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A Model to Identify Short-Term Efficiency Improvements of Network Organized Forces

Modeling and Simulation

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Abstract

Network-organized forces are hypothesized to give better efficiency and robustness through more efficient utilization of resources, less idle time and increased flexibility. In the long-term one may expect all military components to be part of one networked unity, but until then, in the short term, one may gain from improving on the fragmented networks of today.

We have developed a model to help identify components that hold *network qualities*. By *network qualities* we understand a great improvement in a component's overall usefulness in a networked context. The model helps us to identify such components and the particular links that would contribute to the components "net-readiness".

The model, a stochastic program, implemented as a multi-stage mixed-integer program, solves a high-level decisions problem at the operational level. It incorporates two aspects that are most important in the context of network-organized forces. The first is a concept of *consumers* and *service providers*. The second is the treatment of uncertainty in order to handle the aspects of flexibility and robustness in decisions, one of the major advantages of network-organized forces.

Introduction

Network-organized forces are hypothesized to give, at large, better efficiency. That is, more efficient utilization of resources and less idle time, increased flexibility and hence increased robustness. These effects are achieved by letting existing resources be utilized by multiple users. From the users' perspective, an increasing number of resources will be available to them. These are resources that previously, mainly due to organizational constraints, were out of their reach. Similar effects are discussed as "network effects" and "network externalities" in the business and economic literature, see for example Katz and Shapiro (5) and Shapiro and Varian (2). In the case of network-organized forces these effects are sought between military components.

In *Network Centric Warfare - Developing and Leveraging Information Superiority* (1) Alberts, Garstka and Stein state:

> *Again, this does not imply all actors will be linked to an actor network, or exclusively or primarily to other actors. Rather that actors (e.g., shooters) will have a far richer collection of links to other battlespace entities than they do with platform-centric operations. In the future they will be linked to each other, directly to sensor entities, or indirectly to sensor entities by virtue of having direct access to their products (individually and/or collectively).*

A relevant question is then: Since it is not an all-to-all network, what links should be established, e.g. how should military planners faced with budget constraints prioritize between a large number of possible links? A *link* in this sense does not only imply means to communicate. It also includes applications that support that particular link, and even more important, there has to be a link at the organizational level: existing procedures must support the link being used and decision makers must know how to utilize the link. Allowing someone to access a service provided by a remote component, e.g. a decision maker to access a sensor, will therefore require connections at all these three levels: a communications link, an application link, and an organizational link. That is, a means to communicate, applications that share data models and ontologies and are capable of exchange of information, and finally an organization that is capable of taking advantage of that particular connection. Figure 1 shows these three layers that are all needed to realize a link at the organizational level. Such comprehensive links will enable network-organized forces.

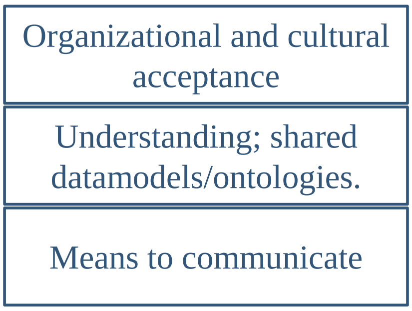


Figure 1, Layers necessary for a link at the organizational level

To make the most out of existing military components, small changes in the way one chooses to organize and divide responsibilities, combined with minor equipment enhancements, may suffice to facilitate "new links" or enable new combination of cooperating components. Given budget constraints and limited capacities at the components, in a pragmatic approach to network-organized forces, a major issue is to identify the most "profitable" new links. That is, which components should be connected; should be able to communicate, should have applications to support their needs, should have procedures set up, should have responsibilities between them made clear, and finally, should be trained for coherent action?

For joint operations, vast number of possible new links is yet to be explored and, at least in the short-term perspective, there are obvious capacity constraints that prohibit total all-to-all networks in the immediate future. We have developed a general optimization model that models the operational level resource allocation problem. In the resource allocation solutions provided by this model we will be able to identify components with "network qualities", clusters of cooperating components and potentially useful links between components. These results may support military analysts in making recommendations for further studies or implementation.

We now present the main ideas of the model and then an example to illustrate the practical use of the model.

The model

The model incorporates two aspects that are most important in the context of network-organized forces. The first is a concept of *consumers* and *service providers*. The second is the inclusion of uncertainty in order to handle the aspects of flexibility and robustness in decisions.

Considering military components as service providers and consumers is convenient and fitting when analyzing network-organized forces, as one may consider the service exchange as the links in the network. Also, if one imagines military components to be one networked unity where everybody may cooperate with everybody else; then the service concept is obviously a relevant approach. The service concept for the military domain is given an extensive treatment in *Networked Services* by Hall et al. (3).

Uncertainty is what quickly ruins a good plan. Nevertheless, uncertainty is rarely handled well. More information is one way to reduce uncertainty. However, for most situations, regardless of effort, achieving perfect information is not an option. The other way to reduce the impact of uncertainty is to provide for flexibility. Flexibility, and from flexibility, robustness, is one of the great promises of network organized forces. A model evaluating network-organized forces will miss one of the major aspects of the concept if it is not able to valuate flexibility.

Service providers and consumers

Services, platforms, components, and tasks

The concept of *services* and *delivery of services* between entities in the organization is central in the model formulation. We here apply a broad understanding of the term *service*. By services we understand anything that one operational component can do to support another operational component. A service may be a logistic service, delivery of information from a sensor, delivery of firepower from a weapon etc. The model implements three entities of which services are delivered between. These three entities are *components*, *platforms* and *tasks*. *Components* are the only service providers. Components will produce *services* that are made available to the other entities. A *component* is attached to a *platform*. Platforms have the ability to move between *areas*. When a platform moves, the attached components will also move together with the *platform*. For example, a frigate may be considered a platform; its weapons and sensors are various components. Also, at a high level, an army company may be considered to be a platform, and similar to the frigate, then the company's platoons, weapons and sensors may be different components. *Tasks* are the third entity-group. A *task* will require certain services to be delivered to an area. If all the demands associated to that task are met, then the task is completed. Unfulfilled tasks will have a negative contribution to the model's objective function.

As previously mentioned, a *component* will produce *services*. To support its production, the component will need *raw materials*; in the model raw material are other services that are delivered from other components or the platforms' internal stock. Produced services may be delivered to other platforms or to tasks. Depending on the type of service there may be limitations to production capacity, different efficiency of production, and constraints on the feasible distance between the producing component and the consuming platform or task.

Solving the model will yield the decisions of *movements of platforms, production of services* by the components and the *delivery of services to platforms* and the *delivery of services as part of solving a task*.

No organizational constraints

The model does not implement any organizational constraints. That is, no explicit organizational relations between the components are modeled. Organizational constraints are left out to assure that components, in the model, are used as freely and efficiently as possible. All components are service providers and/or consumers and they may deliver their services to whoever demands their services. Likewise, they may consume services from whoever is able to deliver the services. The solution provided by the model is equal to that of one centralized rational decision maker with access to all knowledge available within the organization. This enables us to study how, and in what combinations the components are used to solve the organization's tasks. If a task is solved by services delivered from more than one component; the components cooperate, this is an indication that coordination between the components is needed - A link between these components is necessary if this solution should be a feasible for real military components facing similar tasks.

Uncertainty

Flexibility and uncertainty

In the model, the specific *tasks* the organization must solve are considered to be uncertain. Different actions by an adversary will result in different tasks to be solved. As long as we do not have perfect information about the actions of our adversaries, we will obviously not know their actions by certainty.

Flexibility, one of the great promises of network-organized forces, is first appreciated in the presence of uncertainty. The Merriam-Webster's Online Dictionary (4) defines flexibility as: *a ready capability to adapt to new, different, or changing requirements*. Unusual and exceptional employment of military components is likely to happen under new, different, or changing requirements. This is when the components' flexibility is appreciated, regardless of whether a component is originally intended for a totally different purposes, or if is has been put to such use before. It is in situations that turn out not to be as planned, but where the decisions makers has to take advantage of whatever resources are available and exploit them in the best possible combinations, that military components may be employed in "unusual" combinations.

As previously stated, flexibility is one of the major advantages that network-organized forces can provide. Back-up solutions and redundancy may be obtained through network-organized forces. The option of having multiple ways to solve a task may yield a robust organization. If we are able to predict how military components may be exploited, and what components should cooperate, under uncertainty to provide for flexibility, we may prepare and even train for such employment of the resources.

Our model is able to appreciate flexibility and will therefore provide flexible decisions where flexibility is needed. By flexible decisions we understand decisions that take into consideration that the future has multiple plausible outcomes, and new information about where the world is heading can make it necessary to change previously made decisions; to make recourse decisions. A flexible component is likely to be a component that is attached to a platform that moves quickly, may operate on its own, and/or the component is capable of delivering multiple services.

Stochastic programming

The problem, as described, is implemented as a multi-stage mixed-integer-program (MIP). The uncertain tasks are represented using well-known techniques from Stochastic Programming:

First, we let the uncertainty (what tasks need to be solved) not be dependent on the decisions made in the model. This suggests that the tasks we will be planning for are not influenced by our decisions at this level; it is not a game between multiple players, but the decisions made in the model is more of a reactive answer to the new information.

Second, the decision process and how information reaches the decision maker are considered as one process. A *stage* is a point in time where it is possible, and also makes sense, to make decisions. For example, it does not make sense to make a new decision if no new information is available. In between the stages are *periods* where the consequences of the decisions are realized. This is illustrated in Figure 2. It is not necessary to make every decision at the first stage; some decisions may be delayed until more information is available, such that it is possible to make recourse decisions at the preceding stages.

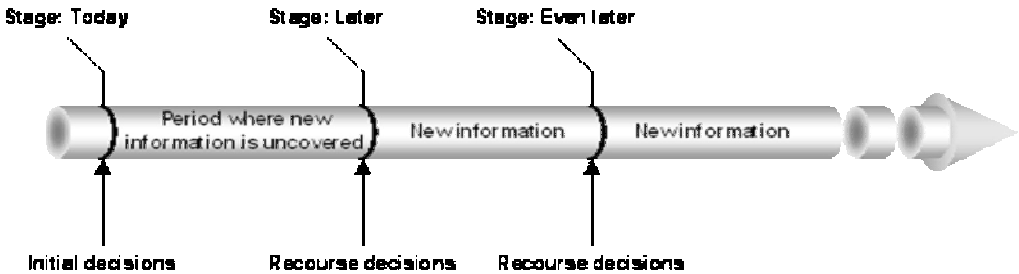


Figure 2, *Stages* and *periods*

For general texts on Stochastic Programming see, for example, Kall and Wallace (6) or Sen and Higle (8)

Task tree

We only make decisions at the stages, as described above, therefore we will only have limited points in time where decisions are made. Also, we limit the number of possible states of the world at the stages. For example, an adversary may do one thing, or he may take another action. This information, the two possible actions of our adversary, yields two possible states. Each state will have a probability assigned to it and an independent set of tasks that need to be solved in that state.

This information may be represented in a task tree as illustrated in Figure 3 and Fi gure 5 in the example. Every node is a distinct state. Associated with each branching there is a probability; a probability of reaching that state, conditional of the earlier state. A path through the tree is often called a scenario, since it is one plausible realization of the future. In Figure 3 there are seven paths through the tree; the world has seven different realizations at *t=2* and we have seven scenarios. Since it does not make sense to make decisions without new information available, there is a link between reaching a new state and the stages in the model. The stages in Figure 3 are *t=0*, *t=1*, and *t=2*, and so we will make decisions at three points.

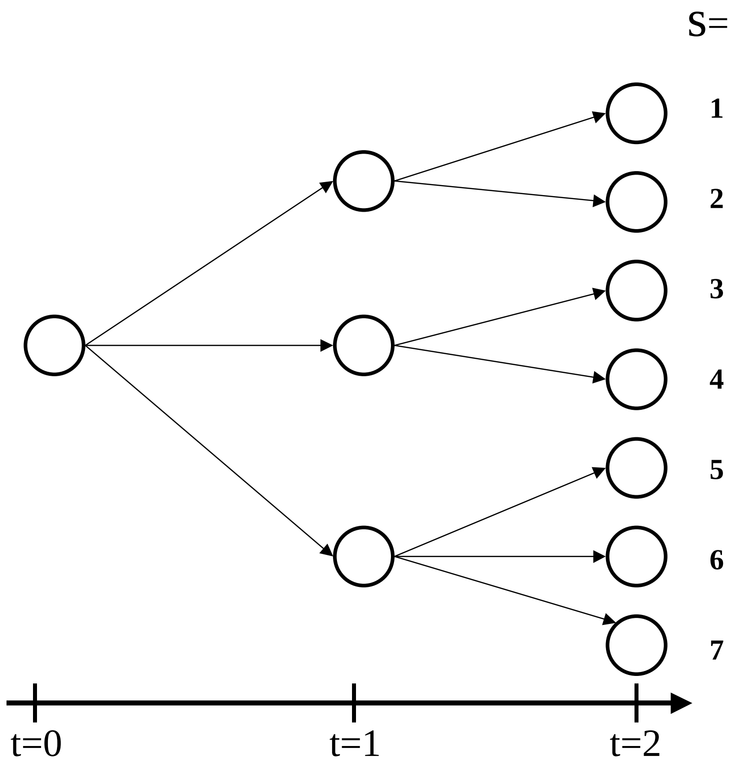


Figure 3, A task tree.

In the model solution there is a set of decisions associated to each node/state; decisions conditional on the history leading up to that node. These decisions may be illustrated in a decision tree as shown in Figure 8 in the example.

Implementing the model

The implemented model is a stochastic multi-period mixed integer program. It is written in the mathematical modeling language *AMPL* (7). The current formulation of the model is NP-complete so there are practical limits to the size of what problems may be solved. The model solves a decision problem at the operational level and is as such also a prototype of a decisions support tool. However, our aim has been to identify components with "network qualities" and links necessary to take advantage of these qualities, and therefore, for this analysis, the strict limits to model size for solver time is not as pressing.

Example

In this section we provide an example to better illustrate the workings of the model.

Setting

There has been a small, semi-successful, terrorist attack against an oil refinery. Further, there are clear indications that follow up attacks may occur in an attempt to seriously harm the local oil production. However, by what means and where these follow up attacks may occur are troubled with some uncertainty. The exposed sites are considered to be oil platforms, tankers, pipelines, and refineries. Personnel at these sites are put on alert, but more powerful means may be necessary in case of a larger or well-coordinated attack. For such attempts, the use of military components may be necessary to prevent the attacks. However, there are not enough military resources available to assign the necessary means to every possible site. Therefore, flexible plans must be made to assign the forces where they best contribute to the current tasks, but where they also can respond when new information is made available and the adversaries' plans are gradually uncovered.

The exposed sites are within five *areas* as shown in Figure 4. There are three areas of *sea* and two *ground* areas. Reacting to the adversaries' plans or actions is associated with tasks to be solved within these areas.

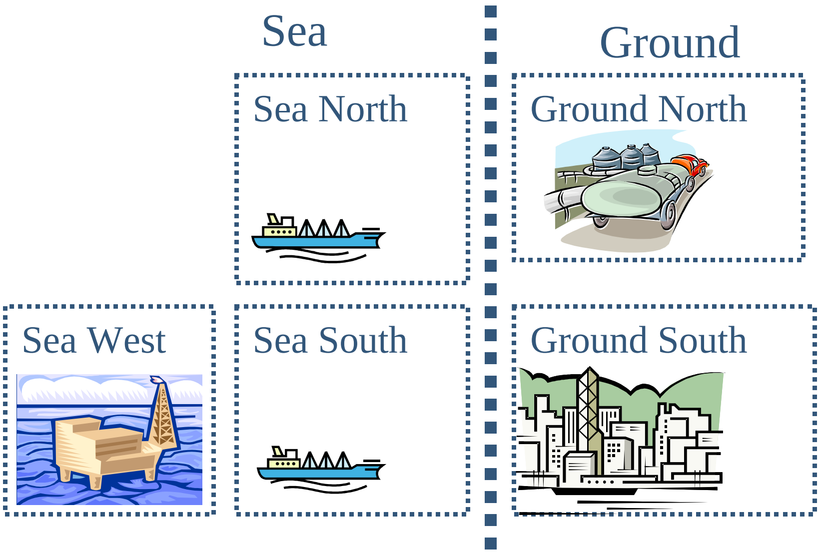
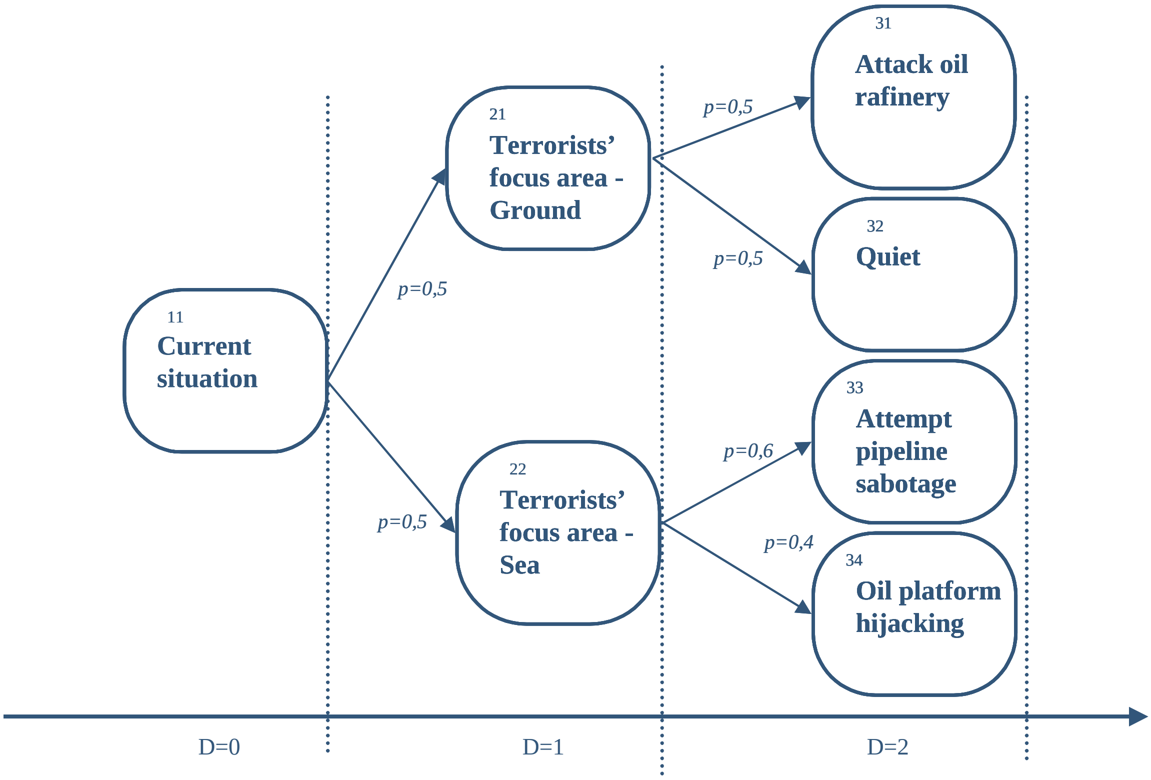


Figure 4, Example: Areas.

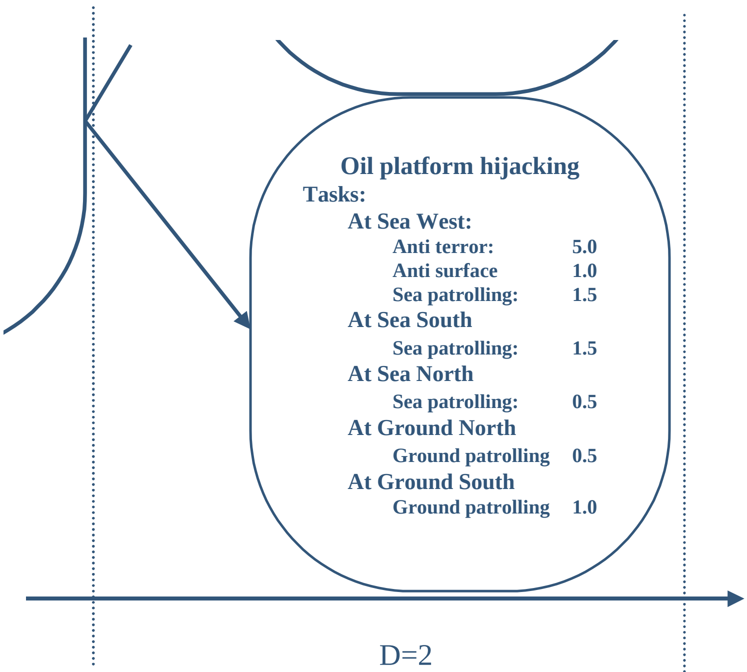
Task tree

Our understanding of the adversaries' actions and what situations we will need to respond to are illustrated inn a high-level task tree. Such a high-level task tree is shown in Fi gure 5.



Fi gure 5, Example: High level task tree.

Fi gure 5 shows a high level tree with a brief description of each state (node in the tree). Next we need to describe the tasks which will need to be solved at the various states. In F igure 6 we have detailed the "Oil platform hijacking" state, Node 34, from the high-level task tree.



F igure 6, Example: Detailed node in the task tree.

In this particular node, if we end up in this state, at each area there are tasks that will need a response. Each task has a parameter describing its scope. Each type of service will have its own unit of measurement. Furthermore, but not included in the figure, tasks may be assigned a priority as a penalty that cumulate if a task is not completed.

Platforms and components, services

There are four platforms available in this example: *a frigate, a coast guard vessel, a home guard unit* and *a special operations unit*. These platforms have each a set of associated components. Further, their components are capable of delivering various services. Delivering a service will help another component deliver its services or contribute in completing a task. Figure 7 summarizes resources available in the example; *the platforms*, the associated *components* and the *services* they are capable of delivering.

Platform	Components	Services
Frigate	Helicopter	Effect ground Patrolling ground Patrolling sea
	Cannon	Anti-surface
	Frigate itself	Patrolling sea
Home Guard Unit	Unit itself	Effect ground Patrolling ground
Coast Guard Vessel	Helicopter	Effect ground Patrolling ground Patrolling sea
	Cannon	Anti surface Effect ground
	Vessel itself	Patrolling sea
Special Operations Unit	Unit itself	Anti-terror Anti-surface Effect ground Patrolling ground

Figure 7, Example: Platforms, associated components and the services they are capable to deliver

The solution

The solution of the model consists of conditional decisions. The decisions can be illustrated in a decisions tree. The nodes in the decisions tree correspond to the nodes or states in the task tree. Figure 8 shows a partly completed decision tree.

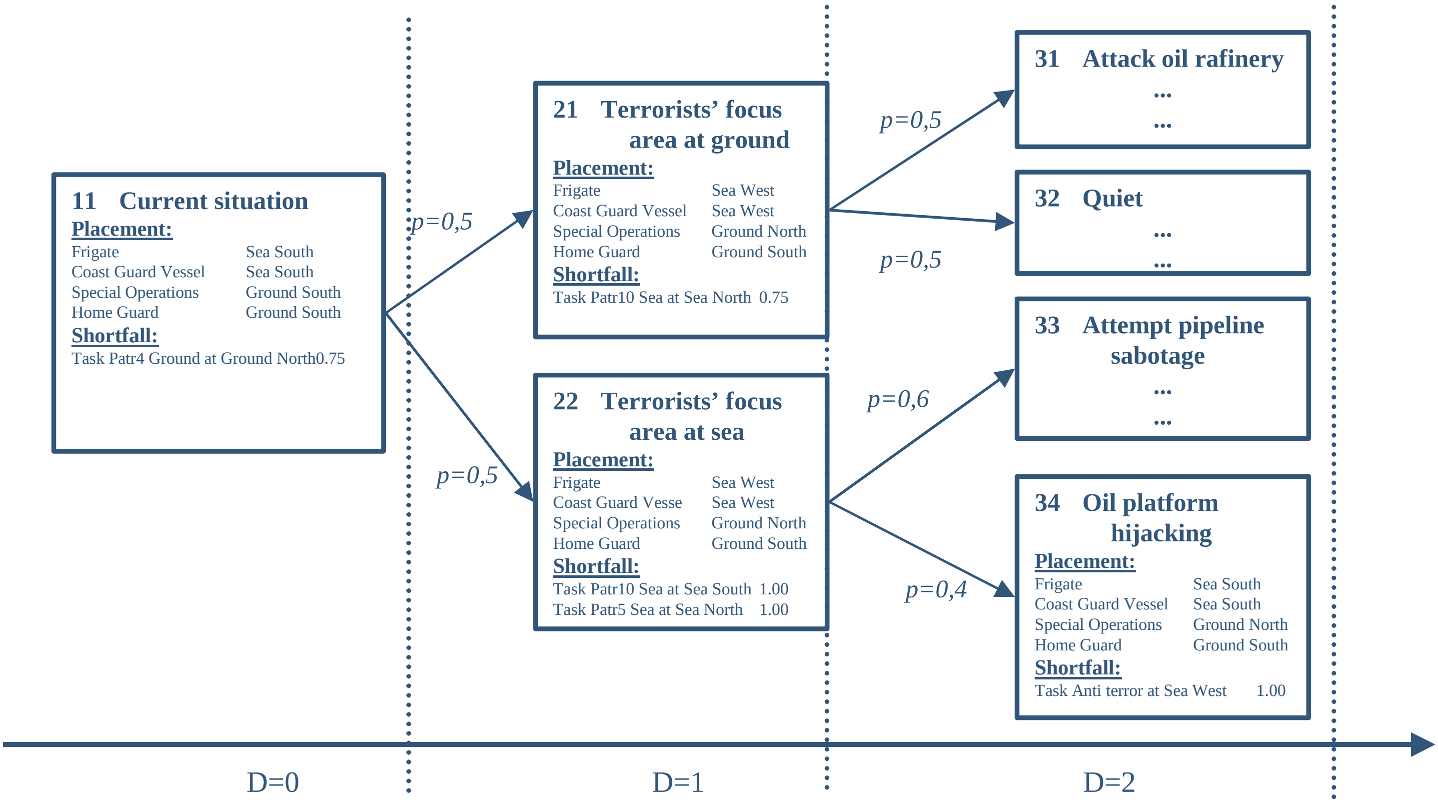


Figure 8, Example: Solution, partly completed decision tree

Cooperation and Coordination

Finally, we have reached the results we are looking for: *advantageous new links*. Derived from the optimal solution, we consider cooperation at four different levels. These four levels are:

1. Platforms placed in the same area at the same time.
2. Components delivering services in the same area at the same time.
3. Components delivering services to the same task at the same time.
4. Components delivering the same service to the same task at the same time.

We will assume that entities that cooperate also will need to coordinate. Therefore, if platform or components cooperate, a total link (all three layers) between the involved entities is necessary.

From the optimal solution we may list all occurrences of cooperation at the four levels mentioned. We examine these lists and consider if these links are sufficiently implemented today. In that way we may identify possible new links or links that may need improvements, since these links already have been proven valuable in the model. Figure 9 shows an extract of these lists derived from the model. In this small example the cannons on both the frigate and the coast guard vessel is needed to solve the given task. Hence, we may advise to investigate further how coordinated use of the two cannons may be implemented.

Components delivering to same task:

....

In Node: 22, Task: PatrAS52
Cannon76 (37) delivers 0.3 Asu til PatrAS52_in_Sea West
Vessel itself (38) delivers 5 VP_S til PatrAS52_in_Sea West
Cannon57 (43) delivers 1.7 Asu til PatrAS52_in_Sea West

....

Components delivering same service to same task:

....

In Node: 22, Task: PatrAS52, Service Asu
Cannon76 (37) delivers 0.3 Asu to PatrAS52_in_Sea West
Cannon57 (43) delivers 1.7 Asu to PatrAS52_in_Sea West

....

Figure 9, Example: Cooperation between platforms and between components

We may also remove the possibility for a link in the model by not allowing cooperation to occur between to entities. A value of that particular link is then indicated as change in the objective. Such values may be compared to the difficulty and costs of implementing or improving on that particular link.

Summary

Network-organized are hypothesized to give better efficiency and robustness through more efficient utilization of resources, less idle time and increased flexibility. In the long-term perspective one may expect all military components to be part of a networked unity, but until then, in the short term, one may gain from improving on the fragmented networks of today.

We have developed a model to help identify components that hold qualities that make them especially useful in a networked context. The model helps us to identify the components and the links necessary to take advantage of the network qualities of such components.

The model solves a high-level decision problem at the operational level. It incorporates two aspects that are most important when considering network-organized forces. The first is a concept of *consumers* and *service providers*. The second is the treatment of uncertainty in order to handle the aspects of flexibility and robustness.

The model is a stochastic program, implemented as a multi-stage mixed-integer program. With the current formulation of the problem we face practical limitations to the size of the problem to be solved. Still, since our aim has been to identify unusual, but useful combinations of collaboration between components, the strict limits to model size for solver time is not as pressing.

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