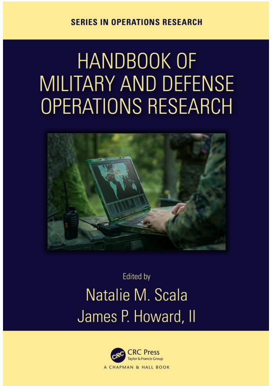

Handbook of Military and Defense Operations Research

Natalie M. Scala, James P. Howard

From BOGSAT to TurboTeam: Collaboration for National Security Teams in the Age of Analytics

Publication details
https://test.routledgehandbooks.com/doi/10.1201/9780429467219-13
F. Freeman Marvin
Published online on: 02 Mar 2020

Chapter 13

From BOGSAT to TurboTeam: Collaboration for National Security Teams in the Age of Analytics

F. Freeman Marvin

13.1 From BOGSAT to TurboTeam: Analytic Collaboration Comes of Age

The late Senator John McCain did not like meetings. He thought most meetings were unfocused, led to unnecessary argument instead of healthy debate, and usually failed to resolve the issues that were the reason for the meeting in the first place (Kostman, 2018). Many analysts in the national security community have had the same experiences in team meetings.

The key to better teamwork is better team meetings, and the key to better team meetings is a process facilitator or a team leader with the skills of a facilitator (Schwarz, 1994). The role of a facilitator is to ensure that the meeting has clear objectives and an agenda, and to keep the discussion on track, manage conflicts, and record action items. The goal is to prevent a BOGSAT – Bunch of Guys/Gals Sitting Around a Table. As Senator McCain observed, meetings often end with little to show for the time and money invested. Teams supported by a process facilitator stand a much better chance of achieving meaningful results. The facilitator focuses on the meeting process, so team members are able to focus on the issue or problem at hand.

However, in the past decade, traditional process facilitators have reached the limit of their ability to improve collaboration in team meetings. One reason is that the role of meetings in organizations has evolved from being mostly about information exchange and discussion to a focus on information analysis and decision-making. The current flat structure and fast pace in many organizations also require process facilitators who can take a leadership role during team meetings. Access to more data and information, new analytic software tools, and remote conferencing technology are clearly challenging the traditional "soft" skills of facilitators.

Today, teams working in national security organizations are more likely to be cross-functional, multi-disciplinary, and inter-agency than ever before. Collaborative teams work on increasingly complex issues that require problems to be identified, data organized and analyzed, decisions implemented, and results evaluated without a lot of wasted time. Meetings are now the place where issues are resolved – not simply debated, where consensus is built – not just put off to the next meeting, and where commitment to action by all participants is critical to success.

In 2005, two experienced national intelligence analysts, Dick Heuer and Randy Pherson, assembled a set of thinking aids they called Structured Analytic Techniques (SATs) to improve the problem-solving and decision-making of facilitated teams (Heuer and Pherson, 2008). SATs are mostly whiteboard exercises that help teams frame problems, brainstorm ideas, and mitigate cognitive biases. Heuer and Pherson developed a few new, innovative SATs, such as Analysis of Competing Hypotheses, or ACH (Heuer, 1999), but most of their SATs had been around for a while and had already been adopted by many national security teams. For example, SATs to organize information and frame problems included Affinity Diagrams and Mind Maps. Techniques to encourage contrarian thinking included Devil's Advocate and Red Hat analysis, and techniques for analysis, diagnosis, and prediction included Scenario Analysis, Role Playing, and SWOT. These techniques are notable in that they do not require computers to implement, and, in fact, most do not involve any calculations.

However, when national security teams are faced with complex problems or tough decisions to make during a meeting, they may be unable to reach a resolution using SATs alone. Recent experiences with a range of national security and public safety teams have shown that there are new ways to combine process facilitation, analytic techniques, and computer software tools right in the meeting room to improve the quality of team collaboration and to do it in near real-time.

Analytic Collaboration involves building on the foundation of process facilitation skills and structured analytic techniques with Simple Analytic Models (SAMs). SAMs are computer models that can be constructed right in the team meeting room when the complexity of a problem exceeds the ability of team members to keep track of all the moving parts in their heads or with a whiteboard SAT (Vennix, 1996). SAMs allow a team to change variables, test possible relationships, and predict outcomes. SAMs

TABLE 13.1: Simple Analytic Models

Task	Simple Analytic Models
Deciding among alternatives	Value Trees
Deciding among courses of action	Strategy Trees
Diagnosing the chances of a failure	Fault Trees
Diagnosing the causes of a failure	Bayesian Networks
Designing a process	Queueing Networks
Designing a portfolio	Portfolio Models

are transparent and can be explained by the team members themselves because they helped to create them. SAMs also help to communicate results to senior leadership and other stakeholders. SAMs provide a collaboration bridge to move teams from intuition to analysis and from debate to action.

Facilitators and team leaders acting as facilitators need to know how to use analytic collaboration tools to turn SATs – diagrams, charts, and matrices – into SAMs. This means that facilitators need to learn some basic modeling skills and some computer software tools, but they do not need to learn how to code. Most SAMs can be built in an Excel spreadsheet or inexpensive propriety software.

This chapter describes how six national security and public safety teams used Analytic Collaboration and SAMs to move from BOGSAT to TurboTeam (Reagan-Cirincione, 1994). The examples span three common team tasks: Deciding, Diagnosing, and Designing. The table above summarizes these examples.

The hope is that this chapter gets your mental wheels turning, prompts you to learn more about Analytic Collaboration, and leads you to discover new ways to improve your own organization's performance. As one team leader exclaimed, "Analytic collaboration enables collective action!"

13.2 Deciding

One common challenge faced by national security teams is choosing among alternatives or different courses of action. Making a decision among alternatives, such as the best weapon system to buy or where to build a facility, could involve assessing and weighing many competing factors. Choices among different courses of action may involve two or more decisions, where the structure, sequence, and timing of the decisions are important to determining the best strategy and where significant uncertainty exists. Teams facing choices of both types can improve their chances of success by moving beyond SATs to SAMs.

13.2.1 From Pros and Cons to Value Trees

The US Food and Drug Administration (FDA) evaluates and approves medical treatment devices as part of its mission to protect the health and safety of the public. The FDA approval process had come under scrutiny after problems with several approved medical devices were reported in the media. A study by the National Academy of Sciences found that, "approvals of devices were inconsistent, [and there was] a perceived lack of transparency in decision making" (Wizemann, 2010).

The FDA decided to develop a new approval process – one that took the uniqueness of each device into account, but was flexible and transparent. The agency chose a class of therapeutic devices that treat mental depression as a test case. A team of clinical psychiatrists and regulatory specialists was formed to recommend a new evaluation and approval process. The team leader wondered how they would be able to find an alternative to the traditional approval process that could optimally protect patients and still promote innovation in support of public health. Just as importantly, she wondered how to provide an easily understood and defensible rationale for each approval decision to convey to the companies submitting devices for approval and the medical and patient advocacy groups.

13.2.1.1 Ben Franklin Weighs the Pros and Cons

The FDA looked at using a variation of a structured technique used by decision makers for over 200 years.

> *In 1772, Benjamin Franklin offered a method of pros and cons to his friend and fellow scientist, Joseph Priestly, to help him made a tough career choice. Franklin wrote, 'I cannot for want of sufficient Premises, advise you what to determine, but if you please, I will tell you how. Divide half a Sheet of Paper by a Line into two Columns, writing over the one Pro, and over the other Con. Then during three or four Days Consideration, put down under the different Heads short Hints of the different Motives that at different Times occur to you for or against the Measure. When you have thus got them all together in one View, endeavour to estimate their respective Weights; and where you find two, one on each side, that seem equal, strike them both out: If you find a Reason pro equal to some two Reasons con, strike out the three. If you judge some two Reasons con equal to some three Reasons pro, strike out the five; and thus proceeding you will find at length where the Ballance lies. And tho' the Weight of Reasons cannot be taken with the Precision of Algebraic Quantities, yet when each is thus considered separately and comparatively, and the whole lies before you, I think I can judge better, and am less likely to make a rash Step; and in fact I have found great Advantage from this kind of Equation, in what may be called Moral or Prudential Algebra. Yours most affectionately, B. Franklin'*
>
> (Jones, 1995).

The approach considered by the FDA team resembled Franklin's technique – a type of Pro/Con checklist to answer the question, "Should the FDA approve medical device A to treat disease X?" For example, a pro might be that device A addresses a severe form of disease X that, if left untreated, could cause death. A con might be that device A is only intended to treat the most mildly affected patients.

Using the Pro/Con checklist, an evaluator assigns one or more pluses or minuses to each pro and con (Quinlivan-Hall & Renner, 1990). Evaluators then add up the pluses and minuses. One plus cancels out a minus. If the evaluator considers the plus very important, a plus might cancel out two minuses. If the evaluator is cautious, it might take two pluses to cancel out a minus. Each factor can also be weighted, and the pluses and minuses multiplied by the factor weights. Although efficient and flexible, it was unlikely this technique could produce a defensible approval process for the FDA.

13.2.1.2 Planting a Value Tree

The FDA team moved beyond its initial approach by using a simple analytic model called a value tree, which is based on multiple objective decision analysis (MODA). MODA models allow a team to include additional considerations, or criteria, beyond the attributes of current alternatives, when making choices. Some of the criteria may conflict with each other, such as quality vs. cost, setting up a tradeoff. Criteria may also include features that do not show up in any of the current options, leading to a search for better alternatives. To build a value tree, the FDA team extended the Pro/Con checklist in three ways.

First, the team reframed its problem from how to approve a particular medical device to how to define the goals and objectives of the FDA that would apply to any device. This approach to making choices is called Value Focused Thinking (VFT) (Keeney, 1992). Instead of beginning with specific alternatives, the team reversed the decision process by first developing a list of the goals and objectives that were important to the FDA using the Nominal Group Technique (NGT), a useful facilitation technique that lets each team member contribute equally to the discussion (Bens, 1997).

The team organized the criteria using a SAT, an Affinity Diagram, and turned the list into a SAM, a value tree. In a value tree, the objectives flow from the top down, creating a taxonomy of criteria and sub-criteria. The team first thought about all the criteria that should be in any new device. For example, a pro such as "the device should address severe forms of the disease that, if left untreated, could cause death," was called "Severity of Disease." A con such as, "the device does not work on severely depressed patients," was called "Patient Population."

Next, the FDA team clarified what distinguished a good medical device from a poor one by creating a measurement scale for each criterion. The measurement scale, or value function, shows how each additional increment of "goodness" for a criterion provides slightly less marginal value, or diminishing returns to scale. The team defined end points at the top and bottom of each scale to show the best and worst possible levels.

Finally, the FDA team assessed the relative priority of each criterion, accounting for both the importance of the factor and the range, or swing weight, from the bottom to the top of its measurement scale. Swing weights account for both the range variation in the measurement scale and the relative importance of the criterion. A common mistake in value tree models is to only capture the importance of the criterion and ignore the significance of the range variation (Hammond, Keeney & Raiffa, 1999).

The FDA team used a simple elicitation technique called "Allocate one hundred coins" for weighting the value tree. For example, the criterion Safety was very important, but the scale on Safety only ranged from Safe to Very Safe. Since the difference between the top and bottom of the scale was not significant, Safety received a relatively low swing weight and therefore would not have much impact on the final approval. All devices had to be safe to be considered for approval. Value trees can easily be built in Microsoft Excel (Kirkwood, 1997). There are also many affordable value tree packages such as Logical Decisions for Windows (n.d., Retrieved from https://www.logicaldecisions.com).

By adding up the weighted scores on the criteria, any medical device for treating depression could be rated using the team's value tree. Competing medical devices are assessed against the same standards. Since the evaluation criteria are carefully defined and documented, there is maximum transparency. Using value trees, the FDA team produced an approval process that could be defended to senior leadership, other stakeholders, and to the public.

13.2.2 From Roadmaps to Strategy Trees

The Tech Base Program (TBP) team at the Army's Chemical and Biological Defense Command (CBDCOM) located at Edgewood Arsenal, Maryland, was responsible for creating a strategy for funding research and development to improve the military's defense against chemical and biological weapons. Since the Army was the executive agent for acquiring all chemical and biological defense equipment for the Department of Defense, the TBP team's work had a large impact on future US defensive capabilities.

Each year, CBDCOM published a set of requirements and requested proposals for new technologies that could meet future needs. These proposals were binned into four business areas: detection, individual protection, collective protection, and decontamination. After proposals were selected one at a time for funding, a technology roadmap would be developed for each business area. The purpose of a technology roadmap was to provide an overall strategy for the projects within a business area, facilitating a more comprehensive and integrated investment program.

13.2.2.1 Highway to the Danger Zone

The team began with a literal interpretation of a roadmap – a line for each project with a start date and an end date. Roadmaps were based on a timeline, in a Gantt chart format, which did not account for any uncertainties in the projects. This meant that a technology roadmap could easily lead down the wrong path if conditions changed or some projects failed.

There were a number of other concerning issues with the approach: stakeholders' perception of a closed process, no consensus on the allocation of resources, and no way to compare the risks associated with each project. The program also faced dwindling dollars and constraints imposed by Joint Service regulations. The technology projects were found to have significant duplication and gaps. In addition, there were concerns about integrating among different business areas. Was there a better way to develop technology roadmaps?

13.2.2.2 Swinging from the Strategy Trees

The TBP team decided to take a new approach that could help create better strategies in an uncertain environment. For each business area, the team built a value tree from a set of strategic goals and objectives defined by senior leadership. It then replaced the Gantt chart scheduling technique with a strategy tree. A strategy tree is a simple analytic model that links the series of decisions that must be made, and the structure, sequence, and timing of each decision to show the potential consequences. Strategy trees have been used for many years in business to explore the expected return on business investments. This SAM is sometimes called a "multi-stage decision model under conditions of uncertainty" or a decision tree (Clemen, 1996). A strategy tree combines the organization's goals and objectives, uncertain events and conditions that may change, and the decisions the organization can make into a SAM to test alternative strategies. The TBP team took the strategy tree technique and added the ability to calculate the uncertainty in each proposed R&D effort to assess the probability of an overall successful outcome. The set of R&D projects taken together provided a realistic picture of TBP investments.

A technology roadmap using strategy trees is a flexible planning model to support strategic and long-range planning, by matching short-term and long-term goals to specific technology solutions. It is an approach that applies to a new product or process and may include using technology forecasting or technology scouting to identify suitable emerging technologies. It is a good way to help manage the risky front-end of innovation efforts. It can also help a program survive in turbulent budget environments by showing viable, but cheaper, paths to success. The team used one of the excellent software tools for making strategy trees called DPL from Syncopation (n.d., retrieved from https://www.syncopation.com).

The SAM used by the TBP team provided three critical advantages. First, the team was able to use the flexibility of the strategy tree to mirror the familiar roadmap structure – the list of decisions that must be made, the options the team has (decision nodes), the things that are uncertain (nature nodes or chance nodes), and the things the team is trying to achieve (value or utility nodes). A value tree shows the relative value of each endpoint or path outcome in the roadmap using a common set of goals and objectives.

Second, the team constructed better options for the sequence of projects. A decision is defined as an "irrevocable commitment of resources." The team identified the key decision points on the roadmap and then was able to make new strategies by simply rearranging the sequence of the decisions and assessing the new outcomes.

Finally, the team could adjust the timing of the funding decisions. The separation in time between decisions can have a big impact on the value of the outcome. The TBP team was able to slide the decision points, future events, and the path outcomes back and forth, left and right on the timeline to evaluate the impact of the timing of program decisions.

13.3 Diagnosing

A second area of team problem-solving and decision-making involves predicting the likelihood of different causes and effects in a system. Diagnostics are important in many organizations, from medical teams to maintenance crews. A team uses inferential reasoning when it confronts a problem or a symptom and is tasked to diagnose the potential causes. A team uses deductive reasoning when it begins with a given cause – a disease or component failure – and must predict the potential effects. Diagnostic SAMs can help a team do both types of reasoning.

13.3.1 From Fishbones to Fault Trees

Commercial aviation safety, both in the air and on the ground, is of critical importance to the economy. The Federal Aviation Administration (FAA) had identified a number of potential accident sequences it wished to evaluate. These accident sequences included problems during take-off such as aircraft system failures and air traffic control (ATC) issues, and emergency events such as fire onboard an aircraft, flight crew member incapacitation, and ice accretion on an aircraft in flight (Dillon-Merrill, 2015). A team of experienced air traffic controllers and aviation safety experts was formed to evaluate the likelihood of various accident sequences in order to develop preventive and mitigation measures.

13.3.1.1 Choking on Fishbones

The team began with 30 Event Sequence Diagrams (ESD) describing the sequence of events from an undesirable initiating event (cause) to its possible outcomes (effects).

This can be thought of as a deductive thinking approach. For example, a bird strike could cause an aircraft engine to fail, shatter control surfaces, or cause no damage at all. The FAA team needed a way to evaluate the reverse question: what are all the ways that an engine could fail, a bird strike being just one way?

The team first looked at using root cause analysis (RCA). RCA is a technique of problem-solving used to identify the root causes of faults or problems – an "effect-to-cause" approach (Bens, 1997). A factor is considered a "root cause" if removal from the problem-fault-sequence prevents the final undesirable outcome from recurring, whereas a "causal factor" is one that affects an event's outcome, but is not a root cause.

Of course, a problem such as an engine failure could have many possible root causes. In RCA, each potential causal factor is traced back to find the root cause, often using a SAT called a Fishbone Diagram, or Ishikawa Diagram. Fishbone Diagrams allow the team to work backward from an "end event" to find the "root causes" of a problem. The usual way that a team works is to ask the "Five Whys" (Bens, 1997). The goal of the technique is to determine the root cause of a defect or problem by repeating the question: why? Each answer forms the basis of the next causal factor. The possible causes are grouped into categories on the main branches off the spine of the Fishbone Diagram. There is an implicit timeline on the Fishbone, where causal factors to the left must occur or be in place before causal factors to the right.

The FAA team ran up against the major problem with Fishbone Diagrams – how to determine which of the potential root causes were enough to cause an event by itself or which could do so only in combination with other causal factors.

13.3.1.2 Finding Fault Trees

The FAA team moved beyond Fishbone Diagrams and developed fault trees for each end event in the ESDs. A fault tree uses logic gates to identify the various combinations of failures, or fault events, unexpected errors, and normal events involved in causing a specified undesired event to occur. A fault tree works from effect-to-cause. For example, an engine failure could be caused by a bird strike, a fuel blockage, or a mechanical defect. The fault tree is a SAM that can compute failure probabilities and the relative importance of system components.

In a fault tree, the undesired outcome is taken as the top event. For example, the undesired outcome of an aircraft operation is an engine failure. Working backward from this top event, the team might determine there are two ways this could happen: a bird strike or a maintenance problem. Here the team would place a gate. The gates in a fault tree work in different ways. In an OR gate, the output event occurs if any of the input events occur. In an AND gate, the output occurs only if all inputs occur (assuming inputs are independent). There are several other types of gates with more specific purposes. The team might identify a design improvement by requiring a backup system in case of bird strikes – this is a safety feature that would change the gate to a logical AND. When fault trees are assigned event probabilities, the SAM can calculate overall failure probabilities. The FAA team also found that some common causes can introduce dependency relationships between events in the ESDs, which would have been difficult to see in a Fishbone SAT.

Fault trees provided three important advantages for the team. First, the FAA team was able to use fault trees to re-organize the ESDs into a more logical hierarchical structure. As the team transferred the causal factors to the fault trees, the team identified the critical AND/OR relationships at each branch.

Second, the team was able to assess the relative probabilities at each branch. The team ensured that the probabilities of OR branches added to one and AND relationships were mutually exclusive. If two AND causes depended on each other, the team combined them into a single causal factor. The fault tree calculated the overall probability of each end event for comparison with other events to see where cost-effective preventive and mitigation measures should be taken.

Third, the team was able to use fault trees to identify the minimal cut sets. Cut sets are all the combination of events that could cause the system to fail. A minimal cut set is a cut set, such that if any event is removed from it, the top event will not necessarily occur, even if all remaining events in the cut set occur. Sorting a cut set by cost allows the team to focus on the "cheapest" failure points; that is, the points of failure that would be most likely to naturally fail or that a potential adversary could most easily attack. The team used a software tool called DPL Fault Tree (Syncopation, 2004) that provides a step-by-step template for building the fault tree and finding the minimum cut sets.

Using the rigorous and structured methodology of fault tree SAMs allowed the FAA team to model the various combinations of fault events that could cause system failures to occur and the relative likelihood of each.

13.3.2 From Causal Diagrams to Bayesian Networks

The Army Communications and Electronics Command (CECOM) had a deadly problem. Army troops fighting in Afghanistan and Iraq had to set up small, forward operating bases in remote locations, often in rugged, mountainous terrain. Their only source of electric power at these bases was from the diesel-fueled generators they hauled with them. But when a generator broke down, the soldiers had to radio for a generator mechanic to fly by helicopter out to the forward base, diagnose the problem and then fly back, a dangerous and costly round trip. Was there a way that an average soldier in the field could perform the diagnostic procedure on a faulty generator?

The Army formed a team of generator mechanics and logistics experts to find a solution to this problem – the Virtual Logistics Assistance Representative (VLAR) team. The VLAR team needed to gather and codify expert knowledge about diesel generator operations and apply that knowledge to troubleshooting the equipment in remote combat zones (Aebischer, 2016).

13.3.2.1 Colliders and Confounders

The primary technique for aiding soldier mechanics who are troubleshooting problems in the field has been the technical manual. These can include simple schematics, such as wiring diagrams, or very comprehensive if-then logic diagrams. For example, if the engine runs erratic, then the fuel could be dirty, and if there is dirty fuel, then there could be water in the fuel filter. However, for complex mechanical equipment, the number of possible combinations of potential causes and failures modes becomes unmanageable with a rule-based diagnostic approach.

Other diagnostic techniques, such as ACH, take advantage of probabilistic inference. The effects of a problem, or observable symptoms, are compared with hypotheses of possible causes to infer the most likely cause. But these SATs have no way to handle two common types of cause-effect situations: colliders and confounders. A collider is a factor which can be caused by two or more other factors, but which can impact those factors “in reverse.” In other words, colliders have a common effect on their causal factors. For example, an engine could be caused to run erratically by dirty fuel or by a leaky fuel line. If the soldier knows the fuel is dirty, that fact has no impact on the probability that the line is leaking. However, if the soldier knows from observation that the engine is running erratically, then finding out that the fuel line is OK will increase the probability that the fuel is dirty. This is called explaining away and makes diagnosis by causal diagram complicated.

A confounder is an unknown factor that lurks in the background in a complex causal system and may impact other factors without being explicitly accounted for. For example, a technical manual’s causal diagram may not mention that the altitude at which the generator is being used has an impact on its performance. Confounders are found in many situations and can make correct diagnosis of problems nearly impossible by untrained soldiers without a simple-to-use tool that could be built into an automated onboard system.

13.3.2.2 Diagnosis with Bayesian Networks

Adopting a Bayesian network model helped the team move beyond the limitations of causal diagrams and other structured techniques. Bayesian networks are SAMs based on Bayes’ Rule that show how effects are inferred to be caused by various conditions or events, and how a fix, or an intervention, will impact the problem (Fenton, 2012). Judea Pearl, professor at UCLA, created the first practical Bayesian network algorithms in the 1980s, and since then they have become easy to apply to a wide range of problems. A Bayesian network looks very much like a causal diagram with nodes connected by arcs to indicate the causal direction.

Bayesian networks provided the VLAR team with three critical advantages. First, the team built the structure of the problem in a format that was familiar to subject matter experts to help them make their assessments. A Bayesian network looks like a causal diagram that establishes the visual framework – a structure – within which to analyze a cause-and-effect system.

Next, the team built a Conditional Probability Table (CPT) for each node in the model. A CPT shows the conditional probabilities of the cause-effect relationship. A true positive is the probability that the presence of a certain factor causes the effect. A true negative is the probability that the effect will not happen in the absence of the factor.

The VLAR team used a new facilitated approach to build the Bayesian network called the DSEV process (Tatman et al., 2015). DSEV stands for define, structure, elicit, and verify. The team carefully defined all the terms in the problem. This prevented confusion about what the team was actually assessing. The initial structure of the model was built in small sections of cause and effect nodes. Before moving on to the next section, the facilitator elicited from the team the confusion matrix for each node. The section of the model was exercised and verified that it behaved the way the team intended it to act. Finally, the team used the Bayesian network to identify the “colliders and confounders” in the generator system. This involves exercising the model over a variety of fault conditions.

Through 2015, the VLAR team saved the Army millions of dollars in direct labor costs and prevented many casualties by reducing requirements for helicopter and ground-convoy movements. The VLAR team used BayesiaLab by Bayesia (Bayesia.com) to create the Bayesian networks. Another tool suitable for smaller organizations is Netica by Norsys (Norsys.com).

Based on the success of the VLAR team, the Army decided to expand the use of the DSEV process and Bayesian network SAMs to build diagnostic tools for all CECOM field equipment (CECOM, 2016).

13.4 Designing

Teams today not only have to make tough choices and evaluate uncertain situations, they may have to design a new system, process, or program. Design teams can improve their designs by using various SATs, but TurboTeams take design thinking to the next level by creating and testing a prototype. A prototype helps gather feedback on the performance of a design in a risk-free environment. Prototypes speed up the process of innovation because they allow a team to understand the strengths and weaknesses of new ideas by "failing many times, quickly and cheaply, in order to reach success." The following sections describe two TurboTeams who used SAMs to improve their designs.

13.4.1 From Flowcharts to Queueing Networks

Three years before the terrorist attacks on 9/11, the US Congress funded the National Domestic Preparedness Program in anticipation of rising international terrorism. The most visible portion of the program was the training and equipping of emergency medical personnel in 120 cities across the country to respond to an attack by terrorists using biological or chemical weapons. The program manager needed to develop common emergency response templates so that when a city was attacked, medical responders from other cities could quickly move in to assist.

One of the proposed response templates was for a Neighborhood Emergency Help Center (NEHC) which could be set up in a school or other local building to provide emergency medical triage for people who thought they might be infected following a biological attack. An NEHC design team was formed with emergency managers, epidemiologists, physicians, nurses, and first responders from five different cities.

13.4.1.1 When Flows Back Up

The NEHC design team began by creating a process flowchart. A flowchart is a logic diagram, often used in software programming that shows the various paths that an item can take based on decisions made at each step in the process. The NEHC flowchart was a map of how people would arrive at the facility, get routed to different stations where they would be processed, and either sent home with medication, held for observation, or immediately rushed to an acute care center.

The flowchart represented the steps as blocks connected with arrows. However, it soon became apparent that team members had several different concepts for how patients should be routed. One process would move people quickly through the facility with minimal treatment in order to handle a large volume of patients. Another option focused on taking lifesaving actions that might prevent more deaths, but risked being overwhelmed by the large number of people expected to seek help.

The team modified the flowchart several times to try to visualize each option. But the team had no way to compare which one was better, or even to assess whether any of the designs would work at all. It was hard to know if people would trickle in throughout the day or descend on the facility all at once. The various kinds of biological agents also had very different effects on people. Some agents produced a massive number of fatalities quickly, while others created large populations of sick people who needed medical attention over a period of time in order to survive. Some data existed on how long it takes to triage and treat patients in hospital emergency rooms during flu season, but for treating most biological agents, the NEHC team would have to take a guess. Most importantly, if the number of medical personnel assigned to operate one NEHC was too big, fewer NEHC facilities could be set up during a crisis while some doctors and nurses might be underutilized. If the staff was too small, patients might be waiting in long lines for medical attention. Which approach was best?

Flowchart SATs are an excellent way to help a team begin to think through alternative designs of a system. Sometimes a flowchart can be used to show the flows of a continuous quantity, like water flowing from a faucet into a bathtub (stock and flow). A flowchart can also try to show the movement of discrete items, such as people shopping in a grocery store and waiting in line at the checkout counter. But a flowchart is only a static representation of the structure of a system and is not able to show what happens when the bathtub starts to overflow or when the checkout line extends out the door and down the street.

13.4.1.2 Jumping into Test Beds

The NEHC team chose a simple analytic model called a queueing network (Cochran, 2019) that would help it explore and validate the alternative designs. Using a laptop with the model projected onto a projection screen in the meeting room, the team was able to drag and drop icons representing various work stations onto a blank canvas and connect them with arrows, replicating each alternative design concept. The team used the available data and expert judgment to assign probability distributions to the icons to define parameters like patient arrivals, service times, number of triage and treatment stations, and other quantitative data. When the team ran its first model, they were astounded by what they saw – a long line of sick people and worried well people extended out the door and down the street!

After several adjustments, patients were flowing smoothly through the facility, but an unrealistically large number of stations and medical staff was needed. Perhaps a different treatment protocol was needed. With the SAM, the team could continue to make changes to the design, in real time, collaborating on new ideas, and testing out their ideas quickly.

A simple analytic queueing network provided four critical advantages over a flowchart. First, the waiting lines the team saw when the initial model ran are not seen in a flowchart. How long could these queues grow before people turned around and left, or worse still, start to die? If the team set up fewer NEHCs in the city and added more staff to each facility to handle peak patient loads, would the staff be underutilized during low demand hours? In addition, when people see a queue, they tend to exhibit certain behaviors. People may decide not to stand in the line at all (balk), to stand for a while, but leave and come back later or not at all (renege), or if there are several lines, to switch from line to line to stay in the shortest (jockey). All these behaviors can greatly impact the number of doctors and other resources needed.

Second, a SAM allows the use of probability distributions to represent the uncertainty in a process, such as patent arrivals. In a flowchart, it is possible to assess *throughput* capability for a station by comparing the average input rate to the output rate. For example, if the team expected an average of ten incoming patients per hour, and the station took no longer than six minutes to triage each patient, it might reasonably assume that, on average, the center could throughput ten patients per hour. However, people do not usually arrive at a grocery store or an NEHC in regular intervals, but sometimes arrive in bunches, and sometimes no-one might come in for hours. Because of this uneven arrival distribution, only a SAM will show the queues that are likely to form.

Third, the queueing network showed the utilization of resources. In any system design, the team wants to acquire and operate just enough processing capacity to keep the flow flowing. A flowchart does not show how these servicing resources are utilized. How many stations should be open during different times of the day? With the SAM, the team could change the number of stations and see the impact on the length of the queue and the waiting times of patients. Not enough capacity, and things bog down. Too much capacity, and medical staff sits idle, wasting time and money.

Finally, the SAM shows how the system represented by the static flowchart will work under different scenarios or different biological agents. The team is able to hold its assumptions constant, while varying the parameters of interest and changing the process flow. This allows a consistent analysis of the problem, letting the team compare one design with another. The team can also perform sensitivity analysis, or a what-if analysis, to see the impact of changing assumptions. This is why a queueing network simulation SAM is a great test bed for a design team. The team used a discrete event simulation tool called ExtendSim (n.d., retrieved from https://www.extendsim.com). ExtendSim is one of several excellent desktop graphical simulation software packages, some with free versions for limited modeling.

The NEHC team was able to model the different design concepts in the meeting room with team members systematically testing each idea in near-real time. The simulations showed the team the impacts of each design on staffing requirements, casualty flows, and other key variables. This rapid, facilitated "build-test-build" approach takes advantage of the collaborative thinking of a multi-disciplinary team, making maximum use of their valuable and limited time, and allows them to "try before they buy" into a particular design concept. The models were then used to predict performance, to provide a baseline to compare with live test results, and to make a final recommendation for an NEHC template to the program manager.

13.4.2 From Knapsacks to Portfolios

Following the terrorist attacks on 9/11, Congress directed the Department of Health and Human Services (HHS) to buy and maintain a national stockpile of drugs and other medical countermeasures (MCM) that could be used to protect the country from a biological weapons attack by terrorists or a naturally occurring pandemic. HHS established the Strategic National Stockpile in 2005 and planned to upgrade and add to it in 2010 using a new program called *Project Bioshield*. An inter-agency Strategy and Implementation Plan Working Group (SIPWG) was formed to develop the acquisition strategy for *Project BioShield*. Deciding what drugs to buy to upgrade the stockpile proved to be a challenge. How had the biological threat evolved over time? What new drugs were under development that might be more effective than what was already in the stockpile? Would it be better to protect additional people with more of the older, cheaper, but less-effective drugs, or invest in more effective, but less available new drugs?

13.4.2.1 Hiking through the Desert

The SIPWG laid out a traditional strategic planning framework, with a mission statement, vision, goals, and objectives. Then the team leader created a matrix using an Excel spreadsheet. Across the top of the matrix, she made column headers for each expected biological threat such as anthrax, tularemia, and the plague, and a few chemical and radiological threats. Down the left side, she listed the current MCMs in the stockpile, such as vaccines, antitoxins, and antibiotics. Some MCMs could be used to address two or more threats, while a few MCMs were specific to one threat. In the cells of the matrix, she noted information about the amounts in the current stockpile, the effectiveness of the drugs for each threat, and the cost to buy more. The team printed this matrix out on a large wallchart and posted it in the SIPWG team room.

A general purpose SAT, such as a matrix, was a good place to start. It helped the team organize the available data and make connections among the different problem elements. The SIPWG members agreed that their mission was to "prioritize near, mid, and long-term goals for acquisition of medical counter-measures," but there was no consensus on a way forward. Someone suggested that they prioritize and sort the rows in the matrix – the list of current MCMs – from highest priority to lowest. Then they could simply go down the list, calculate the cost for adding more of each MCM, and propose to acquire MCMs in priority order until the BioShield funds ran out. In setting the priorities, another member suggested using a SAT called *Weighted Ranking* to assign a "risk" weight to each of the threats according to how likely and how severe they expected the threat to be. If some MCMs still had usable quantities in the stockpile, that amount could be subtracted from the quantity needed for new acquisition.

When weighted and sorted, the SIPWG noticed that by using this "cut line" approach, several of the more broadly applicable MCMs used up all the BioShield funds and left nothing to buy the many more "targeted" drugs needed to counter specific threats – some with significant risk weight. To counter this problem, another suggestion was made to simply buy a flat percentage of each MCM until the funds ran out, somewhere in the range of 30% of each requirement. This seemed like a fair and equitable allocation of the BioShield funds.

But neither of these methods accounted for potential new MCMs that were in development at various Technology Readiness Levels (TRLs) and might not be available for several years, or for the differences in medical efficacy of each MCM. Some scientists on the SIPWG had experience applying mathematical programming to maximize the return on investment for drug development projects. They called these "knapsack" problems because the idea is to fit as many items from a list as possible into a constrained space (like a hiker's knapsack) in order to maximize value to the organization. The SIPWG leads thought that this optimization approach, while being theoretically sound, might take too long and not be transparent enough to explain to senior leadership.

13.4.2.2 Learning to Play Football

The SATs applied by the SIPWG were a good beginning in framing the problem and organizing the data. However, when they had finished prioritizing the items on the list, they had no direction for where to go next. In fairness to the team, SATs for resource allocation are simply not powerful enough to be useful.

On the other hand, optimization modeling approaches to resource allocation can take too long, require data that are not available, or are not transparent to the team, stakeholders, or decision-makers. And most disturbing, when a budget constraint is tightened or relaxed, the mix of items funded in the optimum knapsack can change illogically. Items that were funded prior to an increase in budget, may get deleted and replaced by other items that previously were not funded!

The SIPWG selected a SAM called Portfolio Decision Analysis, also called Multiobjective Portfolio Analysis with Resource Constraints (Parnell, Bresnick, Tani & Johnson, 2013), or more simply, Marginal Benefit to Cost Analysis (MBCA). The idea behind this SAM is to produce an easy to understand "Order of Buy" that the SIPWG desired, but in a logically defensible way.

Portfolios are simply bundles of things that you want to buy. A bag of groceries is a portfolio. The idea is to look at all the combinations of food that a family might want to buy, including how much of each, and pack the shopping cart with small, medium, or large amounts of each that will give the best mix of food for the budget at the checkout counter. The shopper always wants to put in the cart the items that will give the overall best value, or the most "bang for the buck." If the shopper gets to the counter and finds that he or she is a little short on funds, an item is removed from the cart that gives the least bang for the buck.

The shopper can plot all combinations of food items on a diagram of cost vs. benefit. This is called the Pareto space, bounded on the top by the Pareto frontier. The frontier curve shows the set of portfolios that give the best "bang for the buck" – the best value for any given cost. The other points in the Pareto space are also feasible "bags of groceries," but just don't give us the best value for our money. The shape of the Pareto space looks like an American football – pointy on both ends and fat in the middle.

Working in weekly meetings over several months, the SIPWG first created a portfolio model structure to solve their acquisition strategy problem. The team used one of many inexpensive software tools called *LDW Portfolio*. First, the team extended their planning matrix by taking the MCM rows and adding any additional MCMs that were known to be in development. The team then created three to five potential funding levels for each row extending out from left to right. These were realistic levels that indicated the cost and relative benefit of buying different amounts of the MCM. The lowest levels (normally the status quo or baseline) were assigned zero marginal benefit, while the highest levels under consideration were assigned 100.

A bottom level score of zero did not mean there was no benefit. In fact, for MCMs that had quantities currently in the stockpile, there may have been significant benefit, but no marginal benefit, as the baseline was the lowest level. Then the benefit assessments took into account the special issue of when the MCM would be available to buy. For example, if the MCM would not be available to enter the stockpile for three years, an appropriate discount factor was applied to its benefit score.

Second, the team reviewed and refined the list of biological and other threats and their relative risks. These became the evaluation criteria and "across criteria weights" for the overall benefit of each MCM row.

Third, the team used a decision analysis weighting exercise to develop "within criteria weights" in order to normalize the 0–100 scales on each row for each criterion, since some rows had more levels than other rows. In addition, the team accounted for the variation in medical efficacy of each MCM against the threat criterion. For example, an MCM that was very effective against the anthrax criterion would get a large relative weight, while an MCM that had no effectiveness against anthrax would get a weight of zero on that criterion.

Fourth, the team did a through reviewing the order of buy and identifying the best mix of MCMs. New or existing MCM levels that provide a large improvement over the baseline and that are available earlier are preferred in the order of buy. The team then ran two models. The simpler model examined the strategy for each MCM of buying the required amount of the next generation product when it becomes available. The simplified model also assumed that a next generation MCM should receive 100% of its benefit regardless of when it becomes available. A more complex model examined several possible acquisition strategies for each MCM, including buying more of the current MCM, waiting for the next generation MCM before buying, or combinations of these two acquisition strategies.

The SIPWG finished with a workshop attended by the team members and a broad set of homeland security officials and other stakeholders. The purpose of the workshop was to gain consensus among the national security community on the priorities for meeting medical countermeasure preparedness and response goals using the decision framework identified by the team. They examined the key tradeoffs that emerged from the first discussion to reach consensus on the implementation plan. The workshop was supported by the portfolio model which integrated the alternative MCM strategies to help the SIPWG visualize key tradeoffs over the three timeframes and to help develop the best value MCM acquisition strategy.

13.5 Lessons Learned

Analytic Collaboration combines group process facilitation, problem-structuring techniques, and simple analytic models in a powerful combination to take any team through a hard decision or problem to an informed and transparent solution. Here are ten tips for using and growing Analytic Collaboration in your own organization.

1. **Team meeting rooms should enable Analytic Collaboration**. Good meeting management is critical to Analytic Collaboration. A good meeting space to collaborate is critical to meeting management. The team collaboration room should be free from distractions such as large windows, pictures on the walls, and unused equipment. If the team doesn't have a dedicated meeting room, the facilitator should prepare an available conference room before each meeting. Move the tables and chairs into a horseshoe shape to allow team members to see each other when they are talking and to turn to face the projector screen when they are building a model. Have lots of wall space to hang flipchart paper in order to keep track of the team's progress.
2. **Focus team discussions on "beating up" the model, not each other**. Analytic Collaboration introduces a valuable new team member: SAM! The model ties together all the information and judgment of the team and makes clear where there are inconsistencies or conflicts. Team members can debate with the model without directly criticizing the other team members. The model allows multiple perspectives or "alternative facts" to be tested and encourages team learning. The model is a neutral participant in the team meeting who gives honest feedback without being judgmental.
3. **Practice good group process**. The best team meetings require more than models and meeting rooms. They require a group facilitator or other designated person to manage a good group process. Good group process involves managing the pace of the meeting and alternating between divergent thinking (NGT, brainstorming,

and open discussion) and convergent thinking (coming to conclusions, a resolution, and action.) The facilitator should create a "parking lot" for issues that may be addressed later and stay focused on the meeting goals and agenda.

4. **Collect relevant information before the meeting.** Preparing for Analytic Collaboration requires bringing data and information to the meeting. Data calls and read-aheads should be sent out to team members as a matter of routine. Be specific about what content and format are expected. Senior leaders, subject matter experts, and other stakeholders should be interviewed or sent a questionnaire when value preferences, risk tolerance, and probability assessments are needed. Bringing data and information to meetings will allow the team to build a SAM that can transform that information into insights.
5. **Set ground rules for Analytic Collaboration during meetings**. Team meetings are more productive when the organization's culture and senior leadership reinforces collaborative values. Meeting ground rules are a good way for an organization to set expectations for responsibility and accountability. Start with the four core principles of collaborative teams: 1) a common purpose, 2) a shared understanding, 3) informed choices, and 4) commitment to action. Have clear ground rules for who sets deadlines and makes the decisions.
6. **Avoid using averages and create probability distributions**. In problem-solving, averages tend to produce misleading results (Savage, 2009). Yet, without a computer, it is hard for a collaborative team to think in terms of distributions. For example, if our 08:30 weekly staff meetings take on average 30 minutes, we might assume that we will be late for a standing 09:00 project meeting half the time. However, even using normal distributions, a simple analytic model shows that after two weeks we will only have a 25% chance of making the new meetings on time and after a month only about a 6% chance! SAMs are easily able to handle these calculations. The hard part is getting your team to think in terms of distributions.
7. **Mitigate biases: cognitive, organizational, and motivational**. Use good facilitation and SATs to counteract potential individual and group biases. Common biases, such as groupthink (Janis, 1982), can be avoided using ground rules (e.g., the team leader does not state his or her opinion first) and by taking turns being the Devil's Advocate. There are many other good techniques a facilitator can use to improve the quality of model assessments and judgments provided by the team.
8. **Learn how to use simple tools well, rather than using complex tools that you don't have time to master.** Analytic Collaboration must be practiced in the meeting room to be effective. Only model clean-up and documentation should be done after the meeting. The facilitator or team leader should select and practice using the software tools before the meeting. Most SAMs can be built in Excel. If the facilitator is not comfortable typing, a computer "technographer" can handle the keyboarding. Grow the model-building skills of the team during meetings for continuous improvement of Analytic Collaboration in the organization.
9. **Build consensus, not compromise**. Analytic Collaboration often increases the conflict within a team because new ideas must be tested in real-time. Some team members may not be comfortable with conflict. Compromise is a common escape tactic used by teams facing conflict, especially teams that are short on time. Contrary to what you learned in kindergarten, you should avoid compromise when practicing analytics. It sounds counterintuitive, but compromises such as horse-trading, agreeing on the lowest common denominator, and "splitting the baby,"

tend to simply postpone inevitable bad results. Resolve large differences first, and if the team can't reach consensus, use the model to conduct sensitivity analysis to show what the results would be under different assumptions (Wilkinson, 2005).

10. **Use voting to understand team differences, but make team decisions by consensus**. SAMs help teams to converge on the best solutions or decisions. The key to convergence in a collaborative team is to poll team members frequently for their inputs to the model. However, model results usually require interpretation by the team. "Up or down" votes can cause unnecessary conflict within the team, when it is more important to understand and explore the reasons behind disagreements. Always strive to reach consensus around the final solution, decision, or recommendation.

References

Aebischer, D. (2016). CECOM Virtual Logistics Assistance Representative (VLAR): Bayesian Networks for Combat Equipment Diagnostics, Presented at INFORMS Business Analytics Conference Franz Edelman Award. Orlando, FL. 2016.

BayesiaLab. (n.d.). Retrieved from https://www.bayesialab.com

Bens, I. (1997). *Facilitating with Ease*. Sarasota, FL: Participative Dynamics.

Clemen, R. T. (1996). *Making Hard Decisions*, *2nd Ed*. Pacific Grove, CA: Duxbury Press.

Cochran, J. J. (2019). ed., *INFORMS Analytics Body of Knowledge (ABOK)*. Hoboken, NJ: Wiley.

Dillon-Merrill, R. L. (2015). Quantifying Risk in Commercial Aviation with Event Sequence Diagrams and Fault Trees, Presented at 2013 Winter Meeting, American Nuclear Society, Washington, DC. 2013.

ExtendSim. (n.d.). Retrieved from https://www.extendsim.com

Fenton, N. E. (2012). *Risk Assessment and Decision Analysis with Bayesian Networks*. Boca Raton, FL: CRC Press.

Hammond, J. S., Keeney, R. L., & Raiffa, H. (1999). *Smart Choices: A Practical Guide to Making Better Decisions*. Boston, MA: Harvard Business School Press

Heuer, R. J. (1999). *Psychology of Intelligence Analysis*. Center for the Study of Intelligence.

Heuer, R. J., & Pherson, R. H. (2008). *Structured Analytic Techniques for Intelligence Analysis*, 2nd Ed. Thousand Oaks, CA: CQ Press.

Janis, I. L. (1982). *Groupthink*, *2nd Ed*. Boston, MA: Houghton Mifflin.

Jones, M. D. (1995). *The Thinker's Toolkit*. New York: Three Rivers Press.

Keeney, R. L. (1992). *Value-Focused Thinking: A Path to Creative Decision Making*. Cambridge, MA: Harvard Univ. Press.

Kirkwood, C. W. (1997). *Strategic Decision Making: Multi-objective Decision Analysis with Spreadsheets*. Belmont, CA: Duxbury Press.

Kostman, J. T. (2018). The McCain Meeting Rule. Retrieved from https://www.linkedin.com/feed/update/urn:li:activity:6441999670280482816/

Logical Decisions. (n.d.). Retrieved from https://www.logicaldecisions.com

Norsys. (n.d.). Retrieved from http://www.norsys.com

Parnell, G. S., Bresnick, T. A., Tani, S. N., & Johnson, E. R. (2013). *Handbook of Decision Analysis*. Hoboken, NJ: Wiley.

Quinlivan-Hall, D., & Renner, P. (1990). *In Search of Solutions: Sixty Ways to Guide Your Problem-Solving Group*. Vancouver, BC: PFR Training Associates Limited.

Reagan-Cirincione, P. (1994). Improving the Accuracy of Group Judgment. *Organizational Behavior and Human Decision Processes*, 58(2). 58, 246–270.

Savage, S. L. (2009). *The Flaw of Averages*. Hoboken, NJ: Wiley.

Schwarz, R. M. (1994). *The Skilled Facilitator*. San Francisco, CA. Jossey-Bass Publishers.

Syncopation. (n.d.). Retrieved from https://www.syncopation.com
Tatman, J. T., et al, (2015). *Bayesian Network Elicitation Facilitator's Guide*. Vienna, VA: Innovative Decisions, Inc.
Vennix, J. A. M. (1996). *Group Model Building*. Hoboken, NJ: Wiley.
Wilkinson, M. (2005). Consensus Building. In S. Schuman (Ed.), *The IAF Handbook of Group Facilitation* (pp. 361–380). San Francisco, CA: Josey-Bass.
Wizemann, T. (2010). *National Academy of Sciences Report of Public Health Effectiveness of the FDA 510(k) Clearance Process*. Washington, DC: The National Academies Press.