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# Performance Assessments of Two-Way, Free-Form, Speech-to-Speech Translation Systems for Tactical Use

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*A critical challenge for military personnel when operating in foreign countries is effective communication with the local population. To address this issue, the Defense Advanced Research Projects Agency (DARPA) created the Spoken Language Communication and Translation Systems for Tactical Use (TRANSTAC) program. The program's goal is to develop speech-to-speech translation technologies enabling English speakers to quickly communicate with the local population without an interpreter. DARPA has funded the National Institutes of Standards and Technology to lead the design and implementation of the TRANSTAC performance evaluations. This article presents these evaluations that enabled the collection of rich quantitative and qualitative metrics.*

**Key words:** Automated speech recognition; English speakers; lab and field evaluations; machine translation; military–civilian communication; offline evaluation; Pashto speakers; text-to-speech; translation software.

The Spoken Language Communication and Translation System for Tactical Use (TRANSTAC) program is a Defense Advanced Research Projects Agency (DARPA) advanced technology research and development program aimed at demonstrating capabilities to rapidly develop and field free-form, two-way, translation systems that enable speakers of different languages to communicate with one another in real-world tactical situations without an interpreter (Schlenoff et al. 2009; Weiss et al. 2008). To date, several prototype systems have been developed for traffic control points, facilities inspection, civil affairs, medical screening, combined training, and combined operations domains in Iraqi Arabic (IA), Mandarin, Farsi, Pashto, Dari, and Thai. Systems have been demonstrated on various size platforms ranging from personal digital assistants (PDAs) to laptop-grade platforms. The primary use cases of these technologies involve U.S. military personnel and local foreign language speakers.

Personnel from the National Institute of Standards and Technology (NIST) have served as the Independent Evaluation Team (IET) of the TRANSTAC Program since 2006. As the IET, NIST is responsible for analyzing the performance of the TRANSTAC systems by designing and executing multiple technology evaluations and analyzing the results of these efforts. This article presents the evaluation methodology that was employed in the April 2010 technology evaluations. This also happens to be the first live evaluation that focused on English to and from Pashto and the first that required the system developers to use smart phones. Detailed results of the evaluations cannot be presented due to restrictions on releasing the data.

## System description

There were a total of four English-to-Pashto and Pashto-to-English translation systems developed by separate teams that were evaluated in April 2010. Each team's system architecture is similar in that they feature three principal components: (a) automated speech recognition (ASR), (b) machine translation (MT), and (c) text-to-speech (TTS). When a person speaks, the ASR turns the spoken input into source text. Next, the MT translates the source text into the output target language text. The final step is where the TTS produces spoken output of the target language text. The process occurs in reverse allowing the technology to translate in both directions (to and from English) enabling English and Pashto speakers to converse with one another.

Evaluations prior to the April 2010 test event featured the TRANSTAC technologies operating on laptop-based systems and rugged mobile computer

platforms. The April 2010 test event marked the first evaluation where the translation software solely operated onboard Nexus One smartphones. These systems functioned without the need for any wireless or cellphone connectivity where the translation software was packaged entirely on the phone. Even though the smartphones featured visual interfaces, test subjects interacted with the eyes-free mode where they could operate the technology using buttons that were either built into the device or connected through its external ports. Because the technologies were tested in both the heavily controlled lab and more-realistic fieldlike environments, the teams provided the test subjects with various system configurations that included numerous microphones and headphone options. Each system incorporated the use of the Nexus One's internal microphones to capture speech. In addition, one of the teams featured a configuration with a headset microphone. While some of the teams used the system's built-in speaker to output speech, some of them added on an external speaker for speech output.

## Evaluation design

An experimental method was designed to evaluate the TRANSTAC technologies given their expected state of maturity. The IET created an evaluation approach that would scale well with the technologies as they evolved, which allows for valid assessments of system performance improvements over time. The evaluation design is highlighted by developing a scalable testing approach, devising the scenarios for training and evaluation, and identifying subjects for the evaluation.

## Developing a scalable testing approach

The April 2010 Pashto evaluation incorporated many elements from previous test events conducted by NIST including the June 2009 Dari evaluation and the November 2008 Iraqi Arabic evaluation. It also featured some new procedures and evaluation scenarios that were not previously used. Each testing approach was specifically created to scale alongside the technologies' maturing capabilities.

Per the Broad Agency Announcement, the following two metrics were the focus for the TRANSTAC evaluation: (a) system usability testing—providing overall scores and assessments to the capabilities of the whole system and (2) software component testing—evaluating individual components of the system to see how well they performed in isolation. The IET employed the system, component, and operationally relevant evaluation framework to attain the two TRANSTAC evaluation goals (Schlenoff 2010; Weiss and Schlenoff 2008). The SCORE framework states that to get a comprehensive picture of how a technology is expected to perform in its intended operating environments, it must be evaluated at the component level, capability level, system level, and in operationally relevant environments. Each of these evaluation types yield insight into the various areas of the performance of the technologies being tested. Examining the full results of all of these evaluations provides a multifaceted perspective of how the technology will perform within its intended environment. Although there is no comparison to testing the system in its actual operating environment, it's often more informative to evaluate the technologies in controlled venues until they are mature enough to move into more challenging environments.

The IET utilized the SCORE framework to evaluate the TRANSTAC technologies by designing system level evaluations with live, operationally relevant dialogues where both quantitative technical performance and qualitative utility assessment data were captured. The live evaluations occurred in two venues, the Lab and the Field, which will be discussed in later subsections of this article. Additionally, the individual software components were quantitatively evaluated by using prerecorded audible utterances and predefined textual utterances. These software component tests became known as the "offline" evaluations.

## Evaluation approaches

For both the live Lab and Field evaluations, the IET developed tactically relevant scenarios to gauge the test subjects' use of the TRANSTAC system. The first 17 scenarios were performed during the Lab evaluations within controlled conference room environments across 3 days of testing. The remaining evaluation scenarios were performed during the Field evaluations outdoors on NIST campus for a day following the Lab. Both the Lab and Field evaluations featured Marines who played the role of the English-speaking test subjects and the Pashto speakers conducting conversations in their native languages using the TRANSTAC technologies. The goal of each conversation was for the speaker pair to accurately convey as many concepts, relevant to their motivations, to one another in their allotted time. Each conversation was inspired by scenarios that provided each speaker with a relevant motivation within one of six tactical domains (Weiss and Menzel 2010). At the conclusion of both evaluation types, each speaker filled out questionnaires and participated in interview sessions with evaluation team personnel enabling qualitative assessments of the TRANSTAC systems. Likewise, the quantitative technical performance data were captured by having bilingual human analysts review the detailed conver-

sations between the English and Pashto speakers after the test event. Specifically, the analysts focused on what the human speakers said compared with what the technologies translated. Based upon the bilingual speaker's analysis, the IET calculated numerous quantitative metrics (Schlenoff et al. 2009).

The IET conducted the *offline* evaluations by testing each of the technologies against identical prerecorded audio and predefined textual inputs so comparisons among the systems would be "apples-to-apples." Each system processed identical utterances from audio recordings produced according to the same procedures that were used for creating the training data. As in prior test events, the offline evaluation was conducted during the live evaluations. The systems processed inputs in audio format, logging both the recognition output to test the systems' ASR capabilities and the MT output. Transcriptions of the audio were also processed to test the systems' MT capabilities independent of speech recognition. Using both of these evaluation approaches enables the IET to measure the progressive development of the TRANSTAC technologies and to predict the impact these systems will have on end-user performance within an array of tactical scenarios.

### Lab evaluation

The Lab evaluations are created to assess the TRANSTAC systems in a heavily controlled and ideal environment that features no background noise and stationary participants (both sitting and standing). This type of venue enables the IET and the technology developers to gauge the best the systems can perform at their current state of maturity. Lab evaluations have been important to carry on throughout the life of the program because previous Lab evaluations provide a means to better understand the technologies' long term progress.

The IET produced 17 spontaneous scenarios for the Lab evaluation that the test subjects performed in 15- to 25-minute timeframes. Depending upon the scenario, the speakers were seated across from one another at a table or stood across from one another with the English-speaker holding and controlling the Nexus One. One team presented a configuration that enabled both the English and Pashto speakers to have separate phones that they used to communicate as opposed to a single phone between them. The English-speaking Marines were assigned specific scenarios based upon their deployment experiences. All of the Pashto speakers had experience as interpreters in Afghanistan and/or as role players in training exercises on U.S. military bases, so these personnel were competent in developing their individual dialogues.

Another Marine acted as a scribe during the conversation, where they were responsible for noting the information that the speaking Marine received from the Pashto speaker during their conversation with the TRANSTAC technology. The scribe did not interact with the TRANSTAC technology or the Pashto speaker during the evaluation. The use of a scribe, not done in previous evaluations, not only added more realism to the conversation, but also allowed the IET to collect additional qualitative data because the scribe filled out a survey questionnaire at the conclusion of each conversation. It should be noted that the test Marines took turns being the speaker and the scribe during the test week. The same procedure was repeated during the Field evaluations.

### Field evaluation

The goal of the Field evaluations was to assess the TRANSTAC systems in a more realistic environment. Purposely, the Field evaluations introduced uncontrolled ambient background noise, sunlight, and wind. The Marines carried the TRANSTAC technologies where some featured external, human-attachable speakers and were allowed to move around within their scenario station. Three unique scenario stations were simulated including a white box truck to support a vehicle checkpoint and forward operating base entry control point scenarios, an area to simulate a local national's home to support census and medical conversations, and another area to simulate a facility in support of facility inspection and combined operations planning dialogues. Although this environment was not realistic compared with intended operating conditions, it introduced numerous factors that were not present within the Lab. For example, the vehicle checkpoint scenario that occurred at the box truck station allowed the speakers the opportunity to move in and around a vehicle including opening doors and other compartments. *Figure 1* provides an image of the outdoor Field setup. Note that the individual scenario stations are on the right of the image, while a large tent is shown on the left that supported team setup and staging.

The Marines and Pashto speakers performed eight spontaneous scenarios in the Field where a scribe was employed in the same manner as was done in the Lab evaluations. Likewise, at the conclusion of each conversation, the English and Pashto speakers completed survey questionnaires and participated in semistructured interviews at the conclusion of each block of four scenarios. This enabled the IET to capture end-user utility and perceived value of the technology. Quantitative technical performance metrics were not assessed from the Field evaluation.

*Figure 1. Field evaluation outdoor setup.*

### *Live evaluation constraints*

The live exercises also allowed the speakers to interact with the TRANSTAC systems in a pseudo hands-free, eyes-free manner. The January 2007 Iraqi Arabic–English evaluation was the first time that this constraint was placed on the technology users. During the testing, neither speaker saw the TRANSTAC screen. The only feedback they were provided from the TRANSTAC system was audio, and their physical interaction was limited to push-to-talk capabilities that were either on the touch screen of the phone or using a button on the side of the phone. The concept behind this was that the Marines needed to keep their attention on their surroundings, so the TRANSTAC system should minimally disrupt their situational awareness.

Unlike previous evaluations, noise masking was not used. Noise masking is a solution that was developed and applied in previous evaluations to selectively mask English utterances so that the foreign language speaker, who is bilingual because he or she also understands English, cannot hear them. Under the noise-masking solution, bilingual speakers wore headphones enabling them to hear the translated foreign speech, but when English is spoken, they hear white noise that inhibits their understanding of the English speech.

Noise masking was not used in this test exercise because the Nexus One hardware did not lend itself well to the noise-masking system that was used previously. Software-based noise-masking was briefly explored but not implemented because of the lack of time necessary to design it.

The disadvantage of not using noise masking was that the Pashto speakers could hear the English speech and could be jaded as to how much they understand from the Pashto translation by understanding the Marine's spoken English. The Pashto speakers were instructed to ignore the English speech, though experience has shown from past evaluations that this is very difficult to do.

### *Offline evaluation*

The offline evaluations were set up in a manner where the selected audio and text utterances were input into each team's Nexus One TRANSTAC system, where the output text and speech was captured and analyzed by IET members. Specific to this most recent test event, the offline evaluation featured a total of 1,245 Pashto and English utterances that were treated as a sequestered data set. The corresponding audio files were input into the TRANSTAC systems, which performed ASR, then executed MT to generate text output files. Likewise, the corresponding transcriptions of these same original audio files were fed into the technologies where only MT was executed to produce text output files.

Analysis of the offline evaluation focused on component level analysis of the TRANSTAC systems using automated metrics and human judgments. The following metrics were used to analyze the offline data:

- ASR
  - Word Error Rate (WER)
- ASR and MT together
  - Bilingual Evaluation Understudy (BLEU);
  - Fine grained concept transfer, performed by bilingual human judges;
  - Likert judgment at utterance level, performed by bilingual human judges.

These metrics are discussed further in the Metrics Section and can be found in greater detail in Schlenoff et al. (2009) and Weiss et al. (2008).

## Evaluation participants

The main participants that interacted with the TRANSTAC systems were the Marines and Pashto speakers. Eight Marines and one Navy surgeon, who were identified and provided by the U.S. Marine Corps Forces, Pacific Experimentation Center (MEC), were present at the evaluation. Six Pashto speakers, who were identified and provided by a Middle East cultural

advisor, were present for the evaluation. Some of the Pashto speakers had served as translators to support the U.S. military in Afghanistan. Detailed demographics about these participants can be found in the following section.

In addition to the Marines and Pashto speakers, there were members of the IET that served various roles during the evaluation including station coordinators, interviewers/observers, quality assurors, audio/visual experts, and data collection specialists (Schlenoff et al. 2009; Weiss et al. 2008).

## Demographics

Demographic information was self-reported by each participant via survey instruments. It was collected during the testing period. Participants were asked to provide basic demographic information such as age and gender, some information on their speech and language influences, e.g., languages they speak, places where they have lived, language(s) spoken at home as children, and how often they use computers and how comfortable they are with using them. Additionally, the Marines were asked to provide demographic information related to their military experience, such as rank, length of service, military occupation specialties, and Operation Iraqi Freedom (OIF) and Operation Enduring Freedom (OEF) deployment durations and locations.

To summarize the Marine demographics, all six English speakers were male and had an average length of military service of 8.67 years ranging from 3 to 13 years. Their ranks include two Captains, one Gunnery Sergeant, one Staff Sergeant and two Sergeants, where three are currently on active duty while the other three are reservists. Six Pashto speakers participated in this evaluation with all being male. All of them had immigrated to the United States, where five of them grew up in Afghanistan, while one lived in Pakistan. One participant had obtained a bachelor's degree, one reported attending some college, and four reported having a high school degree.

## Participant preparation

The English and Pashto speaker training was conducted based upon specific sets of rules provided to each speaker group. These rules were emphasized as IET members explained their roles within the evaluation.

## English speaker rules

This training began with each speaker being given specific rules to abide by when they were using the technologies in the evaluation scenarios. The most significant one for the English speakers was

- Your conversation should stay reasonably within the bounds of the scenario's motivation, but you should not feel confined to the talking points specified and are free to reasonably expand upon the motivation. For example, a vehicle checkpoint scenario could reasonably turn into a medical assessment if the driver claims to need medical attention.

Example dialogues were then discussed highlighting appropriate interactions (a single speaker talking at a time, the English speaker directing the microphone and/or speaker at the Pashto speakers when appropriate, etc.) along with undesirable interactions (both speakers talking at the same time, long-winded Pashto speakers where their natural responses would be minimal, etc.).

## Pashto speaker rules

The Pashto speaker training was centered on a list of rules that were provided to these speakers at the onset of their training. These included

- You should provide consistent and relevant answers (example—if you stated you have two children and the technology did not like "two," then you should not change your answer to another number. Rather rephrase your answer or move on, as directed by the English speaker).
- You should pay attention only to the Pashto speech coming out of the technology. Do NOT respond to the English speech from the Marine or from the technology. However, you should expect that you won't receive perfect translations, meaning that a system output of "House mine" reasonably means that this house is mine if the question asked is "Who owns this house?"

The Pashto speakers were presented with examples of both appropriate and inappropriate interactions.

## Metrics

The IET intends the metrics to reflect the goal of the TRANSTAC program: The deployed use of speech-to-speech MT technology that enables consistently successful communication between U.S. military users and local civilians whom they encounter. The TRANSTAC community is in agreement that the two aspects that best identify the ability of TRANSTAC systems to meet that goal are (a) the semantic adequacy of the translations, leading to justified user confidence in the system's translations, and (b) the ability of English and Pashto speakers to successfully carry out a task-oriented dialogue in a narrowly focused domain of known operational need under conditions that reason-

ably simulate use in the field. The latter of those two aspects is presented in the following section. The former is elaborated upon in the rest of this section.

## End-user feedback from test participants

After each live Lab and Field scenario, the Marines and the Pashto speakers filled out a detailed survey asking them about their experiences with the TRANSTAC systems. The surveys explored how easy the system was to use, how well they perceived it worked, and errors that the users encountered when interacting with the system. The Marines and Pashto speakers also participated in semistructured interviews after each morning and afternoon block of live evaluations. These interviews, led by IET members, further explored various questions including "What did you like? What didn't you like? What would you change?" etc., to obtain more candid and pointed feedback on the technologies.

## High level concept transfer for live evaluations

Semantic adequacy of the translations was assessed by six bilingual judges telling us whether the meaning of each utterance came across. The high-level concept metric is the number of utterances that are judged to have succeeded. Thus, failed utterances are not directly scored (other than taking up time). The high-level concept metric is an efficiency metric that shows the number of successful utterances per unit of time, as well as accuracy. This metric is roughly quantitative.

## Low level concept transfer for offline evaluations

Low level concept transfer is a quantitative measure of the transfer of the low-level elements of meaning in each utterance. In this context, a low-level concept is a specific content word (or words) in an utterance. For example, the phrase "The school past the bazaar before the clinic" is one high-level concept but is made up of three low-level concepts (school, past the bazaar, before the clinic).

We had an analyst who is a native speaker of each source language identify the low-level elements of meaning (low level concepts) in representative sets of input utterances from the offline data sets and then asked a panel of five bilingual judges to tell us which low-level concepts were successfully transferred into the target-language output (where failures are deletions, substitutions, or insertions of concepts).

Progress from one evaluation to the next may be presented as a comparison of odds ratio. Odds of successful concept transfer is a more quantitative measure of translation adequacy than the Likert-type judgments of semantic adequacy—the Likert-type judgments give the bilingual judges the opportunity to take into account the relative importance of the various concepts while the low-level concept transfer does not.

## Likert scores for offline evaluations

The next metric is a judgment of the semantic adequacy of the translations. The standard is to measure this by having a panel of bilingual judges rate the semantic adequacy of the translations an utterance at a time. We asked our panel of five bilingual judges to assign a Likert-type score to each utterance, choosing from a seven-point scale.

- +3 Completely_adequate
- +2
- +1 Tending_adequate
- 0
- −1 Tending_inadequate
- −2
- −3 Inadequate

## Automated metrics

Automated metrics are intended to enable the technology developers to better understand what aspects of performance account for the end-to-end success of their systems. It is the intent to identify the automated metrics that can be run quickly and easily yet will correlate strongly with judgments of semantic adequacy provided by bilingual judges. The automated metrics focus on the core technologies. For speech recognition, we calculated WER—using SCTK version 2.2.2 and automated procedures for normalizing the hypothesis and reference texts. For machine translation, we calculated BLEU. BLEU was calculated with four reference translations and is the default version using unigrams through 4-grams.

## Conclusion

The NIST IET learned numerous lessons from the April 2010 test event that will be explored for the August 2010 Dari test exercise. These included (a) shortening the training time for the speakers because the technologies are very straightforward, (b) allowing the English speakers the ability to look at the Nexus One during the interaction to view the output English ASR and Pashto to English MT, (c) enhancing the observation capabilities of the technology developers so they can better view successful and challenging interactions, and (d) targeting English speakers from previous evaluations because they require a smaller learning curve to use the translation systems. Many of these lessons are becoming evaluation improvements that are expected to be deployed in August 2010.

## NIST disclaimer

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