**Cost-Effectiveness of Propeller Health System for Adults in the United States**

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**Abstract**

**Background:** Propeller health system (PHS), a tele health asthma management system for asthma medication overuse monitoring, reduces exacerbations and symptoms in adults with asthma. The study objective was to estimate the cost-effectiveness of PHS and usual care compared to usual care from a US payer perspective.

**Methods:** We estimated payer costs, quality-adjusted life years (QALYs), and the incremental cost-effectiveness ratio (ICER) of PHS and usual care compared to usual care using a state-transition simulation model that included sensitivity analyses. Every 2 weeks, patients transition between controlled/uncontrolled asthma and exacerbation health states. The best available evidence informed the clinical and cost input estimates. Life time use of PHS use was assumed to estimate a lifetime horizon.

**Results:** The mean lifetime discounted costs and QALYs for men (women) were $58,540 ($59,999) and 14.28 (15.06) for usual care and $61,236 ($62,786) and 14.80 (15.63) for PHS resulting in $5,216 ($4,931) /QALY. One way sensitivity analyses indicated that the results were sensitive to the cost of hospitalization, probability of subjects having oral corticosteroid (OC) burst for uncontrolled asthmatics, and probability of emergency room visit for the uncontrolled asthmatics.

\**Conclusion:** The results suggest that PHS and usual care compared to usual care alone improves QALYs at an increase in direct medical costs. Even so, the probability of cost-effectiveness at a willingness to pay threshold of $50,000/QALY is 97.6%.

**Introduction**

Asthma is a respiratory disease characterized by chronic symptoms such as airflow obstruction, bronchial hyper-responsiveness, and inflammation of the airways. In the United States, 8.6% of children and 7.4% of adults currently have asthma1.

Current guidelines from the Agency for Healthcare Research and Quality and available evidence indicate that most people with asthma can be symptom free if they receive appropriate medical care, use of inhaled corticosteroids when prescribed, and modify their environment to reduce or eliminate exposure to allergens and irritants2.

The current approach to asthma management includes monitoring symptoms, measuring lung function, encouraging use of medications that control and prevent symptoms, reducing the triggers of asthma, educating the patient, and maintaining a collaborative patient-provider relationship3. The main goals of therapy are to minimize current symptoms future risk.

Recently, PHS has been implemented in a randomized controlled study to determine the effectiveness of tele health management strategies in providing optimal care to asthma patients and have successfully identified populations that have decreased the over use of SABA after a 12 month period of implementing PHS for asthma management4.

This article presents a report of a *de novo* economic evaluation of PHS from a US payer perspective. Our aim is to identify the cost-effectiveness of PHS and usual care compared to usual care alone such as to make the report relevant to US and potentially other countries in implementing such tele health strategies. The analysis presented in this article is unique in that there has never been a comparative effectiveness analysis of a real-time telehealth strategy such as the PHS.

**Methods**

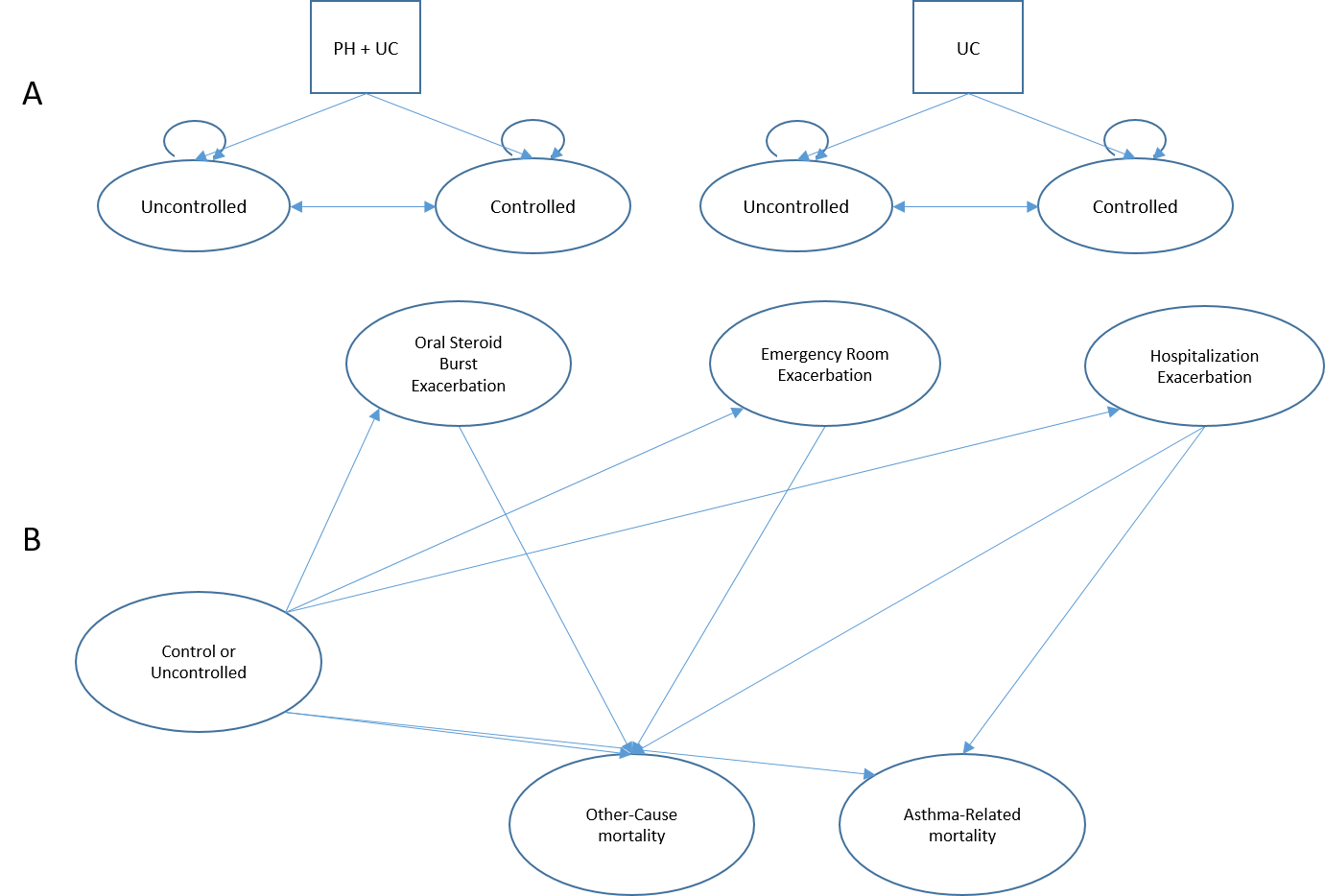
**Model Overview**

A Markov model programmed in Microsoft Excel (Fig 1) was used to simulate two treatment options in adults and to estimate incremental clinical and economic outcomes including asthma exacerbations, health care resource utilization, asthma-specific quality of life, quality-adjusted life years (QALYs), payer costs, and incremental cost-effectiveness ratios (ICER). The treatment alternatives were PHS and usual care (PHS+UC) vs. usual care alone. Usual care was defined by the comparison arm of the PHS trial used for the evidence generation of the model inputs. Generally, usual care was defined as the routine care provided to patients by their health care providers.

Life time of PHS and usual care was assumed to estimate a lifetime horizon (60 years). The lifetime PHS use is assumed due to potential drop in SABA overuse that may result in stoppage of PHS use. All patients were assumed to adhere to the given therapies. Costs and outcomes were discounted at 6% and 1.5% per annum respectively.

**Model Structure**

The model is hierarchically structured where patients transition between level 1 (highest level) controlled and uncontrolled state and through these states they transition into two states (lower level): exacerbation and death. Patients transitioned through these health states using 2-week transition probabilities. Two weeks was considered an appropriate length of time to capture the majority of morbidities associated with exacerbations and has been used in other asthma cost-effectiveness models5. The model structure is implementing the Asthma Policy Model’s structure that modeled asthma in three main states with the addition of a higher level structure that corresponds to the control level of patients6. Although the structure of this model was similar to past CEA publications, the underlying population, perspective inputs, and assumptions remain unique and of particular importance to US payers.



**Fig 1.** Cohort Model Structure for PHS plus Usual Care versus Usual Care Alone. **A:** Highest level transition states from controlled to uncontrolled. **B:** Transition from controlled/uncontrolled to exacerbation and/or death.

**Model population**

The model’s patient population reflects that of the US adult asthmatics. The model cohort matches the PHS trial population with an average age of 36.

Table 1. Model inputs by Asthma Control Status

|  |  |  |  |
| --- | --- | --- | --- |
| Model Input | Controlled | Uncontrolled | Source |
| **Transition Probabilities** |  |  |  |
| Probability of Asthma Related Mortality per 2 week | 0.00015 (0.0002)\* | 0.00238 (0.0012)\* | De Vries et al 7 |
| Additional risk of death given asthma hospitalization | 0.01165 (0.0018)\* | | Sullivan et al8 |
| Probability of OC burst per 2 week | 0.0963 (0.0049)\* | 0.1005 (0.0067)\* | Sullivan et al8 |
| Probability of ER visit per 2 week | 0.0023 (0.0008)\* | 0.0057 (0.0017)\* | Sullivan et al8 |
| Probability of Hospitalization per 2 week | 0.0023 (0.0008)\* | 0.0023 (0.0011)\* | Sullivan et al8 |
| Probability of Controlled Asthma using PH system per 2 week |  | 0.04 (0.0148)\* | Merchant et al4 |
| Probability of Controlled Asthma using UC per 2 week |  | 0.03 (0.0184)\* | Merchant et al4 |
| Probability of Uncontrolled Asthma using PH system per 2 week | 0.01 (0.0081)\* |  | Merchant et al4 |
| Probability of Uncontrolled Asthma using UC per 2 week | 0.01 (0.0087)\* |  | Merchant et al4 |
| **Cost** |  |  |  |
| Usual care pharmacotherapy | $113 (28.23) | | Ayres et al.9 |
| Mild Exacerbation (OC burst) Unit Cost | $147 (12) | | Market Scan10 |
| ER Unit Cost | $673 (55) | | Market Scan10 |
| Hospitalization Stay Unit Cost | $11,209 (913) | | Market Scan10 |
| PHS one time registration cost | $100 (25( | | UC Denver Source |
| PHS biweekly recurring cost | $25 (6.25) | | UC Denver Source |
| **Utility** |  | |  |
| Non Exacerbation State | 0.67 (0.15) | | Chen11 |
| OC Burst | 0.57 (0.36) | | Price et al12 |
| ER visit | 0.45 (0.37) | | Price et al12 |
| Hospitalization | 0.33 (0.39) | | Price et al12 |

All values in parentheses are standard error of the mean.

\* Values that were annual rates that were recalculated to probabilities in 2 weeks.

**Clinical inputs**

The best available evidence was used to estimate the clinical and cost inputs (Table 1). Where possible we used evidence from a meta-analysis of asthma trials over using distributional assumptions or single trial evidence. Merchant et al.’s randomized control trial informed the transition probabilities regarding the control and uncontrolled states4. Healthcare resource utilization associated with asthma control levels were informed by Sullivan et al13. The asthma-specific quality of life and health-related quality of life utilities were informed by a meta-analysis of asthma studies14.

*Risk of Asthma-related Mortality for Controlled and Uncontrolled Asthmatics*

There is small but significant relationship between asthmaexacerbations (i.e. asthma hospitalizations) and death13. We uniformly modeled this association between hospitalization and death across treatment alternatives as well as all-other-cause mortality rate based on the US age and gender-specific population.

*Exacerbations*

Asthma exacerbations were split into three mutually exclusive categories in order of increasing severity: 1. Oral corticosteroid (OC) burst, 2. Emergency room visit, or 3. A hospitalization event.

*Quality of life*

Asthma-specific quality of life was estimated using the Asthma Quality of Life Questionnaire (AQLQ) from Chen et al11. and Price et al12. The estimated utility values for each health state were mapped from AQLQ to EQ-5D as was done in Campbell et al5. The utility estimates for the exacerbation states came from a study conducted in the UK at four specialty asthma centers among moderate-to-severe asthma patients.

**Cost inputs**

We conservatively assumed the same level of health care resource utilization for both arms even though there may be potential reduction in resource use for the intervention (PHS+UC) arm. PHS utilization cost was estimated based on short pilot trial administrative report within UC Denver Anschutz Medical Campus Breathing Institute. Resource utilization rates that were captured as asthma exacerbations included asthma hospitalizations, asthma emergency room visits, and oral corticosteroid bursts. One general practitioner visit rate was assumed for the OC burst exacerbation because at least one visit is required for prescription of OC.

Unit costs for physician visits, emergency room visits, and hospital stays were based on average paid amounts for asthma diagnosed (ICD-9 493.xx) services from 2005 Market Scan data10. All costs were reported in 2016 US dollars using the medical care component of the Consumer Price Index to inflate costs prior to 2008.

**Scenario, subgroup and sensitivity analyses**

The lifetime horizon where patients were under the PHS in addition to usual care was the base-case scenario.

An alternative scenario where one year horizon of PHS in addition to usual care followed by a lifetime horizon of usual care for the PHS arm was considered.

Additionally, multiple subgroups of varying age (40, 60, and 80) and gender were undertaken to identify the cost-effectiveness of PHS within the different subgroup populations.

We also undertook a one-way and probabilistic sensitivity analysis (PSA) to estimate the influence that the range of input values had on the incremental cost effectiveness ratio (ICER). The one-way sensitivity analysis varied one input parameter at a time using the lower and upper 95% interval bounds of the assumed distribution (Appendix 1), if there were no reasonable alternative lower and upper bounds, and recorded the change in the incremental cost per QALY. Standard errors in Table 1 and distributional assumptions of the inputs were used to generate the 95% bounds. Transition probabilities and utilities were assumed to follow a beta distribution while cost distribution were assumed to be gamma. Through 1000 random draws of the input parameter distributions, the PSA (Appendix 2) informed 95% intervals for outputs of the model.

**Results**

**Base case analysis (Lifetime use of PHS)**

Base case analysis results were presented as per patient averages (Table 2). The PHS arm resulted in extended life years (Lys) and improved QALYs. Discounted Lys were 23.71 (22.46) for the PHS arm for females (males) and 22.86 (21.68) for the usual care arm; undiscounted Lys were 31.80 (29.60) for the PHS arm and 30.53 (28.47) for the usual care arm. Discounted QALYs were 15.63 (14.80) for the PHS arm for females (males) and 15.06 (14.28) for the usual care arm; undiscounted QALYs were 20.96 (19.51) for the PHS arm for females and 20.12 (18.76) for the usual care arm. With a total cost difference of $3,403 ($3,293) and QALY difference of 0.57 (0.52) the incremental cost-effectiveness ratio for PHS plus usual care compared to usual care alone was $6,022 ($6,370) / QALY for females (males).

Table 2. Base case and scenario result

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Cost | LY | QALY | ICER |
| **Base case**  **Female** |  |  |  |  |
| PHS + Usual Care | $76,760 | 23.71 | 15.63 |  |
| Usual Care | $73,357 | 22.86 | 15.06 |  |
| Difference | $3,403 | 0.85 | 0.57 | $6,022/QALY |
| **Male** |  |  |  |  |
| PHS + Usual Care | $74,866 | 22.46 | 14.80 |  |
| Usual Care | $71,573 | 21.68 | 14.28 |  |
| **Difference** | **$3,293** | **0.78** | **0.52** | **$6,370/QALY** |
| **Scenario**  **Female** |  |  |  |  |
| PHS + Usual Care | $74,782 | 23.15 | 15.26 |  |
| Usual Care | $73,357 | 22.86 | 15.06 |  |
| Difference | $1,426 | 0.29 | 0.19 | $7,376/QALY |
| **Male** |  |  |  |  |
| PHS + Usual Care | $72,974 | 21.95 | 14.47 |  |
| Usual Care | $71,573 | 21.68 | 14.28 |  |
| Difference | $1,401 | 0.27 | 0.19 | $7,668/QALY |

**Scenario Analysis result (One year PHS then usual care)**

Scenario analysis of one year PHS then transition to usual care resulted in higher ICER values compared to the lifetime assumption. Lifetime costs of PHS were $74,782 ($72,974) for females (males). Discounted Lys and QALYs for the PHS arm were 23.15 (21.95) and 15.26 (14.47) for females (males), respectively. The ICER equaled $7,376 (7,668) / QALY for females (males).

**Sensitivity analysis result**

The one-way sensitivity analysis indicated that the probability of asthma-related mortality for uncontrolled patients was the most influential. In the base case, the probability of asthma-related mortality was set as 0.00238. When varied based on the 95% bounds (0.0006118, 0.0053), the ICER ranged from $4,832 to $12,138, respectively. The results were also sensitive to the cost of non-exacerbation state from ($3,397 to $8,251), utility of non-exacerbation state ($6,409 to $4,249), and the probability of asthma-related mortality for controlled patients ($5,232 to $7,080) (Fig.2).

**Figure 2.** Tornado Diagram of One-way Sensitivity Analysis on US Cost per QALY Outcome. (Parameters that had less than a US $100 difference in the ICER were not displayed)

**Figure 3.** Cost-Effectiveness Acceptability Curve. (Displays the probability of an intervention strategy being cost-effective over a range of willingness-to-pay threshold for an additional quality-adjusted life year).

The cost-effectiveness acceptability curve illustrates the probability of PHS being cost effective at a range of willingness-to-pay threshold. At a $15,000 / QALY threshold, PHS had the best net health benefit in 54% of the simulations (Fig. 2).

**Fig 3.** Cost-Effectiveness Acceptability Curve of Subgroups.

The cost-effectiveness acceptability curve of subgroups illustrates the probability of PHS being cost effective at a range of willingness-to-pay threshold. The results indicate that females have a higher probability of PHS being cost effective at lower WTP thresholds. Additionally, younger adults also have a higher probability of PHS being cost effective at lower WTP thresholds.

**Discussions**

The objective of this article was to estimate the costs and consequences of Propeller Health system plus usual care compared to usual care alone from a US payer perspective. We found the incremental value of PHS to usual care was $6,022 ($6,370) / QALY and the scenario analysis only implementing PHS for one year yielding $7,376 ($7,668) / QALY for females (males). The outcome was most sensitive to differences in probability of asthma mortality in uncontrolled population.

There currently are no empirical evidence regarding the cost-effectiveness of real-time monitoring of asthma management, but Ryan et al. published the only other clinical and cost-effectiveness analysis of tele management of asthma in UK. Interestingly, Ryan et al reported that self-monitoring of asthma was not cost-effective. The present research adds to this gap in identifying the cost-effectiveness of telehealth management of asthma.

There are limitations to this study. The findings were based on a simulation model. The long term cost and consequences may not provide the most robust and valid result as a randomized controlled trial yet efforts were made to provide the best evidence as inputs to the simulation model. The model structure utilized similar peer-reviewed asthma CEA models. The findings from the base case and scenario analysis were not very different and demonstrated only a small difference in cost and QALYs.

Another limitation was the inability to use the patient-level meta-analysis for the purposes of estimating health-related quality-of-life utilities. Further research should be conducted to identify and utilize better input values that better reflect the HRQoL utility values.

Additionally, the exact information regarding routine care for each patient was not captured through the trial such as implementation of asthma registry, emphasis on ACT testing, monitoring of SABA refills, and referral to specialty care. Although these information was not captured, the trial study design was a randomized control study therefore baseline characteristics may be assumed to be randomly allocated with similar distribution of asthma management routine in each group which may not have substantial impact on the results of this analysis.

The findings suggest that PHS along with usual care improves QALYs at an increase in direct medical costs. The cost-effectiveness of PHS at a WTP of $50,000 indicates a highly cost-effective solution to asthma management. The findings also suggest that PHS is more cost effective for the younger adult population as well as females which may guide decision makers with regards to their patient population.

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**Appendix**

**Appendix 1**. One-way Sensitivity Analysis Assumptions and Values

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Lower** | **Upper** | **Ref** |
| Probability of Asthma-related Mortality for 2 weeks for Uncontrolled Patients | 0.000612 | 0.005309 | Beta dist 95% CI |
| Additional risk of death given asthma hospitalization | 0.008431 | 0.015376 | Beta dist 95% CI |
| Probability of Asthma-related Mortality for 2 weeks for Controlled Patients | 3.08E-07 | 0.000732 | Beta dist 95% CI |
| Probability of OC Burst per 2 week | 0.087612 | 0.114055 | Beta dist 95% CI |
| Probability of Emergency Room Visit per 2 week | 0.002908 | 0.009504 | Beta dist 95% CI |
| Probability of Asthma Hospitalization per 2 week | 0.000697 | 0.004835 | Beta dist 95% CI |
| Probability of OC Burst per 2 week for controlled asthma | 0.086949 | 0.106074 | Beta dist 95% CI |
| Probability of Emergency Room Visit per 2 week for controlled asthma | 0.001018 | 0.004092 | Beta dist 95% CI |
| Probability of Asthma Hospitalization per 2 week for controlled asthma | 0.001018 | 0.004092 | Beta dist 95% CI |
| Usual care pharmacotherapy per 2 weeks | 52.83646 | 142.934 | Gamma dist 95% CI |
| Mild exacerbation unit cost | 97.63679 | 144.6347 | Gamma dist 95% CI |
| Emergency room unit cost | 445.5216 | 660.9275 | Gamma dist 95% CI |
| Hospitalization stay unit cost | 7430.513 | 11006.27 | Gamma dist 95% CI |
| One time cost of PH system registration | 57.15864 | 154.6264 | Gamma dist 95% CI |
| Cost of PH system per 2 weeks (recurrent) | 14.28966 | 38.65659 | Gamma dist 95% CI |
| Utility score for Non Exacerbation State (Chronic Asthma) | 0.57 | 0.89 | Brown 76 2007, Norman 2013 |
| Utility score for OC Burst | 0.326 | 0.65 | van Nooten 2013, Wilson 87 2014 |
| Utility score for ER visit | 0.326 | 0.65 | van Nooten 2013, Wilson 87 2014 |
| Utility score for Hospitalization | 0.326 | 0.59 | van Nooten 2013, Norman 2013 |
| Probability of Controlled Asthma using PH system at 2 wks | 0.014072 | 0.07141 | Beta dist 95% CI |
| Probability of Controlled Asthma under Usual Care at 2 wks | 0.002742 | 0.072084 | Beta dist 95% CI |
| Probability of Uncontrolled Asthma using PH system at 2 wks as initially controlled | 6.52E-05 | 0.029481 | Beta dist 95% CI |
| Probability of Uncontrolled Asthma under Usual Care at 2 wks as initially controlled | 1.9E-06 | 0.030877 | Beta dist 95% CI |

**Appendix 2**. Probabilistic Sensitivity Analysis Standard Errors and Parameter Values

|  |  |  |  |
| --- | --- | --- | --- |
| **Variable** | **Standard Error** | **α** | **β** |
| Probability of Asthma-related Mortality for 2 weeks for Uncontrolled Patients | 0.001225168 | 3.747321 | 1573.903 |
| Additional risk of death given asthma hospitalization | 0.001775211 | 42.56058 | 3610.439 |
| Probability of Asthma-related Mortality for 2 weeks for Controlled Patients | 0.000204886 | 0.560417 | 3652.44 |
| Probability of OC Burst per 2 week | 0.006748711 | 199.1965 | 1783.803 |
| Probability of Emergency Room Visit per 2 week | 0.001695581 | 11.37628 | 1971.624 |
| Probability of Asthma Hospitalization per 2 week | 0.001075159 | 4.558367 | 1978.442 |
| Probability of OC Burst per 2 week for controlled asthma | 0.004880287 | 351.7918 | 3301.208 |
| Probability of Emergency Room Visit per 2 week for controlled asthma | 0.000792245 | 8.397234 | 3644.603 |
| Probability of Asthma Hospitalization per 2 week for controlled asthma | 0.000792245 | 8.397234 | 3644.603 |
| Usual care pharmacotherapy per 2 weeks | 28.23 | 16 | 7.0575 |
| Mild exacerbation unit cost | 12 | 150.6347 | 0.977729 |
| Emergency room unit cost | 55 | 149.5551 | 4.497406 |
| Hospitalization stay unit cost | 913 | 150.7177 | 74.36843 |
| One time cost of PH system registration | 25 | 16 | 6.25 |
| Cost of PH system per 2 weeks (recurrent) | 6.25 | 16 | 1.5625 |
| Utility score for Non Exacerbation State (Chronic Asthma) | 0.15 | 5.913867 | 2.9128 |
| Utility score for OC Burst | 0.36 | 0.508515 | 0.380497 |
| Utility score for ER visit | 0.37 | 0.362411 | 0.44474 |
| Utility score for Hospitalization | 0.39 | 0.14494 | 0.299662 |
| Probability of Controlled Asthma using PH system at 2 wks | 0.014828272 | 6.091872 | 156.7155 |
| Probability of Controlled Asthma under Usual Care at 2 wks | 0.018433353 | 1.838851 | 70.28362 |
| Probability of Uncontrolled Asthma using PH system at 2 wks as initially controlled | 0.008119091 | 0.756736 | 105.5055 |
| Probability of Uncontrolled Asthma under Usual Care at 2 wks as initially controlled | 0.008719456 | 0.429344 | 74.0026 |