Autonomous Salting Robot: A Deicing Revolution

A thesis submitted in partial fulfillment
of the requirements for the degree of

Bachelor of Science in Electrical Engineering and the Honors Program

by

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entitled

**Autonomous Salting Robot: A Deicing Revolution**

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**Abstract**

The Autonomous Salting Robot (ASR) by Saltonomous Industries addresses two issues threatening individuals living in icy conditions: injury due to slipping and falling while salting walkways and avoidance of salting due to the laborious nature of the task. Introducing the ASR eliminates these problems by offering consumers an autonomous method of deicing walkways and driveways. The target market for the ASR consists primarily of households, expanding to include businesses and municipalities as Saltonomous Industries grows. The two essential working principles for the robot are (1) magnetic line following and (2) salt spreading technology. Given $600 from the University of Nevada, Reno’s College of Engineering and a timeline of one semester to build the company, design the system, and develop a working prototype, the team was successful in engineering solutions to all problems encountered to produce a final product ready for market.
# Table of Contents

A. Summary and Overview  ................................................................................................. 1
   Background ..................................................................................................................... 1
   Work Objective Statements ............................................................................................. 1
   Methods ........................................................................................................................... 1
   Conclusions and Significance ......................................................................................... 2

B. Project Description ................................................................................................... 2
   I. Introduction and Background ..................................................................................... 2
   II. Business Plan ............................................................................................................ 4
      Business Focus ............................................................................................................ 4
      Company Description ............................................................................................. 4
      Mission Statement .................................................................................................. 4
      Product ..................................................................................................................... 4
      Services .................................................................................................................... 4
      Market Analysis ....................................................................................................... 5
         Target Market and Market Need .............................................................................. 5
         Geography ............................................................................................................ 5
         Consumers ........................................................................................................... 7
         Businesses .......................................................................................................... 10
         Municipalities ....................................................................................................... 11
         Growth and Trends ............................................................................................... 11
         Industry Distribution and Buying Patterns ............................................................ 12
         Market Acceptance ............................................................................................... 12
      Market Strategy ......................................................................................................... 15
      Company Strengths .................................................................................................. 15
      Goals ....................................................................................................................... 15
      Communications Strategies ..................................................................................... 15
         Advertising Budget ............................................................................................... 16
      Critical Risks ............................................................................................................ 17
         Product Risk ........................................................................................................... 17
         Market Risk ............................................................................................................ 17
         Financial Risk ......................................................................................................... 18
         Competitive Risk .................................................................................................. 18
      Financial Projections ................................................................................................. 18
         Cash Flow Statement ............................................................................................. 18
         Income Statement ................................................................................................. 20
         Balance Sheet ......................................................................................................... 22
         Funds Required and Use ......................................................................................... 22
   III. Technical Focus: Key Products and Services ......................................................... 23
      Technical Methods and Materials ............................................................................. 23
         Methods .................................................................................................................. 23
         Materials ............................................................................................................... 24
      Prototypes and System Configuration ....................................................................... 25
         Circuit Design ......................................................................................................... 25
         Flowchart .............................................................................................................. 26
List of Tables
Table 1: The coincidence of one or more inches of snow and near freezing temperatures for each location of interest based on the data in Fig. 3 and Fig. 4. ........................................7
Table 2: The number of households in the cities of the geographical market, representing the number of private homes that could incorporate the services of the ASR..................8
Table 3: Age demographics for residents of the geographical market for the ASR........8
Table 4: Median household incomes for individuals residing in the geographic market. ...9
Table 5: Number of businesses in the target geographical market that could benefit from the services of the ASR..........................................................11
Table 6: The marketing budget for Saltonomous Industries, showing a cost of $16,000 for the first year. .................................................................................................17
Table 7: The Gantt Chart for the ASR, showing all tasks were completed in a timely manner.....................................................................................................................19
Table 8: Five-year income statement prediction..........................................................21
Table 9: Balance Sheet for a five-year cash flow prediction........................................22
Table 10: The materials list to implement the ASR design, detailing vendors and quantities required for each component..........................................................24
Table 11: The materials list to implement the ASR design, detailing vendors and quantities required for each component..........................................................30
List of Figures

Fig. 1: The first main type of deicing mechanism currently on the market is the handheld device. This category includes three subcategories with varying levels of efficiency and ease-of-use. These three types are shown from least efficient and most difficult to use (a) to most efficient and easiest to use (c). ................................................................. 3

Fig. 2: The second category of deicing devices currently on the market require the user to push a large container filled with deicing material. The user walks, causing the wheels to rotate, and the deicing material is distributed across the walkway or driveway.................... 3

Fig. 3: The average monthly temperatures (°F) for the geographical locations of the ASR. All eight areas show near freezing temperatures in December and January, and some even display such temperatures into February and March...................................................... 5

Fig. 4: The average monthly snowfall (in.) for the geographical market of the ASR. All eight locations show significant snowfall in January. Seven of these locations, the exception being Fallon, also experience snowy conditions in December. The month of February brings snow in three of the eight locations. It should be noted that snowy conditions are defined as one or more inches of snow. .............................................. 6

Fig. 5: Survey response data to the question, “Have you ever salted your walkway or driveway?” showing 49.6% responding yes and 50.4% responding no. ......................... 13

Fig. 6: Survey response data to the question, “Have you ever slipped and/or fallen on ice?” showing 91.1% responding yes and 8.9% responding no. ............................. 13

Fig. 7: Survey response data to the question, “Would an automatic salting system encourage you to salt your driveway or walkway if necessary?” showing 89.4% responding yes and 10.6% responding no ........................................... 13

Fig. 8: Survey response data to the prompt: “Type of automation preferred,” showing 8.9% preferring time-based, 48% preferring weather-based, 51.2% preferring manual initialization, and 8.1% preferring another method........................................... 14

Fig. 9: Survey response data to the question, “Are you interested in this product in the following areas?” showing 66.7% interested in the product for use in residential areas, 22% interested in the product for use in small business environments, 13% interested in the product for use in municipal areas, 7.3% not interested in the product, and 10.6% interested in the product for use in other areas. .............................................. 14

Fig. 10: Survey response data to the question, “How much would you pay for an automatic salting system?” showing 7.3% offering less than $50, 26% offering between $50 and $100, 31.7% offering between $100 and $200, 18.7% offering between $200 and $400, 13% offering between $400 and $600, and 3.3% offering above $600. .... 14

Fig. 11: Quarterly cash flow predictions following the customer buy trend of winter products.......................................................... 20

Fig. 12: Quarterly breakeven analysis showing support for selling a minimum of 195 units per quarter to make a profit .................................................. 21

Fig. 13: The final version of the ASR circuit schematic, detailing the interface of all electrical components.................................................. 25

Fig. 14: Algorithm flowchart for Arduino programming and system control ........................................ 27

Fig. 15: Final prototype of the ASR.......................................................... 28

Fig. 16: Plow design using 3D printing software......................................................... 28

Fig. 17: Final circuit implementation for the ASR prototype..................................... 29
Fig. 18: Initialization of the ASR magnetometers and temperature sensing, followed by the activation of the rover. The two front sensors are active to follow the magnetic line appropriately. .......................................................... 32
Fig. 19: Detection of the magnetic line by both front sensors occurs, triggering the back two magnetometers to begin reading data to follow the magnetic line. .......................... 33
Fig. 20: The Gantt Chart for the ASR, showing all tasks were completed in a timely manner.............................................................. 33
A. Summary and Overview

Background
A significant problem affecting those living in ice-prone winter climates is injury due to slipping and falling. According to a survey of 125 individuals conducted by Saltonomous Industries, 91.2% reported having slipped and/or fallen on ice. This is a particularly alarming statistic because injuries caused by icy paths can be largely avoided by simply salting the dangerous areas. Although this solution does seem straightforward, in the same survey mentioned previously, about half of the participants (49.6%) admitted to shirking the task. The reasons for this neglect vary from a lack of time, to safety risks to the individual salting, to the physically burdensome nature of the activity, among many others. The introduction of the Autonomous Salting Robot (ASR) seeks to serve both those at risk of falling and those responsible for maintaining safe premises. By autonomously salting over the entire danger zone, risk of injury is significantly reduced while greatly increasing convenience.

Work Objective Statements
Though various companies have attempted to address the issues recognized by Saltonomous Industries, the products they developed have significant shortcomings. All products on the market pose a safety risk to the individual salting the pathway. The level of sophistication remains relatively primal, both in methods of dispersion and in ability to cover large surface areas. Those devices that do perform better in these areas come at a price that can hardly be justified by the low quality and limited features of the product. The ASR will revolutionize the salting and deicing industries by providing a means for autonomously salting affected areas. The implications of such a system are varied, including increased convenience and safety to the user, improved quality of salting due to even dispersal, decreased environmental impact through the use of alternative deicing materials, and decreased injury risk to users of the dangerous pathways.

Methods
The rover consists of a combination of mechanical and electrical interfaces. A tracked robot provides the mechanical foundation upon which all other components are mounted. A wedge plow attached to the front of the robot allows for its mobility through small amounts of snow. The salt spreader fixed atop the rover’s platform is capable of dispersing salt over a 5-ft. range, where the angles of spreading can be customized. An Arduino board facilitates control of the robot, allowing data communication between the board and a weather sensor, four triple-axis magnetometers, and three motors. To guide the robot’s salting path, magnetic tape is secured along the pathway, providing the most efficient route for the robot. Magnetometers track the path, sensing the strength of the magnetic field produced by the magnetic tape. There are two ways to initiate salting: the user can manually initialize the robot to perform its task by the press of a button or a weather sensor attached to the robot can sense potentially hazardous weather conditions approaching and salt preemptively.
**Conclusions and Significance**
The ASR is a revolutionary product that will change the approach to deicing ice-prone areas. The service offered by the robot improves the quality of life of its users by reducing risk of injury and decreasing the level of stress associated with dangerous weather conditions. It accomplishes these goals by offering an autonomous system of salting not currently available on the market.

**B. Project Description**

**I. Introduction and Background**
The main problem the Autonomous Salting Robot aims to tackle is the fact that salting walkways, driveways, and other pathways can often be a laborious task, especially for the ageing population. As a result, people may not salt as well as they should or may not salt at all. This leads to a decrease in safety for the individuals or businesses who have the responsibility of salting as well as other users of the unsafe conditions. Injuring oneself due to slipping and falling on icy surfaces is a major problem, especially during the cold winter months. Users expect to be safe when traversing walkways and pathways, and businesses and homeowners are responsible for eliminating dangerous threats to avoid premises liability claims. The ASR addresses the aforementioned concerns by salting walkways, driveways, and pathways autonomously. Using the feature of autonomy, the task of salting becomes less burdensome, thereby increasing the convenience to the user. As the robot has the capability of receiving weather information from various onboard sensors, there is no need for the user to actively remember to salt affected areas; the sensors will relay information to the robot, which it can use to decide whether or not salting is necessary. The robot, with its tracked wheels and snow plow, can more easily navigate the hazardous terrain than the user.

In short, the basis for solving the problems detailed above involves using the following major components: an Arduino board to control the robot, a tracked robot to act as the base upon which all other components are mounted, a snow plow to allow for mobility of the robot even through snow, and magnetic tape to guide the robot’s path using magnetometers.

The ASR fills a gap in the market and addresses a problem that has gone largely unaddressed by competitors in the deicing industry. Currently, there exist two basic product models for deicing devices: a handheld device and a push-cart mechanism. Within the handheld division, there are three levels of subdivision (Fig. 1).
Fig. 1: The first main type of deicing mechanism currently on the market is the handheld device. This category includes three subcategories with varying levels of efficiency and ease-of-use. These three types are shown from least efficient and most difficult to use (a) to most efficient and easiest to use (c).

The class of product shown in Fig. 1 (a) [1] is least effective because it does not guarantee even dispersal of salt. In addition, it requires the user to walk over the entire desired surface area while continuously shaking the device [1]. This is both dangerous and fatigue-inducing because the user runs the serious risks of slipping and exhausting the arm. The products shown in Fig. 1 (b) [3] and Fig. 1 (c) [4] distribute salt more evenly through their spreading mechanisms, but both pose similar risks to the user as those of Fig. 1 (a).

The second major category of deicing devices use a push-cart approach that disperses salt as the wheels of the device turn (Fig. 2) [2].

Fig. 2: The second category of deicing devices currently on the market require the user to push a large container filled with deicing material. The user walks, causing the wheels to rotate, and the deicing material is distributed across the walkway or driveway.

Though this reduces fatigue created in the arm, it still requires the user to walk over the surface area to be salted, thereby failing to eliminate slipping and tiring concerns.

Though the aforementioned products aid the user in fulfilling the task of salting their driveways and walkways, they fail to solve problems associated with safety risks and time consumption for the consumer. Saltonomous Industries recognizes this neglect and addresses both issues with the ASR. Remaining just as effective in deicing as even the best of the competing devices, the ASR also ensures that the user is protected and that the task of deicing is not neglected. Due to the autonomy of the ASR system, the individual responsible for dispensing salt over the walkway or driveway in question is neither in danger of slipping while walking over the area nor subject to the fatigue associated with the laborious task of salting. Additionally, the ASR alleviates the responsible party of the
stress associated with finding time to salt walkways or driveways. Whereas with the other products, the user may be inclined to neglect his or her responsibility due to a lack of time or a lack of desire to brave the cold weather, the ASR autonomously performs the task when the weather conditions require salting.

II. Business Plan

Business Focus
To successfully engineer the ASR and form a profitable company, a business plan was developed.

Company Description
Saltonomous Industries is a startup enterprise located in Reno, NV created by four electrical engineering seniors. The company was founded in 2016 with the clear goal of improving lives and modernizing winter safety with a device known as the Autonomous Salting Robot (ASR). The ASR was conceived after noting an opportune gap in the deicing market for an automated solution. Saltonomous Industries has a current operating budget of $600 (USD) to be used in creating a working prototype of the ASR.

Mission Statement
Saltonomous Industries strives to innovate reliable and effective products that promote and improve the safety, convenience, and quality of life of our valued customers. We endeavor to pioneer the autonomous salting industry by providing devices that effectively and efficiently salt walkways, driveways, and streets at minimal effort and cost to Saltonomous’ customers. We safeguard the value and integrity of the company and hold paramount the well-being and satisfaction of all members of the Saltonomous community.

Product
The flagship product, the Autonomous Salting Robot (ASR), will combine two existing technologies to provide customers with a safe and convenient winter experience. The ASR allows for completely autonomous deicing of walkways, driveways, and sidewalks through the use of magnetic line following and battery-operated granular spreading technologies. Line following is accomplished through the use of magnetic tape, which holds a large advantage over optical line following in harsh conditions that can obscure the optical difference between the line and its surroundings. Customers will benefit from an experience in deicing that eliminates the need to remember to deice or even go outside to perform the task. By separating the consumer from the deicing activity, the ASR can significantly improve one’s winter experience. The ASR’s technology is proprietary in nature and, as such, holds a large competitive advantage in the deicing market. No other products exist that give customers the features and benefits of the ASR.

Services
In addition to selling the ASR, magnetic tape, and deicing material, Saltonomous Industries provides an installation service for the magnetic tape. As the route taken by the ASR is
extremely customizable, the consumer can request the installation service to most efficiently secure the magnetic tape along the desired path.

**Market Analysis**

**Target Market and Market Need**

Saltonomous Industries is a start-up based in Reno, Nevada. The company has found its niche: the goods and services it offers are applicable to consumers, small and large businesses, and municipal operations in areas that are prone to snowy and icy winter conditions. To analyze the market need and properly identify the target market, the following categories are considered: geography, consumers, businesses, and municipalities.

**Geography**

Due to the fact that Saltonomous Industries is located in Reno, it serves local communities, including Reno, Sparks, Carson City, Incline Village, Truckee, South Lake Tahoe, Fernley, and Fallon. All these areas have common climates, as they experience mild to dangerous weather conditions during the winter season.

To understand the average temperature conditions in the locations previously mentioned, data was gathered concerning both average temperatures and average snowfall. The data for average temperatures is presented in Fig. 3 [5-12].

![Fig. 3: The average monthly temperatures (°F) for the geographical locations of the ASR. All eight areas show near freezing temperatures in December and January, and some even display such temperatures into February and March.](image-url)
Next, the average snowfall in the same locations analyzed above was examined. Figure 4 summarizes the snowfall data gathered [31-38].

![Average Monthly Snowfall](image)

**Fig. 4**: The average monthly snowfall (in.) for the geographical market of the ASR. All eight locations show significant snowfall in January. Seven of these locations, the exception being Fallon, also experience snowy conditions in December. The month of February brings snow in three of the eight locations. It should be noted that snowy conditions are defined as one or more inches of snow.

Using the data in Fig. 3 and Fig. 4, it becomes clear that the greater Reno area is a very suitable market for the ASR. Analyzing the average temperatures and amount of snowfall in each area for a coincidence of precipitation and freezing temperatures leads to the data presented in Table 1.
Table 1: The coincidence of one or more inches of snow and near freezing temperatures for each location of interest based on the data in Fig. 3 and Fig. 4.

<table>
<thead>
<tr>
<th>Location</th>
<th>Snow and Freezing Temperatures in December</th>
<th>Snow and Freezing Temperatures in January</th>
<th>Snow and Freezing Temperatures in February</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reno, NV</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Sparks, NV</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Carson City, NV</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Truckee, CA</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>South Lake Tahoe, CA</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Incline Village, NV</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Fernley, NV</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Fallon, NV</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
</tbody>
</table>

In Table 1, a box containing a ‘Yes’ is representative of a time that icy conditions can occur (freezing temperatures in conjunction with snowfall), and therefore also represents a time that the ASR can be used to prevent ice formation on walkways, driveways, and roads. The data from Table 1 proves that the areas that comprise the geographical market are indeed in need of a product that would allow them to prevent dangerous ice formation. This is especially applicable in the months of December, January, and February.

The ASR market is initially relatively small, as Saltonomous Industries is a startup. After about three years, when the company has had the opportunity to turn a profit, the ASR will expand across the United States, and eventually, across the world, to areas whose weather conditions mimic those of the greater Reno area.

Next, the demographics of the consumer base are analyzed to further detail the target market for the ASR.

**Consumers**

When determining potential consumers for the ASR, a number of demographics must be analyzed. These demographics include the following categories: number of households, age, and income.
First, statistics concerning the number of households in each city of the geographical market are collected and are presented in Table 2 [23-30].

Table 2: The number of households in the cities of the geographical market, representing the number of private homes that could incorporate the services of the ASR.

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of Households</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reno, NV</td>
<td>102,582</td>
</tr>
<tr>
<td>Sparks, NV</td>
<td>36,455</td>
</tr>
<tr>
<td>Carson City, NV</td>
<td>23,445</td>
</tr>
<tr>
<td>Truckee, CA</td>
<td>12,803</td>
</tr>
<tr>
<td>South Lake Tahoe, CA</td>
<td>15,087</td>
</tr>
<tr>
<td>Incline Village, NV</td>
<td>7,667</td>
</tr>
<tr>
<td>Fernley, NV</td>
<td>7,975</td>
</tr>
<tr>
<td>Fallon, NV</td>
<td>3,979</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>209,993</strong></td>
</tr>
</tbody>
</table>

From Table 2, the total number of households in the initial market is about 209,993 households. This is equivalent to the number of locations that could purchase and benefit from the product. The marketing team estimates that 275 units will be sold in the first year, the majority of which will be purchased by households. In the second year, this number is expected to increase to 900 units. As the robot proves its efficiency, convenience, and effectiveness, and the company name is bolstered by the robot’s success and high ratings, Saltonomous Industries will strive to expand to encompass the entire growing market.

Next, the ages of the residents in the geographical market are examined (Table 3) [23-30]. The age demographic of the target population extends from those under the age of five through the ageing population, defined as those over the age of 65.

Table 3: Age demographics for residents of the geographical market for the ASR.

<table>
<thead>
<tr>
<th>Location</th>
<th>Under 5 Years of Age</th>
<th>Over 65 Years of Age</th>
<th>Total Population</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reno, NV</td>
<td>16,901</td>
<td>28,249</td>
<td>241,445</td>
</tr>
<tr>
<td>Sparks, NV</td>
<td>6,918</td>
<td>11,339</td>
<td>96,094</td>
</tr>
<tr>
<td>Carson City, NV</td>
<td>2,835</td>
<td>10,795</td>
<td>54,521</td>
</tr>
<tr>
<td>Truckee, CA</td>
<td>1,075</td>
<td>1,271</td>
<td>16,299</td>
</tr>
<tr>
<td>South Lake Tahoe, CA</td>
<td>1,367</td>
<td>2,127</td>
<td>21,706</td>
</tr>
<tr>
<td>Incline Village, NV</td>
<td>394</td>
<td>1,553</td>
<td>8,777</td>
</tr>
<tr>
<td>Fernley, NV</td>
<td>1,553</td>
<td>2,291</td>
<td>19,418</td>
</tr>
<tr>
<td>Fallon, NV</td>
<td>693</td>
<td>1,107</td>
<td>8,458</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>31,736</strong></td>
<td><strong>58,732</strong></td>
<td><strong>466,718</strong></td>
</tr>
</tbody>
</table>
Although all ages benefit from the ASR and the functions it offers, those under the age of five and those over the age of 65 benefit in a significant manner. Whereas traditional salting equipment excludes the over 65 years of age demographic due to the dangerous activity required to operate the devices, the ASR is safe for use by seniors. The risk of slipping on ice while salting is eliminated, as is the fatigue induced by salting a walkway or driveway by hand. In addition to its ease of use, the ASR is highly recommended for this particular demographic because it works to prevent falls caused by icy walkways that could prove seriously debilitating or even fatal for this population. Similarly, young children, defined here as children under the age of five, are particularly prone to injury caused by slipping. This is due to the fact that young children have difficulties with balance, especially when their balance has been disturbed. They also have lower reaction times and relatively less muscle strength [22]. Therefore, both categories of individuals are particularly benefitted by the improved safety that the ASR offers.

Another important factor to consider when analyzing potential markets is the affordability of the product being offered based on the incomes of the target population. Table 4 summarizes median household incomes for individuals in the geographic market [23-20].

Table 4: Median household incomes for individuals residing in the geographic market.

<table>
<thead>
<tr>
<th>Location</th>
<th>Median Household Income, $</th>
<th>Percentage of Income to Pay for ASR, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reno, NV</td>
<td>47,012</td>
<td>0.43</td>
</tr>
<tr>
<td>Sparks, NV</td>
<td>52,795</td>
<td>0.38</td>
</tr>
<tr>
<td>Carson City, NV</td>
<td>47,668</td>
<td>0.42</td>
</tr>
<tr>
<td>Truckee, CA</td>
<td>77,320</td>
<td>0.26</td>
</tr>
<tr>
<td>South Lake Tahoe, CA</td>
<td>39,793</td>
<td>0.50</td>
</tr>
<tr>
<td>Incline Village, NV</td>
<td>73,329</td>
<td>0.27</td>
</tr>
<tr>
<td>Fernley, NV</td>
<td>52,001</td>
<td>0.38</td>
</tr>
<tr>
<td>Fallon, NV</td>
<td>39,580</td>
<td>0.51</td>
</tr>
</tbody>
</table>

Based on the analysis of the average income of an individual living in the areas of Table 4, the ASR is an affordable product for all locations. For each area, the cost of the ASR is less than or equal to 0.51% of the total median household income. This means that most households in these regions can safely allot the market price of $200 to purchase an ASR without causing serious financial strain.

Additionally, in the overall current culture of continuously increasing time strain, the function of the ASR provides some relief for individuals. As people become busier with ever-growing to-do lists, responsibilities, and time commitments, an ever-decreasing amount of time is left to complete chores and other second-class tasks. Salting one’s driveway or walkway is both labor intensive and time consuming, making it an easy task to put off, perform incompletely, or refuse to complete at all. This results in a decrease in safety for the individual or business with the responsibility of salting and the users of the unsafe conditions. Individuals who work and/or have children are busy both in the
mornings and in the evenings. With concerns of getting to work on time, preparing children for school, and completing other necessary morning activities, mornings leave little time to worry about salting potentially dangerous areas. The evenings do not offer a more convenient time, as individuals are tired from work and must engage in additional responsibilities. The ASR salts driveways and walkways autonomously, thereby making the task of salting less burdensome.

**Businesses**

In addition to homeowners, businesses stand to significantly benefit from the services of the ASR. Not only do salted walkways and driveways around the business promote the safety of employees, they also protect the business against potential lawsuits.

Driveways and walkways surrounding business establishments are no exception to ice formation. To protect the safety of employees working at and customers eliciting the services from these businesses, salting of walkways and driveways is required. In order to accomplish this, the company must either hire an outside source to perform the salting or must share the responsibility of salting among employees. The drawbacks of both options are many fold. Hiring someone to salt dangerous areas requires allotting a certain percentage of the company budget to this service. This is not desirable for the CEO and managers of the company, as the goal is always to maximize profit and eliminate unnecessary costs. Sharing the responsibility of salting among company employees runs a serious risk of the salting being neglected. Employees are busy completing projects and meeting deadlines, and they may feel they do not have time to take out of their day for the purpose of salting. Managers will also be unhappy with this scenario, as it decreases the productivity of their employees by decreasing the amount of time that can be spent working. Both options come with the unavoidable con of putting the safety of the individual performing the salting at risk. By going out into the cold, wet, and potentially icy conditions, the individual puts himself or herself in danger of injury.

By purchasing the ASR, however, there is no need for individuals to brave the dangerous conditions. The robot autonomously salts the affected areas to lessen the burden of salting. Weather information can be received from an onboard sensor to ensure timely salting of walkways for maximized safety. Alternatively, the user can manually activate the robot so that salting occurs only when explicitly desired by the user. Employing the robot is also more cost effective than hiring an individual to perform the salting. This is because the company pays only a one-time cost of acquisition and installation, whereas an outside source would be paid hourly each time salting must occur.

In the long run, money is not only saved by avoiding paying an additional worker to perform salting, but the company also saves money by preventing potential premises liability claims. A premise liability claim is one incurred when a resident or property owner is responsible for injuries sustained on said property due to dangerous conditions on the premises [14]. One common example of claims are injuries inflicted due to slipping and falling on icy paths. This can be easily avoided at a relatively lower cost by incorporating the ASR.
In total, there are about 42,853 businesses in the geographical market that could benefit from the ASR. Statistics regarding each city are presented in Table 5 [23-30].

Table 5: Number of businesses in the target geographical market that could benefit from the services of the ASR.

<table>
<thead>
<tr>
<th>Location</th>
<th>Number of Firms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reno, NV</td>
<td>21,577</td>
</tr>
<tr>
<td>Sparks, NV</td>
<td>6,193</td>
</tr>
<tr>
<td>Carson City, NV</td>
<td>6,630</td>
</tr>
<tr>
<td>Truckee, CA</td>
<td>2,370</td>
</tr>
<tr>
<td>South Lake Tahoe, CA</td>
<td>2,648</td>
</tr>
<tr>
<td>Incline Village, NV</td>
<td>1,964</td>
</tr>
<tr>
<td>Fernley, NV</td>
<td>852</td>
</tr>
<tr>
<td>Fallon, NV</td>
<td>619</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>42,853</strong></td>
</tr>
</tbody>
</table>

Municipalities
Currently, Saltonomous Industries focuses on reaching the homeowner and business market base. In the future, the company expects to expand its goods and services to include municipalities. This includes government buildings, public schools, libraries, and more. By using the ASR, cities show a concern for their citizens by promoting their safety in public areas. Unfortunately, at this time, the company does not have the funds to advertise to such a broad market and has therefore chosen to first put significant resources into attracting businesses and homeowners.

Growth and Trends
Currently, the industry for deicing walkways and driveways is extremely small. All devices on the market are primarily advertised as fertilizers, though they have a secondary use as salt spreaders. Even so, the salting methodologies employed are not significantly convenient to the user (see Introduction and Background). Due to the fact that the ASR finds itself in a widely untapped industry, that of autonomous salting, the industry category analyzed here is that of autonomous technology.

The autonomous systems industry shows great potential for the future. According to Siemens, the use of robots to aid in the completion of both simple and complex tasks will increase from its current 10% to 25% by 2025. To bolster this growth, spending in the industry will move from the $11 billion recorded in 2005 to $67 billion in 2025 [21]. This marks a 509% increase, demonstrating that the growth of robotic systems will be both vast and rapid.

One of the greatest hurdles preventing widespread integration of robotic systems into common households and businesses is the significant cost of acquisition. Though still a problem, this obstacle will be significantly reduced in coming years as the growth of the
industry continues in a steady upward trend. This reduction in cost, which is already underway, can be attributed to a variety of factors. First, as the products are recognized as increasingly advantageous to users, their popularity and sales will increase. As more units are integrated into society, the units will decrease in price. Additionally, the price of technologically advanced components used in the production of the robots will decrease, allowing them to be installed more frequently in unmanned systems. As designers become more eager to include the technologically advanced components due to their lower price, the robots can increase in intelligence and expand their functions [21].

In addition to general growth in the market, a variety of trends increase the demand for autonomous systems. The first is simply the innovation of mankind. Humans are consistently working toward improving convenience and quality of life, and it has been found that incorporating robots to adopt either more mundane or highly complex, dangerous tasks satisfies both desires. A general fascination with developing robots that mimic human behavior further drives the industry. The ever-increasing power of technology makes the very existence of these systems possible by providing the complex sensory and high level computing powers required for success [20].

**Industry Distribution and Buying Patterns**

The ASR will be available for purchase in numerous locations. In-store purchasing will be available at a number of hardware and outdoor stores. Online options for purchase will include the Saltonomous Industries company website as well as second-party vendors such as Amazon and eBay. Consumers will be interested in buying the ASR due to its perceived quality and advertised features that cannot be found in any other system currently on the market.

The buying patterns for the ASR are relatively consistent. Consumers must make a one-time purchase of the robot and pay for installation of the robot and magnetic tape in the desired locations if requested. Due to natural wear and tear caused by the harsh environment in which the ASR operates, consumers will be required to purchase servicing to fix any reparable damage or purchase a new robot if the robot becomes too old and damaged. In addition to acquisition and maintenance costs for the robot, consumers must make yearly purchases of salt or other deicing materials to be used by the robot.

**Market Acceptance**

To gauge the desire for a product like the ASR, a survey was conducted. The survey consisted of six questions intended to determine the threat of ice formation on walkways to individuals, the influence and effect of an autonomous salting robot, and acceptable price ranges in the eyes of the consumer. A total of 125 individuals took part in the survey. The complete survey is available in Appendix A.

First, participants were asked whether they had ever salted their driveways or walkways. About equal numbers stated they had or had not salted their walkways or driveways (Fig. 5).
The second question concerned the safety of individuals in icy conditions. The vast majority reported having slipped and/or fallen on ice in the past, shown in Fig. 6.

Thirdly, participants were asked whether or not the ASR could cause a change in behavior. Once again, the majority responded that an autonomous salting system would be effective in promoting salting of their walkways and driveways (Fig. 7).

The fourth question on the survey prompted users to identify the preferred initialization method of automation for the robot. The two most highly desired methods proved to be weather-based with the use of sensors or an explicit pushing of a button to initiate salting (Fig. 8).
The next question explored the locations people believed use of the ASR would be most applicable. Most responded that residential would be best, followed by businesses (Fig. 9).

The fifth question was concerned with the amount of money consumers felt would be appropriate to spend on the ASR. The majority fell between $50 and $400 (Fig. 10).

In summary, the market acceptance research indicates that consumers are ready for and eager to incorporate an autonomous salting system into their everyday lives. They
recognize the need for such a product and understand the improvement in the quality of life the ASR offers, both due to the increased safety it guarantees and its convenience of use.

**Market Strategy**
To successfully market the ASR to the target audience described in the *Market Analysis*, the strengths of the company must be thoroughly understood. The goals of the marketing plan must be evaluated to allow for a projection of the success of the company. Finally, all communication strategies that Saltonomous Industries will use will effectively advertise the goods and services offered by the company.

**Company Strengths**
Saltonomous Industries currently offers the ASR, salt, and alternative deicing materials, such as alfalfa meal, for the environmentally conscious. The company also provides installation services for the magnetic tape that guides the robot’s path. As the company expands, other future products include a customizable robot, a wall-mount salting system, an in-ground sprinkler salting system, and a salting system mounted to cars. The main competitive advantages that the products of Saltonomous Industries have over other forms of salt dispersion devices currently on the market are their autonomy as well as their safety and convenience.

**Goals**
There are many goals that the company’s marketing plan aims to achieve to ensure successful functioning of current and future Saltonomous Industries operations. One such goal is to increase sales by 227% from the first to the second year. As the company becomes more established and broadens its target market across the United States and the world, a 37.5% increase in sales between the third and fourth years is expected, reaching up to about a 50% increase from the fourth to the fifth year. Additionally, on social media platforms, the company aims to reach 100,000 followers after the first three years. By the first year, Saltonomous Industries hopes to utilize eight advertising channels.

**Communications Strategies**
To achieve the goals established, the tactics and strategies employed by the company are many-fold. There are multiple affordable ways to appeal to the cold prospects of the company. First, the company website will promote the ASR as well as future goods and services offered by Saltonomous Industries. The goal of the website is to make customers feel connected and to make the company accessible. The website will incorporate effective user interface techniques to attract users to the site. Individuals will also be able to join a mail and email list, which will update them on company successes and novel products. Consumers will be able to communicate with the management team of Saltonomous Industries as well as other members of the Saltonomous community to voice any concerns or questions they may have. Additionally, the website will include tutorials and other helpful tools to guarantee satisfaction. Within the site, there will be multiple online videos. While some videos will explain the basic functioning of the ASR and demonstrate its usage, others will promote company products using case studies. In these case studies, the
company will recruit volunteers satisfied with Saltonomous Industries’ goods and services who will speak to the benefit and novelty of the company's products.

Another affordable way to advertise is by listing the Saltonomous Industries’ location on Google maps. This will give local presence and will allow for individuals to leave comments and reviews to be used in evaluating the business’ progress and understanding the customer base more thoroughly.

Finally, Saltonomous Industries will use the social platforms of Instagram, Facebook, and Twitter for promotion purposes. It will post photos, advertise deals, provide explanations of completed projects and other customers’ satisfaction with them, and present information that may be new or surprising to consumers.

More expensive methods of advertising include print advertising in magazines, radio advertising, and billboard advertising. The use of more expensive advertising techniques will be especially important during the first and fourth quarters of each year, when the ASR will be in higher demand. During the second and third quarters, more affordable methods will be employed.

To appeal to the warm prospects of the company, a slightly different set of tactics will be used. These include permission-based email, loyalty programs, and customer appreciation events. Emails will be gathered and used only when the owner has given explicit permission to do so. This helps ensure that those who receive company emails will be more likely to read the content as opposed to simply trashing it upon receipt. These emails will include updates, exclusive deals, and other important supporting information. Additionally, loyalty programs will be offered to the customers who frequently purchase goods and services offered by Saltonomous Industries. Types of rewards provided through these programs include advanced access to recently released company products, free shipping, and coupons that offer retail at a significantly reduced price. Finally, the company will hold a bi-annual customer appreciation event to thank the most loyal and highest paying customers for their business.

*Advertising Budget*

A certain percentage of revenue must be directed toward the annual marketing budget of the company. Table 6 outlines the cost and quantity of each advertising technique Saltonomous Industries aims to realize.
Table 6: The marketing budget for Saltonomous Industries, showing a cost of $16,000 for the first year.

<table>
<thead>
<tr>
<th>Advertising Method</th>
<th>Cost Per Unit</th>
<th>Number of Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Website*</td>
<td>$0</td>
<td>1</td>
</tr>
<tr>
<td>Online Videos</td>
<td>$500</td>
<td>3</td>
</tr>
<tr>
<td>Google Maps</td>
<td>$0</td>
<td>1</td>
</tr>
<tr>
<td>Social Media**</td>
<td>$0</td>
<td>3</td>
</tr>
<tr>
<td>Billboard</td>
<td>$1,500</td>
<td>3</td>
</tr>
<tr>
<td>Magazine</td>
<td>$1,000</td>
<td>1</td>
</tr>
<tr>
<td>Customer Appreciation Events</td>
<td>$1,500</td>
<td>1</td>
</tr>
<tr>
<td>Radio***</td>
<td>$25</td>
<td>300</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$16,000</strong></td>
<td></td>
</tr>
</tbody>
</table>

*The website will be designed using free templates available on wix.com. Initially, the website will be designed and managed by the COO. This task will be delegated to the CMO as the company hires additional personnel.

**Social media advertisements will initially be designed and managed by the COO. This task will be delegated to the CMO as the company hires additional personnel.

***The cost of a 30 second advertisement is $25.

Critical Risks
Having carefully worked through and planned the formation of Saltonomous Industries, the management team has predicted critical risks to the company as well as proposed solutions in the event that they are realized. These risks can be divided into four major categories: product risk, market risk, financial risk, and competitive risk.

Product Risk
As Saltonomous Industries is pioneering the autonomous deicing industry, there are various product risks that may hinder the production-as-planned of the ASR. The primary concern is encountering problems with sensing the magnetic field produced by the magnetic tape in extreme weather conditions. To address this issue, extensive testing will be performed to find the optimal sensitivity of the magnetometers to operate successfully in these extreme conditions. Finally, the algorithm to obtain weather information from the various onboard sensors may prove to be inaccurate, leading to salting when the task is unnecessary. To obtain potentially more accurate weather predictions, Wi-Fi communication can be established between the robot and the home/business, gathering weather information from weather forecast sites.

Market Risk
In addition to product risks, there are market risks associated with providing a new product on the market. These risks are related to the market developing in a way that is different from what is expected. Global warming is a major issue facing society today, and these changes in weather patterns can result in an alteration in need of the geographical market currently established for the ASR. To combat this problem, the company can shift its geographical market to areas where the climate will become colder. Furthermore, there are
certain areas within the company’s current geographical market that receive too much snow for the ASR to be useful. As a result, Saltonomous Industries must continue to engineer and develop new solutions for more convenient snow removal processes for the areas in which the ASR will operate. Lastly, individuals and businesses may not be as interested in the product as they initially claimed. To address this issue, the company must perform a more detailed market analysis to uncover new needs and desires of the target market. Additional features may need to be included in the product to attract more customers.

**Financial Risk**
There is always some risk that companies will run out of money or mismanage money, which may lead to bankruptcy. The main solution to decrease the likelihood of financial troubles is to hire and/or collaborate with experts in the financial field to evaluate the company’s finances before launching new products and services. Acquiring the aid of an individual with the necessary expertise will provide a level of comfort to the management team as well as loyal investors in the company.

**Competitive Risk**
Finally, there is the potential that a competing product or service may become available on the market that provides superior methods than those offered by Saltonomous Industries. Currently, the company is ahead of the competition, as no product exists that offers the level of sophistication of the ASR. To maintain this competitive advantage, the company will continue to engineer innovative solutions to improve the autonomy of the system and provide additional features to further the uniqueness of its products.

**Financial Projections**

**Cash Flow Statement**
The cash flow for Saltonomous Industries is predicted based on a starting investment or loan of a minimum of $100,000.00. This creates an ideal environment to stay profitable for the first few quarters, allowing heavy research and the pursuit of investors and other forms of income. The cash flow is also created on the worst-case scenario of no investors and does account for loan repayment (Table 7). The two $10,000 cash investments in years one and two stem from founder investment, funding via a crowdfunding site, and friends and family. The additional $600 in the cash investment of year one comes from university investment in the senior design project for which the ASR was created.
Table 7: The Gantt Chart for the ASR, showing all tasks were completed in a timely manner.

<table>
<thead>
<tr>
<th>Revenue</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of units</td>
<td>275</td>
<td>900</td>
<td>1600</td>
<td>2200</td>
<td>3300</td>
</tr>
<tr>
<td>Products Sold</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Robot Consumer</td>
<td>$ 55,000.00</td>
<td>$180,000.00</td>
<td>$320,000.00</td>
<td>$440,000.00</td>
<td>$660,000.00</td>
</tr>
<tr>
<td>Salt Units ($25)</td>
<td>$ 3,437.50</td>
<td>$ 11,250.00</td>
<td>$ 20,000.00</td>
<td>$ 27,500.00</td>
<td>$ 41,250.00</td>
</tr>
<tr>
<td>Installation ($100)</td>
<td>$ 13,750.00</td>
<td>$ 45,000.00</td>
<td>$ 80,000.00</td>
<td>$110,000.00</td>
<td>$165,000.00</td>
</tr>
<tr>
<td>Loan Status</td>
<td>$100,000.00</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td>Cash Investment</td>
<td>$ 10,600.00</td>
<td>$ 10,000.00</td>
<td>$ -</td>
<td>$ -</td>
<td>$ -</td>
</tr>
<tr>
<td><strong>Total Revenue</strong></td>
<td><strong>$182,787.50</strong></td>
<td><strong>$246,250.00</strong></td>
<td><strong>$420,000.00</strong></td>
<td><strong>$577,500.00</strong></td>
<td><strong>$866,250.00</strong></td>
</tr>
</tbody>
</table>

**Costs**

**Fixed Costs**

**Initial Costs**

| Office equipment | $ 10,000.00 | $ - | $ - | $ - | $ - |

**Operating Costs**

| Office rent       | $ -       | $36,000.00 | $36,000.00 | $36,000.00 | $36,000.00 |
| Insurance         | $ 4,800.00 | $ 4,800.00 | $ 4,800.00 | $ 4,800.00 | $ 4,800.00 |
| Telephone and IT  | $ 2,400.00 | $ 2,400.00 | $ 2,400.00 | $ 2,400.00 | $ 2,400.00 |
| Administrative Costs | $ 9,600.00 | $ 9,600.00 | $ 9,600.00 | $ 9,600.00 | $ 9,600.00 |
| Marketing         | $ 16,000.00 | $ 10,000.00 | $ 4,000.00 | $ 4,000.00 | $ 4,000.00 |
| Loan Repayment    | $ 4,639.82 | $ 18,559.28 | $ 18,559.28 | $ 18,559.28 | $ 18,559.28 |
| **Total Fixed Costs** | **$47,439.82** | **$81,359.28** | **$75,359.28** | **$75,359.28** | **$75,359.28** |

**Variable Cost**

| Wages per Founder (4 employees) | $ 96,000.00 | $ 96,000.00 | $ 96,000.00 | $192,000.00 | $240,000.00 |
| Customer Services 2000 users is $800 | $ 110.00 | $ 360.00 | $ 640.00 | $ 880.00 | $ 1,320.00 |
| Production Costs   | $32,500.00 | $ 90,000.00 | $160,000.00 | $220,000.00 | $330,000.00 |
| **Total Variable Costs** | **$128,500.00** | **$186,000.00** | **$256,000.00** | **$412,000.00** | **$570,000.00** |

| **Total Cost** | **$175,939.82** | **$267,359.28** | **$331,359.28** | **$487,359.28** | **$645,359.28** |
| **Net Profit**  | **$ 6,847.68** | **$(21,109.28)** | **$ 88,640.72** | **$ 90,140.72** | **$220,890.72** |
The quarterly cash flow predicts drops in customers expected each second and third quarter. This is due to the fact that the ASR is a winter product, resulting in lower purchases in summer months and higher purchases in winter months. In Fig. 11, the upward trend of the company is seen, as well as the quarter profits dependent upon the units sold.

![Cashflow and Customer Predictions](image)

*Fig. 11: Quarterly cash flow predictions following the customer buy trend of winter products.*

**Income Statement**

The income statement covers five years of projection for sales and production. The values of the income statement correspond to values in the cash flow. The income statement shows the continued growth in ASR sales (Table 8).
Table 8: Five-year income statement prediction.

<table>
<thead>
<tr>
<th>Revenue</th>
<th>2017</th>
<th>2018</th>
<th>2019</th>
<th>2020</th>
<th>2021</th>
</tr>
</thead>
<tbody>
<tr>
<td>Product Sales</td>
<td>$61,875.00</td>
<td>$202,500.00</td>
<td>$360,000.00</td>
<td>$495,000.00</td>
<td>$742,500.00</td>
</tr>
<tr>
<td>Installation</td>
<td>$27,500.00</td>
<td>$90,000.00</td>
<td>$160,000.00</td>
<td>$220,000.00</td>
<td>$330,000.00</td>
</tr>
<tr>
<td><strong>Total Revenues:</strong></td>
<td><strong>$89,375.00</strong></td>
<td><strong>$292,500.00</strong></td>
<td><strong>$520,000.00</strong></td>
<td><strong>$715,000.00</strong></td>
<td><strong>$1,072,500.00</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Expenses</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of Goods Sold</td>
<td>$44,687.50</td>
<td>$146,250.00</td>
<td>$260,000.00</td>
<td>$357,500.00</td>
<td>$536,250.00</td>
</tr>
<tr>
<td>Wages</td>
<td>$96,000.00</td>
<td>$96,000.00</td>
<td>$96,000.00</td>
<td>$192,000.00</td>
<td>$240,000.00</td>
</tr>
<tr>
<td>Rent</td>
<td>-$</td>
<td>$36,000.00</td>
<td>$36,000.00</td>
<td>$36,000.00</td>
<td>$18,000.00</td>
</tr>
<tr>
<td>Interest</td>
<td>$4,639.82</td>
<td>$18,559.28</td>
<td>$18,559.28</td>
<td>$18,559.28</td>
<td>$18,559.28</td>
</tr>
<tr>
<td>Operating Costs</td>
<td>$32,910.00</td>
<td>$27,160.00</td>
<td>$21,440.00</td>
<td>$21,680.00</td>
<td>$22,120.00</td>
</tr>
<tr>
<td><strong>Total Expenses:</strong></td>
<td>$178,237.32</td>
<td>$323,969.28</td>
<td>$431,999.28</td>
<td>$625,739.28</td>
<td>$834,929.28</td>
</tr>
</tbody>
</table>

| Net Income   | (88,862.32) | (31,469.28) | 88,000.72  | 89,260.72  | 237,570.72 |

The breakeven analysis in Fig. 12 estimates the total quarterly sales required to create the perfect balance of income and revenue. This breakeven analysis is dependent upon the wages at the time (here the estimate is $20,000 per quarter, or $5000 per founder). The wages vary throughout the five-year predictions, but the $5,000 was chosen to show the peak of the prediction.

**Fig. 12:** Quarterly breakeven analysis showing support for selling a minimum of 195 units per quarter to make a profit.
**Balance Sheet**
The balance sheet simplifies the cash flow and expands upon where the additional income will go in later years. Table 9 shows that the return on investment will start to be seen strongly in the third, fourth, and fifth years.

*Table 9: Balance Sheet for a five-year cash flow prediction.

<table>
<thead>
<tr>
<th>Assets</th>
<th>Balance Sheet</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Saltonomous Industries</strong></td>
<td></td>
<td>2017</td>
<td>2018</td>
<td>2019</td>
<td>2020</td>
</tr>
<tr>
<td><strong>Current Assets</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cash</td>
<td>$110,600</td>
<td>$10,000</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Accounts receivable</td>
<td>$72,188</td>
<td>$236,250</td>
<td>$420,000</td>
<td>$577,500</td>
<td>$866,250</td>
</tr>
<tr>
<td>Inventory</td>
<td>$5,000</td>
<td>$5,000</td>
<td>$5,000</td>
<td>$5,000</td>
<td>$5,000</td>
</tr>
<tr>
<td>Prepaid expenses</td>
<td>$32,500</td>
<td>$90,000</td>
<td>$160,000</td>
<td>$220,000</td>
<td>$330,000</td>
</tr>
<tr>
<td><strong>Total current assets</strong></td>
<td>$220,288</td>
<td>$341,250</td>
<td>$585,000</td>
<td>$802,500</td>
<td>$1,201,250</td>
</tr>
<tr>
<td><strong>Fixed (Long-Term) Assets</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Property, plant, and equipment</td>
<td>$10,000</td>
<td>$9,400</td>
<td>$8,800</td>
<td>$8,200</td>
<td>$7,600</td>
</tr>
<tr>
<td>(Less accumulated depreciation)</td>
<td>($600)</td>
<td>($600)</td>
<td>($600)</td>
<td>($600)</td>
<td>($600)</td>
</tr>
<tr>
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<td>$8,800</td>
<td>$8,200</td>
<td>$7,600</td>
<td>$7,000</td>
</tr>
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<td><strong>Wages</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wages</td>
<td>$96,000</td>
<td>$96,000</td>
<td>$96,000</td>
<td>$192,000</td>
<td>$240,000</td>
</tr>
<tr>
<td><strong>Total Wages</strong></td>
<td>$96,000</td>
<td>$96,000</td>
<td>$96,000</td>
<td>$192,000</td>
<td>$240,000</td>
</tr>
<tr>
<td><strong>Total Assets</strong></td>
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<td>$446,050</td>
<td>$689,200</td>
<td>$1,002,100</td>
<td>$1,448,250</td>
</tr>
<tr>
<td><strong>Liabilities and Owner's Equity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Current Liabilities</strong></td>
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<td></td>
<td></td>
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<tr>
<td>Accounts payable</td>
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<tr>
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<td>$119,438</td>
<td>$204,750</td>
<td>$280,875</td>
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<tr>
<td><strong>Total current liabilities</strong></td>
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<td>$364,750</td>
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<td>$750,438</td>
</tr>
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<td><strong>Long-Term Liabilities</strong></td>
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<td></td>
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</tr>
<tr>
<td>Notes Payable</td>
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<td>$80,000</td>
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<td><strong>Total long-term liabilities</strong></td>
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<td>$80,000</td>
<td>$65,000</td>
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<td>$25,000</td>
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<tr>
<td><strong>Owner's Equity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Owner's investment</td>
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<td>$60,612</td>
<td>$115,450</td>
<td>$269,225</td>
<td>$432,812</td>
</tr>
<tr>
<td>Retained earnings</td>
<td>$96,000</td>
<td>$96,000</td>
<td>$144,000</td>
<td>$192,000</td>
<td>$240,000</td>
</tr>
<tr>
<td><strong>Total owner's equity</strong></td>
<td>$119,087</td>
<td>$156,612</td>
<td>$259,450</td>
<td>$461,225</td>
<td>$672,812</td>
</tr>
<tr>
<td><strong>Total Liabilities and Owner's Equity</strong></td>
<td>$325,688</td>
<td>$446,050</td>
<td>$689,200</td>
<td>$1,002,100</td>
<td>$1,448,250</td>
</tr>
</tbody>
</table>

**Funds Required and Use**
Saltonomous Industries is requiring a minimum of $100,000 to begin the venture of the ASR as well as an additional $10,000 at the end of the first and second years to sustain viability. This money will be attained via loan, investments, and/or donations. The funds will be dedicated immediately to operations, production, and marketing. The company plans to build an inventory of 50 units to provide quick shipment of the product for the first quarter of sales. The funds will also be used to cover wages for each of the founders.
III. Technical Focus: Key Products and Services

Technical Methods and Materials
The ASR was conceived to solve the problem of the lack of an automated solution for deicing walkways, sidewalks, and driveways. Because of this, there are a few key features the ASR must have. The two main features of the ASR include autonomous movement and the ability to spread deicing material.

Methods
The two primary methods behind proper functioning of the ASR are magnetic line following and salt spreading.

The autonomy of the ASR is accomplished through non-optical line following. There are alternatives to line following, including LIDAR and image processing, but they were deemed too expensive and technologically challenging when compared to line following. The popular implementation of a line following system is to create a high contrast black line on a white surface which can be sensed with visible or infrared light. There are issues with this technique in the particular application of the ASR. If an optical line following system were implemented, issues could arise with debris or light snow covering the black line designating the path. If the line were to be covered by contaminants, it would become difficult for the robot to discern between the line and the surface on which it is placed. Due to this complication, the idea of a non-optical line following system was conceived. The alternative system for the ASR is based around magnetic tape, which can be placed on a surface, emanating a magnetic field normal to the surface. The advantage of the magnetic tape over optical line following is its immunity to debris and snow which would render an optical system inoperable. The nature of the magnetic field allows it to penetrate obstructions, giving the ASR a clear line to follow, even in harsh conditions. Sensing of the line is accomplished with triple-axis magnetometers, which are electrical devices sensitive to changes in magnetic field intensity.

The method by which deicing material is transferred to the ice prone surface is accomplished with a handheld, off-the-shelf product that spreads material using a battery-powered motor system. This product is called the Scotts® Wizz™. Before deciding on the Scotts® Wizz™ device, many alternative solutions were considered. Initially, a gravity-fed hopper system with a fan to spread the salt was entertained. Issues with this technique included the need for a high amount of current for the fan, considerable design time required to mate the hopper with the fan, and the need for an agitator in the hopper to allow the deicing material to flow to the fan. Another proposed solution was a system that used a pump to spray a salt-water mix onto the ice-prone surface. The issue here was the potential practical problem of requiring the end user to prepare the salt-water mixture before enabling the ASR. Additionally, a decrease in the flow of salt as a result of salt crystallization in the spraying nozzle posed a serious concern. Ultimately, the Scotts® Wizz™ was selected because of its low power, reliability reported by users of the product, modularity, and ease of implementation in the ASR design.
Materials
To bring the ASR design to fruition, a variety of parts were ordered. The materials were selected based on what was needed to successfully complete each task as well as the circuitry demands. The design of the ASR is accomplished with the components outlined in Table 10.

Table 10: The materials list to implement the ASR design, detailing vendors and quantities required for each component.

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Distributor</th>
<th>Qty.</th>
</tr>
</thead>
<tbody>
<tr>
<td>KOOKYE Robot Smart Car Platform</td>
<td>Amazon</td>
<td>1</td>
</tr>
<tr>
<td>Battery charger</td>
<td>Dxcom</td>
<td>1</td>
</tr>
<tr>
<td>battery charger cover</td>
<td>Dxcom</td>
<td>1</td>
</tr>
<tr>
<td>11.1V LiPo batteries</td>
<td>Robot Shop</td>
<td>2</td>
</tr>
<tr>
<td>H-bridge</td>
<td>Robot Shop</td>
<td>2</td>
</tr>
<tr>
<td>DC to DC converter</td>
<td>Robot Shop</td>
<td>2</td>
</tr>
<tr>
<td>Ultrasonic Range</td>
<td>Robot Shop</td>
<td>2</td>
</tr>
<tr>
<td>LCD screen</td>
<td>Adafruit</td>
<td>1</td>
</tr>
<tr>
<td>Temperature Sensor</td>
<td>Adafruit</td>
<td>1</td>
</tr>
<tr>
<td>SPST Reed Relay - NO</td>
<td>Digikey</td>
<td>2</td>
</tr>
<tr>
<td>DPDT relay</td>
<td>Digikey</td>
<td>2</td>
</tr>
<tr>
<td>hall effect sensors (high sensitivity)</td>
<td>Digikey</td>
<td>7</td>
</tr>
<tr>
<td>hall effect sensors 2 (less sensitivity)</td>
<td>Digikey</td>
<td>7</td>
</tr>
<tr>
<td>pushbutton</td>
<td>Digikey</td>
<td>2</td>
</tr>
<tr>
<td>protoboard</td>
<td>Digikey</td>
<td>2</td>
</tr>
<tr>
<td>buzzer</td>
<td>Digikey</td>
<td>1</td>
</tr>
<tr>
<td>box</td>
<td>Digikey</td>
<td>1</td>
</tr>
<tr>
<td>Scotts Wizz Hand-Held Spreader</td>
<td>Home Depot</td>
<td>2</td>
</tr>
<tr>
<td>L-bracket</td>
<td>Home Depot</td>
<td>2</td>
</tr>
<tr>
<td>magnetic tape</td>
<td>Home Depot</td>
<td>2</td>
</tr>
<tr>
<td>nuts and bolts and screws</td>
<td>Home Depot</td>
<td>&gt;12</td>
</tr>
<tr>
<td>1in*30in Magnetic tape</td>
<td>Home Depot</td>
<td>12</td>
</tr>
<tr>
<td>3D print</td>
<td>DLM</td>
<td>1</td>
</tr>
<tr>
<td>Packing Tape</td>
<td>Home Depot</td>
<td>2</td>
</tr>
<tr>
<td>SuperGlue</td>
<td>Home Depot</td>
<td>1</td>
</tr>
<tr>
<td>Spray Paint</td>
<td>Home Depot</td>
<td>1</td>
</tr>
</tbody>
</table>
Prototypes and System Configuration

Circuit Design
To enable the ASR to function as desired, all electrical components are interconnected and mapped onto a circuit schematic displayed in Fig. 13.

Fig. 13: The final version of the ASR circuit schematic, detailing the interface of all electrical components.

Pins A4 and A5 on the Arduino are reserved for the I2C communication protocol when serial communication is desired. As such, only one device can communicate with the Arduino at a time. The design consists of five serial devices including four magnetometers and a temperature/pressure sensor. In order to select the device to communicate with the Arduino, the Maxim 4617 3-bit multiplexer was selected because of its fast switching speed and relevance to the requirements of selective communication. SDA and SCL switching occurs in two multiplexers to keep the signals separated. The three control bits on each multiplexer are connected to the same three digital pins, as communication occurs with a pair of SDA and SCL signals corresponding to the desired device.

The relay (RL1) that controls the Scotts® Wizz™ electric motor is actuated with a digital pin on the Arduino, allowing the spreader to be controlled in software. Current for the Scotts® Wizz™ electric motor is supplied by a DC-DC converter (U6).

The dual H bridge (U7) is connected to the left and right motors of the tracked chassis. The benefit of the dual H bridge is that it allows for fine speed control of the motors in both the forward and backward directions. Six digital lines from the Arduino control this module, including two that generate pulse width modulated square waves.

The button (S1) is connected to a digital pin on the Arduino configured as input pull-up, allowing the button to simply be connected to ground on the other side.
Ambient temperature and pressure are sensed by the BMP280 (U1), which communicates temperature and pressure data over serial communication protocol to the Arduino. The ASR can be started either by this module or by the user’s push of a button.

Flowchart
For the ASR to operate successfully, the Arduino microcontroller was programmed in a robust and efficient manner. The algorithm for the software to be loaded on the Arduino is detailed in the flowchart shown in Fig. 14.
Fig. 14: Algorithm flowchart for Arduino programming and system control.
From the flowchart, the operation of the ASR's software can clearly be seen. Initially, decisions are made regarding initiation of the salting procedure. The ASR can either be manually or automatically started, depending on the user’s preference. Once the ASR has been started, threshold values are calculated for each magnetometer, the spreader turns on, and the robot initiates forward movement. After this initialization process, a loop is entered which monitors the two front magnetometers and adjusts the drive motors accordingly to follow the magnetic line. This loop continues until the end of the path is detected, at which point the deicing spreader deactivates and the ASR initiates backward movement. After this reverse initialization, another loop is entered which monitors the two back magnetometers and adjusts the motors accordingly to follow the magnetic line. This loop continues while the ASR has not reached the beginning. Once the ASR has returned to its starting point, the second loop is exited and the ASR returns to its initial state, waiting to start again.

**Prototype**
The current prototype of the ASR is shown in Fig. 15.

![Fig. 15: Final prototype of the ASR.](image1)

The CAD drawing used to 3-D print the snow plot is provided in Fig. 16.

![Fig. 16: Plow design using 3D printing software.](image2)

**Circuit Implementation**
Using the circuit schematic presented in Fig. 13, the functional circuit was implemented as shown in Fig. 17.
The implemented circuit contains four magnetometers, two multiplexers, one relay, one Arduino, one dual H bridge, one LiPo battery, one DC-DC converter, one button, and two LEDs.

**Budget**
The budget for Saltonomous Industries is restricted to $600. The goal was to remain within the provided amount, which was successfully accomplished. The majority of the budget was spent on foundational items such as the tracked robot, the spreader, the Arduino controller, the magnetometers, and the batteries. Additional funds were used for electrical components, sensors, and mechanical necessities. The financial state of the team is summarized in the budget table (Table 11).
Table 11: The materials list to implement the ASR design, detailing vendors and quantities required for each component.

<table>
<thead>
<tr>
<th>Product Name</th>
<th>Distributor</th>
<th>Qty</th>
<th>Cost Ea.</th>
<th>Cost Ext.</th>
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<td>Amazon</td>
<td>1</td>
<td>$96.99</td>
<td>$96.99</td>
</tr>
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<td>Battery charger</td>
<td>Dxcom</td>
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<td>11.1V LiPo batteries</td>
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<td>Ultrasonic Range</td>
<td>Robot Shop</td>
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<td>$5.00</td>
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<td>LCD screen</td>
<td>Adafruit</td>
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<td>$23.95</td>
<td>$23.95</td>
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<td>Temperature Sensor</td>
<td>Adafruit</td>
<td>1</td>
<td>$9.95</td>
<td>$9.95</td>
</tr>
<tr>
<td>SPST Reed Relay - NO</td>
<td>Digikey</td>
<td>2</td>
<td>$0.98</td>
<td>$1.96</td>
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<td>DPDT relay</td>
<td>Digikey</td>
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<td>$1.63</td>
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<td><strong>$89.70</strong></td>
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Results and Evaluation

Process, Problems, and Solutions
The first step in beginning the prototyping phase of the project was to order all required parts (Table 11). When all items arrived, the first order of business was construction of the tracked robot. Once assembly was complete, the Hall-effect sensors were tested using magnetic tape, a multimeter, and a power supply to determine the range of values provided by the sensors and the maximum distance from the tape at which the sensors could be held before losing detection of the magnetic field. This resulted in the first major issue of the project, as the sensors (both medium and ultra-high sensitivities) were required to be no more than 1 cm from the tape to allow for detection. The impracticality of this limitation was severe and the team was required to alter its approach to magnetic sensing. After consulting with Dr. Shen, the Hall-effect sensors were replaced with four magnetometers. When these modules were tested, it was observed that they could be located much farther from the magnetic tape while still accurately sensing the magnetic field produced. The new mode of magnetic sensing proved to be more reliable and robust than the Hall-effect sensors but required more complex understanding of data acquisition.

In addition, the change in sensors used required a redesign of the system circuit to accommodate the five sets of SDA and SCL lines. Each magnetometer as well as the temperature sensor require one SDA and one SCL line. Therefore, 5 SCL lines and 5 SDA lines would be needed. As the Arduino Uno has only one SDA input and one SCL input, two multiplexers were required to switch between the sensors used: one for the SCL line and one for the SDA line.

When the sensor issues had been resolved, the next step was to disassemble the salt spreader so that the team could understand its internal circuitry for incorporation into the ASR system. This task proved challenging, but the team was successful in integrating the salt-spraying motor into the circuit to be controlled by the Arduino.

Next, all components were mounted and preliminary testing could begin. The first objective in programming was to create a script that would allow the ASR to achieve successful forward movement through magnetic line following. Once this was complete, the backward movement was accomplished as well. Throughout the entire process of testing magnetic line following, there was a major problem with reliability. Sometimes the robot would function without any issues whereas other times, without changing the code or any physical component of the robot or the track, the robot would completely lose the line or start moving in a bizarre manner. After spending a significant amount of time combing through the code to discover the source of error, no major advances were made, as nothing could fix the behavior in a reliable manner. As a result, the team developed the hypothesis that the erroneous readings were due to magnetic interference present inside the SEM building at UNR. In an effort to eliminate extraneous magnetic fields, the robot was moved to an outdoor location. When tested there, the robot operated consistently and without issue. This proved to be better for the team because the ASR is intended for outdoor use.
Serial Data
For successful operation, the ASR employs four magnetometers to track the magnetic path and a temperature sensor as a way to automatically begin salting. By hooking up the serial cable to the Arduino, the serial data is able to be read. As show in Fig. 18, first the robot takes readings form the magnetometers to find an appropriate average value for each sensor when the sensors are not reading a magnetic field. The readings taken by the sensors when the robot is maneuvering its path are compared to these averages to determine whether or not the sensors are above the line. Then the program waits to begin execution by either the push of the button or, for demonstration purposes, a temperature reading falling above the threshold value. Once salting is initiated, the front magnetometers (sensor 0 and sensor 1) read the magnetic field produced by the tape.

Selected range: 4 Ga
Selected Measurement Mode: Single-Measurement
Selected Data Rate: 15 Hz
Selected number of samples: 1
0: 604.44 1: 122.36 2: 488.52 3: 1184.04
0: 249.32 1: 126.04 2: 491.28 3: 1182.20
0: 249.32 1: 122.36 2: 490.36 3: 1184.96
0: 603.52 1: 123.28 2: 492.20 3: 1182.20
0: 602.60 1: 124.20 2: 491.28 3: 1184.04
0: 603.52 1: 124.20 2: 491.28 3: 1183.12
0: 604.44 1: 124.20 2: 489.44 3: 1180.36
0: 601.68 1: 122.36 2: 492.20 3: 1184.04
0: 603.52 1: 125.12 2: 493.12 3: 1180.36
0: 603.52 1: 123.28 2: 489.44 3: 1180.36
Sensor 0 average: 532.59
Sensor 1 average: 123.74
Sensor 2 average: 490.91
Sensor 3 average: 1182.57
Baseline Temperature = 75.06 *F

Temperature = 75.06 *F
Temperature = 75.09 *F
Temperature = 75.13 *F
Temperature = 75.25 *F
Temperature = 75.61 *F
Temperature = 76.10 *F
Temperature = 76.57 *F
Temperature = 77.05 *F
Temperature = 77.70 *F
0: 604.44 1: 125.12
0: 604.44 532.59 1: 125.12 123.74
0: 603.52 532.59 1: 125.12 123.74

Fig. 18: Initialization of the ASR magnetometers and temperature sensing, followed by the activation of the rover. The two front sensors are active to follow the magnetic line appropriately.
When the two front sensors both sense a magnetic field, backwards movement is initiated, as shown in Fig. 19. The back two magnetometers (sensor 2 and sensor 3) are then used to direct the robot’s movement until it reaches the end of its path.

![Figure 19: Detection of the magnetic line by both front sensors occurs, triggering the back two magnetometers to begin reading data to follow the magnetic line.](image)

**Future Work**

The Gantt detailed in Fig. 20 provides the full timeline of the ASR project. Each task was completed on time and in an efficient manner.

![Gantt Chart: Autonomous Salting Robot (ASR)](image)

![Figure 20: The Gantt Chart for the ASR, showing all tasks were completed in a timely manner.](image)

Although the senior capstone course has been completed, there are more advances that could be made to improve the product. Additional features could be added to the ASR, such as a housing unit for convenient storage of the robot, an automated charging unit for easy charging of the battery, and a mechanism that refills the salt spreader for maximum
automation. A significant improvement to the ASR would be a change in the temperature sensing capabilities of the robot. Currently, the software only reads ambient temperature to determine whether or not to initiate salting. To more accurately predict when snow will fall, pressure sensing must also be employed. This is beyond the expertise of the team, so Saltonomous Industries would need to hire a meteorologist to aid in the calibration of the temperature/pressure sensor. Finally, to address the lack of aesthetics of the magnetic tape, Saltonomous Industries hopes to introduce magnetic wire that could be embedded in the driveway or walkways in the desired locations. For individuals who would be willing to repave or make other necessary changes to their driveways, a magnetic wire could replace the magnetic tape, thereby making the mechanism producing the magnetic field more obscure.

IV. Management and Team Profile

Saltonomous Industries spearheads the design and production of the ASR. The company is managed by four senior Electrical Engineering students at the University of Nevada, Reno, each holding a specific position within the company.

Helena Knapen is the Chief Executive Officer. As such, she is responsible for communicating with outside sources, especially EE 491 instructors. She must set primary goals for the team and ensure that all team members are aware of and carrying out their assigned responsibilities. She leads team meetings and facilitates conflict resolution among team members and external groups. As the marketing leader, it is her responsibility to ensure that the product will be well received so that the hard work of her team can be rewarded.

Elisabeth Knapen is the Chief Operations Officer. Some of her primary responsibilities include scheduling, ensuring that the team stays on target according to the Gantt Chart (Fig. 20), reserving rooms for team meetings, and coordinating availability among team members for work times. Elisabeth must also document important team information, especially material discussed in team meetings and action items, and submit all team assignments. Lastly, she must collaborate closely on strategies with the CEO and ensure that the goals established by the CEO come to fruition.

Morgan Regan is the Chief Financial Officer. This position puts her in charge of all management of finances for the project, ensuring that the team stays within budget and projecting revenue as well as financial success and stability of the company. She is the liaison for the team in communicating with Tony Piazza to ensure all parts are ordered, purchased, and received correctly and in a timely manner for prototype building. In addition, her role requires initiating and maintaining the renting of any additional resources or facilities required by the team.

Anthony Braido is the Chief Technical Officer. He leads the technical design of the ASR, ensuring that all individually designed modules fit together to form a functional product by Innovation Day. During the design phase, he is responsible for researching materials that will best suit the needs of the product. In addition to leading the assembly of the prototype,
Anthony is in charge of testing the prototype and ensuring that all specifications are met. While maintaining the structural and functional integrity of the system, he must encourage innovation and creativity among all members of his team.

V. Summary and Conclusions
Saltonomous Industries’ ASR provides a service that increases the safety and convenience to the user, increases the quality of salting through even dispersal, and decreases negative environmental impacts by offering the use of alternative deicing materials. The ASR is a revolutionary product that significantly decreases slipping hazards in ice-prone weather conditions. The robot will benefit all those who must use dangerous pathways while simultaneously offering legal protection and peace of mind to those responsible for maintaining safe conditions on their premises. As there are no competing products offering the level of autonomy and quality of salting of the ASR, the entire deicing industry will greatly improve with the robot’s introduction into the market.

The intended methods proved successful in operating the robot, as the ASR is fully functional and automated. At its current stage, the ASR can be initiated by the push of a button or temperature sensing, can complete forward and backward movement accurately following the magnetic line, and can activate and deactivate the salt spreader appropriately. Future work on the ASR will allow for additional improvements and developments of the product.

The past experience and division of specialties of each team member within Saltonomous Industries allowed for tasks to be completed efficiently and thoroughly. With each team member spearheading a separate portion of the project, great attention and care were given to all aspects of the project.

The development of the ASR challenged the team, requiring integration of information from across their educations. Through hard work, innovation, and teamwork, the project was a success.

C. References Cited
1.2?s=lawn-garden &ie=UTF8&qid=1488258892&sr=1-2&keywords=handheld+spreader


D. Facilities, Equipment, and Other Resources

The equipment that was used for this project was found primarily within the Senior Capstone Lab in SEM 341. Such resources included a soldering iron, a dc power supply, screwdrivers, electrical tape, a multimeter, an oscilloscope, and a computer with the Arduino programming environment. The De la Mare library was used to 3-D print a snow plow for the front of the robot. The UNR walkways outside of the SEM building were also used as testing sites.

E. Special Information and Supplementary Documentation
Appendix A: Market Analysis Survey

Senior Project - Autonomous Salting Robot

If you have lived or live in a climate in which you need to salt your driveway, would you like a robot that would autonomously salt your driveway for you? Please answer the questions below to help us determine the features and ideal price range of our Senior Engineering Design project! This device will be a robot on which a salt spreader is mounted that can be customized to follow the path of your driveway or walkway so that you don't have to worry about remembering to salt your driveway or be outside longer than necessary during the cold winter months! For those of you who have never salted a path before or have no plans of living in a city where salting is necessary, please participate and help us make our project great!

* Required

1. First Name *

2. Have you ever salted your driveway or walkway? *
   - Mark only one oval.
   - Yes
   - No

3. Have you ever slipped and/or fell on ice? *
   - Mark only one oval.
   - Yes
   - No

4. Would an automatic salting system encourage you to salt your driveway or walkway if necessary? *
   - Mark only one oval.
   - Yes
   - No

5. Type of automation preferred? (select one or more) *
   - Check all that apply.
   - Time based (e.g. activates at 6:00 PM every day)
   - Weather based (e.g. activates when an impending storm is sensed)
   - Only when you tell it to (e.g. push button to start)
   - Other: 

https://repa.ne/6rtol14/47/658/2a32r235982001472a726467186461/
6. Are you interested in this product in the following areas? (select more or one) *
   Check all that apply.
   [ ] Residential
   [ ] Small business
   [ ] Municipal
   [ ] I'm not interested in this product
   [ ] Other: __________________________________________

7. How much would you pay for an automatic salting system? *
   Mark only one oval.
   [ ] <$50
   [ ] $50-$100
   [ ] $100-$200
   [ ] $200-$400
   [ ] $400-$600
   [ ] >$600

8. Any other suggestions you may have for us to make our project amazing?
   ___________________________________________________
   ___________________________________________________
   ___________________________________________________
Appendix B: Data Sheets

3.1 Block diagram

Figure 1 shows a simplified block diagram of the BMP280:

![Block diagram of BMP280]

Figure 1: Block diagram of BMP280

3.2 Power management

The BMP280 has two separate power supply pins

- \( V_{DD} \) is the main power supply for all internal analog and digital functional blocks
- \( V_{DDIO} \) is a separate power supply pin, used for the supply of the digital interface

A power-on reset generator is built in which resets the logic circuitry and the register values after the power-on sequence. There are no limitations on slope and sequence of raising the \( V_{DD} \) and \( V_{DDIO} \) levels. After powering up, the sensor settles in sleep mode (see 3.6.1).

Warning. Holding any interface pin (SDI, SDO, SCK or CSB) at a logical high level when \( V_{DDIO} \) is switched off can permanently damage the device due caused by excessive current flow through the ESD protection diodes.

If \( V_{DDIO} \) is supplied, but \( V_{DD} \) is not, the interface pins are kept at a high-Z level. The bus can therefore already be used freely before the BMP280 \( V_{DD} \) supply is established.

3.3 Measurement flow

The BMP280 measurement period consists of a temperature and pressure measurement with selectable oversampling. After the measurement period, the data are passed through an optional IIR filter, which removes short-term fluctuations in pressure (e.g. caused by slamming a door). The flow is depicted in the diagram below.
Adjustable DC/DC Power Converter (1.25V - 35V/3A)  
RB-See-365

This is a DC/DC step-down voltage regulator that converts input voltage between 3.2V and 40V into a smaller voltage between 1.25V and 35V, capable of driving a 3A load with excellent line and load regulation. In some projects, you might need different voltages (3-35V) for your devices. Without this kind of DC power source, you’ll find it time-consuming to buy a new one. The delay of project is so annoying. No worries. This module can accelerate prototyping, because you can get the voltage you need (such as 3.3V, 5V and 9V) as easy as blinking eyes.

Note: Input must be >1.5V higher than output.

Features
- Wide output voltage range
- Ensured 3A output load current
- Input voltage range up to 40V
- Excellent line and load regulation
- Low power standby mode, typically 80uA
- High efficiency up to 92%
- Precise potentiometer for voltage adjustment
- Thermal shutdown and current limit protection

Specifications
- Input voltage: 3.2V - 40VDC
- Output voltage: 1.25V - 35VDC
- Max. output Current: 3A
- Max. efficiency: 92%
- Output ripple: ≤100mV
- Switching frequency: 65KHz
- Operating temperature: -45°C to +85°C
- Dimensions: 43mm x 21mm x 14mm(l) x (w) x (h)
- Weight: 12 g
RB-Itc-141
L298 Dual H-Bridge DC Motor Controller

This module is based on the very popular L298 Dual H-Bridge Motor Driver Integrated Circuit. The circuit will allow you to easily and independently control two motors of up to 2A each in both directions. It is ideal for robotic applications and well suited for connection to a microcontroller requiring just a couple of control lines per motor. It can also be interfaced with simple manual switches, TTL logic gates, relays, etc.

Features

- Motor supply: 7 to 24 VDC
- Control Logic: Standard TTL Logic Level
- Output Power: Up to 2 A each
- Enable and Direction Control Pins
- Heatsink for IC
- Power-On LED indicator
- 4 Direction LED indicators

Specifications

- Module Type: Driver
- Version: 1
- Operation Level: Digital 5V
- Weight: 35.00g
- Board Size: 5.5 x 5 x 2.9cm
HE700 Miniature Dual In-line Reed Relay

Description
The HE700 is a miniature reed relay in a DIL package with a choice of normally open, normally open high voltage, normally closed or changeover contacts capable of switching up to 30Vdc at 10A. It is available with 5V, 12V, and 24V coils and diode suppression and also available with magnetic shield option.

Features
- Miniature dual in-line package
- Optional coil suppression diode to protect coil drive circuits
- External magnetic shield option
- Diode suppression option
- RoHS Compliant

Benefits
- One relay, various contacts choices reducing space and cost without compromising reliability
- Lower power coil consumption than competing electromechanical devices.
- Hermetically sealed switching contacts immune to the effects of its environment
- Transfer molded package gives maximum component protection

Applications
- Security Systems
- Telecom Equipment
- Process Control Systems
- Industrial Equipment
- Instrumentation

Agency Approvals

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<th>Agency</th>
<th>Agency File Number</th>
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<td>E97268</td>
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(Notes: Contact Littelfuse for specific agency approval ratings)

Dimensions
Dimensions in mm (inch)

Table 1: Dimension

<table>
<thead>
<tr>
<th>Relay Type</th>
<th>Body Type</th>
<th>L</th>
<th>W</th>
<th>H</th>
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<tr>
<td>HE700</td>
<td>Transfer Molded</td>
<td>19.05 (0.750)</td>
<td>7.22 (0.284)</td>
<td>5.50 (0.217)</td>
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<td></td>
<td>External Shield</td>
<td>20.14 (0.793)</td>
<td>7.62 (0.300)</td>
<td>5.82 (0.229)</td>
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</tbody>
</table>

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Specifications are subject to change without notice.

Visit us at littelfuse.com
MAX4617/MAX4618/MAX4619
High-Speed, Low-Voltage, CMOS Analog Multiplexers/Switches

General Description

The MAX4617/MAX4618/MAX4619 are high-speed, low-voltage, CMOS analog ICs configured as an 8-channel multiplexer (MAX4617), two 4-channel multiplexers (MAX4616), and three single-pole/double-throw (SPDT) switches (MAX4619).

These CMOS devices can operate continuously with a +2V to +5.5V single supply. Each switch can handle rail-to-rail analog signals. The off-leakage current is only 1nA at TA = +25°C and 10nA at TA = +85°C.

All digital inputs have 0.8V to 2.4V logic thresholds, ensuring TTL/CMOS-logic compatibility when using a single +5V supply.

Features

- Fast Switching Times
  - 15ns TON
  - 10ns TOFF
- Pin Compatible with Industry-Standard 74HC4051/74HC4052/74HC4053 and MAX4581/MAX4582/MAX4583
- Guaranteed On-Resistance
  - 10Ω max (+5V Supply)
  - 20Ω max (+3V Supply)
- Guaranteed 1Ω On-Resistance Match Between Channels (single +5V supply)
- Guaranteed Low Off-Leakage Current:
  - 1nA at +25°C
- Guaranteed Low On-Leakage Current:
  - 1nA at +25°C
- +2V to +5.5V Single-Supply Operation
- TTL/CMOS-Logic Compatible
- Low Crossstalk: <96dB
- High Off-isolation: <33dB
- Low Distortion: <0.017% (60Hz)

Applications

- Battery-Operated Equipment
- Audio/Video Signal Routing
- Low-Voltage Data-Acquisition Systems
- Communications Circuits

Ordering Information

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<thead>
<tr>
<th>PART</th>
<th>TEMP RANGE</th>
<th>PIN-PACKAGE</th>
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<tr>
<td>MAX4617</td>
<td>0°C to +70°C</td>
<td>16 TSSOP</td>
</tr>
<tr>
<td>MAX4618</td>
<td>0°C to +70°C</td>
<td>16 Narrow SO</td>
</tr>
<tr>
<td>MAX4619</td>
<td>0°C to +70°C</td>
<td>16 Plastic SO</td>
</tr>
</tbody>
</table>

For ordering information, please refer to the end of the data sheet.

Pin Configurations/Functional Diagrams

For pricing, delivery, and ordering information, please contact Maxim Direct at 1-888-629-4642, or visit Maxim’s website at www.maximintegrated.com.
3-Axis Digital Compass IC  
**HMC5883L**

The Honeywell HMC5883L is a surface-mount, multi-chip module designed for low-field magnetic sensing with a digital interface for applications such as low-cost compassing and magnetometry. The HMC5883L includes our state-of-the-art, high-resolution HMC118X series magneto-resistive sensors plus an ASIC containing amplification, automatic degaussing strap drivers, offset cancellation, and a 12-bit ADC that enables 1° to 2° compass heading accuracy. The I²C serial bus allows for easy interface. The HMC5883L is a 3.0x3.0x0.9mm surface mount 16-pin leadless chip carrier (LCC). Applications for the HMC5883L include Mobile Phones, Netbooks, Consumer Electronics, Auto Navigation Systems, and Personal Navigation Devices.

The HMC5883L utilizes Honeywell’s Anisotropic Magnetoresistive (AMR) technology that provides advantages over other magnetic sensor technologies. These anisotropic, directional sensors feature precision in-axis sensitivity and linearity. These sensors’ solid-state construction with very low cross-axis sensitivity is designed to measure both the direction and the magnitude of Earth’s magnetic fields, from milli-gauss to 8 gauss. Honeywell’s Magnetic Sensors are among the most sensitive and reliable low-field sensors in the industry.

<table>
<thead>
<tr>
<th>FEATURES</th>
<th>BENEFITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-Axis Magnetoresistive Sensors and ASIC in a 3.0x3.0x0.9mm LCC Surface Mount Package</td>
<td>Small Size for Highly Integrated Products. Just Add a Microcontroller Interface, Plus Two External SMT Capacitors Designed for High Volume, Cost Sensitive OEM Designs Easy to Assemble &amp; Compatible with High Speed SMT Assembly</td>
</tr>
<tr>
<td>12-Bit ADC Coupled with Low Noise AMR Sensors Achieves 2 milli-gauss Field Resolution in ±8 Gauss Fields</td>
<td>Enables 1° to 2° Degree Compass Heading Accuracy</td>
</tr>
<tr>
<td>Built-in Self Test</td>
<td>Enables Low-Cost Functionality Test after Assembly in Production</td>
</tr>
<tr>
<td>Low Voltage Operations (2.15 to 3.6V) and Low Power Consumption (100 µA)</td>
<td>Compatible for Battery Powered Applications</td>
</tr>
<tr>
<td>Built-In Strap Drive Circuits</td>
<td>Set/Reset and Offset Strap Drivers for Degaussing, Self Test, and Offset Compensation</td>
</tr>
<tr>
<td>I²C Digital Interface</td>
<td>Popular Two-Wire Serial Data Interface for Consumer Electronics</td>
</tr>
<tr>
<td>Lead Free Package Construction</td>
<td>RoHS Compliance</td>
</tr>
<tr>
<td>Wide Magnetic Field Range (+/-8 Oe)</td>
<td>Sensors Can Be Used in Strong Magnetic Field Environments with a 1° to 2° Degree Compass Heading Accuracy</td>
</tr>
<tr>
<td>Fast 160 Hz Maximum Output Rate</td>
<td>Enables Pedestrian Navigation and LBS Applications</td>
</tr>
</tbody>
</table>