PTSI Final Report: Transforming the Psychological Health System of Care in the US Military

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Chapter 4: Mathematical modeling

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Mathematical models are well known to the Department of Defense. The very birth of Operations Research, which relies heavily on mathematical models, was DoD-driven during World War II. Among the products of this work were efficient linear programming algorithms to improve war time logistics; the theory of optimal search, which proved invaluable to U.S. efforts in the North Atlantic to find and destroy enemy submarines; optimal location theory, which proved most useful for placement of radar stations in Britain to detect incoming enemy aircraft; and much more.

Less well developed then were models of human health and behavior and interventions to improve health. But the subsequent seven decades have seen much good work in this area—less on hardware-dominated tactical operations and more on human systems. For instance, epidemiology is now a mature field involving many different types of mathematical models of behavior-influenced disease progression and control. Mathematical modeling is relatively new to PTSD, with barely a handful of papers addressing the topic.

A goal of this project has been to incorporate both qualitative and quantitative modeling-based work as a way to capture the potential benefits of a multidisciplinary examination of the burden of PTSD and how it might be addressed in the military health system going forward. Our mathematical modeling work takes a "systems" perspective, embedding the soldier into the military system and then structuring various PTSD-focused models around that, with the type of structure depending on the types of decisions and policies the model may guide and influence. From the systems point of view, we seek first to frame the problem to understand the overlapping and intertwined subsystems—both formal and informal—that influence the treatment of PTSD, both positive and negative. Then, from an aggregate level, we seek to project DoD (and also Veterans Administration) PTSD treatment workloads over the coming years and even decades.

Mathematical models come in many varieties: deterministic and probabilistic; equation-based versus algorithm-based versus simulation-based; optimizing versus descriptive; and so on. Our approach is simulation-based and descriptive in response to the complexity of PTSD. Simulations also come in varieties: Monte Carlo (probabilistic) simulation; System Dynamics (deterministic) simulation; and even the new agent-based (micro rule-based) simulations. Our work utilizes both System Dynamics and Monte Carlo simulations.

Simulation modeling methods have increasingly been used to understand health care systems and inform policy decisionmaking.[1] Simulation models have a wide variety of uses. Among others, they support *"what if" experiments and workload projections*. A simulation model of a PTSD treatment system can project the multi-year consequences of PTSD workloads and costs under a wide variety of "what if" scenarios ranging from those largely outside the control of the PTSD system (such as the intensity of engagements in future wars) to those under the control of the PTSD system—such as deployment of additional resources and/or use of new evidence-based treatments. This use can inform projections of budgets and needs for professional manpower and facilities.

Another use is to *improve systems understanding*. Sometimes, a model's primary use is problem framing, through which decisionmakers and other stakeholders—such as the PTSD-afflicted Soldiers and Marines, their families, friends, and personal support organizations—can learn from the model development and structure the shared importance of the many intertwined stakeholders in helping to ameliorate the symptoms of PTSD. From a DoD perspective, such a framing model can justify government resources being devoted to family, friends, and supporting organizations outside the DoD, as these are also seen as critical in a comprehensive treatment program.

Since the beginning of Operation Enduring Freedom (OEF) in 2001 and later during Operation Iraqi Freedom (OIF) beginning in 2003, a handful of simulation and systems models have been developed that combine and apply theory and empirical data. They provide insights about how the psychological health burden from the two wars is likely to play out over a long period.

No model perfectly depicts reality. As George Box and Norman Draper famously wrote, "[A]ll models are wrong, but some are useful."[2] Also, model complexity does not necessarily imply greater or even equal usefulness as compared to a simpler model. Here a quote often attributed to Albert Einstein is appropriate: "Everything should be made as simple as possible, but not simpler." We have tried to follow these two propositions in our three developed models, which we describe below.

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[1] See, for example: How Modeling Can Inform Strategies to Improve Population Health: Workshop Summary (2015) http://www.nap.edu/download.php?record_id=21807

[2] Box, George E.P. and Norman R. Draper. *Empirical Model-Building and Response Surfaces*. New York: Wiley, (1987).

First, however, we review the two other most relevant models in the published literature that were not developed for the present project.

RAND Model

The first of the PTSD-related models from the literature was developed at RAND Corporation and used a simulation approach to predict costs from PTSD and depression related to OEF/OIF.[3] It assumed outright that 15 percent of modeled individuals experience PTSD over the model's time window. It presented results in terms of the expected costs for 50,000 simulated E-5 service members due to PTSD, depression, and suicide over a two-year period following return from deployment: with respect to *status quo* treatment in which 30 percent of individuals with a mental health condition receive treatment and 30 percent of treatment is evidence-based, and excluding lives lost to suicide, the RAND model predicts total two-year costs of $119.8 million under the baseline, $51.2 million at low-cost, and $149.0 million at high cost. The baseline predicts that 94.5 percent of these costs are due to lost productivity, 5.1 percent due to mental health treatment, and 0.4 percent due to medical costs of suicide.

The RAND model also predicts two-year costs per case of PTSD, depression, and co-morbid PTSD and depression. Excluding suicide mortality, the baseline model predicts a $5,635 cost per PTSD case with no care, $5,664 cost per PTSD case with usual care, and $7,933 cost per case with evidence-based care. Including the cost of lives lost to suicide, the baseline model predicts an $11,986 cost per PTSD case with no care, $13,935 cost per PTSD case with usual care, and $7,933 cost per case with evidence-based care.

Atkinson, Guetz, and Wein Model

The second model used a simulation approach to explain acute stress symptoms empirically observed during OIF and to predict future PTSD onset resulting from the conflict through 2023.[4] The researchers exposed virtual service members to a random number and magnitude of traumatic events based on historical deployment characteristics. The model assumed an innate stress threshold for each service member, consistent with a theoretical model described in the psychological

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[3] For more, see Tanielian & Jaycox (2008) *Invisible wounds of war : psychological and cognitive injuries, their consequences, and services to assist recovery*. Santa Monica, CA: RAND Corporation.

[4] For more, see Atkinson, Guetz, & Wein (2009) A dynamic model for posttraumatic stress disorder among U.S. troops in Operation Iraqi Freedom. *Management Science, 55*(9), 1454–1468.

literature. Service members for whom the traumatic stress experienced exceeds their stress threshold were said to experience PTSD after a random delay. This model predicted the total number of service members that will experience PTSD at each time through the end of the current wars and under various drawdown scenarios.

The Atkinson, Guetz, and Wein model presented results in terms of the number of OIF Army soldiers and Marines expressing PTSD by each year over the 20-year period 2003–2023. The model assumed three OIF withdrawal scenarios. The actual withdrawal occurred within the model scenario range, such that model predictions provide a reasonable window for actual PTSD prevalence.[5] While the study provided a detailed examination of traumatic exposure and PTSD onset over OEF/OIF, it did not consider the effect of treatment, nor the possible remission of PTSD.

The model predicts that 278,000–313,000 service members will have exhibited PTSD symptoms by 2023. These values correspond to roughly 40 percent of active-duty Soldiers and Marines and roughly 32 percent of Army Reservists that deployed to Iraq during OIF. The model predicts that were service members to deploy only once, the lifetime PTSD rate would be roughly 30 percent. However, such a deployment policy would expose many more service members to combat in order to maintain the same troop levels, resulting in upwards of 30 percent more lifetime PTSD cases.

We now turn to the three models developed for the present project.

Model 1: A conceptual systems model of PTSD

With what we refer to as Model 1 (developed as part of this project), Ghaffarzadegan and Larson[6] developed a qualitative representation of the system, seeking to answer a basic question: What are the interrelations between psychological, sociological, and medical factors in a case of PTSD treatment? The main inputs for the model were published articles and reports about PTSD in military and the Veterans Administration. With the model, the researchers uncover several root causes of complexity of treating PTSD.

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[5] The model withdrawal scenarios assumed a yearlong drawdown to zero from September 2008 troop levels (140,000 troops) beginning in February 2009, 2010, or 2011. The actual drawdown took place in two steps, with half of the troops drawn down in September 2009–September 2010 (to 61,200 troops) and the rest drawn down in September 2011–September 2012.

[6] Ghaffarzadegan and Larson (2015) Posttraumatic Stress Disorder: Five Vicious Cycles that Inhibit Effective Treatment. *U.S. Army Medical Department Journal*, (4-15), 8–13.

The study's outcome is a big-picture model. The model demonstrates how military personnel with PTSD are situated in a complex web of partially overlapping structures, some formal as operated by the Department of Defense (and later, the VA), and some informal as provided by family and friends.

Beyond evaluating different causal reasons for complexity of PTSD treatment, Model 1 points to five major vicious cycles (figure 4-1). The figure represents multi-layer dynamics: individual, family/friend, and societal layers. In the individual layer, one's own health and actions influence treatment. In the second layer, family/friends affect treatment. In the societal layer, many patients' behaviors are observed and create public perceptions and the associated labels, which ultimately feed back to individual layer dynamics.

The vicious cycles, represented as loops in figure 4-1, are labeled R1 to R5: R1) cascading illness and medical complexity; R2) cascading illness and exclusion from family and friends; R3) stigma and social exclusion; R4) self-fulfilling prophecy; and R5) the malingerer stigma.[7] In this context, a vicious cycle is a feedback loop that, over time, creates cascading negative influence on the PTSD sufferer, and exacerbates his or her mental health situation. These cycles, as time passes, make PTSD less likely to be treated.

To illustrate, we briefly review R1. If a patient does not actively seek care, the illness progresses over time and his or her medical condition worsens. Studies indicate that some patients with PTSD also develop other psychiatric disorders. Increasing complications render medical interventions progressively less effective. Patients' responses in the form of drug abuse can further complicate health conditions. The entire process ends up in a cascading pattern that eventually pushes mild medical illnesses into chronic and life-threatening conditions.

[7] Additional information about these cycles is in Ghaffarzadegan and Larson (2015).

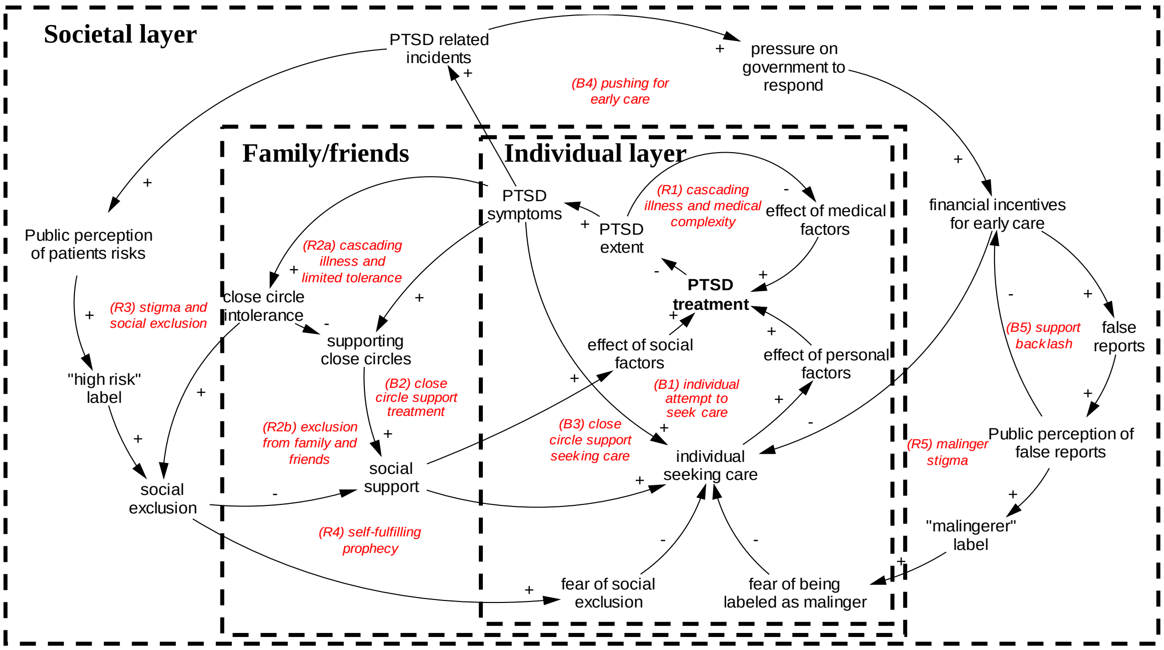

Figure 4- 1: A Conceptual Model of PTSD Treatment

Overcoming vicious cycles is very difficult, requiring policies and patience over the long term. Without early interventions, these cycles result in a downward spiral into depression, family discord, and possible divorce, substance abuse, joblessness, homelessness, and even suicidal ideation or action.

Like a snowball that gets bigger and bigger as it rolls downhill, vicious cycles are difficult to stop as they gain momentum. This analysis points to the need to prevent these situations from developing, potentially even from the beginning. Two conceivable policy steps are early effective screening and resiliency-related interventions (e.g., better recruitment procedures or resiliency-related trainings). Attention should be paid to military personnel and their families.

Model 1 was a first step for problem framing and understanding interconnections and complexities surrounding any individual military personnel with PTSD. In the next stages, we needed models that help quantify such effects and compare and contrast effects of improving resiliency and early treatment. Such quantitative models should include uncertainty in diagnosis, individuals' health, access to care, and military personnel readiness. The models should also help compare PTSD prevalence and healthcare system costs under different policies and scenarios.

In response, two additional models were developed for this project: a system dynamics model of PTSD prevalence and a Monte Carlo simulation model.

Model 2: a population-level System Dynamics model of PTSD

With Model 2, we moved toward quantifying effects of different interventions on PTSD prevalence, asking these basic questions: What are the trends in the population of PTSD patients among military personnel and veterans in the postwar era? What policies can help mitigate the effects of PTSD? And what are the healthcare cost implications of potential policies?

To answer these questions, Ghaffarzadegan and colleagues[8] developed a system dynamics simulation model of the PTSD population, with a broad boundary. Taking a systems approach, the model incorporates both military personnel and veterans (other works typically have a narrower perspective and focus on only one group). It encompasses veterans of pre-2000 wars as well as the more recent wars in Iraq and Afghanistan, and can track cases over entire lifetimes. The model is complex and includes more than 100 equations.

Structurally, Model 2 depicts the flow of people from recruitment into the military, from the military to the post-military stage, and from the post-military stage to death. The model incorporates the chances of deployment, of experiencing trauma, and of developing PTSD given trauma. In the model, people do not necessarily reveal PTSD symptoms immediately; the diagnosis may be delayed, in some cases happening after separation from the military. Since the model includes two subsystems, military and post-military, it helps estimate PTSD-related healthcare costs for both the DoD and VA.

The model uses a variety of data sources. The structure is informed by previous work by the researchers, other published articles, and reports. Model parameters and time series (2000-2014) come from the DoD, Institute of Medicine, and the VA. We ran the model for the period 2000–2025. The period 2000–2014 was used for model validation and examination of the model's fidelity in replicating the historical data. Then the model forecasts the 2015–2025 period. To create scenarios for forecasts, U.S. involvement in wars and the intensity of future wars (in comparison to OIF) were used as inputs. The outputs are PTSD prevalence, number of PTSD cases diagnosed and undiagnosed in both the military and the VA, and PTSD-related healthcare costs. Figure 4-2 is an example of one of Model 2's outcomes.

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[8] Ghaffarzadegan et al (2015) *A Simulation-Based Analysis of PTSD Prevalence among the US Military Personnel and Veterans in 2025*. Under Review (Millbank Quarterly), 1–11

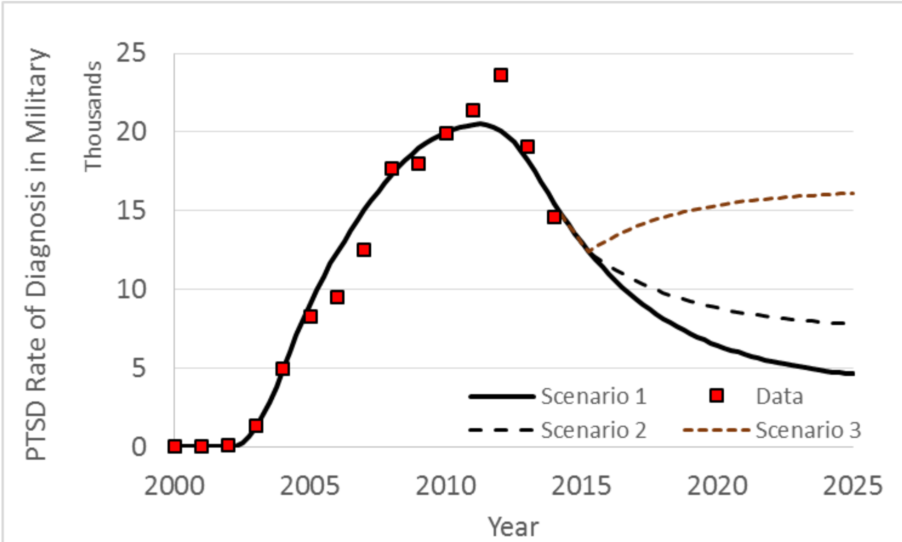

Figure 4-2: PTSD diagnosis rate in military [new cases per year].

Note: The model fits the data for 2000–2014 and predicts the trends for 2015–2025 for three scenarios. Scenario 1 is minimum deployment to intense/combat zones (1% of military personnel); Scenario 2 is 2% deployment to intense/combat zones; and Scenario 3 is 5% deployment to intense/combat zones.

In their paper written based on the model, Ghaffarzadegan and colleagues test four policies aimed at improving resiliency, screening, treatment, and a combination of the three. A user can test different combinations of these policy measures under different scenarios of future wars, and examine PTSD prevalence and costs as outputs. Model 2 yielded four major results.

1. The model predicts that the population of patients and system costs are very sensitive to U.S. involvement in future wars, and that screening and treatment policy interventions have marginal effects in comparison. In fact, more screening increases short-term healthcare costs by increasing demand for health services.
2. In a very optimistic scenario, Model 2 estimates PTSD prevalence among veterans in 2025 to be 10 percent.[9] The figure includes undiagnosed cases of PTSD.
3. Effective policies for periods of war and for postwar periods are different. During wars, resiliency-related policies are the most effective policies for decreasing PTSD; however, in a postwar period, there is no silver bullet to overcome the problem of PTSD. This is consistent with what was argued in Model 1 regarding the difficulty of controlling the vicious cycles of PTSD.

[9] This is the percentage of veterans with active PTSD during this year. It is not a cumulative measure.

4. It takes a long time, on the order of 40 years, to ameliorate the psychiatric consequences of a war. This is also consistent with the data on Vietnam War-era PTSD patients.

The paper also provides detailed discussions about healthcare costs for the DoD and VA regarding PTSD. The costs are limited to direct healthcare costs. In reality, there are also social costs associated with PTSD, but these were not considered in this analysis. In an optimistic scenario (about 1–2% deployment to intense/combat zones in the next 10 years), the model's prediction of PTSD healthcare costs for the military in 2025 ranges from $130 to $160 million/year (in 2012 dollars). With greater involvement in future wars (about 5% deployment to intense/combat zones), the costs potentially increase to $260 million/year. For the VA, the cost estimates are one order higher, with average estimates of $2.9 to $3.2 billion/year (in 2012 dollars). With greater involvement in future wars, this cost can also increase to $3.6 billion/year.

Beyond prevalence and cost estimations, Model 2 stresses that PTSD is a multi-organizational problem. A systems approach needs to consider both military and post-military stages together since an effective policy in one stage may create problems for the other stage. The models should also look at long-term dynamics, considering delays between developing PTSD and showing symptoms. The analysis also shows that a focus on resiliency and decreasing the chances of developing PTSD is potentially one of the most effective policies, which is consistent with Model 1's suggestions.[10]

Model 3: A Monte-Carlo simulation model of PTSD

Fingerhut[11] developed the third of the three models specific to the present project, using a Monte Carlo simulation approach to predict PTSD prevalence and clinical demand of individuals over five decades after OEF/OIF, following the population over the period 2003–2064. This approach creates representative service members that replicate the deployment schedule, PTSD risk, care-seeking behavior, and treatment of actual service members from the two conflicts. After randomly assigning each virtual service member's deployment and trauma exposure as well as any possible PTSD onset, recognition, and treatment events over the period of study, the study aggregates each individual's simulated history to determine population level statistics and trends. This study also provides a series

[10] Model 2 can work as a "flight simulator" and is a framework for policy experiments. Installation of the simulation software is not needed. It can be tried at https://goo.gl/Dej8wL.

[11] See Fingerhut (2015) *A Simulation Model to Predict Long-Term Posttraumatic Stress Disorder Prevalence Following Operation Iraqi Freedom and Operation Enduring Freedom*. MIT Technology and Policy Program. Massachusetts Institute of Technology.

of sample policies designed to replicate possible decisions a policymaker could implement to affect the PTSD burden.

The model uses empirically observed distributions of parameters from across the mental health system of care (traumatic exposure, onset, recognition, care seeking, and treatment) within a relatively simple structure to estimate the time dynamics of a series of individual and population parameters. This approach enables policymakers to understand what each of these observed factors—as well as potential changes in their values—means in terms of macro-level parameters of interest (such as population prevalence and clinical usage). This approach also enables researchers to understand how certain unobservable values may change over time and motivate dynamic observation of these factors within a population of interest.

Model 3 manipulates a time-series form of input, and is thus able to provide time-series output. That output takes the form of prevalence estimates from the population perspective, that is, each point in calendar time provides a snapshot of what a real-world population prevalence estimate would look like, given changes over time in deployment, combat, and other similar factors.

The model predicts a peak rate of active-case PTSD of nearly 200,000 by 2016 (17% of the population that deployed to date), declining to 150,000 by 2025 (15% of the population). These predictions reflect best-case assumptions about PTSD recognition, care seeking, and treatment efficacy that represent the most optimistic rates in these factors observed in recent empirical studies. The model predicts a long-term active-case PTSD rate of 19 to 23 percent under assumptions that reflect realistic limitations in these factors. Model 3 further predicts that 29 percent of OEF/OIF combat veterans will experience PTSD at some point in their lives.

In terms of care seeking and treatment, under best-case care-seeking assumptions, Model 3 predicts that 80 percent of the ever-PTSD population (23% of the full OEF/OIF population) will seek treatment at some point in their lives. Under the realistic recognition, care seeking, and treatment assumptions, 48 to 63 percent of the ever-PTSD population (14–18% of the OEF/OIF population) is expected to seek treatment. Under best-case model assumptions, clinical demand peaks at 3 percent of the OEF/OIF population per year in 2010, decreasing to 0.5 percent of the OEF/OIF population in 2025. Under the best-treatment efficacy assumptions (including the most effective treatments currently available and low rates of treatment dropout and PTSD recurrence), 59 percent of the ever-treated population is expected to remit PTSD symptoms successfully and permanently. Under realistic treatment assumptions, this figure drops to only 21 percent under the realistic treatment assumptions. This decrease is driven for the most part by decreased care seeking (i.e., for follow up treatment) and decreased treatment efficacy probabilities, as well as by an increased dropout probability and increased probability of PTSD recurrence even if treatment was successful.[12]

Conclusion

The three models specific to this project described above are initial efforts to depict in systems contexts our knowledge about PTSD treatment systems structures—both formal and informal, each model embedding the all-important psychological and social processes underlying the PTSD burden in the populations studied. They provide a good first look at the implications various policy and managerial actions could have on future PTSD prevalence, clinical demand, and cost. For those interested in additional details, each model is fully developed in separate refereed published papers and/or technical reports, as cited in this chapter's footnotes, and in the references.

Going forward, there are two key questions. First, *how might these models be used*? Our suggestion is to view the models as living entities, evolving and improving over time as new knowledge becomes available. Doing so will require professionals in the DoD to take ownership of the models and have timely access to all sorts of model-related information as it becomes available.

Second, *what is the anticipated new knowledge*? It ranges from administrative factors such as multi-year projected budget levels that may constrain system resources to new scientific knowledge about the efficacy of new treatments for PTSD. Within the models, budget constraints may appear only indirectly in terms of total numbers of professionals and facilities available for PTSD treatment. Putting new scientific knowledge to work will require going into the details of the models, the feedback loops, the flow parameters, the response delays, and so on and updating them to be compatible with the new scientific results. New science will, in turn, affect budgets and facilities, up or down. It may be, for instance, that a new treatment protocol is quite costly but demonstrates a very high chance of lifetime cessation of PTSD symptoms after, say, two years of such treatment. A protocol of that sort, if discovered, would be expensive in the short term and very cost effective in

[12] Note that the results of model 2 and 3 are not directly comparable, as the metrics used were different. Model 3 did not include cost calculations.

the long term. All this shows how scientific knowledge of treatment effects can cause major changes in the DoD resource-intensive systems model.

One final thought: our observation, not only in the DoD but also in the VA and in virtually all large service systems, is that professionals of all types tend to focus on their own work and specialties and not understand the systemic connections through which their actions to improve their own work often have unintended side effects that encumber the system as a whole. One major value of systems models is that they show clearly how everything affects everything else. They demonstrate clearly the hazards of local optimization, showing how even appealing local changes have the potential to be detrimental to the total system. In that sense, then, systems models provide an integrated, unifying framework for key decision makers from throughout the system to discuss their problems intelligently and dispassionately. This attribute may be one of the major arguments in favor of systems models.