# Robotic Assistant for Mobility-Impaired Patients (RAMP)

Pwint Htwe, Alex Wong, Karar Majeed, Hanan Al Jarash
George Mason University, phtwe, awong12, kmajeed2, haljaras@gmu.edu

*Abstract*— ***There are currently 10 million American who need mobility assistance leading to an increase of 40 percent in demand for registered nurses by 2020 while the supply of registered nurses will only increase by 6 percent. This supply-demand gap can be partially addressed by a robot assistant to help an individual with limited mobility performs daily tasks.***

***A detailed analysis of the tasks performed by a Mobility-Impaired Patient was conducted and used to establish requirements for the robot: (i) to relocate items on behalf of the user, (ii) go to remote locations and relay video images to the user. Based on these requirements a robot was designed and constructed. Design alternatives are evaluated for designing the system to ensure the safety, cost, and energy efficiency. Design alternatives of RAMP are broken down into three stages; 1) base, 2) elevation, and 3) frame. The simulation was made in AutoCAD before building the model. After comparing and analyzing all alternatives, Omni wheels, leadscrew, and alumni frame have the best result due to their efficiency, safety, and cost-effectiveness.***

***The results of verification tests show that the robot can be controlled on a straight line with maximum deviation errors of +/- 0.05 m. The robot can be stopped at a location in the visual line of sight within a maximum deviation of +/- 0.05 m. Beyond the visual line of sight, the RAMP can be controlled in a straight-line and stopped with a maximum deviation of 0.05 m from the center and 0.07 m from an object respectively. In future tests, we hope to verify that the robot can lift and carry items weight no more than 1.5 kg, open doors with lever handles and can receive images with the delay of 10 secs. The manufacturing cost of RAMP is $4000 per robot and the expected break-even point would be reached in 17 months.***

Keywords—mobility assistant; robot assistant; healthcare assistant shortage; hospital; nursing home; disability.

## I. INTRODUCTION

It is challenging to meet the need of the 10 million individuals with limited mobility. With the demand rising for nurses and the increase of assisted living costs, a robotic system will reduce the hourly rate from 4 to 3 hours per visit which will result in a saving of $10,950 yearly [7]. According to a survey done by American Nurses Association found that nurses complained that they do not spend enough time with each patient [2][3][4]. The Robotic system will allow the nurses to be able to spend more time with patients by performing simple tasks. The proposed solution is an ambulatory impaired patient assist system that will allow a leg injured user to gather information about his/her home without ever having to physically move around, relocate any assets of his choosing to fit his immediate needs, allow two-way communication between the user and other people in the immediate vicinity.

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## II. STAKEHOLDER ANALYSIS

There is four stakeholders relevant to the RAMP system: (1) Patients, (2) Insurance Companies, (3) In-Home Healthcare Services and (4) patients Family. The major tension regarding our stakeholders is that caregivers are afraid of being replaced and losing their jobs with the RAMP system.

### A. Problem Statement

Currently, there is no a cost-efficient system in place that enables the 10 million ambulatory impaired individuals facing limited mobility to perform daily tasks such as object relocation without relying on a nurse/caregiver.

### B. Win-Win Analysis

With the introduction of robotic systems, caregivers are afraid of losing their jobs, but the system does not seek to replace them. In fact, the system aims to help caregivers by reducing their manual labor tasks and allow them to prioritize the high patient demand. The Win-Win scenario is to meet the demand, reduce costs of in-home healthcare, keep jobs, and make patients' lives easier and safer.

## III. NEED STATEMENT

With 10 million individuals who need mobility assistance, shortage of caregivers, and the cost of assisted living getting higher, there is a need for a system to assist ambulatory impaired individuals with their daily tasks.

## IV. CON-OPS

The proposed solution is a Robotic Assistant for Mobility-Impaired Patients (RAMP) system that will allow a mobility impaired individual to gather information about his/her home without ever having to physically move around, relocate any assets of his/her choosing to fit his/her immediate needs, and allow two-way communication between the user and other people in the immediate vicinity.

## V. REQUIREMENTS

### A. Mission Requirements

**1.0** The RAMP system shall help leg mobility patients with at least 90% of daily in-home tasks

**1.1** The RAMP system shall help in relocating 90% of the user's assets within one floor of the patient's home.

**1.2** The RAMP system shall gather 90% of the user's information of the environment within one floor of the patient's home.

*B. Functional Requirements/RAMP Components*

F.1 The RAMP system shall provide a navigation function
F.2 The RAMP system shall provide a linear mobility function (mobility function based on Omni Wheels)
F.3 The RAMP system shall provide a vertical mobility function (mobility function based on the leadscrew and the claw)
F.4 The RAMP system shall provide a two-way communication
F.5 The RAMP system shall provide a storage function
F.6 The RAMP system shall provide an object retrieval function

*C. Functional Design*

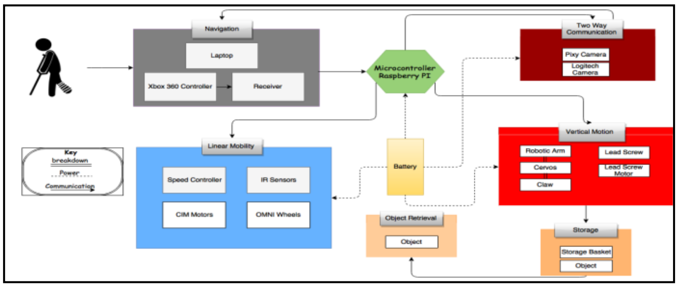


Fig. 1. Functional Design

Figure 1 depicts how each component builds each function of the overall RAMP system. Navigation is comprised of a laptop and Xbox 360 controller which is connected a receiver. All the information from the navigation function is then broadcasted into the Microcontroller, Raspberry Pi. The microcontroller then broadcasts to the mobility and two-way communication function. For the mobility function, it is comprised of a speed controller, CIM motors, IR sensors and Omni wheels. Two-way communication is comprised of a pixy camera and Logitech camera. In conjunction with the two-way communication function is the shift function which is comprised of the robotic arm made of the servos, claw, and the leadscrew which is attached to the leadscrew motor. The last function is the storage function which is comprised of the storage basket and objects of retrieval along with object retrieval. The entire system is powered by a battery shown in the center of the diagram.

*D. Mechanical Design*

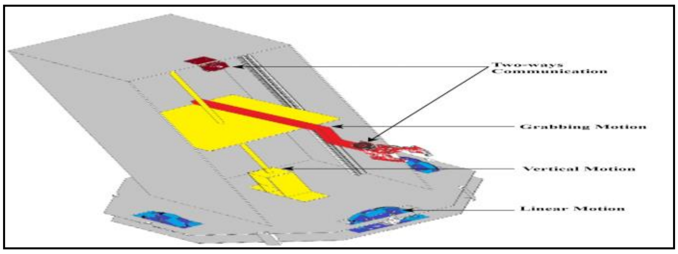


Fig. 2. Mechanical Components for RAMP Functions

Figure 2 shows mechanical components used in each RAMP function. The blue parts of the RAMP operate linear mobility function. The yellow parts handle the vertical mobility function; the red parts for grabbing motion; and the maroon parts for two-ways communication, respectively.

*E. Electrical Component*

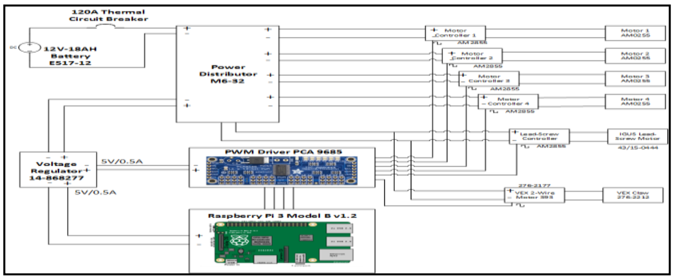


Fig. 3. Circuit Diagram

The electrical design is illustrated in Figure 3. The linear mobility function is composed of Omni wheels, CIM motors, gearbox, and motor controllers which are connected to the power distribution panel (PDP) and PWM driver. The two-ways communication function is made of two cameras which are connected to the voltage regulating module and raspberry pi. The vertical mobility function included a leadscrew nut, leadscrew, coupler, and leadscrew motor which is connected to the PWM driver and PDP. The object retrieval function is composed of VEW claw, VEX servo which is connected to PWM driver and PDP. Both PDP and VRM are connected to the battery and they disturb 12V and 5V respectively. PWM driver is connected to the raspberry pi and control the motor speed using PWM signals. The whole system can be controlled by Xbox controller using wireless sign. Figure 4 shows the electronic components set up in more details.

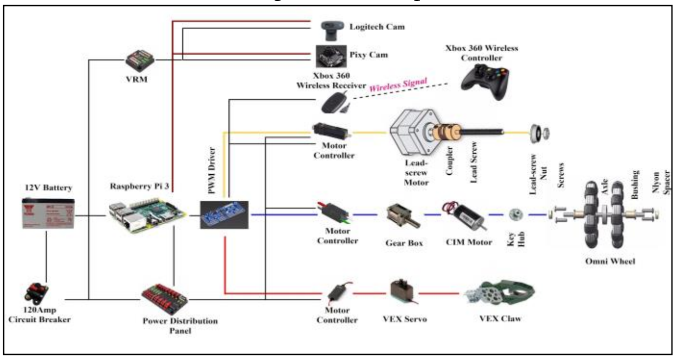


Fig. 4. Electrical Components Diagram

*F. Method of Analysis*

We compared different criteria to make our choice for the control interface. Ease of learning criteria measures how difficult it is to learn each interface control. Multi-Directional control measures how easy it is to manipulate each robotic function and direction of the RAMP system. Error rate measures how often each control interface has an error occur. A higher score represents the most favorable option with the highest score being 10 and the least favorable score being 1.

The wireless Xbox 360 controller received the highest score 8.6 due to the ease of learning, multi-directional control, and low error rate.

### G. *Hardware Material Analysis*

TABLE I. MATERIALS ANALYSIS

| Category | Weight of Importance | Soft Wood | Plastic | Aluminum Sheets | Steel |
|---|---|---|---|---|---|
| **Cost** | 0.4 | 7 | 8 | 6 | 2 |
| **Weight** | 0.3 | 8 | 7 | 6 | 3 |
| **Density** | 0.3 | 2 | 3 | 8 | 8 |
| **Score** | 1 | 5.8 | 6.2 | 6.6 | 4.1 |

Table I shows the alternatives and the different criteria we compared to pick our material. So, we wanted a system that was cost efficient, we wanted a material which was lightweight but has a high load capacity. For the cost, 10 being cost-effective and 1 being high cost. Second for material weight, 10 being very light and 1 being super heavy. Finally, for density 10 being the densest and 1 being the least dense. The aluminum sheets received the highest score with a 6.6 and it is our chosen material.

### H. *Elevation Component Analysis*

For elevation component, we compared a leadscrew, a ball screw, and an 80/20 Aluminum. We wanted something which inexpensive and has a high load capacity. 80/20 Aluminum is the cheapest among the three alternatives and has a high load capacity. However, it creates friction during operation and it is not suited to be used as an elevation components. So, we chose between a leadscrew and a ball screw. We decided to choose a leadscrew because it is comparatively cheap and has a variety of range of leads and diameter, long lasting and smoother application due to the self-lubricated system, and it has almost no audible noise and moves back and forward easily unlike a ball screw. Details of each design alternatives can be seen in Table III and a linear scale (0 as the worst and 5 as the best) is used to measure the value of some features.

TABLE II. ELEVATION COMPONENTS ANALYSIS

| Features | Lead Screw | Ball Screw | 80/20 Aluminum |
|---|---|---|---|
| **Cost** | $70 | $200 | $30 |
| **Material** | Steel | Steel | Aluminum |
| **Weight** | 0.6lb | 0.5lb | 5.5lb |
| **Noise** | 5 | 4 | 0 |
| **Friction** | 5 | 4 | 0 |
| **Load Capacity** | 3 | 5 | 3 |
| **Self-lubrication** | YES | NO | NO |

### I. *Wheel Analysis*

For elevation component, we compared Dura Omni wheels, Mecanum wheels and, and Pneumatic wheels. We decided to go with Dura Omni wheels because they are light-weighted, cost-effective, high load capacity, less complexity in coding. Details of each design alternatives can be seen in Table III and a linear scale (0 as the worst and 5 as the best) is used to measure the value of some features.

TABLE III. WHEELS ANALYSIS

| Specification | Dura Omni Wheel | Pneumatic Wheel | Mecanum Wheel |
|---|---|---|---|
| **Cost per Unit** | $35 | $37 | $69 |
| **Weight** | 0.99lb | 1.13lb | 1.3lb |
| **Load Capacity** | 120lb | 120lb | 80lb |
| **Frame Material** | Black Polycarbonate | Black Polycarbonate | Steel |
| **Roller Material** | Nylon | Rubber | SBR Rubber |

## VI. ENGINEERING LAWS

Engineering equations are used to calculate forces, speeds, weights, and torques required for different parts of robot movements.

### A. *Forces on Robot Arm and Leadscrew*

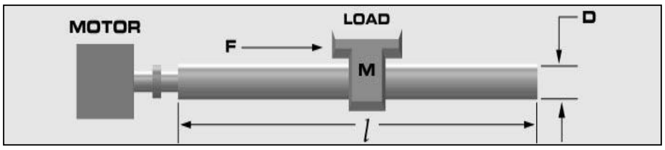


Fig. 5. Leadscrew

Figure 5 shows the direction of the force, distance, and diameter of the leadscrew. They are used in the calculation of torque for leadscrew.

$$\mathbf{T(Arm) = F * r * \sin(\theta)}$$

T = torque (N-mm)

F = linear force (N)
r = distance where the force is applied (mm)
θ = the angle between F and r
**T(Leadscrew) = [F * L] / [2*π*efficiency]**
L = Length of screw in meters (mm)
F = Force to rotate thread (Torque /Mean Radius) (N)
EFFICIENCY = 0.9 for leadscrew (no unit)

### *B. Optimal Speed Calculation*

To ensure the safety of users, we set the kinetic energy of RAMP to be less than 220J which is strong enough to kill a person at impact. Through this set value, we calculated the optimal speed. First, we calculated the safe speed for the RAMP when it is not carrying anything and when it is carrying max capacity, the results are 4.8 m/s and 1.4 m/s. From the results, we concluded that if RAMP's speed is around 1m/s, the chance of casualty at very low. So, we decided to set RAMP's speed to 1 m/s. The following calculations explain in details on how the weight of RAMP with or without loads, and how the optimal speed is calculated.

#### *1) Velocity Calculation*

$$KE = (½)*m*v^2$$
KE = kinetic energy
m = mass
v = velocity
KE < 220 Nm
$(½)\ mv^2 < 220$ Nm
$(½) * 18.86 * v^2 < 220$
Velocity needed when RAMP is not carrying load,
v < 4.83 m/s
KE < 220 Nm
$(½)\ mv^2 < 220$ Nm
$(½) * 217.7 * v^2 < 220$

Velocity needed when RAMP is carrying max load is less than 1 m/s

## VII. TEST PLAN

### *A. Test 1*

Test 1 is the linear motion test and its objective is to verify that the drivetrain can move in all 8 directions and to ensure that the drivetrain is flexible and robust enough to handle a variety of different commands. Equipment used in this test are the drivetrain, an Xbox 360 controller, and a laptop. Different testing methods used in Test 1 are shown in Table IV.

TABLE IV. TEST 1 (DRIVETRAIN LINEAR RANGE OF MOTION TEST)

| Method | |
|---|---|
| 1 | Mark the origin of the test using masking tape with an X. Ensure that the marking is big enough for a person standing 5 meters can see. |
| 2 | From the origin, using a tape measure, measure a vertical line of length X. Ensure this vertical line is perpendicular to the origin. This will be known as the center line. (Repeat for 5, 10, 15 meters) Measure two additional vertical lines parallel to the centerline of the same length but .35 meters apart from the center line. These will be known as the sidelines. |
| 3 | At the end of the center line mark with a triangle to indicate the end of the route. Ensure that the marking is big enough for a person standing 5 meters can see. The base of the triangle faces the centerline |
| 4 | Mark the front and tail of the RAMP system using masking tape. Person A shall stand adjacent to the direction in which is being tested. Example, if the north direction is tested, person A shall stand either in the east or west direction facing the RAMP system with full visibility of the 2 side lines. |
| 5 | The RAMP system shall be placed at the origin marked with the X. Ensure that the RAMP system is fully in between the two sidelines. |
| 6 | Using the Xbox controller, person B shall pilot the RAMP system north by shifting the left analog toggle in the π/2 direction until he/she concludes that the RAMP system has successfully driven past the ending mark (triangle) then proceeds to stop immediately. |
| 7 | Person A shall record deviations the RAMP system had from its intended path by observing the two sidelines. |
| 8 | Person A shall also record the distance between the triangle base and tail of the RAMP system |
| 9 | Repeat this test procedure for different distances and directions. |
| 10 | The user uses the joysticks on the Xbox 360 controller:<br>1.) North – Shift left analog toggle in the π/2 direction<br>2.) South – Shift left analog toggle in the 3π/2 direction<br>3.) West – Shift left analog toggle in the π direction<br>4.) East – Shift left analog toggle in the 2π direction<br>5.) North – East – Shift analog toggle in the π/4 direction<br>6.) North – West – Shift analog toggle in the 3π/4 direction<br>7.) South – West – Shift analog toggle in the 5π/4 direction<br>8.) South – East – Shift analog toggle in the 7π/4 direction |

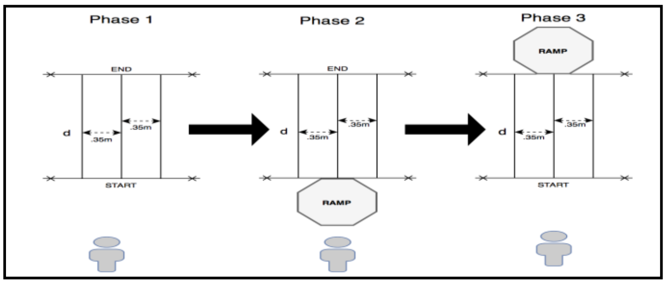

Fig. 6. Linear Test Process

Figure 6 shows the linear test process. The user shall be standing directly behind the RAMP system. The user will direct the RAMP system forward and we shall record the sideway deviations from the middle.

### *B. Test 2*

Test 2 is the linear motion test on different surfaces. Its objective is to determine if different floors (tile, wood, carpet) effect the RAMP system's range of motion and to ensure that the RAMP system will be robust enough to handle different surfaces within a home setting. Equipment used in this test are the drivetrain, an Xbox 360 controller, and a laptop. Different testing methods used in Test 2 are shown in Table V.

TABLE V. TEST 2 (DRIVE TRAIN LINEAR RANGE OF MOTION ON DIFFERENT SURFACES)

| | **Method** |
|---|---|
| 1 | On a wooden floor, mark the origin of the test using masking tape with an X. Ensure that the marking is big enough for a person standing 5 meters can see. |
| 2 | From the origin, using a tape measure, measure a vertical line of length X. Ensure this vertical line is perpendicular to the origin. This will be known as the centerline.<br>Measure two additional vertical lines parallel to the centerline of the same length but .35 meters apart from the center line. These will be known as the sidelines. |
| 3 | At the end of the center line mark with a triangle to indicate the end of the route. Ensure that the marking is big enough for a person standing 5 meters can see. The base of the triangle faces the center line |
| 4 | Mark the front and tail of the RAMP system using masking tape. Person A shall stand adjacent to the direction in which is being tested. Example, if the north direction is tested, person A shall stand either in the east or west direction facing the RAMP system with full visibility of the 2 sidelines. |
| 5 | The RAMP system shall be placed at the origin marked with the X. Ensure that the RAMP system is fully in between the two sidelines. |
| 6 | Using the Xbox controller, person B shall pilot the RAMP system north by shifting the left analog toggle in the $\pi/2$ direction until he/she concludes that the RAMP system has successfully driven past the ending mark (triangle) then proceeds to stop immediately. |
| 7 | Person A shall record deviations the RAMP system had from its intended path by observing the two sidelines. |
| 8 | Person A shall also record the distance between the triangle base and tail of the RAMP system |
| 9 | Repeat this test procedure for tile and carpet surfaces. |

## VIII. VALIDATION TESTING PLAN

The validation test plan, milestones for each test, and individuals assigned to each test are shown in Table VI.

TABLE VI. VALIDATING TEST PLAN AND MILESTONE

| Test Item | Test Case | # Test Run | Mile-stone | Assign ed to |
|---|---|---|---|---|
| 1.0 Drivetrain | 1.1 Linear Tests<br>1.2 Rectangular Tests<br>1.3 Diagonal Tests<br>1.4 Curve Tests<br>1.5 Surface Tests | 60 | 03/28 | Karar, Alex, Pwint |
| 2.0 Camera | 2.1 Field of view Tests<br>2.2 Delay Tests<br>2.3 Quality assurance Tests | 36 | 04/04 | Alex, Karar |
| 3.0 Robotic Arm | 3.1 Max weight capacity of arm Tests<br>3.2 Grip strength Tests<br>3.3 Vertical arm movement speed Tests | 45 | 04/28 | Pwint, Alex, Hanan |
| 4.0 Overall System | 4.1 Task accomplishment<br>4.2 obstacle avoidance | 40 | 05/05 | Pwint, Alex, Hanan |

## IX. RESULTS

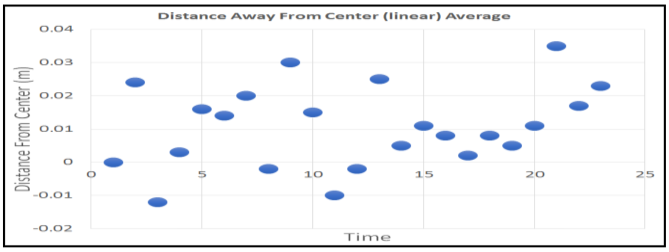


Fig. 7. Linear Test Result

Figure 7 shows the linear test result. As we can see in the figure, the RAMP system has a center deviation of -0.02 to 0.04 meters. Negative numbers represent deviations to the west and positive numbers represent deviations to the east.

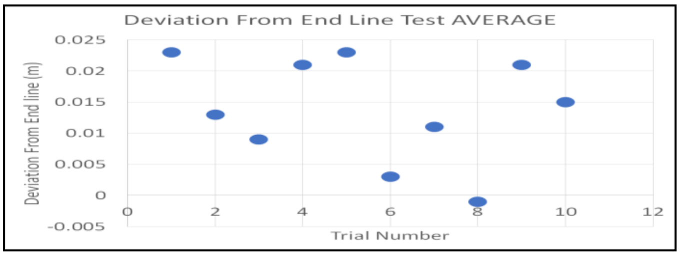


Fig. 8. Linear Test Result Deviation

Figure 8 shows the deviation of linear test results. As we can see in the figure, the RAMP system promptly stops at a range of 0 - 0.025 meters at the end line which is within our mission requirements.

## X. BUSINESS CASE

The approach of our team towards the business aspect is by producing 8 RAMP systems for field testing in the first 3 months, adjusting the design based on the validation testing and customer feedback. Following the results, we shall produce addition 52 RAMP systems in the first year. With a learning curve of 85% we shall produce 167 the 2nd year, 204 the 3rd year, 213 the 4th year and 215 the 5th year. Yearly cost and fixed cost are shown in Table VII and Table VIII, respectively.

TABLE VII. YEARLY COST

| Recurring Costs | Cost |
|---|---|
| Marketing Employee | $50,000 |
| 4 Managers/Engineers | $240,000 |
| Advertising | $25,000 |
| Robotic Lab Rent | $75,000 |
| Robotic Parts (per unit) | $700 |
| 4 Part time employees | $40,000 |
| Total Operational Cost | $430,000 + # of Robotic Parts |

TABLE VIII. FIXED COST

| Fixed Costs | Cost |
|---|---|
| Consulting | $50,000 |
| Website | $5,000 |
| Total | $55,000 |

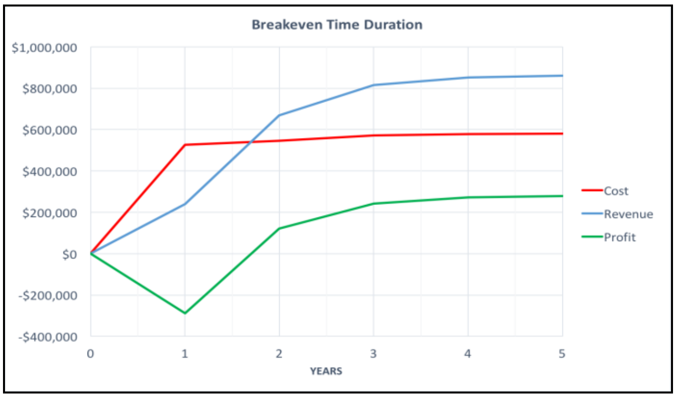


Fig. 9. Time Duration

Figures 9 shows the calculated costs of this project we project to sell each RAMP system for $4000 and the expected break-even point would be reached in 17 months. With a discount rate of 8%, the NPV and ROI are shown in Table IX.

TABLE IX. NPV AND ROI VALUES

| NPV | ROI |
|---|---|
| -$265,740.74 | -54% |
| $103,823.73 | 22% |
| $193,060.00 | 42% |
| $200,589.65 | 47% |
| $190,233.00 | 48% |

## ACKNOWLEDGMENT


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