**3.4 The Motors for Drive Wheels**

In this section, the process for selecting the motor, that will drive the wheels of the VPS, is explained. The process involves several critical steps. In section 3.4.1, the different types of motors are analyzed to determine the best type of motor to drive the VPS. In section 3.4.2, the qualitative values and scoring system, for the types of motors, is justified. In section 3.4.3, the torque and RPM requirements, for the VPS, are calculated and specific motors are selected. In section 3.4.4, the specific motors are analyzed and a motor is selected. In section 3.4.5, the decision matrices, for the specific motors, are justified.

**3.4.1 Motor Type Decision Matrix**

In the following table different types of motors are analyzed to determine the best type of motor to drive the VPS. The values in this table are not for any one specific motor, but generalized to represent the norm for the type of motor. These values come from the trade study performed by the VPDT. The justification for how these qualitative values were assigned is covered in section 3.4.2.

Table X -Motor type raw data

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Motor Type | Efficiency | Torque | RPM | Position Control | Speed Control | Cost |
| Stepper | low | low | low | high | high | med |
| DC Brushed | med-high | high | high | low | low-med | low |
| DC Brushless | high | high | high | low | med | med |
| DC Brushed w/encoder | med-high | high | high | high | high | med-high |
| DC Brushless w/ encoder | high | high | high | high | high | high |

The above table is then normalized by assigning these qualitative values with a numerical score from 0 to 10. The areas of interest are then given a weight based on how much that area should affect the choice. These weights are then multiplied by the numerical score and summed together to give the total score for the motor type (Shown in the table below). The justification for choosing these weights and scores is discussed in section 3.4.2.

Table XX - Motor type decision matrix, where the chosen motor is highlighted

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| motor type | efficiency | torque | RPM | position control | speed control | cost |  |
| weight | 0.1 | 0.2 | 0.1 | 0.1 | 0.25 | 0.25 | Total |
| Stepper | 0 | 0 | 0 | 10 | 10 | 5 | 4.75 |
| DC Brushed | 7.5 | 10 | 10 | 0 | 2.5 | 10 | 6.875 |
| DC Brushless | 10 | 10 | 10 | 0 | 5 | 5 | 6.5 |
| DC Brushed w/encoder | 7.5 | 10 | 10 | 10 | 10 | 2.5 | 7.875 |
| DC Brushless w/ encoder | 10 | 10 | 10 | 10 | 10 | 0 | 7.5 |

According to the decision matrix, in Table **XX**, the DC brushed motor with an encoder is the best option for the VPS.

**3.4.2 Motor Type Justification**

In the following sections, the criterions for analysis are justified and the scoring system is explained.

**3.4.2.1 Efficiency**

The Efficiency of the motor is an important factor to consider when buying a motor. Higher efficiency allows the motor to use less electrical energy to achieve the required mechanical energy[5]. This allows for less wasted energy and longer battery life[5]. During the trade study the VPDT discovered that certain types of motors are more efficient than others[1][3]. As seen in Table **X**, the DC brushless motors are the most efficient, while the stepper motors are the least efficient. The motor types were assigned a value of “high” for most efficient, and “low” for least efficient. The other motors were assigned values in between, such as “low-med”, “med”, and “med-high.” These values were then converted to a numerical score, from 0 to 10, by assigning the “low”, “low-med”, “med”, “med-high”, and “high”, the values of “0”,”2.5”,”5”,”7.5”, and ”10” respectively. The efficiency category was given a weight of 10%, because it affects the battery life of the VPS.

**3.4.2.2 Torque**

The motors torque effects how much tractive effort the VPS can produce[6]. The higher the torque, the easier it is for the motor to turn the wheels of the VPS[7]. During the trade study the VPDT discovered that certain types of motors were capable of higher torques than others[2][3]. As seen in Table **X,** the DC motors are capable of providing the most torque, while stepper motors typically provide lower torque. The motor types were assigned a value of “high” for high torque, and a value of “low” for low torque. These values were then converted to a numerical score, with “0” being “low”, and “10” being “high”. The torque category was given a weight of 20%, because being able to move the robot is extremely important.

**3.4.2.3 Revolutions Per Minute (RPM)**

The motors RPM represents how fast the motor turns, which effects how fast the VPS can move[6]. Having high RPM, combined with having larger wheels, equals a faster robot[6]. During the trade study the VPDT discovered that certain types of motors typically have higher RPM than others[2]. As seen in Table **X**, the DC motors are capable of providing the most RPM, while stepper motors typically provide lower RPM. The motor types were assigned a value of “high” for high RPM, and a value of “low” for low RPM. These values were then converted to a numerical score, with “0” being “low”, and “10” being “high”. The RPM category was given a weight of 10%, because the VPS is competing in a timed competition and should not be slow. This category could of received a higher weight but during the trade study the VPDT learned that by increasing the wheel size we can also increase the speed of the VPS[6].

**3.4.2.4 Position Control**

Position control determines how accurately the motor can position the attached wheel. The more position control a motor has, the more control the VPS will have over its position on the course. During the trade study the VPDT discovered that certain types of motors typically have more position control than others[1][2][3]. As seen in Table **X**, the DC motors with encoders, and the stepper motors, are capable of providing the most position control, while the DC motors without encoders typically provide less position control. Stepper motors have native position control by design, as they rotate in precise steps[1][2][3]. DC motors by themselves have little to no position control. By adding an encoder, the system becomes a closed loop system, and the VPS can use the feedback from the motor to, more accurately, control position[4]. The motor types were assigned a value of “high” for high position control, and a value of “low” for low position control. These values were then converted to a numerical score, with “0” being “low”, and “10” being “high”. The position control category was given a weight of 10%, because the VPS will have to align itself with the games on the course, as well as stay on the line. Other sensors, such as the ones used for line following, will aid in this alignment, otherwise this category would have received a higher weight.

**3.4.2.5 Speed Control**

Speed control determines how accurately the motor can control the speed of the attached wheel. The more speed control a motor has, the more control the VPS will have over its position on the course, as well as how fast it’s going. During the trade study the VPDT discovered that certain types of motors typically have more speed control than others[1][2][3]. As seen in Table **X**, the DC motors with encoders, and the stepper motors, are capable of providing the most speed control, while the DC motors without encoders typically provide less speed control. Stepper motors have native speed control by design, as they rotate at precise speeds[1][2][3]. DC motors by themselves have some speed control, but factors such as wheel slippage and orientation of the motor can cause speeds to vary[8]. By adding an encoder, the system becomes a closed loop system, and the VPS can use the feedback from the motor to, more accurately, control speed[4]. The motor types were assigned a value of “high” for high speed control, and a value of “low” for low speed control. The other motors were assigned values in between, such as “low-med”, “med”, and “med-high.” These values were then converted to a numerical score, from 0 to 10, by assigning “low”, “low-med”, “med”, “med-high”, and “high”, the values of “0”,”2.5”,”5”,”7.5”, and ”10” respectively. The speed control category was given a weight of 25%, because the VPS will have to overcome inconsistencies in the speed of each wheel to remain on the line. The speed control will also aid in making sure the vehicle maintains the correct speed to complete the course in the desired time.

**3.4.2.6 Cost**

The VPDT is required to remain within a certain budget; therefore the cost of the motor is a major decision factor. During the trade study the VPDT discovered that certain types of motors typically cost more than others[1][9][10][11][12]. As seen in Table **X**, the DC brushless motors with encoders cost the most, and the brushed DC without encoders cost the least. The motor types were assigned a value of “high” for highest cost, and “low” for lowest cost. The other motors were assigned values in between, such as “low-med”, “med”, and “med-high.” These values were then converted to a numerical score, from 0 to 10, by assigning the “low”, “low-med”, “med”, “med-high”, and “high”, the values of “0”,”2.5”,”5”,”7.5”, and ”10” respectively. The cost category was given a weight of 25% because motors are one of the most expensive items that are required for the VPS.

**3.4.3 Calculations for Required Motor Specifications**

Before selecting specific motors for consideration, the torque and RPM required to move the VPS need to be calculated.

**3.4.3.1 Assumptions**

Several assumptions need to be made in order to make appropriate calculations for the motor's minimum required specifications. These assumptions are based on research of similar robots[6][13]:

* The VPS will weigh no more than
* The VPS will weigh no less than
* The maximum speed will be
* The maximum acceleration will be
* The VPS will have two drive wheels
* The weight on each drive wheel will be ¼ of the total weight of the VPS (This is because the VPS will have two drive wheels and two casters)
* The radius of each wheel, mounted to the motor, will be approximately
* The operating surface will be on a flat plane (i.e. the maximum incline will be )
* The rolling resistance coefficient between the wheels and the wood operating surface will be approximately 0.001[14]
* The coefficient of friction between the wheels and the wood operating surface will be approximately 0.6 [15]

**3.4.3.2 Tractive Effort Calculation**

In order to calculate the torque needed from the motor, first the total tractive effort required to move the VPS at the desired speed and acceleration, needs to be calculated.

|  |  |
| --- | --- |
|  | Equation(**Y)[6]** |
|  |  |

Where is the total tractive effort (), is the force necessary to overcome rolling resistance (), is the force required to climb a grade (), and is the force required to accelerate to max velocity ().

Expanding Equation(**Y**),

|  |  |
| --- | --- |
|  | Equation(**YY)[6]** |
|  |  |

Where is the force necessary to overcome rolling resistance (), is the gross vehicle weight (), and is the rolling resistance coefficient.

|  |  |
| --- | --- |
|  | Equation(**YYY**)[6] |
|  |  |

Where is the force required to climb a grade (), is the gross vehicle weight (), and is the max incline ().

|  |  |
| --- | --- |
|  | Equation(**YYYY**)[6] |
|  |  |

Where is the force required to accelerate to max velocity (), is the gross vehicle weight (), is max vehicle speed (), 32.2 is the acceleration due to gravity (), and is the time it takes to reach ().

Solving Equation(**YY**), using the weight range of to , and the rolling resistance of 0.001 (values from assumptions above),

|  |  |
| --- | --- |
|  | Max |
|  | Min |

Solving Equation(**YYY**), using the max incline angle of (values from assumptions above),

|  |  |
| --- | --- |
|  |  |

Solving Equation(**YYYY**), using the weight range of to , of , and of ,

|  |  |
| --- | --- |
|  | Max |
|  | Min |

Substituting solved Equations **YY**, **YYY**, **YYYY**, back into Equation(**Y**),

|  |  |
| --- | --- |
|  | Max |
|  | Min |

**3.4.3.3 Torque Required From the Motors**

Now to find the torque required from the motors to achieve the calculated in section 3.4.2.2,

|  |  |
| --- | --- |
|  | Equation(**YYYYY**)[6] |
|  |  |

Where is the total torque required from all motors, is the total tractive effort from Equation(**Y**) (), is the radius of the wheel (), is the resistance factor. The resistance factor accounts for the frictional losses between the caster wheels and their axles and the drag on the motor bearings. Typical values range between 1.1 and 1.15 (10% to 15%).[6]

Solving Equation(**YYYYY**), using the range of to , the wheel radius of , and the of 1.15,

|  |  |
| --- | --- |
|  | Max |
|  | Min |

Since the VPS has two wheels this value is divided by two to get the torque required for each wheel,

|  |  |
| --- | --- |
|  | Equation(**YYYYYY**)[6] |
|  |  |
|  | at max weight |
|  | at min weight |

As seen above, whatever motor goes into the VPS must be able to generate a torque of at least .

**3.4.3.4 Calculate Wheel Slippage**

The next step is to make sure the VPS won’t experience wheel slip at the assumed conditions,

|  |  |
| --- | --- |
|  | Equation(**YYYYYYY**)[6] |
|  |  |

Where is the max tractive torque (), is the friction coefficient between the wheel and the ground, is the weight on one wheel (), and is the radius of the wheel ().

Solving Equation(**YYYYYYY**), using of 0.6, as , and as 3,

|  |  |
| --- | --- |
|  | Max |
|  | Min |

The wheels will not slip if the following condition is satisfied,

|  |  |
| --- | --- |
|  | Equation(**YYYYYYYY**)[6] |
|  |  |

Solving Equation(**YYYYYYYY**), using the from Equation(**YYYYY**), the from Equation(**YYYYYYY**), and two wheels,

|  |  |
| --- | --- |
|  | At Max Weight |
|  | At Min Weight |

As seen, above wheels will not slip at any weight of the VPS between to .

**3.4.3.5 Calculate Required RPM**

The next and final step is to calculate the RPM required to achieve the desired speed,

|  |  |
| --- | --- |
|  | Equation(**YYYYYYYYY**)[16] |
|  |  |

Where is revolutions per minute, is the maximum speed, and is the radius of the wheel.

Solving Equation(**YYYYYYYYY**), using the of , and of ,

|  |  |
| --- | --- |
|  |  |
|  |  |

As seen, above the motors for the VPS must be capable of 38.2 RPM, to achieve the desired speed.

3.4.4 Items Under Consideration

Now that the required specs of the motor have been determined, in section 3.4.3, and the most appropriate type of motor has been determined, in section 3.4.1, specific motors can be analyzed to determine the exact motor to drive the wheels on the VPS.

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