transportation for the given case.

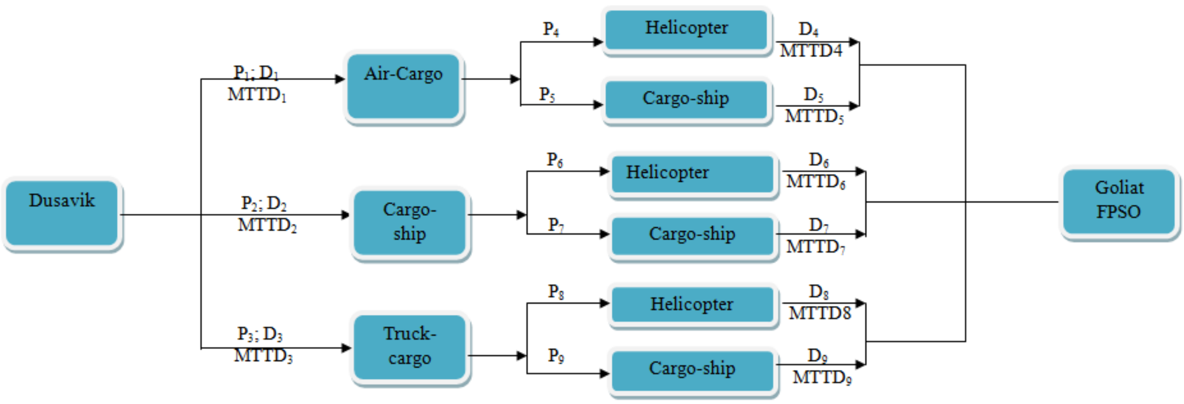

Figure 6. Spare part Transportation Block Diagram for given case study

3.2. Data Collection

The data used in this study have been collected using different approaches such as meeting and discussion with ship agents, email request, telephone conversation, and using of Statens vegvesen route planner– route planner developed by Norwegian Public Roads Administration. Transportation time (e.g. from Dusavika to Polarbase), distance between two nodes, and average allowable speed are part of the collected data. Table 1 shows example of collected data. T_1 and T_2, in table 1, are approximated travel time from Dusavik to Polarbase and from Polarbase to Goliat FPSO, respectively. Total time (T_T) is the summation of T_1 and T_2.

Table 1. Distance, Transport mode, Average speed and Travel time

Transport Mode	Distance (D_1) Dusavik-Polarbase	Average Speed	Time (T_1) (hrs)	Distance (D_2) Polarbase – Goliat FPSO	Average Speed	Time (T_1) (hrs)	Total Time (T_T) (hrs)
Air-cargo	-	-	8 – 11,5	-	-	0,5 -1	8,5 – 12,5
Cargo-ship	930 nm	11 knots	84,55	46nm	11 knots	4,50	88 – 90
Truck-cargo	2392 km	64 km/hr	37,38	-	-	-	40 - 45

For each mode of transportation numerical time to delivery data's are collected and estimated for both winter and summer seasons, in order to analyze the effect of harsh weather conditions. The numerical data's represent TTD from Dusavik to Polarbase and from Polarbase to Goliat FPSO, for e.g. table 2 shows sorted TTD data for cargo-ship.

Table 2. Examples of TTD

Frequency	Dusavik- Polarbase		Polarbase – Goliat FPSO	
	Summer TTD (hr)	Winter TTD (hr)	Summer TTD (hr)	Winter TTD (hr)
1	87	87	5	6
2	88	88	5	6
3	88	88	5	6,5
4	88,5	90	5,5	7
5	89	92	5,5	7
6	90	93	5,5	7
7	90	93	5,5	7

3.2. Data Analysis

The following assumptions have been made, for data analysis: (1) weight and size of the spare part is within acceptable range. Hence, air-cargo, cargo-ship, and truck-cargo can be used to transport the spare part. (2) Total planned delivery time equals 100hrs (from Dusavik – Polarbase – Goliat FPSO).

3.2.1. Best Fit Distribution and Estimation of MTTD

To fit a model to time to delivery data, one can estimates the parameters of the chosen model (distribution) based on the data set. This is referred to as parameter estimation. Several parameter estimation methods are available, such as Maximum likelihood (MLE) methods. In this paper, Weibull ++8 distribution wizard, is the tool to estimate the best fit distribution for the given data. Then, by implementing the best fit distribution for the given data, mean time to delivery (MTTD) are estimated.

Table 3. Summary of MTTD

Transport Mode		Best-fit	$MTTD_1$ (hrs)	Transport Mode	$MTTD_2$ (hrs)	$MTTD_T$ (hrs)
Air-Cargo	Summer	Log-logistic	8,6760	Helicopter	1,2427	10,0
				Cargo-ship	5,8321	14,5
	winter	G-Gamma	10,0403	Helicopter	2,0941	12,5
				Cargo-ship	8,1979	18,5
Cargo-ship	Summer	3P-Weibull	90,2786	Helicopter	1,2427	91,5
				Cargo-ship	5,8321	96,5
	winter	3P-Weibull	94,0720	Helicopter	2,0941	96,5
				Cargo-ship	8,1979	102,5
Truck-cargo	Summer	3P-Weibull	45,6187	Helicopter	1,2427	47,0
				Cargo-ship	5,8321	51,5
	winter	2P- Exponential	55,8098	Helicopter	2,0941	58,0
				Cargo-ship	8,1979	64,0

In table 3, $MTTD_1$ is mean time to delivery from Dusavik to Polarbasen; $MTTD_2$ is from Polarbasen to Goliat FPSO; and $MTTD_T$ is the sum of $MTTD_1$ and $MTTD_2$. From the result, for summer season, the shortest route, with minimum total MTTD**,** is from Dusavik to Polarbase by means of air-cargo and Polarbase to Goliat FPSO by means of helicopter. The minimum MTTD is about 10 hours, which implies that by using the fastest available means of transportation the latest spare part delivery in Goliat FPSO will be after 10 hours. If there is some heavy fog condition, during summer, helicopter might not be good option, from Polarbase to Goliat FPSO. So, the only option will be cargo-ship and that will increase minimum MTTD by around 4,5 hours and in this case the latest delivery will be after around 14,5 hours.

But, as per our assumption, the total planned delivery time from Dusavik to Goliat FPSO via Polarbase is 100hrs., and the probability that air-cargo be selected might not be 1. So, it's feasible to consider the other options such as truck-cargo and cargo-ship. Alongside, the question of how probable is to have the spare part onsite, with in planned delivery time, with a given specific $P(m_i)$ (probability that mode m_i be selected), must be answered. Therefore, we have to estimate spare part deliverability and the overall network deliverability in order to say the probability of deliverability of the spare part for given planned delivery time equals some 'specific' value.

3.2.2. Estimation of Spare part Deliverability and Network Spare part Deliverability

In this section, estimation of overall network deliverability with in planned delivery time (how probable is to have the spare part at Goliat FPSO with in planned delivery time) and spare part deliverability for each mode i.e. from Dusavik to Polarbase and from Polarbase to Goliat FPSO) will be carried out.

Spare part Deliverability for each Mode

Using Weibull ++8, we determine probability of undeliverability, U(t). Then, to estimate spare part deliverability, D(t), for each mode at the end of different time interval we use the following formulation: D(t) = 1 – U(t).

Table 4. Deliverability of each mode at the End of Different Time Interval

Interval Time (hrs)	Air-cargo		Cargo-ship		Truck-cargo	
	U(t)	D(t)	U(t)	D(t)	U(t)	D(t)
0	1	0	1	0	1	0
10	0,1526	0,8474	1	0	1	0
20	0,0001	0,9999	1	0	1	0
30	0	1	1	0	1	0
40	0	1	1	0	0,9377	0,0623
50	0	1	1	0	0,1634	0,8366
60	0	1	1	0	0,0081	0,9919
70	0	1	1	0	0,0002	0,9998
80	0	1	1	0	0	1
90	0	1	0,5307	0,4693	0	1
100	0	1	0	1	0	1

Table 4, from Dusavik to Polarbase, shows how probable is to have the requested spare part at Polarbase at the end of different time interval. From table 4, we can deduce that spare part deliverability to Polarbase with in 90 hrs. i.e. $D_{air\text{-}cargo}$(t=90hr), $D_{truck\text{-}cargo}$(t=90hr), equals 1 and $D_{cargo\text{-}ship}$(t=90hr), equals 0,4693. Then, we only left with 10 hrs, and Table 5, shows the spare part deliverability at the end of different time interval from Polarbase to Goliat FPSO.

Table 5. Deliverability Helicopter and Cargo-ship

Interval Time (hrs)	Helicopter		Cargo-ship	
	U(t)	D(t)	U(t)	D(t)
0	1	0	1	0
1	0,5304	0,4696	1	0
2	0,1454	0,8546	1	0
3	0,0328	0,9672	1	0
4	0,0065	0,9935	1	0
5	0,0012	0,9988	0,9136	0,0864
6	0,0002	0,9998	0,3757	0,6243
7	0	1	0,0423	0,9577
8	0	1	0,0008	0,9992
9	0	1	0	1
10	0	1	0	1

Network Spare part Deliverability

We need to estimate the overall network spare part deliverability, in order to take into consideration the probability that mode m_i be selected, $P(m_i)$. This is because, there is always assigned or given probability to select one mode of transportation from available options. Type of spare part, climatic condition, urgency level, condition of infrastructure, packing costs, location of consignor and consignee, speed limit, and frequency of service are some factors which govern selection of mode of transportation; and each mode can have different $P(m_i)$. Hence, in this section we assigned some $P(m_i)$ values to each modes, based on assumptions, and we estimate the overall spare part deliverability. Please refer figure 6 in parallel to figure 7, for better understanding of the assigned value of P_i, D_i, and $MTTD_i$. For this particular section the given data's are for summer season.

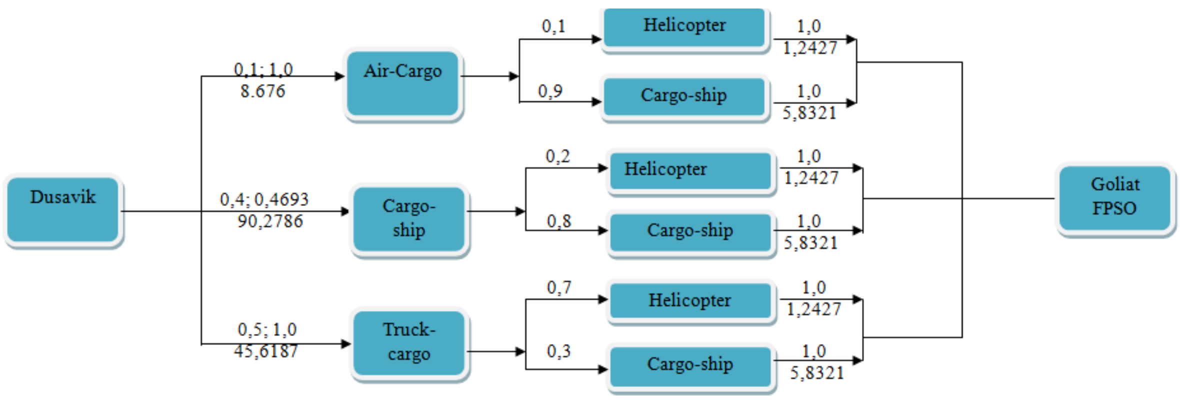

Figure 7. CTN for given case study with specific $P(_{mi})$, $D(_{mi})$, and $MTTD(_{mi})$

For the given case study, the spare part must first transport to Polarbase from Dusavik, then to Goliat FPSO. Therefore, we have to breakdown the given planned delivery time in to two, based on the maximum MTTD of the available mode of transportation. So, in order to calculate the overall network deliverability, first we have to calculate deliverability of the spare part to Polarbase with in 90 hrs. i.e. $D_{air\text{-}cargo}(t{=}90hr)$, $D_{truck\text{-}cargo}(t{=}90hr)$, and $D_{cargo\text{-}ship}(t{=}90hr)$. We choose 90 hrs, based on the maximum MTTD of the available mode of transportation, and we include the probability $P(m_i)$. From Polarbase to Goliat FPSO, we have two options i.e. helicopter and cargo-ship. Hence, we estimate the spare part deliverability, considering the associated $P(m_i)$, for the given delivery time, 10hrs .

Table 6. Summary of Network spare part Deliverability

Mode of Transport	Deliverability 1 (D_{N1})			Mode of Transport	Deliverability 2 (D_{N2})			Network Deliverability
	P_m	D_m	$D_{N1}(t{=}90hr) = P_m * D_m$		P_m	Dm	$D_{N2}(t{=}90hr) = P_m * D_m$	$D_N = D_{N1} * D_{N2}$
Air-cargo	0,1	1,0	0,1	Helicopter	0,1	1,0	0,1	0,01
				Cargo-ship	0,9	1,0	0,9	0,09
Cargo-ship	0,4	0,47	0,1877	Helicopter	0,7	1,0	0,7	0,1314
				Cargo-ship	0,3	1,0	0,3	0,0563
Truck-cargo	0,5	1,0	0,5	Helicopter	0,2	1,0	0,2	0,10
				Cargo-ship	0,8	1,0	0,8	0,40

In Table 6, D_{N1} and D_{N2} are spare part deliverability from Dusavik to Polarbasen and from Polarbasen to Goliat FPSO, respectively. D_N, network spare part deliverability is the overall probability to have the spare part onsite. Based on the analysis for the intended planned delivery time, using truck-cargo from Dusavik to Polarbase and then cargo-ship from Polarbase to Goliat FPSO is the most suitable way of transportation of spare part, for this particular case, and we have 40% probability to have the spare part at Goliat FPSO within 100hrs.

4. CONCLUSION

In this paper, we have proposed spare part transportation management plan for O & G industries operated in high north. The results obtained from data analysis showed that one can use spare part transportation block diagrams (TBD) to analyze different means of spare part transportation connected network-wise, and also to investigate path for the spare part transportation, from manufacturer to onsite or from operator/owner warehouse to onsite are examined.

The proposed plan is very helpful to support its user to estimate how probable is to have the requested spare part onboard, within planned delivery time. Alongside, estimation of mean time to delivery between two nodes, estimation of probability of deliverability for each mode, and calculation of the overall deliverability can be easily carried out using the proposed plan.

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