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Selection of Design Idea:

I decided to select the designs by elimination method. As it was difficult to evaluate each and every idea generated in the report 2. I decided to evaluate each and every mechanism required to perform a certain function. I started evaluation from my Morph chart. My morph chart is as follows:

1. Movement:
   - 1.1 Wheels
   - 1.2 Rotor Blade
   - 1.3 Caterpillar Tracks
   - 1.4 Legs (Crawling Mechanism)
2. Steering
   - 2.1 Ackerman Steering Mechanism
   - 2.2 Davis Mechanism
   - 2.3 Rudder
   - 2.4 Differential Drive
   - 2.5 Another set of wheels
   - 2.6 Rotating wheelbase or Rotating Track
   - 2.7 Dead Weight
   - 2.8 Differential Gear box with brakes for individual wheels.
   - 2.9 Legs (Crawling Mechanism)
3. Speed Control
   - 3.1 Gearbox
   - 3.2 Belt Drive
   - 3.3 Chain Drive
   - 3.4 Electronic circuit
   - 3.5 Dead weight
4. Stopping Mechanism
   - 4.1 Disc Brakes
   - 4.2 Cutting off the power supply.
   - 4.3 Automatic self-destruction of the vehicle at the end point.

Consider the following:

Movement		**Scores**					**Score X Weight**			
	Wt.	**1.1**	**1.2**	**1.3**	**1.4**		**1.1**	**1.2**	**1.3**	**1.4**
Cost	0.13	4	2	1	1		0.52	0.26	0.13	0.13
Easy to manufacture vehicle having	0.2	4	2	3	1		0.8	0.4	0.6	0.2
Simple	0.17	4	3	2	1		0.68	0.51	0.34	0.17
Feasible using 2 DC motors	0.35	1	1	1	0		0.35	0.35	0.35	0
Weight	0.15	3	4	1	1		0.45	0.6	0.15	0.15
SUM	**1**						**2.8**	**2.12**	**1.57**	**0.65**
Hence selecting Wheels for movement.										

Steering		**Scores**									**Score X Weight**								
	Wt.	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**	**2.8**	**2.9**	**2.1**	**2.2**	**2.3**	**2.4**	**2.5**	**2.6**	**2.7**	**2.8**	**2.9**
Cost	0.13	4	5	3	8	7	4	6	3	1	0.52	0.65	0.39	1.04	0.91	0.52	0.78	0.39	0.13
Easy to manufacture vehicle having	0.15	3	2	2	7	6	5	3	2	1	0.45	0.3	0.3	1.05	0.9	0.75	0.45	0.3	0.15
Weight	0.15	5	6	8	5	5	4	3	1	1	0.75	0.9	1.2	0.75	0.75	0.6	0.45	0.15	0.15
Feasible using 2 DC motors	0.19	5	6	3	9	6	6	6	3	0	0.95	1.14	0.57	1.71	1.14	1.14	1.14	0.57	0
Feasible using non programmable circuit	0.19	5	5	2	8	7	7	3	6	2	0.95	0.95	0.38	1.52	1.33	1.33	0.57	1.14	0.38
Accuracy	0.19	2	8	7	5	4	8	3	8	8	0.38	1.52	1.33	0.95	0.76	1.52	0.57	1.52	1.52
SUM	**1**										**4**	**5.46**	**4.17**	**7.02**	**5.79**	**5.86**	**3.96**	**4.07**	**2.33**
Hence selecting Differential Drive for Steering mechanism.																			

Speed Control		**Scores**						**Score X Weight**				
	Wt.	**3.1**	**3.2**	**3.3**	**3.4**	**3.5**		**3.1**	**3.2**	**3.3**	**3.4**	**3.5**
Cost	0.13	4	5	3	5	5		0.52	0.65	0.39	0.65	0.65
Easy to manufacture vehicle having	0.2	4	4	2	4	3		0.8	0.8	0.4	0.8	0.6
Weight	0.17	3	4	2	5	3		0.51	0.68	0.34	0.85	0.51
Accuracy/ Reliability	0.5	4	3	2	4	1		2	1.5	1	2	0.5
SUM	**1**							**3.83**	**3.63**	**2.13**	**4.3**	**2.26**

Hence selecting electronic circuit for Speed control.

Stopping Mechanism		Scores				Score X Weight		
	Wt.	**4.1**	**4.2**	**4.3**		**4.1**	**4.2**	**4.3**
Cost	0.13	1	3	1		0.13	0.39	0.13
Easy to manufacture vehicle having	0.2	1	3	3		0.2	0.6	0.6
Additional components are not required	0.17	1	3	3		0.17	0.51	0.51
Accuracy	0.5	3	2	1		1.5	1	0.5
SUM	**1**					**2**	**2.5**	**1.74**

Hence selecting the option to cut off the power supply to the circuit.

Depending upon the above evaluation and selection process. I decided to make vehicle having wheels and speed and direction control using electronic non programmable circuit. The above decision criteria was based on the knowledge, time limit, cost, ease of manufacturing of the systems and components.

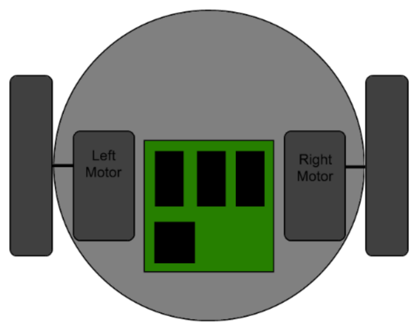

Figure 1 Basic Idea

Design Idea:

The vehicle had to move in figure 8. In order to achieve the desired motion I decided to give differential speed to the two wheels of the vehicle which would cause the vehicle to move in circle and a timing circuit will cause the inputs to change and the vehicle will move in circle of opposite direction thus completing the pattern 8. The timing circuit will be timed according to the time required for the vehicle to complete one round and the timing will be calculated from the speeds at which the motors rotate, the radius of the wheel and track width of the car.

I decided to use PWM (Pulse Width Modulation) circuit to adjust the speed of the motors. Pulse width modulation is the process of switching the power to a device on and off at a given frequency, with varying on and off times. These on and off times are referred to as "duty cycle". The diagram below shows the waveforms of 10%, 50%, and 90% duty cycle signals.

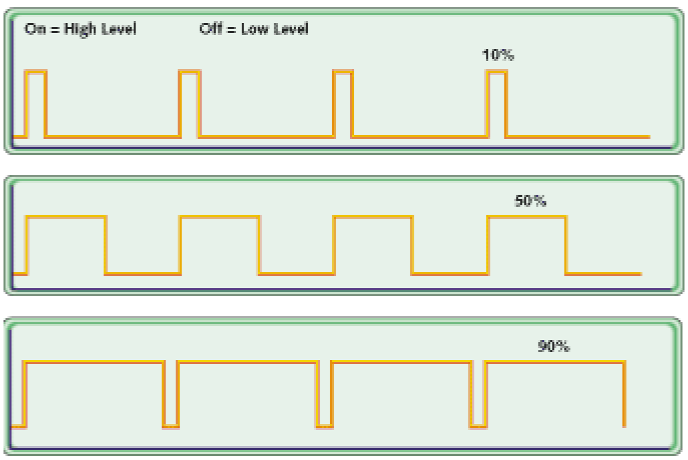

Figure 2 PWM Outputs

As you can see from the diagram, a 10% duty cycle signal is on for 10% of the wavelength and off for 90%, while a 90% duty cycle signal is on for 90% and off for 10%. These signals are sent to the motor at a high enough frequency that the pulsing has no effect on the motor. The end result of the PWM process is that the overall power sent to the motor can be adjusted from off (0% duty cycle) to full on (100% duty cycle) with good efficiency and stable control.

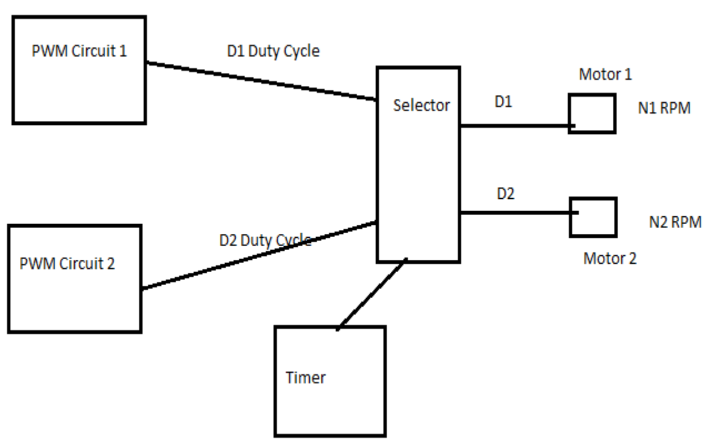

Figure 3 Basic Idea for different speeds

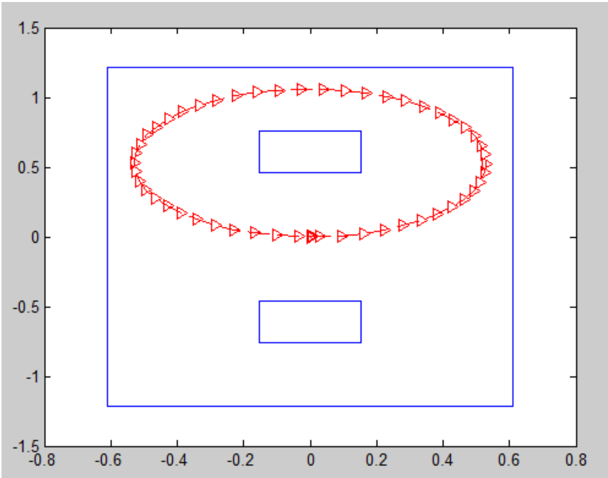

Figure 4 Top circle in anticlockwise direction

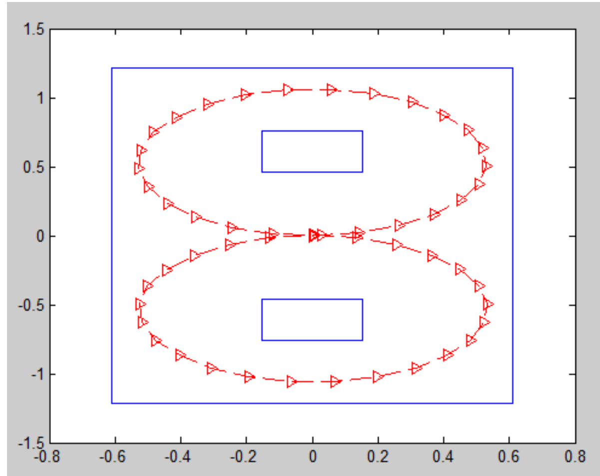

Figure 5 Bottom circle in clockwise direction

The dotted curve shows the path to be followed by the vehicle.

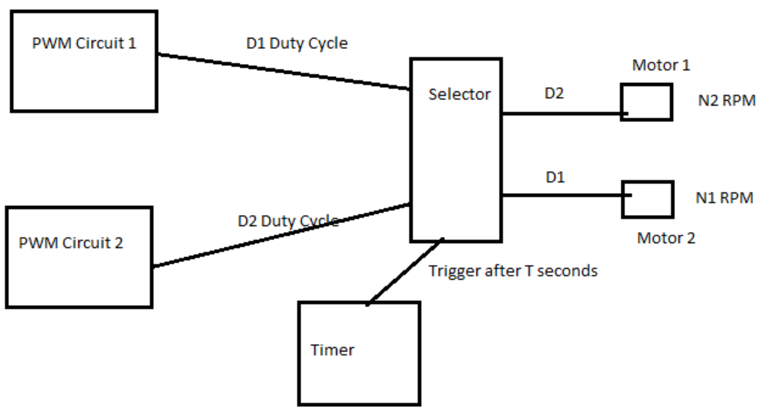

Figure 6 Basic idea switching the motor speeds and stopping the motors

The timer will trigger the selector after T seconds (time required to complete one round) causing the PWM’s to switch and the faster one will now rotate slowly and the slower one faster. Thus, the vehicle will now rotate in a move on a circular path in another direction thus completing the 8 pattern as shown in the figure.

Analysis of Playing Field:

Playing field is as follows:

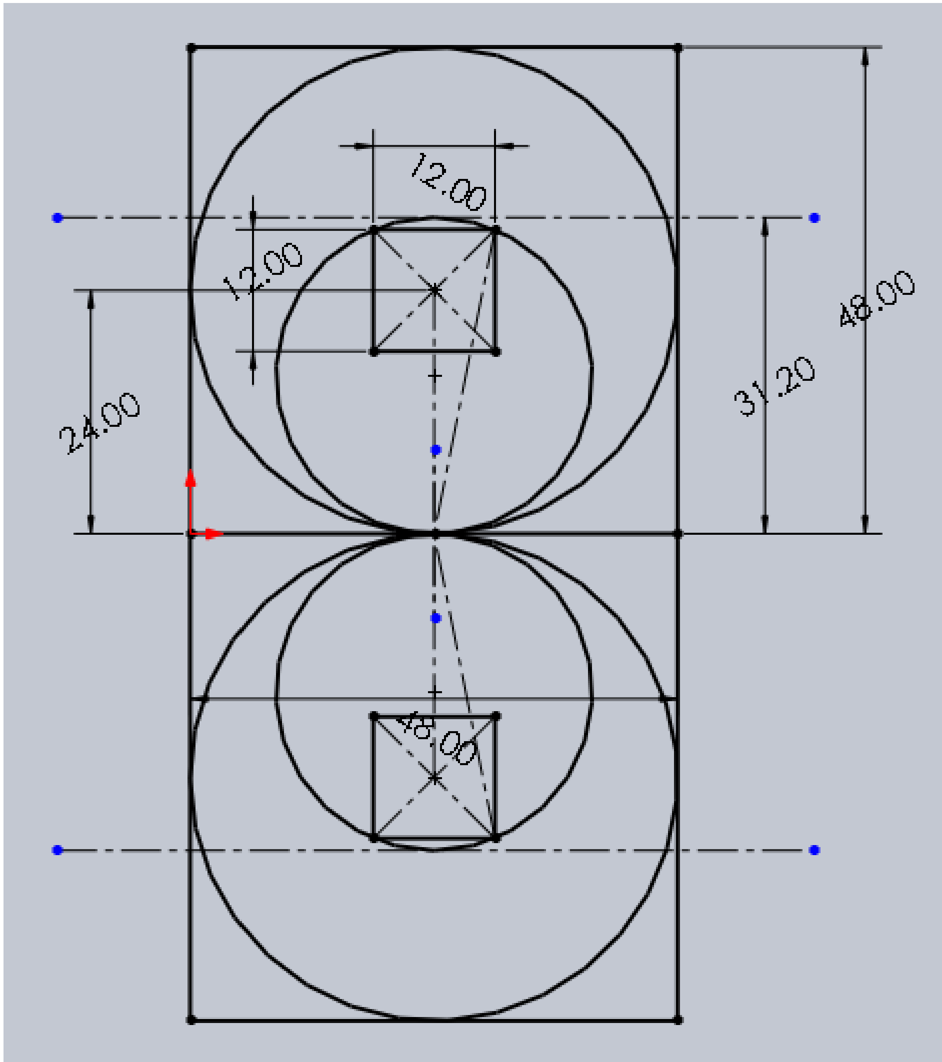

Figure 7 Playing Field

Assuming the boxes of largest size 12 X 12 inches. Hence the vehicle should follow the path between the two circles of diameter 31.2 inches and 48 inches (i.e. 0.3964 m and 0.6096 m), in order to avoid touching the blocks and falling off the plywood. Hence the path of the vehicle should be such that inner wheel does not touches the blocks and the outer wheels does not fall off the plywood.

Analysis of Motion of the Vehicle:

The two wheels will be rotated at two different speeds Nr RPM and Nl RPM. If right wheel is given Nr RPM and left wheel Nl RPM the vehicle will move in a left hand circle. After T seconds the speeds are interchanged now the vehicle will move in a right hand circle. Thus, completing the figure 8.

Let,

rw	Radius of wheels (m)		R	Radius of the turn of vehicle (m)
t	Track width of vehicle (m)		w	Rotational speed of the vehicle (rad/s)
Vr	Velocity of wheel rotating at Nr (RPM)		T	Time to complete 1 circle (s)
Vl	Velocity of wheel rotating at Nl (RPM)		2T	Time to complete full round (Figure of 8) (s)
V	Average velocity of the vehicle (m/s)			

The mathematical model governing the motion of the vehicle can be easily derived as follows:

We Know that,

V= (Vr+Vl)/2; R=V/w; T=2*3.14/w;

The differential velocity will cause the vehicle to turn by small angle of about ϴ and ϴ will be given as:

ϴ= ∫w.dt= (∫Vr.dt - ∫Vl.dt)/t;

Thus, we can get the location (X and Y coordinate) of our car as follows:

Vx= Vcosine(ϴ); Vy= Vsine(ϴ);

X= ∫Vx.dt; Y= ∫Vy.dt;

Thus converting the above physical model into a SIMULINK and MATLAB model and performing simulations in order to obtain the motion of the vehicle, the time required to complete one round, the dimensions of the various parts etc.

In order to perform simulations the following parameters were assumed and the model was simulated and iterations were performed in order to make the vehicle behave in the desired way such that, the vehicle will not touch the blocks and also will not fall off the plywood.

rw= 0.0025 m; t=0.125 m; Nr=300 rpm; Nl=250 rpm.

Some of the other constraints were as follows:

The vehicle must fit within a 6x6x12 inch box (Hence track width has to be less than 6 inches i.e. 15 cm) (assuming t=0.125 to incorporate thickness of wheels and any manufacturing error). Also, the speed of the vehicle should be such that the vehicle does not skid off the plywood due to the centrifugal force acting of the force from this I got the condition that :

mu (sliding coefficient of friction) > V^2/R;

Assuming mu=0.5 (Due rubber tires and wooden arena)

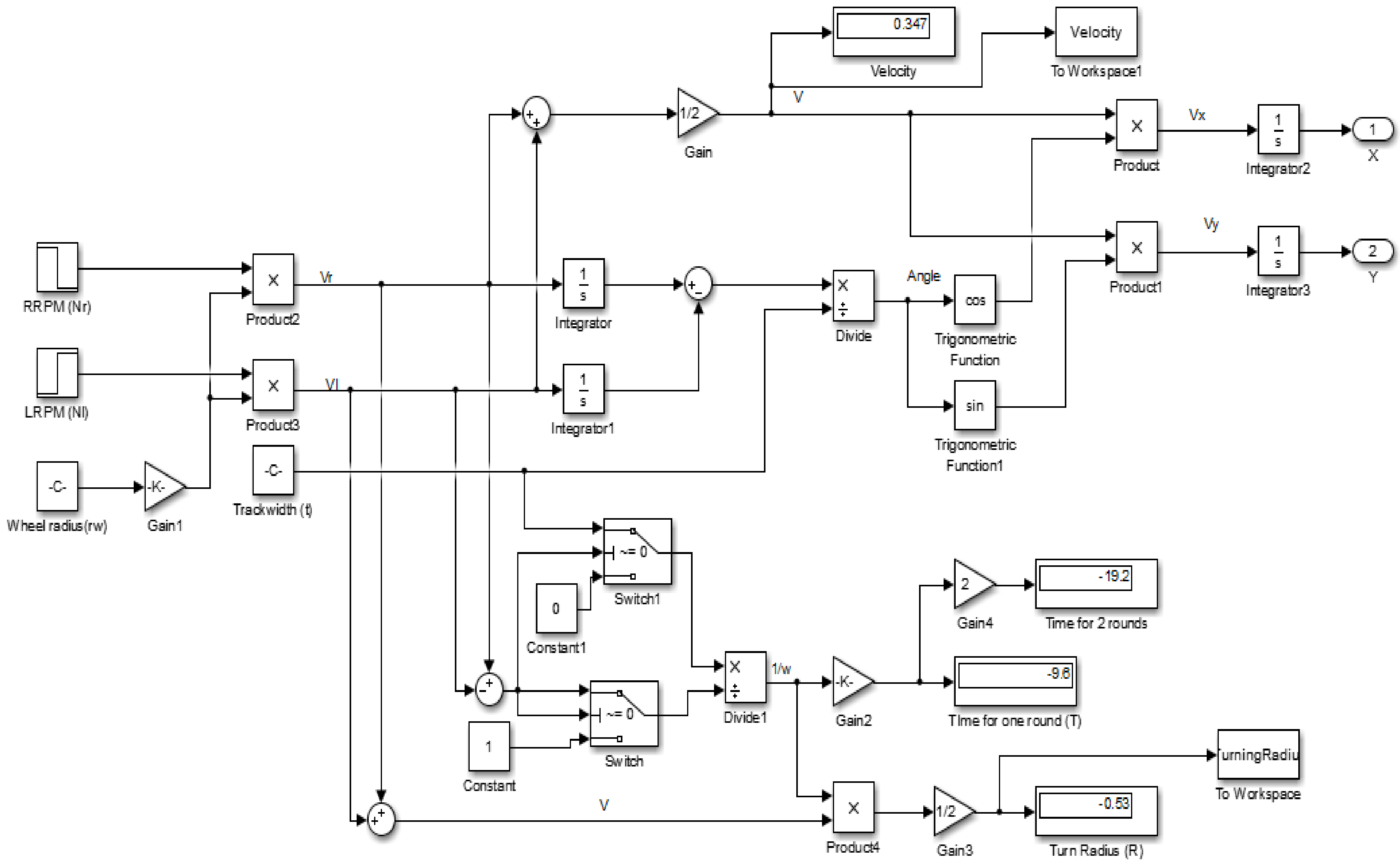

Figure 8 SIMULINK Model

Step 1: The following MATLAB Program was used to set the initial parameter values:

```
Clc
clear all
WheelRadius=0.028; % radius of wheel
TrackWidth=0.1; % track width of car
 mu=0.5; % Coefficient of friction
```

Step 2: The SIMULINK model shown in the Figure above was run to calculate the time required to complete one round, velocity of the vehicle, path followed by the vehicle.

Step 3: The values obtained in step 2 were used to see the path followed by the vehicle, to check whether the inner wheel touches the blocks or not, the outer wheels falls off the plywood or not, and the vehicle does not skid off the plywood. Following MATLAB code was used to check the above conditions:

```
% plywood coordinates for drawing plywood
ply=[0.6096, 0; 0.6096,  1.2192; -0.6096, 1.2192; -0.6096, -1.2192; 0.6096,  -1.2192; 0.6096,  0];
plot(ply(:,1),ply(:,2));
hold on

%reference point coordinates for drawing reference point
ref=[0,0];
plot(ref(:,1),ref(:,2));
hold on

% Building coordinates for drawing Building
B1=[0.1524  0.4572; 0.1524  0.762; -0.1524  0.762; -0.1524  0.4572; 0.1524  0.4572];
plot(B1(:,1),B1(:,2));
hold on
B2=[0.1524  -0.4572; 0.1524 -0.762; -0.1524 -0.762; -0.1524 -0.4572; 0.1524 -0.4572];
plot(B2(:,1),B2(:,2));
hold on

% Path followed by the vehicle yout(X,Y) coordinates of vehicle motion obtained from SIMULINK
plot (yout(:,1),yout(:,2),'r');
hold on

% Checking whether the innerwheel touches the blocks or outer wheel falls off the plywood TurningRadius
% is obtained from SIMULINK Model adding and sustracting from ORad and IRad respectively 0.015 as a
% safety factor
ORad=TurningRadius(1,1)+(TrackWidth(1,1)/2)+0.015;
IRad=TurningRadius(1,1)-(TrackWidth(1,1)/2)-0.015;
if IRad > 0.3964
   disp('Inner wheel does not touch the block');
else
   disp('CHANGE THE VALUES: Inner wheel touches the block');
end
if ORad < 0.6096
```

```
   disp('Outer wheel does not fall off the plywood');
else
   disp('CHANGE THE VALUES: Outer wheel falls down the plywood');
end

% Checking whether the vehicle skids or not Velocity is obtained from SIMULINK Model
Radius=TurningRadius(1);
temp=Velocity.^2/Radius;
if mu > temp
   disp('The vehicle will not skid');
   else
   disp('The velocity is too high the vehicle may skid due to centrifugal force');
end
```

The above steps were performed number of times.
Number of iterations were performed and the results tabulated as follows:

	Nr	Nl	t	rw	2T	R	Results
1	300	230	0.125	0.0025	85.714	0.4732	Inner wheel touches the block
2	300	230	0.125	0.025	8.5714	0.4732	Inner wheel touches the block and Vehicle Skids
3	200	150	0.125	0.025	12	0.4373	Inner wheel touches the block and Vehicle Skids
4	200	120	0.125	0.025	7.5	0.25	Inner wheel touches the block and Vehicle Skids
5	150	120	0.125	0.025	20	0.5625	Outer wheel falls off and Vehicle Skids
6	150	120	0.1	0.25	16	0.45	Inner wheel touches the block
7	145	120	0.1	0.028	17.14	0.53	All Good
8	145	120	0.1	0.03	16	0.53	All Good
9	145	120	0.1	0.04	12	0.53	The vehicle may skid
10	145	120	0.1	0.035	13.71	0.53	All Good

This way the dimensions of the wheels was decided to less than 0.035m and track width as 0.1m.

Circuit:

The circuits were created and simulated in Demo version of Proteus software.

PWM Circuit:

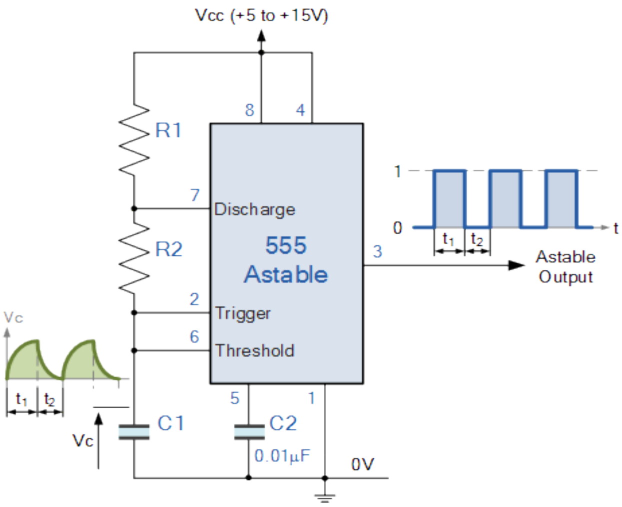

Figure 9 IC 555 as Astable Oscillator

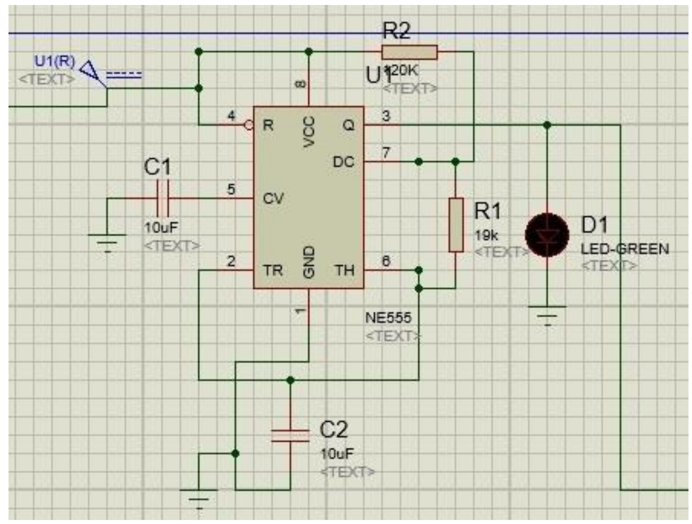

Figure 10 Actual Circuit made in Proteus

It consists of IC NE555 working in Astable mode.
Following formulaes are used to determine the ON time, OFF time of the IC and to determine the Duty cycle of the output in order to control the speed of the motor:

ON time= t1= 0.693(R1 + R2).C1

OFF time= t2= 0.693((R2).C1

Total Oscillator Time T= t1 + t2

Duty Cycle= t1/T

% Duty Cycle= Duty Cycle X 100

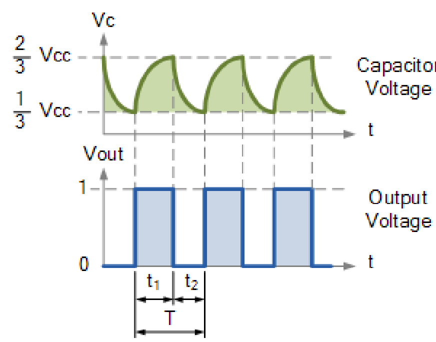

Figure 11 Output of Astable at PIN 3 of IC 555

As too little information is available about the specified Radio Shack DC motors (part number 273-223, 258 or 047) . The Duty Cycle cannot be determined right away. The values of R1, R2 and C1 would be determined after making the model and by performing tests on it. Depending upon the performance of the vehicle R1, R2, and C1 would be determined.

PWM circuit shown in Figure 10 was created and simulated in Proteus software:

Timer Circuit:

Turning Mechanism: I decided to use IC NE555 in astable mode to switch the two PWM's in order to switch the speeds of the motors. The circuit is similar to PWM the only difference is that the high time is pretty high and low time is pretty low. The high time is equal to the time required by the vehicle to complete one circle (T seconds). Determined from SIMULINK Model. The low time is kept higher than the ON time in order to avoid swapping of the sources again. As it is required only once in order to take turn.

Stopping Mechanism: Another IC555 astable circuit is used in order to cut off the power supply to the circuit at the end of the round i.e. when the vehicle is about to complete the 2nd circle. The ON time for this circuit would be equal to the time required by the vehicle to complete 2 circles or complete round (* pattern) i.e. 2T seconds. The timer circuit shown in Figure 12 was simulated in Proteus software:

The equations governing the behavior of astable oscillator is as follows:

ON time= t1= 0.693(R1 + R2).C1

OFF time= t2= 0.693((R2).C1

Total Oscillator Time T= t1 + t2

Duty Cycle= t1/T

% Duty Cycle= Duty Cycle X 100

The following iterations were performed to approximate the values of R1, R2 and C in order to achieve the desired timings so that the vehicles would follow an 8 pattern path and come to a stop at the end.

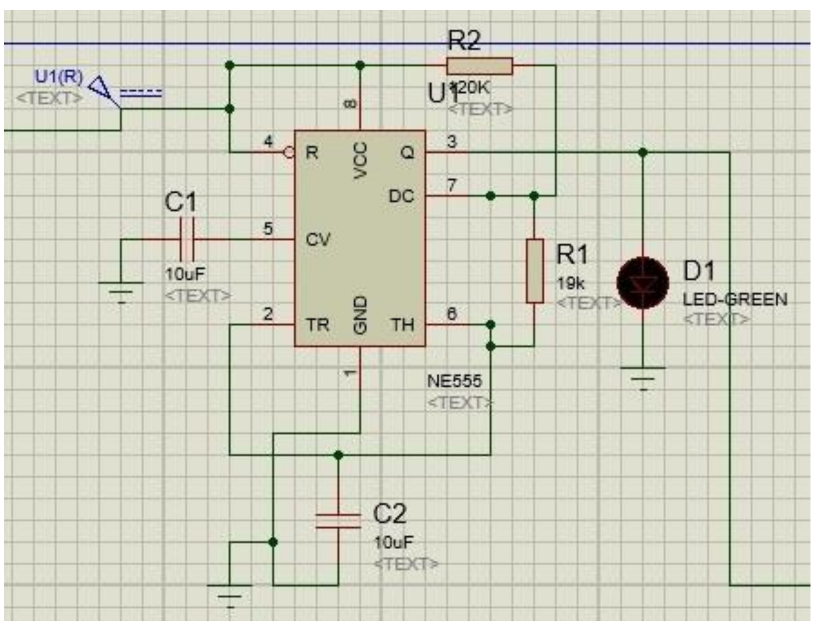

Figure 12 IC 555 as Astable oscillator

Capacitance	Resistance	Resistance	OFF Time	ON Time	Time	Duty Cycle	Frequency
C	R1	R2	TL	TH	T	D	F
uF	Kohm	Kohm	Sec	Sec	Sec	%	Hz
1000	10	50	34.65	41.58	76.78	54.1547278	0.01302423
1000	20	20	13.86	27.72	41.88	66.1891117	0.02387775
1000	3	8	5.544	7.623	13.262	57.4800181	0.07540341
1000	4	7	4.851	7.623	12.564	60.6733524	0.07959249
1000	5	6	4.158	7.623	11.866	64.2423732	0.0842744
1000	6	5	3.465	7.623	11.168	68.2575215	0.08954155
1000	7	4	2.772	7.623	10.47	72.8080229	0.09551098
1000	8	3	2.079	7.623	9.772	78.008596	0.1023332
1000	9	2	1.386	7.623	9.074	84.0092572	0.11020498
100	19	120	8.316	9.6327	18.0782	53.2835127	0.05531524
100	50	50	3.465	6.93	10.47	66.1891117	0.09551098
100	100	100	6.93	8.6625	15.705	55.1575931	0.06367399
100	21	122	8.4546	10.2564	18.846	54.4221585	0.05306166
100	22	123	8.5239	10.395	19.0554	54.5514657	0.05247856
100	23	124	8.5932	10.5336	19.2648	54.6779619	0.05190814
100	24	125	8.6625	8.665965	17.45349	49.6517602	0.05729513
100	25	126	8.7318	15.6618	24.5696	63.7446275	0.0407007
100	26	127	8.8011	8.8011	17.7292	49.6418338	0.05640412
100	27	128	8.8704	8.8704	17.8688	49.6418338	0.05596347
100	28	129	8.9397	8.9397	18.0084	49.6418338	0.05552964
100	0.05	120	8.316	8.316	16.752	49.6418338	0.05969436
1	100	100	0.0693	0.0693	0.1396	49.6418338	7.16332378

Selector Circuit:

I decided to use IC 74157 (Multiplexer) as an input selector. The output of the first timer circuit is connected to the selector pin of the IC 74157. The working of multiplexer is as shown in the Figure 13:

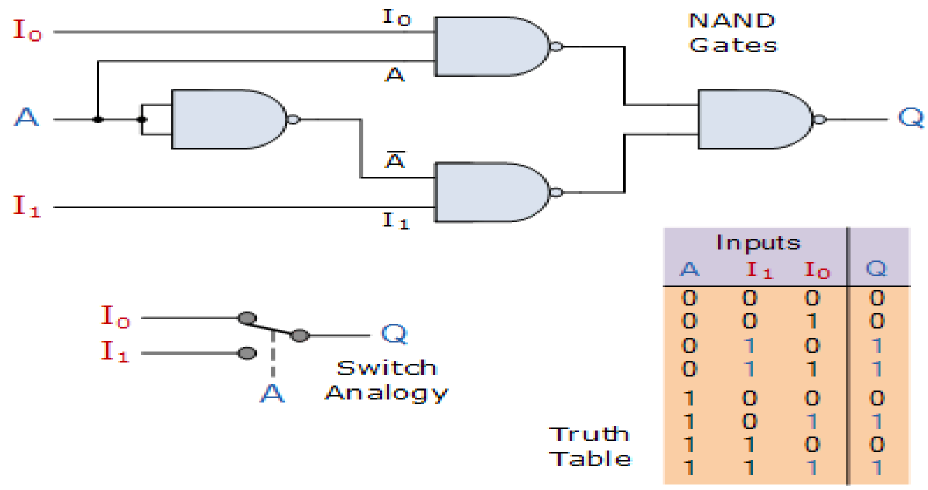

Figure 13 2:1 Mux Logic

I decided to make use of two 2:1 multiplexers as I need two outputs to run two motors at two different speeds. The following circuit was made and simulated in Proteus software.

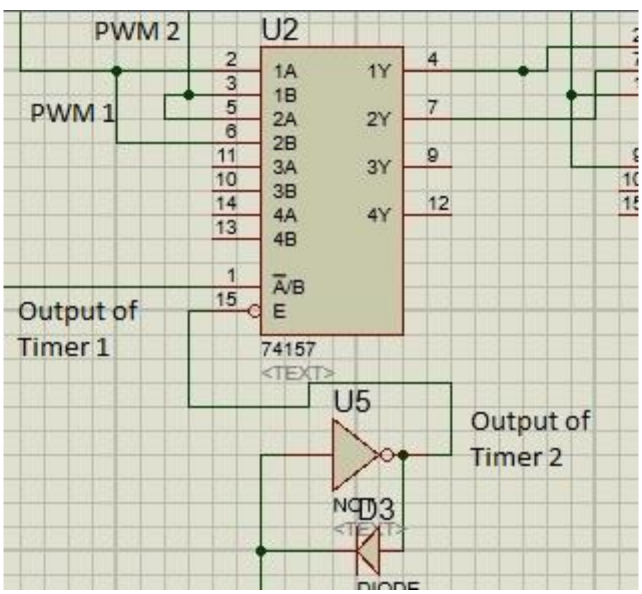

Figure 14 IC 74157 for switching the outputs and for stopping the motors

The output of timer 2 is given to the Enable pin of the IC (pin 15) via a NOT gate. The arrangement is made in such a way that when the output of that timer circuit is high pin 15 of the IC is grounded which causes the IC 74157 to function normally. When the output of timer 2 falls IC 74157 is disabled i.e. pin 15 is grounded through the diode disabling the IC 74157.

IC L293D is used to drive the DC motors as the output of IC74157 has low current. IC L293D amplifies the current which will be sufficient enough to drive the motors.

Actual Circuit:

The actual circuit was made and simulated on Proteus software is as follows:

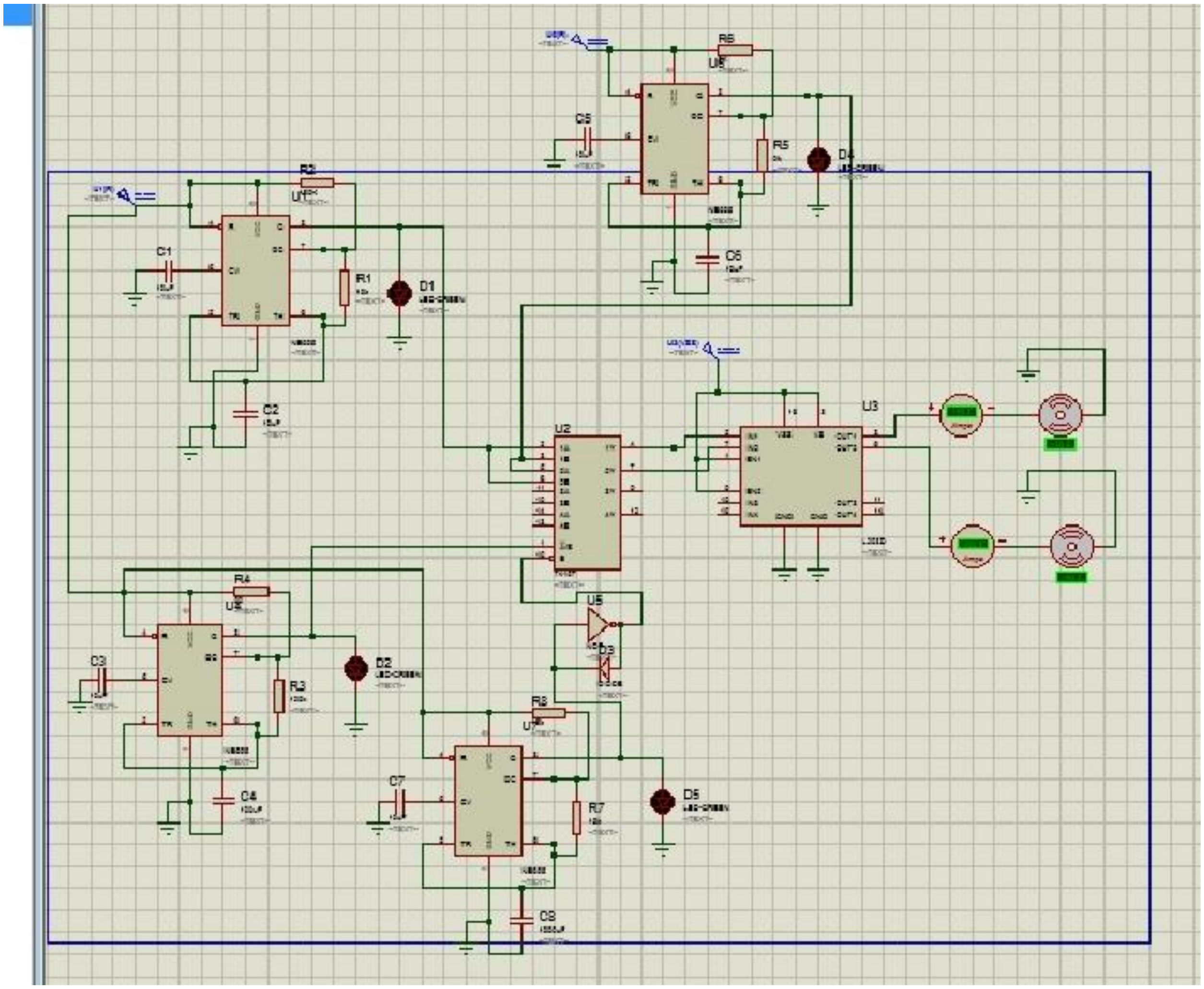

Figure 15 Actual Complete Circuit Diagram

The enlarged parts of the above circuit diagram are shown in Figure 16 and Figure 17:

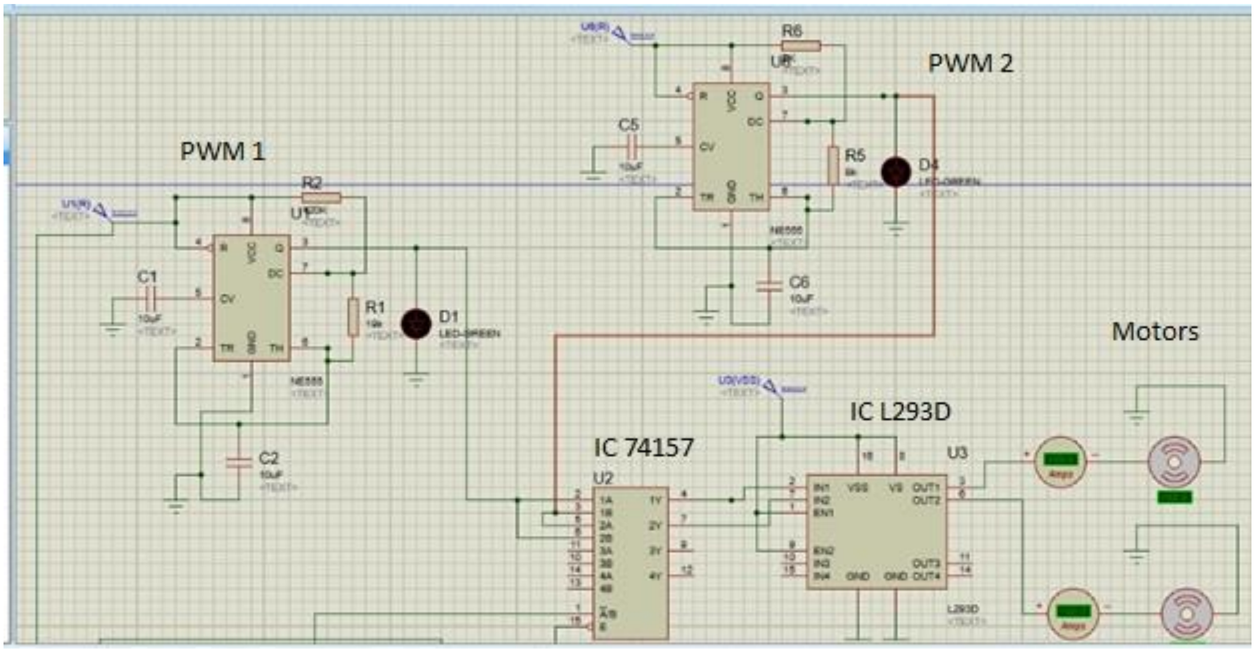

Figure 16 PWM 1 and 2, IC 74157, IC L293D and Motors

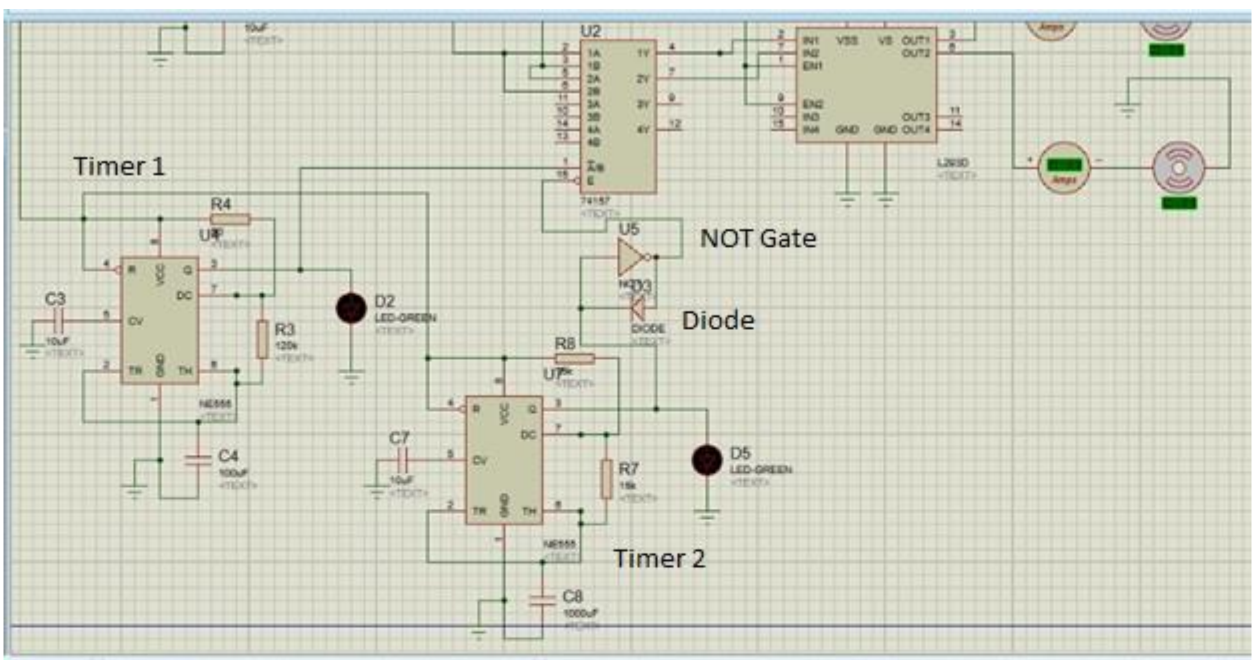

Figure 17 Timer 1 and 2

The following figure shows the outputs across various pins:

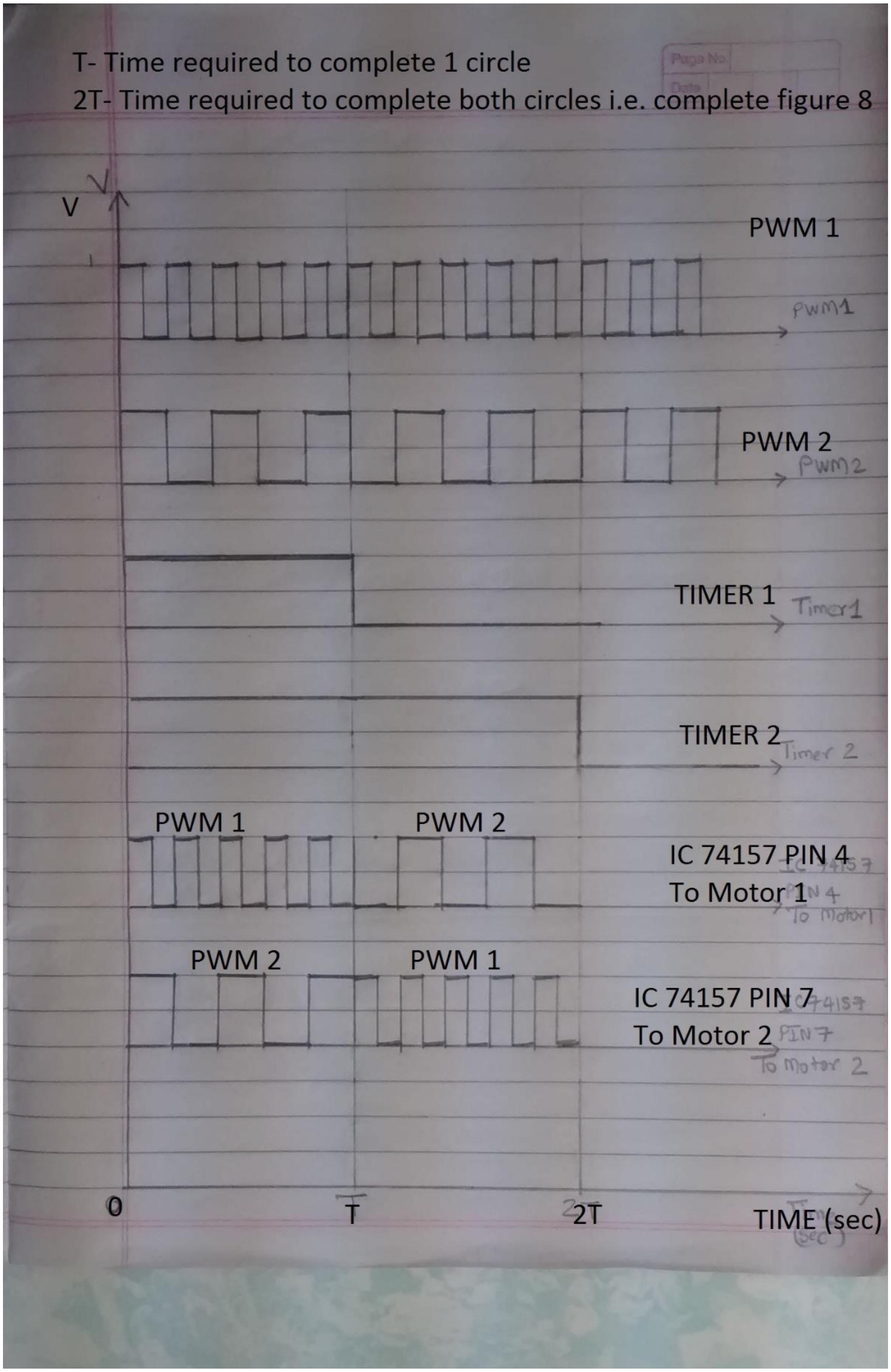

Figure 18 Outputs at various points.

The output of the SIMULINK model is:

For Nr=145rpm Nl=120rpm rw=0.035m t=0.1m

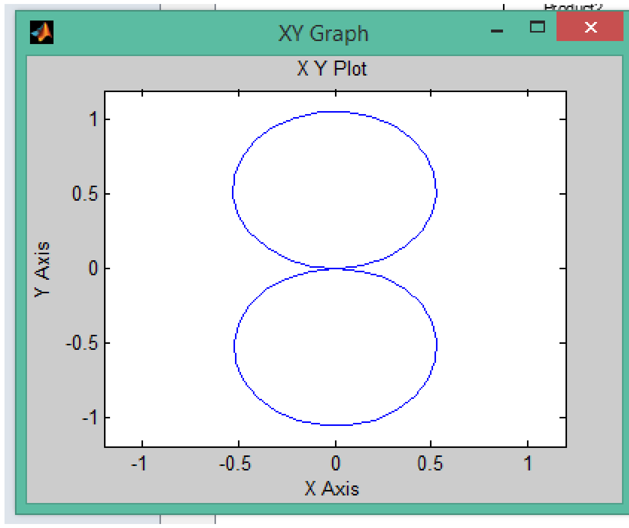

Figure 19 Path followed by vehicle (Output of SIMULINK)

Output of MATLAB Program is:

	Nr	Nl	t	rw	2T	R	Results
10	145	120	0.1	0.035	13.71	0.53	All Good

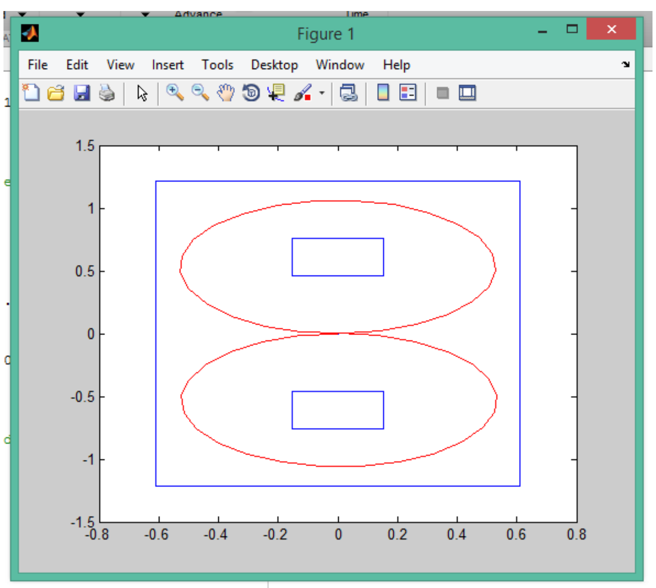

Figure 21 Path Followed by Vehicle (MATLAB output)

```
>> plotting
Inner wheel does not touch the block
Outer wheel does not fall off the plywood
The vehicle will not skid
```

Figure 20 MATLAB output

Feasibility Question:

Some of the feasibility questions are as follows:

- Will the vehicle follow the 8 pattern without using programmable electronic circuit?
  As seen in Figure 19 and Figure 21 we can see that the vehicle follows an 8 pattern path. Also, Figure 15, Figure 16 and Figure 17 shows that no programmable electronic circuit was used.
- Can the vehicle come to stop after completing the 8 pattern?
  As seen in Figure 18 we can see that the supplies to motor is cutoff after 2T seconds, i.e. after the vehicle has completed 8 pattern path. Hence the vehicle will come to stop.
- Will the vehicle fall off the plywood?
  From Figure 20 we can see that the vehicle will not skid or fall off the plywood considering idealistic scenarios.
- Will the vehicle touch the boxes?
  From Figure 20 we can see that the vehicle will not touch the boxes.
- Is it possible to run the motors at 145 and 120 rpm using just PWM circuit?
  By decreasing the duty cycle of the PWM we can control the speed of the motor and bring it down to 145 and 120 rpm. But if it's not possible then I can use a pair of standard gears in order to reduce the speed of rotation of the wheels.

The actual values of R1, R2 and C cannot be determined accurately at this stage as the SIMULINK model is too idealized. The SIMULINK model does not take into consideration the following effects:

- The mass of the vehicle and its front to rear distribution as it may cause the following effect:
  If the weight on rear wheels is high the vehicle may oversteer causing it take a circle of smaller radius and touch the blocks. If the front weight is high it may cause the vehicle to understeer causing it to take circle of bigger radius due to which the vehicle may fall off the plywood.
- If the CG is too high it may cause the vehicle to topple.
- Due to centrifugal force the inner wheel is going to lose weight and the outer wheel is going to gain weight. This will increase the load on the outer motor and the load on the inner motor will decrease. This will cause the inner wheel to rotate at higher speed and the outer one at higher speed. This will cause the vehicle to understeer and may cause the vehicle to fall off the plywood.
- The compliance and manufacturing defects in the system may cause the track width to be different than the actual desired value.
- Due to mass the system may not start and stop instantly, thus the actual path would deviate from the actual estimated path.
- Also due to inertia of the system it is not possible to stop the vehicle at the reference point exactly for that, timing of the timer circuit should be adjusted in such a way that the circuit dies off before the vehicle reaches the reference point. So that the vehicle will come to halt somewhat close to the reference point.

Due to all these factors it is difficult to determine the actual values of the Resistors, Capacitors, Wheel Radius, and Track width at this stage. All the above calculations are approximate. The actual values are close to these. Fine tuning and adjustments can be made once an actual model is made and tested on the actual tracks, testing will lead to the determination of actual values of these parameters.

Cost Analysis:

The cost analysis was done by taking into consideration that this device is going to manufactured in mass quantities. Hence assuming approximate charges for bulk quantities of the following components and parts I roughly estimated the cost of the device.

Sr. No.	Components	Qty.	Cost
1	Wheels	4	$8.00
2	4 9V Rechargeable Batteries + 1 Charger	1	$23.99
3	Diode 1N4007	1	$0.05
4	IC 7404 (NOT Gate)	1	$3.00
5	Breadboard Jumper wire	100	$3.00
6	PCB	1	$10.00
7	IC 555	4	$0.60
8	Soldering	NA	$0.70
9	IC 74157	1	$2.50
10	Capacitors	8	$0.20
11	Resistors	10	$0.10
12	Battery holder clips	2	$0.20
13	L293D	1	$1.50
14	3V DC Motors	2	$8.00
15	Lego parts and wood or foam	-	$10.00
	TOTAL		**$71.84**

Weight Analysis:

The weight of the device was roughly estimated by taking into consideration the mass of each component and roughly estimating the unknown weights. Thus the approximate weight of the device is going to be as follows:

Sr. No.	Components	Qty.	Weight (gm)
1	Wheels	4	50.00
2	9V Batteries	2	100.00
3	Diode 1N4007	1	0.30
4	IC 7404 (NOT Gate)	1	0.93
5	Breadboard Jumper wire	100	28.35
6	PCB	1	45.36
7	IC 555	4	2.36
8	Soldering	NA	1.00
9	IC 74157	1	0.70
10	Capacitors	8	10.00
11	Resistors	10	10.00
12	Battery holder clips	2	2.00
13	L293D	1	0.60
14	3V DC Motors	2	8.00
15	Body parts and Fasteners	-	200.00
	TOTAL		**459.60**