Decision Making Model for choosing Voice-Operated Intelligent Speakers for Graduate Students

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Abstract

The recent technological advancements have shed light on some futuristic inventions and possibilities. One of these inventions and technologies has been home automation especially due to the rise of Internet of Things. One of the main areas of advancement in home automation has been Voice-operated speakers. Given the surprising success of the Amazon Echo -- a smart speaker that responds to your voice commands, plays music, and controls your smart home -- this area has become a vying one. With Google Home entering the arena, complete with the backing of the company's ubiquitous search engine, the Echo's place on top is no longer secure. There are also a lot of new products entering the market with unique features. These criteria would make the decision-making process an arduous one both for producers and the buyers of these products. This project offers some criteria to facilitate the decision-making process involving smart, voice activated speakers. The Hierarchical Decision Model (HDM) has been used to establish a model based on perspectives, criteria, and alternatives. Furthermore, with the aim of better demonstrating the practicality of the study, five real voice operated speaker products are evaluated based on the perspectives and criteria weights obtained from the HDM model and scores.

Keywords: Hierarchical Decision Model (HDM), voice-operated speakers, Technology Adoption, Internet of Things

1. Introduction

a) Overview of home automation:

The technological revolution of the last decades has brought some futuristic inventions to existence. The technological breakthroughs were largely facilitated by the information revolution: The internet provides the links that connect the world together, whilst mobile computing renders that connectivity ubiquitous and instantaneous. This revolution did not only make the lives of users easier, but also, created more opportunity for innovators to build newer products aimed at easing life further. The continuity of innovation and invention brings along great products with great usefulness and an ease -of-use that make their incorporation to every day's life a formality.

One of the trends that a lot of technologists are getting interested in nowadays is: Home automation. Techopedia.com [1] defines it as a technological solution that enables automating the bulk of electronic, electrical and technology-based tasks within a home. It uses a combination of hardware and software technologies that enable control and management over appliances and devices within a home. And in a more technical sense, it is a step toward what is referred to as the "Internet of Things," where everything has an assigned IP address, and can be monitored and accessed remotely.

Home automation system can be designed and developed by using a single controller which can control and monitor different interconnected appliances. Different types of home automation systems offer a wide range of functions and services, some of the common features are appliance control, thermostat control, remote control lighting, live video surveillance, monitor security camera, and real time text alerts. [2]

Home automation is picking up at a fast rate. Being able to control different appliances remotely is already an amazing thing. However, the challenge of the industry is to be able to make completely autonomous artificial intelligence (A.I.) that can interact with the user pretty much in the same way another person would. Which is why a lot of tech giants like Google [3] are investing colossal amounts of money in the area A.I and Machine learning. Those investments led to the development of some reliable personal assistants. The personal assistants available in the markets such as: Apple Siri, Microsoft Cortana, Google now, and Amazon Alexa are not advanced A.I. by the previous definition, but every user was impressed by the reliability and performance of such systems. A performance that led some companies to consider building them into their own devices and market them under the name: **Voice-operated smart speakers.**

b) Overview of Smart Speakers

A voice-operated smart speaker is an electronic device that can do everything a regular speaker does but also can connect to other home devices and communicate with them mainly through Bluetooth and/or the internet. Smart speakers are the easiest and cheapest way to achieve some level of home-

automation. These devices have been gaining in popularity because they are easy to use: All you have to do is buy them with no additional networking or cable-work needed to be done to use them. Additionally, a couple of these devices are made by tech giants like Google and Amazon, and these companies struck some deals with home-appliances manufacturing companies such as (GE, and Honeywell) to have their devices able to interface with each other. And last, these devices' integration into our lives represents the first leap into this era where everything is interconnected and people are able to talk to their machines.

Smart speakers' popularity led many technology companies to consider their manufacturing and marketing. Among the many manufacturers of these speakers are: Google home, Amazon Alexa, Mycroft, Jibo and Ivee. They all have a set of shared features and characteristics and some other ones that are specific to each one. In this project a hierarchical decision model was developed to help come up with perspectives, and criteria that will make a potential customer buy one speaker and not the other. The developed models' target audience was graduate students, while the perspectives and criteria were retrieved through literature review. The results of the research were quite interesting as they showed which Alternative did best considering the criteria. But also, some insights about what are the main features and criteria that people are most looking for in a smart speaker. In what follows we will discuss the model and the results in detail.

2. Overall objective

Apart from the main goal of creating a decision-making model to help graduate students choose a voice-operated personal assistant that can be used as a home automation hub, the overall objective of this project is to improve the group's understanding of the Hierarchical Decision Model (HDM), to understand its strengths and limitations, as well as leverage its capabilities to provide relevant information to decision-makers.

3. Problem definition

Problem statement: *Create a decision-making model to assist graduate students in choosing a voice-operated personal assistant that can be used as a home automation hub.*

In order to create a useful model for decision-makers, the team had to make important decisions regarding the scope of the analysis. An initial research about the available products showed the complexity of the market. Smart-speakers seem to be one of many possible outputs of the convergence of multiple technologies, two of the main ones being intelligent personal assistants (such as Apple Siri and Microsoft Cortana) [4] [5] and Internet of Things home automation technologies (such as Nest and ZigBee) [6] [7].

From this wide range of technologies and competitors, the team started refining the problem scope with the objective of establishing a basis of comparison that is narrow enough to include comparable competitors, but broad enough to include potential choices with additional functions. The product category the group decided to focus on was *voice operated smart-speakers with home automation*

capabilities. This excludes Apple Siri and Microsoft Cortana, which are personal assistants but do not currently exist in a proprietary smart-speaker format. After that, the team analyzed the available products and narrowed the pool down excluding products that targeted a different demographic customer (Mattel Aristotle, which was meant for children) [8], products that do not provide relevant differentiation and run the same personal assistant as a competitor (such as the LG SmartThinQ Hub, which is similar to Echo and runs Alexa) [9], among others. Finally, the alternatives were narrowed down to five competitors: Amazon Echo, Google Home, Ivee, Mycroft, and Jibo. More details about these five products can be found at Chapter 4.

As previously mentioned, the method of evaluation adopted was the Hierarchical Decision Model (HDM). To use this model, the team defined perspectives and criteria for analysis, which will be explained in Chapter X.

4. Relevant Providers

After careful consideration and analysis, the project team narrowed down the pool of competitors to the following: Amazon Echo, Google Home, Ivee, Mycroft, and Jibo. In this chapter, we will provide additional information regarding the products in their current availability.

Amazon Echo

The Echo is Amazon's smart speaker powered by the company's intelligent personal assistant Alexa [10]. The device is a cylinder-shaped speaker, 9.25 inches tall, 360º omni-directional audio, Wi-Fi and Bluetooth connectivity, and it costs $179.99. Here, the software is the main attraction: according to Amazon, there are more than 10,000 skills already available for Alexa and the number is still growing. The company encourages the development of new skills and integration with different products through its website, which provides training for developers, a software development kit (SDK), as well as challenges (with over $40,000 in prizes) [11].

Google Home

Home is the smart speaker version of Google Assistant, a direct competitor to Echo. The device is also cylinder shaped, but shorter at 5.62 inches; it features a touch panel on top, which can be used to control volume, among other things [12]. Compared to Alexa, the Home is cheaper, priced at $129. Another differential is that through Google Assistant, the Home can be used to control the company's various apps, such as Gmail, Calendar, etc. The SDK for developing *actions* is available through Google's Developers website, as well as a variety of backend tools [13].

Ivee

Developed with funding from the crowdsourcing platform IndieGogo, Ivee provides some of the same basic functions as Echo and Home. It has a cylindrical shape mounted on a wider circular base, 5 inches in height [14]. At the time of its campaign, it was ahead of competitors by offering "skills" like being able to call an Uber, however this is no longer a differential as the others have not only caught up, but surpassed it in terms of skills [15]. The company does not provide a developer's kit, which most of its competitors do and that is how they managed to quickly increase the number of "skills". With a lower price of $99, this device stands out as the cheapest option among the alternatives considered for this project.

Mycroft

Like Ivee, Mycroft was funded through an IndieGogo campaign. Designed for maximum customization, it was built on open hardware and open software principles. As open hardware, it is available for Raspberry Pi and Linux desktops [16]. As open software, its AI's (Mycroft Core) source code is available on GitHub [17]. The device used for comparison in this project is called Mark 1, it is a speaker with a simple visual interface, which resembles a radio alarm clock. Initially priced for its crowdsourcing campaign at $164, it rests in the exact middle of the products used in this comparison, but with potential for further development [18].

Jibo

According to its developers, Jibo is a "social robot for the home." That means that not only is it capable of interpreting and responding to voice commands, as well as interacting with other Internet of Things "IoT" devices, it also has a "social component" built in. It has a small screen with a white animated circle that expresses emotions and a camera with face recognition [19]. With a much higher price ($749 in its crowdfunding stage) and a focus on social aspects, the team debated if this could be considered a valid competitor to other devices in this project [20]. The main reason why we decided to keep it on the list is it does perform the core functions stated in the problem definition. Added functions are a bonus, which can be of interest to some decision-makers who put a premium on design and sociability.

FIGURE 1: Final competitors for comparison. Amazon Echo [10], Google Home [12], Ivee [14], Mycroft [16], and Jibo [19].

5. Literature Review

a) Model Development

HDM is a methodology to analysis strategic decisions in a hierarchical structure by formulating consensus among participants who are mostly experts in specific areas related to decisions. It is mostly applied for evaluating alternatives or selecting best fitting options to accomplish a pre-specified objective [21] [22].

In the general form HDM has five levels named as Mission-Objective-Goal-Strategy-Action (MOGSA), yet there is no restriction on the numbers of levels, but elements at the same level have to be "preferentially independent". As HDM structure is set, pair-wise comparisons among sub-elements for each branching nodes are made. The weights of each criterion are derived from pairwise comparisons. Thus, in the generalized form of HDM researchers need to make pairwise comparisons among objectives, goals under each objective, and strategies under each goal separately [23].

With the intention of evaluating alternatives, performance scores of alternatives for each criterion are required as well. Performance scores can be determined by using scoring for scalar scores or desirability functions for discrete scores. A desirability function is a transformation function which converts actual performance value to a score ranging from 0 to 1 based on market desirability or expert opinion [23] [22]. Simply, HDM breaks down contributing factors to an objective into perspectives and criteria on different hierarchical levels and enables the analysis of contribution of each factor or criterion to the objective. Then each option is evaluated in terms of the criteria to have a final point of achieving the objective, between 0 and 1 [24]. Final score for each alternative is calculated by using *Equation 1*.

$$TV_n = \sum_{k=1}^{K} \sum_{jk=1}^{Jk} w_k \times f_{jk,k} \times V(t_{n,jk,k})$$

***Equation 1**: Calculation of the Technology Value (TV) [37]*

Where,

TV_n: Technology value of alternative (n)
W_k Weight of criterion (k)
$F_{jk,k}$ Relative importance of factor (jk) with respect to criterion (k)
$t_{n,jk,k}$ Performance and physical characteristics of technology (n) along with factor (jk) for criterion (k)
$V(t_{N,JK,K})$ Desirability value of the performance and physical characteristics of technology (n) along factor (jk) for criterion (k).

Since each available product represents a separate option (or namely a technology), from the perspective of the user, individual products are treated as analogous to decision options for the course of this study. The list of available options is derived from mainstream products available in the market. An evaluation model was constructed as a hierarchical decision making model with four levels: objective, perspectives, criteria, and alternatives as the research model shown in figure (model).

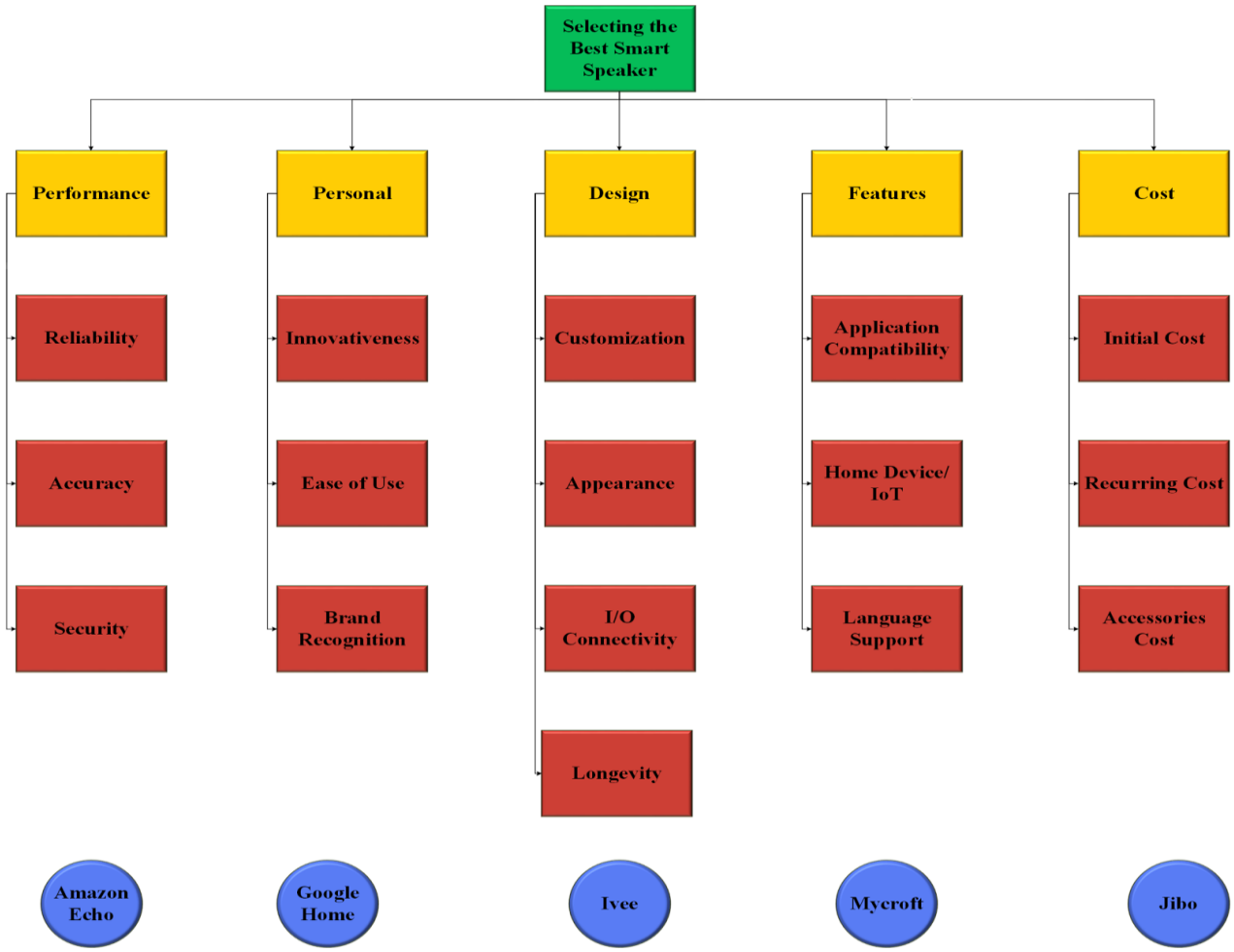

Figure 2 The HDM model with four levels: the objective, perspectives, criteria, and alternatives

b) Model Validation and Data Collection

The targeted users of smart voice operated speakers in this research are graduate students and to reflect this, the sample in the project comprised of PSU graduate students as experts. Our prospective experts had to study each of our alternatives and the literature revolving relevant matters extensively to be able to be convincing as experts. Therefore, 7 Portland State University graduate student were invited to contribute to our research, and a link for data collection was sent to them by email. This link would allow our experts to complete a set of pairwise comparisons for the perspective, sub-criteria, and alternative levels. A screenshot of the decision model website is illustrated in Figure below.

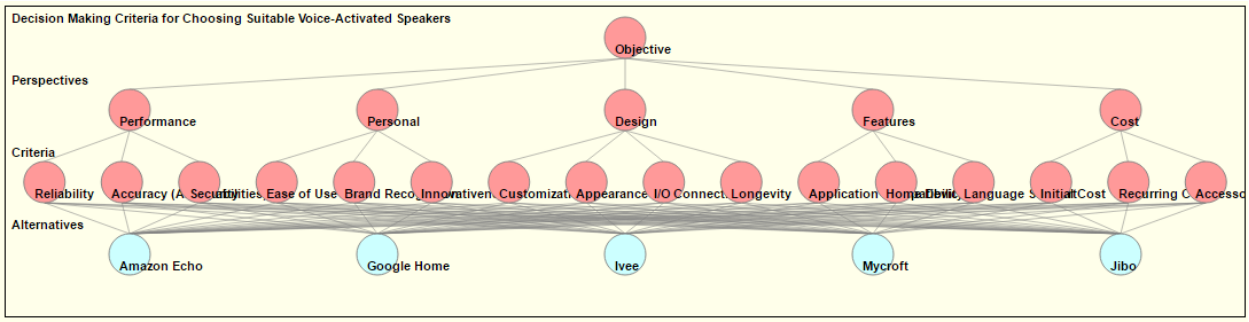

Figure 3: Screenshot of HDM software used by experts

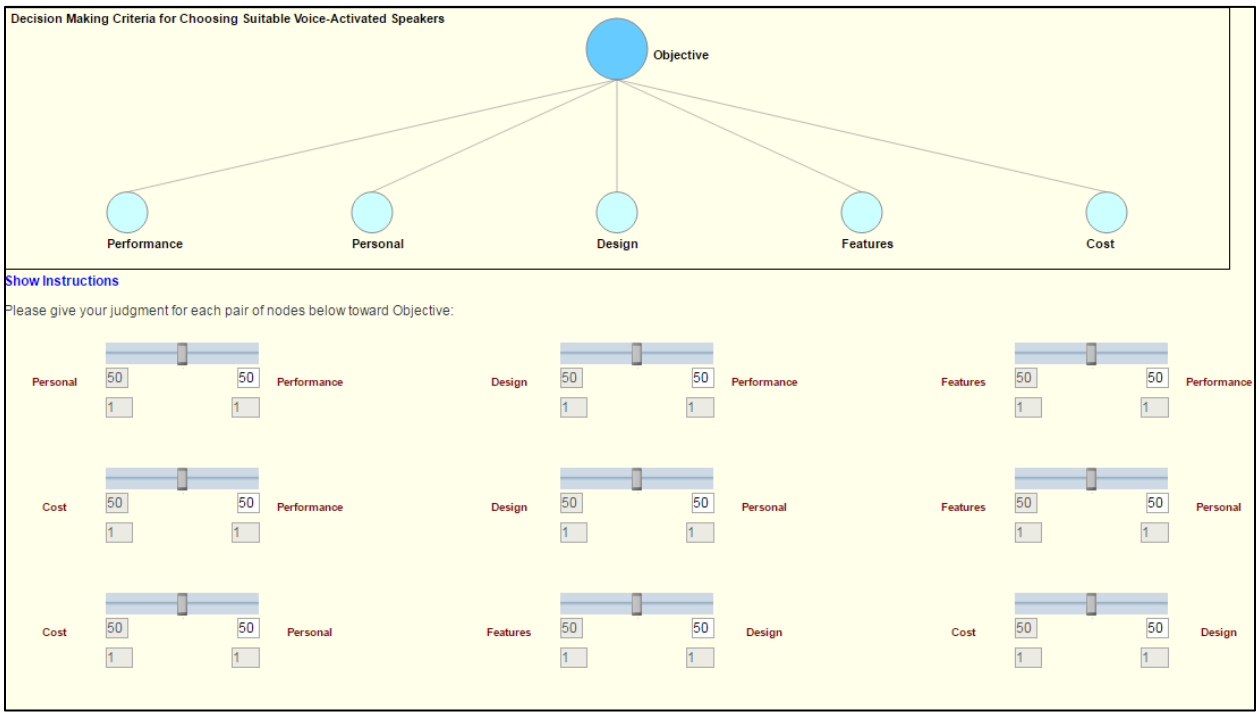

Figure 4: Screenshot of HDM software used by experts

Each expert should pairwise compare different perspective with each other (criteria and alternatives based on criteria in the later stages) by assigning a number between 1-99 to one of them which would assign 100-n reciprocally to the other perspective (If you give 60 to performance, the personal perspective would get 40). The experts had also helped in validating the model before starting the comparison process. Due to the limitations in time, software, and the painstaking process of decision making, perspectives and criteria and alternatives had to be changed, modified, merged, or eliminated many times. The process continued until it was in a condition which was not susceptible to any of those advantages while not losing a lot of accuracy in terms of material. It is important to mention that in this project; the experts are our team members and two other PSU graduate students who possessed a lot of knowledge about our products.

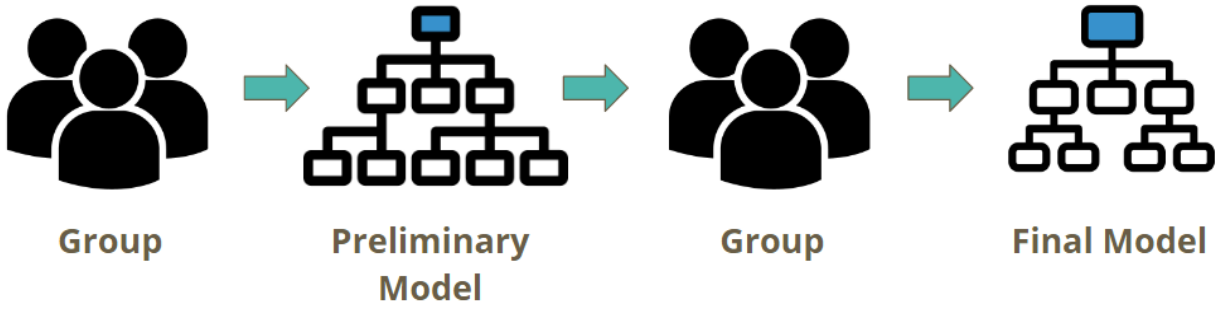

Figure 5: The Validation Process

6. Criteria Selection and Model Building

There are many different perspectives influencing decisions of purchasing technology products as voiced-operated intelligence speakers. People use these devices not only for voice-operated intelligent personal assistant, but also can be used as a home automation hub. We started with a model including five perspectives and many important criteria per perspectives. These perspectives and criteria were collected from the experts and literature. As a group, we eliminated some criteria and redefined others to make the model more useful and suitable. For example, we eliminated "perceived privacy protection" in term of the personal perspective because it can be showed in "security" in the performance perspective. Consequently, we came up with five perspectives and sixteen criteria to research adoption decision for voiced-operated intelligence speakers as follows:

a) Performance

Performance plays a big role in the assessment of the adoption criteria for voiced-operated intelligence speakers. One of the main factors within the performance perspective is accuracy of the devices. Accuracy is the degree of conformation of evaluate and process data (by device) to the actual value. Since voice-operated intelligent speakers need to receive and operate information from users, accuracy is a significant criterion for users. Hence, performance in term of device-specific perspective can express its operation and usefulness which affect consumers' purchasing. In this case, the experts focus on three main criteria which are reliability, accuracy, and security.

- Reliability is a technology's ability to possess the quality of being reliable in attaining non-scattered results in repeated trials [25,26]
- Accuracy including artificial intelligence (AI) capabilities represents the degree to which the device is accurate in returning the asker for information and its ability to be accurate in fetching information and performing commands. [25,27]
- Security in this case stands for Ability to keep personal data safe. [28,29]

b) Personal

Personal perspective shows internal demands of consumers that the customers incline to consider buying the device. This perspective represents characteristics of life modes in their society or community based on their activities, interests and opinions. This personal perspective consists of three significant criteria which are ease of use, brand recognition and innovativeness.

- Ease of use denotes the degree to which an individual believes using a particular system would entail little physical and mental effort [30].
- Brand recognition shows measure of brands' capacity to enable individuals to identify themselves with them and express social status [31, 32]
- Innovativeness is tendency towards new technology based on consumers' purchase intentions [32, 33].

c) Design

Product design can affect consumers' approachability. Voice-operated intelligent speakers have different design which can attract users such as display screen, appearance, or how it looks like. Moreover, this product will be used in a house, so it can be considered as a home decoration. In this case, design displays appearance, robustness and I/O support of devices including four criteria which are customization, appearance, I/O connectivity and longevity.

- Customization is technology system interface's ability to be tailored according to each user, and devices' ability to upgrade [34].
- Appearance shows execution of design in a technology [31, 35].
- I/O connectivity is devices' ability to interface with other devices through multiple connections such as cables and battery (physical or wireless) [36].
- Longevity is defined as device's lifespan in view of solidity and futurism.

d) Features

Adoption of voice-operated intelligent speakers is influenced by features of products. Since feature is evaluated as a set of operations the device is able to perform for its user, it is a big factor that can attract consumers and lead them to buy devices. Moreover, it shows high-standard ability to compete with other brand. A feature can be viewed as an attribute or property of the device that describes the device's ability to satisfy its purpose. Therefore, information related factors are critical to this technology's adoption, and factors such as application compatibility, Home device (IoT) and language support are considered in this study.

- Application compatibility shows technology's ability to let different relevant applications run on it smoothly such as Spotify, Uber, etc. [37, 38].
- Home device including Internet of Things (IoT) shows device's ability to communicate between the device and other Internet-enabled devices and systems in home [36].
- Language support signifies device's ability to understand different languages.

e) Cost

As graduate students, cost perspective is a huge factor influencing purchase intention of them. The cost perspective in this research includes initial cost, recurring and accessories cost. Accessories can differ based on each product and brand. They can include external application price and expansion accessories. Furthermore, as the name suggests, initial cost refers to the cost of purchasing these products.

- Initial cost is the first price to buy the item.
- Recurring cost represents cost of using the item such as maintenance, subscription, etc.
- Accessories cost comes up with buying device accessories, and their necessities to device operation

To sum up, the final HDM model consists of four levels. First, the objective is choosing the best voice-operated intelligent speaker for graduate students. Second, perspectives consist of five important factors which are performance, personal, design, features and cost. Third, sixteen criteria were described as significant factors in each perspective. Finally, five alternatives which are Amazon Echo, Google Home, Ivee, Mycroft, and Jibo were collected only products that are currently available.

7. Data Analysis and Results

In this section, we will go through the results of our model. The following two figures show the distribution of weights. **Fig 6** shows the distribution of weights for each criterion under each perspective, whereas **Fig 7** shows the overall distribution of weights in the entire model.

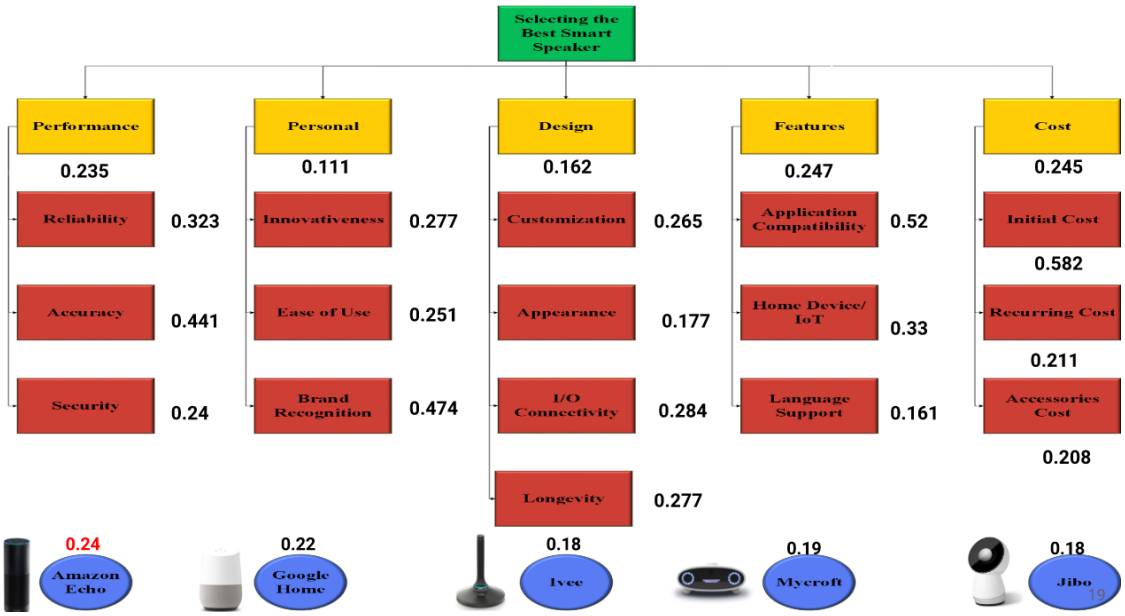

Figure 6 The results for each criterion under each perspective

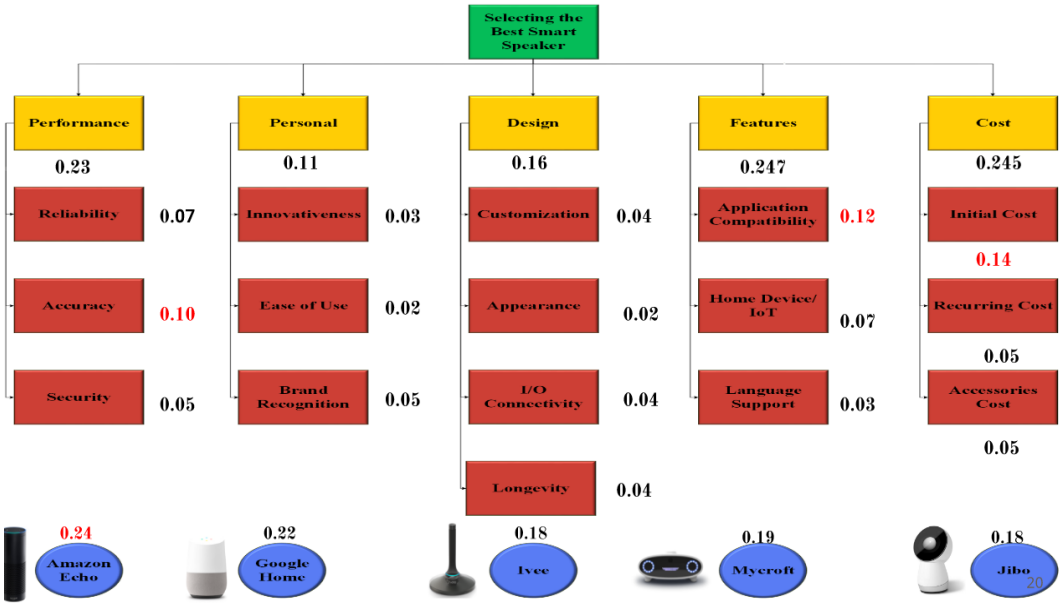

Figure 7 The overall results in the entire model

Fig 8 is a radar chart displaying how well each alternative does with respect to the 5 perspectives of selection of our model. It is obvious that the Amazon Alexa (Or Echo) is the device that achieves the best overall score when all criteria are considered. By contrast, we can see that Ivee has everybody beaten as far as price goes, whilst Jibo for instance beats everybody in terms of design. The radar chart is good in that it shows the interested customer how these devices compare for individual perspectives.

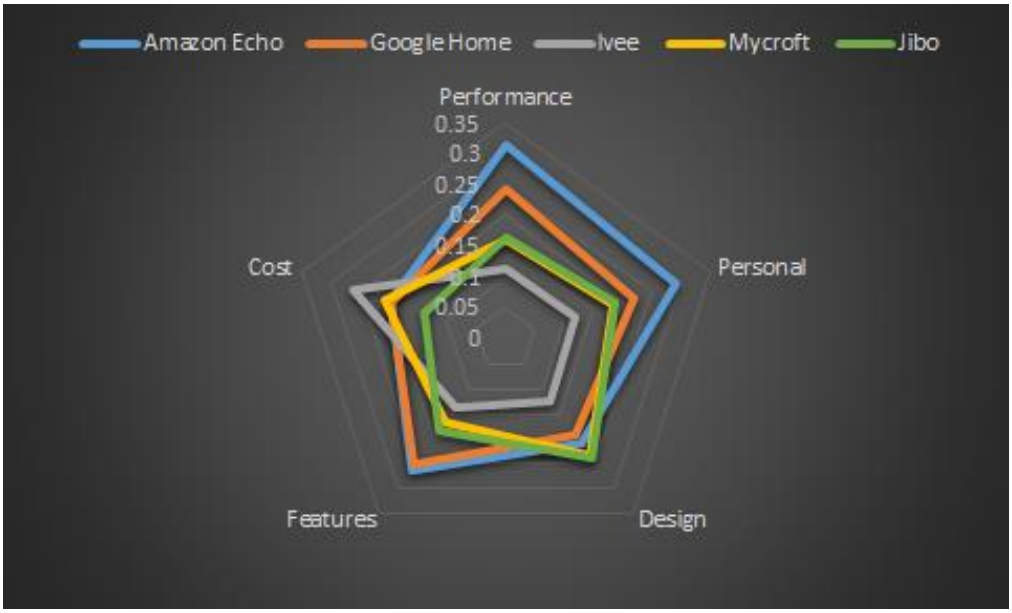

Figure 8 The radar chart of five perspectives in each alternative

Fig 9 shows the distribution of weights of the different perspectives with Performance, Features and Cost being the most important ones. This chart is relevant mostly for the companies making these devices. Looking at the chart gives us a swift and quick understanding of what it is that could be important for buyers and hence, manufacturers could focus on them in the development of their products.

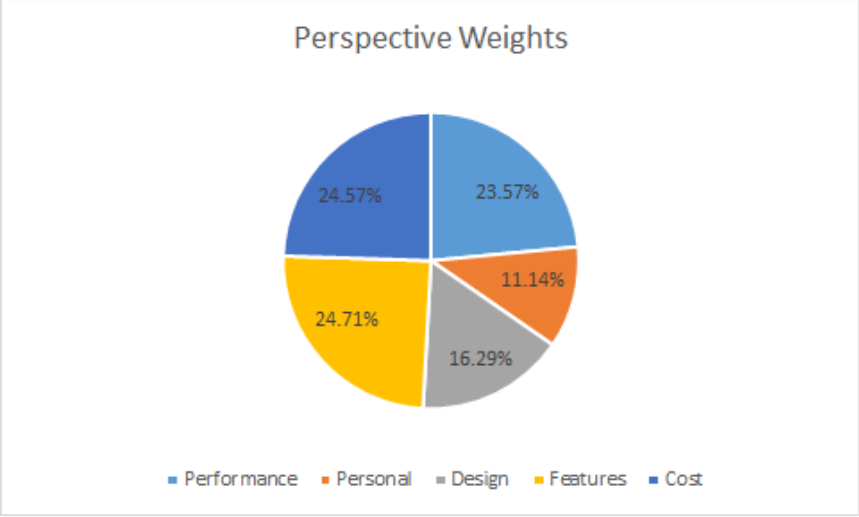

Figure 9 The results in each perspective

Fig 10 displays the different weights of the different criteria. Among those, it is conspicuous that cost, accuracy and application compatibility were the top criteria selected by the experts. Notice that

other criteria such as appearance and innovativeness could have been more important had the target audience been changed.

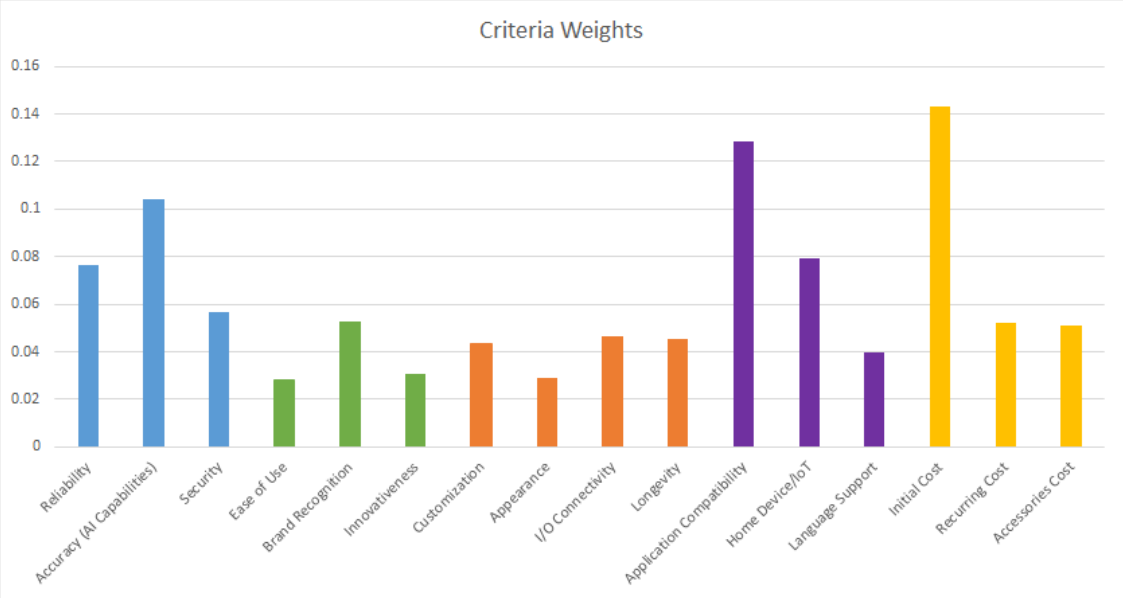

Figure 10 The overall results in each criterion

Table 1 The alternative results by each expert

Objective	Amazon Echo	Google Home	Ivee	Mycroft	Jibo	Inconsistency
Expert 1	0.23	0.25	0.21	0.19	0.12	0.01
Expert 2	0.32	0.2	0.17	0.18	0.12	0.02
Expert 3	0.21	0.21	0.19	0.2	0.2	0
Expert 4	0.25	0.2	0.1	0.17	0.27	0.05
Expert 5	0.23	0.23	0.19	0.2	0.14	0.02
Expert 6	0.21	0.23	0.18	0.21	0.16	0.01
Expert 7	0.21	0.2	0.19	0.17	0.23	0
Mean	**0.24**	**0.22**	**0.18**	**0.19**	**0.18**	**0.015**
Minimum	**0.21**	**0.2**	**0.1**	**0.17**	**0.12**	
Maximum	**0.32**	**0.25**	**0.21**	**0.21**	**0.27**	
Std. Deviation	**0.04**	**0.02**	**0.03**	**0.01**	**0.05**	
Disagreement						**0.031**

Table 2 The HDM statistical result

Source of Variation	Sum of Square	Deg. of freedom	Mean Square	F-test value
Between Subjects:	0.02	4	0.005	**3.02**
Between Conditions:	0	6	0	
Residual:	0.04	24	0.002	
Total:	**0.06**	**34**		
Critical F-value with degrees of freedom 4 & 24 at 0.01 level:				**4.22**
Critical F-value with degrees of freedom 4 & 24 at 0.025 level:				**3.38**
Critical F-value with degrees of freedom 4 & 24 at 0.05 level:				**2.78**
Critical F-value with degrees of freedom 4 & 24 at 0.1 level:				**2.19**

Finally, **tables 1-2** show how each alternative was scored by each expert. The inconsistency score of each expert, the minimum and maximum that each alternative received from each expert along with the disagreement score. It is worth mentioning that our alternatives' scores' differences were not that marginal, which is why it was important to develop other charts to assess how each alternative beats another one based on a selection of a few criteria.

8. Limitations and Future Research

This model is robust considering our target market (graduate students), however it would need to be adjusted to fit another demographic, such as senior citizens or children. The model is built so that the criteria and perspectives are appropriate for other groups, but the weights for each criterion would need to be changed to match what other demographics may want out of voice-operated intelligent speakers. For instance, in our model, initial cost, application compatibility, and accuracy were the highest weighted criteria, but if senior citizens were to rate this, they would likely put a heavier weight on other criteria such as ease of use and security. The model could easily be re-used, but one must keep in mind that different groups would weigh the factors differently.

Our group served as the expert panel for this project, however we may not have the true expertise needed to properly and accurately rate each alternative. We performed a literature review to research all the characteristics of each alternative, but it must be mentioned that much of the materials we reviewed were essentially marketing materials. These sources cannot be fully objective as each company is simply trying to present their own product as the best on the market. Undoubtedly, we would benefit by purchasing each individual product and fully testing each one out for ourselves. We did not have the

resources to do such thorough research, but to truly develop the expertise needed to properly and objectively rate each alternative, we would need to have more experience with each alternative.

There are many other alternatives on the market, but we have limited our study to the five speakers listed. We chose to leave out other alternatives that seemed similar to the ones we already had to reduce redundancy. We also chose to keep the more recognizable alternative brands as we believe those are most likely to be the options that most consumers would prefer. By reducing the number of alternatives, it also keeps the model from becoming too time consuming for the experts to complete the pairwise comparisons.

Our team also kept the number of criteria to a reasonable number to maintain the model simplicity and allow for an easier expert review process. While adding more criteria may bring more useful considerations to the table, overall, we believe it would complicate the process and make the model too consuming for a proper and concise analysis.

9. Conclusions

We believe our model provides an initial point of view for analysis of a promising emerging technology. It serves as a starting point to consider all the perspectives and criteria that would go into the purchase of voice-operated intelligent speakers. For new users, our model helps to give a better understanding of the different options available on the market. While some users may weigh the criteria differently, they will still need to consider all these criteria that we have laid out. The model can also serve to give product engineers an initial evaluation model that takes into consideration not only the quantitative information, but also qualitative aspects such as ease of use or innovativeness.

The results show that, for graduate students, initial cost, application compatibility, and accuracy of the technology prove to be the most important criteria in purchasing voice-operated intelligent speakers. We believe this is in line with what we would expect to see, considering the weights that we outlined. We feel comfortable that this would be the resulting conclusion and those results in fact serve to reinforce our model's reliability. Graduate students have to watch their spending, so obviously, the initial cost should be important. Grad students also use a lot of applications on their smart devices because we are familiar enough with technology that we rely on the convenience that apps can provide. Therefore, application compatibility is important to this demographic of consumers. Finally, accuracy is an important factor as it probably would be for other demographics as well. Consumers today want technology to work for them, and thus the simple need for accuracy in technology seems self-evident.

This model provides a useful approach to analyzing which voice-operated intelligent speaker best suit a consumer's needs. While keeping the limitations in mind, one could successfully use it while making their purchase, and we feel confident that it would ultimately be a helpful decision making tool.

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