A proactive approach on solving Hospital Associated Infections (H.A.I)

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***Abstract*— Hospital Associated Infection (HAI) remains the most pressing issue in clinical environments. Rather than waiting for the infection to grow to a detectable level (the traditional wisdom), we propose a proactive approach - predicting possible HAI via real-time gathering of contextual data, prompt decision making based on visual feedbacks powered by machine learning algorithms so healthcare professionals can immediately take preventive measures.**

I. INTRODUCTION

According to the Center for Disease Control (CDC), HAIs are infections that patients acquire during the course of receiving treatment for other conditions within a healthcare setting. Common cases of HAIs include antibiotic resistant super-bugs such as MRSA which has become increasingly common in healthcare settings. These infections cost healthcare systems billions of dollars in additional expenses each year; The extra expenses incurred from HAIs are then passed to patients and healthcare insurers which increase the overall cost of medical services for everyone. Although HAIs commonly effect patients, hospital staff are not immune to contracting an HAI. Recently, HAIs have gained increased attention due to high profile cases such as the Ebola outbreak in 2014 which resulted in two nurses contracting the Ebola virus while giving treatment to an Ebola patient in Texas. Realizing the magnitude of this problem, we have developed a software applications that uses automatic checklist, threat map and social trends to predict and reduce occurrences of HAI. Our goal is to select one or a combination of these features to present to potential customers within the healthcare industry.

In this paper, we will discuss the development process,tools used which include a noSQL database, IBM Bluemix mobile builder and a web client using a combination of Nodejs, php, together with javascript. A large portion of this paper will cover the user evaluation of our application with its three features. We will discuss the method used to evaluate our application along with an analysis of the results. Using the data received from our evaluation we will then present a case for choosing one or more of the features to include in our final version of the application.

II. APPLICATIONS DEVELOPED

Through brainstorming ideas on ways to prevent or reduce HAIs through the use of software and through our innitial issue research, we all agreed that being proactive instead of reactive to HAIs would give us the best chance at making a difference. We decided that we needed to focus on predicting HAIs through the use of contextual and real-time data that would give healthcare workers the opportunity to identify at risk patients and to direct their resources more efficiently to the patients that need attention the most. We also realize that not all healthcare institutions will have the budget to digitalize everything and even when they do, there are physical limitations on where we can put smart chips in. For example, we can detect if a nurse had washed her hand before a certain procedure or not by installing sensors near hand-wash stations but we cannot detect if a medical tape was accidentally left on a bed linnen (infected) surface or not. Ultra wideband precision tracking system like Pozyx (pozyx.io) can keep track of nurses' hand positions (2D & 3D) and help detect if a task has been done. With the help of analytic and machine learning tools, knowing precise hand positions can even detect contextual mistakes. Unfortunately, within the scope of this project, we did not have the budget and time to test out Pozyx system in real life situations. We used a simulator instead where a script modifies entries in the database directly. However, it is important to note that this precision tracking is behind all the statistics that the automatic checklist and the threat map will be using.

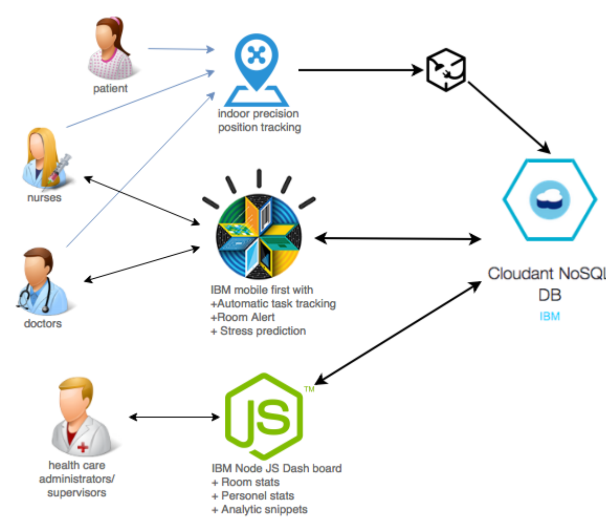

Fig. 1. App Structure

A. *Threat Map*

The threat map feature uses the surveillance of real-time data to indicate which patients are at a higher risk of contracting an HAI. Our research indicated that hospitals are often understaffed which creates an environment among staff members that are more likely to make mistakes such as not washing their hands. The goal of a threat map is to identify high risk patients which is intended to direct hospital staff resources at those patients. During busy times on a hospital floor a nurse would be able to visualize which patients are at a higher threat level, this would create an understanding within the nurse that when they visit the high risk patient, they need to follow strict protocol.

The threat map works by mining data for each patient from internal databases such as the hospitals Electronic Health Record (EHR) as well as lab and pharmacy databases. This data includes information about the patient such as their age, current illness and condition along with environmental data such as the number of nurse visits and visitors the patients has received and when the patients room was last cleaned. From these variables we were able to create a rating for each which were then aggregated to produce and overall threat rating ranging from low, medium to high for each patient. The threat rating is then displayed on a screen and mapping to the associated patients room. Hospital staff can then monitor each room which will be the displayed as a colored icon; green indicates the patient is at a low threat of contracting an HAI, yellow indicates a medium threat and a red icon means the patients is at a high risk of contracting an HAI. Giving the hospital staff a visual display of which patients/rooms are at a higher threat level will help them quickly and efficiently allocate resources and will serve as a reminder that they need to follow exact protocol when working with a high threat level patient.

To give a better understanding of how the threat map works we will describe a short scenario of how it would be utilized within a hospital setting. A 70 year old male has just received knee surgery and is now recuperating in room four on floor three of a hospital. At the nurses station on floor three is a monitor that is displaying a threat level for each room on the floor. Currently room four with our patient is colored yellow to indicate that the patient is at a medium risk of contracting a HAI. This is primarily due to the patients age and invasiveness of his knee surgery. Within 30 minutes our patient has received six visitors and has been visited by a nurse three time. This activity has caused our patients threat level to increase into the high threat level. The monitor at the nurses station now indicates that room four is at a high threat by displaying a red icon for room four. As another 30 minutes pass the situation on floor three of the hospital continue to get busier as more patients are admitted to the hospital. Rushing to complete their task the nurse assigned to our patient is about to deliver his evening medicine when she looks at the display monitor and sees his room is colored red indicated he is a high risk of contracting an HAI. Understanding the severity of the situation the nurse decides to wash their hands and put on protective gear such as a clean face mask and clean disposable smock. These actions are vital for prevent HAIs. As another 30 minutes pass a custodian is assigned to room four and throughly disinfects the room and removes all waste; the result of disinfecting the room and disposing of waste has decreased the threat level in our patients room from high back to a medium threat level. The next day our patient is released from the hospital with acquiring a HAI.

B. *To Do Check-List*

Based on the results of precision tracking system, we build the ”Automatic To-Do Check List”. From our issue research survey, we understand that the work flow of a nurse can be really complicated in operational situations (a big reason why simple common mistakes still happen regardless of well-received formal trainings). With this feature, nurses will just have to remember the rooms s/he is responsible for and once s/he enters the room, a list of pending tasks per room will pop up on the screen of mounted mobile device. This is particularly helpful when nurses have to switch back and forth between rooms with different work flows/ procedures. The software will also help with executing the correct order of tasks. Tasks are ranked by pre-designed execution order and once a task is done, it will be automatically removed from the displayed list.
For example, in a scenario where a nurse enters room 101, he walks toward the patient’s bed. The sensor tracks his position and immediately issues an alert on the White Wolf mobile app when he is 1 feet away from the patient. The nurse looks at the mounted screen and realizes that he was supposed to wash hands first. The nurse then proceeds to the hand-wash station. The precision tracking system recognizes that his hands are over the sink with hand-washing movements and automatically checks off (remove) the ”Hand washing” task from the list. All of a sudden, the nurse was informed that he has to go to another room for an emergency. Once he gets to that room, the nurse wants to quickly double check what he is supposed to do. He looks at the app. Based on his current position (new room), the app displays a corresponding task list, in appropriate order. He quickly executes the tasks without unnecessary communication or overlapping with other nurses in the room (particularly helpful when other nurses have to pay attention to the tasks they are doing). When he comes back to room 101, he notices that someone helped him with some tasks while he was working on the emergency case. The nurse checks the app and instantly figures out what else he needs to do for patient in this room.

C. *Trends Application*

Big data had been approved effective in predicting some trends or changes. In 2009, Google analyzed the huge number of search queries gathered and revealed there is a flu-like illness in New Zealand. This achievement somewhat commit to the world that how valuable data is, and therefore motivate more people to mine their data and explore possible implementations. For instance, the institute of Cognitive Science Osnabrck carried this basic concept forward and run a similar project combined social media data, e.g. Twitter, with CDC data to infer spatial and temporal spreading of diseases. After the data-oriented finding, Google not only extended the trends analysis but released more related APIs for public to analyze their queried data.

To tackle the HAI issue, We also believe that prevention is better than cure. Therefore, we applied the Google trends APIs to web applications and mobile applications. With our trends feature, users can query with specific keywords and see how the trends on Google goes which helps them to anticipate possible outbreak and be well-prepared for that.

Take a simple scenario for example. A nurse who find many patients in hospital share some symptoms, e.g. cough and fever, or many rooms in threat map indicate some similarities,e.g. most rooms have a small standard deviation in threat level, may try to query the trends with keyword 'flu' or related words. When the trends indicate a huge increasing in the number of flu-related query, the nurse may envision a possible outbreak of flu and inform the hospital this possibility. Then the hospital may allocate more staffs in the following shifts to be well-prepared for the incoming patients, and increase the security level by requiring people in hospital wear surgical masks and wash hands often to reduce possible HAI. Another scenario is, a person notices that many people around him get cold so he tries to query the flu trends with our mobile app and find there are upward trends in flu-related keywords. With the possible outbreak in mind, he washes hands more frequently and always keep room airy and exercise more to protect himself.

III. The Development Process

A. Development model

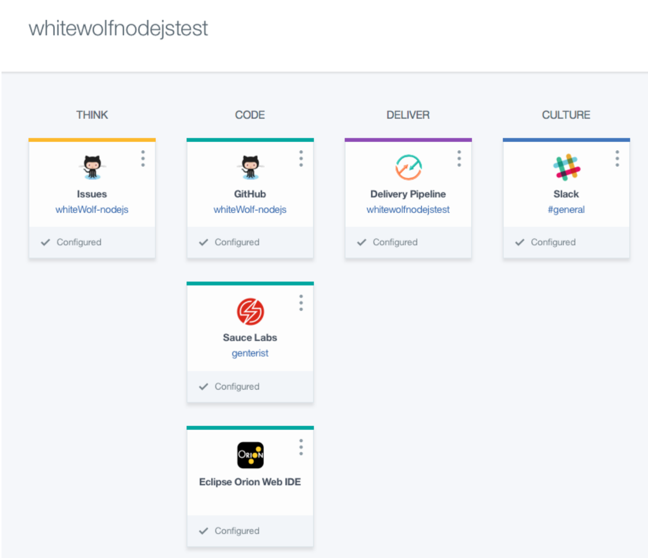

Fig. 2. Tool chain

Fast/short Agile iterations were used in the project with tool chain shown in Figure 2. It is important to note that the entire tool chain is cloud based, automatic integration of "THINK", "CODE", "DELIVER", "CULTURE" with automatic feedbacks. We start with GitHub issues where we discuss user stories and possible solutions for each iteration. Working issues will be coded up using IBM's Eclipse Orion Web IDE. Codes will then be committed to a GitHub repo. Upon each successful commit, GitHub repo will use web sockets to contact SauceLab where automatic tests of the new codes will be done (on SauceLab's side - a third party with free trial). If all tests are passed, IBM Delivery Pipeline will load the codes from our repo to IBM's infrastructure and compile. Containers for the application will be created and deployed on IBM Cloud Foundry infrastructure. Status of the build and deployment will be automatically updated in our team Slack group. After that, the feedback loop is back to the beginning where new issues will be discussed and managed in GitHub.

B. Database

In this project, we use IBM Cloudant noSQL database for the main reason of portability and flexibility between the platforms involved. Different devices can generate json objects and send them to the database server. All json objects do not necessarily need to have the same order of data fields or even need to have all the data fields. However, the IDs (names) of the datafields must be agreed prior. A Cloudant "View" document will be created and that document will map the origial datafields with the new order/structure of mapped json objects available to each client/platform. We are well aware that the design of database is crucial to effective privacy protection and reliable machine learning performances which will be discussed in the "Pending development" section.

C. Mobile Client

To add mobile functionality to our application we took advantage of IBM bluemix mobile application builder. Bluemix is a cloud platform that combines platform as a service with infrastructure as a service along with cloud services that can be easily integrated into existing applications. For the purposes of building a mobile version of our application we utilized bluemix to create the shell of our mobile interface and bluemix was used to connect the UI out common noSQL database. Using bluemix gave use the option to create and test the application using the Android and Apple iOS platforms. However, halfway through the project IBM started requiring payment to download objective-C and Swift code so we primary used the Android platform to complete the mobile application. Once we were able to create the shell UI, we add additional functionality such adding graphics and additional tables that displayed the information from our database.

D. Web Client

Applied techniques: php/Node.js/javascript on Bluemix.

To build a quick prototype and an easy backup system we used php and its framework- CodeIgniter. However, during the implementation and integration of Google Trends and Bluemix we found that php may not be applicable due to its DB client(sag) for Bluemix. We then transferred to use Node.js which offered easy and direct implementation of Google Trends and easy configuration of dependencies.
The initial idea of trending application was to apply Google

trends APIs with scheduler to inform users possible outbreaks in advance by sending push notifications to user devices(e.g. smart phones or browsers.) However, the notification part is pending since we found some flaws in Google trends prediction with in-depth study. Specifically, further research indicated that Google flu trends were overestimated. In 2013, Nature.com reported that Google flu trends' estimate for flu during Christmas break is about double the CDC's. Some researchers believe that Google trends could be improved if Google was less secretive and could release terms used to track trends. Furthermore, constructing a reliable statistics model for prediction may require expertise in statistics. During the development process, the trending application was then covered into our system as an analysis feature.

E. Pending development

The next major milestone will be a strong endorsement from industry experts. We submitted our project to GE Healthcloud challenge and are being judged by a board of GE Health executives together with industry experts and venture capitalists. A finalist position awarded by them will prove that our ideas are highly applicable and appreciated. It will mean more funds for us to continue develop this project further.
Should we move further, privacy and security will be on the top of our list. We plan to use the HIPPA compliant PubNub web service to maintain the flows of our data traffics between precision sensors, admin dashboards, and mobile clients. We will have to re-design the database structures to minimize the risk of privacy leaks and to prepare our app for sophisticated machine learning deployments.
Ideally, we want our application to be able to predict the fatique of nurses based on their actions/tasks/movement, and predict the chance of getting HAI based on historical room statistics. Powerful IBM Watson machine learning and artificial intelligence can be deployed seemlessly since all of our application is on IBM cloud.

IV. Application Evaluation

A. Evaluation Method

We use Qualtrics to craft our user study survey with a general structure of

1) The White Wolf project and HAI issue in general
2) About the automatic task tracking solution
3) About the HAI threat map solution
4) About using trends to predict HAI solution
5) Conclusion

Most of the times during the survey, participants will see text boxes labeled "Your thoughts" right after a short descriptive paragraph. All they need to do is typing what was on their minds at that moment and each response cannot be less than 50 characters. Some survey questions will be based on scenarios/demo videos where we present them the details of each scenario with questions in between. This unconventional survey serves several purposes. First, it attracts participants with related backgrounds and discourages the ones who just want to get the survey done for credits (especially true with Amazon's Mechanical Turk). The main reason is time. People with related backgrounds will have no trouble typing up responses into the "your thoughts" boxes. People with no background or weak attention will type up bogus responses in either very short or very long amount of time. Second, it puts our ideas into context with progression of time - a very important factor since our application focuses on real-time issues. Survey responses shown that some participants were able to understand our ideas better through scenarios. The result of our user study survey is a very detailed report with detailed feedbacks regarding the graphic user interface, work flows of the application, in-context demonstrations of how the application will be used, and the potentials/impacts of the software in real life. The survey can be viewed at https://github.com/genterist/whiteWolf/blob/master/WhiteWolf-UserStudy.pdf

B. Evaluation Results

Most of our participants agree with our project main concept of "better predict than confirm" H.A.I (Figure 3). Some participants in the 20% detractor group actually misunderstood our concept thinking it was about choosing either prediction or confirmation. The real goal is to put more emphasis on early prediction/remediation while still taking steps to confirm if H.A.I exists or not.

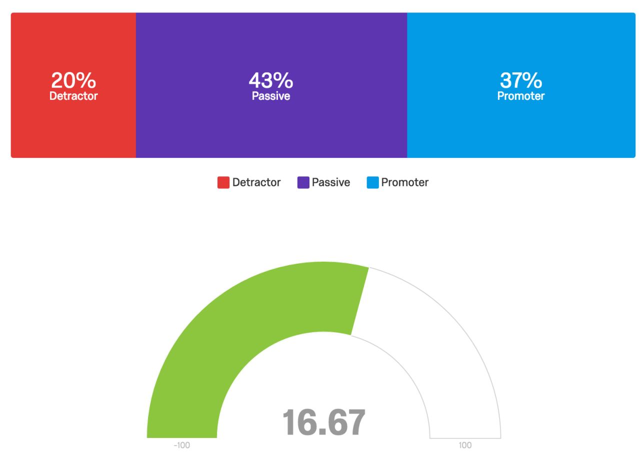

Fig. 3. importance of HAI prediction

With first impression, participants rated our project "Very good" (4 stars out of 5). Project looks and feels, usability and relevance were rated highest among qualitative properties. However, as they went deeper into the survey and got presented with scenarios, they rated our project uniqueness the top one. This proves that our ideas are all very original, different yet very relevant.

1) Threat Map Evaluation: Although we wanted to understand what evaluators thought of our application, we also wanted to gather data that would help us improve the algorithm for generating threat levels. We really wanted to know if the contributing factors that we included in our

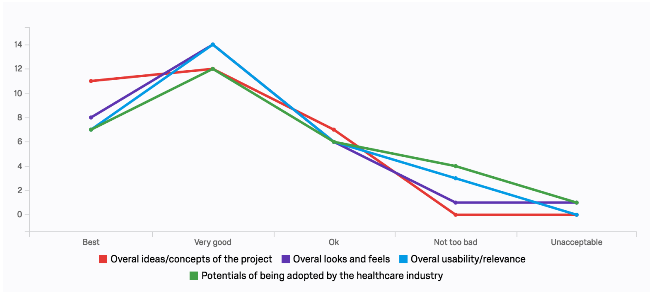

Fig. 4. Project general evaluation

methodology were accurate and if not which factors should we be considering. Overall the evaluators seemed to agree with the contributing HAI factors that we included in our methodology. Survey participants concluded that a patients current illness, medical history and invasive procedures such as inserting a catheter as being factors the contribute to HAI the most. Interestingly an evaluator suggested we apply the threat map ratings not only to the patients but also to the hospital staff in terms of how likely they are to be a cause of a HAI. This was something that we had not previously considered but makes very intuitive sense to investigate further. A lot of HAIs are caused by hospital staff not following the correct protocol; assuming that each nurse is assigned a specific patient, we could associate the spread of HAIs to specific hospital staff members. The staff threat level could then be incorporated into job training to make sure the nurse understands the protocols and it could be used for disciplinary and hiring decisions.

Since our application is passive and does not require a user to actively engage with the software we wanted to see how intuitive our red, yellow, green rating would be to hospital staff members. After explaining the purpose of the threat map feature we asked the question ”Briefly explain what you think has happened when a patients room icon has changed from YELLOW to RED and what actions you would take in that case? We received a mixed bag of answers to include the answer that we were anticipating such as the patients is at an increased risk of contracting an HAI so the nurse should use extreme caution when interacting with the patient. However, we did receive multiple responses that indicated to us that the evaluators were unsure of what a change in the colored icons indicated. Some of those responses ranged from ”I don’t know” to ”the patient has died” and finally ”Call securities and call someone to help because it is very dangerous”. These type of responses demonstrated that we did not do a great job at explaining what the color icons indicated and what a change in a color meant. As we progress, we will consider modifying the way we display the HAI risk level for a given patient.

Finally, to gain an overall understanding of what our evaluators thought of the threat map we had them rate the concept, usability, practicality, potential, and uniqueness on a scale ranging from best to unacceptable. The results showed that each of the five categories for the threat map were rated at ”best” or ”very good” by 70% to 85% of the 27 total evaluators. At a first glance this seemed positive but the ”To Do Check-List” and the ”Trends Application” both score similarly in the five categories so it’s difficult to grade each of the features against each other. However, if we aggregate each of the five categories for each of our three features we are able to see a difference in an overall aggregated rating. Since their were 27 evaluators and five categories to rate each feature, that would create 135 total responses for each feature. Using this method to analyze, 79% of the responses for the threat map were at the ”best” or ”very good” rating, while the ”To do checklist” fielded 72% of the responses at the ”best” and ”very good” rating and lastly the trends feature captured 69% of the ”best” and ”very good” rating categories.

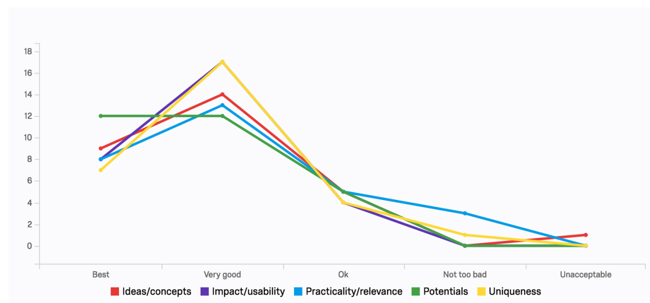

Fig. 5. Threat map evaluation

2) Automatic checklist eval section: Overal, 47.7% of our survey participants agreed that this idea is very unique (a high number considering 100% is spread into 5 categories of ”Best”, ”Very”, ”Ok”, ”Not too bad”, ”Unacceptable”). 43% agreed that the fabric of this idea is very good and 40% believe the idea has the ”best” potential in real world deployment. One of the main concern from participants is

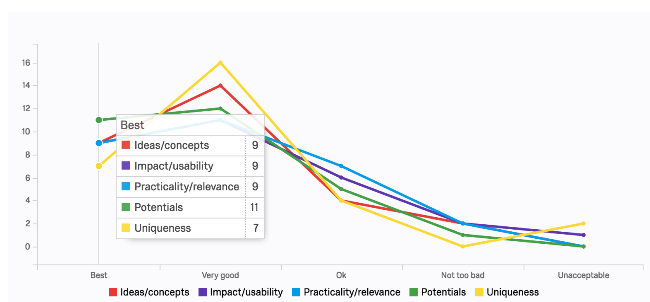

Fig. 6. Automatic checklist evaluation

how much of the involvement nurses have to be when this solution is deployed. It reflected clearly in the responses when users were first asked about this solution. Most of them later on realized how the precision tracking work and had an ”ah ha!!” moment knowing that nurses do not have to do anything with the task check list. They just do their work and the system cross out the tasks for them automatically. Most

of the participants then expressed their love for the solution. Another concern is how does the application track tasks in emergencies. In our original design, we expect healthcare experts to establish task list per job code, room code, and/or patient code so the application will just pull up tasks from specified task lists in database and cross out done tasks one by one. From survey feedbacks, we realized the need for a different kind of task tracking. It is true that in special situations, you do not know what task you will have to do.We call the other tracking mode ”raw positions” where system will let nurses know the lastest 10 to 15 places where the nursers’ hands were. Nurses can mannualy switch to this reporting mode by touching a switch on the mobile app.
Other than some misunderstanding of how the tracking technologies were used, almost all participants demonstrated excitements, and appreciations. They love the simple design of the module, the simplicity and the automation. We also ran an independant analysis on words distribution and sentiment sensing. The distribution of ”good” and ”great” are high among mentioned words from participants and their sentiments are possitve.

3) Trends Evaluation: Our evaluation metrics are based on ideas/concepts, impact/usability, practicality/relevance, potentials, and uniqueness. Refer to Fig. 7 summarized from our survey, more than 70% participants give positive feedback on our trending feature. However, when asked to answer questions more specific to health-care or techniques, there is a big gap that most participants only know one field of them. This can imply that HAI is not well-perceived by people and people also don’t know to what extent modern techniques evolves and how could these techniques improve our life. In our survey, about one second of participants have been worked at hospitals and the other one second has engineering background. This evidence somewhat proves the first implication above.

The threats to validity of this evaluation should be: 1) the sampling precision 2)insufficient prior knowledge. As we mentioned above, the participants of this survey could be mainly categorized into engineering or health-care groups, which may not well-represented the whole population. On the other hand, since not all participants are familiar with all the concepts or techniques in our solutions they may not give appropriate rating and comments.

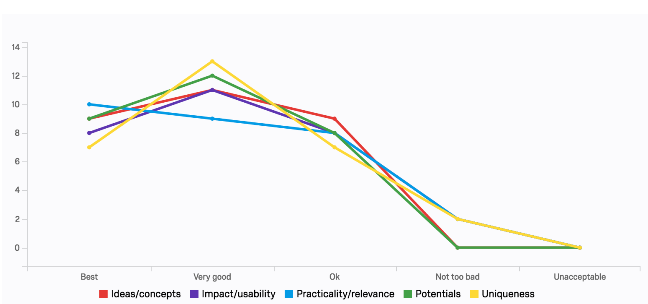

Fig. 7. Trend evaluation

V. Conclusion

Our team believed that:
1. We need to change the culture of how we perceive and react to HAI. Instead of waiting for HAI to get to detectable level, we need to focus more on predicting HAI. In a long run, it will increase the speed of patient flow resulting in higher revenue for the institution and lesser stress for nurses.
2. Instead of statistical data (mostly from machines and lab results), we need to focus more on gathering contextual data (movements of nurses and their hands). We believe it is not harder to design a system that can identify abnormalities in contextual data when compared to a system designed for statistical data. Understand the context of an incident can also be very beneficial to many stakeholders.
3. We need to focus on real-time data collection, data sharing and data processing. Each and every second, there are million of usable data floating around both inside and outside an institution.
For those reasons, we believe that none of our solution is better than the other but rather, the best software will be the combition of all features backing each other - the automatic checklist gives intelligence to the threat map, the trend alalysis will use data gathered by those two modules to form useful predictions.