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Simulation Program for Predicting Tractor Field Performance

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Abstract: Researchers working in all areas of farm machinery have a need for gathering information relating to the performance of tractors in the field. As field study of factors affecting tractor field performance is so expensive and time consuming, computer models and simulation programs help agricultural engineers to determine the effects of relative parameters. Also in agricultural machinery or mechanization curricula students take limited courses about tractors, such as mechanics of tractor, tractor field performance, tractor-implement systems, tillage operation, field works, etc. In order to study tractor field performance, tire performance, soil conditions and implement type, simulation programs and computer models help educators to illustrate related problems. Also simulation software help students to better understand the performance aspects of tractors in the field from the pure science aspects of the subject matter. Indeed simulation software program provides a quick and relatively inexpensive method to evaluate tractor performance. This paper presents a user friendly and flexible computer program that can be used for predicting tractors field performance. This program was written in Visual Basic programming language and developed for predicting tractors performance on agricultural soils. Visual Basic was considered an excellent programming language for developing Graphical User Interfaces (GUI). The interface was designed with Visual Basic 6.0 and can be used to predict the performance as well the tractor's specific volumetric fuel consumption for agricultural soils using either bias-ply or radial-ply tractor tires. The tractor performance prediction program mainly consists of three sections, Menu, Run and Select options. Each section has a number of subsections based on the design criteria for the program development. Provision for changing model parameters, adding new model, saving data using Excel's spreadsheet and printing the results are provided. Relative magnitudes of the many factors affecting field performance of a tractor can, therefore, be determined using computer modeling or simulation without conducting expensive field tests. This software would also help manufacturers, designers and tractor operators to improve tractor performance by analyzing the many factors involved.

Key words: Tractor . prediction . field performance . interface design . visual basic

INTRODUCTION

Decreasing in fuel resources and consequently increasing in fuel prices persuade agricultural engineers the efficient use of energy in agricultural production systems. Agricultural tractors consume about 20 percentage of total energy, required for a farm. Therefore optimizing performance of agricultural tractors could bring energy losses down.

Engineeres working in all areas of farm machinery and mechanization have a need for gathering information relating to the performance of tractors in the field. As field study of factors affecting tractor field performance is so expensive and time consuming, computer models and simulation programs help agricultural engineers to determine the effects of relative parameters.

These days the use of computer models and simulation programs is proven effective tool in education, especially technical education. Computer models and simulation programs would help researchers to determine the relative importance of many factors affecting field performance of tractors without conducting expensive, as well as time consuming, field tests. They also can help manufacturers to improve the tractor performance by

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comparing and analyzing various parameters that influence tractor performance. Simulation software also helps students to better understand the performance aspects of tractors in the field from the pure science aspects of the subject matter. Further more, by presenting the course material in a visual and an attractive manner enhances student's understanding of the course material, holds student's attention and encourages their involvement. The rapid progress in developing new software and the trend in enhancing the existing application software and programming languages always tend to facilitate the interaction between users and computers. As a result, many simulation programs have been developed.

In agricultural machinery or mechanization curricula students take limited courses about tractors, such as mechanics of tractor, tractor field performance, tractor-implement systems, tillage operation, field works, etc. In order to study tractor field performance, tire performance, soil conditions and implement type are to be considered. As a result, a lot of empirical formulae as well as charts are involved [1-3]. These sorts of problems are traditionally skill based rather than theory based. As a result educators have to illustrate problems keeping the hands-on approach in mind.

Considerable research has been conducted in developing computer-based models and simulation programs to service the educational and research needs in the farm machinery area of agricultural engineering and mechanization [4-8]. Lotus-compatible templates for predicting tractor performance and ballast requirements for operation on soils were developed by Zoz [4] based upon the traction prediction equations of Brixius [2]. Grisso *et al.* [5] demonstrated the template flexibility and educational potential by comparing bias-ply versus radial tires, dual versus single tires and the influence of travel speed, tire size, ballast distribution, soil condition using 2WD and 4WD tractors. The Zoz spreadsheets [4] for predicting tractor performance were further expanded to account for radial tires in [6]. In [7] an existing PC-based haulage vehicle simulator, known as SimTrans, was adapted and evaluated for predicting the performance of agricultural tractors on hard surfaces, assuming no wheel slip. The SimTrans was able to predict fuel flow accurately under steady state conditions, but under unsteady conditions, the fuel flowmeter was not precise enough [7]. More recently, a computer-based model and simulation program for predicting 2WD and 4WD/MFWD tractors performance on agricultural soil was developed in a C++ programming environment [8].

The objective of this research was to develop a tractor performance program in Visual Basic as a new method to predict performance of tractors for both bias-ply and radial tires. The program can predict the performance parameters as well as fuel consumption of a given tractor by accessing databases concerning tractors specifications, tire information, soil condition and traction equation coefficients. Also this program shows students how to design an application program relevant to their future carrier. The program has been evolved during a course on Computer Programming given to the undergraduate students of agricultural machinery in the faculty of agriculture, university of Tehran. With some improvements, the developed simulator can be used in other courses in future. For example, it can be adapted as a new method to predict tractor field performance and fuel consumption. Therefore, the program should provide an intuitive Graphical User Interface (GUI) by linking databases concerning tractor specification, tire information, soil conditions and traction equation coefficients. Throughout this paper SI units are used and whenever possible, American Society of Agricultural Engineers (ASAE) standards have been followed.

MATERIALS AND METHODS

Traction prediction equations: Tractor performance is influenced by tire parameters, soil condition, implement type and tractor configuration [2]. Upadhyaya and Wulfsohn [3] conducted a thorough review of traction prediction equations. They categorized the relationships according to the way the equations were developed, namely, into three groups: (1) analytical methods, (2) semi-empirical, parametric or analog methods and (3) empirical methods. The primary focus of this study is utilizing the empirical approach. More specifically, the traction prediction equations of Brixius [2] have been used in the development of the computer program for predicting tractor performance. It should be noted that any of these relationships could be used to develop a computer application for predicting tractor performance.

In this research, the following traction equations are considered and it will be shown that the program developed in Visual Basic programming language becomes rather easy for the user to predict the performance of a selected tractor and model. The model used a general form of the Brixius [2] equations where the Gross Traction Ratio (GTR), Motion Resistance Ratio (MRR) and Net Traction Ratio (NTR) are expressed as:

$$\mathrm{GTR} = \mathrm{MRR} + \mathrm{NTR} = \frac{T/r}{W} \quad (1)$$

Where,

Table 1: Recommended traction equation coefficients

Traction coefficient	A1	A2	A3	A4	A5	A6	A7
Bias-ply tires [2]	0.88	0.1	7.5	0.04	5	3	1
Radials tires [6]	0.88	0.1	9.5	0.032	5	3	0.9
Belt tracks [8]	1.20	0.025	17	0.03	5	6	1.75

T = Input tire torque (kN.m)
r = Rolling radius (m)
W = Dynamic wheel on load (kN)

Brixius expressed GTR and MRR as a function of mobility number (Bn) and wheel slip (s). He determined the dimensionless numbers in the equations using a curve-fitting technique.

$$GTR = A_1 \times \left(1 - e^{-A_2 B_n}\right) \times \left(1 - e^{-A_3 s}\right) + A_4 \quad (2)$$

$$MRR = \frac{A_7}{B_n} + A_4 + \frac{0.5s}{\sqrt{B_n}} \quad (3)$$

$$NTR = \frac{P}{W} = GTR - MRR \quad (4)$$

Where

$$B_n = W_n \left(\frac{1 + A_5 (\delta / h)}{1 + A_6 (b/d)} \right) \quad (5)$$

The mobility number, Bn, combines the wheel numeric, W_n = CI bd/W, the deflection ratio (δ/*h)* and the section width-to diameter ratio *(b/d)*. In the expression for slip, *Pax* is axle power and *Vt* (*rω*) is wheel speed at no-load. The NTR in Equation (4) is a force in direction of travel developed by the traction device and transferred to the vehicle. It includes the force produced at the drawbar and the motion resistance of any unpowered wheels. Thus, *P = NT − MRU,* where *P* is the drawbar pull and *MRU* is motion resistance of unpowered wheels, calculated from equation (3) by setting the slip dependent term equal to zero. Dynamic wheel load, W, can be calculated in terms of P, static load and dynamic weight transfer. Finally, the Tractive Efficiency (TE) of a driving tire is defined as:

$$TE = \frac{NT \times V_a}{T \times \omega} = \frac{NT \times V_a}{T \times (V_t / r)} = \frac{NT}{GT}(1 - s) \quad (6)$$

Where,
T = Input tire torque (kN.m)
ω = Angular velocity (rad s^{-1})
r = Rolling radius (m)
V_a = Travel speed (m s^{-1})

The equations for bias-ply tires have been approved by the Power & Machinery Division ASAE Standards Committee [10].

Equations 1-6 include seven coefficients (Ai, i =1, 2,…,7) based on tires type. Numerical values of these coefficients can be different for different tractive devices. Al-Hamad *et al.* [6] modified Brixius equations [2] by coming up with a new set of coefficients for radial tires [6]. The coefficient values are listed in Table 1 for bias-ply and radial tires and belt-tracks [8].

The fuel consumption estimates used in cropping and machinery budgets are based on the average annual fuel consumption, Qave[L/h] from Agricultural Machinery Management engineering practice (ASAE Standards 2002). Fuel consumption is also measured by the amount of fuel used during a specific time period. A measure of the energy efficiency of a tractor is the Specific Volumetric Fuel Consumption (SVFC), which is given in units of L/kW.h. SVFC is generally not affected by the engine size and can be used to compare energy efficiencies of tractors having different sizes and under different operating conditions. Equations (7) and (8) estimate Qave and SVFC above 20% load for Diesel type of fuel:

$$Q_{ave} = 0.223 P_{pto} \ (L/h) \quad (7)$$

$$SVFC = 3.91 + 2.64 - 0.203\sqrt{738X + 173} \,(L/kW.h) \quad (8)$$

Where,
P_{pto} = The maximum PTO power of tractor (kW)
X = The ratio of equivalent PTO power required by an operation to Ppto

Equations for estimating Qave and SVFC for other type of fuels are summarized in Table 2. SVFC for diesel engines typically ranges from 0.244 to 0.57 L/kW.h. For ease of computation, the reciprocal of SVFC is often used and is called here as Specific Volumetric Fuel Efficiency (SVFE) with units of kW.h/L with corresponding ranges from 2.36 to 4.1 kW.h/L. Fuel efficiency varies by type of fuel and by percent load on the engine. Equations listed in Table 2 model fuel consumptions 15% higher than typical Nebraska Tractor Test (NTT) performance to reflect loss of efficiency under field conditions.

Table 2: Expressions for estimating Q_{ave} and SVFC for a specific operation

Fuel type	Qave	SVFC
Gasoline	$0.305Ppto$	$0.305Ppto$
LPG[a]	$0.366Ppto$	$3.41+ 2.69X - 0.04\,646X$

[a]Liquefied petroleum gas

Fig. 1: Main GUI of Tractor Performance Prediction (TPP) program

Computer modeling: A flexible, object oriented, user friendly, application program was needed for predicting the performance and fuel consumption of tractors on agricultural soils. Thus, a program written in Visual Basic (VB) programming language was developed specifically for this purpose. VB was considered an excellent programming language for developing Graphical User Interfaces (GUI). The 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 available components of VB toolbox provides the developer with a large library for building graphical applications. Therefore simulator core is written in Microsoft Visual Basic 6, hereafter named VB.

VB is an object-orientated language which is focused on the user and his interaction with the program. In an application it is the user who controls the flow by actions through the GUI, normally by the mouse or keyboard. VB contains classes, which has methods and properties that can perform operations and set attributes in the object. VB works with three components, class modules (classes), modules and forms. Each class contains information about an object and its methods and properties. The modules contain a set of procedures that should be executed each time they are called. Finally, the forms represent the visible part in VB. We can create buttons, textboxes and lists and so on in order to communicate with the program.

Besides these, there are several APIs that can be added to the VB-environment that can be used to create objects to control other applications without implementing that object. We just create an instance of the object and it is ready to use.

The Tractor Performance Prediction (TPP) program mainly consists of three sections, Menu, Run and Select options. Each section has a number of subsections based on the design criteria for the program development. The program starts with an opening screen as shown in Fig. 1. The screen consists of a menu with options File, Select, Run and Help. A Run Program button to predict the field performance and SVFC of the selected tractor of a particular model and a panel with Select options button to access three databases of tractor specifications, traction constants, bias-ply, radial and front tires data.

The tractor specification screen is shown in Fig. 2. The tractor specification database contains information such as makes and models for a number of agricultural tractors. The other parameters included are tractor power, tractor type (2WD, 4WD/MFWD), tire type and size, number of tires, static weight on front and rear axles, wheel base, draft height and angle, distance behind rear axle and wheel speed at no-load. The soil parameter, cone index value is also included in this database. In this menu, the fuel type used by the tractor of a particular model cab be selected through option button.

The user can edit, remove, or add a tractor and its specifications. The traction constants database (not shown here) contains the coefficients for bias-ply and radial tires. Users can change the default values (Table 1) of the coefficients A1 to A7, if wish. A tractor selection database, as shown in Fig. 3, contains a number of tractors manufactured by different companies and the corresponding model numbers. For the present case study, entry 22: CASE-IH 7230, MFWD, 172 hp is selected. This database is linked to the tractor specification database and in effect linked to the other databases.

Corresponding to a selected tractor and model, the various inputs from the different databases can be fed to the main part of the program (Fig. 4). The input data set could be displayed to the student for any change if needed without affecting the databases or saved as new data set. Information such as fuel and tire type can be chosen through option buttons in this screen.

Tractor field and fuel performance can then be predicted by clicking the *simulate* button in Fig. 4 or the *Run Program* button in the starting windows of TPP

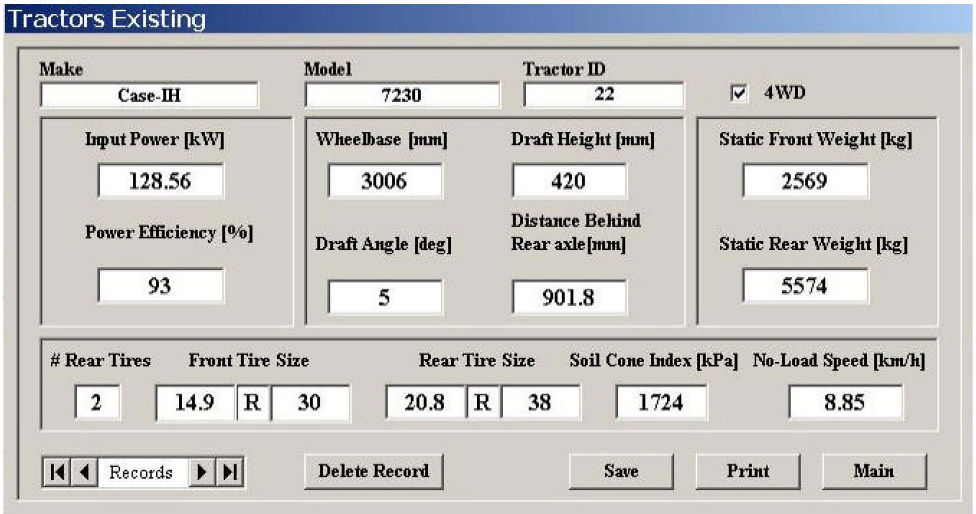

Fig. 2: Tractor specification database

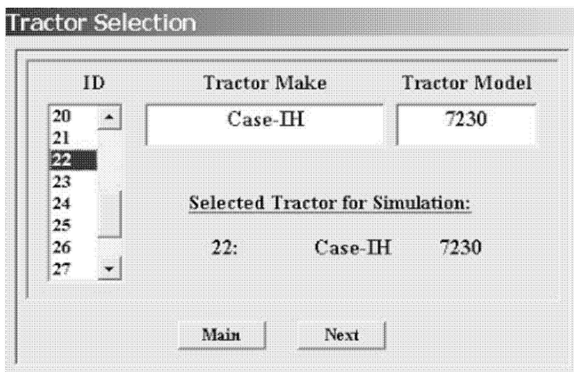

Fig. 3: Tractor selection database

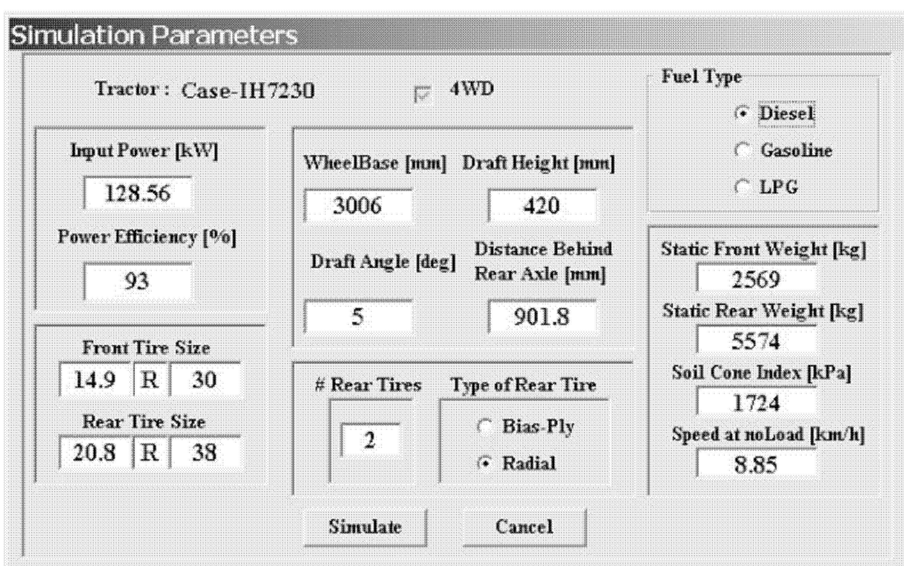

Fig. 4: Input data to the simulator

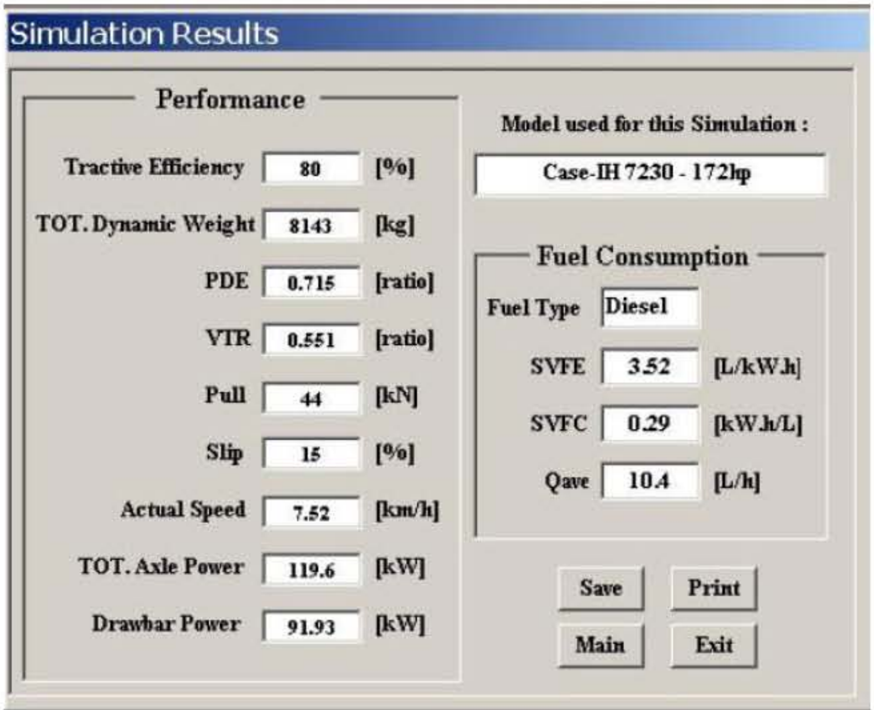

Fig. 5: Simulation results windows

(Fig. 1). Prediction of performance parameters was done for a selected tractor and model, i.e. CASE-IH 7230. Tire data, soil cone index, fuel type and no load speed could be viewed and changed if needed prior to commencing simulation. At the beginning of simulation, initial values of tractive efficiency, current and previous and static weights on the rear wheels of the tractor are assigned.

Tractor performance parameters such as tractive efficiencies, dynamic weights on front and rear axles, motion resistance ratio, net traction ratio, wheel slip, actual speed, drawbar pull, drawbar power and dynamic traction ratio were predicted for the selected tractor and model. The simulation continued until a convergence occurred in which the difference of two successive values of tractive efficiency was less than a prescribe tolerance. The simulation results for these parameters are shown in Fig. 5.

CONCLUSIONS

A computer modeling tool that can be used in teaching tractors field performance to undergraduate students of agricultural system management and mechanization curriculum has been developed. The program is written in a Visual Basic (VB) programming environment for educational and research needs. Learning how to design an application program relevant to their future carrier was of prime concern. VB is a flexible, object-oriented, user friendly language which is focused on the student and his interaction with the program.

In an application of this sort it is the student who controls the flow by actions through the intuitive interface, normally by the mouse or keyboard. This makes 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 developed software is aimed to predict the field performance as well the tractor's fuel Specific Volumetric Fuel Consumption (SVFC) on agricultural soils using either bias-ply or radial-ply tractor tires. Relative magnitudes of the many factors affecting field performance of a tractor could, therefore, be determined using computer modeling or simulation without conducting expensive and the time consuming field tests. Provision for changing model parameters, editing or expanding available databases, adding new models, saving data using Excel's spreadsheet and printing the results are provided. These features provided by the facilities of VB programming make the program highly flexible and interactive to the users in both research and education in agricultural system management. The teacher can customize design problems using tractor marks/models that are familiar to the student.

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