Portland State University
Maseeh College of Engineering and Computer Science
Department of Engineering and Technology Management

ETM 530/630 – Decision Making
Spring 2017

Individual Project Paper

Adoption Criteria Evaluation of Smart Vacuum Cleaners for Home Use

Hakan Kutgun

ABSTRACT

As robots start reshaping our world, we see more and more smart devices doing humankind's bidding in every area of our daily lives. One of the emerging technologies in this area is smart vacuum cleaners which add value to the life of masses by providing convenience and reducing the time spent on daily chores.

The level of convenience provided, plays a significant role in the adoption decision of these products, however there is little to no information on factors playing significant role in people's adoption decision. The aim of this research is to highlight the important perspectives and their underlying criteria regarding adoption of smart vacuum cleaners for the US home users using HDM. By combining responses of more than 20 experts from the perspective of home users, a model for evaluating smart vacuum cleaners based on the perspectives and their criteria weights of US home users is developed, regardless of the alternatives present in the market.

The comparison of alternative products in the market is left out of scope of this research as it is dependent on era and market availability. Products available can be scored at any time and for any market, according to the weighted factors as the result of this research. Additionally, as a global market, the prioritization of decision making criteria may be different for other locations or cultures, for which a new round of evaluation for the factors may be required for future research.

Keywords: Hierarchical Decision Model, HDM, AHP, smart vacuum cleaners, technology adoption, emerging technologies, decision making

INTRODUCTION

With the advances in robotics and rapid commercialization of technology, robots are entering our homes. This brings the question of how to make robots integrated into people's lives [2,3,5] in domestic environments. Yet there is limited study on how people adopt domestic robots as consumers [4] and virtually none for smart vacuum cleaners. Since survival of any technology as a marketable product relies heavily on mass adoption [1], this information is vital to the future of this technology. There are many companies presenting alternatives for smart vacuum cleaners, leading of them being iRobot. However since the variety of alternatives change from time to time and one region to another, this study is focuses on the consumers' criteria in evaluation regardless of alternatives.

According to a recent interview[1] with Colin Angle, CEO and co-founder of iRobot, "20 percent of vacuums in the world are now robots, and over 70 percent is iRobot's market share". This shows the market is still far from being mature and there's huge potential for competition. Meanwhile iRobot's success, as represented by company value increasing 81% over the past year[2], is a strong indication that the market is on the rise and promises a bright future. Therefore the customer expectations and criteria for adoption of smart vacuum cleaners are very valuable information for smart vacuum cleaner manufacturers.

In order to shed light on customer expectations and criteria for adoption of smart vacuum cleaners, a hierarchical decision model (HDM) is developed for "Adoption Criteria Evaluation of Smart Vacuum Cleaners for Home Use" and evaluated by more than 20 home users currently using or considering buying a smart vacuum cleaner in the near future.

[1] http://technode.com/2016/11/08/real-challenge-roomba-not-ai-irobot-ceo-says/
[2] http://www.nanalyze.com/2016/11/robotic-vacuums-irobot-irbt/

METHODOLOGY

Since nature of adoption is multi-dimensional, it is crucial to understand how people view and evaluate each dimension. Hierarchical decision model (HDM) is selected as the tool to understand and model the multi-dimensional decision making dynamics. HDM is a methodology similar to analytic hierarchy process (AHP) to analyze strategic decisions in a hierarchical structure by formulating consensus among participants who are mostly experts in specific areas related to decisions [6]. It is chosen mostly due to its ability to reveal complex decision making processes in a quantifiable and repeatable manner. Repeatability is the key since the aim of this research is to develop a decision making model that is applicable to future and other regions, independent of technology alternatives available. Another factor making HDM the ideal tool for this research is its ability to incorporate qualitative data into an understandable, quantitative model. Since the human factor is the primary driving force in the decision making process under investigation, HDM will make it possible to translate subjective considerations from a wide range of experts into a solid body of weighted objective criteria. This will allow us to extract the underlying information generated by experience and expertise, that is available only to the bearer and make use of it to develop an all encompassing model.

HDM is mostly applied for selecting best fitting options or evaluating decision making factors in order to accomplish a pre-specified objective. For the purpose of this research, it is used for the latter. For this purpose below steps are followed:

1. Conduct literature review to find information regarding decision making factors.
2. Evaluate preliminary findings with an expert panel to develop decision making criteria.
3. Group criteria under perspectives and finalize HDM model with expert panel

4. Send model to a wider range of experts for evaluation.

In summary qualitative data obtained from literature review were further reviewed by a limited group of experts. Then the filtered factors were organized in a hierarchical structure for their contribution towards the objective to be quantified by a wider range of experts. Discussions regarding findings are included following the results obtained.

DATA AND DATA SOURCES

As outlined above, this research is followed through 4 steps. For the first step, a preliminary list of decision making factors was obtained through literature review. Due to topic of smart vacuum cleaners being relatively fresh, there's a significant lack of scholarly articles. Because of this, initial list of decision making factors are distilled from online reviews for existing products[3]. Then the preliminary findings are shared with a focus group consisting of 4 experts. Expert group consisted of 4 US home users who have been using smart vacuum cleaners more than a year, with one of them being an early adopter, using smart vacuum cleaners form more than 5 years. The expert panel consisted of a variety of backgrounds regarding experience with smart vacuum cleaners, location, sex and day-time occupation. The location, sex and day-time occupation are considered as they are related to user profiles regarding smart vacuum cleaners. Each profile has different use habits; for example people with full time day jobs tend to program their cleaner to work while they are out during the day. Therefore they value schedule features much more than low noise levels as they are almost never around when the smart vacuum cleaner is actually working. The breakdown of experts is listed in Table 1.

[3]Major sources: amazon.com, cnet.com, robotic-vacs.com, faveable.com, allhomerobotics.com

Table 1 – Breakdown of expert panel

Experts	**Smart vacuum cleaner user for**	**Living in**	**Sex**	**Day-time occupation**
Expert 1	1 year	TR	Female	Full-time job
Expert 2	1.5 years	US	Male	Full-time job
Expert 3	2 years	US	Female	Part-time job
Expert 4	5 years	US	Female	House-keeper

At the end of the expert panel, factors leading the adoption of smart vacuum cleaners are listed as in Table 2.

Table 2 – List of factors contributing to smart vacuum cleaner adoption by home users

Factor	**Explanation**
Cleaning performance	Automated cleaning performance on different floors and around objects
Run time	Cleaning time on a full charge
Time to charge	Time to charge the battery full
Ease of use	Ease of set up, programming and deployment
Low noise	Noise level during cleaning
Schedule	Schedule cleanings, charge time, silent time etc.
Going around obstacles	Going around furniture, not falling from stairs, ability to limit cleaning area
Remote	Remote control availability
Smart App	Smart app availability, features and user interface
Dirt sensor	Dirt sensor

Warranty	Length and coverage of manufacturer warranty
Brand recognition	Brand recognition and consumer trust
Sales price	Cost of purchasing standard device
Operating costs	Cost of consumables like bags, battery etc.
Accessories	Cost of additional accessories like dirt and area sensors

One other interesting finding of the expert panel was regarding interaction of smart vacuum cleaners with pets. It is a well known fact that pets usually don't like vacuum cleaners (mostly due to its loud and strange noise). It turned out they dislike self propelled noisy devices that are unattended even further; according to experts who have pets and smart vacuum cleaners at the same time. However it was identified later as a general attribute affecting all smart vacuum cleaners, therefore discarded as a non-discriminating factor in evaluating possible alternatives.

Decision making factors are organized as criteria under 5 perspectives: Performance, convenience, accessories, support, and cost. HDM model is constructed as shown in Figure 1 at the end of the expert panel.

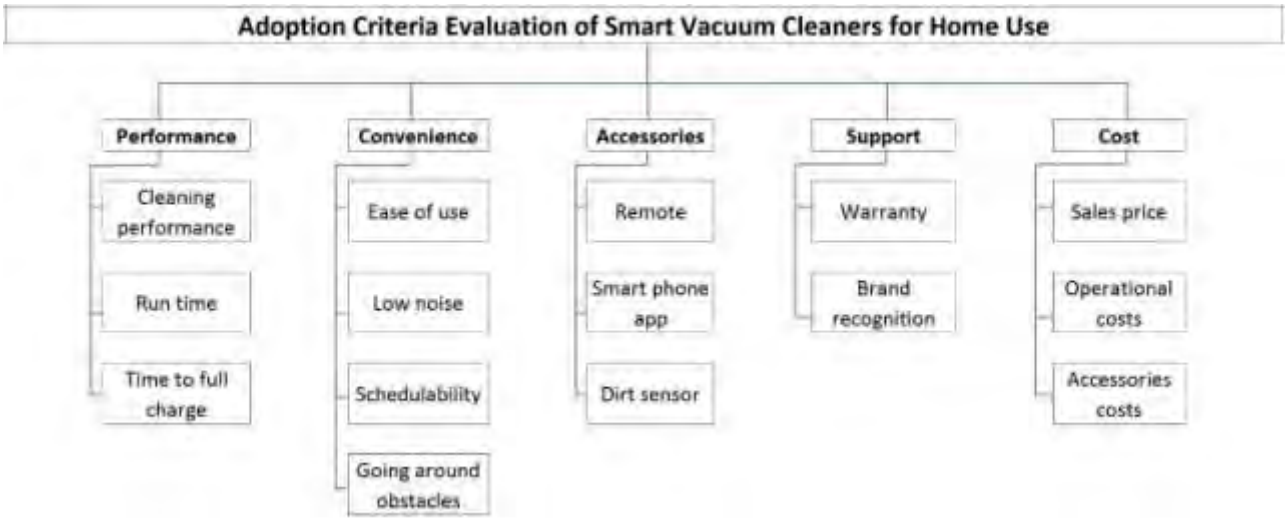

Figure 1 – HDM Model, Unweighted

The model is then constructed with the links of criteria to relevant perspectives using online HDM tool of PSU ETM department[4] as shown in Figure 2 and Figure 3.

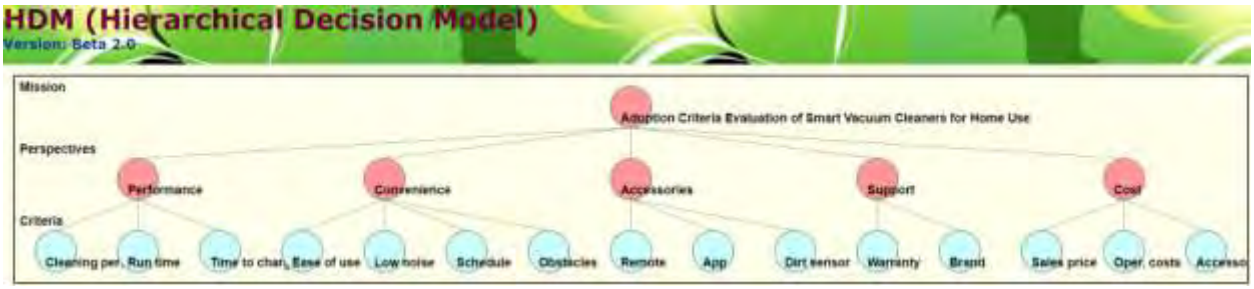

Figure 2 – HDM constructed using online tool

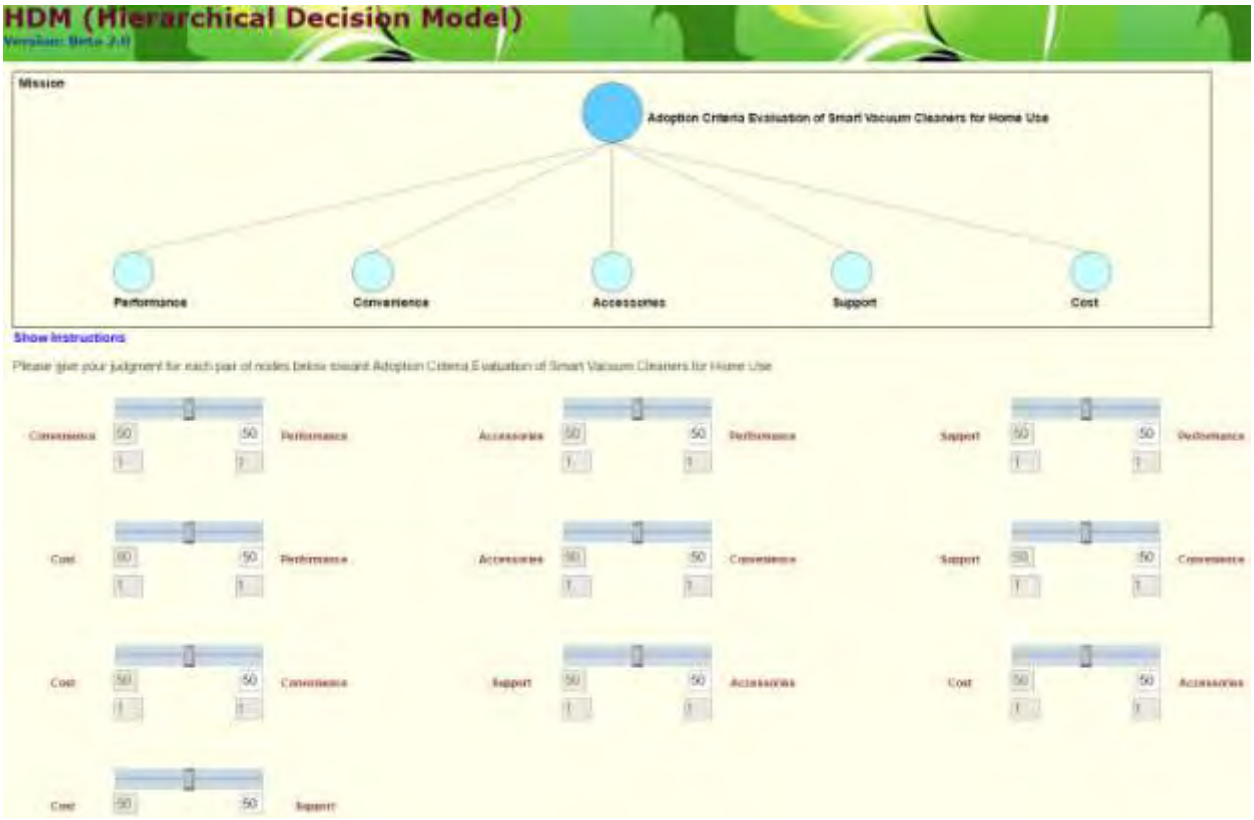

Figure 3 – Expert data entry user interface

The evaluation link (bit.ly/svc_hdm) is sent to around 50 people that are known to live in the US. There was limited information regarding smart vacuum cleaner ownership or intention of the people that the link was sent to. Among those the link has been sent, only those who already have a smart vacuum cleaner or consider buying one in the near future are

considered “experts” for this purpose and only those were asked to submit a response using online HDM tool. To exploit additional data for future use, a very short questionnaire consisting of 2 questions is sent along the HDM link:

1. Do you currently own a smart vacuum cleaner?
2. Do you currently have a resident pet?

The question regarding pets was due to the remark being passed during the first expert panel and was asked for future reference.

Out of around 50 invitations for evaluation sent, 21 responses were received from people that comply with the definition of expert for the purpose of this research, as described above. Of the experts who evaluated the criteria, 81% were female, 43% owned a smart vacuum cleaner at the time of the survey, and 33% had a resident pet at the time. The break down of those 21 experts is given in Table 3 (blank cells means “No” or information unavailable).

Table 3 – Breakdown of experts who responded to weigh the HDM

Expert	Sex	Owns a smart vacuum cleaner?	Has a pet?
Expert 01	Female	Yes	
Expert 02	Female		Yes
Expert 03	Female	Yes	
Expert 04	Female		Yes
Expert 05	Female		
Expert 06	Female		
Expert 07	Male		
Expert 08	Female	Yes	Yes
Expert 09	Male	Yes	
Expert 10	Female		
Expert 11	Female	Yes	
Expert 12	Female	Yes	
Expert 13	Female		
Expert 14	Female		Yes
Expert 15	Female		
Expert 16	Female	Yes	
Expert 17	Male		Yes

Expert 18	Female	Yes	Yes
Expert 19	Male		
Expert 20	Female		Yes
Expert 21	Female	Yes	

The results of experts' evaluations are discussed in the next section.

ANALYSIS AND KEY FINDINGS

HDM is weighted according to the responses obtained from 21 experts as shown in Figure 4.

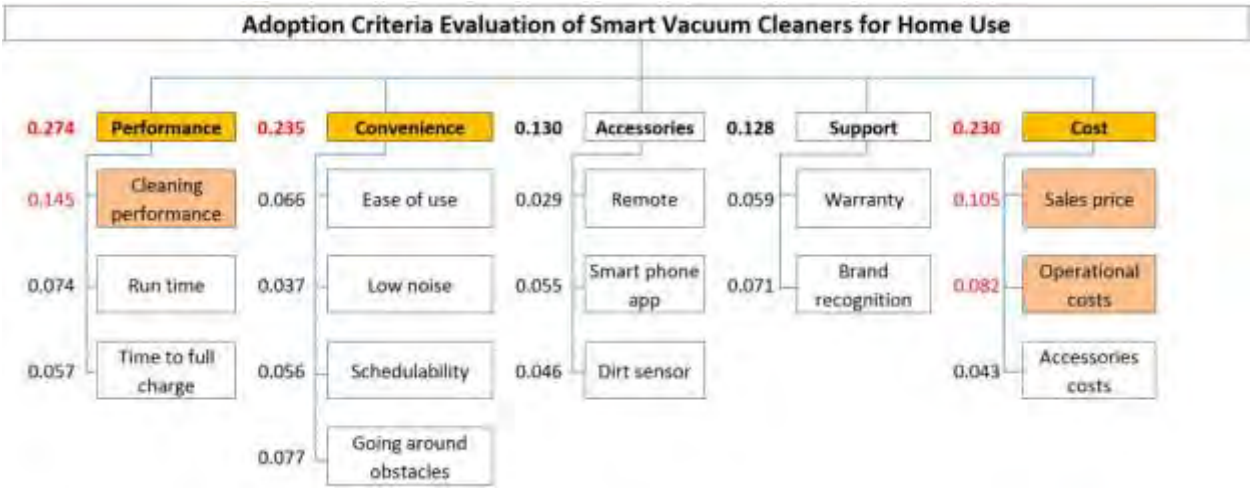

Figure 4 – HDM Model, Weighted

The most important perspective came out to be performance (.274) followed by convenience (.235) that was only marginally above cost (.230). It was interesting to see performance being the superior perspective with respect to convenience, considering the main force driving people to buy smart vacuum cleaners was thought to be convenience. As it happens most of the adopters in US don't want to sacrifice performance more than they gain convenience for. Although the close call between performance and convenience also states that deficiency in one of them can be compensated by the other to some extent.

It was also interesting to see cost coming third in the eye of the user, albeit with a very small margin. This means that adopters at this stage embraced the rule of diminishing returns and are willing to pay premium for increased convenience and performance. This gives the edge to the producer of high-performance products at a disproportionately higher price point. This is a clear indication that the technology is yet far from price wars and commoditization. Detailed results regarding perspectives (level 1) are given in Table 4 and Figure 5.

Table 4 – HDM Level 1 (perspectives) weighted results

Adoption Criteria Evaluation of Smart Vacuum Cleaners for Home Use	Performance	Convenience	Accessories	Support	Cost
Expert 01	0.27	0.22	0.12	0.11	0.29
Expert 02	0.25	0.21	0.1	0.13	0.3
Expert 03	0.22	0.23	0.18	0.14	0.23
Expert 04	0.56	0.17	0.05	0.12	0.09
Expert 05	0.3	0.34	0.14	0.13	0.09
Expert 06	0.23	0.31	0.24	0.11	0.1
Expert 07	0.23	0.38	0.09	0.12	0.18
Expert 08	0.25	0.24	0.12	0.14	0.24
Expert 09	0.21	0.22	0.14	0.14	0.29
Expert 10	0.21	0.21	0.17	0.14	0.27
Expert 11	0.22	0.23	0.15	0.17	0.22
Expert 12	0.19	0.23	0.16	0.13	0.29
Expert 13	0.34	0.21	0.08	0.16	0.21
Expert 14	0.26	0.24	0.08	0.13	0.3
Expert 15	0.24	0.24	0.14	0.14	0.24
Expert 16	0.48	0.14	0.06	0.12	0.2
Expert 17	0.23	0.22	0.16	0.14	0.24
Expert 18	0.19	0.35	0.18	0.11	0.17
Expert 19	0.23	0.22	0.14	0.11	0.3
Expert 20	0.29	0.2	0.13	0.09	0.29
Expert 21	0.36	0.13	0.1	0.11	0.29
Mean	0.274	0.235	0.130	0.128	0.230
Minimum	0.19	0.13	0.05	0.09	0.09
Maximum	0.56	0.38	0.24	0.17	0.3
Std. Dev.	0.09	0.06	0.05	0.02	0.07

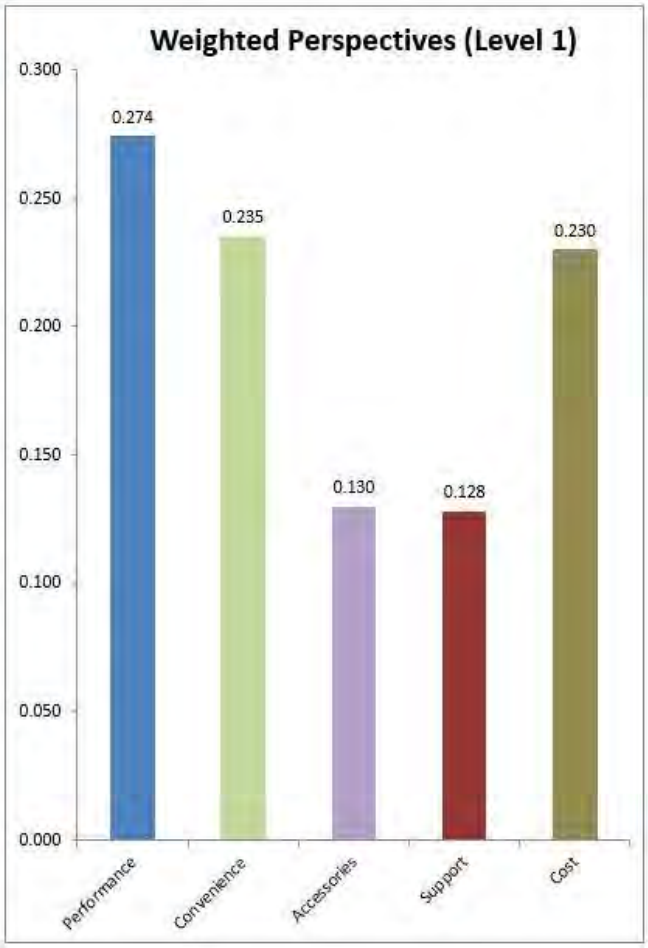

Figure 5 - Level 1 (perspectives) weighted results graphical representation

Accessories and support were lagging far behind in terms of impact; which is another indication that users are yet far from being a loyal customer base to a specific brand. Although the market leader, iRobot currently has a whopping market share of 70%, this picture can change in the future if iRobot fails to transform their already existing user base into a loyal customer base with a sustainable edge in performance, convenience and cost.

Looking down to the criteria level (level 2) top three factors strike us as cleaning performance (.145), followed by sales price (.105) and operating costs (.082). It is interesting to observe that no single criteria from the second most important perspective (convenience) made it into top three, although one following closely as fourth (going around obstacles with .077).

Cleaning performance has such a powerful impact on adoption that it single handedly over shadows 2 other perspectives, accessories (.130) and support (.128). No other criteria even come close. If the cost perspective had a criterion called “life cycle cost” as a combination of sales price and operating costs, only then it would be able to push cleaning performance to the second spot.

Although the ranking of first two criteria are pretty solid, it may be argued that, for a different set of users, going around obstacles (.077) or run time (.074), even brand recognition (.071) may replace operating costs (.082) as the third criteria.

Detailed results regarding criteria (level 2) are given in Table 5 and Figure 6.

Table 5 – HDM Level 2 (criteria) weighted results

	Adoption Criteria Evaluation of Smart Vacuum Cleaners for Home Use															
	Performance			Convenience				Accessories			Support		Cost			
	Cleaning performance	Run time	Time to charge	Ease of use	Low noise	Schedule	Going around obstacles	Remote	Smart App	Dirt sensor	Warranty	Brand recognition	Sales price	Operating costs	Accessories	Inconsistency
Expert 01	0.12	0.03	0.12	0.05	0.03	0.05	0.08	0.03	0.04	0.05	0.05	0.06	0.15	0.08	0.06	0.01
Expert 02	0.09	0.09	0.07	0.05	0.04	0.06	0.06	0.02	0.03	0.05	0.08	0.05	0.17	0.09	0.04	0.01
Expert 03	0.09	0.08	0.06	0.05	0.04	0.07	0.08	0.03	0.08	0.07	0.06	0.08	0.11	0.06	0.05	0.01
Expert 04	0.31	0.2	0.06	0.08	0.02	0.03	0.04	0	0	0.04	0.09	0.03	0.07	0.02	0.01	0.02
Expert 05	0.12	0.1	0.08	0.08	0.05	0.1	0.12	0	0.1	0.04	0.02	0.11	0.03	0.04	0.02	0.04
Expert 06	0.17	0.04	0.02	0.13	0.07	0.05	0.06	0.12	0.05	0.08	0.03	0.08	0.04	0.05	0.01	0.02
Expert 07	0.14	0.04	0.05	0.11	0.07	0.11	0.09	0.01	0.03	0.04	0.07	0.05	0.13	0.04	0.02	0.03
Expert 08	0.12	0.06	0.07	0.08	0.03	0.04	0.09	0.02	0.04	0.06	0.09	0.06	0.1	0.09	0.05	0
Expert 09	0.12	0.06	0.03	0.1	0.02	0.04	0.06	0.03	0.08	0.02	0.04	0.1	0.17	0.04	0.08	0.03
Expert 10	0.08	0.13	0	0.06	0.06	0.04	0.05	0.07	0.04	0.07	0.04	0.1	0.13	0.09	0.05	0.03
Expert 11	0.09	0.04	0.09	0.05	0.04	0.05	0.1	0.03	0.09	0.03	0.03	0.14	0.07	0.1	0.05	0.02
Expert 12	0.16	0.01	0.02	0.05	0.06	0.05	0.06	0.04	0.07	0.05	0.07	0.05	0.09	0.15	0.05	0
Expert 13	0.27	0.05	0.02	0.11	0.01	0.03	0.06	0.03	0.02	0.03	0.14	0.03	0.1	0.09	0.03	0.01
Expert 14	0.1	0.05	0.11	0.05	0.03	0.06	0.1	0.02	0.02	0.03	0.08	0.05	0.16	0.09	0.05	0.01
Expert 15	0.09	0.08	0.08	0.06	0.05	0.05	0.08	0.02	0.08	0.04	0.05	0.09	0.09	0.11	0.04	0
Expert 16	0.32	0.11	0.04	0.05	0.03	0.01	0.04	0.02	0.01	0.03	0.05	0.08	0.09	0.07	0.03	0.03
Expert 17	0.1	0.06	0.07	0.05	0.03	0.07	0.07	0.04	0.1	0.03	0.06	0.09	0.1	0.08	0.06	0.01
Expert 18	0.07	0.1	0.02	0.05	0.02	0.09	0.19	0	0.17	0.01	0.05	0.05	0.07	0.07	0.03	0.03
Expert 19	0.19	0.02	0.02	0.03	0.02	0.09	0.09	0.03	0.04	0.07	0.04	0.07	0.1	0.14	0.05	0
Expert 20	0.14	0.05	0.1	0.05	0.03	0.05	0.07	0.02	0.02	0.09	0.03	0.06	0.14	0.09	0.05	0
Expert 21	0.15	0.15	0.06	0.04	0.03	0.03	0.03	0.03	0.04	0.04	0.06	0.06	0.09	0.13	0.07	0
Mean	0.145	0.074	0.057	0.066	0.037	0.056	0.077	0.029	0.055	0.046	0.059	0.071	0.105	0.082	0.043	**0.01**
Minimum	0.07	0.01	0	0.03	0.01	0.01	0.03	0	0	0.01	0.02	0.03	0.03	0.02	0.01	0
Maximum	0.32	0.2	0.12	0.13	0.07	0.11	0.19	0.12	0.17	0.09	0.14	0.14	0.17	0.15	0.08	0.04
Std. Dev.	0.07	0.05	0.03	0.03	0.02	0.03	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.03	0.02	0.01
Disagree.																**0.032**

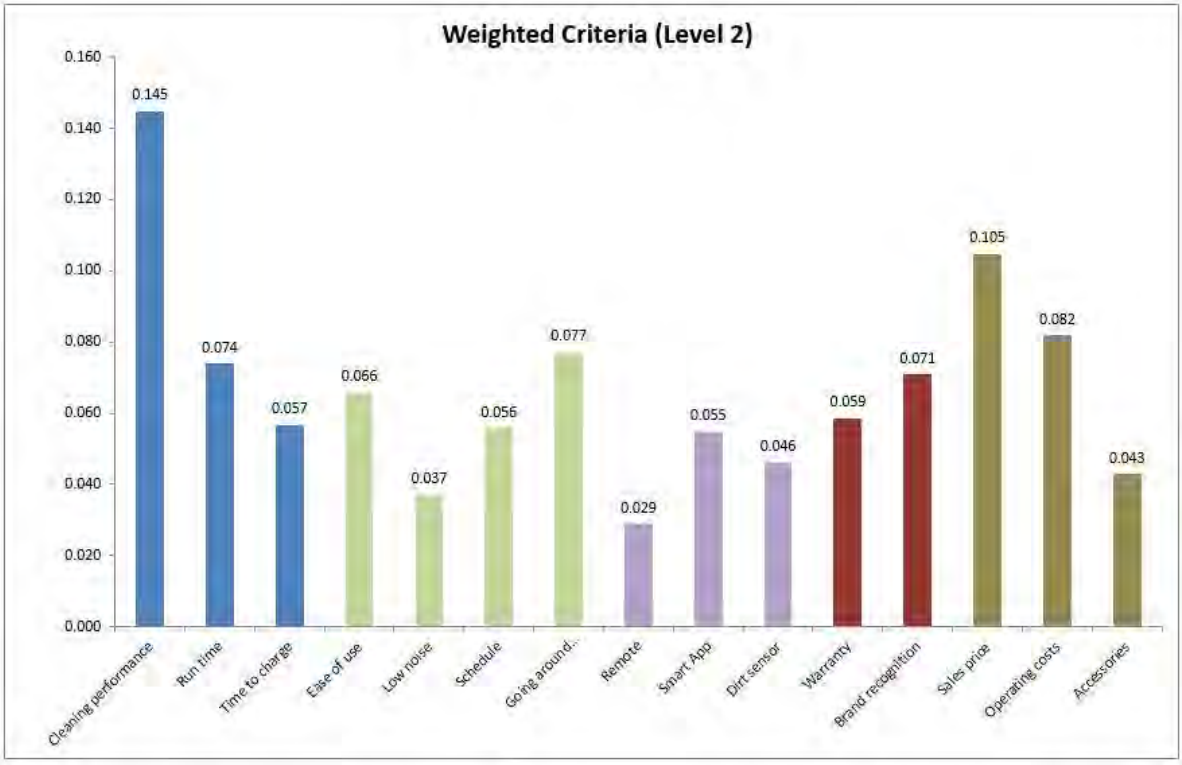

Figure 6 - Level 2 (perspectives) weighted results graphical representation

In summary, whether it is a new entry to the market or a company looking to reinforce its dominant edge in competition, cleaning performance is the most important criterion a company should focus in order to create a loyal customer base. Although sales price comes as the second most important criteria, the market is yet far from maturity and price wars as indicated by perspectives of performance and convenience leading before cost in general. So there's yet room for a new competitor to emerge and disrupt the market with superior performance and convenience even if it is at a higher price point. This means opportunity for new companies and caution for existing ones.

STATISTICAL ANALYSIS OF THE RESULTS

Referring back to Table 4, it can be seen that standard deviation of all perspectives is relatively low with respect to the average; which means that the evaluations of experts are closely clustered around the mean. This means experts are pretty much in agreement aside from one or two outliers for each perspective. Likewise, referring back to Table 5, one can easily see the inconsistency of experts is very low with a mean of a mere 1%. Disagreement is also very low at the level of 3.2% among all experts. These numbers mean that the experts involved in this study "know what they are talking about" and "talk about the same thing". With 97% agreement among 21 experts that are 99% consistent, it is safe to conduct inductive reasoning and attribute the criteria weights to the majority of users in the US.

Furthermore, the statistical F-test for evaluating the null hypothesis (Ho:ric=0) is obtained from the online HDM tool and given in Table 6.

Table 6 – HDM Statistical results

Source of Variation	Sum of Square	Deg. of freedom	Mean Square	F-test value
Between Subjects:	0.25	14	0.018	**13.26**
Between Conditions:	0	20	0	
Residual:	0.37	280	0.001	
Total:	**0.62**	**314**		
Critical F-value with degrees of freedom 14 & 280 at 0.01 level:				**2.15**
Critical F-value with degrees of freedom 14 & 280 at 0.025 level:				**1.91**
Critical F-value with degrees of freedom 14 & 280 at 0.05 level:				**1.73**
Critical F-value with degrees of freedom 14 & 280 at 0.1 level:				**1.53**

From all the experts who participated in study, the benchmark (critical) F-value is given as 2.15 for 99% confidence level, as seen in Table 6. With an F-test value of 13.26, which is well over 2.15, the HDM weights which were given by participating experts can be used as is with well above 99% confidence.

FUTURE RESEARCH

The objective of this research was to give recommendations to smart vacuum cleaner manufacturers for better adoption of their products. However with the weighted HDM obtained, current or future alternatives for different markets can be evaluated by the users to make a selection for future research.

The numerical results of HDM are pretty solid as indicated by statistical analyses, but there's always room for improvement. In order to improve the results even further, expert base can always be expanded to include more input. Additionally a sensitivity analysis may be useful for determining the third criteria among operating costs (.082), going around obstacles (.077), run time (.074) and brand recognition (.071). As they are in a close call it may be useful to be certain about the boundaries and ranking of these criteria.

As strong as the results obtained are, even with improvements suggested above, this research only reflects the adoption preferences of users in the US with their habits and viewpoints. As habits and viewpoints change from one location to another, the expert panel and HDM weighting should be repeated for different markets with local users as experts, for the results of criteria weights to be applicable elsewhere. Additionally a comparative study of criteria weights obtained from different markets/regions would provide more comprehensive insight into impactful adoption criteria on a global scale.

One interesting factor that came up during expert panel discussions was regarding household pets, mainly cats and dogs. Since there is not a smart vacuum cleaner with “pet friendly” features, that factor was kept out of scope of this research as a non-discriminating factor. However it was identified as “definitely a point of improvement” by the expert panel. This also brought the option of asking the weighting experts if they owned a pet and 2 experts turned out to have a household pet and smart vacuum cleaner at the same time. When directed the same question, they responded that a “pet friendly” smart vacuum cleaner would be “an absolutely great idea” although they also mentioned “they had no idea how that would be”. Nevertheless, development ideas for such a feature are identified as a user demand by this study, which is another area for future research.

REFERENCES

1. Kogut B., Zander U, (Aug. 1992) “Knowledge of the Firm, Combinative Capabilities, and the Replication of Technology,” INFORMS Organization Science, Vol. 3, No 3, pp. 383-397

2. Breazeal, C. (1999) “Robots in Society: Friend or Appliance?,” Agents99 Workshop on Emotion-based Agent Architecture

3. Dautenhahn, K., et al.: What is a Robot Companion - Friend, Assistant or Butler? (2005)

4. Forlizzi, J., DiSalvo, C.: Service Robots in the Domestic Environment: a Study of the Roomba Vacuum in the Home. In: Proceeding of the 1st ACM SIGCHI/SIGART conference on Human-robot interaction, ACM Press, Salt Lake City, Utah, USA (2006)

5. Friedman, B., Kahn Jr., P.H., Hagman, J.: Hardware Companions?: What Online AIBO Discussion Forums Reveal About the Human-Robotic Relationship. In: Proceedings of the SIGCHI conference on Human factors in computing systems, ACM Press, Ft. Lauderdale, Florida, USA (2003)

6. Kocaoglu, Dundar F. (1983) "A participative approach to program evaluation." *IEEE Transactions on Engineering Management* pp. 112-118.