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TELLING THE T&E STORY USING ANALYTICS-BASED NARRATIVE VISUALIZATION

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ABSTRACT

There continues to be growing pressure to sell off spectrum currently allocated for defense purposes in favor of private sector applications, prompting concerns that we will soon reach a point where Department of Defense (DoD) needs can no longer be met. In response, the Range Commanders Council (RCC) Frequency Management Group (FMG) developed a baseline set of standard metrics to measure spectrum utilization, demand, efficiency, and operational effectiveness. Using this standard (RCC 707-14) as a foundation, a Spectrum Management Metrics Toolkit (SMMT) has been developed to calculate, plot, and display these metrics. The challenge now is leveraging these metrics to inform and construct the arguments needed to maintain access to needed spectrum.

The purpose of this paper is to describe progress toward the development of a methodology and a set of analytics based on the RCC standard to build such a compelling narrative. The methodology is based on a data analytics and communication concept, called "Story Points," which seeks to guide users in the discovery, composition, and delivery of targeted narratives and supporting graphics derived through mining available data sources.

INTRODUCTION

Today's military operations increasingly rely on the ability to maintain full access and reliable control of the radio frequency (RF) spectrum for communications, radar, electronic warfare, remote fires, avionics, global positioning, logistics, medical support, test and evaluation (T&E), training, and signals intelligence uses. Meanwhile, there is correspondingly rapid growth in demand for commercial broadband wireless services and other commercial uses requiring access to RF spectrum. Unquestionably, access to spectrum is central to a wide range of business and consumer communication, research and development (R&D) and information technology (IT) purposes, such as private and public telecommunication operations (e.g., mobile phone networks, wireless Internet communication, aviation, shipping, defense, public safety), broadcasting, radar, astronomy

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and various other applications including countless short-range, low-power wireless devices [1]. Contention for access to RF spectrum has led to an ongoing series of spectrum auctions allowing commercial concerns to acquire licenses to spectrum that has historically been allocated for federal use.

Despite concerted efforts to retain control of key bands of the spectrum, the prospect of relieving strained federal budgets continues to drive further sell-offs. Even more problematic has been the perception that the DoD is an inefficient user of the spectrum, doesn't need all it has, and is unjustifiably hoarding spectrum.

That narrative has gained traction, in part, by exploiting the tendency to confuse "efficiency" with "utilization." Utilization is the proportion of the available time that a resource is being used or is in operation, usually expressed as a percentage.[1] The argument essentially asserts that if music's not playing (analogously speaking) at every point on the dial 24 hours a day, the spectrum is not being used efficiently. In effect, higher activity is equated with higher productivity. Given this logic, one could argue that leaving a fire truck parked in the firehouse, as opposed to driving it continuously, is inefficient. An equivalent T&E situation is reserving, but not having to issue a flight termination command during on a missile test.

To be efficient means "productive of the desired effects [with minimal] waste."[2] Efficiency, therefore, should be judged in the context of the "desired effects." For those seeking to leverage spectrum for commercial broadband services, the desired effect is to maximize profits for the company's shareholders. In contrast, the desired effect of the T&E and training communities is deterrence through developing and sustaining superior warfighting capabilities. The two clearly can't be easily compared.

The basic challenge is one of deciding how to best use a public resource weighing the relative importance of each competing application. It is like deciding whether that prime piece of real estate in a city's main shopping district should be used for a firehouse or for that office building proposed by a major investor, thus becoming a balancing act weighing potential economic gains versus the risk of life and property loss. Or it's like deciding whether the best use of the Redwoods national forest is as a tree farm versus as a monument to natural beauty and a protected habitat for rare species.

Ultimately, if the DoD hopes to maintain access to the spectrum it needs for T&E and training purposes—whether for exclusive use or shared—it will have to change the narrative that now frames the debate. Minimally, that narrative must establish the DoD's need for assured access to the spectrum, communicate the impacts of further restricting

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1 For example, in the depot maintenance, repair, and overhaul (MRO) domain, technician efficiency is defined as standard hours earned building to inventory divided by the total number of shift hours available. Pressure to maintain high efficiency as defined here gives rise to unintended behaviors, including over-production (resulting in excess inventory), cherry picking, and sandbagging.

2 https://www.merriam-webster.com/dictionary/efficient

access, and demonstrate responsible stewardship in the use of the spectrum. Much of the difficulty in doing so in the past stems from the lack of well-defined metrics and tools to:

- Accurately estimate current and future spectrum needs;
- Account for *actual* versus *scheduled utilization* of the spectrum that is allocated, so as to demonstrate responsible stewardship of the spectrum; and
- Quantify the cost and schedule implications of the loss of needed spectrum.

The Spectrum Efficiency Through Metrics (SETM) effort directly supports these goals by applying frequency metrics standards to monitor, assess, and improve the efficient use of spectrum while simultaneously working to give leaders the tools needed to defend continued access to T&E spectrum. The effort leverages many years' worth of research invested to define a baseline set of standard metrics for spectrum utilization, demand, efficiency, and operational effectiveness. These metrics are formalized in the RCC FMG Spectrum Management Metrics standard [2].

SPECTRUM MANAGEMENT METRICS TOOLKIT OVERVIEW

Perhaps the most visible product of the SETM effort will be a set of tools designed to calculate, plot, and display frequency management metrics. Collectively, we refer to this set of tools as the Spectrum Management Metrics Toolkit (SMMT).

Based on the metrics defined in RCC-707-14, the SMMT is designed to support calculation and display of frequency management metrics in several categories, including: Spectrum Occupancy, Utilization, Efficiency, Frequency Scheduling Operational Metrics, Predictive and "What-if" Metrics.

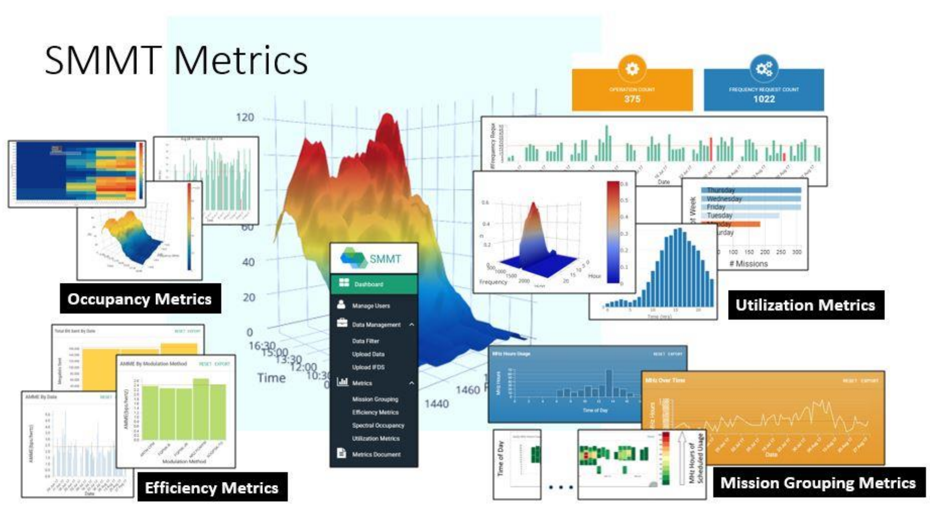

Figure 1. Sampling of SMMT Metrics

For further information on this toolkit, see [3],

TELLING THE T&E STORY USING ANALYTICS

Metrics like those in the RCC standard can be powerful in and of themselves. They become even more so when presented and embellished as part of a narrative that tells a compelling story or argument. Part of the SETM research seeks to surface better ways to organize metrics displays individually or in combination to support two goals: (i) highlight important observations in the data to facilitate better management of spectrum, and (ii) surface and better communicate spectrum needs and the impact of inaccessibility to that spectrum.

With regard to spectrum management, the question being addressed is, "How can we apply the metrics to surface opportunities to improve the effective use of spectrum?" For example, users may wish to display metrics side-by-side to investigate possible causal relationships leading to more efficient spectrum use. With regard promoting better access to needed spectrum, the question is, "How can we organize the display of the metrics to compose and communicate compelling narratives?" Using an example constructed from teacher turnover statistics spanning multiple years (Figure 2), we identified several constructs that would be useful in building such a narrative (Figure 3).

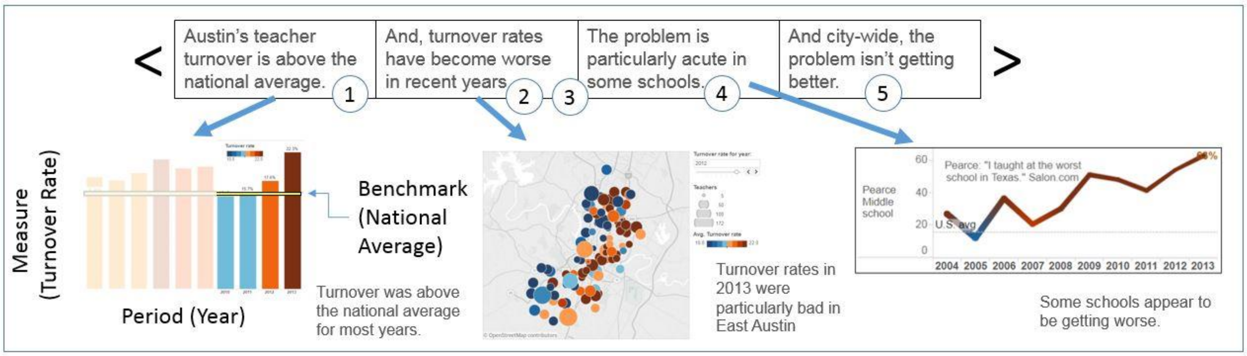

Figure 2. Narrative Visualization Example – Teacher Turnover

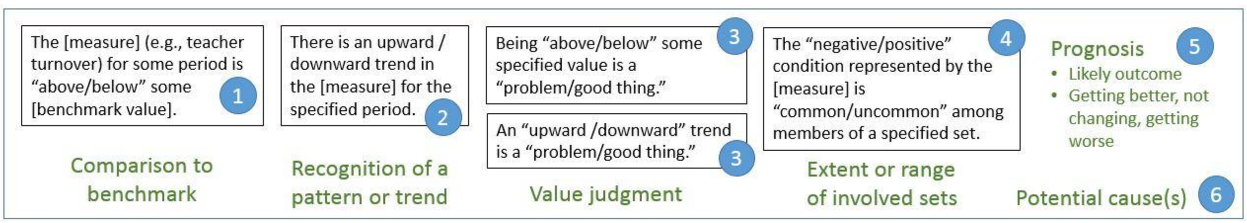

Figure 3. Narrative Visualization Composition Elements

Narrative elements may include (i) comparison to a benchmark value; (ii) identification of a potential trend or cluster membership; (iii) a value judgment (e.g., observed trend is positive); (iv) a definition of the scope or range of the sets involved; (v) the prognosis (i.e., likely future outcome or impacts); and (vi) indications of potential causal factors.

The resulting methodology is based on a data analytics and communication concept, called "Narrative Visualization" or "Story Points,"[3] which seeks to guide users in the discovery, composition, and delivery of targeted narratives and supporting graphics derived through mining available data sources.

[3] See https://www.tableau.com/about/blog/2014/5/82-preview-tell-story-your-data-story-points-30761

Based on sample data collected thus far, we were able to construct several examples of possible narratives, as described below. One purpose behind this exercise was to identify the SMMT extensions needed to surface, evolve, store, display, and share such narratives.

A familiar example of the Narrative Visualization concept in the T&E community is shown in Figure 4, which illustrates how one might annotate a single chart to draw attention to key observations. The narrative visualization elements used in the example are indicated by darkened versus obscured text at the bottom of the figure.

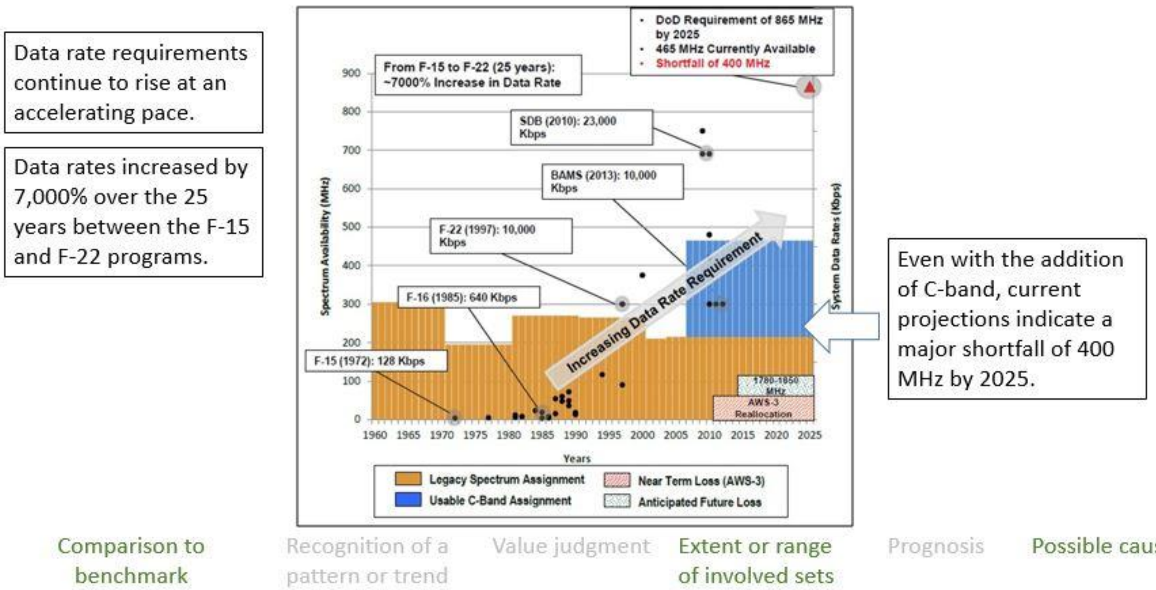

Figure 4. Increasing Data Requirements

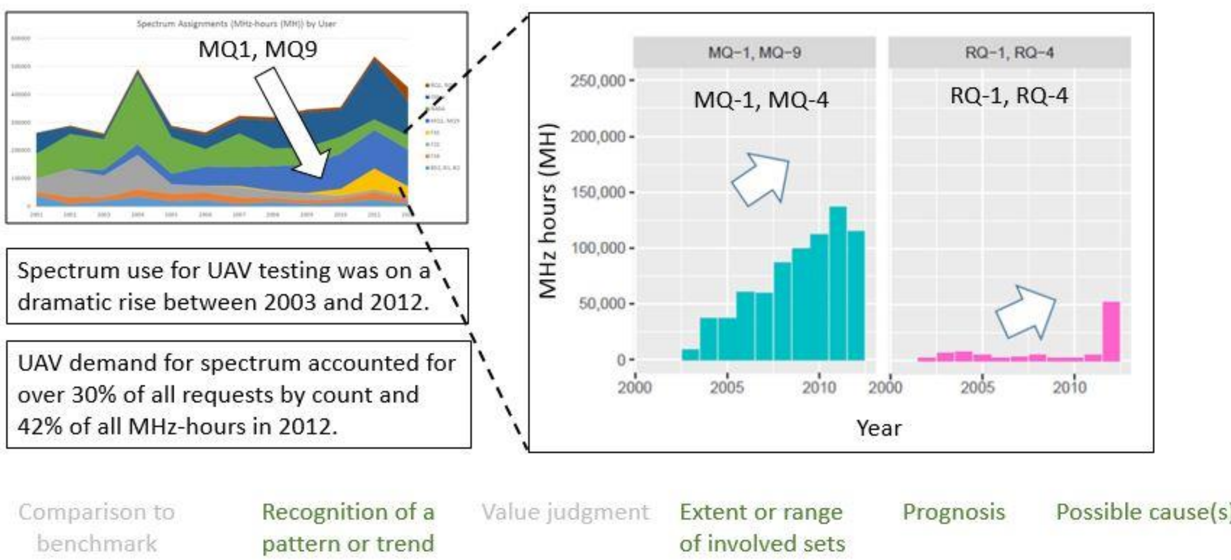

Figure 5. UAVs Account for Significant Portion of Overall Spectrum Use

In Figure 5, one can see that MHz-hours (MH) scheduled by the various Combined Test Force (CTF) users has been on a steady increase between 2001 and 2012. Taking a closer look, we find that overall growth in spectrum demand was driven largely by demands associated with unmanned aerial vehicle (UAV) testing (Figure 5).

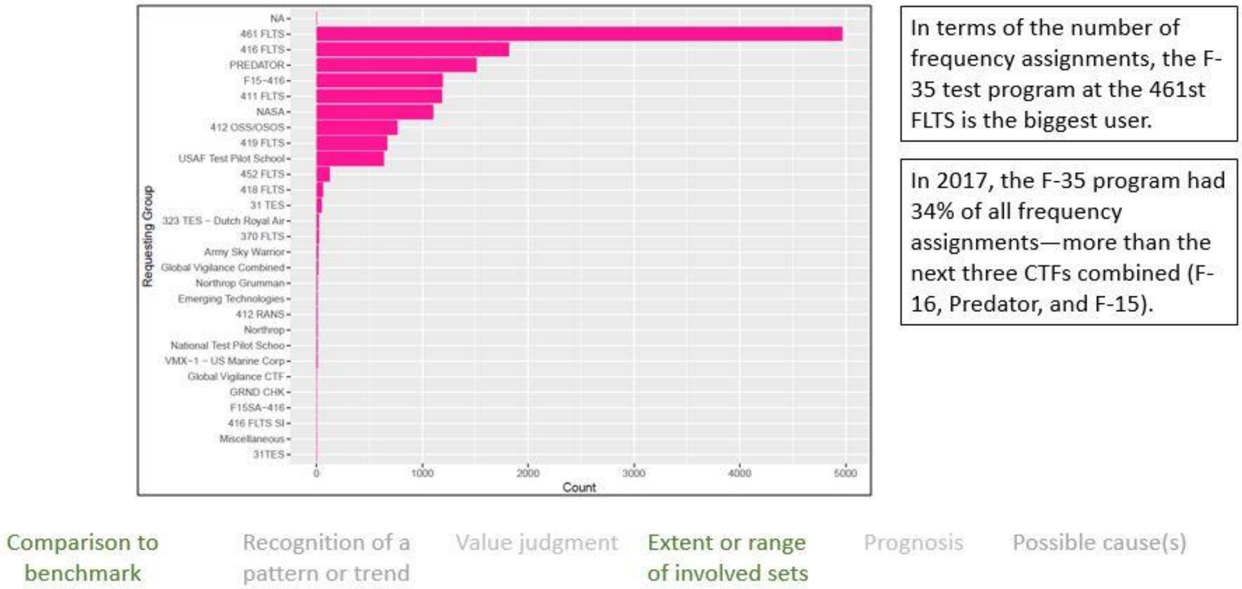

Figure 6. F-35 Top Dog at EAFB

More recently, another major test program came on line—the F-35. The priority given to the F-35 test program versus others is evident in the relative number of flights scheduled and the number of frequency assignments made for the F-35. In 2017, for example, the 461st Flight Test Squadron (FLTS), which runs the F-35 test program, was by far the biggest user (Figure 6). This figure might prompt the question, "Are the other CTFs asking for and getting the frequency they need?" and "If not, how much will test program completion be delayed?"

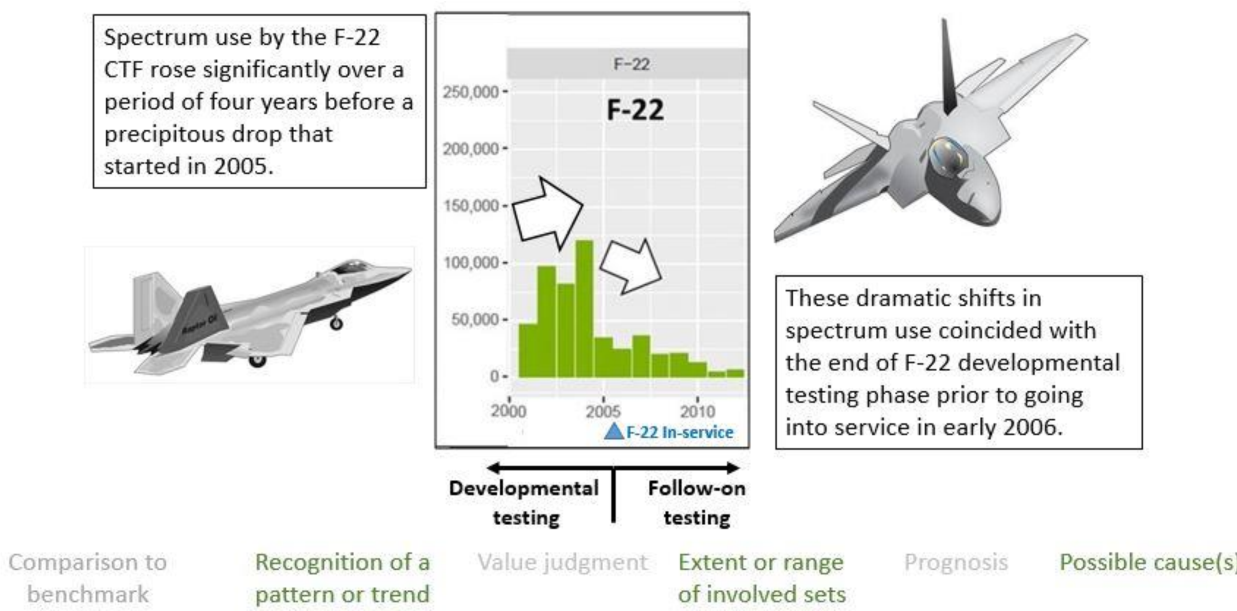

Figure 7. F-22 Completes Developmental Testing

In the example shown above, the F-35 program was involved in the developmental test phase whereas most of the other test programs had transitioned into their follow-on testing phase. When a program shifts from developmental testing to its follow-on testing phase, the number of test flights and the amount of telemetry frequency required can drop significantly. This pattern is evident in the example shown in Figure 7 for the F-22.

Given that there are multiple test programs underway at any given time, what can be expected in the way of their collective telemetry frequency needs? Figure 8 indicates that peak demand for spectrum increased year over year, and sometimes at a dramatic pace. In 2007, for example, peak demand at Edwards Air Force base (EAFB) appeared to be on track to double every nine years. The Navy's Echo range, on the other hand, looked like it might easily double every three years.

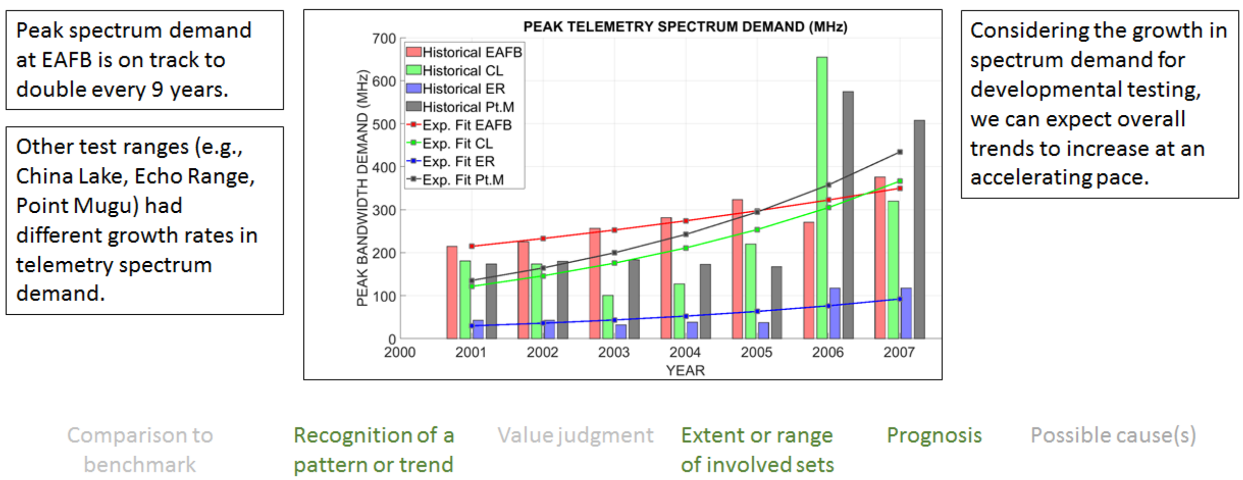

Figure 8. Spectrum Demand Rising for Follow-on Testing

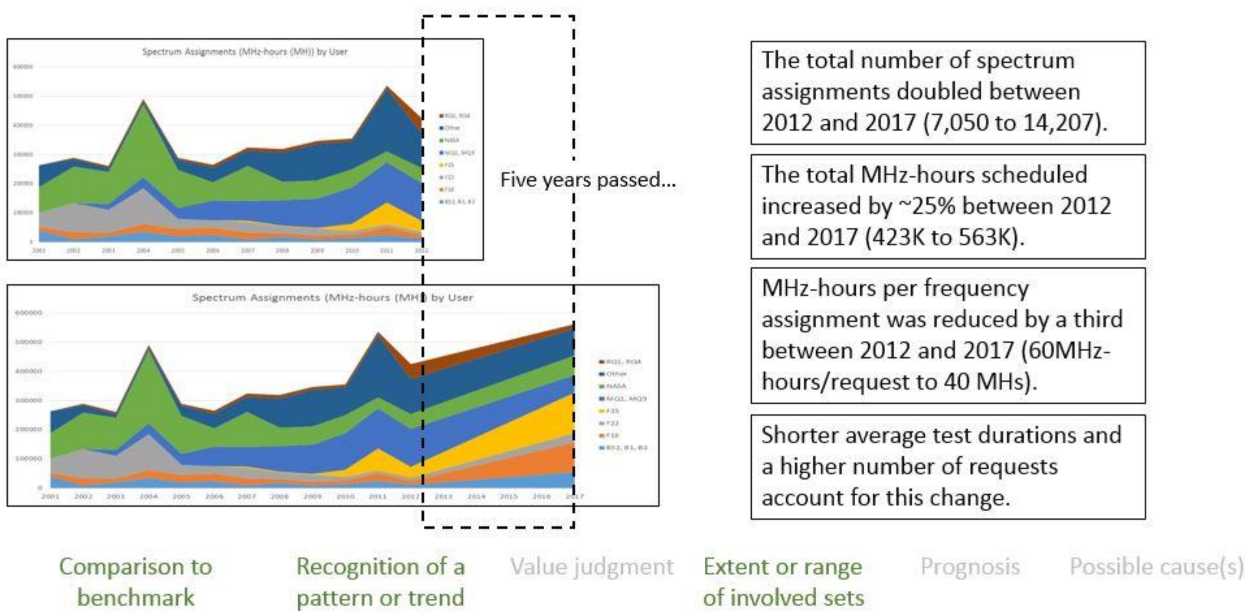

Figure 9. Spectrum Assignments Double While MHs per Frequency Assignment Are Cut by a Third

Earlier, we saw that between the years of 2001 through 2012, the number of frequency requests and the demand for telemetry frequency was on a steady, albeit somewhat flat climb. So, what happened during the intervening years? Based on the data shown in Figure 9, looking only at the five-year period between 2012 and 2017, the total number of spectrum assignments doubled while the total MHs increased by 25%. Meanwhile, the MHs per frequency assignment was reduced by a third. This was caused by two factors. First, the number of frequency requests per operation doubled. This may have been caused by outfitting the test articles with more radios to send additional telemetry data. Second, there was a drop in the number of hours flown per test mission, on average. F-35 missions, for example, dropped their normal duration by half.

At some point, a steady increase in frequency needs will ultimately approach a saturation point. It would appear that EAFB is nearing or has already reached that point (Figure 10). In fiscal year 2017, the average MHz assigned per frequency request was 9.5 MHz. Given that the total MHz available in the L- and S- bands was 285 MHz, the maximum number of concurrent assignments at any one time was thirty. Based on a box plot showing the number of concurrent assignments by time of day (from 7AM to 7PM), the actual number of assignments from 10AM to noon exceeded this threshold more than a third of the time. In terms of frequency, the total MHz scheduled exceeded what was available roughly 25% of weekdays between 10AM and noon. The shortfall in spectrum appears to have been accommodated for by flying on weekends and shifting to the C-band.

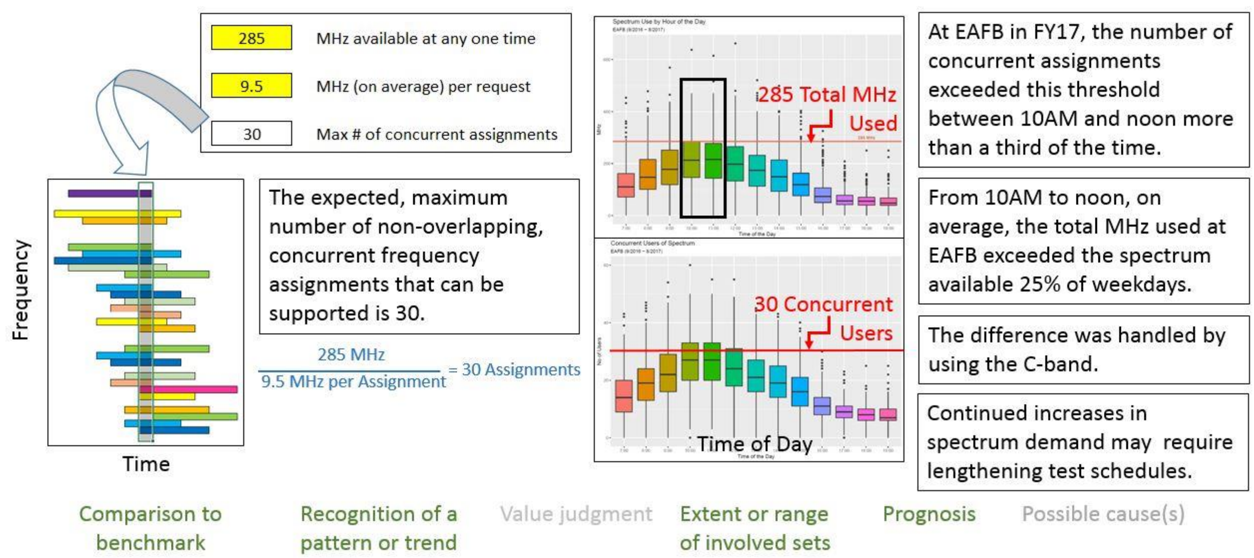

Figure 10. EAFB Approaching Saturation Point

One consequence of a spectrum loss and further crowding is a reduction in the number of test operations that can be accommodated each day coupled with a lengthening of test program schedules. This situation is illustrated by the example shown in Figure 11. In this case, testing operations conducted between 2010 and 2012 at one of the DoD's test ranges were accomplished using much of the allotted spectrum in the L- and S-bands. By 2016, an increase in bit rate requirements for these test programs—necessitated largely by the need for high definition video—effectively cut in half the number of simultaneous test operations that could be supported. Adding shifts to cover more than the typical 0600-1800 day might be a partial solution, but is constrained by the need for good lighting for the cameras. Even a change in modulation methods from analog FM to SOPQSK would have little impact in this case. Without other solutions, the calendar time it takes to complete test programs of this type could easily double, thereby undercutting our ability to stay ahead of our adversaries.

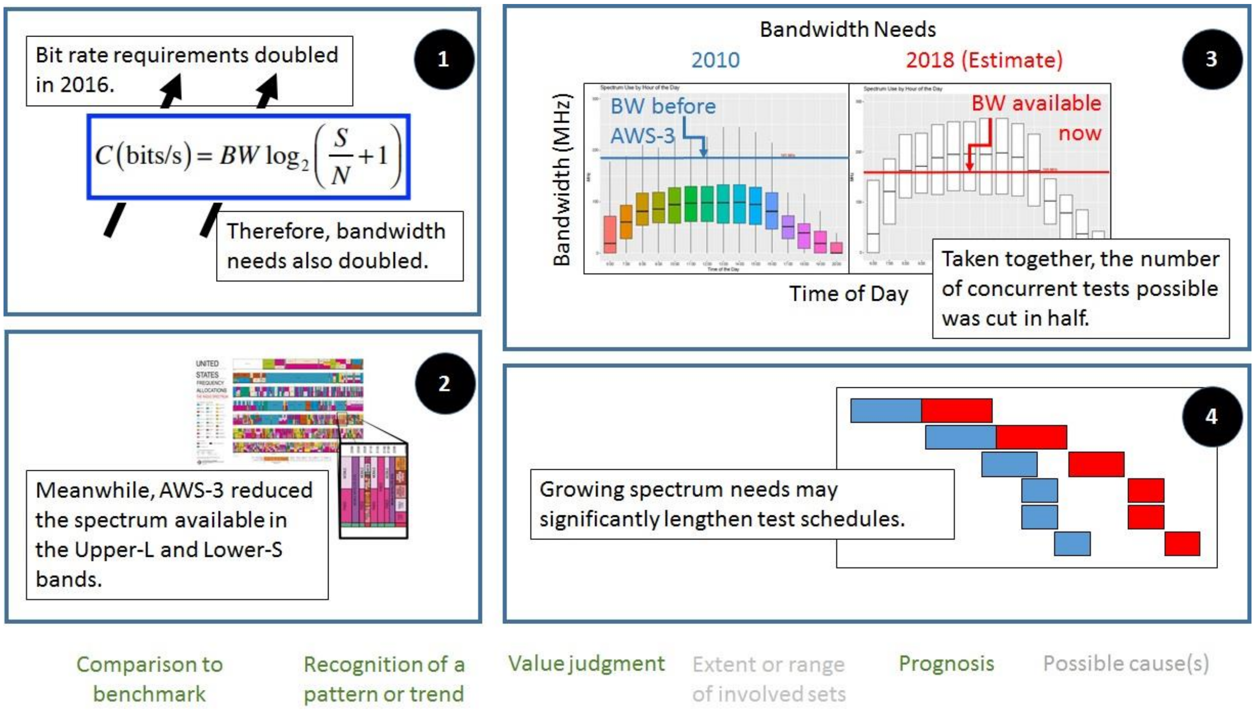

Figure 11. Continued Increases in Bit Rate Requirements May Lengthen Test Schedules

Having studied how to compose these kinds of narratives, the task now involves defining and building extensions to the SMMT to support their construction and maintenance.

CONCLUSIONS

Assured access to electronic spectrum is essential to the success of U.S. military operations both now and in the future. T&E spectrum needs are a vital component of that requirement. It is in that domain of spectrum application that we develop and maintain a decisive technological advantage. The two are inextricably linked. As more advanced technologies emerge, T&E spectrum needs will continue to grow. Many project that growth to be exponential. Meanwhile, the more crowded the spectrum becomes, the more it will become necessary to spread testing missions in time. Of course, doing so lengthens the development time between new generations of fielded weapons technology. Longer lead times, in turn, make it easier for enemy concerns to close the gap and achieve technological parity, or worse.

As evidenced by the past, economic pressures to increase the scope of commercial spectrum use will continue to drive further reallocations of DoD spectrum. If the DoD hopes to maintain the spectrum it needs for T&E purposes, it will have to clearly

demonstrate both the need for that spectrum and the responsible, efficient use of the spectrum. It must also dramatically improve its ability to quantitatively establish the technical, cost, schedule, and safety implications of reduced access and control.
The emergence of the RCC's frequency management metrics standard coupled with tools like the one presented in this paper seek to provide the means to better manage and defend needed T&E spectrum.

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