IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 7, Issue 3, March 2020

Development of an Android App for Predicting Stability of a Tractor

Divya Shukla[1], Tanisha Pandey[2]

Student, Department of Agricultural and Food Engineering, IIT, Kharagpur, India[1,2]

Abstract: Stability and traction is a subject of great concern to farm mechanization engineers and researchers. A very limited effort has been made to create an interface that can accurately simulate the output of a 2WD tractor with a suspended working implement on different kinds of soil. The Application offers an interactive user interface to estimate the performance of a chosen tractor and model by connecting databases such as tractor specifications and traction equation coefficients. Android Technology has been developed for 2WD tractors fitted with radial- and bias- tyres, in order to assess tractive performance as well as suitable field stability conditions. The minimal load to be maintained on the front axle of the tractor was kept as 20 % of the tractor's overall static weight.

Keywords: Prediction model, Tractive performance, radial-ply tyre, bias ply tyre, android studio, android application.

I. INTRODUCTION

Farming plays a significant part in India's economic growth. Given the great use of tractors, its suitability for varying load and surface conditions must be analysed and remedial steps should be recommended for safe and efficient operation. One realistic solution is to do performance monitoring, which is time-consuming and exercising. Another way to examining the dynamics and stability of tractors is to go for computer simulation. Computer models and simulation systems for tractor performance prediction assist researchers to assess the relative importance of several factors influencing tractor field performance without pricey evaluations as well as time-consuming field tests. These also help investigators and manufacturers to improve the efficiency of the tractor by comparing and evaluating different parameters that affect tractor efficiency. The soil-vehicle interface is the prime reason for low traction efficiency (for transmission output of nearly 90 percent, estimated around 60 percent on farmland). Computer models or simulation tools enhance performance for researchers and tractor manufacturers.

With the rapid advancement of computer software and hardware, it's important to take benefit of the recently released programming tools like Android Studio to build Android App for farm machinery research programs. The application will predict the efficiency metrics for a given tractor by using tractor model databases, tire details and coefficients of traction formula.

II. THEORETICAL CONSIDERATIONS

All the formulas used were taken from, “Principles of farm machinery” by Kepner,R.A, Bainer, R. and Berger, E.L. 1978.

A. *Power Relationship in Agricultural Tractors*

According to ASAE standards D497.4 MAR99, Power at a given location in the drive train can be used to estimate power at another location. For example, PTO power can be estimated from net flywheel power by multiplying the net flywheel power by 0.90. If drawbar power is desired, choose the tractor type and tractive condition to determine the ratio. Fig. 1 below demonstrates the power relationship at the various outlets in an agricultural tractor.

B. *Soil Reaction on implement*

The cutting width of the machine or implement can be given as:

- For mould board plough

WTH = n*w

where n = number of bottoms of MB plough and w = cutting width of each bottom of MB plough.

- For cultivator

WTH = n

where n = number of cultivator tines.

- For offset disc harrow

$WTH = 0.95\ N*S_d – 0.6*D_d$

where N = number of disc blade on a gang, S_d = disc spacing and D_d= diameter of disc blade.

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 7, Issue 3, March 2020

C. *Dynamics of 2WD tractor*

The forces acting on tractor-implement combinations is considered to be under dynamic condition when determine the various forces acting on tractor-implement system. The effect of inertia force of the tractor was also considered to study its dynamic behaviour. In the analysis the centre of gravity of the tractor was assumed to be in the vertical plane passing through the midpoint of both the axles.

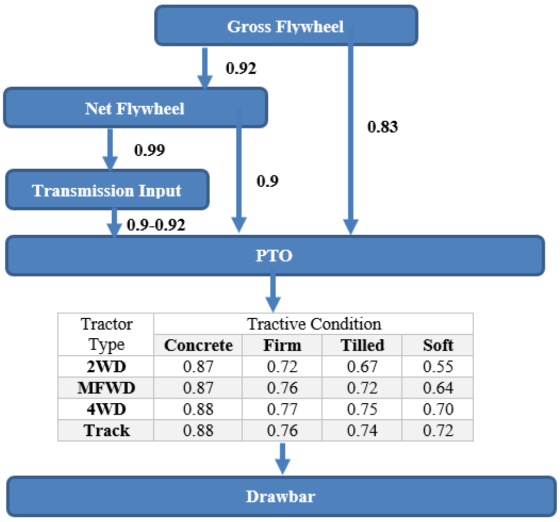

Fig 1 Power relationship for agricultural tractors

Similarly, the centre of gravity of tillage Implement was assumed to be in the vertical plane passing through the midpoint of the cross shaft parallel to the direction of motion. The dynamic reactions against the rear and front wheels were considered acting ahead of rear and front axle centres. These distances were determined using a relationship

e = p*r

Where, p is motion resistance ratio (MR/R, MR the motion resistance, R the dynamic wheel reaction) and r is the rolling radius.

D. *ASABE model for draft prediction*

$$D = F_j(A + B \times Va + C \times Va \times Va) \times W \times H$$

Where, A, B, C are machine specific parameters, F = Soil texture adjustment parameters

j = 1 for fine, 2 for medium textured soil, 3 for coarse textured soil

Va = Actual velocity (kmph), W = width of the implement (m) and H = Tillage depth (cm).

As the linkage forces is not available, pull required to the implement:

$$P = \left(\frac{D}{9.81}\right) + Wm * sin\beta$$

Where, P = pull required(kg), Wm = Weight of the implement (kg) and β= land slope, degree

Vertical component of the pull:

V = P * sin (β)

TABLE 2 THE VALUES OF CORRECTION COEFFICIENTS IN ASABE EQUATION FOR FIELD OPERATIONS

Tillage Implements	Machine Specific Parameters			Soil texture adjustment Parameters		
	A	B	C	F1	F2	F3
M.B. Plough	652.0	0.0	5.1	1	0.70	0.45
Cultivator Primary Tillage	46.0	2.8	0.0	1	0.85	0.65
Secondary Tillage	32.0	1.9	0.0	1	0.85	0.65
Disc Harrow Primary Tillage	364	18.8	0.0	1	0.88	0.78
Secondary Tillage	254	13.2	0.0	1	0.88	0.78

DOI 10.17148/IARJSET.2020.7307

Following assumptions were made in developing the dynamic equations of tractor implement combination:
1. Centre of gravity of tractor is located without operator.
2. Angular motion of wheel of tractor is ignored.
3. Implement is operating at uniform depth.
4. The sinkage and deflection of tires are reasonably small as compared to the rolling radii of tires and hence neglected.
5. Air resistance is neglected.
6. The two lower links are of equal length and coincide together when viewed from the sides i.e. two lower hitch points lie at the same height above the ground level.
7. Centre of resistance is located at a distance of two-third of depth of operation from ground surface.
8. The centre of gravity of M.B plough is assumed to be in the vertical plane passing through the mid-point of the cross shaft parallel to the direction of motion.

- Dynamic reaction on tractor

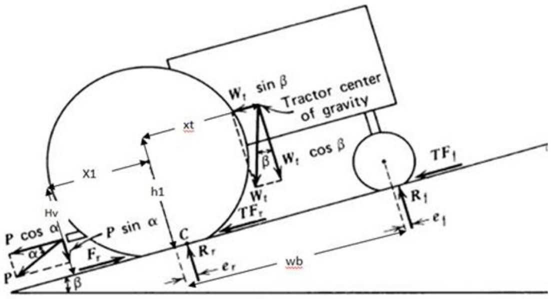

Fig. 2 Schematic representation of dynamic reaction on tractor

$$Rr = \frac{1}{(wb+ef-er)}\left\{ Wt*(wb+ef-xt)+\left(Wt*h1\left(\left(\frac{acc}{9.81}\right)+sin\beta\right)\right)+ \atop v*(x1+wb+ef)+d*Hv \right\}$$

$$Rf = Wt*cos\beta + v - Rr$$

Where, wb = Wheel base, ef = eccentricity of front tire, er = eccentricity of rear tire, xt = Tractor CG from rear axle, d = Draft, x1 = Hitch point from tractor rear axle, acc = acceleration of tractor, Hv = Tractor hitch height above ground, Wt = Total weight of the tractor, h1 = Tractor CG above ground level, Rr = Dynamic reaction on rear wheel, Rf = Dynamic reaction on front wheel .

D. *Traction Performance Parameters for a Single Wheel*

- Coefficient of rolling resistance of tires of tractors

Rolling resistance comprises of two major components, the internal rolling resistance is caused by the tire flexing wheel rotates and the external rolling resistance that is the energy loss in deforming the soil is caused due to continually climbing out of the depression made. Coefficient of rolling resistance is defined as the ratio of rolling resistance and dynamic weight on wheel. The coefficient of rolling resistance of driving tire is calculated by:

a) For bias ply tire using an equation developed in the development in the Department of Agricultural and Food Engineering at IIT Kharagpur:

$$\rho = \frac{1.2}{Bn} + 0.035 + \frac{0.77*s}{\sqrt{Bn}}$$

b) For radial ply tire using Brixius equation:

$$\rho = \frac{0.9}{Bn} + 0.032 + \frac{0.5*s}{\sqrt{Bn}}$$

The coefficient of rolling resistance for towed wheel is calculated by putting S=0 in the above equation.

- Tractive force from soil tire interaction

Maximum tractive force for any surface is calculate by:

DOI 10.17148/IARJSET.2020.7307

a) For bias ply tire using an equation developed in the development in the department of Agricultural and Food Engineering at IIT Kharagpur:

$$Fb = \left(\frac{Rr}{2}\right) * (0.66 * (1 - e^{-0.09Bn}) * (1 - e^{-5.25S}) + 0.035$$

b) For radial ply tire using Brixius equation:

$$Fb = \left(\frac{Rr}{2}\right) * (0.88 * (1 - e^{-0.1Bn}) * (1 - e^{-9.5S}) + 0.032$$

- Required Tractive Force

The tractive force required can be calculated by:

$$Fr = d + (Rr * \rho r) + \left(Wt * \frac{acc}{9.81}\right) + (Wt * sin\beta) + Rf * \rho f$$

E. *Tractor performance prediction program*

For both bias-ply and radial ply tires, a modular, object-oriented, consumer-friendly application system was required to estimate the field and haulage performance of 2WD tractors on agricultural lands. Thus, an android app is to be developed specifically for this purpose. The program starts with an opening screen in which tractor's specification, implement parameters and soil parameters has to be entered. After entering all the specifications, the result screen opens by pressing the enter key.

The output screen for field performance shows tractor performance data such as tractive efficiency (TE), net traction ratio (NTR), and wheel slip (S). These parameters are defined as follows.

- Wheel slip

When a tractor pulls a load, the tire stretches and the soil moves in response to the applied drawbar pull, which causes wheel slip. It is expressed as the ratio of decrease in the speed to the theoretical speed and is given by:

$$S = 1 - \frac{V_a}{V_t}$$

Where V_a= Actual velocity and V_t = Theoretical velocity.

- Coefficient of traction

It is ratio of drawbar pull to the dynamic weight on the driving tire.

$$COT = \frac{P}{Rr}$$

Where, P = Pull (N) and Rr = dynamic tractor rear wheel reaction (N).

- Tractive efficiency

Tractive efficiency of a driving wheel is the ratio of output power and input power. For a single wheel it can be calculated as:

$$\text{TE} = \frac{\text{NTR}}{\text{GTR}}(1 - S)$$

Where, NTR = Net Traction ratio, GTR = Gross Traction Ratio and S = slip.

III. METHODS AND MATERIALS

A. *Data Management and Analysis*

A spreadsheet is used to develop a database for Draft and other Parameters from Budni tractor test reports. The Draft and Slip data were collected from the tests at different gear of tractor. After entering the tractor test data into the spread sheet accuracy of existing ASABE and different prediction models were checked by predicting the Draft and slip from these models using Budni tractor test report and comparing that with the laboratory data.

B. *Simulation of Tractive Performance of Tractors*

An Android application on the Android Studio Platform is being developed. Android Studio is the standard integrated development environment (IDE) for Google-running Android platform. For developing an application, the user has to work separately for the front end and the back end. For the front end the code must be written on the .xml files and for the back end the code must be written on .java files. In .java files the code is written in java language and the application works on that code only. This application has three parameter checks, CG location of the tractor, Stability check and tractive performance of tractor with mounted implement. For each option first of all, one has to select the tractor model or enter the specification (fig.3). If CG location is selected, then one has to enter some data as shown in Fig. 6 The specification screen for the tractor displays in Fig. 4, which contains information such as tractor model, tractor power at rated engine speed, static weight distribution, wheelbase. The tyre database contains tyre type (radial or bias-ply) and parameters such as tyre size, section width, overall diameter and static loaded radius. The Stability input screen is shown in Fig. 9. In which one has to enter the hitch location and CG location w.r.t rear axle centre, Turning Radius, track width of the tractor etc. However, if tractive performance is selected then one has to select the tractor and the implement options and after that an input screen will occur in which one has to enter the implement specifications as shown in fig. 15, 16 and 17 for different implements. After that Operating parameters are shown in Fig. 18 and tractive performance output parameters are shown in Fig. 19.

TABLE 3 INPUT AND OUTPUT PARAMETERS

Sl. No.	Category	List of parameters
1	Tractor related Parameters	Static weight, wheel base, tyre sizes, tractor power, speeds in different gear at rated rpm etc.
2	Implement related Parameters	Type of implement, Size, weight.
3	Soil related Parameters	Soil Type and Soil cone index
4	System related Parameters	Actual forward speed, mode of operation, depth of operation etc.
5	Output Parameters	Tractive efficiency, wheel slip, actual speed, COT, draft. Critical Pull, Critical Speed and CG location.

C. *Screens of Application*

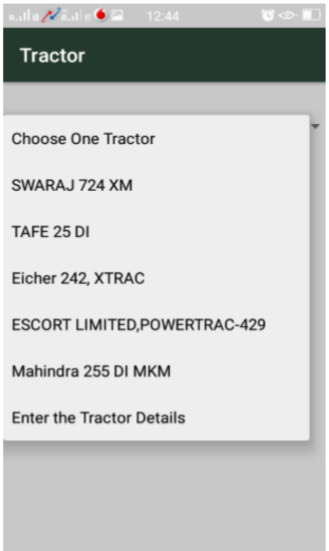

Fig. 3 Tractor selection screen

Fig. 4 Tractor specifications screen

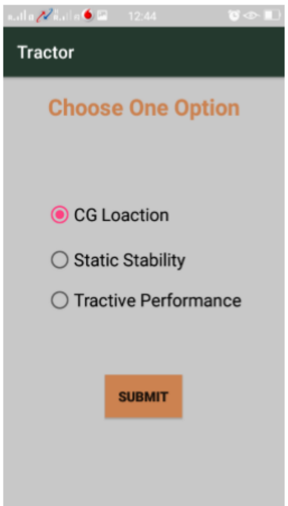

Fig.5 Screen for Operation check

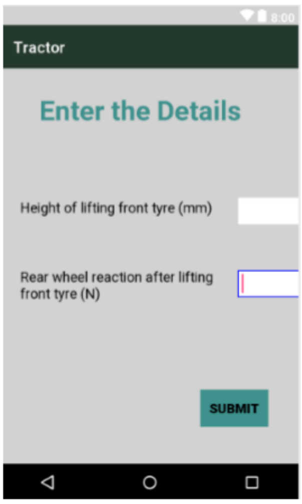

Fig.6 Input screen for calculating CG location

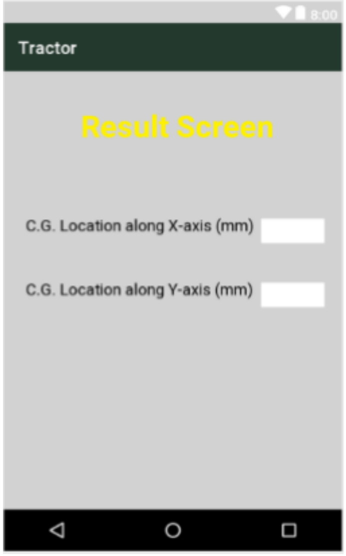

Fig.7 Result screen of CG operation

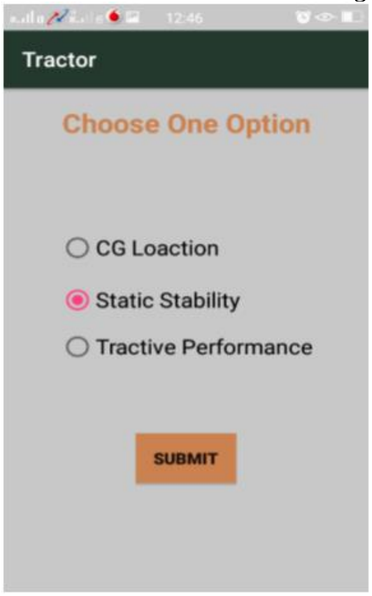

Fig.8 Screen for Operation check

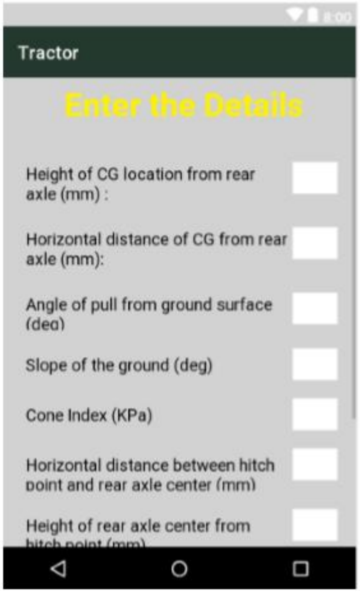

Fig. 9 Input screen for calculating Stability parameters

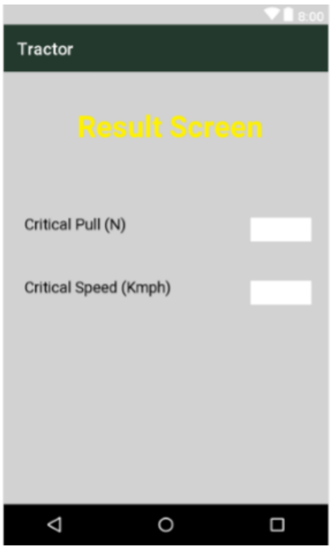

Fig. 10 Result screen for stability parameters

IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Vol. 7, Issue 3, March 2020

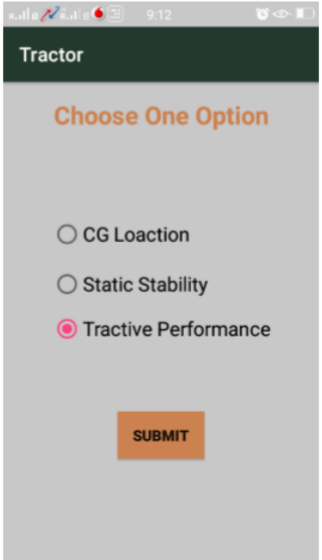

Fig. 11 Screen for Operation check

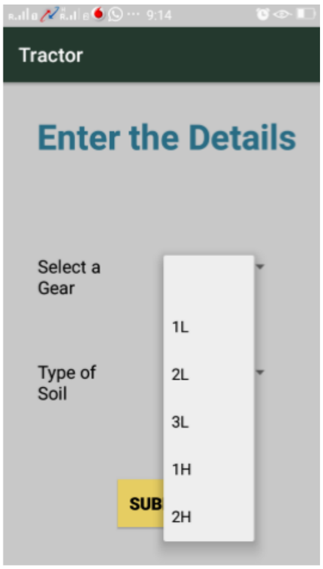

Fig. 12 Input screen for selecting the operating gear

Fig. 13 Input screen for selecting the operating soil type

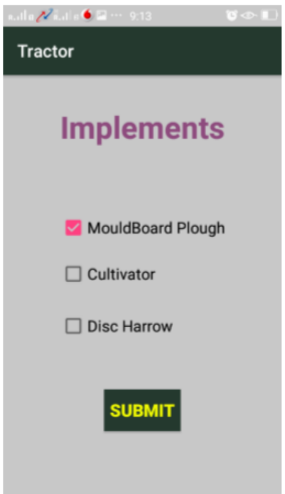

Fig. 14 Screen for Implement check

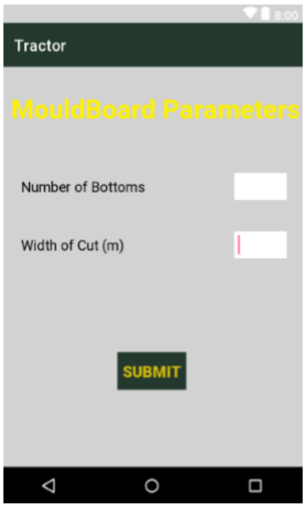

Fig. 15 Input screen for MB Plough

IARJSET
ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Vol. 7, Issue 3, March 2020

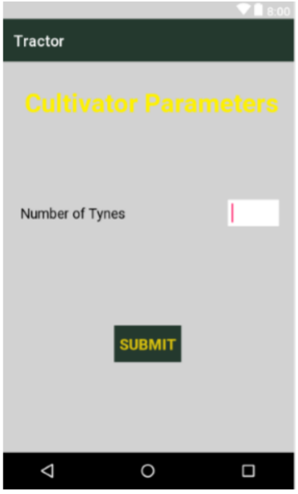

Fig. 16 Input screen for Cultivator

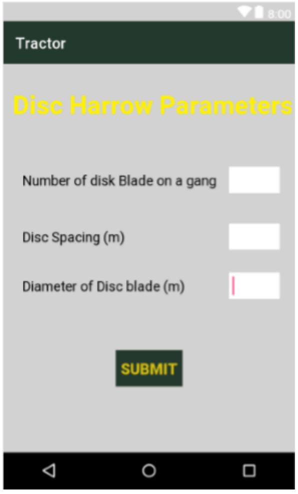

Fig. 17 Input screen for Disk Harrow

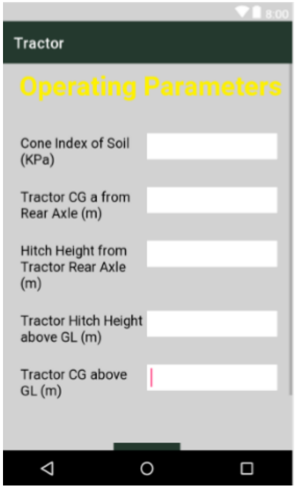

Fig. 18 Input screen for operating parameters

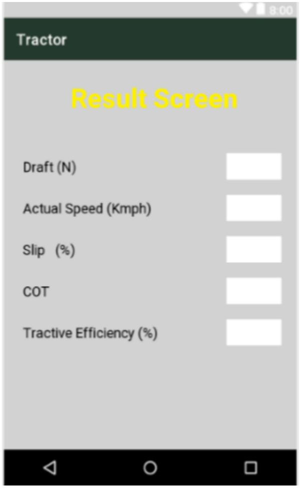

Fig. 19 Result screen for tractive performance

D. *Flow Chart*

The flowchart, which has been followed for simulation of tractive performance in Figs. 20, the result parameters has been calculated by iterative method for best results. The Application can predict the tractive performance and also predict the stability parameters and can be used for 2-wheel drive tractors by following this programming structure.

E. *Comparison of Predictions of Computer Simulation with Results of Field*

Experiments The results of field experiments were analysed and compared with computer simulation results of drawbar pull, wheel slip, drawbar power, actual velocity, coefficient of traction, Tractive efficiency.

IV. RESULTS AND DISCUSSION

The comparison between the experimental and predicted results of field operation is given in Tables 4 to 9. The data indicate that for MB plough, the developed application under predict slip by 6 to 25 per cent for radial-ply tire and over predict by 9 to 15 per cent for bias-ply tire. For cultivator, the developed application over predicts slip by 7 to 27 per cent for radial-ply tire and 6 to 30 per cent for bias-ply tire. For disc harrow, the developed application over predicts slip by 2 to 16 per cent for radial-ply tire and under predict slip by 3 to 6 per cent for bias-ply tire.

As Brixius model was used for radial ply tire, so it might be possible that Brixius equation is not valid for Indian condition. It was found that for MB plough and cultivator the developed application under predicts the draft by 12 to -7 per cent for radial-ply tire and 11 to 15 per cent for bias-ply tire. And for cultivator the application under predict draft by 10 to 24 per cent for radial-ply tire and under predict by 13 to 17 per cent for bias-ply tire. However, for disc harrow the application over predict draft by 3 to 4 per cent for radial-ply tire and under predict by 1 to 3 per cent for bias-ply tire. For the validation of CG location parameters, the test reports have been taken of different tractors available in database of the application from Central Farm Machinery Training and Testing Institute, Budni. And after comparing the results, very less variation in predicted values from measured values were found.

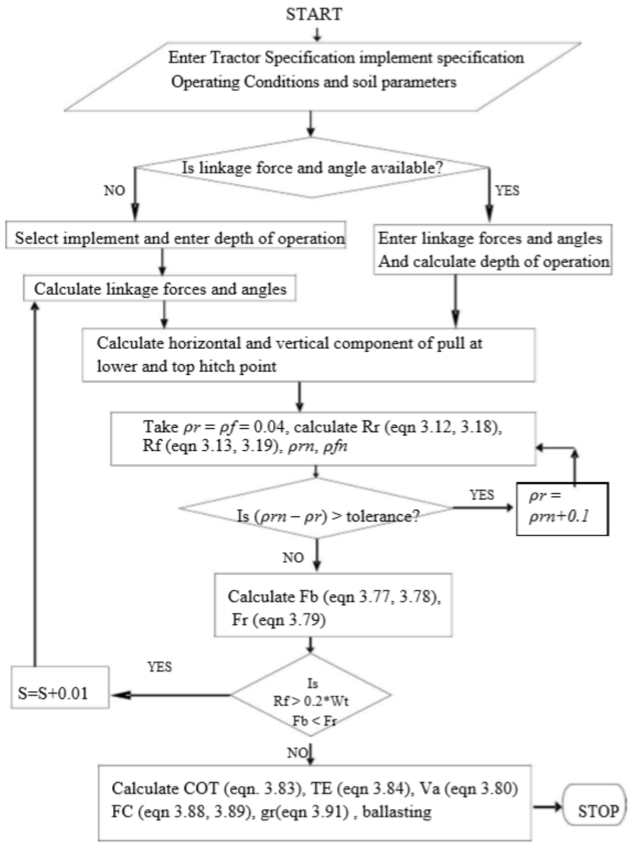

Fig. 20 Flowchart for predicting tractor performance in field

TABLE 4 COMPARISON BETWEEN EXPERIMENTAL AND PREDICTED RESULTS OF FIELD OPERATION WITH MB PLOUGH FOR RADIAL-PLY TIRE

Gear	Slip, %			Draft kN			Drawbar power, kW			Tractive efficiency, %		
	Experimental (E)	Predicted (P)	Variation (P-E)*100/E	Experimental	Predicted	Variation	Experimental	Predicted	Variation	Experimental	Predicted	Variation
L1	36.53	27.10	-25.81	6.88	5.99	-12.93	11.12	12.28	10.43	55.22	64.80	17.34
L2	35.54	29.10	-18.12	6.78	6.34	-6.48	11.68	12.18	4.30	56.21	62.89	11.88
L3	34.44	30.13	-12.51	6.67	6.69	0.299	12.24	12.51	2.22	67.27	62.38	-7.27
L4	33.14	31.05	-6.30	6.63	7.14	7.69	12.78	12.59	-1.56	58.16	61.91	6.45

TABLE 5 COMPARISON BETWEEN EXPERIMENTAL AND PREDICTED RESULTS OF FIELD OPERATION WITH MB PLOUGH FOR BIAS-PLY TIRE

Gear	Slip, %			Draft kN			Drawbar power, kW			Tractive efficiency, %		
	Experimental (E)	Predicted (P)	Variation (P-E)*100/E	Experimental	Predicted	Variation	Experimental	Predicted	Variation	Experimental	Predicted	Variation
L1	36.02	34.10	15.63	7.20	5.97	-15.76	11.40	8.28	-27.37	64.90	56.58	-13.19
L2	34.66	34.10	6.05	6.94	6.27	-13.40	11.67	8.88	-23.95	65.83	56.97	-12.15
L3	33.19	35.10	9.39	6.82	6.56	-11.36	11.87	9.04	-23.82	66.37	56.45	-14.04

TABLE 6 COMPARISON BETWEEN EXPERIMENTAL AND PREDICTED RESULTS OF FIELD OPERATION WITH CULTIVATOR FOR RADIAL-PLY TIRE

	Slip, %			Draft kN			Drawbar power, kW			Tractive efficiency, %		
Gear	Experimental (E)	Predicted (P)	Variation (P-E)*100/E	Experimental	Predicted	Variation	Experimental	Predicted	Variation	Experimental	Predicted	Variation
L1	24.06	24.10	0.16	5.78	4.35	-24.74	8.84	8.81	-0.32	64.39	64.77	0.59
L2	23.40	25.03	7.26	5.66	4.60	-18.72	8.94	8.84	-1.09	64.60	64.43	0.26
L3	21.89	25.34	15.76	5.62	4.78	-14.94	9.17	8.81	-3.95	65.36	64.76	-0.92
L4	19.74	25.13	27.15	5.57	4.96	-10.95	10.00	9.12	-8.79	66.90	65.08	-2.72

TABLE 7 COMPARISON BETWEEN EXPERIMENTAL AND PREDICTED RESULTS OF FIELD OPERATION WITH CULTIVATOR FOR BIAS-PLY TIRE

Gear	Slip, %			Draft kN			Drawbar power, kW			Tractive efficiency, %		
	Experimental (E)	Predicted (P)	Variation (P-E)*100/E	Experimental	Predicted	Variation	Experimental	Predicted	Variation	Experimental	Predicted	Variation
L1	26.46	28.11	6.23	4.99	4.34	-13.02	7.73	7.76	0.37	62.16	59.29	-4.62
L2	25.07	28.38	13.20	5.29	4.58	-13.42	7.84	7.72	-1.64	62.76	59.02	-5.96
L3	22.36	29.10	30.14	5.65	4.74	-16.10	7.95	7.62	-4.23	63.25	59.35	-6.16

TABLE 8 COMPARISON BETWEEN EXPERIMENTAL AND PREDICTED RESULTS OF FIELD OPERATION WITH DISC HARROW FOR RADIAL-PLY TIRE

Gear	Slip, %			Draft kN			Drawbar power, kW			Tractive efficiency, %		
	Experimental (E)	Predicted (P)	Variation (P-E)*100/E	Experimental	Predicted	Variation	Experimental	Predicted	Variation	Experimental	Predicted	Variation
L1	28.61	26.75	-6.48	5.92	5.69	-3.89	7.87	8.03	2.03	65.53	67.29	2.68
L2	25.87	25.00	-3.36	5.78	5.23	-9.51	8.37	8.43	0.71	70.64	73.95	4.68
L3	24.56	23.90	-2.67	5.64	4.99	-11.52	8.58	8.62	0.46	69.34	74.26	4.92

TABLE 9 COMPARISON BETWEEN EXPERIMENTAL AND PREDICTED RESULTS OF FIELD OPERATION WITH HARROW FOR BIAS-PLY TIRE

Gear	Slip, %			Draft kN			Drawbar power, kW			Tractive efficiency, %		
	Experimental (E)	Predicted (P)	Variation (P-E)*100/E	Experimental	Predicted	Variation	Experimental	Predicted	Variation	Experimental	Predicted	Variation
L1	26.02	28.10	7.99	5.57	5.75	3.14	8.37	10.36	23.74	64.14	76.96	19.97
L2	24.14	26.03	7.23	5.56	5.74	3.24	9.27	10.53	13.53	65.70	77.26	9.95
L3	22.60	20.97	-7.21	5.57	5.76	3.32	9.83	10.68	8.70	66.60	77.47	5.20
L4	21.26	23.13	8.79	5.50	5.75	4.55	10.30	10.75	4.40	67.64	77.61	-0.15

V. CONCLUSION

A flexible, user friendly Application with the help of Android Studio was developed for the field performance simulation. The developed application was validated using the Budni test reports of the tractor models available in database. The various studies conducted led to the following conclusions:

1. The database prepared is quite useful for researchers and engineers.
2. By the help of developed application, the calculation of CG location of any particular tractor model or any tractor very easily or in no time.
3. The developed application can predict the suitable stability conditions of 2 WD tractors with bias-ply and radial-ply tires and suspended implements in the field which can ensure the safety of the driver.
4. The developed tractive performance prediction application has ability to predict tractive performance of 2 WD tractors with bias-ply and radial-ply tires for mounted implements.
5. For field operation with 2 WD tractors equipped with bias-ply and attached with MB plough the developed software was found to under predict slip by 9 to 15 per cent and draft by 11 to 16 per cent.
6. For field operation with 2 WD tractors equipped with bias-ply and attached with cultivator the developed software under predicted slip by 7 to 18 per cent and draft by 12 to 16 per cent.
7. For field operation with 2 WD tractor equipped with bias-ply and attached with disc harrow the developed software was found to under predict slip by 3 to 6 per cent and draft by 4 to -1 per cent.

ACKNOWLEDGMENT

Authors avail this unique opportunity and proud privilege to express my profound sense of gratitude and indebtedness to my project supervisor **Dr. Rajendra Machavarm**, Professor, Department of Agricultural and Food engineering, IIT, Kharagpur, for his efficacious advises perpetual and prolific encouragement and creative criticism during the course of the work and preparation of the project.

REFERENCES

[1]. Al-Hamed, S.A., Grisso, R.D., Zoz, F.M. and Von Bargen, K. 1994. Tractor performance spreadsheet for radial tires. Computer and Electronics in Agriculture, 10, 45–62.
[2]. Brixius, W.W. 1987. Traction prediction equations for bias ply tires. ASAE Paper 87-1622, 8 pp.
[3]. Kepner,R.A, Bainer, R. and Berger, E.L. 1978. Principles of farm machinery. Third edition, CBS Publishers and distributors, New Delhi.
[4]. Tiwari, V.K. 2006. Traction potential of bias ply tyre used in agricultural tractors. Unpublished PhD Thesis, Agricultural and Food Engineering Department, IIT, Kharagpur.
[5]. S.K. Upadhyaya, D. Wulfsohn, G. Jubbal (1989). Traction prediction equation for radial ply tires. Journal of Terramechanics, 26 : 149-175
[6]. Kumar, R., Pandey, K.P.(2009). A program in Visual Basic for predicting haulage and field performance of 2WD tractors. Computer and Electronics in Agriculture, 67 (1–2) : 18–26.
[7]. Kumar, R. (2011). Dynamic behavior of a 39kW diesel tractor for field and haulage performance Unpublished M.Tech Thesis, Agricultural and Food Engineering Department, IIT, Kharagpur.
[8]. B. Kolatora, I. Białobrzewskib (2011). A simulation model of 2WD tractor performance. Computers and Electronics in Agriculture 76 : 231–239.
[9]. Iman Ahmadi (2011). Dynamics of tractor lateral overturn on slopes under the influence of position disturbances (model development). Journal of Terramechanics 48 : 339-346.
[10]. Bo Liu a, A. Bulent Koc (2013). SafeDriving: A mobile application for tractor rollover detection and emergency reporting Computers and Electronics in Agriculture,98 : 117–120.
[11]. Kumar, R. (2011). Dynamic behavior of a 39kW diesel tractor for field and haulage performance Unpublished M.Tech Thesis, Agricultural and Food Engineering Department, IIT, Kharagpur.
[12]. Kumar, N. (2011). Integration of engine, gear and implement load for best fuel economy for a 32kW tractor. Unpublished M.Tech Thesis, Agricultural and Food Engineering Department, IIT, Kharagpur.
[13]. Sahu, R. (2015). Computation and simulation of implement for filed performance. Unpublished M.Tech Thesis, Agricultural and Food Engineering Department, IIT, Kharagpur.