A NEW PROGRAM FOR PREDICTING OFF-ROAD VEHICLE MOBILITY

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1. INTRODUCTION

Simulation programs and computer models for predicting off road vehicles` mobility help researchers to determine the relative importance of many factors affecting field mobility of off road vehicles without conducting expensive, as well as time consuming, field tests. They also help designers and researchers to develop and improve the off road vehicles` mobility by comparing and analysing various parameters that influence their mobility. The development of new software and programming languages always facilitate the use of computers in many different areas.

Actually, many conducted vehicles` mobility researches based on developing empirical equations exist. These equations can be adapted and used in the process of design and implementation of simulation programs both service educational and research needs in terra mechanics area.

The first steps in developing a method for off road vehicles` performance evaluation include tires` testing on natural terrain surfaces to develop linked vehicles` performance - terrain conditions. The analytical approach is concerned with predicting the performance of a traction device in terrain; in this regard, the distribution of normal and shear stress at the soil-tire/track interface and the geometry of the 3-D contact surface must be firstly determined. There are two other approaches; empirical and semi-empirical. The empirical approach is based on cone index results for predicting the off-road vehicles` mobility by using dimensionless tire performance coefficients; this is the main task of the present paper. The semi-empirical approach is usually involved in measuring soil deformation parameters, then calculating the soil shear-stress and deformation under a traction device that is assumed to be similar to generated shear by a torsion shear device. Bekker [1-2] assumed the normal stress under a flat plate depends on sinkage, plate width and soil coefficient.

Freitag [3] developed the first dimensionless wheel numeric and empirical mobility models based on wheel numeric. The wheel performance was measured at different weights on standard soils using soil bin and test lanes on terrain. Turnage [4-7] developed the method further, and presented separate mobility models dependent on soil properties for friction and cohesion soils. For cohesion soil the author used an average cone index, and a cone index gradient for the friction soils. Wismer & Luth [8] combined mobility models with soil shear model and included the slip into mobility models. This model became one kind of basic mobility model for several later researches. Gee-Glough [9-10] found out, that soil shear strength was somewhat correlated with penetration resistance, and added a soil shear factor into the model. Brixius [11-12] developed a more generalized expression for tractive characteristics of bias-ply pneumatic tires. The approach is based on a modified mobility number. Maclaurin [13-16] studied the influence of soil surface properties and tire patterns on wheel performance using WES-method as a frame of reference. Rowland [17],

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Rowland and Peel [18], developed WES modelling depending on a new wheel numeric, and extended it also for tracked vehicles. The author presented the concept of mean maximum pressure MMP, which is the maximum allowable calculated soil contact pressure at a no-go situation. Several authors in different countries have used available models, or presented improved versions of empirical mobility models using penetrometer resistance as soil parameter.

The mobility of a vehicle is influenced by a lot of parameters which make the evaluation process complicated. Including more parameters in the evaluation process will probably give more accurate results, but it is not definitely true. However, accurate results will be expected if the included parameters are thoroughly analyzed and well assessed. The total vehicle mobility is influenced by many factors, as shown in the chart shown in Fig.1 [19].

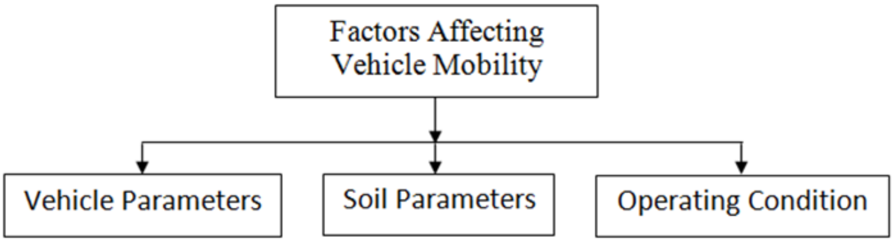

Figure 1 General scheme of factors affecting vehicle mobility [19]

The methods used to quantify off-road vehicles` mobility depend - to a large extent- on the purpose for which the vehicle is used; for military vehicles, the ability to traverse particular terrains and the speed with which this can be achieved are the most important aspects of performance while, for agricultural vehicles, the efficiency with which a task can be completed or the impact of the operation on the terrain may be of greater significance. The shift in emphasis between vehicle and terrain characteristics is often reflected in the terminology used: traffic-ability, for example, is defined as “the ability of a section of terrain to support mobility”, whereas mobility describes the efficiency with which a given vehicle can travel from one point to another across a given section of terrain [20]. Figure 2 presents an overview of the research interest, and illustrates the primary components of any predictive mobility modelling tool [20].

The aim of the paper was to develop a generalizing mobility program in Visual Basic.net 2008 as a new technique to that could be used to predict key measures of mobility such as wheel numeric, motion resistance ratio, torque ratio, net traction ratio and tractive efficiency, which can be used to represent off-road vehicles of varying parameters affected by different terrain (soil parameters).

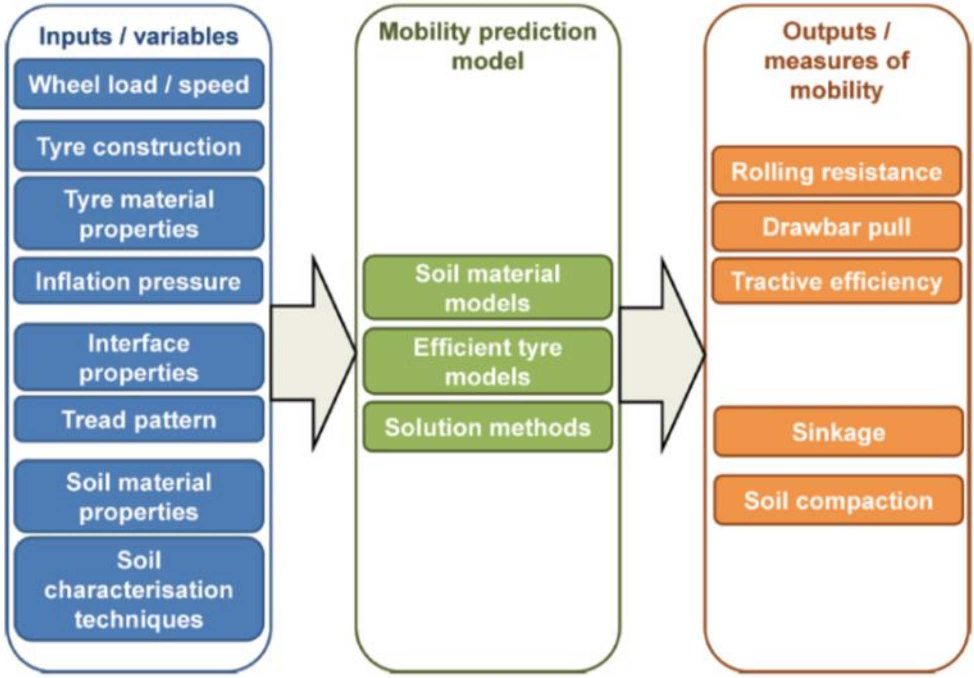

Figure 2 Overview of research interest [20]

2. OFF-ROAD VEHICLE MOBILITY EQUATIONS

The equations used to predict off-road mobility are numerous and depend on many parameters related to both vehicles and the terrains. In the following the mobility prediction equations have been used in developing the computer program.

2.1 Wheel numeric

The wheel numeric is a dimensionless variable calculated using a special formula, which includes tire and soil parameters. Different authors have proposed different empirical wheel numeric models for determining the best fitting combinations of tire dimensions and deflection with observed tire performance. The wheel numeric is defined in the Table 1 with different methods.

Table 1 Wheel numeric equations proposed by different researchers

No.	Method	Equation	
1	Wismer & Luth [8]	$C_n = \frac{CI\ b\ d}{W}$	(1)
2	Freitage [3]	$N_C = \frac{CI\ b\ d}{W}\sqrt{\frac{\delta}{h}}$ for clay, and $N_S = \frac{G\ (b.d)^{3/2}}{W}.\frac{\delta}{h}$ for sand	(2)
3	Turnage [4-7]	$N_{CI} = \frac{CI\ b\ d}{W}\sqrt{\frac{\delta}{h}}.\frac{1}{1+\frac{b}{2.d}}$	(3)
4	Brixius [11-12]	$B_n = \frac{CI\ b\ d}{W}\left(\frac{1+\frac{5\delta}{h}}{1+\frac{3b}{d}}\right)$	(4)
5	Rowland & Peel [18]	$N_R = \frac{CI\ .b^{0.85}\ .d^{1.15}}{W}\sqrt{\frac{\delta}{h}}$	(5)
6	Maclaurin [13-16]	$N_m = \frac{CI\ .b^{0.8}\ d^{0.8}\ \delta^{0.4}}{W}$	(6)

2.2 Motion resistance ratio, (μmrr)

The general equation of the motion resistance ratio is written as:

$$\mu_{mrr} = \frac{RR}{W} \tag{7}$$

The motion resistance ratio is a dimensionless variable calculated by using wheel numeric formulas proposed by various researchers, this is shown in Table 2.

Table 2 Motion resistance ratio equations proposed by various researchers

No.	Method	Equation	
1	Wismer & Luth [8]	$\mu_{mrr(Wismer\ \&\ Luth)} = \frac{1.2}{C_n} + 0.04$	(8)
2	Freitage [3]	$\mu_{mrr(Freitage)} = \frac{1.2}{N_s} + 0.04$	(9)
3	Turnage [4-7]	$\mu_{mrr(Turnage)} = 0.04 + \frac{0.2}{N_{CI} - 2.5}$	(10)
4	Brixius [11-12]	$\mu_{mrr(Brixius)} = \frac{1}{B_n} + \frac{0.5\ s}{\sqrt{B_n}} + 0.04$	(11)
5	Rowland & Peel [18]	$\mu_{mrr(Rowland\ \&\ Peel)} = 3\ (1+S)\ N_R^{-2.7}$	(12)
6	Maclaurin [13-16]	$\mu_{mrr(Maclaurin)} = 0.017 + \frac{0.435}{N_{CI}}$	(13)

7	Ashmore [21]	$\mu_{mrr(Ashmore)} = -0.1(\frac{W}{W_r}) + \frac{0.22}{C_n} + 0.2$	(14)
8	Gee-Glough [9-10]	$\mu_{mrr(Gee-Glough)} = 0.049 + \frac{0.287}{N_{CI}}$	(15)
9	Dwyer [22-23]	$\mu_{mrr(Dwyer)} = 0.05 + \frac{0.287}{N_{CI}}$	(16)

The third mechanism, based on both geometry and the effect of local deformities, is the transformation of sharp, singular edges of the observed unevenness into smooth segments of the enveloping curve.

2.3 Torque ratio, (μtr)

The general equation of the torque ratio is written as:

$$\mu_{tr} = \frac{T}{r * W} \tag{17}$$

The torque ratio is a dimensionless variable calculated using wheel numeric formulas proposed by various researchers, this shown in Table 3.

Table 3 Torque ratio equations

No.	Method	Equation	
1	Wismer & Luth [8]	$\mu_{tr(Wismer\ \&\ Luth)} = 0.75\ (1 - e^{-0.3C_n s})$	(18)
2	Freitage [3]	$\mu_{tr(Freitage)} = 0.75\ (1 - e^{-0.3N_s s})$	(19)
4	Brixius [11-12]	$\mu_{tr(Brixius)} = 0.88\ (1 - e^{-0.1B_n})(1 - e^{-0.75s}) + 0.04$	(20)
7	Ashmore [21]	$\mu_{tr(Ashmore)} = 0.47\ (1 - e^{-0.2C_n s}) + 0.28(\frac{W}{W_r})$	(21)
9	Dwyer [22-23]	$\mu_{tr(Dwyer)} = 0.796 - \frac{0.92}{N_{CI}}$	(22)

2.4 Net traction ratio, (μntr)

The general equation of the net traction ratio is written as:

$$\mu_{ntr} = \frac{NT}{W} = \mu_{tr} - \mu_{mrr} \quad (23)$$

The various net traction ratios are given in Table 4.

Table 4 Equations for traction ratio

No.	Method	Equation	
1	Wismer & Luth [8]	$\mu_{ntr(Wismer\ \&\ Luth)} = \mu_{tr(Wismer\ \&\ Luth)} - \mu_{mrr(Wismer\ \&\ Luth)}$	(24)
2	Freitage [3]	$\mu_{ntr(Freitage)} = \mu_{tr(Freitage)} - \mu_{mrr(Freitage)}$	(25)
4	Brixius [11-12]	$\mu_{ntr(Brixius)} = \mu_{tr(Brixius)} - \mu_{mrr(Brixius)}$	(26)
5	Rowland & Peel [18]	$\mu_{ntr(Rowland\ \&\ Peel)} = 0.12\ N_R^{0.88}(1 - 0.61(1 - S)^4)$	(27)
6	Maclaurin [13-16]	$\mu_{ntr(Maclaurin)} = 0.817 - \frac{3.2}{N_{CI} + 1.91} + \frac{0.453}{N_{CI}}$	(28)
7	Ashmore [21]	$\mu_{ntr(Ashmore)} = \mu_{tr(Ashmore)} - \mu_{mrr(Ashmore)}$	(29)
8	Gee-Glough [9-10]	$\mu_{ntr(Gee-Glough)} = \mu_{ntr_{max}}\ (1 - e^{-k\,s})$	(30)
9	Dwyer [22-23]	$\mu_{ntr(Dwyer)} = \left(0.796 - \frac{0.92}{N_{CI}}\right).(1 - e^{-(4.838+0.061.N_{CI}).S})$ at 20% wheel slip	(31)

2.5 Tractive efficiency, (TE)

The general equation of the traction efficiency is written as:

$$TE = \left[\frac{\frac{NT}{W}}{\frac{T}{r.W}}\right](1 - s) = \frac{\mu_{ntr}}{\mu_{tr}}(1 - s) \quad (32)$$

Table 5 shows the equations for traction efficiency ratio.

Table 5 Tractive efficiency equations

No.	Method	Equation	
1	Wismer & Luth [8]	$TE_{(Wismer\,\&\,Luth)} = \frac{\mu_{ntr(Wismer\,\&\,Luth)}}{\mu_{tr(Wismer\,\&\,Luth)}}(1-s)$	(33)
2	Freitage [3]	$TE_{(Freitage)} = \frac{\mu_{ntr(Freitage)}}{\mu_{tr(Freitage)}}(1-s)$	(34)
4	Brixius [11-12]	$TE_{(Brixius)} = \frac{\mu_{ntr(Brixius)}}{\mu_{tr(Brixius)}}(1-s)$	(35)
7	Ashmore [21]	$TE_{(Ashmore)} = \frac{\mu_{ntr(Ashmore)}}{\mu_{tr(Ashmore)}}(1-s)$	(36)
8	Gee-Glough [9-10]	$TE_{(Gee-Glough)} = \frac{\mu_{ntr(Gee-Glough)}}{\mu_{tr(Gee-Glough)}}(1-s)$	(37)
9	Dwyer [22-23]	$TE_{(Dwyer)} = \frac{\mu_{ntr(Dwyer)}}{\mu_{tr(Dwyer)}}(1-s)$	(38)

3. OFF-ROAD VEHICLES` MOBILITY PREDICTION PROGRAM

A mobility software program has been fully created using Microsoft Visual Basic.net 2008. This is designed to calculate and plot the following; the wheel numeric, the motion resistance ratio, the torque ratio, the net traction ratio, and the traction efficiency.

Mobility contains several forms to calculate and plot the above mentioned equations every form contains easy ways to enter values of the equation. Then the mobility parameter is plotting chart of the equation using Microsoft .NET framework 3.5.1 and MSChart. It can compare the charts for each change of the values and use all functions of Microsoft Visual Basic.net 2008 (in the program) to modify the chart such as (chart name, Chart axis, etc.)

The MSChart control allows plotting data in charts according to any specifications. It can create a chart by setting data in the controls` properties page, or by retrieving data to be plotted from another source, such as a Microsoft Excel spread sheet. The information in this topic focuses on using an Excel worksheet as a data source. Figure 3 illustrates the relationship between the three programs and the role of each.

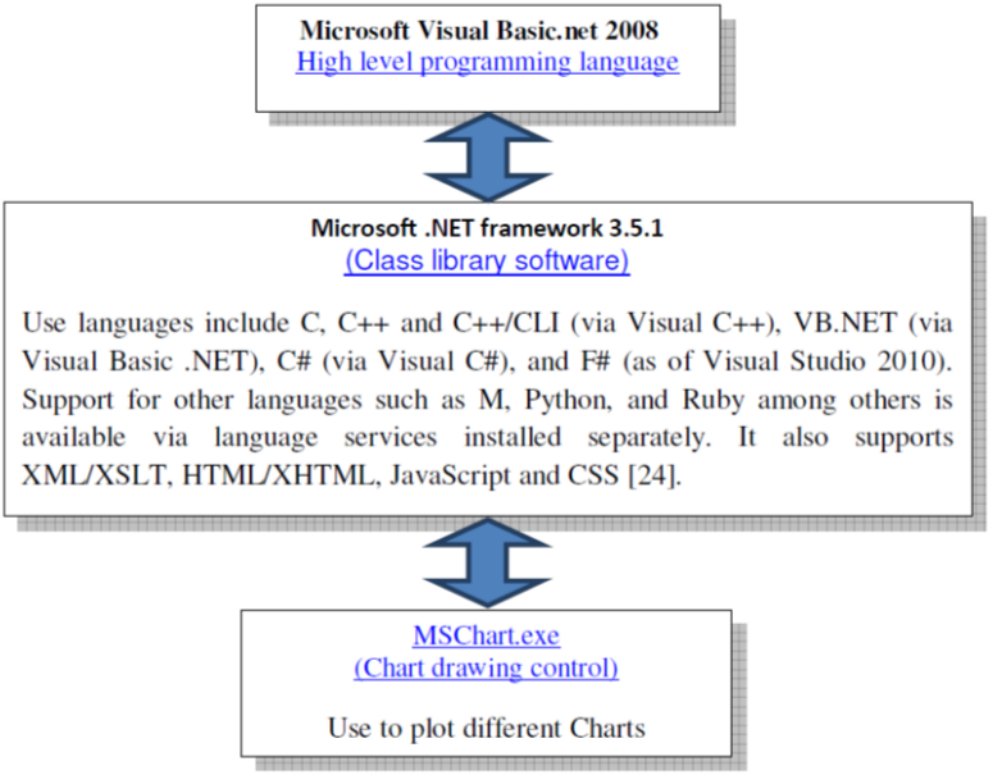

Figure 3 Relationship between the three programs and the role of each

The mobility program starts with an opening screen as shown in Fig. 4. The program mainly consists of two main sections, constant parameters and calculations menu as shown in Fig. 5. Each section has a number of subsections based on the design criteria for the program development. In the first section all constant parameters should be inserted. In the second section selection of calculation methods has to be done and plotting graphs with entering the variable parameters such as weight on tire, tire section width, overall tire diameter, tire section height, cone index and cone index gradient. The screen consists of five tabs (wheel numeric, motion resistance ratio, torque ratio, net traction ratio and traction efficiency), this helps in evaluating and comparing vehicles` mobility by using different methods as previously mentioned. The flow diagram of the program simulation part is shown in Fig. 6.

Figure 4 The opening screen of the mobility program

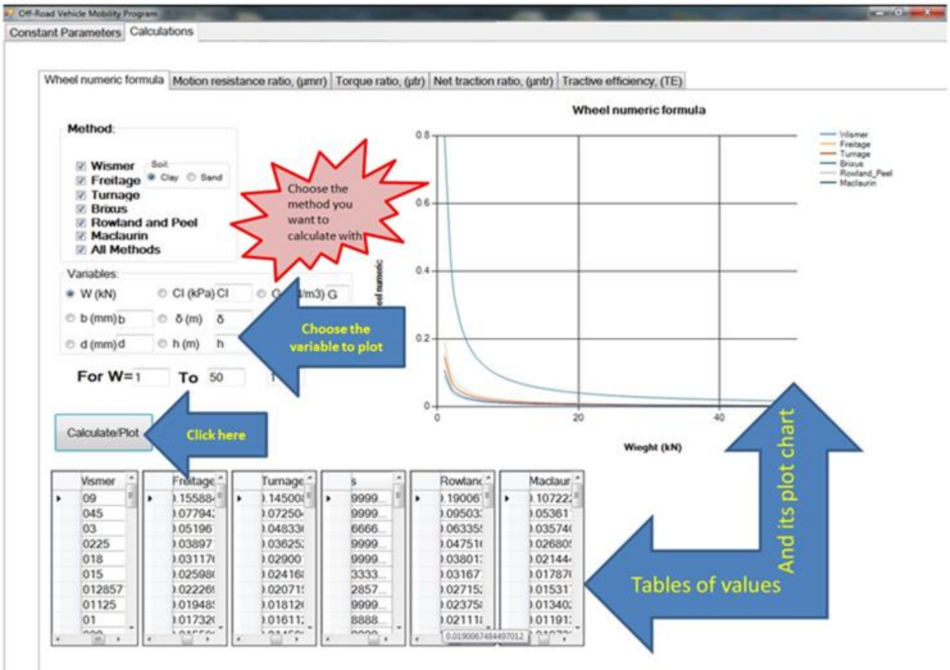

Figure 5 The calculation methods and plotting the relationships in the chart screen

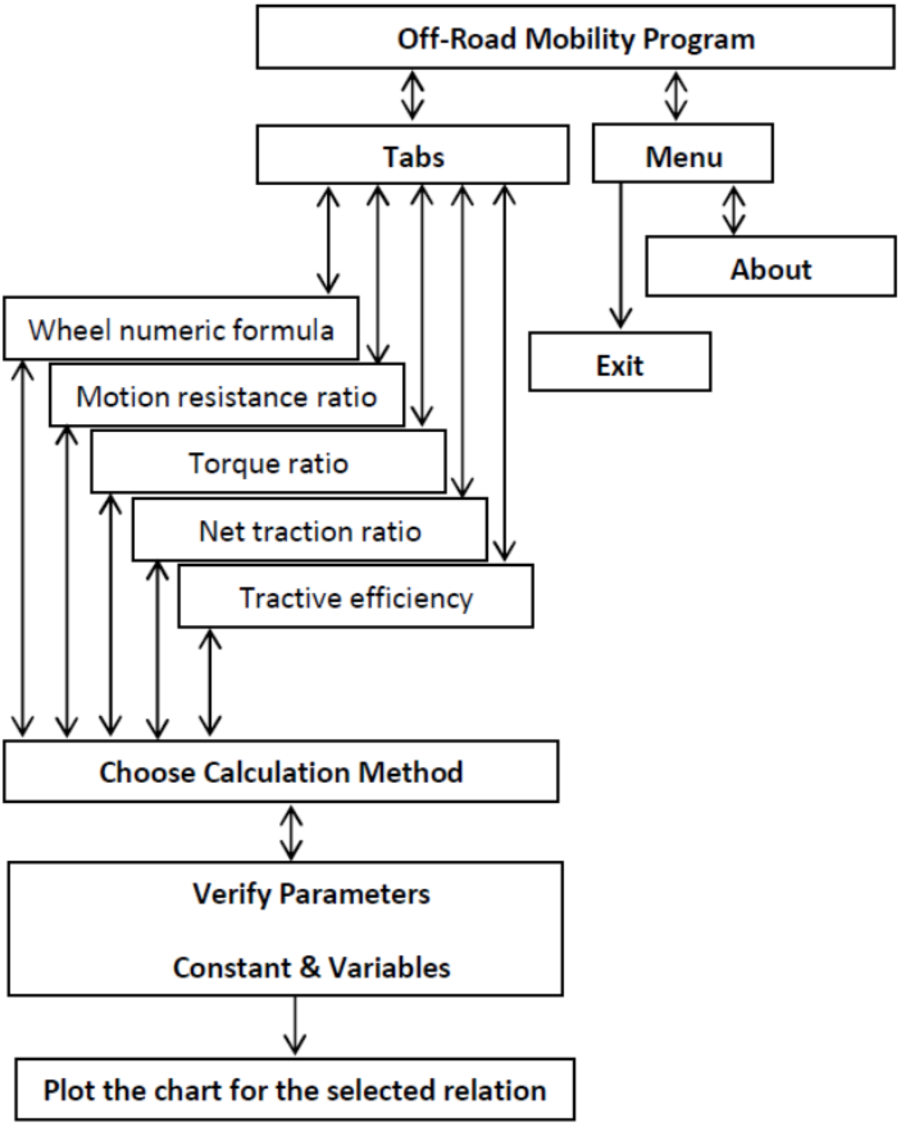

Figure 6 Flow diagram of Off-Road Mobility Program

The prediction equations of Wismer & Luth [8], Freitage [3], Turnage [4-7], Brixius [11-12], Rowland & Peel 18], Maclaurin [13-16], Ashmore [21], Gee-Glough [9-10], and Dwyer [22-23] were used in the computer model development for predicting the off-road vehicles` mobility. To validate the model, predicted mobility variables were compared against results, same numerical values were obtained for mobility variables. Samples of results from the program of the various parameters of predicting vehicles` mobility are shown in Figures 7 and 8.

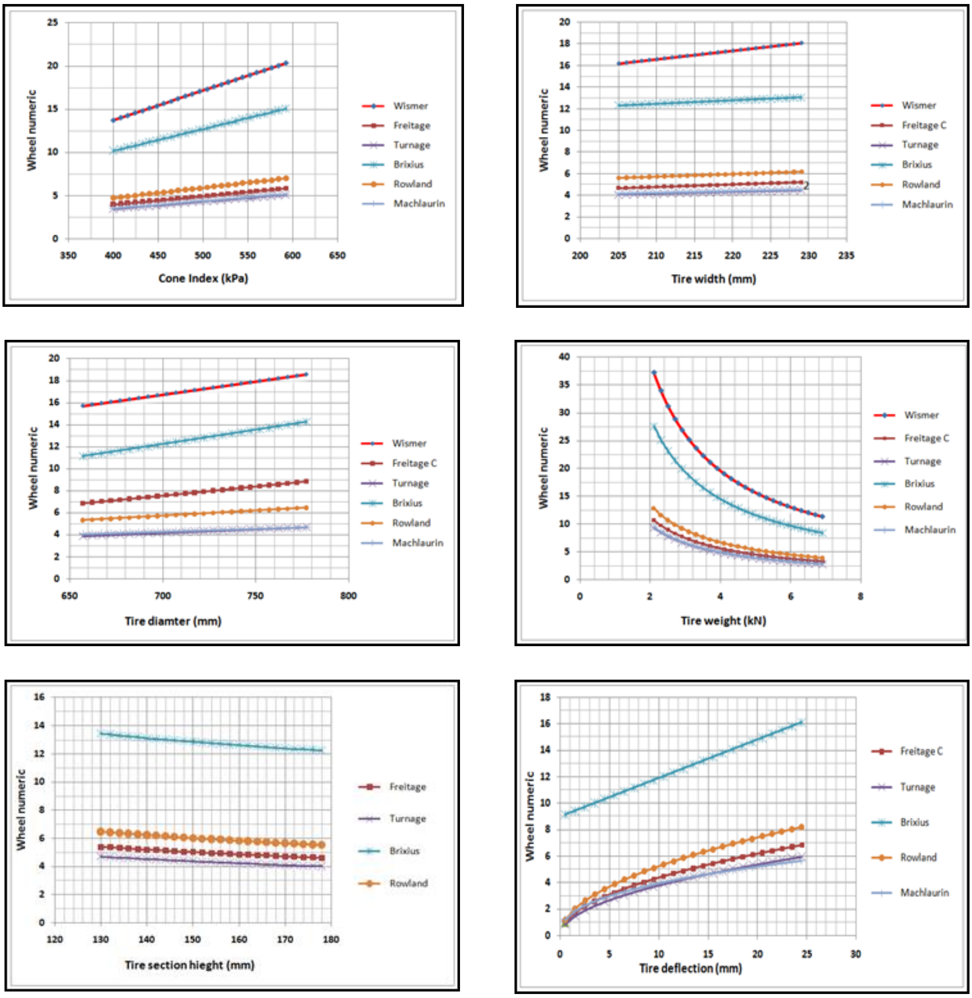

Figure 7 Variation of wheel numeric with soil cone index, tire width, tire diameter, tire weight, tire section height and tire deflection

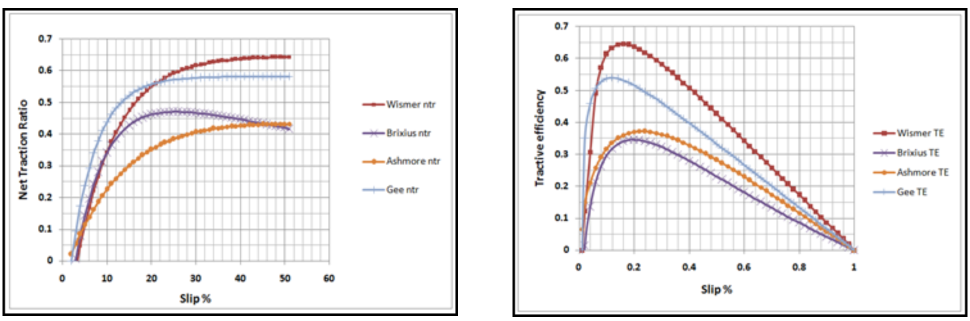

Figure 8 Variation of net traction ratio and traction efficiency with slip

4. CONCLUSION

A Microsoft Visual Basic.net 2008 programming for predicting off-road vehicles` mobility has been created; this program can be used for educational and research purposes. The program uses some empirical equations proposed by various researchers in the terrain-vehicle system area. The items in menus and object driven windows were vital in making the program relatively easy to learn and operate compared to the programs developed using any software tool available prior to the visual programming tools. The intuitive user interface to the model is a visual object-oriented window, which allows the selection of the off-road vehicle mobility parameters, the prediction method, the vehicles` specifications, the terrains` parameters, and the simulation. It can also access other windows to edit or expand available databases. These features provided by the facilities of visual programming make the program sufficiently flexible and interactive to the users in both research and education in terra mechanics area. The program has been proven to be easily using, simple, and efficient.

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