Evaluating the User Interfaces of an Integrated System of In-Car Electronic Devices

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Abstract—**The Project54 system integrates electronic devices in police cruisers and provides a speech user interface and a GUI. It also incorporates the original user interfaces provided by the devices' manufacturers. We evaluate how the different interfaces are used by officers in the field and report on three lessons on designing in-car user interfaces.**

I. Introduction

THE Project54 system [1], integrates electronic devices in police cruisers and also connects these devices to central databases over wireless networks [2]. In the integrated system in-car and remote devices can share data. The police officer can interact with the system using a speech user interface (SUI), a GUI displayed on a touch screen, or the original manufacturers' user interfaces. Controlling the system by voice allows the officer to keep his or her eyes on the road and hands on the wheel while driving.

As of February, 2005, the Project54 system is installed in approximately 300 cruisers in the US, about 240 of those in the state of New Hampshire. In this paper we report on a quantitative and a qualitative evaluation of the system's user interfaces in the field. For the quantitative evaluation we interviewed six New Hampshire State Police officers by asking them a set of nine prepared questions. For the qualitative evaluation we accompanied the same six officers on patrol, recorded our experiences (observed officer interactions with the Project54 system and officer comments about the system) and later analyzed these experiences. We spent about two to four hours on patrol with each officer.

II. Background

Nulden conducted field studies of police work with the goal of assessing how information technology (IT) solutions can help with law enforcement work [3]. His findings are summarized in three general characteristics of law enforcement work that should be taken into account when designing an IT solution for police. Researchers at Texas A&M worked on improving the functionality of police cruisers using advanced electronics through the ALERT project [4]. The project addressed the need to integrate various electronic devices in police cruisers. However, the project did not result in the acceptance of a standard for integration; rather it was a proof-of-concept effort.

Speech recognition in cars is of great interest to researchers as well as industry. An ambitious effort uniting car manufacturers, telecommunications equipment manufacturers, mobile telephone network operators, and universities is the SpeechDat-Car data collection effort. SpeechDat-Car collected in-car speech data from multiple languages [5]. The data is available in databases that can be used to improve the performance of speech recognition in cars. In-car speech user interfaces have been developed by a number of groups. Wahab et al worked on creating a dashboard system for intelligent vehicles that would be able to handle data and speech communication [6]. They paid special attention to combating noise in the car that interferes with voice communication. Muthusamy et al created a prototype system for information retrieval in cars [7]. The system has a voice interface (input and output), and it can be used for voice dialing, Internet operations and help with navigation. Hunt [8] describes work on in-car speech recognition at Dragon Systems UK R&D. Kun et al [1] describe a system that integrates multiple in-car devices and lets the user interact with them using a SUI. Using a SUI to interact with in-car devices promises to make such interactions safe, however poor SUI design can result in unsafe interactions which in turn can lead to accidents [9].

III. The Project54 System

The Project54 system installed in a police cruiser is shown in Fig. 1. The center console houses a PC that is at the center of the system. The PC interacts with all the in-car devices through a Controller Area Network (CAN). The Project54 system software runs on the PC. This software implements the SUI and the GUI and keeps both synchronized with each other as well as with the original user interfaces provided by the manufacturers. Three of these original interfaces (controlling the lights and siren, radio and radar) are in the center console in the system in Fig. 1.

A. *Speech user interface (SUI)*

The SUI uses a commercial speech recognition (SR) engine (we have worked with several recognizers and are

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currently using the Microsoft SAPI 5 recognizer). It also uses a commercial text-to-speech (TTS) engine. The SUI gets speech input from a directional microphone on the visor which reduces the influence of sounds that are not coming from the driver of the vehicle – this improves SR engine performance. The SUI also uses a push-to-talk button on the steering wheel. Recognition is started when the PTT button is pressed and it is stopped when the button is released. SR performance is also improved through the introduction of grammars. Grammars describe rules that the SR engine "believes" govern utterance generation. Grammars are switched by the SUI in response to officer utterances. For example, the officer may be filling in a form in which one of the fields describes the gender of a person. The officer may say 'Gender' to signal that he/she will tell the SUI the gender of the person next. At this point the SUI loads a simple grammar which only lists the two genders and one or two other utterances (such as "cancel").

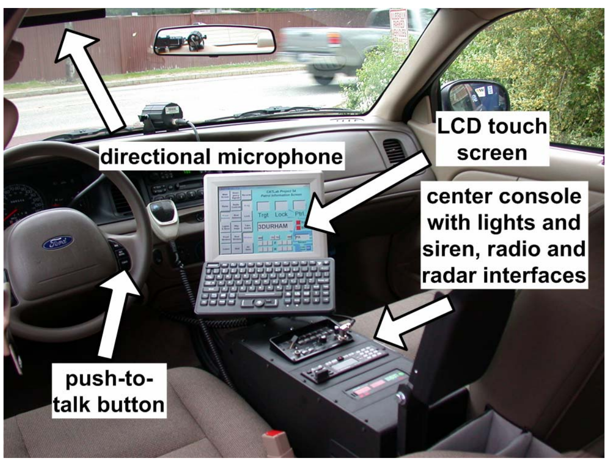

Fig. 1. Project54 system user interface in a cruiser.

In our system human-computer interaction is relatively simple: the officer utters a phrase and the SUI reacts to this utterance. The SUI may execute a command, fill in a data field or initiate data retrieval. The SUI does not initiate interaction.

When the user utters a command the SUI responds by saying the recognized utterance. This allows the officer to check if the recognition was correct. While this is a very useful feature it also slows down the interaction. In many cases the officers do not need, or have the patience, to listen to the SUI repeat the entire command they just issued. The officers can cut off any SUI utterance by pressing the PTT button. This makes sense when hearing even a fragment of the SUI's utterance makes it clear that the officer's utterance was recognized correctly. However, cutting off the SUI is risky when the utterances are novel, for example when the officer is spelling a name or entering a plate number using voice. In such cases there is no way to know if the utterance was recognized correctly without listening to the entire SUI utterance (or looking at the GUI).

The SUI can also be set up to echo the officer's utterance (the speech input is just sent back through the speakers). This is a useful feature during training. The officers can learn how to operate the PTT button in order not to cut off their utterances, what the effects of environmental noises are on the signal-to-noise ratio, etc.

Utterances that the SUI does not recognize are either misrecognized as another command or unrecognized. A misrecognized command leads to the execution of the wrong command which usually has to be undone.

B. GUI and original manufacturer interfaces

The system also provides a GUI and incorporates the original manufacturers' user interfaces. The GUI and the original user interfaces can be used in case the speech interface is not available or when speech interaction is not practical or desirable.

The GUI is most useful when there is a large amount of data to be presented to the officer. For example, when the officer queries a driver license database, the query may return a large amount of data, enough to fill several screens. With the GUI the officer can peruse this information at will. Of course, this is only safe if the cruiser is parked.

We included the original manufacturer's interfaces primarily as a backup to our system. We felt that having them available will make officers more comfortable with a computer-based system. After all, if our system were to crash, the officer could still operate the in-car devices using the original user interfaces. In that case the officer would just have a traditional cruiser, without any device integration.

The SUI, GUI and the original user interfaces are synchronized by the Project54 system. Thus, the officer can mix the way he or she interacts with the system to suit the situation at hand. For example, if the officer is driving and wants to query a vehicle registration database, he or she should use the SUI. However, if the officer parks the cruiser, the same query may be initiated faster using the GUI.

IV. Quantitative Evaluation (Interviews)

As part of this study, we accompanied six officers on patrol. Before starting each patrol we asked the police officers to answer nine questions. The questions were presented in the form of a questionnaire and the officers responded in writing. A member of the Project54 team was present while the officers filled out the questionnaire.

A. Officer responses

The questionnaire had two parts. In the first part we wanted to find out the relative frequency with which officers use the speech user interface (SUI), the Project54 graphical user interface (GUI) and the manufacturer's original user interfaces (UIs). Therefore, we asked the officers to estimate how often they used these devices. They could pick one of the following four responses: several times an hour, several times a day, a few times a week or never. We also wanted to find out the length of time the officer had the Project54 system installed in his or her cruiser (less than a month, one to three months, more than three months).

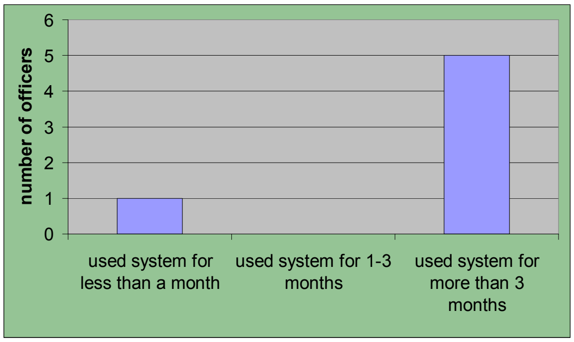

Fig. 2. Length of time the officers used the system.

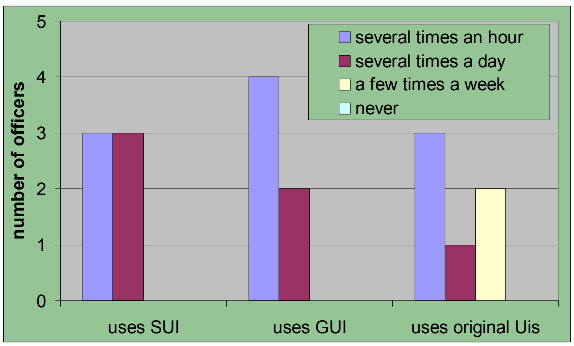

Fig. 3. Self-reported use of user interfaces.

As shown in Fig. 2, at the time of their interview, five of the six officers had used the system for over three months and one officer had used it for less than a month. Fig. 3 shows the officers' estimates of how often they use the Project54 SUI and GUI and how often they use the original manufacturer-provided UIs.

The second part of the questionnaire attempted to determine how well the Project54 SUI was received by officers. The officers were asked to indicate their level of agreement with the following statements:

1. You like using the Project54 system.
2. You are satisfied with the accuracy of speech recognition in the car.
3. Using voice commands improved your productivity.
4. Using voice commands made operating your cruiser safer.
5. Given the choice, you would prefer to continue using the Project54 system instead of using the in-car devices as stand-alone devices.

The questionnaire employed the Likert scale and officers could select between the following four options: strongly agree, agree, disagree and strongly disagree.

Fig. 4 shows that the officers liked the system and were more or less satisfied with SR accuracy. The majority of the officers did not think that their productivity was improved because of the SUI but they did believe that operating the cruiser was safer with the SUI. Finally, given the choice they said they would keep using the system and not go back to using only the original manufacturer UIs.

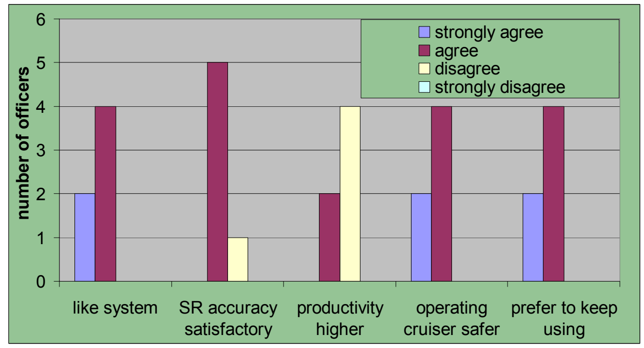

Fig. 4. Officer responses.

B. Discussion of questionnaire results

The data in Fig. 3 is encouraging – it shows that officers do use the Project54 system interfaces, apparently more often than they use the original UIs. It also shows that our design decision to make the original UIs accessible was the right decision since the officers continue to use some of them. It is worth pointing out that the absolute frequency of interaction with a given user interface is not necessarily a significant piece of evidence of acceptance of the given interface. The actual frequency of interaction depends both on acceptance and on need. For example, an officer who patrols a busy highway may pull over drivers several times an hour. Each time this officer gets ready to pull over a car he or she will turn the lights and siren on and, if a radio connection to headquarters is available, will query vehicle registration and driver license databases. For these actions the officer may use the Project54 system. On the other hand an officer who patrols a rural area may spend a large amount of time outside of the cruiser, going over paperwork or talking to subjects. Even when in the cruiser, this officer may not encounter much traffic and will consequently not use the cruiser's lights or its radio connection. Therefore, this officer will not use the Project54 SUI or GUI very often even if he or she is comfortable using the system.

The data in Fig. 4 is also encouraging. Officers like the system and want to continue using it. This positive attitude is a crucial requirement for the success of the system. As described in section V, our observations confirmed that the officers were eager to make the system work. All six officers also felt that the SUI made in-car interactions with the cruiser's electronic devices safer. As described in section V our driving experience with officers showed that this is almost always the case. Officers do not have to take their eyes off the road to change radio channels and query remote databases. However, some of them use the GUI while driving for tasks that are not safe to execute while driving, such as scrolling through results of a records query (this activity is similar to interacting with a driver navigation display while driving, which is documented to cause accidents [9]).

The officers were not completely satisfied with speech recognition accuracy, with five officers agreeing (but not strongly) that the recognition rate is satisfactory, and one officer disagreeing. We have recently finished a long term study aimed at quantifying the performance of the SUI [10]. The results of this study show that the SUI recognition rate is around 85% which, while workable, is not excellent. This seems to be reflected in the officers' responses about the recognition accuracy.

By a four-to-two majority officers do not believe having the SUI made them more productive. This result surprised us since using the SUI enables officers to query remote databases while driving, which we expected them to link with productivity. Three factors might have contributed to this outcome. One is that two officers patrolled areas in which the radio system did not allow access to remote data. The second is that the other officers had had access to vehicle and drivers' records in the car before the Project54 system was installed in their cruisers [2]. Their old system did not have a SUI; however, officers may have felt that they were able to access data just as easily with this application as they are now with the Project54 system. Of course they would not feel this way if they were regularly executing queries while they were driving. Finally, the third factor might have been that a majority of the six officers we talked to do not patrol major highways, which is where they would be likely to encounter a lot of traffic and where they would be likely to execute records queries while they are driving.

V. Qualitative Evaluation

While accompanying the officers on patrol we collected information about how they interacted with the Project54 system in two ways: by taking notes of officer actions and by writing down officer comments.

A. *Using the SUI to control lights and sirens*

All but one of the officers used the SUI to operate the lights and siren at least some of the time. One of the officers said that this was his favorite feature of the system, while another was very pleased with the "Lights off" command that turns all lights and sirens off. As shown in Fig. 1, the original manufacturer's user interface for the lights and siren is easily accessible in the center console of the cruiser. Officers use this interface at least some of the time.

B. *Using the SUI to control the radar*

None of the officers used the SUI to control the radar. The delay introduced by the SUI is too long to be able to successfully capture the speeds of vehicles of interest. Officers used the original manufacturer's user interface to operate the radar.

C. *Using the SUI to access databases*

Four of the six officers we interviewed had access to off-board databases through their in-car digital radio. The radio could access these databases using so called data-capable channels, for which the radio system is configured for data transmission as well as for voice transmission. Two officers patrol in areas where radio coverage does not provide a data-capable channel. The four officers with access to data-capable channels used the SUI to access off-board databases. The databases most often accessed were of two basic types: vehicle records databases and driver records databases. The officers would usually proceed by first accessing a vehicle database and then accessing the driver records database. Two of the officers would access the vehicle database before they pulled over a vehicle. One of these two officers specifically mentioned liking speech input for data queries and was observed entering plate numbers verbally several times an hour. However, this same officer was also observed as he looked at the LCD screen of the Project54 system scrolling through the returned results instead of listening to the speech feedback of the SUI. Once they pulled over a vehicle officers would approach the driver, take his or her driver's license back to the cruiser and use either the system's GUI or the SUI to enter data from the license and check the driver's records. Two of the officers said they used the SUI to execute driver record queries. Accessing the vehicle records database was not always possible before the vehicle was pulled over. When this happened some of the officers would initiate this query before they walked over to the vehicle. This was done with the expectation that, by the time the officer returned to the cruiser, the query would be complete.

It was interesting to observe that while entering data using the SUI officers would cut off the computer's responses by pressing the PTT button. As they used the system day after day, these officers became so familiar with it that they did not need the voice feedback past the first couple of phonemes. Of course this approach is risky. One of the officers was observed as he attempted to enter "KURT" as the first name of the driver. However, the system made a mistake and understood "KRT." Since the officer did not listen to the system feedback he did not notice this and he executed the wrong query.

D. *Using the SUI to control the radio*

The radio can be tuned to about 200 preprogrammed channels. The officer can select one of these channels by manipulating four buttons on the radio control head and, if necessary, observing the eight-digit LCD display on the control head. Of course, this is difficult to do while driving. Using the Project54 SUI the officer can say the name of a radio channel and the software interacts with the radio control head to accomplish the tuning. There is no need for the officer to take his or her eyes off the road or hands off the wheel.

Officers who patrol rural areas often use the radio to interact with local police departments. These officers change the radio channel relatively often. Four of the six officers we interviewed fall into this category. They all used the SUI to change radio channels.

E. SUI recognition performance

Officers found the recognition rate of the SUI adequate. Several officers noted that recognition is adversely affected by noises generated inside or outside the cruiser. Noise sources that, according to officers, diminished recognition were the FM radio, the police radio, noise from the radar device and noise from the siren. It is worth noting that siren noise may have been a problem in an indirect way, by causing the officer to change his speaking voice (for example through the Lombard effect).

The police radio interferes with speech recognition when there is voice traffic on the radio channel the radio is tuned to and at the same time the officer is trying to issue a voice command. This was especially the case in cruisers where the radio speakers were placed behind the driver, level with the driver's head. The in-car directional microphone will therefore not filter out sounds coming from the radio speaker as it would if the speaker was placed in any other location.

Officers were open to suggestions regarding improving SUI recognition performance. One of the officers specifically mentioned that he realized that some of the recognition errors were due to his mistakes or interference from the police radio. Others accepted suggestions about how best to use the SUI. For example, one of the officers learned the "Lights off" command while on patrol with us. Another officer learned that pushing the PTT button too late or releasing it too soon may cause SR errors. This officer complained to us that the SUI often recognized "Missouri" when the officer said "New Hampshire." We showed him that by pushing the PTT button just a little after starting to say "New Hampshire" he could consistently get the SR engine to recognize "Missouri."

VI. Lessons Learned

A. Speed and safety of interaction influence the acceptance of a user interface

We found that officers used a user interface by balancing the speed and safety of interaction with a device that the interface provided. Fig. 5 illustrates how fast and how safe it is to interact with in-car devices using the different user interfaces while driving. In the figure, UI denotes an original manufacturer's user interface and SUI and GUI are user interfaces implemented by the Project54 system.

As illustrated in Fig. 5, executing records queries without using the SUI ("UI radio records") is often very slow. The delays come from having to interact with the dispatcher who is often already busy working with other officers. If the dispatcher is available, the officer has to tell the dispatcher what data to retrieve and then has to wait for the dispatcher to read back the results. Telling the dispatcher the details of the inquiry takes roughly the same amount of time as telling the Project54 system what the inquiry should be. However, the dispatcher may be able to read back relevant information quicker than the current version of the Project54 system. Overall, performing records queries using the Project54 SUI is faster on average than asking the dispatcher to do so because the officer does not have to wait for the interaction to start. Consequently the SUI was the interface of choice of all of the officers. One of the officers used the GUI to review records, while driving. As we show in Fig. 5, this may be a fast way, but it is not a safe way, to interact with the Project54 system.

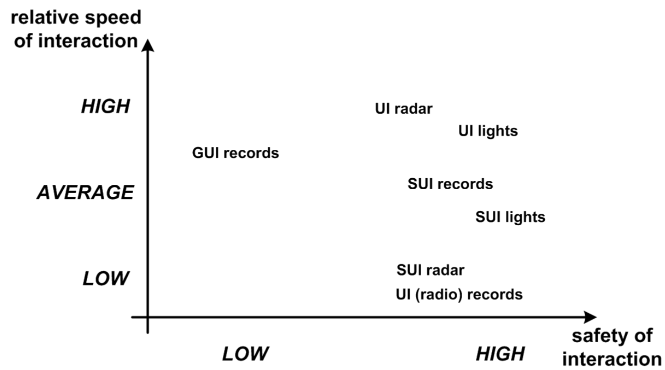

Fig. 5. Relative speed of interaction and safety of interaction with user devices while driving.

When officers operate the lights and siren of the cruiser they may only require moderately fast responses from these devices. For example, when they park the cruiser at a road construction site they will turn their rear strobe lights on but do not have to have them turn on instantaneously. At other times, officers want the response to be near-instantaneous, for example when they need to quickly start pursuing a vehicle and they need to enter busy traffic to do so. The user interface of the lights and siren that is provided by a manufacturer has buttons and levers. Operating these mechanical forms of input changes the status of the lights and siren without perceptible delay. Using the SUI to control the status of the lights and siren ("SUI lights" in Fig. 5) does introduce a delay – at a minimum the SUI needs to listen to the entire utterance of the officer (e.g. "Strobes" uttered after the PTT button is pressed and before it is released), which may take a few hundred milliseconds. For some officers this kind of delay is not a problem and they use the SUI to control the lights and siren. For others, it is easier to reach the lights and siren user interface in the center console (see Fig. 1) and control the lights manually ("UI lights" in Fig. 5). Consequently, officers used both the SUI and the original manufacturer's user interface to control the lights.

Operating the cruiser's radar involves noting the vehicle that is in the radar's sights at a given time and pushing a button to record the speed of the vehicle at a given moment. This is often done when the cruiser is parked by the side of the road and the targeted car is moving at high speeds possibly surrounded by other vehicles. Speed of operation of the radar's buttons is crucial in acquiring valid and incriminating data – e.g. in 500 milliseconds a car traveling at 100 km/h (about 60 miles/hour) traverses almost 14 meters (over 45 feet). Using the SUI to control the radar when trying to lock in on the speed of a vehicle is impractical because it takes the officer several hundred milliseconds to press the PTT button, say "Lock" to save the speed of a vehicle and release the PTT button. None of the officers used the SUI to control the radar ("SUI radar" in Fig. 5).

B. Designing interaction flow

Just as officers evaluate the usefulness of the SUI to control a given device they also evaluate the most efficient way of using the SUI for a particular task. Therefore, one may find that the interaction flow in practice does not completely follow the designed one. A good example is the way officers interact with the Project54 SUI. As mentioned in section V, officers would not always listen to the SUI's verbal responses but would cut the response off and proceed with another voice input of their own or some other task. We programmed the SUI to provide verbal responses because we felt they would be useful. Of course if the same response is repeated many times a day it is not likely to be useful and probably even becomes annoying. In our SUI pressing the PTT button cuts off the SUI speech output. We expected this feature to be used infrequently (e.g. when the officer decided that he or she asked the wrong question and thus did not want to hear the answer). In practice the officers cut off the SUI speech output all the time.

C. Training

Officers using the Project54 SUI are sometimes confused by SUI errors. One officer was confused by the fact the SUI misrecognized his "New Hampshire" utterance with "Missouri" fairly often (see section V). The officer did not have enough experience with computer systems in general and SR systems in particular to realize that the cause of a recurring error should be easily identifiable. We explained to this officer what the problem was (not operating the PTT button correctly) and that he could reliably make the SUI fail in this way by operating the PTT button in a certain way. We came to this conclusion during prior testing of the SUI. Of course we benefited from having the knowledge of how the SUI operates and how it may behave if it is operated improperly. The lesson learned from this experience (apart from reaffirming a variation on Murphy's Law: if there is a weakness in a SUI the user will find it) is that user training can greatly improve SUI performance. Training should help users learn how to operate the system properly (e.g. do not start talking to the system before you push the PTT button). However, training should also attempt to teach users about the inner workings of the SUI so that they could deal with situations that they have not encountered in training.

VII. Conclusion

Our evaluation of the Project54 system's user interfaces showed that officers use all three available types of user interfaces. The officers select the appropriate user interface based on the speed and safety of interaction the interface provides with a given electronic device.

We were surprised to see how efficiently the officers used the SUI. In order to speed up the interaction they did not listen to predictable SUI responses. A future version of the SUI should allow flexible interaction with the officer. While the officer is learning to use the SUI the responses should guide the officer in the interaction. But these guiding messages may have to change to messages that just quickly remind the officer of where in the interaction he or she is. Also, data query responses should be modeled on the interactions between officers and dispatchers. Currently the SUI vocalizes the query results in the same order as they are sent to the cruiser from the central database. However, dispatchers first parse the query results and give the officers information in the order that is likely to work best for the officer. Officers sometimes have follow-up questions as well. A similar system should be implemented for the SUI. Note that this approach would require painstaking work since different databases use different data formats (different naming conventions, different organization, etc.).

Officers may deal with problems better if they understand the inner workings of the user interface software. A balance has to be struck between overwhelming the officers with too much information and empowering them.

We expect that our three major observations about the Project54 user interfaces (speed/safety evaluation, efficient use, training improvement) will hold for other in-car user interfaces.

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