

Introducing Simulation Software as an Educational Tool to Enhance Student Understanding of Tractor Field Performance*

MAHMOUD OMID

Department of Agricultural Machinery, Faculty of Bio-System Engineering, University of Tehran, Karaj, Iran. E-mail: omid@ut.ac.ir

This paper presents a computer program that can be used for teaching tractor performance to undergraduate students of agricultural system management. One of the best ways to apply theory is the usage of simulation software and visualization techniques. Simulation software helps students to understand the performance aspects of tractors in the field from the pure science aspects of the subject. 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. Other features include provision for changing model parameters, adding new models, saving data using Excel spreadsheets and printing the results.

Keywords: Tractor performance; simulation software; visual basic.

INTRODUCTION

PROBLEMS IN ENGINEERING technology are traditionally skill based rather than theory based. As a result, the instructor has to illustrate problems keeping the hands-on approach in mind. Adaptation of technology in teaching is nothing new. Today we can hardly think of teaching without books and overheads; these are hardly controversial technologies anymore.

In an agricultural machinery curriculum students take a number of courses involving tractors, such as mechanics of tractors, tractor field performance, tractor-implements systems, tillage operation, field works, etc. For instance to study tractor field performance, tyre performance, soil conditions, and implement types are to be considered. As a result, a lot of empirical formulae as well as charts are involved [1–3]. Simulation software helps students to understand the performance aspects of tractors in the field from the pure science aspect of the subject matter. The rapid progress in developing new software and the trend in enhancing the existing application software and programming languages tend to facilitate the interaction between users and computers. As a result, many computer modelling and simulation programs have been developed. Lotus-compatible templates for predicting tractor performance and ballast requirements for operation on certain 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 tyres, dual versus single tyres, and the influence of travel speed, tyre size, ballast distribution and soil condition using 2WD and 4WD tractors. The Zoz spreadsheets [4] for predicting tractor performance were further expanded to account for radial tyres 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 reasonably accurately under steady-state conditions, but under unsteady conditions, the fuel flowmeter was not precise enough although the trends were correct [7]. Finally, in [8], a computer-based model and simulation program for predicting tractor performance on agricultural soil was developed in a C++ programming environment.

The objective of this work was to show students how to design an application program relevant to their future carrier. 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, tyre information, soil conditions and traction equation coefficients. The program can then predict the performance parameters as well as fuel consumption of a given tractor by accessing databases concerning tractor specifications, tyre

* Accepted 14 August 2006.

Table 1. Recommended traction equation coefficients

Traction coefficient	A1	A2	A3	A4	A5	A6	A7
Bias-ply tyres [2]	0.88	0.1	7.5	0.04	5	3	1
Radials tyres [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

information, soil condition and traction equation coefficients. Throughout this paper SI units are used and whenever possible, American Society of Agricultural Engineers (ASAE) standards have been followed.

TRACTOR FIELD PERFORMANCE MODELING

Tractor performance is influenced by tyre 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:

- analytical methods;
- semi-empirical, parametric or analog methods;
- 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 (1987) equations where the gross traction ratio (GTR), motion resistance ratio (MRR) and net traction ratio (NTR) are expressed as:

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

where T [kN.m] is input tyre torque, r [m] is rolling radius, and W [kN] is dynamic wheel on load. Brixius expressed GTR and MRR as a function of mobility number (B_n) and wheel slip (s). He

determined the dimensionless numbers in the equations using a curve-fitting technique.

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

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

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

where mobility number,

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

combines the wheel numeric,

$$WN = CI \frac{bd}{W},$$

the deflection ratio (δ/h) and the section width-to-diameter ratio (b/d). Equations 1 to 4 include seven Traction coefficients (A_i , $i = 1, 2, \dots, 7$) based on tyres 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 tyres [6]. The A_i values are listed in Table 1 for bias-ply and radial tyres. Coefficients to represent the belt-tracks traction equations for Belt Tracks are also included in Table 1 [8].

The NTR in Eq. (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 Eq. (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 tyre is defined as:

$$\text{TE} = \frac{NTV_a}{T\Omega} = \frac{NTV_a}{T(V_t/r)} = \frac{NT}{GT}(1 - s) \quad (5)$$

where Ω [rad/s] is angular velocity, r [m] is rolling

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

Fuel type	Q_{ave}	SVFC
Gasoline	$0.305P_{pto}$	$3.15 + 2.74X - 0.203\sqrt{697X}$
Liquefied petroleum gas	$0.366P_{pto}$	$3.41 + 2.69X - 0.04\sqrt{646X}$

radius and V_a [m/s] is travel speed. The equations for bias-ply tyres have been approved by the Power & Machinery Division ASAE Standards Committee [10].

The fuel consumption estimates used in cropping and machinery budgets are based on the average annual fuel consumption, Q_{ave} [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/kWh. 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 (6) and (7) estimate Q_{ave} and SVFC above 20% load for Diesel type of fuel:

$$Q_{ave} = 0.223P_{pto} \text{ [L/h]} \tag{6}$$

$$SVFC = 3.91 + 2.64X - 0.203\sqrt{738X + 173} \text{ [L/kW.h]} \tag{7}$$

where P_{pto} [kW] is the maximum PTO power of tractor and X is the ratio of equivalent PTO power required by an operation to P_{pto} .

Equations for estimating Q_{ave} 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/kWh. For ease of computation, the reciprocal of SVFC is often used and is called here as specific volumetric fuel efficiency (SVFE) with units of kWh/L with corresponding ranges from 2.36 to 4.1 kWh/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.

SIMULATOR DESIGN

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 tyres 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), tyre type and size, number of tyres, 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



Fig. 1. Main GUI of tractor performance prediction(TPP) program.

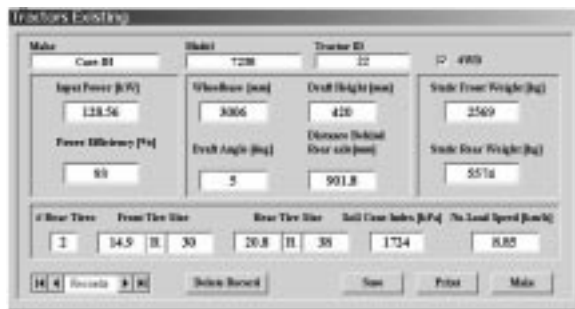


Fig. 2. Tractor specification database.

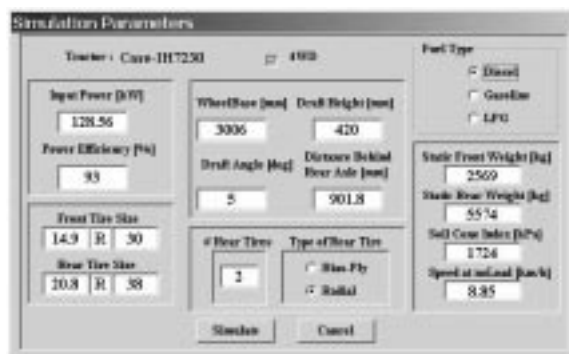


Fig. 4. Input data to the simulator.

this database. In this menu, the fuel type used by the tractor of a particular model can be selected through an 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 tyres. Users can change the default values (see Table 1) of the coefficients A_1 to A_7 , 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 tyre 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 (see Fig. 1). Prediction of performance parameters was done for a selected tractor and model, i.e. CASE-IH 7230. Tyre 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. The simulation screens (tractor performance screens) are intuitive to users and highly flexible in specifying the type of output from the simulation.

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.

EDUCATIONAL AND RESEARCH BENEFITS

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 computer modelling and simulation programs have been developed.

The software developed in this paper helps the students to understand the engineering aspect of dynamics from the pure science aspect of the subject matter—a key feature in satisfying our

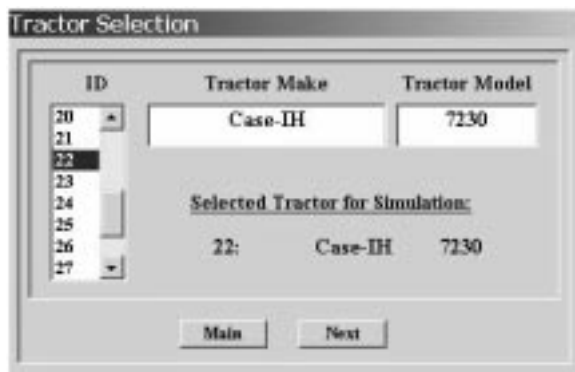


Fig. 3. Tractor selection database.

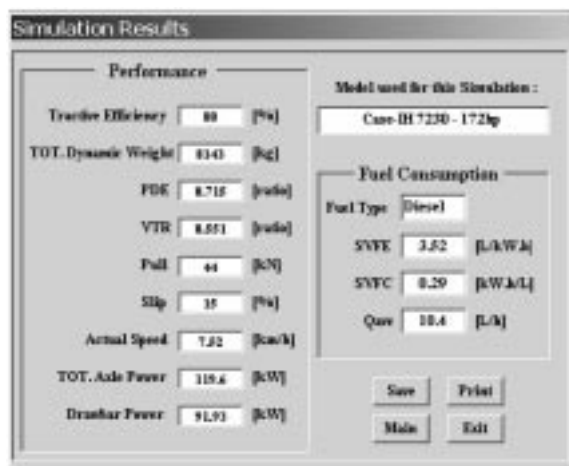


Fig. 5. Simulation results windows.

program requirement. Also, by presenting the course material in a visual and an attractive manner, it enhances students' understanding of the course material, holds students' attention and encourages their involvement. Furthermore, this methodology for predicting tractor performance helps researchers to determine the relative importance of many factors affecting field performance of tractors without conducting expensive, as well as time consuming, field tests. It is also beneficial to researchers and manufacturers to improve the tractor performance by comparing and analyzing various parameters that influence tractor performance.

The current version of software has been evolved during a course on Computer Programming given to the undergraduate students of agricultural machinery in the faculty of Bio-System Engineering, at Tehran University. The various parts of program such as the design of GUI, menus, ADO, event handling procedures, linking the databases together in visual basic environment, etc., were explained during the course. Learning how to design an application program relevant to their future carrier was of prime concern. As a result, students developed a number of small projects which carried about 60% of their total grade.

CONCLUSIONS

A computer modelling tool that can be used in

teaching tractor field performance to undergraduates of agricultural system management curriculum was developed. The program was implemented in a Visual Basic (VB) programming environment for use in educational and research needs. VB offers 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.

The developed software is aimed at predicting the field performance as well the tractor's fuel-specific volumetric fuel consumption on agricultural soils using either bias-ply or radial-ply tractor tyres.

Provision for changing model parameters, editing or expanding available databases, adding new models, saving data using Excel spreadsheets 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 software has been used as an educational tool to demonstrate these comparative features to undergraduate classes. The teacher can customize design problems using tractor marks/models that are familiar to the student.

Acknowledgments. The financial support provided by the research sponsor at Tehran University under research award #1305051-1-01 is gratefully acknowledged.

REFERENCES

1. R. D. Wismer, H. J. Luth, Off-road traction prediction for wheeled vehicles, *ASAE Paper 72-619*, (1972), p. 16.
2. W. W. Brixius, Traction prediction equations for bias ply tyres, *ASAE Paper 87-1622*, (1987), p. 8.
3. S. K. Upadhyaya and D. Wulfsohn, Review of traction prediction equations, *ASAE Paper 90-1573*, (1990), p. 23.
4. F. M. Zoz, Predicting tractor field performance, *ASAE Paper 87-1623*, (1987), p. 12.
5. R. D. Grisso, S. A. Al-Hamed, R. K. Taylor, F. M. Zoz, Demonstrating tractor performance trends using Lotus templates, *Appl. Eng. Agric.*, **8**(6), 1992, pp. 733-738.
6. S. A. Al-Hamed, R. D. Grisso, F. M. Zoz and K. Von Bargen, Tractor performance spreadsheet for radial tyres, *Comput. Electron. Agric.*, **10**, 1994, pp. 45-62.
7. P. W. L. Lyne, E. R. de la Harpe, A. C. Hansen and D. J. Clark, Development of a vehicle performance simulator: aims, objectives and initial results, *J. Agricultural Engineering in SA*, SA Inst. Ag. Eng., **28**, 1996, pp. 92-101.
8. R. D. Grisso and F. M. Zoz, *Modified Traction Equation to Predict the Performance of Belt Tracks*, (2000).
9. S. A. Al-Hamed and A. A. Al-Janobi, A program for predicting tractor performance in Visual C++, *Comput. Electron. Agric.*, **31**, 2001, pp. 137-149.
10. ASAE D497.4, Agricultural machinery management data, *ASAE Standards*, 2000, St. Joseph, MI.
11. ASAE EP496.2, Agricultural machinery management, *ASAE Standards*, 2002, St. Joseph, MI.
12. M. Omid, Tractor field performance prediction via simulation software, *Proc. 1st Int. Conf. of Agri. Mechanization Development Methods*, (CD), Karaj, Iran, 2004.

Mahmoud Omid is an Associate Professor at Tehran University, Faculty of Agricultural Bio-System Engineering, Karaj, Iran. He received his MS degree in 1994 and the Doctor's degree in 1997, both from the University of Electro-communications (UEC) in Japan. His main areas of research interest are fuzzy logic, machine vision, knowledge-based expert systems, CAD, neural networks, multimedia techniques, object-oriented databases and decision-support systems in Agriculture. Dr. Omid is currently the Director of Information Technology Center, College of Agriculture and Natural Resources, University of Tehran, Karaj, Iran.