

Article

Time to Rescue for Different Paths to Survival Following a Marine Incident

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Abstract: The time required for rescue is a critical factor for surviving a marine incident. The regulatory framework, International Maritime Organization (IMO) Polar Code, utilizes a risk-based approach. It states that the vessel operators are to define the time required for rescue but never less than 5 days. Based on experience from the classification society DNV GL, utilization of the minimum requirement of five days is the current industry standard when conducting risk assessments. The dimensioning of search and rescue resources is a national issue. There are no international requirements defining the adequacy of the resources for different geographical areas. The remoteness and lack of resources present within the IMO Polar Code area imposes a significant challenge for mariners in distress. The time required for rescue is highly dependent on multiple variables. Based on this study, the number of persons to be rescued, the number and type of evacuation platforms and the distance each evacuation platform must travel significantly impacts the time required for rescue. In addition, the meteorological and oceanographical (metocean) conditions play a significant role when determining the efficiency of a search and rescue operation.

Keywords: time to rescue; IMO Polar Code; Arctic; search; rescue; passenger vessel

1. Introduction

Providing adequate SAR facilities dimensioned to handle the large passenger vessels in the Arctic is challenging from an economic, practical and logistical perspective. Large distances, lack of infrastructure and harsh metocean conditions represent risks that must be handled.

A substantial increase in the polar cruise tourism activity is expected, especially around Svalbard [1]. Several frameworks address the additional risks associated with this kind of activity [2,3]. However, few quantitative studies address one of the key elements essential for survival—the time to rescue (TTR). The time to rescue is mainly determined by the availability of SAR resources, which to a great extent is determined by geographical distances, political decisions and the financial strength of the business/governmental funding.

This paper assesses the time to rescue (TTR) for different scenarios, utilizing different paths to survival (PTS) and investigates the factors influencing the outcome.

2. Definitions

There is no international consensus with regards to the interpretation and definition of many of the commonly used expressions relevant for the topic. In this paper the following definitions are utilized:

- Evacuation platform—means to evacuate the crew/passengers from the water, survival craft or shore to a place of safety/temporary place of safety.
- FRC—fast rescue craft/mob-boat.
- JRCC—joint rescue coordination center, coordination of the resources to be utilized in the SAR operation.
- Place of safety—location where rescue operations are considered to terminate; where survivors' safety or life is no longer threatened; where their basic human needs (such as food, clothing, accommodation, and communications and medical needs) can be met; and from where transportation arrangements can be made for their next or final destination [4].
- PTS/Path to survival—the crew/passengers of a vessel of distress will have different options with regards to maintaining survival until being rescued. The chosen combination of options is defined as a path to survival. The preferred paths will depend on elements like:
 1. Condition of vessel
 2. Available equipment
 3. Metocean conditions
 4. Number of people involved
 5. Access to SAR resources
 6. Governing procedures
 7. Organization and competence, including systems for training
 8. Personnel judgment

An example of a path to survival (PTS) can be from a survival craft to FRC, further transportation by FRC to SAR-vessel.

- Rescue—the crew/passengers are considered to be rescued when they are placed in a place of safety or a temporary place of safety. The temporary place of safety will prohibit further escalation of the incident on an individual level, e.g., onboard a helicopter, at a temporary place of safety or onboard a SAR-vessel.
- SAR vessel—a purposely built vessel with competent crew, including FRCs and helicopter support facilities, coming to aid the vessel of distress.
- Survival Craft—lifeboat or life raft.
- Temporary place of safety—a location where persons are protected from hazards to life and health and provided with basic humanitarian services such as shelter from the elements, warmth, first aid medical treatment, food, water and sanitation, where communications with the JRCC and a means of accounting for and identifying surviving persons are provided and from which the survivors may be safely transferred to a place of safety [4]. Ideally this will be located close to a helicopter fuel depo to enable efficient refueling of the helicopter.
- Time to rescue (TTR)/time to recover—is the length of time beginning with the completion of the ship abandonment and ending when all persons have been recovered from survival crafts into a place of safety or a temporary place of safety [4].
- Vessel of distress—the vessel that is seeking help due to an unforeseen incident.

3. Model

The approach outlined in this paper is based on a case study approach. The research design is based on the “gaps and holes” methodology [5] with the aim of advancing theoretical explanations. The subjects of the case study have defined the input parameters required for a theoretical model.

They have been obtained based on earlier incidents/accidents. In addition, parameters have been gathered from full scale training/exercises involving the SAR providers. The objective of the study has been to utilize the model to assess the efficiency of different approaches to rescue.

Based on simple relationships between travel speed, distance, time, resources available and downtime (e.g., rest/maintenance), the TTR was calculated for different paths to survival. This required input parameters representing real life conditions. Each path to survival was broken down into subprocesses to provide an adequate model-resolution in the time domain. Most of the defined parameters are based on expert opinions, gathered from experienced SAR-operators. These values assume:

- (1) Adequate metocean conditions to conduct an efficient operation
- (2) Adequate number of competent personnel to conduct the operation in a safe manner
- (3) No technical breakdowns

Due to large sensitivity, many of the parameters have external and internal mechanism; the above assumptions were required to narrow down the process of time to rescue to comparable units. As a result, the model is deterministic and does not consider robustness or reliability. Due to the above assumptions, the model can be regarded as a “best case”. The model has been generated utilizing the computer program Python 3.7.

The model has further been validated by comparing the results to real incidents, e.g., the helicopter operation carried out on Viking Sky, the rescue of the crew of Northguider and the SAR-operation carried out during the Maxim Gorkiy incident [6].

3.1. Discrepancies between the Model and a Real Scenario

Modeling of TTR involves handling a substantial amount of uncertainty. Every vessel that comes to rescue will have its own specific resources, including level of training and number of personnel.

The following discrepancies are to be expected between the model and a real scenario:

- Number of available evacuation platforms—the available number of helicopters and FRCs might be reduced during the operation due to technical failures, maintenance intervals and grounding incidents.
- Level of crew training will greatly affect the efficiency and risk involved in the operation.
 - o The ability to get personnel from the survival crafts onboard the evacuation platform will be affected by the sea state.
 - o The model does not consider any time spent for searching. With a controlled evacuation and the IMO Polar Code requirement of equipment for communication between the survival crafts, this should not represent a large challenge. It is however, to be recognized that this will require functional communication equipment, which represents an uncertainty if comparing the model with a real scenario.
 - o For operations that have an extended duration, the survival crafts are expected to be scattered over an extensive area. Transportation and coordination of the effects caused by the scattering effect are not considered in the model.
 - o The model considers a controlled evacuation and rescue effort. It does not consider a melee situation, picking up individual survivors from the sea.
 - o In a real situation, a combination of survival paths is to be expected. The model only assesses each survival path individually.
 - o The resources mobilized to the scene of the accident will be a dynamic process. This will change throughout the operation and will be affected by mechanisms like availability, access to well rested crew, technical breakdowns, maintenance intervals and duration of the operation.
- The model does not consider the effects of bad weather delaying or stopping the operation.

3.2. Assigned Values

Based on best practice and practical experience from real-time operations, the following values have been assigned to the different variables and utilized in the model:

- Transit speed of the SAR-vessel = 15 (knots) (ice free waters)
 - o Distance from SAR-vessel to survival craft when commencing FRC operations = 1 (nautical mile) [7].
 - o Distance from survival craft to temporary place of safety (e.g., shore/vessel of opportunity) = 4 (nautical miles)
 - o Time used for preparations before departure for the helicopter = 60 (min). Requirement from the Governor of Svalbard [8]
 - o Time used for preparations before departure for the SAR-vessel = 60 (min)
- Number of FRC's utilized in the operation/carried onboard the SAR vessel = 2
- Average speed of the FRCs = 15 (knots) [9]
- Time utilized per person to embark from the survival craft to the FRC = 1.5 (min) [9]
- Time per person utilized to embark off the FRC = 0.3 (min) [9]
- Time utilized to lower and hoist the FRC = 3 (min) [9]
- Time utilized to refuel the FRC = 15 (min) [9]
- Refueling interval for the FRC = 60×4 (min) [9]
 - o Number of passengers carried onboard the FRC (excluding FRC crew) = 10 (persons) [9]. This is based on the capacity of the MOB boats utilized by the Norwegian Coast Guard. According to SOLAS requirements [10], the MOB boat is only required to carry 5 persons sitting, in addition to one person on a stretcher.
- Number of helicopters involved in the operation = 2
- Speed of helicopter (AS332L1 Super Puma) = 120 (knots) [11]
- Average time utilized to hoist 2 persons simultaneously = 2.5 (min) [11]
 - o Time utilized for each person to depart from the helicopter, including landing procedures = 0.5 (min)
- Time utilized for refueling of helicopter = 10 (min) [11]
- Refueling interval of helicopter = 4 (h) [11]
- Time utilized for helicopter critical maintenance/daily check = 30 (min) [11]
- Critical maintenance interval = 24 (h) [11]
- Number of passengers onboard the helicopter (excluding helicopter crew) = 15 persons
 - o Time for maintenance and refueling is executed when the FRC or helicopter is at the SAR-vessel, at the temporary place of safety or at the helicopter base.
- Additional helicopter crews are brought into the operation to ensure proper rest time.
 - o The time required from when a distress call is initiated until it is received by the JRCC is not considered as it is expected to be relatively short.
 - o All equipment has an up-to-date maintenance schedule and no major maintenance intervals (putting the helicopter out of service) are occurring during the rescue operation.
 - o The temporary place of safety has unlimited capacity to handle survivors.

Due to the elements mentioned above, it is to be expected that in a real scenario the time to rescue is to be significantly longer than the absolute values identified by the model. However, the model gives an indication of the sensitivity associated with the different paths to survival.

3.3. Paths to Survival

Surviving a marine incident is a result of a combination of measures. The combination of measures is defined as a path to survival (PTS). An example of a path to survival is PTS3. The survivors are initially located inside a survival craft. From the survival craft, they are evacuated on to an FRC and further onto a SAR-vessel. The model assesses the following paths to survival (Table 1).

Table 1. Paths to survival considered in this document.

Path to Survival	Evacuation From	Means Loading	Platform	Evacuated To	Means Unloading
PTS1	Vessel of distress/survival craft	Hoist	Helicopter	Shore/nearby vessel of opportunity	Walk
PTS2	Survival craft	Hoist	Helicopter	Helicopter base	Walk
PTS3	Survival craft	Hoist & crawl	Helicopter & FRC	SAR-vessel	Walk
PTS4	Survival craft	Crawl	FRC	SAR-vessel	Walk
PTS5	Shore	Walk	Helicopter & FRC	SAR-vessel	Walk
PTS6	Vessel of distress/shore	Walk	FRC	SAR-vessel	Walk

PTS3 and PTS5 assume that the helicopter immediately will start to transport survivors to the SAR vessel as it is transiting to the scene of the accident. In PTS3 and PTS4, the FRC operation (transporting survivors from the survival crafts to the SAR-vessel) is not commenced until the SAR-vessel is located less than 1 nautical mile from the scene of the accident.

Each path to survival has been broken down to individual subprocesses. The time required for conduction of each subprocess was calculated and accumulated. For the paths to survival, this includes the following subprocesses in chronological order, Table 2:

Table 2. The individual processes associated with the paths to survival.

Process Number	Processes
1	Mobilize and transport the SAR resources to the scene of the accident.
2	Lower the FRC on the SAR vessel (for scenarios where applicable).
3	Transport the survival crafts/shore with an evacuation platform (helicopter/FRC).
4	Load the survivors from the survival craft/shore to the evacuation platform (helicopter/FRC) within the capacity of the evacuation platform.
5	Transport the evacuation platform back to the SAR vessel/reception facility.
6	Hoist the FRC on the SAR vessel (for scenarios where applicable).
7	Unload the survivors from the evacuation platform.
8	Maintenance, if critical maintenance intervals were exceeded.

For incidents involving a large number of persons, the processes 2 to 9 were conducted continuously until all the survivors were rescued.

The time required to conduct each process has been accumulated. The time required for some of the processes is directly correlated with the number of persons involved, e.g., embarking from a survival craft to a FRC, while other processes are not correlated with the number of persons involved, e.g., hoisting/lowering of FRC.

4. Results

The model has been run to assess different paths to survival for three scenarios. To capture the effects different parameters had on the time to rescue, the scenarios were chosen to differ in both distance from infrastructure and number of persons to be rescued. Both the number of persons to be rescued and the distance from infrastructure were chosen based on realistic numbers associated with marine activities along the coast of Svalbard.

4.1. Scenario 1—Small Passenger Vessel (Carrying Up to 600 Passengers) Operating in a Region 200 Nautical Miles from Helicopter Base and Nearest SAR Vessel

The scenario assesses a relatively small passenger vessel carrying up to 600 passengers, at a distance of 200 nautical miles from the nearest helicopter base and 200 nautical miles from the nearest SAR-vessel. This can be representative for the expedition cruise vessels operating in remote regions.

PTS2 has been left out of the plot as it would have taken more than 80 h to complete the task. This path of survival proved however to be efficient for a lower number of passengers, involving only one or two flights.

The plot (Figure 1) reveals that it will take about 14 h until the first marine resource is available at the scene of the accident and can start the rescue by FRCs. However, for PTS3 and PTS5 the helicopters can start to move survivors from the scene of the accident to the approaching SAR-vessel/temporary place of safety immediately upon being deployed, and the FRCs will be involved in the operation as the SAR-vessel arrives at the scene on the incident.

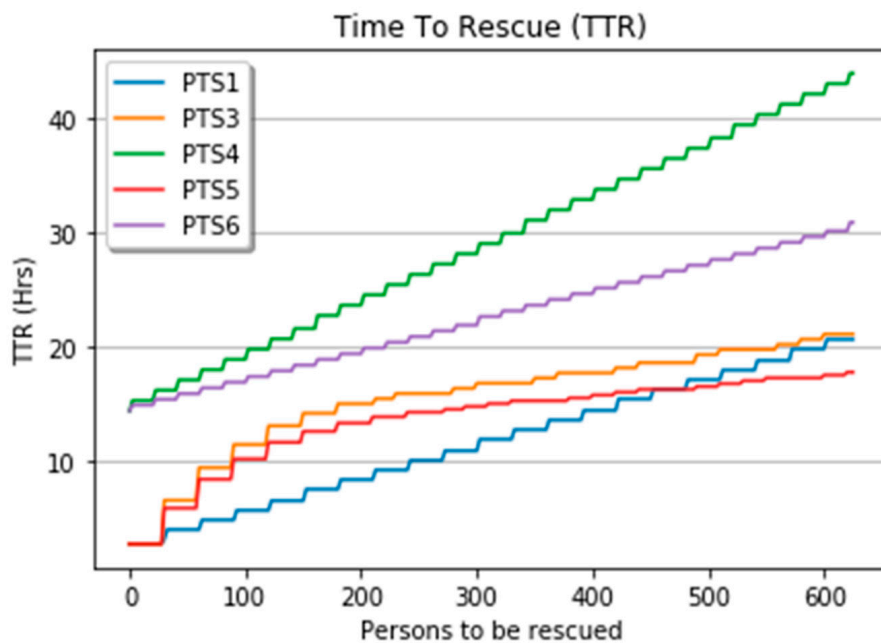


Figure 1. Time to rescue for small passenger vessel operating in a remote region.

For vessels in Scenario 1 involving 600 people, there is a relatively marginal difference between PTS1, PTS3 and PTS5. They all have in common that the helicopters are deployed to the scene of the incident and that one starts the evacuation by helicopter immediately upon arrival. In PTS1 the survivors are shipped to the shore/nearby vessel of opportunity while in PTS3 and PTS5 they are shipped back to the approaching SAR-vessel. The effect of FRCs contributing to the operation is not critical for vessels carrying less than 500 people due to the relatively long response time associated with the marine resources. The helicopter will be the critical asset and have completed most of the evacuation before the SAR-vessel arrives.

For vessels carrying less than about 500 persons, utilizing the helicopter for evacuation of personnel from the survival crafts to an onshore safe haven/vessel of opportunity (PTS1) is the preferred solution.

4.2. Scenario 2—A Larger Passenger Vessel Operating in Vicinity of Infrastructure and a SAR-Vessel

The second scenario is based on a passenger vessel carrying up to 3000 passengers, operating in closer vicinity to infrastructure, 50 nautical miles from a helicopter base and 50 nautical miles from a SAR vessel.

It is evident (Figure 2) that there is little time required to get the SAR resources in position. The effectiveness of the FRC operation compared with a helicopter hoisting operation outweighs the reduced travelling time of the helicopter. The most efficient means of rescue is the utilization of FRCs in combination with helicopters (PTS3 and PTS5). It is also evident that avoiding hoisting and enabling the personnel to “walk” onto the evacuation platforms increases efficiency substantially, reducing the TTR with about 33%, from 46 to 31 h. This would require the survivors to evacuate to land by themselves. In a real scenario, a temporary place of safety should be established at the same location.

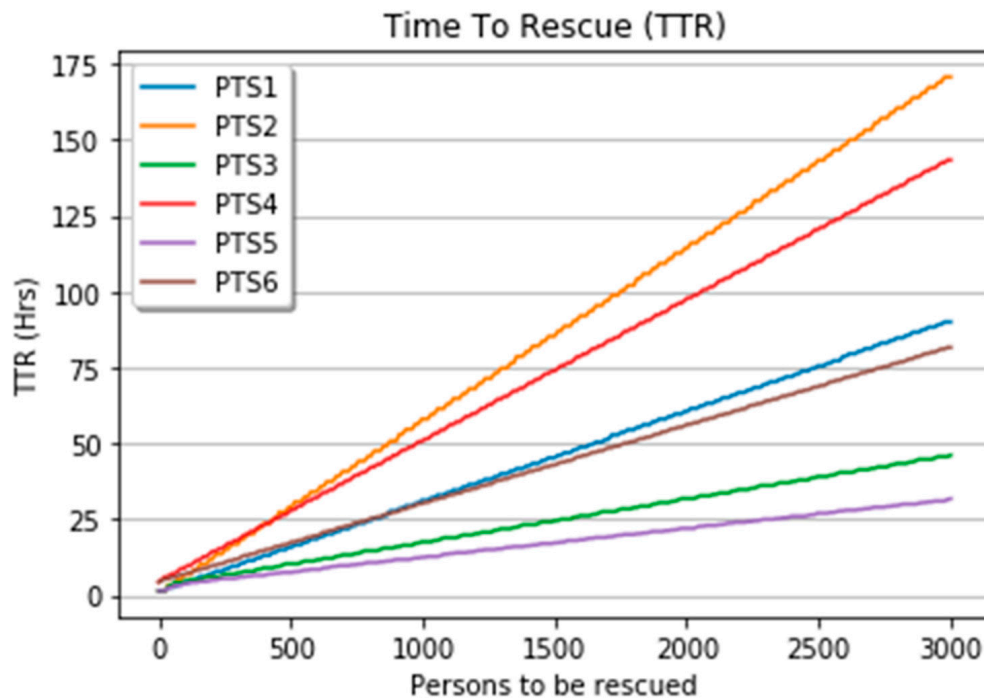


Figure 2. Time to rescue for a larger passenger vessel operating in vicinity of infrastructure and a SAR-vessel.

4.3. Scenario 3—A Larger Passenger Vessel Operating in a Remote Region

Scenario 3 is based on a relatively large cruise vessel (up to 3000 persons onboard) operating in a remote region, 200 nautical miles from a helicopter base and 200 nautical miles away from the nearest SAR-vessel.

The plot (Figure 3) for PTS2, flying the survivors directly back to the helicopter base is removed from the plot as it would take more than 400 h and is not regarded as a feasible option.

Due to the long response time for the SAR-vessel, it is evident that with the exception of PTS1, establishing and flying the survivors to a safe haven/vessel of opportunity near the scene of the incident, the operation will not reach its full effectiveness until about 14 h into the operation. The helicopter is an important asset, but the FRCs play an important role for the larger part of the operation.

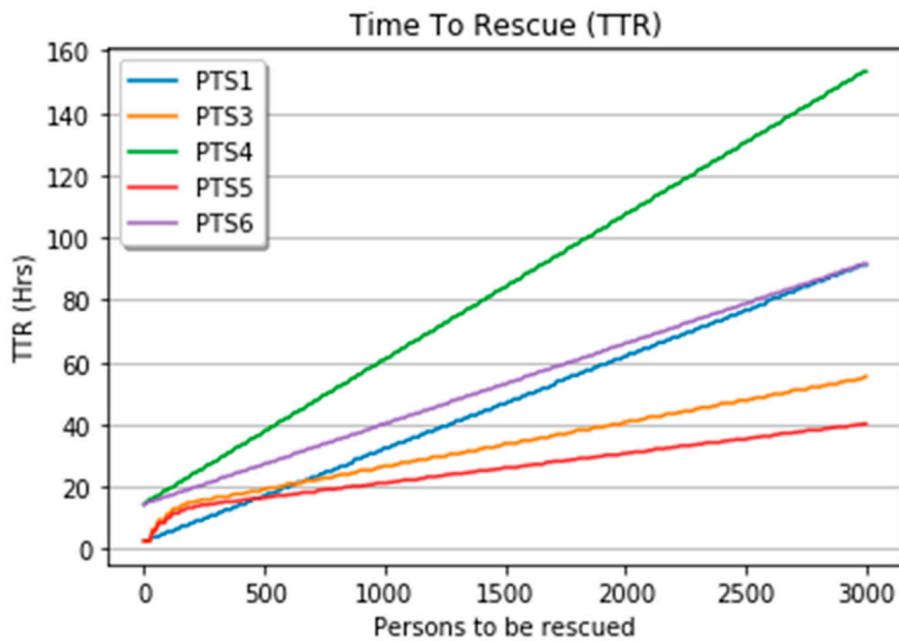


Figure 3. Time to rescue for a larger passenger vessel operating in a remote region.

4.4. Uncertainty Associated with the Results

The uncertainty associated with the model is defined as the model's ability to provide an accurate answer that represents the time to rescue associated with a real scenario. Due to the static nature of the input parameters and the lack of ability to cover unforeseen events, the model represents a best-case scenario with 100% operational efficiency.

The uncertainties associated with the result increase for operations of longer duration. This is due to the effect of several mechanism, e.g., human fatigue caused by prolonged working h, fatigue due to continuums repetitive operations (e.g., operator of FRC winches will have conducted several hundred hoists during a relatively short time frame), stretching of maintenance intervals for essential equipment, additional resources being introduced to the operation and variable metocean conditions.

The model assumes twin hoisting (hoisting 2 survivors simultaneously). It is experienced that when the helicopter approaches its full carrying capacity, it is preferred to conduct single hoist operations due to the challenge of the stowage of the survivors inside the helicopter.

If the survivors are in a physical state that requires single hoisting, e.g., being on a stretcher (e.g., due to serious injuries or hypothermia), the efficiency of the helicopter operation is reduced by more than 50%, further increasing the TTR substantially. Stowage of survivors on stretchers inside the helicopter is also highly time consuming. It is of very high importance that the survivors are in a physical state that enables an efficient hoist and stowage.

The efficiency of a SAR operation is highly dependent on numerous unknown variables. Based on experience from SAR-helicopter operators [11], the efficiency in a hoisting operation is reduced when rolling motion is encountered on the vessel/survival crafts the survivors are to be hoisted from. The rolling motion is related to a variety of parameters like vessel size, vessel heading, vessel metacentric height, sea state and wave periods. This study assumes 100% efficiency in the rescue operation. Due to factors like bad weather, lack of/improper communication/logistical challenges etc., the operational efficiency can be reduced significantly. In a real scenario, this could result in a substantial increase in the TTR, and this study is to be regarded as a best case.

5. Discussion

5.1. Model Results—Scenario 1

In Scenario 1 it is evident that PTS1, freighting the survivors by helicopter to a temporary place of safety established onshore/vessel of opportunity, is efficient, especially when the number of survivors is relatively low (e.g., below about 500 persons). This will require establishment of a safe haven, in addition to a fuel depo near the scene of the accident. The time utilized for the operation is greatly affected by the distance from the survival crafts to the temporary place of safety and fuel depo (Figure 4).

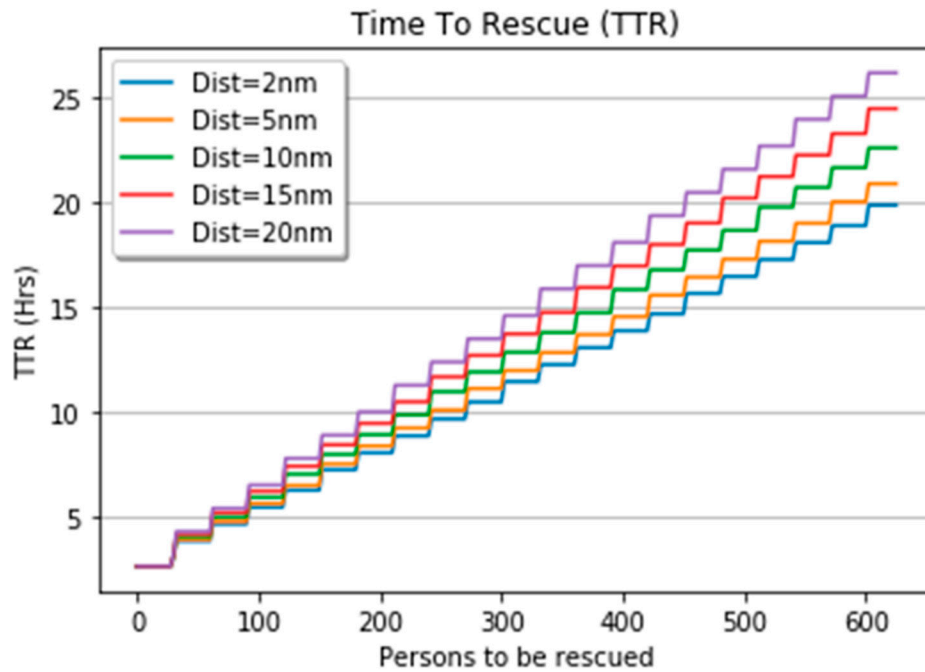


Figure 4. Time to rescue for different distances from scene of the incident to safe haven.

Increasing the distance from the incident to the temporary place of safety from 2 nautical miles to 20 nautical miles will result in an increased flying time per round trip for the helicopter. Based on Figure 4 it is evident that the increase in distance (from 2 nautical miles to 20 nautical miles) will reduce the efficiency of the operation by about 20%. However, the potential waiting time associated with multiple helicopter operations taking place in a limited airspace simultaneously will reduce the efficiency for short distances.

A more robust and realistic approach would be to focus on PTS3, as utilizing this approach, the helicopter will have access to required helicopter support systems at each drop off of survivors at the SAR-vessel. Utilization of this methodology was seen in the Maxim Gorkiy incident [6].

This is especially true when the number of survivors is approaching 600 or above, as the efficiency of PTS1 and PTS3 converges around this point.

Introducing a marine asset to the operation will also contribute to increasing redundancy and handling the scattering effect caused by the survival crafts.

Shipping survivors directly back to the helicopter hub will not be a feasible option unless the number of survivors is relatively low, involving only a few helicopter flights. This will also reduce the need for establishment of an onshore safety haven. An example of this was seen during the evacuation of the crew of the fishing vessel Northguider [11].

5.2. Model Results—Scenario 2

In Scenario 2 it is evident that PTS3 and PTS5 provide the lowest TTR. These paths to survival enable a simultaneous operation of 2 FRCs and 2 helicopters.

The lowest evacuation time observed is PTS5 where all the survivors are located onshore. In a real scenario, it would be advisable to establish a safe haven at this location (if possible), and at a later stage evacuate them in a controlled manner.

It is worth noting that even at these distances, very close to onshore infrastructure, PTS1 came out about average. This option does not take into account that FRC and smaller local vessels of opportunity could be utilized for evacuating personnel onto the shore. Few SAR-vessels have the capacity to handle 3000 survivors, and additional accommodation resources must be brought into the scene of the accident, either as other vessels or by establishing an onshore safe haven.

Based on the findings above it is evident that an onshore temporary place of safety would be an asset also for incidents that took place in close vicinity of onshore infrastructure.

5.3. Model Results—Scenario 3

In Scenario 3, marine resources are essential for the operation and they reduce the TTR by more than 50% compared to only utilizing helicopters. It is also clear that the time utilized by the marine resource to reach the scene of the accident only represents a small portion of the total time required for the rescue operation.

An operation that is to have a duration of several days will need to supply its own support functions. This includes additional personnel, FRC fuel, helicopter fuel, technical personnel and food. Establishing the logistics required for an efficient operation will require substantial efforts and time. Parallel to the first responders rushing to the scene of the accident, a logistics support system should be initiated and mobilized.

5.4. Common Denominators for All Scenarios

It is evident that for all scenarios the TTR is expected to be in the range of days, not h.

It is further apparent that three different key factors highly influence the TTR; the number of persons to be rescued, the number of evacuation platforms available and the distance to be travelled by the individual evacuation platforms.

The number of persons to be rescued represents a major driver when determining the TTR.

When the resources are at the scene of the incident, the number of evacuation platforms, e.g., number of FRCs and helicopters available, is critical in determining the time to rescue. Each individual platform provides rescue capacities as long as they can operate in parallel. The cumulative capacity of the evacuation platforms highly affects the total speed of the evacuation, which further defines the total time required for the rescue operation. Utilizing a substantial number of evacuation platforms in parallel will, however, demand a high capacity reception facility to handle the high and steady influx of survivors.

The distance travelled by the evacuation platforms is determined by the distance from the survival crafts to the temporary place of safety established onshore/vessel of opportunity/SAR-vessel. As this distance has to be travelled twice (back and forth) when picking up the survivors it will highly influence the TTR. It is of uttermost importance that the SAR-vessel maneuvers close to the survival crafts and that the temporary place of safety is established in close vicinity of the scene of the incident. The location of the helicopter fuel depots also plays a significant role when assessing the efficiency of the helicopters.

When evacuating a vessel in distress, involving an extensive number of rescue platforms will reduce the TTR up to a certain point. Beyond that, it will only increase the robustness of the operation. It is also important to consider the capacity of the reception facilities. The capacity of the reception facilities and the capacity of the evacuation has to be harmonized for an efficient operation. During the

Viking Sky incident, the onshore casualty reception facility was manned with about 100 volunteers from the Red Cross in addition to professional health workers, providing first aid and psychological support [12].

During the Viking Sky incident 397 persons were evacuated in about 16 h, giving an average time of 2.4 min per person. Five helicopters were involved in the operation, and the helicopters were refueled at the same time as they were dropping off the survivors. However, only one helicopter was able to conduct hoisting operations at the vessel at any time due to issues caused by turbulence, [12–14]. The indications of reduced efficiency during utilization of several helicopters together is also addressed in the guidelines defined by [15]. They state that an efficiency of 50% is to be expected for the second helicopter arriving at the scene of the accident.

It is evident that the distance from the nearest helicopter base/SAR-vessel influences the TTR. In scenario 3 the lowest TTR was about 40 h utilizing a combination of helicopters, FRCs and a SAR-vessel. Out of this time the SAR-vessel utilizes about 13 h and the helicopters utilizes about 1.6 h to get to the scene of the incident. This represents respectively about 30% and 2.5% of the total TTR. From a cost/benefit perspective, the recommended focus should be on increasing the rate of survivor evacuation by increasing the number of evacuation platforms not only focusing on reducing the response time.

In PTS 5 and PTS6 the survivors were able to reach shore by their own means. If the location is suitable, it would most likely be advisable to establish a temporary place of safety at this location instead of moving the survivors.

During the Maxim Gorkiy incident about 325 people were rescued in about 3.5 h [6]. This means an average of 0.65 minute per person. This achievement was achieved utilizing multiple helicopters landing and refueling onboard KV Senja, in addition to survivors directly climbing/being onto the aft deck of the SAR-vessel. The large discrepancy between the evacuation speed (time utilized per person) in the Maxim Gorkiy scenario compared with the evacuation time in the Viking Sky or Northguider scenario is mainly due to survivors evacuating directly from the survival crafts onto the aft deck of KV Senja from the life boats by walking/climbing. This reduced the need for FRC/hoisting operations which are time consuming.

To be able to conduct this operation on calm seas was a necessity. Despite the extraordinary good conditions, there were incidents where helicopters almost slide off the helideck and lifeboats obtained considerable damage under the stern/side of KV Senja, due to the rolling motion of the vessel.

Conduction of part of the operation was beyond normal regulatory directives but a chosen option due to the limited time available.

This incident proves the importance of multiple evacuation platforms being utilized simultaneously. It also indicates the increase in speed when having a system that enables the survivors to “walk” off the evacuation platform instead of being hoisted/lifted.

5.5. Robustness of the Operation

The model is based on 100% functionality of all technical equipment. Malfunction and technical breakdowns are to be expected for an operation that is to have a duration of several days. Due to lack of infrastructure, reduced availability of critical spare parts and technical competence, the operation can be significantly delayed when comparing to a real SAR operation; according to the results from the application of the model.

To reduce the likelihood of the above-mentioned mechanism, it is important to evaluate different aspects of the robustness of the operations, Table 3.

PTS6 assumes that the survivors have been able to reach a protected location onshore. With the exception of PTS6, it is clear that none of the PTS's are clearly favorable. It is however clear that mobilizing many assets to the scene of the accident is of high importance to increase the robustness of the operation.

Table 3. Robustness of the different paths to survival.

Survival Path	Robustness Weather	Robustness Technical	Robustness Human Element
PTS1	High	Low	Medium
PTS2	High	Low	Low
PTS3	Medium	Medium	Medium
PTS4	Low	High	High
PTS5	High	Medium	High
PTS6	High	High	High

The weather limitations associated with FRC operations will also affect the robustness of the operation. According to JRCC Bodø, personnel transfer by FRC is not advisable in seas above 1 m unless the FRC operators have special training and the survivors are fit [6]. For most of the offshore sector in the North Sea, the wave height limitations for a specially trained crew is defined to be a significant wave height of 4.5 m [16].

If the survivors seek a sheltered location or the shore, the probability of efficient FRC operations would significantly increase.

The effect of having a SAR-vessel at the scene of the accident increases both the robustness from a technical and a human element perspective. The vessel would provide valuable assets like helicopter logistic support, food, water, medical facilities and improved abilities for communication.

5.6. Human Resources Required in an Efficient SAR Operation

When dimensioning a SAR-system it is important to consider the human resources involved in the operation. For an operation that is to be conducted on a continuous basis for several days it is important to follow standard operation procedures to prevent development of fatigue and reduce the likelihood of failures.

Below (Table 4) is an example of the human resources involved in transportation and reception of survivors from survival crafts. This does not take into account the resources needed for staffing of SAR-vessel operations, first aid treatment or accommodation of the survivors.

Table 4. Human resources required for a multiday SAR operation.

Operation	Minimum Number of Persons Conducting Operational Tasks	Minimum Number of Persons Allocated to the Operation on a Continuous Basis (3 Shifts)
FRC operation		
FRC crew	3	9
Crane operators	2	6
Reception facilities (only registration)	2	6
Total FRC operation	7	21
Helicopter operation		
Pilots	2	6
Winch operator	1	3
Mechanic	1	3
Vessel HKO + 2 NAVKIS	3	9
FDO (Flight Deck Officer)	1	3
FDA (Flight Deck Assistant)	1	3

Table 4. Cont.

Operation	Minimum Number of Persons Conducting Operational Tasks	Minimum Number of Persons Allocated to the Operation on a Continuous Basis (3 Shifts)
FDM (Flight Deck Crew)	4	12
Mechanic preparing heli-fuel	1	3
Reception facilities (only registration, no medical treatment)	2	6
Total Helicopter operation	16	48
Total all transportation operations		69

The table indicates what would ideally be required for a multiday SAR operation. The figure does only take into account the evacuation processes and does not address the personnel required for, e.g., casualty treatment or organizing logistics. Much of the above-mentioned personnel would not be available as the first responders rush to the scene of the accident. Mobilization and transportation of additional required personnel to the scene of the incident should be initiated in the early phases of the operation.

It is also worth considering mobilization of the human resources required for the survivor reception facilities, including the staffing of safe havens. In the Viking Sky incident, there were about 100 persons involved in the reception and premedical treatment of the survivors [12].

6. Conclusions

Despite the uncertainty associated with the model, there are several learning points identified. Increasing the number of evacuation platforms greatly affects the TTR. Utilization of FRCs and helicopters simultaneously proved to be the beneficial for all three scenarios. However, this requires access to helicopter support functions (e.g., ability to refuel) and the reception facilities to be dimensioned to handle a large influx of survivors.

For incidents taking place in remote areas (far from infrastructure and SAR-vessels), the time required for the SAR-vessel to arrive at site affects the rate of rescue. The following generalization can be made for the most efficient path to survival:

- Less than 40 survivors—PTS2, utilizing helicopters, freighting the survivors directly back to the helicopter base.
- 50 to about 600 survivors—PTS1, utilizing helicopters, establishing a temporary place of safety onshore while waiting for arrival of SAR-vessels as long as helicopter fuel is available in the vicinity.
- More than about 600 survivors—PTS3, utilizing a combination of all evacuation platforms available.

In all cases the survivors would benefit from seeking sheltered waters/the shore to increase the efficiency of the rescue operation.

It is also evident that access to helicopter fuel/support facilities is essential for prolonged operations involving helicopters. All paths to survival, except PTS2, require this in the vicinity of the scene of the incident. The issue of access to helicopter support facilities was also essential for the successful outcome of the Maxim-Gorkiy incident [6]. Shore-based depots located in vicinity of the scene of the accident, available before any SAR-vessels arrive, utilized in combination with SAR-vessels with helicopter facilities is regarded as the most beneficial approach.

7. Recommendations

The general learning points can be divided into two different categories: vessel operator recommendations and SAR operator recommendations.

7.1. Vessel Operator Recommendations

From the perspective of a vessel operator, the following issues are to be considered:

- For vessels containing more than a couple of hundred persons, the time to rescue is expected to be days not h for most areas of the Arctic/Antarctic.
- The number of persons onboard is a key parameter when estimating TTR. As a result, it is to be expected a longer TTR for a large passenger vessel than for a smaller vessel.
- The availability of SAR-resources is critical when determining TTR, and it is to be recognized that prolonged helicopter operations are not a viable option for a large part of the Arctic/Antarctic due to lack of support infrastructure, e.g., helicopter fuel.
- Rescue by marine resources will require relatively calm waters (wave height below 1 meter is recommended by JRCC Bodø) [7].
- The survivors should try to avoid spreading over a large geographical area (reduce the scattering effect) and seek sheltered waters or preferably evacuate to onshore. This will increase the probability for efficient evacuation operations, reduce the probability for conducting helicopter hoisting operations and reduce the TTR and increase the probability of survival
- Having a companion vessel (twin vessel operation) can increase safety. This will require special training and purposely built equipment to enable efficient ship to ship transfer of personnel. This is only a viable option in calm waters.
- Installation of helicopter support facilities onboard passenger vessels/vessel of convenience can substantially increase both the efficiency and the duration of helicopter operations.

7.2. SAR Operator Recommendations

From the perspective of a SAR operator, the following issues are to be considered:

- Dispatching a combination of purposely built and trained marine SAR-resources to the scene of the accident to provide a safe haven, helicopter support facilities and enabling of FRC operations are essential to reduce the TTR and increase the robustness of the operation.
- Mobilization of additional resources (including personnel) is critical for logistics and support of an extended operation that is to last for several days.
- Maximize of the number of evacuation platforms available at the scene of the incident will in most cases reduce the TTR.
- The reception facilities must be dimensioned for the capacities provided by the cumulative capacity provided by the evacuation platforms.
- For many scenarios involving a substantial number of passengers, an onshore temporary place of safety is a critical asset. Equipment and personnel should be readily available at the helicopter base and pre-established helicopter fuel depots should be available in the geographical area of interest.
- Contingency plans addressing mobilization and transportation of additional essential SAR-personnel to the scene of the accident should be prepared as an efficient operation of an extended duration will most likely involve more than 100 SAR personnel at the scene of the accident.
- It is important to consider the safety, food and water required to support the SAR-resources brought to the scene of the accident.
- Helicopter fuel depots—the depots should be located at short distances from each other to reduce the time utilized for transportation. The depots should enable helicopter operations for a duration equivalent to the time required for SAR-vessel to reach the area.

8. Concluding Remarks

In the risk assessment required by the IMO Polar Code, a majority of the vessel operators aim for the minimum time to rescue requirement of “minimum 5 days” [1].

Being rescued within the timeframe defined will require an enormous functional SAR-system in place, in addition to favorable metocean conditions. This is especially valid for larger vessels carrying more than a couple of hundred people. Within the IMO Polar Code area, the SAR-resources are sparse and far apart. When conducting the risk assessment as defined in the “Polar Water Operation Manual”, it is important to consider the elements described in this manual to ensure the time defined as “time to rescue” is valid for the area of operation.

It is also of importance that the governmental agencies responsible for the SAR facilities are actively communicating the availability and functionality of the SAR system within geographical areas. This information is essential input for the marine industry to enable defining a realistic time to rescue.

9. Epilog

Deficiencies in a vessels SOLAS equipment [9] will cause incompliance with the governing rules and regulations. Such a vessel would be detained and prohibited from leaving port as the functionality of the safety equipment would be regarded as not adequate to provide the functionality required for survival in the event of an incident involving the vessel.

Bad weather will also reduce the functionality of the safety equipment. A relatively high significant wave height will prohibit launching of the lifeboats/life rafts and evacuation of the vessel in distress would not be possible.

A vessel with compliant SOLAS equipment would not be restricted from leaving port, despite a valid weather forecast defining conditions where the functionality of the safety equipment is severely reduced. In this event, the vessel operators purposely put the vessel in a position where they should know that the safety is compromised.

This paradox imposed on the marine industry is relatively recent. In previous times the vessels traveled slowly, and the weather predictions were unreliable or unavailable. In more recent times the accuracy and availability of weather forecasts has improved significantly, and most vessels can avoid bad weather, if prioritized.

For vessels operating on the high seas, avoidance of bad weather is at times difficult. However, most cruise/passenger vessels operate in coastal waters for a larger part of the time. Avoidance of situations where the functionality of the safety equipment is significantly reduced is perfectly possible with today’s technology. This will require prioritizing safety and a willingness to bear the cost associated with the implications of the mitigation measures.

Slogans like “Never compromise on safety” are frequently observed in the marine industry. However, as the industry accepts the risks associated with lack of functionality of safety equipment associated with bad weather, safety is compromised every day, in all parts of the world. Operating with risk acceptance criteria that compromise on safety is not necessarily a bad thing—a human life has a price. It is, however, important that this fact is accepted and communicated to relevant parties, including the passenger who puts his/her life in the hands of the vessel operator.

It should be noted that the paper is based on the results of a series of search and rescue exercises conducted in the waters north of Spitzbergen, Norway from 2016 to 2018, [17–20].

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