Interactive Voice Uncertainties for Emergency Communication Suspends Automation

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Abstract - **Freedom Fone (FF) is an Interactive Voice Response (IVR) System that integrates with the Global System for Mobile (GSM) telecommunications [1]. Sahana is a disaster information management expert system working with Internet technologies [2]. The Project intent was to mediate information between the FF and Sahana through the Emergency Data Exchange Language (EDXL) interoperable content standard [3]. It goal was to equip Sarvodaya, Sri Lanka's largest humanitarian organization, with voice-enabled disaster communication. The 3.52 Mean Opinion Score (MOS) for voice quality was an early automation challenge in introducing Automatic Speech Recognition (ASR). A 4.0 MOS was determined as a cut-point for classifying reliable voice data [4]. The Percent Difficult (PD) in an emulated speaker-independent scenario was 29.44% and a speaker-dependent scenario was 13.24%. Replacing human operators with ASR software proved inefficient [5] and [6]. This paper discusses uncertainties that are barriers to integrating voice enabled automated emergency communication services for response resource analysis and decision support.**

Keywords-interactive voice response; automatics speech recognition; voice quality; emergency communication; interoperability.

I. Introduction

The number of Internally Displaced Persons (IDPs) from the January 2011 Floods in the Eastern Province of Sri Lanka was the same volume as it was during the 2004 Indian Ocean Tsunami in Sri Lanka (i.e. one million IDPs). Disasters: floods, cyclones, epidemics, and landslides are a common trend in Sri Lanka. Rescue and relief organizations are continuously challenged with managing crises in this island.

The innovation was designed to complement the humanitarian operation of Sri Lanka's largest community embedded organization: Lanka Jathika Sarvodaya Shramadana Sangamaya (Sarvodaya). They respond to all national and local hazard events, aiding victims with rescue and relief services. A survey concluded that telephone calls were their predominant choice for exchanging disaster information [6].

Analysis, [7], on the use of technology choice, in Asia (including Sri Lanka), conclude that simple telephone calls, by a large margin, precedes all other text and broadband based applications. The comparative study in [8] has evidence of low skilled data entry operator errors with voice-based applications to be relative less than Short Message Service (SMS) texting or Internet-forms. Hence, a voice-enabled technology, like FF, has a demanding stake in disaster information communication; especially, in low computer-literate societies like Sri Lanka. it is, indistinguishably, important that a categorical representation of the voice information in an expert system like Sahana is present for rapid analysis and decision support.

Feasibility study to enable FF with Emergency Data Exchange (FF4EDXL) was a research project that adopted emergency content standards as a basis to study the design challenges for exchanging emergency information between voice and text based systems. The action research field tested the integration with Sarvodaya emergency coordinators to evaluate the complexities, usability, and utility when applied in a community-based emergency management setting [5] and [6]. The field testing provided foresight to determine the design strategies in streamlining Sarvodaya's disaster communication needs

In [5] the authors discuss the key uncertainties around human computer interactions and process efficiencies experienced at the central hub. In this paper, the authors' focus is on the voice quality empirical evidence that are challenging factors for adopting speech based automation techniques.

II. Technologies

A. Freedom Fone (FF)

FF is a voice based, interactive, two way information system. It is essentially a software Private Branch Exchange working through the Session Initiation Protocol. The end-users interact through fixed or mobile phones with the system. It doesn't need Internet access.

The IVR uses FreeSWITCH openGSM gateway and a compatible GSM modem (e.g. Mobigater and 2N UMTS). Implementation and information management is through a PHP web based software console with a back-end MySQL database. The audio is compressed and stored as MP3 and

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WAV formats. Interactions with the GSM modem for email and SMS communications are through the Simple Mail Transfer Protocol and Post Office Protocol 3.

This user friendly information system consists of interactive voice menus, voice messages, SMS and polls. FF removes the computer literacy and language constraints [1]. A user can call to this IVR, and listen to the information recorded on the system or can leave a voice message as their response to the system. The IVR 'campaign' feature is one that is capable of automatically dialing the intended recipient to deliver the voice message.

B. Emergency Data Exchange Language

EDXL is a group of content standards that support semantic and process interoperability. It enables coherent work flows between various emergency management systems and organizations. EDXL standards were integrated in to the project because they are open source XML-based protocols with clearly defined elements, capable of supporting data interchange across multiple channels. Since XML enables interoperability, an EDXL-enabled system will more easily integrate with other national or international systems [3].

The project developed software used the EDXL Situational Reporting (EDXL-SITREP) content standard. Its specification contains pre defined message elements that would provide a set of standard reporting formats for XML-based emergency reporting messages.

C. Sahana Eden Situational Reporting Module

Sahana is a free and open source software project [2]. The modular software provides various web services to handle disaster situations. It's efficiencies are intended to minimize the casualties from a certain incident and complement the emergency coordination between governments, aid organizations, civil society and victims [9].

Sahana “Eden” is written in Python using the Web2Py framework with REST model architecture. It can support data storage with any common relational database, such as MySQL, PostgreSQL, and SQLite. Internet Protocol and GSM Terminal devices can interact with the system through the user interfaces. Internet Protocol and GSM Terminal devices can interact with the system through the user interfaces [10].

The project developed an EDXL Situational Reporting (EDXL-SITREP) compliant module for managing standardized incident information (termed as “Eden-SitRep” in this paper) . The basic data model comprised a *Root* element with qualifying mandatory information and a set of reports: *Field-Observation*, *Casualty-Illness*, *Situation-Info*, *Response-Resource*, and *Management-Summary* with each report further structured by a set of mandatory and optional XML sub elements [3].

III. Research Design

A. Research locations and participants

Sarvodaya has a hazard Information Hub (HIH), namely their incident management center, nested in the town of Moratuwa (20Km south of the capitol city: Colombo). Volunteers at Sarvodaya's HIH, referred to as HIH Operators (HIHO) by the project team, were trained to monitor hazard information through various websites and subscriptions (e.g. email bulletins or SMS alerts) for 'events of interest' that might be cause for concern (e.g., a cyclone originating in the Bay of Bengal). From here, relevant information bulletins would be relayed to selected individuals, typically Sarvodaya village leaders, in the communities. These individuals - referred to as CERT members – are responsible for activating local community emergency response plans (e.g. disseminating a local warning or supplying incident reports).

Sarvodaya CERT members from four Districts: Colombo, Matara, Nuwara-eliya, and Ratnapura were selected for the field testing. The regions were selected to cover geographical and population diversities. Colombo (the country's capitol in the west) and Matara (in the south) are two urbanized coastal cities. Nuwara-eliya and Ratnapura are relatively smaller towns in the heart of the tea cultivation lands. Nuwara-eliya is the highest elevated town in Sri Lanka. Matara, Ratnapura, and Nuwara-eliya are less than 180Km from Colombo.

CERT members were exposed to the FF technology and procedures with training to interact with the FF system. Each District had between ten and fifteen CERT members volunteer in the evaluation process. They used their personal mobile phones that had a service through one of the five cellular telecommunications operators.

B. Situational Reporting

The upstream situation reports mainly focused on reporting the facts that were observed and any immediate implications of an event. Situation reports are used to give most up to date details for decision makers of an incident. It provides a quick and easy way to report and disseminate the information to relevant authorities for rescue and relief operations. This kind of reporting is typically used during incidents like natural disasters, sudden breakdowns, accidents, military clashes, so on and so forth.

Researchers identified nine information elements, part of the Field-Observation report, that were necessary and sufficient for constructing a meaningful report. These elements were: *Prepared-By*, *Authorized-By*, *Report-Purpose*, *Reporting-Location*, *Observation-Location*, *Incident-Onset*, *Observation-Text*, *Action-Plan*, and *Immediate-Needs*. The nine elements were enumerated from 1 – 9. When the CERT members recorded a message in the FF IVR, they would first mention the data element number then record the respective content. This provided a delimiter for the evaluators to distinguish between the nine pieces of information that constituted a single record (or report).

C. Test design

The evaluations were based on controlled-exercises with CERT members, first, formulating incident scenarios based on their past disaster response experiences; thereafter, reporting those incidents following the given guiding standardized situational reporting format. The CERT members used their personal mobile phones to communicate the information from a natural environment. Those messages were recorded in the FF IVR system stationed at the Sarvodaya HIH.

As illustrated in in Figure 1, CERT would first *assess an incident. Call FF* and *leave a message*, namely record a Field-

Observation report, to begin the situational reporting work flow. A Field-Observation report described the nature of the incident (e.g. a bridge inundated with flood water) and request for immediate rescue and relief resources (e.g. need for a boat and crew to shuttle people and goods across the bridge). HIHO would *replay the message* through the FF web interface to *extract information*. The local language (Sinhala or Tamil) extraction, they must translate into English, then *enter data* in to Eden-SitRep in text form. Thereafter, *complete all Situation-Information* by categorizing the incident, marking the location on a map, and setting the time details, filling other pertinent attributes. Upon committing the HIHO will *get a confirmation*, namely the report ID. HIHO will *send the confirmation (via SMS)* to the respective CERT member.

After the situational report is completed, the HIHO *analyze all Field-Observations* reported to derive or *plan the resources* required to respond. Subsequently, the HIHO will *get a report* that is a comprehensive Response-Resource report. They *create the report in audio form*, with the "Audacity" audio recording software tool and *uploaded to FF*. An SMS is sent to the CERT member(s) to *alert" "report is ready"* for review and that their resource request was processed with those resources ready deployment. The CERT members can *listen to the report* through FF.

The envisioned automation would be for an ASR engine to transform the Field-Observation report audio message received from the CERT in FF to text. Then another software process to parse that information in to the relevant SITREP categorical data elements, before automatically creating a new record in Eden-SitRep. An HIHO would still need to peg the location on a map and complete the Situation-Information. Similarly, once the Response-Resource report is generated, a Text-To-Speech engine would automatically create the relevant audio file and upload it to FF. The automation would replace most HIHO functions described in Figure 1. Given, the underdevelopments of ASR and Text-To-Speech for local languages, the project had HIHO perform those tasks.

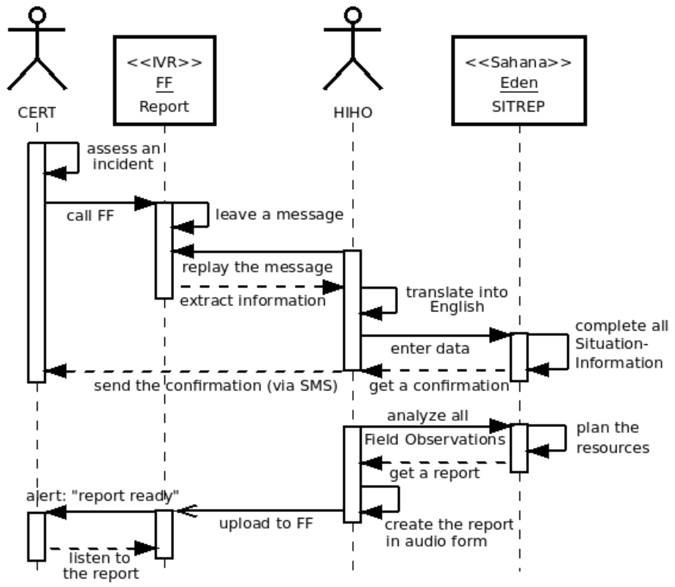

Figure 1: Situational reporting messaging sequence

IV. Methodology

A. Two exercise scenarios

CERT members in the four pilot districts were subject two exercises emulating a speaker-dependent and a speaker-independent process. The reader may refer to [11] and [12] in order to gain knowledge on speaker-dependent and speaker-independent computer science paradigms. Recordings from the first and second exercises that consisted of simple, meaningful, short sentences produced required speech samples. All sample voice recordings were received by the IVR system through the telecommunication networks in the form of a telephone call, with CERT members speaking into a mobile phone from the other end of the telephone line.

Speaker-dependent exercise involved Sarvodaya members responding to a set of questions related to disaster information. The questions were combined with a choice of answers to select from. They voiced the applicable answer through the the phone handset and was recorded in the FF IVR. The multiple choice questionnaire resembled a speaker-dependent system where the evaluators had a sense of the answers. Therefore, their cognition could predict the answer, in spite of any distortion in the voice recording.

Speaker-independent exercise did not restrict the CERT members to a selected set of answers. They were given a reference guide to follow a sequence of questions. The participating CERT member spoke naturally and freely to record the information with vocabulary and sentences of their own choice (i.e. large vocabulary continuous speech scenario). The evaluators analyzing this information, besides knowing the question, were unaware of the answers. This process emulated a speaker-independent system with no prior cognition to recognize or anticipate the patterns of the received speech data.

B. Voice quality tests

International Telecommunications Union (ITU) P.800 recommends several methods to test transmission quality in one's own laboratory [13]. MOS and PD are two such evaluation schemes. These two tests were applied to evaluate the voice sample quality from the two exercise scenarios.

In justifying the reliability of the infrastructure, MOS determines how satisfactorily telephone connections and FF IVR system may be expected to perform. This is a subjective evaluation method with human evaluators exposed to the voice samples and asked to rate them on a scale of 1 – 5 (1=Bad, 2=Poor, 3=Fair, 4=Good, and 5=Excellent).

Evaluators were asked to determine the difficulty of transforming that information to categorical text-based information. If the audio was free of any intolerable noise and the information could be clearly deciphered, then it was labeled *clear*; else noted as *unclear*. An intermediate label termed *partial* was used when only parts of the information were clear. The number of empty answers were distinctly labeled *missing*.

To include the extra element: missing and partial responses besides the clear and unclear elements was because missing information or incomplete information can lead to false predictions and subsequently lead to inappropriate responses.

V. Results

There were 51 participants in the speaker-dependent exercise and 48 in the speaker-independent exercise. Each participating CERT member produced two recordings; i.e. one for each exercise type. Three and seven evaluators assessed the speaker-dependent and speaker-independent exercises, respectively.

The MOS evaluation considered each recording as a single sample; thus 51 and 48 samples for the two scenarios. Therefore, the speaker-dependent exercise resulted in 153 (3 x 51) opinions and speaker-independent exercise in 336 (7 x 48) opinions. Figure 2 and Figure 3 show the District-wise distribution of the MOS values.

However, each voice sample could be partitioned in to 10 for the speaker-dependent and 9 for the speaker-independent elements, which produced 1530 (51 x 3 x 10) speaker-dependent and 3024 (48 x 7 x 9) difficulty ratings. During the second iteration of the exercise; thus, the speaker-independent exercise, the researchers realized that one data element was redundant; hence, the 10 elements during the first and 9 elements during the second exercise. Figure 4 and Figure 5 show the District-wise distribution of the PD values.

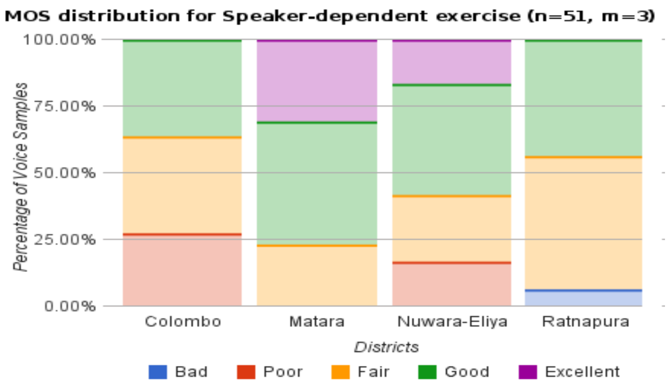

Figure 2: District-wise MOS distribution for speaker-dependent exercise

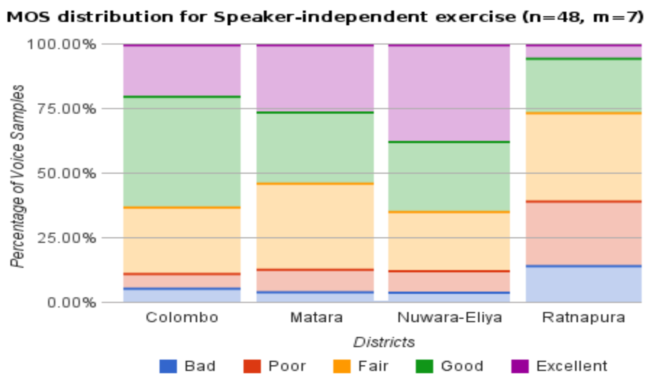

Figure 3: District-wise MOS distribution for speaker-independent exercise

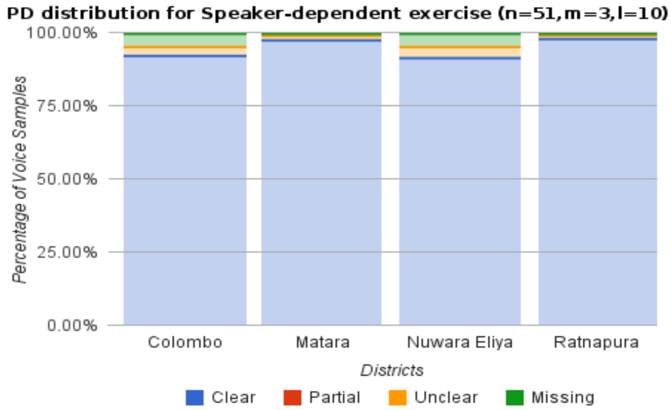

Figure 4: District-wise PD distribution for speaker-dependent exercise

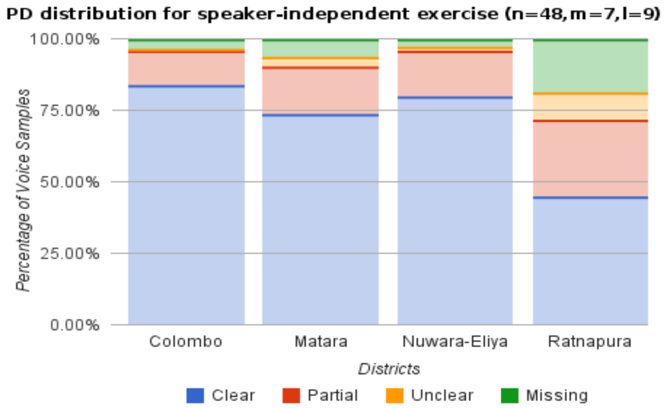

Figure 5: District-wise PD distribution for speaker-independent exercise

The MOS and PD in Table I are the overall ratings for all four districts. The PD value in Table I is are all voice elements that were unclear, partial, or missing. Thus, 1 – PD would give the percentage of clear (or undistorted) voice samples.

TABLE I: Summary of MOS and PD for the two exercises

Exercise	MOS	PD
Speaker-dependent	3.39	13.24%
Speaker-independent	3.52	29.44%

The authors wish to acknowledge that the sample quantities and evaluators are asymmetric between the two exercises; however, the results provide sufficient evidence to complement the qualitative findings. Figure 6 shows the variance in the speaker-dependent and speaker-independent exercise MOS values.

The MOS and PD are subjective evaluations. It would be recommended that subsequent evaluation methods also adopt an objective method does not involve human evaluators but possible calibrated instruments of some sort. Given that the broader scope of the FF4EDXL project was to investigate all Sahana and FF integration opportunities, the research team found the MOS and PD methods sufficient for surviving the purpose of empirically ruling out the ASR and TTS automation reliabilities.

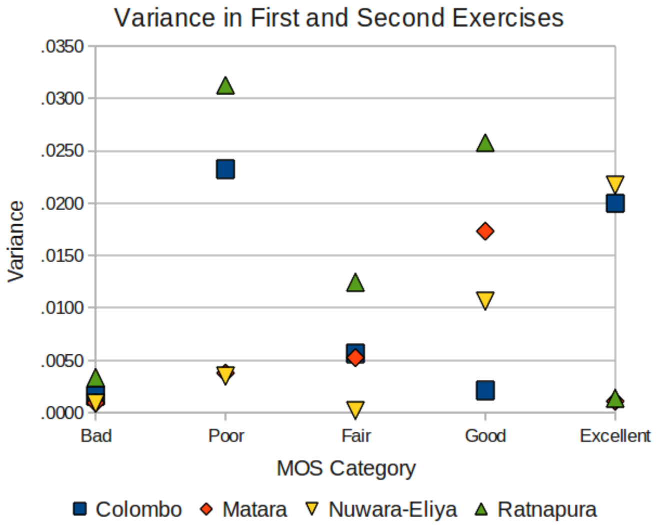

Figure 6: Variance in speaker-dependent/independent MOS

The data displayed in Figure 6 is obtained by calculating the the variance of the exercise data tuples: speaker-dependent and speaker-independent for each of the five MOS categories.

VI. Discussion

The project encountered a few technical difficulties in operationalizing FF and Sahana. However, the Sarvodaya participants agreed that the innovation proved useful and acceptable for their disaster communication needs. FF4EDXL lessons to date suggest that streamlining the work flow is not easy until the bottlenecks are rectified. Further research and developments are necessary to improve the efficiencies before a full scale implementation can take place.

It can be argued that the precision of exchanging complete information between FF and Eden-SitRep, largely, depended on the voice quality. The unreliable voice data disabled the HIHO aptitude to fulfill EDXL-SITREP requirements. This shortcoming, subsequently, would lead to inaccurate resource planning for crisis response.

A. MOS below expectation

The District-wise MOS stack plots, in Figure 2 and Figure 3, illustrate varying patterns with a diverse range of ratings. These can be related to the urban rural divide and access to reliable communications. Ratnapura and Nuwara-eliya District exercises were conducted in a rural environments. Moreover, both these districts are in the hill country with rough tropical forestry terrains. Relatively, the Colombo and Matara District exercises were carried out in an urban setting close to the main cities. The Colombo and Matara exercise locations were close to the coastal belt of Sri Lanka; thus, less prone to terrestrial effects.

The two exercises resulted in similar MOS value of 3.39 for the speaker-dependent and 3.52 for the speaker-independent field tests (Table I). These values are below the MOS 4.0 cut-point suggested for voice-based emergency communications in [4]. It was estimated for only 53.84% of the speaker-dependent and 51.84% of the speaker-independent voice samples to be good or excellent.

The variance plot for the two exercises, Figure 6, points to bad quality voice sample percentages to approximately be the same. However, Figure 6 shows noticeable variances in the different MOS categories for each of the Districts.

Kajackas et al. [14] discuss the speech quality impairing factors limiting the Quality of Service (QoS). These degradation factors are time variant caused by changing communication conditions such as the weaker QoS occurring at cell edges (i.e. signal weakness is proportional to the distance away from the cell tower). This would explain the Figure 6 illustrated variances in the District-wise MOS for the two exercises; i.e. there is no set pattern as the quality is time variant. The low MOS in Ratnapura, relative to the others, was apparent because users were struggling to receive a clear signal (Figure 5 and Figure 6).

B. Difficulty in deciphering information

Information ambiguity, in crises management, is unacceptable as it could lead to false predictions and inappropriate actions. Therefore, information completeness is of utmost importance.

Human cognition is capable of processing and reasoning in manifolds than a machine. An experienced mind can identify those errors to interpolate the missing, unclear, or spatially clear pieces of information. Another countermeasure would be to call the CERT member to verify the information.

A 5% PD would be acceptable and the frequency and likelihood for the need to confirm the information would be tolerable. However, the results: 13.24% and 29.44% for the two exercises, given in Table I, are below expectation.

Meant time to completion analysis, in [5], estimated an average 8.57 minutes for the HIHO to complete the process of listening to the voice message and then transferring that to Eden-SitRep. The average time of a Field-Observation report voice recording was 1.38 minutes. The external human Observers, monitoring the HIHO actions during the exercises, documented that the HIHO were replaying the audio recording repeatedly in order to decipher the information. This is a consequence of the high PD.

Intuitively, the speaker-dependent exercise revealed that it was easier to decipher information relative to the speaker-dependent exercise. Given that both exercises resulted in similar MOS scores but the PD results significantly differed (Table I), it can be argued that, in the presence of noise, a speaker-dependent system would increase the reliability.

Investments in training both CERT and HIHO to properly use common structured language pertaining to disaster information communication may possibly improve the efficiencies and reduce the PD. However, in a community-based voluntary emergency management setting, one cannot expect untrained volunteers to be skilled in the domain specific communication. Moreover, emergency communication requires *large vocabulary continuous speech* recognition techniques for multiple accents and dialects. Therefore, integrating any kind of ASR for automation would be impossible under these conditions; at least, until such time the communications infrastructure can promise higher quality for voice.

C. Other factors

Another, disaster related, quality impairing factor is, the telephone networks, themselves, being victims of a disaster. The Dialog Axiata (previously Dialog Telekom) experience from the 2004 Tsunami was that it took them 3 days to restore 66% and 4 days to restore 100% of the GSM infrastructure [15]. With partial network infrastructure QoS would be questionable; thus, further effecting the voice to text information exchange efficiencies.

The final IVR audio file received through the, project used, 2N UMTS modem was a MP3 (Moving Picture Expert Group Audio Layer III). In multiple network topological scenarios, the coding and decoding process at various interconnections is known to degrade the voice quality [16]. Once, the degraded GSM voice data is received by the modem and compressed to an MP3 the noise gets further amplified.

D. Recommendation

A workable solution would be with VoIP (Voice over the Internet Protocol) with MP3 quality audio transmissions. Such high quality data would be less prone to noise and could possibly be subject to ASR to complement the HIHO work flow and subsequently improve situational reporting efficiencies.

Noise cancellation algorithms are also available. These can be adopted to cleanse the voice messages before processing to decipher the information. The project did not experiment this aspect and would be considered in future research.

VII. Conclusion

The users agree that the FF IVR is an easy to use and usable solution for communicating disaster information for crisis response. Given that mobile phones serve a dual utility of daily use besides emergency communication, it solves the sustainability part of the equation. However, the IVR shortcomings at the central hub for reliable processing of the voice data in support of decision making must be addressed. The low quality voice and difficulties of deciphering information for categorical text based representation disallows for applying any kind of ASR for automation. Until network QoS is improved, use of ASR for automating voice-enabled solutions should be suspended. There is a demanding need for further research in the voice platform to offer inclusive applications to offer developing nations such important public goods.

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