A Decision Support System for Design of Transmission System of Low Power Tractors

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ABSTRACT: A decision support system (DSS) was developed in Visual Basic 6.0 programming language to design transmission system of low horsepower agricultural tractors, which involved the design of clutch and gearbox. The DSS provided graphical user interface by linking databases to support decision on design of transmission system for low horsepower tractors on the basis of modified ASABE draft model. The developed program for design of tractor transmission system calculated clutch size, gear ratios, number of teeth on each gear, and various gear design parameters. Related deviation was computed for design of transmission system of tractors based on measured and predicted values (simulated). The related deviation was less than 7% for design of clutch plate outer diameter and less than 3% for inner diameter. There was less than 1% variation between the predicted results by the developed DSS and those obtained from actual measurement for design of gear ratio. The DSS program was user friendly and efficient for predicting the design of transmission system for different tractor models to meet requirements of research institutions and industry. Comput Appl Eng Educ 9999:1–11, 2015; View this article online at wileyonlinelibrary.com/journal/cae; DOI 10.1002/cae.21648

Keywords: decision support system; tractor transmission system; low power tractors; simulation; ASABE equation

INTRODUCTION

Computer models and simulation programs for design of tractor transmission system helped researchers and students to determine various parameters related to tractor transmission without going through the complex and iterative design procedure. It also helped researchers and manufacturers to improve design of tractor transmission system by comparing and analyzing various parameters that influenced tractor transmission system design. The rapid progress in developing new software and trend in enhancing the existing application software and programming languages facilitated the interaction between users and computers [1]. A lot of research was conducted in developing computer-based models and simulation programs to meet educational and research needs in the farm machinery branch of agricultural engineering [2].

Design of a gear involved analysis and treatment of geometric factors to optimize the parameters like surface compressive stress, tooth stress, tooth bending stress, etc. Radzevich [3] gave a detailed procedure for designing the spur gear. Buckingham and Buckingham [4] gave information in tabular form for calculating gear ratios that permitted the use of a simple and direct method in finding a suitable set of different gears for a wide variety of requirements and applications. Mitra and Prasad [5] gave a detailed procedure for designing the spur gear along with the standard table for backlash

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values and simple process for calculation of contact ratio. Ramamurti et al. [6] described a design methodology for design of two-speed gearbox based on input power, input speed, and net reductions in gearbox. The user was given the choice of selection of materials for shaft and gear. The methodology specified the shaft dimensions, gear specifications, bearing selection, overall space occupied, and the self weight of the gearbox. Chong et al. [7] described a new generalized four steps methodology to design multi-stage gear drives by integrating the dimensional and the configuration design process in a formalized algorithm. In the first step, the user provisionally set the number of reduction stages. In the second step, gear ratios of every stage were chosen by using the random search method (within the specified ratio change), and in the next step the ratios were used as the basic inputs for the dimensional design of gears. In the third step, the values of the basic design parameters of a gear were chosen. In the final step, the configuration design was carried out by using the simulated annealing algorithm to calculate design parameters, such as pitch parameters and outer diameters. The positions of the gears and shafts were determined to minimize the geometrical volume of a gearbox while satisfying spatial constraints. These steps were carried out iteratively until a desirable solution was acquired. Argyris et al. [8] developed a tooth contact analysis program for design of worm gear system. The program was written in Visual Basic (VB) language and enabled to combine numerical computation and graphical illustration. Thompson et al. [9] describe the detailed procedure of spur gear design with a goal to reduce the total volume and weight. They developed a program in MATLAB® software with optimization toolbox to optimize the gear design. They concluded that the three-stage design was clearly superior and offered a potential weight reduction of as much as 20% over the two-stage design at the higher ratio.

Simulation software to predict tractor performances was developed from different programming tools [10]. Presently, VB and Visual C++ languages, MATLAB's SIMULINK and PG-Sim were used to develop such programs [2,11,12]. The availability of visual language, e.g., VB was easy to users. Mondal et at. [13] developed a program in VB 6.0 to design 16 + 4 speeds gearbox for TAFE tractor.

ASABE models [14] were not suitable for predicting the drawbar power of tractors in Indian soil conditions. Modified ASABE models were accurate in predicting the draft of tractor implement system when used under Indian cohesive/frictional soils [15,16]. The calculation of clutch size, gear ratio, and number of teeth on each gear was not included in these models. It was highlighted the need to conduct research in developing computer-based models and simulation programs to improve the design of tractor transmission system by analyzing the relative importance of various parameters. Keeping in view of limitations of the available softwares, a decision support system (DSS) in VB was developed to design transmission system for low power two wheel drive (2WD) tractors. The developed program also provided a new computational tool which allowed the students to familiarize with fundamental concepts and introduction to gear trains, gear terminology, transmission ratios along steps in transmission system design.

THEORETICAL CONSIDERATIONS

The tractor drive train included power transmission elements between the engine and drive wheels along with PTO drive. It consisted of the clutch, gearbox, differential, final drives, and PTO. The gear design parameters, gear kinetics, geometry, and synthesis defined by the Radzevich [3] were used in the development of program. Additionally, a compatible clutch design would also enhance the efficiency of the system. The modified ASABE model for prediction of draft and power requirements was used in the developed software for more accurate design of tractor gearbox. The sub-systems of the DSS included design of clutch and gearbox along with modified ASABE model for draft prediction.

Design of a Clutch

Low horsepower Indian tractors were fitted with manually operated clutch. They had good torque exertion capability and facilitated shifting of gears as a result of relatively low inertia. Dry single-disk friction clutch was often used in drive trains which

Table 1 Different Gear Parameters Used in the Developed Software

Parameter	Driving gear	Driven gear
Pitch circle diameter	$d_1 = z_1 m$	$d_2 = z_2 m$
Base circle diameter	$d_{b1} = d_1 \cos\alpha$	$d_{b2} = d_2 \cos\alpha$
Tip circle diameter	$d_{t1} = d_1 + 2m + 2x_1 m + 2y_m$	$d_{t2} = d_2 + 2m + 2x_2 m + 2y_m$
Root circle diameter	$d_{r1} = d_1 - 2(1.25 - x_1)m$	$d_{r2} = d_2 - 2(1.25 - x_2)m$
Working pitch circle diameter	$d_{w1} = d_1 \frac{\cos\alpha}{\cos\alpha_w}$	$d_{w2} = d_2 \frac{\cos\alpha}{\cos\alpha_w}$
Tooth thickness on pitch circle	$s_1 = \frac{p}{2} + 2x_1 m \tan\alpha$	$s_2 = \frac{p}{2} + 2x_2 m \tan\alpha$
Addendum	$D_1 = d_{w1} - d_{r1}$	$a_2 = d_{t2} - d_{w2}$
Dedendum	$D_1 = d_{w1} - d_{r1}$	$D_2 = d_{w2} - d_{r2}$
Total depth	$D_{t1} = a_1 + D_1$	$D_{t2} = a_2 + D_2$
Circular pitch	$p = \pi m$	
Actual center distance	$a_0 = m \frac{z_1 + z_2}{2}$	
Working pressure angle	$a_w = \cos^{-1}\left(\frac{a_0}{a} \cos\alpha\right)$	
Total profile correction factor	$x_1 + x_2 = (z_1 + z_2)\left(\frac{inv_w - inv\alpha}{2\tan\alpha}\right)$	
Topping	$y_m = [a_0 + (x_1 + x_2)m] - a$	
Contact ratio	$CR = \frac{\sqrt{r_{a1}^2} - r_{b1}^2 + \sqrt{r_{a2}^2} - (a_0 \sin\alpha)}{\pi m \cos\alpha}$	
Top clearance	$c = a - \left[\frac{d_{t1} + d_{r2}}{2} + y_m - 2.25_m\right]$	
Diametral pitch	$p = \frac{1}{m}$	
Face width	$B_f = \frac{F_t K_v}{0.44 \times p u_t \times 0.525}$	

provided higher capacity and durability at low cost. During running condition, the pressure distribution was adjusted in such a manner that the product pressure was constant. There was uniform pressure distribution over the entire new contact friction surfaces. In the design of clutches, it is assumed that maximum time the friction lining operated in uniform wear condition.

Design of Gearbox

The design of a tractor transmission system required determination gear ratios in different gears, number of teeth on each gear, center to center distance between gears, and various design parameters for each gear. It was assumed that dynamic loading in the tooth was due to profile errors, circular pitch error, and deflection of teeth under load. Load applied on the tooth was not uniformly distributed because of the deformation of tooth due to torque, deflection of shaft, location of bearing, and misalignment. Load concentration factor (K) of 1.1, shock factor (K_0) of 1.1, and dynamic load factor (K_d) of 1.1 were taken for calculating the number of teeth on each gear during programming. Different gear parameters and formulas used for developing the program are given in Table 1.

Modified ASABE Model for Draft Prediction

The American Society of Agricultural and Biological Engineers [14] defined equation (1) for estimation of draft requirement of various agricultural implements and machine for a variety of soil conditions. The equation (1) was modified for predicting the draft under field condition using the data collected for various field operations in medium textured soil at Indian Institute of Technology (IIT), Kharagpur in India. Additional correction coefficients K_1 and K_2 were introduced to account for variations in draft when calculated by using modified ASABE draft model for medium textured soils (2) for mold board plough, cultivator, and disc harrow.

$$Di = Fj(A + BVa + CVa^2)WcH \quad (1)$$

$$Dim = K_1(F_2(A + BVa + CVa^2)WcH) + K_2 \quad (2)$$

The values of correction coefficients K_1 were 1.735, 0.809, and 0.73 and K_2 were 1,618, 4,048, and 1,406 for mold board plough, cultivator, and disc harrow, respectively [16]. The values of K_1 and K_2 were determined by finding the best fit equations for observed and predicted (by ASABE model) values of draft for the same set of machine, soil, and operating parameters. The coefficient of determination for three operations (ploughing, harrowing, and tilling) ranged from 0.90 to 0.93 [16]. The cutting width (W_c) of major tillage implements viz., mold board plough, cultivator, and disc harrow were calculated by equations $W_c = nw$, $W_c = n$ and $W_c = 0.95N_dS_d - 0.6D_d$, respectively.

DSS Design Process

Development of DSS for tractor transmission system of low power tractors includes three internal stages i.e., analysis, algorithm design, and coding stage [17].

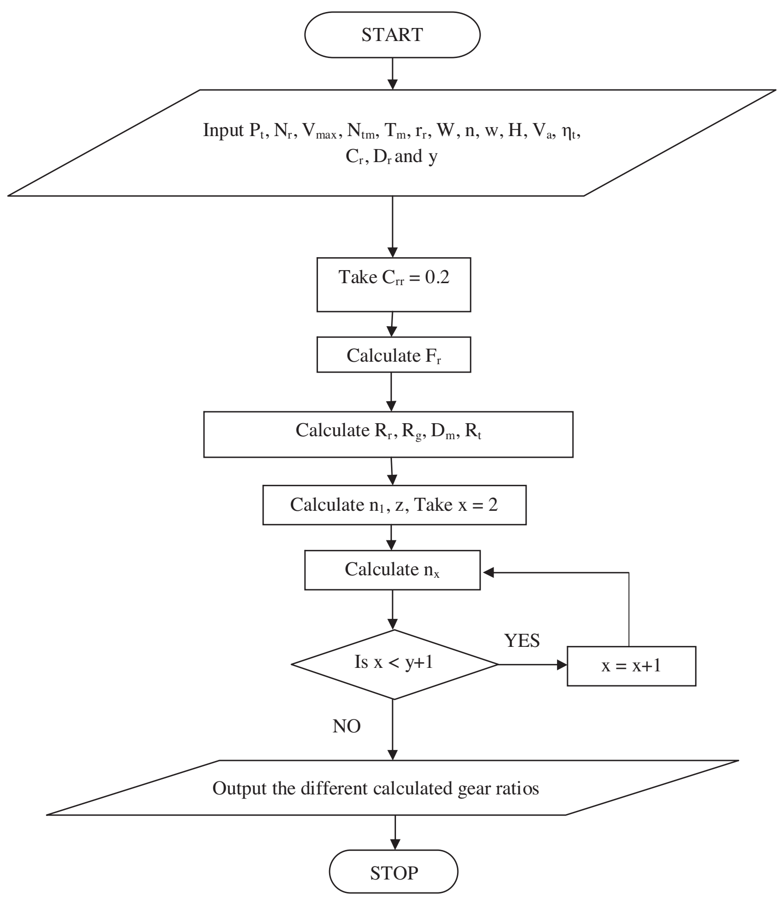

Figure 1 Flowchart for calculation of different gear ratios.

Analysis. It needed to produce and display the design parameters for transmission system in user friendly and easily accessible approach. The DSS developed based on the input of certain parameters. The DSS accurately calculates the output parameters through the written codes (design equations) to determine various results.

Algorithm Design. It involved development of instructions in a logical manner so that execution of the instruction resulted in the solution of the problem. The use of flowchart made it simpler at the programming stage to avoid algorithmic ambiguity. The various input parameters and equations used for calculation of design parameters were included in the module shown in the flowcharts (Figs. 1 and 2). Figure 1 shows the flowchart for calculation of different gear ratios and Figure 2 shows for gear parameters.

Coding. An accurate and efficient coding were the major and important aspects of DSS for proper working of application. VB program with dedicated coding was developed for design of transmission system of agricultural tractor. Modified ASABE draft model (Eq. 2) for medium textured soils of India with machine and soil specific parameters was used in coding. Different clutch and gear design formulas were also coded to develop program modules (Table 1). Integrated development environment (IDE) was used to compile the program. It was checked for errors by debugging each stage of the code. Debugging helped to avoid too many untraceable errors of transmission system design program.

MATERIALS AND METHODS

A DSS in visual basic (VB) was developed for design of tractor transmission system on the basis of modified ASABE model (Eq. 2) for Indian soils and operating conditions. The developed program was flexible, object oriented, and user friendly and was developed using VB 6.0 as front end. The program was developed in two sub-systems i.e., clutch design and gearbox design. Several sequential GUI screens were developed to complete the process and get the desired output. The developed screens were very intuitive and easy to select the values and enter the required design parameters wherever required. The developed software was validated for design of tractor transmission system using the actual measured readings obtained for three low power agricultural tractors at Indian Institute of Technology, Kharagpur in India. The

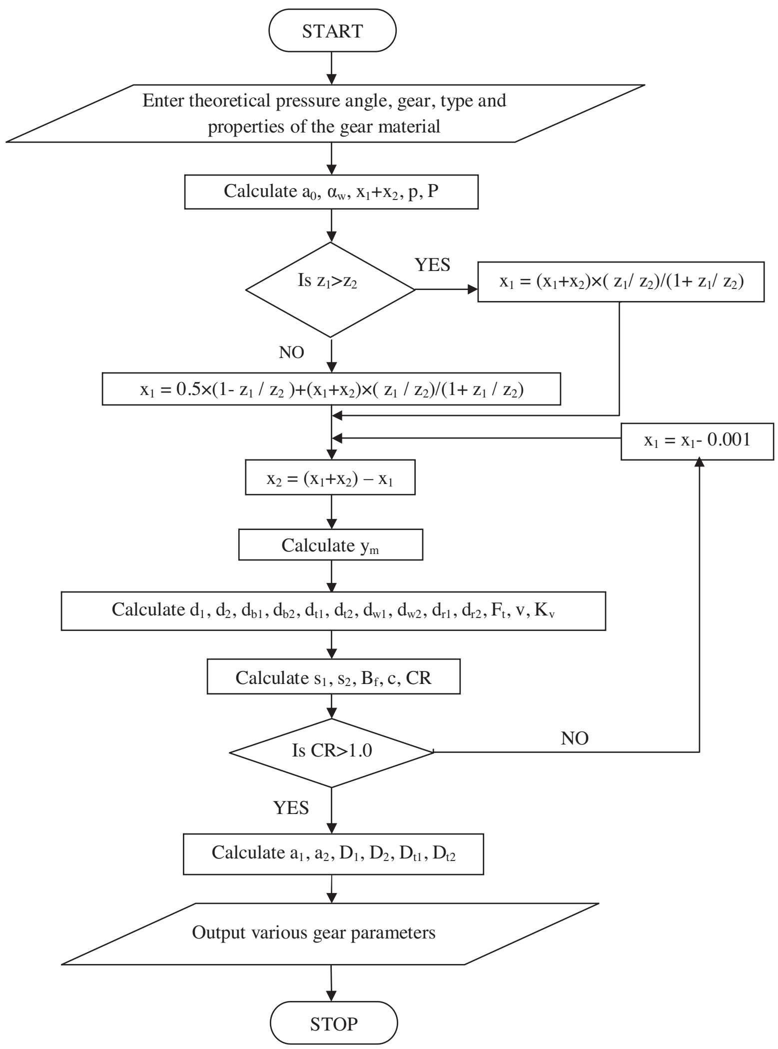

Figure 2 Flowchart for calculation of different gear parameters.

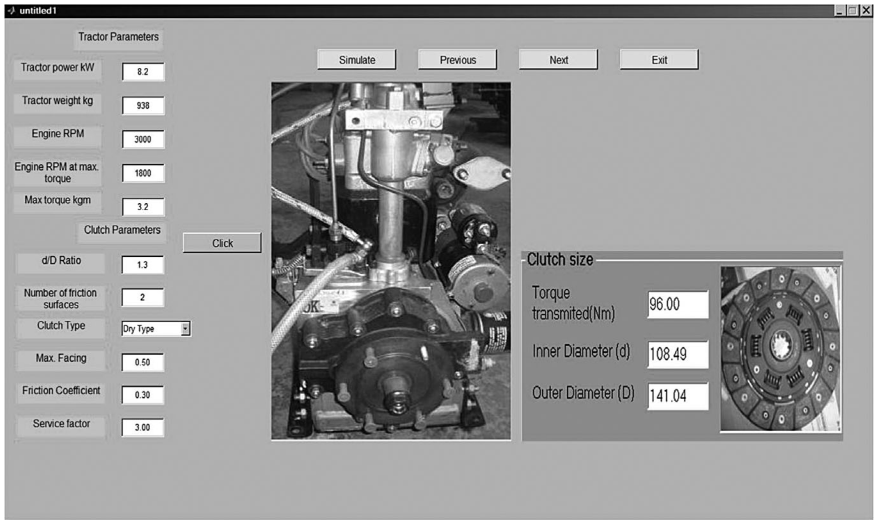

Figure 3 Input and output GUI of simulated clutch size.

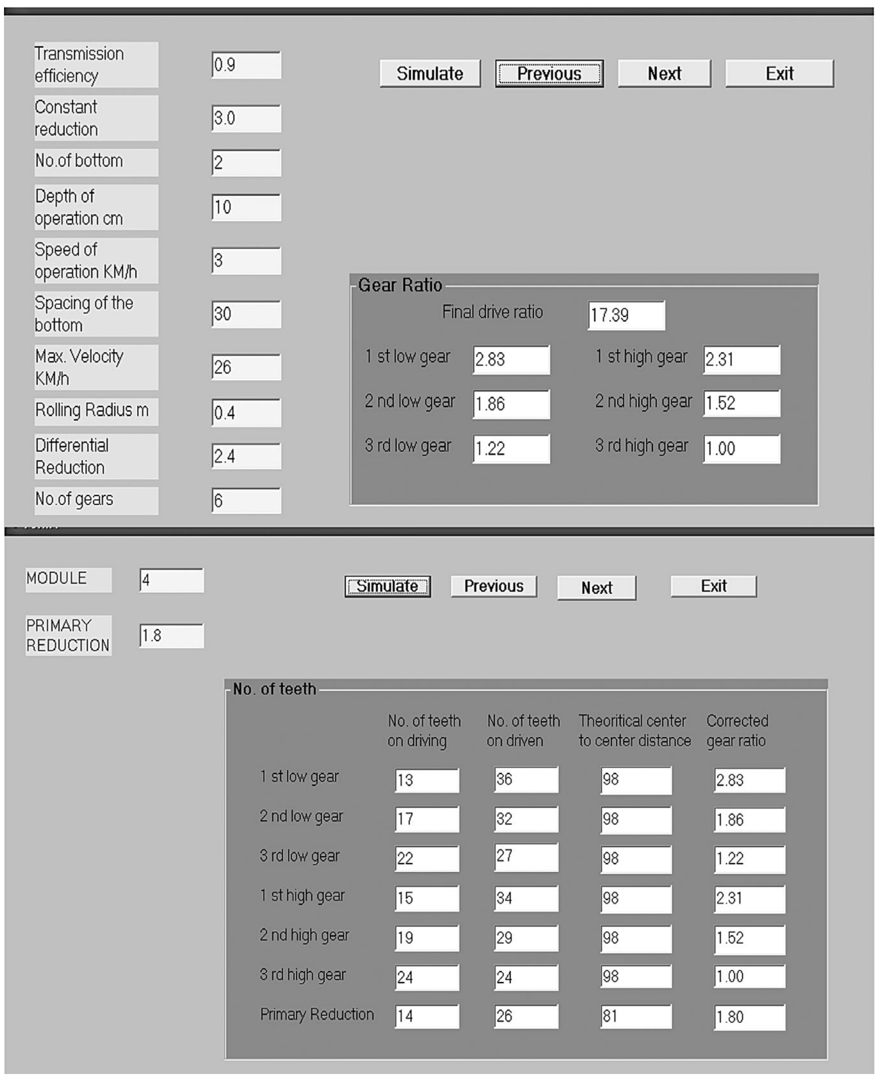

Figure 4 Input and output GUI of simulated gear ratios and number of teeth at different gear ratios.

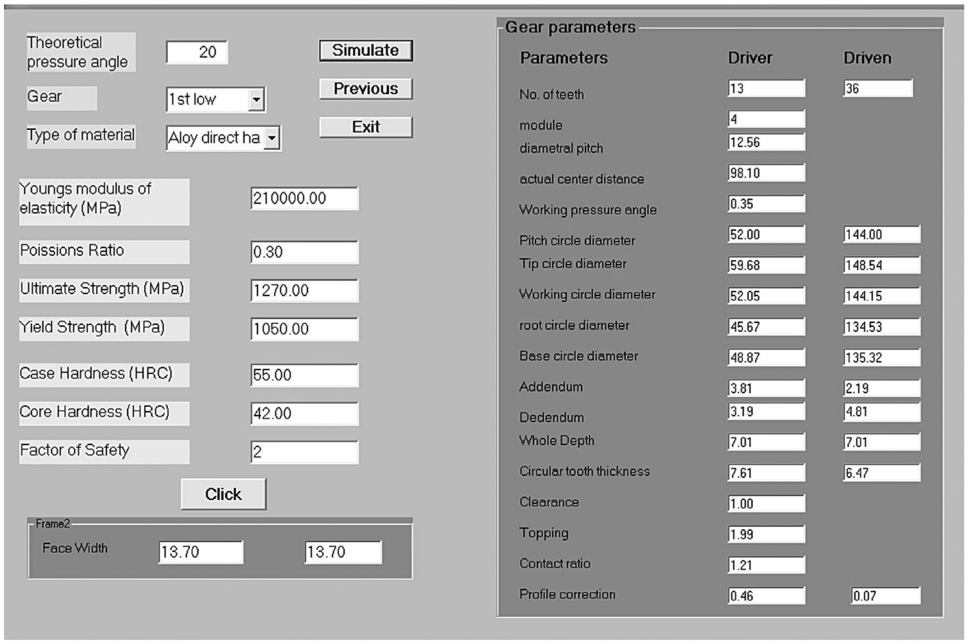

Figure 5 Input and output GUI of different gear parameters for design.

developed software was also evaluated by 27 undergraduate students using a questionnaire.

Clutch Design

The design of a clutch was done according to conditions that met the requirement of low horse power tractor clutch. The design of clutch required tractor engine specification (tractor power, tractor weight, engine RPM, maximum torque), clutch parameters (d/D ratio, number of friction surfaces) and clutch type and spline friction factor (s_f). Simulation of different inputs was done before deciding desired design parameters. The GUI for clutch design was shown in Figure 3 and included the basic databases for the simulation to predict parameters for clutch design. The user could edit, remove, or add specific parameters and simulate for better results. This GUI also provided an option to select the clutch type from pop-up menu and to simulate to predict design parameters and performance. The output results of design of clutch size were shown in Figure 3 and ended with the final result required by the user. The developed program determined the torque transmitted (Nm) and inner and outer diameters (mm) of clutch.

Gearbox Design

Flowchart for calculation of the different gear ratio's module is shown in Figure 2. The GUI for design of gear consisted of four buttons, i.e., Simulate, Previous, Next, and Exit. The input and output (after simulation) windows of GUI for gear ratios and number of teeth were shown in Figure 4. On choosing next button, GUI was opened which consisted of an option to enter the input parameters needed to find out the different gear ratios. These parameters were transmission efficiency (η_t), constant reduction (C_r), number of bottom (n), depth of operation (H), speed of operation (V_a), bottom spacing (w), maximum velocity (V_{max}), rolling radius (r_r), differential reduction (D_r), and number of gears (y). Finally, the output screen of simulated gear ratios indicated

Table 2 Questionnaire to evaluate the developed DSS

Sl. No.	Question	Average (SD)
1.	The flowchart of the program helped in understanding steps involved in transmission system design	4.8 (± 0.61)
2.	The details (like equations and nomenclature) in the program were presented very well	4.2 (± 0.81)
3.	The contents of the program were presented in easy to understand format	4.7 (± 0.68)
4.	The contents of the program were informative from educational and research point of view	4.5 (± 0.40)
5.	The program was well organized	4.7 (± 0.76)
6.	The program was easy to use	4.3 (± 0.53)
7.	The program helped in learning about transmission system	4.6 (± 0.42)
8.	The information given in the program was clear and concise	3.9 (± 0.88)
9.	The program enhanced interest in transmission systems design	4.5 (± 0.84)
10.	I would prefer to use this program for design of tractor transmission system	4.7 (± 0.71)
	Overall score	4.49 (± 0.66)

1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree.

Table 3 Comparison of Clutch Size of Measured and Software Simulated Values

	Clutch plate inner diameter (mm)			Clutch plate outer diameter (mm)		
PTO power (kW)	O	P	RD	O	P	RD
10.03	110	108.47	1.41	150	141.02	6.24
18.64	250	242.5	3.09	310	290.5	6.71
26.09	290	283.6	2.26	342	322.08	6.18

O, observed value; P, predictedvalue by software; RD, relative deviation (%).

the gear ratio in each gear and total final drive reduction ratio (F_r). This screen provided a simulate button to predict its performance. The output screen for number of teeth calculation was shown in Figure 4 and it indicated the number of teeth on pinion (z_1) and gear (z_2).

Calculation of Different Gear Parameters. The GUI as shown in Figure 5 allowed the user to enter the theoretical pressure angle (α). The screen also provided pop-up menu option to select the pair of gears for which the parameters were determined and most importantly the type of material which was used for gear production. After selecting the type of material, choose "Click" button provided on the screen so that the screen showed the various material properties for the selected material. On choosing "Simulate" button provided on GUI screen, the output screen of gear parameters was opened as shown in Figure 5. Tangential force (F_t), peripheral velocity (v) and velocity factor (K_v) were used to design the driver and driven gears along with face width (B_f).

Validation of the Developed DSS

Three tractors of 10.03, 18.64, and 26.09 kW PTO power were selected to test the developed DSS. The developed program was validated for design of tractor transmission system by measuring the actual readings obtained for the tractors and comparing with the predicted values using the developed program. The tractors were dismantled to measure the clutch and gear parameters. The gear ratios for different gears were calculated from the measured readings of number of teeth on each gear. The various gear parameters for a particular gear were also calculated. The related deviation (RD) was computed based on measured and predicted values (simulated) for design of transmission system of tractors. The RD was defined as follows:

$$RD = \frac{1}{N}\sum_{i=1}^{N}\frac{|P_i - O_i|}{P_i} \times 100 \qquad (3)$$

Where, P_i was the predicted value from the program, O_i was the observed value from the measurement of actual gear, and N was the number of observations.

Questionnaire to Evaluate Developed DSS

A questionnaire given in Table 2 was developed to evaluate the DSS by 27 undergraduate students. The questionnaire had questions about the developed DSS for design of transmission system of low power tractors. There were no right or wrong answers to the questions. The students were asked to rate the DSS on scale of 1 to 5 with "1 = strongly disagree, 2 = disagree, 3 = neither agree nor disagree, 4 = agree, 5 = strongly agree," respectively. The results of the survey are reported in Table 2.

RESULTS AND DISCUSSION

The DSS program was written in VB programming language with a new method of predicting tractor performance using modified ASABE draft model. The program provided an intuitive user interface by linking databases such as tractor specifications, implements data, tyre size, and modified ASABE model of draft equation to predict the transmission design for a selected power range of tractors. The developed VB based program provided flexibility to either select or edit input parameters to design the tractor transmission to match the tractor implement combination based on soil conditions. The modified ASABE models predicted the draft of implements for design of transmission system. The output results of the program could be exported in spreadsheet format for further analysis.

Clutch Parameters

The output screen for design of clutch size indicated the clutch design parameters such as torque transmitted (T), outer diameter (D), and inner diameter (d). The calculated RD values for clutch design data set were given in Table 3. Clutch plate inner diameter data set indicated that maximum and minimum RD was

Table 4 Comparison of Gear Ratios of Calculated and Software Simulated Values

		Gear ratio		
PTO Power, kW	Gear selected	O	P	RD
10.03	L1	2.77	2.83	2.12
	L2	1.88	1.86	1.08
	L3	1.23	1.22	0.82
	H1	2.26	2.31	2.16
	H2	1.53	1.52	0.66
	H3	1.00	1.00	0.00
18.64	L1	20.64	20.62	0.10
	L2	14.32	14.31	0.07
	L3	10.81	10.80	0.10
	L4	6.61	6.60	0.15
	H1	5.04	5.00	0.8
	H2	3.50	3.48	0.57
	H3	2.64	2.63	0.38
	H4	1.61	1.59	1.26
26.09	L1	9.06	9.02	0.44
	L2	5.71	5.68	0.53
	L3	4.02	4.00	0.50
	L4	2.68	2.63	0.02
	H1	3.38	3.36	0.60
	H2	2.13	2.12	0.47
	H3	1.49	1.48	0.70
	H4	1.00	1.00	0.00

O, observed value; P, predictedvalue by software; RD, relative deviation (%).

found for 18.64 and 10.03 kW tractors but for the outer diameter it was maximum for 18.64 kW PTO power tractor. The RD values also indicated that the variation of the predicted results from those found in the actual design was less than 7% in clutch plate outer diameter and less than 3% in inner diameter. This difference may be due to general calculation (Table 1) and accuracy level of the various prediction models used in developing the DSS.

Gear Ratios

One tractor of 10.03 kW PTO power was tested in six forward gears and two tractors of 18.64 and 26.09 kW PTO power were tested in eight forward low and high gears (L1, L2, L3, L4, H1, H2, H3, and H4). Data set of testing of gear ratio indicated (Table 4), variation of less than 1% in most of the cases for predicted results by the developed program and from those found in the actual measurement. The maximum RD was 2.16% in H1 gear and zero in H3 gear for 10.03 kW PTO power tractor. The minimum RD was 0.02% (L4) and 0.07% (L2) for 18.64 and 26.09 kW PTO power tractors, respectively. The variation in RD may be due to some instrumental error in measuring the tractor transmission data or using various prediction models and formulas used in developing the program.

Gear Parameters

The comparison of various gear parameters obtained from calculated and software simulated values for different PTO power tractors were shown in Figure 6. For circular pitch (*p*), zero RD

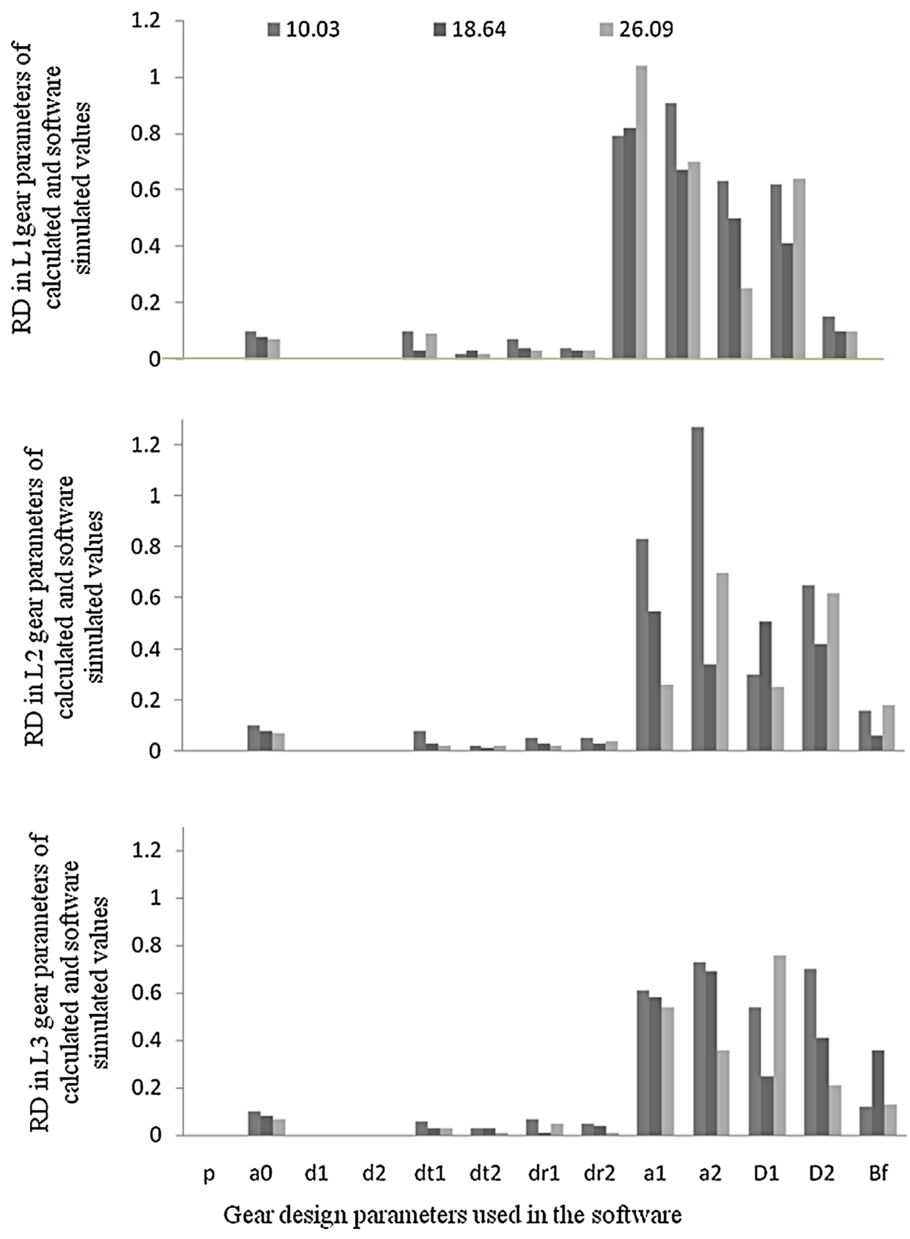

Figure 6 Related deviation of various gear parameters obtained from calculated and software simulated values for different gears.

was observed in calculated and software predicated values in all gears of gearbox of three different low power tractors. Maximum RD was observed in addendum (a_2) of driven gear for 10.03 and 18.64 kW PTO tractors but not in case of 26.09 kW PTO tractor of L3 gear. Maximum RD was in a_2 in three tested gears (L1, L2, and L3) of 10.03 kW PTO tractor. In case of 18.64 kW PTO tractor, maximum RD was found in a_1 in L1 and L2 gears. In 26.09 kW PTO tractor, maximum RD was in dedendum of a driver gear (D_1) in L3 gear.

The related deviation in predicted results from the developed DSS was less than 7% as compared to the measured values for design of transmission system of low power tractors. Therefore, the developed DSS predicted results with reasonable accuracy. Therefore, it may be concluded that the DSS was flexible and effective for design of transmission system of low horse power tractor. This will ultimately help researcher and educational professionals in selection of the right size of transmission system based on tractor-implement system, soils, and operating parameters.

Survey Results and Feedback on developed DSS

Table 2 shows the findings of the survey to evaluate the developed DSS. The comments of the students about the program were mainly positive. The majority of the students were highly satisfied in terms of ease of use and simplicity of the instructions in the program. The overall score for 10 questions in the questionnaire was 4.49 out of 5.0. This indicated that students agreed that DSS based design of tractor transmission system was helpful, informative, fast, and easy to use. The students strongly felt that the flow chart of the program helped in understanding steps involved in tractor transmission systems design. The question "information given in the program was clear and concise" got the lowest score of 3.9. The following advantages and disadvantages of the developed DSS were observed based on feedback of 27 undergraduate students for design of transmission system of low power tractor.

Advantages

- The program did not require users to have in-depth knowledge about introduction to gear trains and gear terminology for design of tractor transmission system.
- It created more interest among users for design of tractor transmission system due to availability of pop-up and drop-down menu facility in the DSS.
- The program was easy to use at most of the places due to availability of Microsoft Operating System.

Limitations

- Software incompatibility issues with other operating system.
- Loss of sense of theoretical and mathematical understanding behind the designing.

CONCLUSIONS

A simulation based user-friendly DSS was developed in a VB programming environment for design of transmission system of low power agricultural tractors. The program used the modified ASABE model for predicting the draft and tractive performances of the tractor. The program could be used to simulate the various design aspects of a gearbox and clutch design through GUI. The model was verified with real and measured data obtained from low power tractor tests. The program was found to have very close prediction for design of tractor transmission system. Therefore, it may be concluded that the developed program was effective and supported in design of transmission system of lower horse power tractors.

NOMENCLATURE

a	theoretical center distance (mm)
a_0	actual center distance (mm)
a_1	addendum of a driver gear (mm)
a_2	addendum of a driven gear (mm)
A, B, C	machine specific parameters
B_f	face width (mm)
c	top clearance (mm)
CR	contact ratio
C_r	constant reduction
C_{rr}	coefficient of rolling resistance
d	clutch plate inner diameter (mm)
d_g	pitch circle diameter of a gear (mm)
d_1	pitch circle diameter of a driver gear (mm)
d_2	pitch circle diameter of a driven gear (mm)
d_{b1}	base circle diameter of a driver gear (mm)
d_{b2}	base circle diameter of a driven gear (mm)
d_{r1}	root circle diameter of a driver gear (mm)
d_{r2}	root circle diameter of a driven gear (mm)
d_{t1}	tip circle diameter of a driver gear (mm)
d_{t2}	tip circle diameter of a driven gear (mm)
d_{w1}	working pitch circle diameter of a driver gear (mm)
d_{w2}	working pitch circle diameter of a driven gear (mm)
D_d	diameter of disc blade (m)
D	clutch plate outer diameter (mm)
D_1	dedendum of a driver gear (mm)
D_2	dedendum of a driven gear (mm)
D_i	implement draft (N)
D_{im}	modified draft (N)
D_{t1}	total depth for a driver gear (mm)
D_{t2}	total depth for a driven gear (mm)
D_r	differential reduction
F_j	soil texture adjustment parameter
F_r	final drive reduction
F_t	tangential force (N)
G	ground surface grade
H	depth of operation (cm)
K	load concentration factor
K_0	shock factor
K_1, K_2	draft correction coefficients
K_d	dynamic load factor
K_v	velocity factor
m	module (mm)
n	number of cultivator tynes/ bottom of MB plough
n_1	first gear ratio
N_d	number of disc blade on a gang
n_p	number of pairs of friction surfaces
n_x x^{th}	gear ratio
N_{eg}	gear rpm
N_r	engine rated rpm
N_{tm}	engine rpm at maximum torque
p	circular pitch (mm)
p	maximum facing pressure (N/mm^2)

P	diametral pitch (mm)
P_r	primary gear ratio
P_t	tractor engine power (kW)
r_r	rolling radius (m)
R_g	grade resistance (N)
R_r	rolling resistance (N)
R_t	total resistance (N)
s	service factor
s_1	tooth thickness on pitch circle for a driver gear (mm)
s_2	tooth thickness on pitch circle for a driven gear (mm)
S_f	spline friction factor
S_d	disc spacing (m)
T	torque transmitted by the clutch (Nm)
T_d	design torque (Nm)
T_m	maximum engine torque (Nm)
T_{mg}	maximum torque at a gear (Nm)
u_t	ultimate strength (N/mm^2)
v	peripheral velocity (m/s)
V_{max}	maximum tractor travel velocity on road (km/h)
V_a	speed of operation (km/h)
w	cutting width of each bottom of MB plough (m)
W	tractor weight (N)
W_c	cutting width of tillage implement (m)
y	number of gears
y_m	topping (mm)
x	gear number
x_1	profile correction factor of a driver gear
x_2	profile correction factor of a driven gear
z	gear reduction ratio
z_1	number of teeth on pinion
z_2	number of teeth on gear
α	theoretical pressure angle (^{0})
α_w	working pressure angle (^{0})
μ	coefficient of friction
η_t	transmission efficiency (decimal)

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