Saber, Universidad de Oriente, Venezuela. Vol. 33: 91-106. (2021). https://doi.org/10.5281/zenodo.5808811
ISSN: 2343-6468 Digital / Depósito Legal ppi 198702SU4231 ISSN: 1315-0162 Impreso / Depósito Legal pp 198702SU187

AGRICULTURAL TRACTORS VIRTUAL POINT ANALYSIS WITH VISUAL BASIC

ANÁLISIS DEL PUNTO VIRTUAL DEL TRACTOR AGRÍCOLA CON VISUAL BASIC

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ABSTRACT

In this report, the virtual point of an agricultural-implement tractor three linkage system was analyzed mathematically using Visual Basic, including a system of equations for the tractor virtual point position, its center of gravity sites, and force transferences. The objectives consisted in presenting X-Y coordinates of the virtual point derived from the three points hitching system, plus the implement center of load for mounted implements. The Visual Basic procedures resulted adequately applicable, easy calculation with the possibility of changes and adaptation to the three triangle analyzed to describe the virtual point. The virtual point resulted concurrence with the tractor-implement gravity center. The total weight 30/70 percent distribution to front/rear wheels was obtained by changing the top link length giving the same results with the two calculation methods.

KEY WORDS: Force conveyance, tractor categories, static analysis.

RESUMEN

En este artículo, el punto virtual del enganche de tres puntos de un tractor agrícola se analizó matemáticamente usando Visual Basic, para generar la posición del punto virtual de un sistema de ecuaciones, posición del centro de gravedad y las transferencias de fuerzas. Los objetivos consistieron en presentar (en coordenadas X-Y) el punto virtual derivado del sistema de enganche de tres puntos para implementos montados, incluido el centro de cargas. Los procedimientos de Visual Basic resultaron adecuadamente aplicables, de fácil cálculo con la posibilidad de cambios y adaptación a los tres triángulos analizados para obtener el punto virtual. El punto virtual resultó coincidir con el centro de gravedad de la unidad tractor-implemento. El peso total del tractor-implemento distribuido el 30/70 por ciento en los ejes delanteros/traseros, se logró con la variación longitudinal del brazo superior del sistema de enganche; coincidiendo el mismo resultado con los dos métodos de cálculos utilizados.

PALABRAS CLAVE: Transferencias de fuerzas, categoría de tractores, análisis estáticos.

INTRODUCTION

The agricultural tractor virtual point has been considered as the center of forces generated by a tractor-implement. In this report, the virtual point was analyzed mathematically by means of Visual Basic. A set of linear and quadratic equations for specifying the tractor virtual point position, tractor gravity center relocation and its forces analyses were derived. Three triangles were defined and stablished that described the total system of information. Kumar *et al*. (2018) determined the virtual hitch point applying simulation by solving a straight-line equation of lower and upper links of the three-points hitching system at particular depth of operation, matching the virtual point with the line of pull. The lower links two points are coincident; the upper link point is midway between the lower links. This system allowed complete control of the implement. Convergence of links center lines in a vertical centered plane passing through the upper link side view of the tractor provides a vertical hitch point or instant center of rotation as shown at point V. Location of Vcan readily be changed by modifying arrangement of links and when the implement is raised or lowered. It is lower than and farther to rear when tool is entering the ground. When discussing the motion of the implement, V is termed the instantaneous center of rotation; at that instant, the implement moves as if it was rotating about that point. According to Macmillan (2017), when discussing the implement forces, V is termed the virtual or effective hitch point; at that instant, the implement behaves as if it were attached to the tractor at that point. The line of pull passes through the effective hitch point that tends to add weight to the tractor rear wheels. The three-hitching points permit joining an implement, forming a tractor-

Recibido: julio 2020. Aprobado: febrero 2021.
Versión final: abril 2021.

implement unity, allowing weigh transference, traction increase, easy hitching, new center of gravity and constant soil depth. The objectives consisted in defining the virtual hitch point by lengthening its links parallel center lines till they cross. Three triangles defined the virtual point, hitching points and the implement center of load. A set of equations that locate the virtual point, the three triangles components (points, sides and angles), the implement center of load, all the hitching system points and forces that actuates; all of them, referenced by a cartesian coordinate system. The solutions were found with Visual Basic Program.

MATERIALS AND METHODS

Applying Visual Basic as calculating codes are partially shown on line. This comprehensive method proposes a mathematical analysis of a set of equations engendered from three triangle defining the tractor virtual point, gravity center and loads allotment. The package is accessible without possessing the Visual Basic program based on its properties. The program was assembled so that changes, improvements and adaptation are possible (PTM 1998, Mohammed 2012).

On apply force transfer and reaction in this report; force transference consisted of knowing how they affect any part, and force reaction in finding out how they affect another body; transfer does not change force direction, reaction does; both methods utilize the same static equations. The center of gravity is defined as the point of equal weight distribution. On any tractor, the CG varies under different conditions. The two-wheel drive tractor CG is typically about 25.4 mm above and 60 mm in front of the rear axle when looking from back to front, and in the center of the tractor body when looking left to right. Approximately, 30 percent of the tractor weight on the front axle, and 70 percent on the rear axle. For four-wheel drive and center-articulated tractors, the CG is located slightly more forward (Badman & Oak 2012, Murphy 2014, Hanna *et al*. 2018). The CG must remain within the tractor's stability baseline. Stability base lines are imaginary lines drawn between points where the tractor tires contact the ground. In this article, on recommended that tractors should be designed by using the 70-30 percent for single traction and about 60-40% for double traction and center-articulated. Whenever mounted or semi-mounted equipment are raised, the CG is also raised, decreasing tractor stability. Any changes in weight from an attachment, the CG shift toward the weight. Implements that are side mounted shift the center of gravity toward the attachment (Tractor Stability 2014). A method to determine the movement of the tractor CG is shown graphically and arithmetically. Two examples are included.

The tractor three points hitching involves four points: A, B, C and V; these points make three triangles: ABV, ABC and ACV, Figure 1. The triangles engender a set of trigonometric and algebraic equations that localize and connect points C and V. The system of forces represented by sign symbols employing static equations and moments summation.

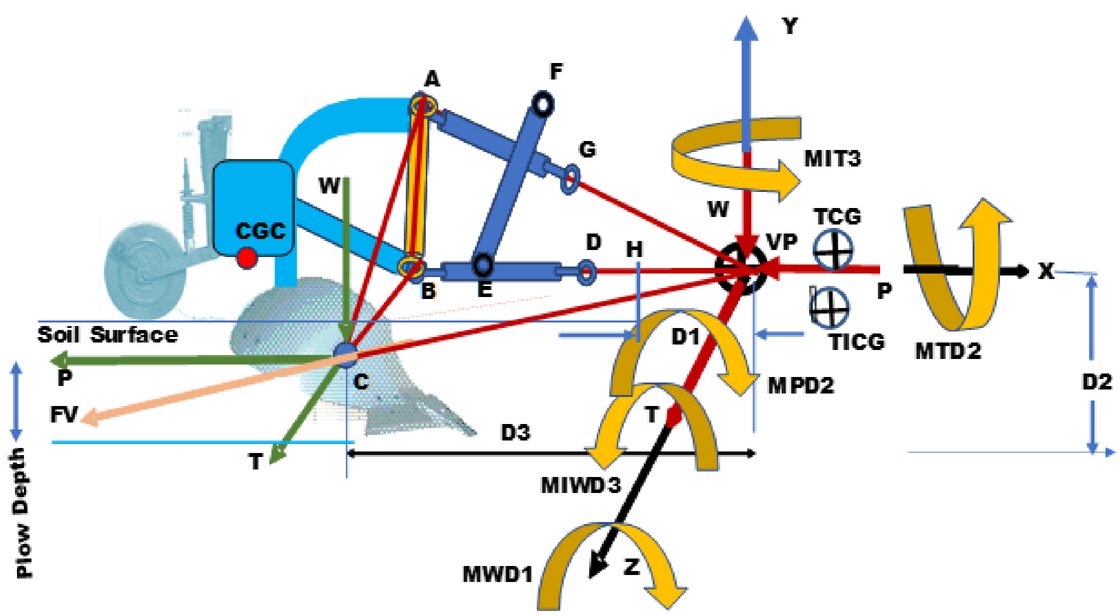

Figure 1. The three triangles, virtual point V and tractor centroids sites.

On employed two methods named PROC 1 applying 70/30 percentages on wheelbase weight distribution and PROC 2 to obtain the CG position based on wheel axles reaction, distance from rear axle and fraction calculation.

Method 1 (PROC 1)

TICG = (((TTIW * FPW) / 100) * TWB) / TTIW 1
TCG = (((W * FPW) / 100) * TWB) / W2
FR = (TTIW * FPW) / 100 'FR = Val(W) + TIW – TRR 3
RR = TTIW – FR4
DRW = RR – RWR5
DFW = FR – FWR6
VP = (((TIW * FPW) / 100) * TWB) / TIW7

Method 2 (PROC 2)

DFW = (TIW * HV) / TWB8
DRW = TIW – DFW9
VP = (DFW * TWB) / TIW10
FWR = (W * HV) / TWB11
RWR = W – FWR12
TCG = (FWR * TWB) / W13
FR = (TTIW * HV) / TWB14
RR = TTIW – FR15
TICG = (FR * TWB) / TTIW16
RWP2 = (RWR / W) * 10017
FWP2 = 100 - RWP218

The two methods achieves the same values by finding the required upper link length. Prove; consider for example, the following Equation 19 procedure:

(TTIW –RWR) *(TWB – XCG) = RWR * XCG19

The examples results are shown in Figures 4 to 12. Table 1 offers a terminologies list employed in the article.

Table 1. Nomenclature.

A	Upper link joint. Triangle point A
A1	Angle between X coordinate and lower links center line
A, B, V	Triangle ABV external link points
A, B, C	Triangle ABC external link points
A, C, V	Triangle ACV external link points
AA, AB, AV	Triangle ABV angles
AC2, AB2, AC2	Triangle ABC angles
AC3, CV3, AV3	Triangle ACV angles
B	Lower links joints
BA, BV, VA	Triangle ABV sides length
BD	Length from point B to point D
BG	Length from point B to point G
C	Implement center of load or forces
CG	Center of gravity
CRW	Length from C to rear wheel axels
CV	Length from C to V
DA	Length from point D to point A
DRW	Rear wheel axle reaction by the implement (kg)
DV	Length from point D to V in lower links
FV	Force of pull from V to C
F_X, F_Y, F_Z	Axis forces at point V
FPW	Front tractor axle reaction percentage (%)
FR	Front axle reaction by tractor-implement weight (kg)
FWR	Front wheel reaction due to tractor weight (kg)
FWP2	Front wheel PROC 2 percentage reaction (%)
GA	Length from G to A
H	Rear tractor axle
HV	Distance from rear axle to virtual point (mm)
ICG	Implement center of gravity
LW	Lower links length (mm)
max	Maximum
M_C	Moment at C due to W
min	Minimum
M_X, M_Y, M_Z	Axis moments at point V
NCG	Tractor new gravity center position due to implement
P	Force of pull in the X direction at point C
PLD	Plow depth
PTO	Power take off
PTOD	Category PTO distance from soil surface (mm)
PROC (K20)	Calculus procedures. Two methods
RR	Rear axle reaction by tractor-implement weight (kg)
RX	X length from C to V
RY	Y length from C to V
RWP2	Rear wheel PROC 2 percentage reaction (%)
RWR	Rear wheel reaction due to tractor weight (kg)
U	Distance from C to B (mm)
U1	Distance from W to C
T	Plow rudder force. Z direction (kg-mm/s^2)
TCG	Distance between rear axle and tractor gravity center

TICG	Distance between rear axle and tractor-Implement gravity center
TTIW	Peso total del tractor-implemento (g)
TIW	Total implement weight (kg)
V	Tractor virtual hitch point
VP	Distance between rear axle and virtual point (mm)
W	Tractor weigh (kg)
TWB	Tractor wheels base length (mm)
XCG	Distance of V from rear tractor axle
y	Distance from V to horizontal line passing by B

RESULTS AND DISCUSSIONS

The Visual Basic flow chart presented in Figure 2 allocates the procedures in six steps to cover the article objectives. According to it, the start of the program occurs from Figure 3, observing that points A, C and V are determined by three triangles: ABV, SBC and ACV that involves the three points hitching systems; firstly, analyzing triangle ABV Form 2, Figure 4, following triangle ABC Form 3, Figure 5, and then triangle ACV Form 4, Figure 6. The CG and force analysis of the hitching systems are carried out with Forms 5 and 6 observed in Figures 7 to 12 shown in the program.

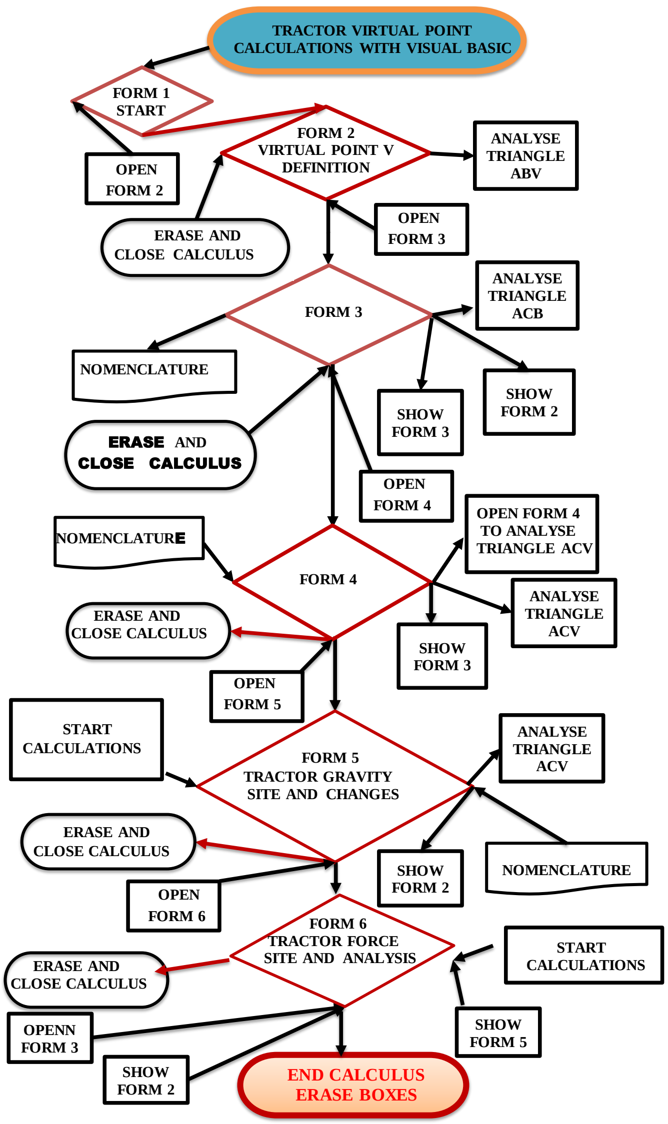

Figure 2. Tractor three hitching point virtual point, gravity center and force analysis Visual Basic flow chart.

Length BD1 represents BD length along the X coordinate, where BD1 is slightly greater than BD. BD1 + DV = X1V in triangle ABV

Program codes

```
‘START WITH FORM1 FOR TOTAL ANALYSIS
‘OPEN FORM 2 FOR TRIANGLE ABV EXAMINATION
```

‘FORM 1

```
‘MOSTRAR EL PRIMER FORMULARIO ABV
Private Sub CMDForm2_Click()
Form2.Show
End Sub 'End FormABV

Private Sub CMDcloseCal_Click()
Beep
Beep
If MsgBox("¿GET OUT?", 36, "TRIANGLE ABV")
= 6 Then
Beep
Beep
End
End If
End Sub 'End Sub cmdCerrarProceso_Click()
```

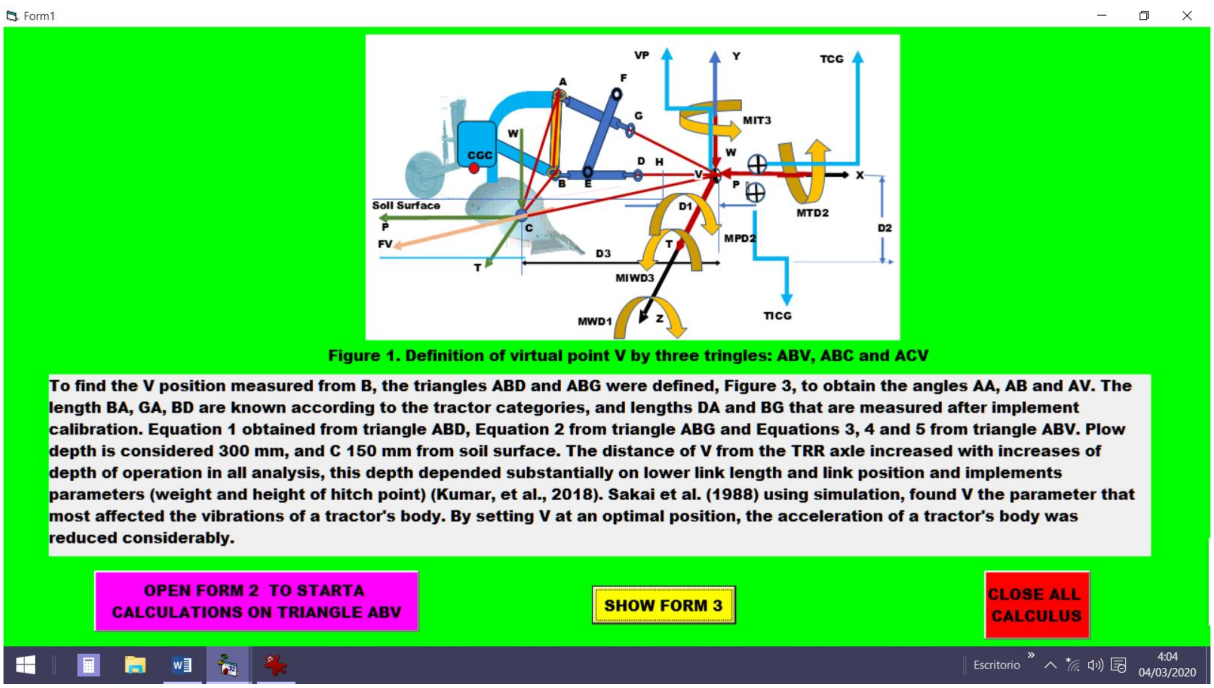

Figure 3. Form 1, definition of virtual point V by three tringles: ABV, ABC and ACV.

'FORM 2

```
'ANALYSIS OF TRIANGLE ABV TO START SIZING POINT V POSITION

'NOMENCLATURE
‘Figure 4 clarifies  most of the terminologies’
'XBH:  Horizontal length from B to H
Private Sub CMDReadCal_Click()

Dim ABR, DA, BG, coAB, DtoR, RtoD, PI, GA, coAA, AAR, AV, BV As Double
Dim y, X1 As Double

PI = 4# * Atn(1#) ‘ PI values
RtoD = 180 / PI ‘Degrees to radians converter
DtoR = 1# / RtoD ‘Radians to degrees converter

'FIND ANGLE ABD
BA = Text1BA
BD = Text1BD
DA = Text1DA
DH = Text1DH
coAB = (BA ^ 2 + BD ^ 2 - DA ^ 2) / (2 * BA * BD)
ABR = Atn(-coAB / Sqr(-coAB * coAB + 1)) + 2 * Atn(1) 'ArCosine
ABD = ABR * RtoD
Text1ABD = ABD
Text1ABD = Format(Text1ABD, "#.###")
```

```
'FIND ANGLE AA
GA = Text1GA
BG = Text1BG
coAA = (BA ^ 2 + GA ^ 2 - BG ^ 2) / (2 * BA * GA)
AAR = Atn(-coAA / Sqr(-coAA * coAA + 1)) + 2 *
Atn(1) 'ArCosine
AAD = AAR * RtoD
Text1AAD = AAD
Text1AAD = Format(Text1AAD, "#.###")

'FIND ANGLE AV
AV = 180 - ABD - AAD
Text1AV = AV
Text1AV = Format(Text1AV, "#.###")

'FIND ANGLE A1.
A1 = ABD - 90
Text1A1 = A1
Text1A1 = Format(Text1A1, "#.###")

'FIND LENGTH VA = (BA*Sin(AB))/Sin(AV)
VA = (BA * Sin(ABR)) / Sin(AV * DtoR)
Text1VA = VA
Text1VA = Format(Text1VA, "#.###")

'FIND LENGTH BV = (BA*Sin(AA))/Sin(AB)
BV = (BA * Sin(AAR)) / Sin(AV * DtoR)
Text1BV = BV
Text1BV = Format(Text1BV, "#.###")
y = BV * Sin(A1 * DtoR)
Text1y = y
Text1y = Format(Text1y, "#.###")

'FIND DV. DV = BV - BD
DV = BV - BD
Text1DV = DV
Text1DV = Format(Text1DV, "#.###")

'FIND Y1
PTOD = Text1PTOD
Y1 = PTOD - y 'For category 2
Text1Y1 = Y1
Text1Y1 = Format(Text1Y1, "#.###")

'FIND X1
X1 = BV * Cos(A1 * DtoR)
Text1X1 = X1
Text1X1 = Format(Text1X1, "#.###")
HV = DV - DH
Text1HV = HV
Text1HV = Format(Text1HV, "#.###")

'FIND DISTANCE FROM B TO H IN THE X
COORDUNATE (BHX)
XBH = Val(BD) + DH + (Val(BD) + DH) * Sin(A1
* DtoR)
Text1XBH = XBH
Text1XBH = Format(Text1XBH, "#.###")
End Sub

Private Sub CMDcloseCal_Click()
Beep
Beep
If MsgBox("¿GET OUT?", 36, "TRIANGLE ABV")
= 6 Then
Beep
Beep
End
End If
End Sub 'End Sub cmdCerrarProceso_Click()

‘MOSTRAR EL PRIMER FORMULARIO ABC
Private Sub CMDForm3_Click()
Form3.Show
End Sub 'End FormABV
```

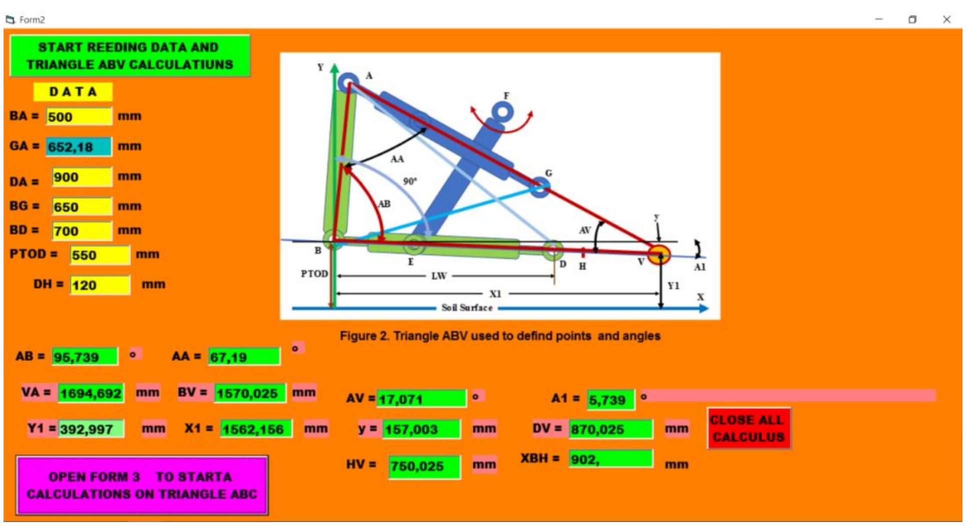

Figure 4. Form 2, triangle ABV analysis.

```
'FORM 3

'START ANALYSIS OF TRIANGLE ABC TO FOLLOW THE IDENTIFICATION OF ‘THE VIRTUAL POINT

'CA:  length CA mm
'CB:  Length CB mm
'CGC: Plow CG depth
'PTOD: Distance from PTO to soil sutface

Private Sub CMDReadCal_Click()

Dim Q3, AA2, K2, K3, CA1, CA2, W3, DV3, CB, CGC, K1, AC2 As Double
Dim X2V, PI As Double

PI = 4# * Atn(1#)
RtoD = 180 / PI
DtoR = 1# / RtoD
CGC = Text1CGC

Y2B = Val(PTOD) + Val(CGC) 'PTOD + CGC: Gravity center of point C. Considered ‘in this example 300 mm
U = Text1U
Text1Y2B = Y2B
Text1Y2B = Format(Text1Y2B, "#.###")

CB = Sqr(U ^ 2 + Y2B ^ 2)
Text1CB = CB
Text1CB = Format(Text1CB, "#.###")
A22 = Y2B / CB 'Cosine of A22
A22R = Atn(-A22 / Sqr(-A22 * A22 + 1)) + 2 * Atn(1) 'ArCosine of A22
A22D = A22R * RtoD
Text1A22D = A22D
Text1A22D = Format(Text1A22D, "#.###")
AB2 = 360 - 90 - ABD - A22D
Text1AB2 = AB2
Text1AB2 = Format(Text1AB2, "#.###")
CA = Sqr((CB ^ 2 + BA ^ 2) - (2 * Cos(AB2 * DtoR) * CB * BA))
Text1CA = CA
Text1CA = Format(Text1CA, "#.###")

K1 = (CB * Sin(AB2 * DtoR)) / CA 'K1 = SinAA2D
AA2R = Atn(K1 / Sqr(K1 * K1 + 1)) 'Inverse Sine Arcsin(X)  Atn(X / Sqr(-X * X + 1))
AA2D = AA2R * RtoD

Text1AA2D = AA2D
Text1AA2D = Format(Text1AA2D, "#.###")
AC2 = 180 - AB2 - AA2D

Text1AC2 = AC2
Text1AC2 = Format(Text1AC2, "#.###")
TXTAC2 = Format(TXTAC2, "#.###")

A1R = A1 * DtoR
W3 = BD / Cos(A1R)
X2V = U + W3 + DV
Text1X2V = X2V
Text1X2V = Format(Text1X2V, "#.###")
EndSub

Rem MOSTRAR EL PRIMER FORMULARIO ABC

Private Sub CMDForm4_Click()
Form4.Show
End Sub 'End Form 2 ABV

Private Sub CMDclosecalculus_Click()
Beep
Beep
If MsgBox("¿GET OUT?", 36, "TRIANGLE ABV") = 6 Then
Beep
Beep
End
End If
End Sub 'End Sub cmdCerrarProceso_Click()

Rem MOSTRAR EL PRIMER FORMULARIO ABV

Private Sub CMDForm2_Click()
Form2.Show
End Sub 'End FormABV
Rem SHOW THE FORM2 ABV
Private Sub CMDForm3_Click(
Form3.Show
End Sub 'End Form 3 TRIANGLE ABV
```

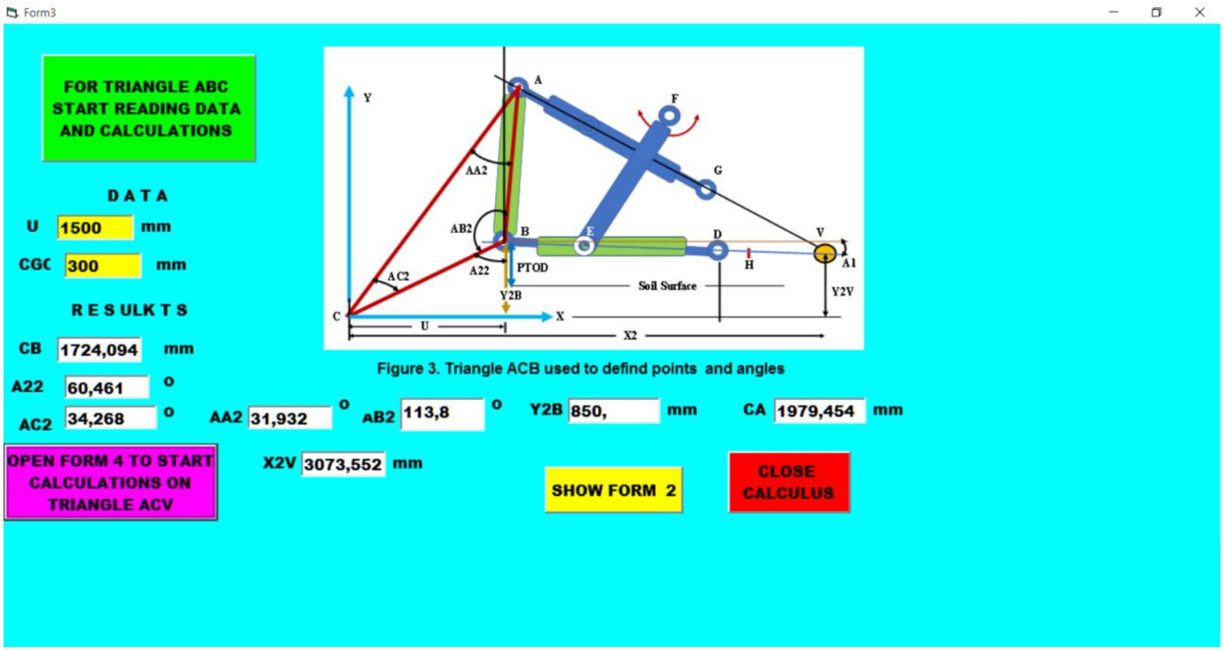

Figure 5. Form 3, triangle ABC analysis.

'FORM 4

'START ANALYSIS TRIANGLE ACV TO END VIRTUAL POINTSSTUDY 'ACCORDING TO DATA PRESENTED

```
Private Sub CMDStartTriangleACVanalysis_Click()

Dim CV, PI, DtoR, RtoD, SAC3, ArSi, AV3, X3V, Y3 As Double

PI = 4# * Atn(1#)
RtoD = 180 / PI
DtoR = 1# / RtoD

AA3D = AAD + AA2D 'From Form2 and Form3 triangles ABV and ABC
Text1AA3 = AA3D
Text1AA3 = Format(Text1AA3, "#.###")

Text1CA3 = CA 'From Form3 triangle ABC
Text1CA3 = Format(Text1CA3, "#.###")

Text1VA = VA  'From Triangle ABV
Text1VA = Format(Text1VA, "#.###")

CV = Sqr(CA ^ 2 + VA ^ 2 - 2 * Cos(AA3D * DtoR) * DCA * VA)
Text1CV = CV
Text1CV = Format(Text1CV, "#.###")
SAC3 = VA * Sin(AA3D * DtoR) / CV
ArSi = (Atn(SAC3 / Sqr(-SAC3 * SAC3 + 1))) * RtoD  'Inverse Sine
Text1AC3 = ArSi
Text1AC3 = Format(Text1AC3, "#.###")

AV3 = 180 - AA3D - ArSi
Text1AV3 = AV3
Text1AV3 = Format(Text1AV3, "#.###")

Y3 = Val(Y2B) 'Y3 = PTOD + CGC  'Considering 150 mm plowdepth
Y3V = Y1  'Y coordinate at point V
Text1Y3V = Y3V
Text1Y3V = Format(Text1Y3V, "#.###")
X3V = U + (((BD + DV) / Cos(A1R)))
Text1X3V = X3V
Text1X3V = Format(Text1X3V, "#.###")
Text1DV = DV
Text1DV = Format(Text1DV, "#.###")
End Sub

Private Sub CMDclosecalculus_Click()
Beep
Beep
If MsgBox("¿GET OUT?", 36, "TRIANGLE ABV") = 6 Then
Beep
Beep
End
End If
End Sub
```

Rem MOSTRAR EL PRIMER FORMULARIO ABV

Private Sub CMDForm2_Click()
Form2.Show
End Sub 'End FormABV
Rem MOSTRAR EL PRIMER FORMULARIO ABV
Private Sub CMDForm3_Click()
Form3.Show
End Sub 'End FormABV

Private Sub CMDForm5_Click()
Form5.Show
End Sub 'End Form 5 ABV

Private Sub CMDForm6_Click()
Form6.Show
End Sub 'End Form 6 ACV

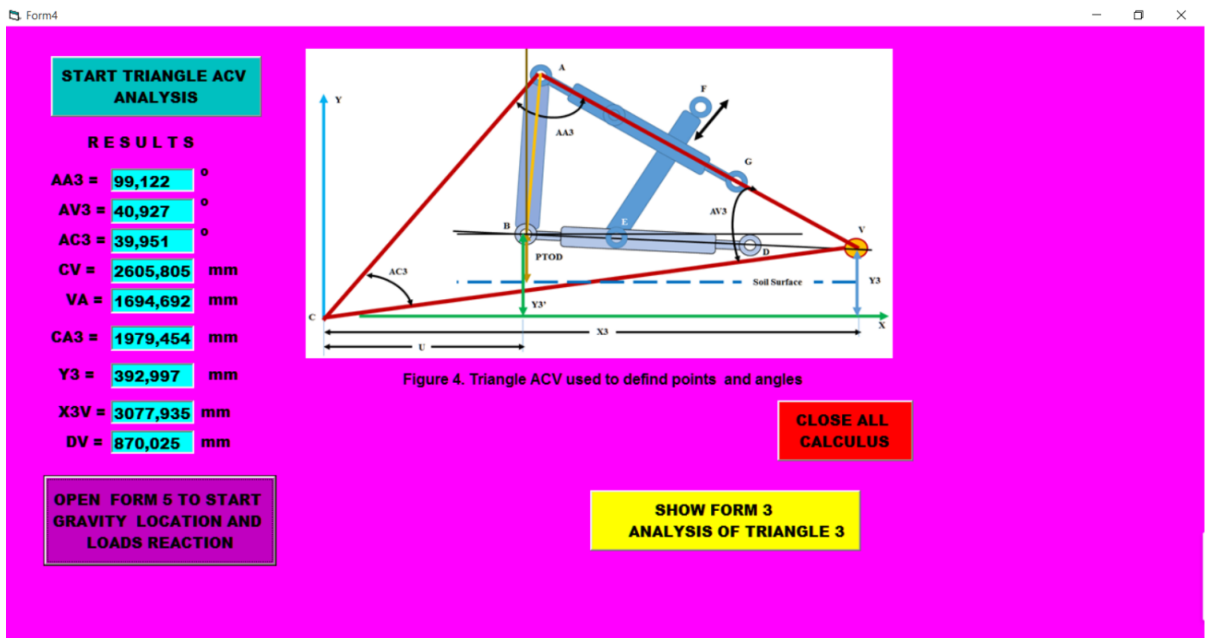

Figure 6. Triangle ACV analysis.

'FORM 5

'START ANALYSIS OF TRACTOR GRAVITY AND WHEELS REACTION

'CHX: Distance of rear axle from point C in X coordinate direction
'DFW: Difference FR - FWR
'DRW: Difference RR - RWR
'FPW: Tractor front weight in %
'FWR: Front wheel reaction due to tractor weight alone
'HV1: Nwe value of HV to be used with PROC = 2
'P: Traction force
'RR: Rear wheel reaction due to tractor and implement weights
'RWR: Rear wheel reaction due to tractor weight alone
'Y3: CG height
'T: Lateral force due soil thrust
'TCG: Distance of tractor CG from rear wheel
'TFR: Tractor Front wheel reaction
'TGW: Distance from rear axle to tractor-implement CG
'IICG: Distance of tractor-implement CG from rear wheel axle
'TIW': Total implement weight
'TRR: Tractor rear wheel reaction
'TWB: Tractor wheel base length (mm)
'VP: Distance of implement CG from rear axle
'W: Tractor weight

Private Sub CMDStartCGcalculation_Click()
Dim FPW, RPW, FWR, RWR, FR, RR, TTIW, DFW, DRW, TRR, TFR, CHX, TWB, RWP2, FWP2 As Double
Dim K20 As Integer
'TRACTOR ALONE. WHEEL REACTIONS AND CG POSITION
PI = 4# * Atn(1#)
RtoD = 180 / PI
DtoR = 1# / RtoD
W = Text1W
TIW = TextTIW
TTIW = Val(W) + Val(TIW)

```
TWB = Text1TWB
PROC = Text1PROC ‘CALCULUS PROCEDURE 1 OR 2
K20 = PROC
FPW = Text1FP
RPW = Text1RP
FWR = (W * FPW) / 100
Text1FWR = FWR
Text1FWR = Format(Text1FWR, "#.###")
RWR = (W * RPW) / 100
Text1RWR = RWR
Text1RWR = Format(Text1RWR, "#.###")

If (K20 = 2) Then GoTo BRINCO20 ‘IF PROC = 2 GO TO BRINCO20 TO USE METHOD 2

‘START METHOD 1 OF CALCULATION

TICG = (((TTIW * FPW) / 100) * TWB) / TTIW 'Tractor CG distance from rear axel
 Text1TICG = TICG
Text1TICG = Format(Text1TICG, "#.###")

TCG = (((W * FPW) / 100) * TWB) / W
Text1TCG = TCG
Text1TCG = Format(Text1TCG, "#.###")

FR = (TTIW * FPW) / 100 'FR = Val(W) + TIW - TRR
Text1FR = FR
RR = TTIW - FR
Text1FR = Format(Text1FR, "#.###")
Text1RR = RR
Text1RR = Format(Text1RR, "#.###")

DRW = RR - RWR
Text1DRW = DRW
Text1DRW = Format(Text1DRW, "#.###")

DFW = Text1FR - Text1FWR
Text1DFW = DFW
Text1DFW = Format(Text1DFW, "#.###")

VP = (((TIW * FPW) / 100) * TWB) / TIW
Text1VP = VP
Text1VP = Format(Text1VP, "#.###")

Text1RWP1 = Empty
Text1FWP1 = Empty
‘END METHOD 1 OF CALCULATION

If (K20 < 2) Then GoTo BRINCO40

BRINCO20:   ‘START CALCULATION WITH METHOD 2
Text1HV = HV 'New value assigned to HV
DFW = (TIW * HV) / TWB
Text1DFW = DFW
Text1DFW = Format(Text1DFW, "#.###")
Text1DRW = TIW - DFW
Text1DRW = Format(Text1DRW, "#.###")
Text1VP = (DFW * TWB) / TIW
Text1VP = Format(Text1VP, "#.###")
Text1HV = Format(Text1HV, "#.###")

FWR = (W * HV) / TWB
Text1FWR = FWR
Text1FWR = Format(Text1FWR, "#.###")
RWR = W - FWR
Text1RWR = RWR
Text1RWR = Format(Text1RWR, "#.###")
Text1TCG = (FWR * TWB) / W
Text1TCG = Format(Text1TCG, "#.###")

FR = (TTIW * HV) / TWB
Text1FR = FR
Text1FR = Format(Text1FR, "#.###")
Text1RR = TTIW - FR
Text1RR = Format(Text1RR, "#.###")
Text1TICG = (FR * TWB) / TTIW
Text1TICG = Format(Text1TICG, "#.###")

RWP2 = (RWR / W) * 100
FWP2 = 100 - RWP2
Text1RWP2 = RWP2
Text1RWP2 = Format(Text1RWP2, "#.###")
Text1FWP2 = FWP2
Text1FWP2 = Format(Text1FWP2, "#.###")

‘END OF METOD 2 OF CALCULATION

BRINCO40:
'CHX = (BD + DH + (BD + DH) * Sin(A1 * DtoR)) + U
CHX = BD + DH * Sin(A1 * DtoR) + U
Text1CHX = CHX
Text1CHX = Format(Text1CHX, "#.###")

Text1Y3Y = Y3V
Text1Y3Y = Format(Text1Y3Y, "#.###")
'Transferring forces from C to NC
End Sub

Private Sub CMDForm6_Click()
Form6.Show
End Sub 'End FormABV

Private Sub CMDclosecalculus_Click()
Beep
Beep
```

```
If MsgBox("¿GET OUT?", 36, "TRIANGLE ABV")
= 6 Then
Beep
Beep
End
End If
End Sub 'End Sub cmdCerrarProceso_Click()

Private Sub CMDForm2_Click()
Form2.Show
End Sub 'End Form 2 ABV
```

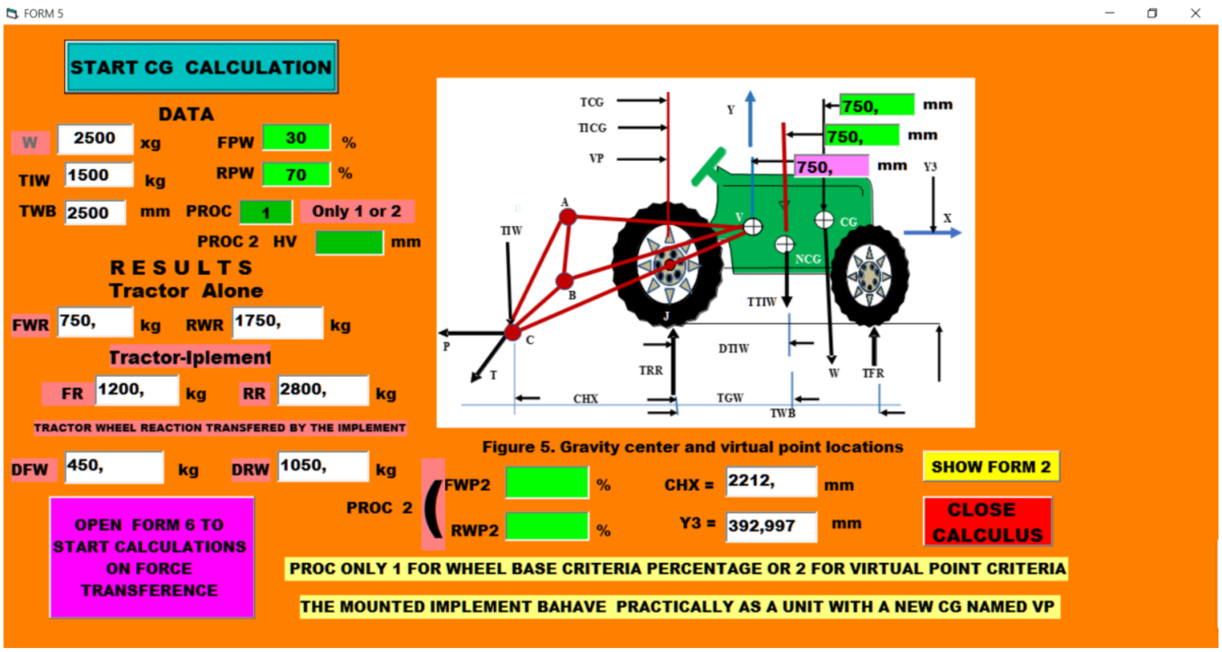

Figure 7. Gravity centers analysis, PROC 1 and 6.743/93.267%

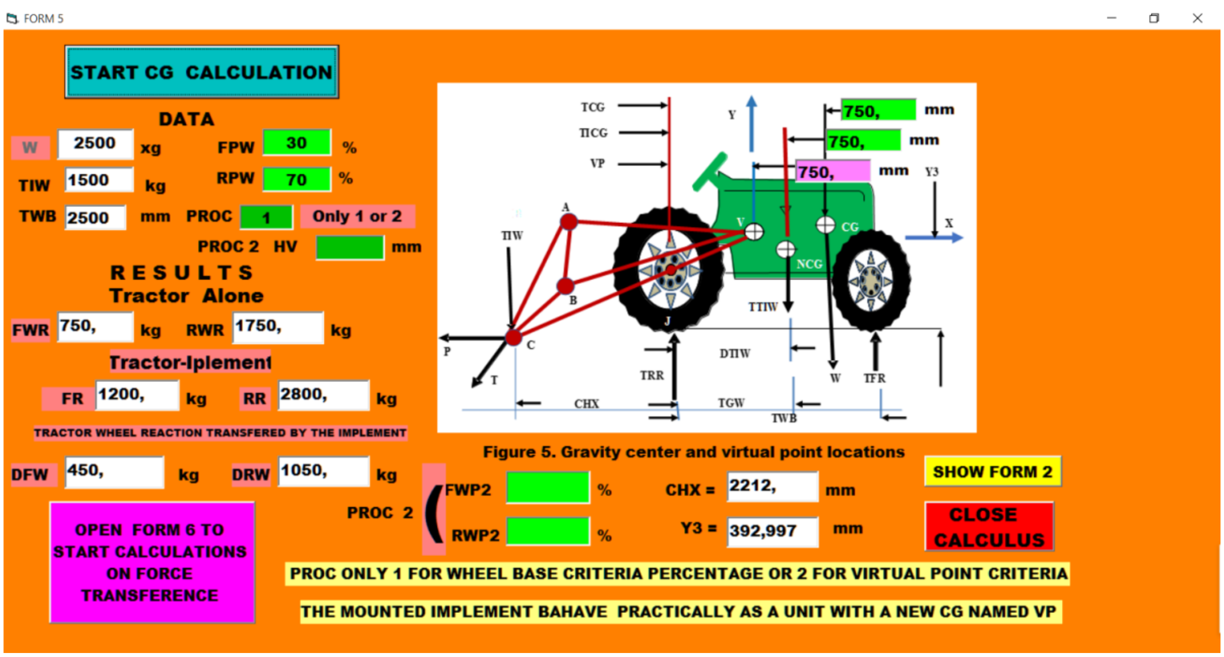

Figure 8. Gravity centers analysis, PROC 1 and 6.743/93.267 %.

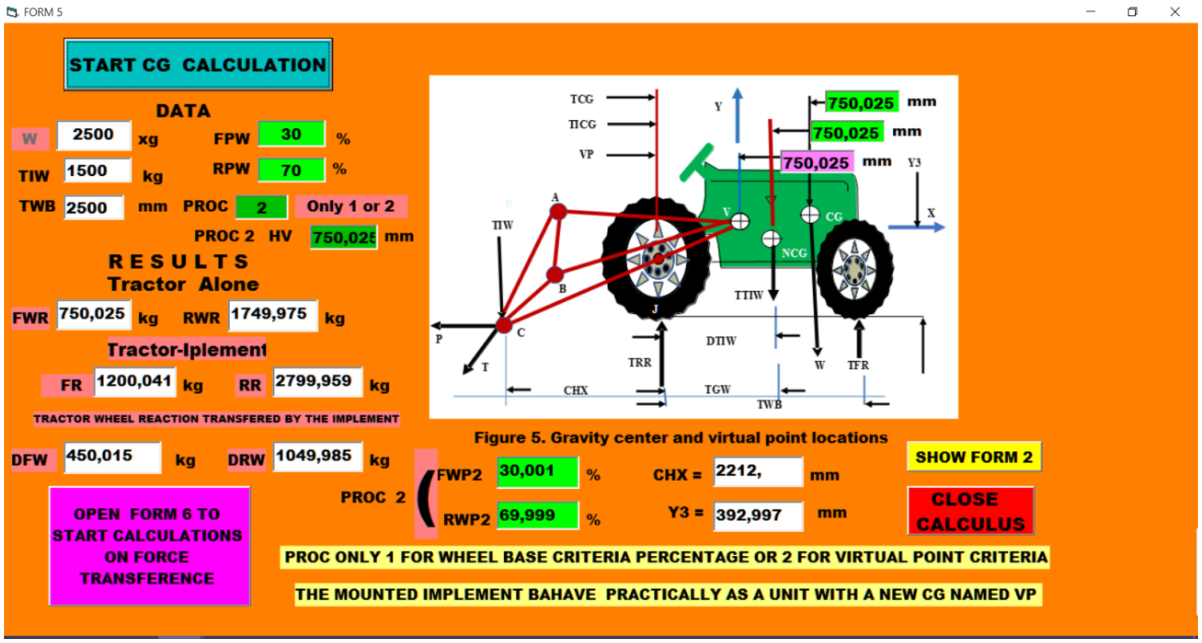

Figure 9. Gravity centers analysis, PROC 1 and 30/60 %.

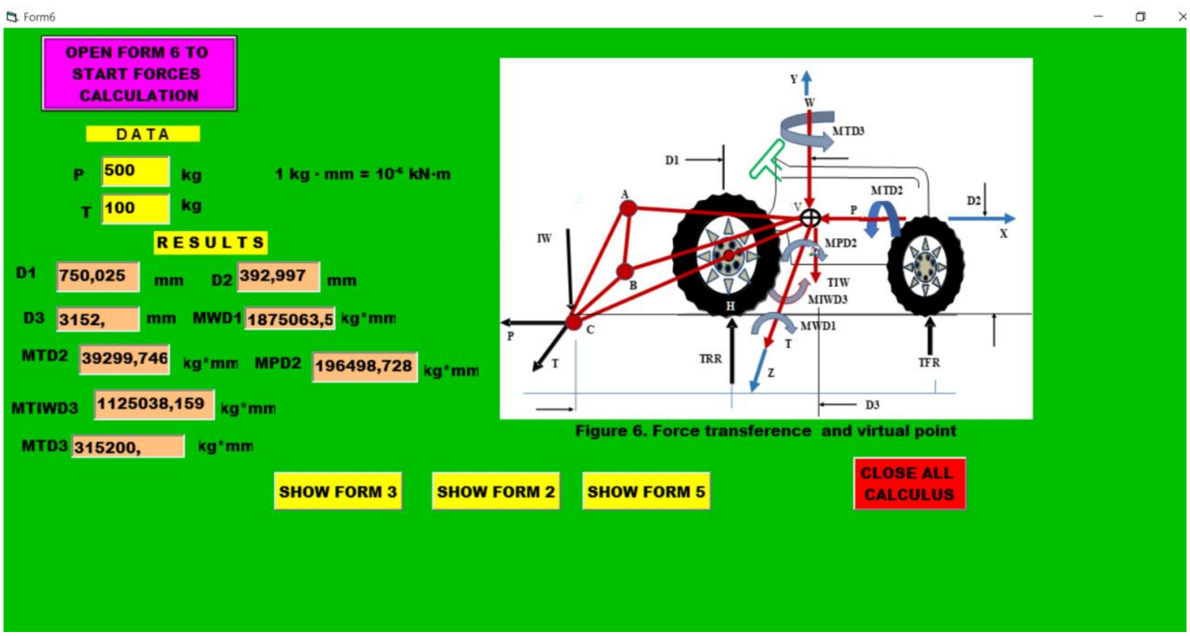

Figure 10. Force analysis, PROC 2.

'FORM 6

'FORCE CALCULUS

'THE C LOADS TRANSFERRED TO V ARE CARRIED OUT APPLYING THE ‘TRANSFERENCE STATIC EQUATIONS

The reactions on the wheel base are determined by applying the ‘following static equations:

'D1: X distance from H to W
'D2: Y distance from P to soil surface
'D3: X distance from C to V

```
'MPD1: Moment P*D1
'MPD2: Moment P*D2
'MTD3: Moment T*D3
'MTD3: Moment T*D3
'MWD1: Moment W*D1
'MTIWD3: Moment tractor total weight * D3
'P: Implement required tractor pull
'T: Implement soil thrust force

Private Sub CMDStartForceCAL_Click()
Dim P, T, D1, D2, D3, MWD1, MTD2, MPD2, MTIWD3 As Double

P = Text1P
T = Text1T

D1 = VP
Text1D1 = VP
If (PROC = 2) Then D1 = HV
Text1D1 = HV
Text1D1 = Format(Text1D1, "#.###")

D2 = Y3V
Text1D2 = D2
Text1D2 = Format(Text1D2, "#.###")

D3 = VP + U + XBH
Text1D3 = D3
Text1D3 = Format(Text1D3, "#.###")

'LOADS TRANSFERENCE TO TRACTOR-IMPLEMENT CG

'1. TRACTOR WEIGHT W
MWD1 = W * D1
Text1MWD1 = MWD1
Text1MWD1 = Format(Text1MWD1, "#.###")

'2. LOAD MTD2 AND T
MTD2 = T * D2
Text1MTD2 = MTD2
Text1MTD2 = Format(Text1MTD2, "#.###")

'3. LOAD MPD2 AND P
MPD2 = P * D2
Text1MPD2 = MPD2
Text1MPD2 = Format(Text1MPD2, "#.###")

'4. LOAD MIWD3 AND D3
MTIWD3 = TIW * D1
Text1MTIWD3 = MTIWD3
Text1MTIWD3 = Format(Text1MTIWD3, "#.###")

'5. LOAD MTD3 AND D3
MTD3 = T * D3
Text1MTD3 = T * D3
Text1MTD3 = Format(Text1MTD3, "#.###")

EndSub

Rem MOSTRAR EL PRIMER FORMULARIO ABV
Private Sub CMDForm2_Click()
Form2.Show
End Sub 'End Form 2 ABV

Rem MOSTRAR EL PRIMER FORMULARIO ABV

Private Sub CMDForm5_Click()
Form5.Show
End Sub 'End Form 5
Private Sub CMDclosecalculus_Click()
Beep
Beep
If MsgBox("¿GET OUT?", 36, "TRIANGLE ABV") = 6 Then
Beep
Beep
End
End If
End Sub 'End Sub cmdCerrarProceso_Click()

Rem MOSTRAR EL PRIMER FORMULARIO ABV
Private Sub CMDForm3_Click()
Form3.Show
End Sub 'End Form6 FORCE CALCULATIONS, ENDING VB CODES
```

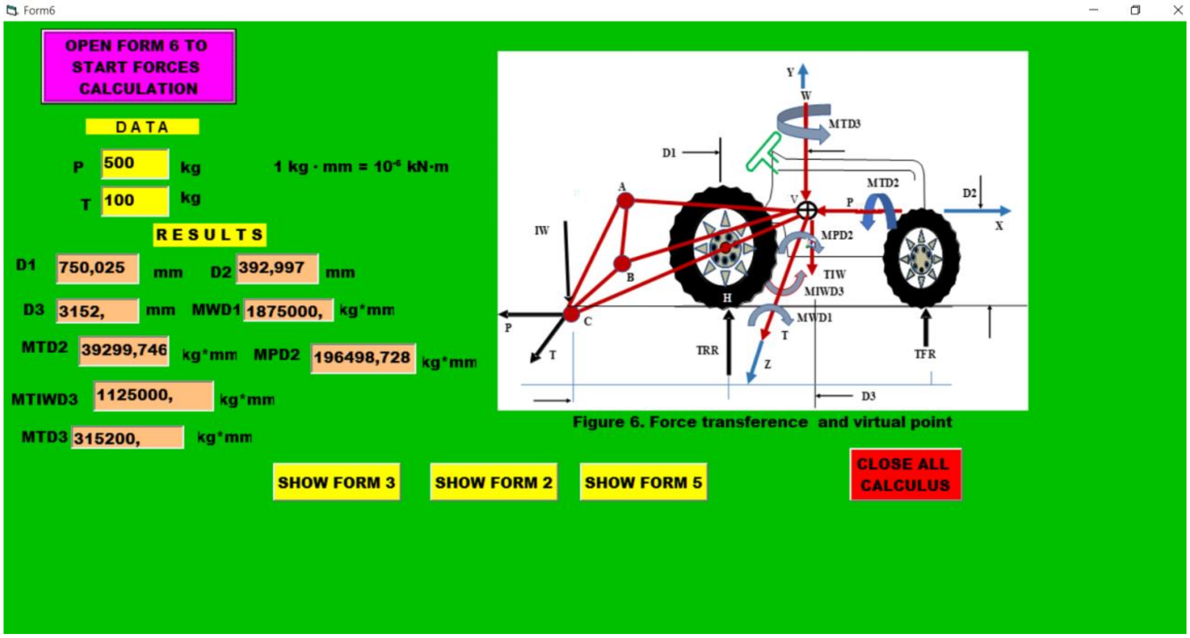

Figure 11. Gravity centers analysis, PROC 1.

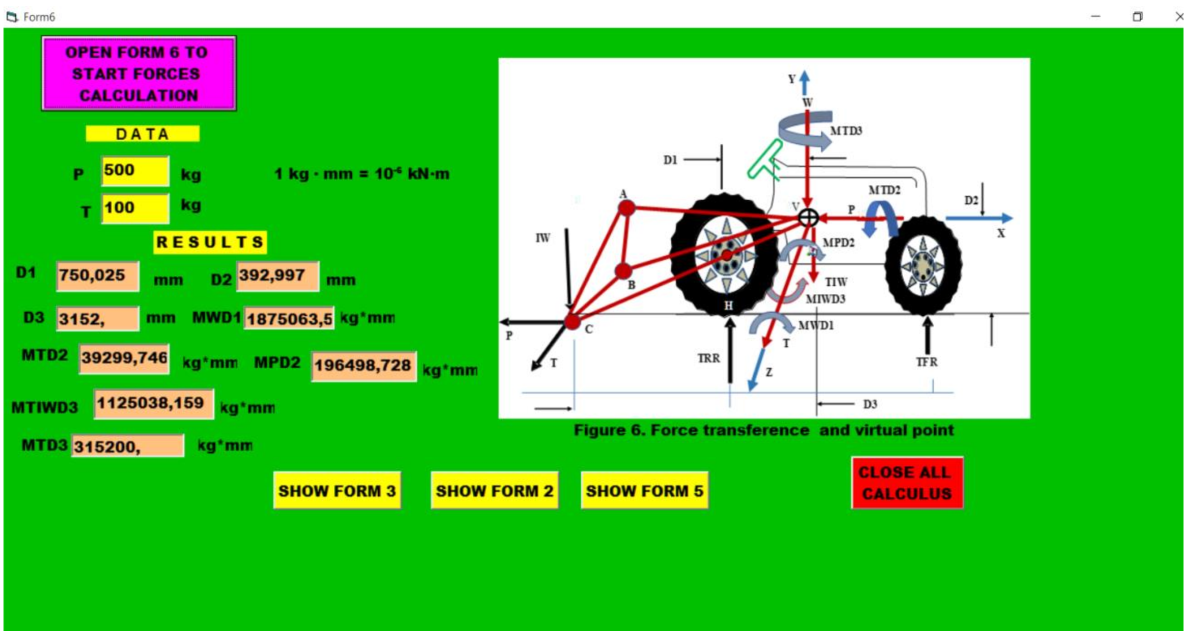

Figure 12. Force analysis, PROC 2.

Module

Global PTOD, ABD, AB, BA, A1, BD, AAD, AA2D, CA, VA, AB2, Y1, DV, U, A1R As Double

Global TCG, TICG, Y3V, TIW, DH, W, XBH, VP, PROC, HV As Double
'END OF PROGRAMING.

To find the V position measured from B or the rear tractor axle (H), Figure 5, the triangles ABD and ABG defined to obtain angles AA, AB and AV. The length BA, GA, BD identified according to the tractor categories and lengths DA and BG measured after implement calibration. The plow depth and C positions considered 300 mm and 150 mm sequentially. The V distance from soil surface and the rear axle reaction increased with increases of operation depth in all analysis, this depth depended substantially on lower link length, links position and implements parameters (weight and elevation of hitch point) (Kumar *et al*. 2018). Sakai *et al*. (1988), using simulation, found V the parameter that most affected the vibrations of a tractor's body. By setting V at an optimal position, the acceleration of a tractor's body reduced considerably. Length BD1 represents BD along the X coordinate, where BD1 is slightly lengthier than BD, BD1 + DV = X1V in triangle ABV.

For PROC 2, Form 5 and Figure 7, analysis with length HV = 168.57 mm as the starting point of wheel base reaction, the results were FWR = 168.57, RWR = 2331.33, FR = 69.87, RR = 3730.13, DFW = 101.20 and DRW = 1398.80 kg. The tractor wheel load distribution percentage was 7.235%/92.765% (Front/Rear); by means of these results with PROC 1, the results were FWR = 180.58, RWR = 2319.13, FR = 289.4, RR = 3710.6, DFW = 108.53 and DRW = 1391.48. The differences between PROC 1 and 2 were around 12 mm and for FWR = 68.57 and FWR = 80.58 was 12.01 mm. Employing the PROC 2 percentage as PROC 1 percentage and FRW value as HV; the same results were obtained. The tractor implement unity CG coincided with point V. The shortened or elongated top link allowed increase or decrease of the triangles ABV and ACV; specially length DV. The point V moved further towards the tractor front. In this article, by several measures, the optimum value of 652.18 mm of link AG produced an HV length of 750.025 for 30.001/69.999 % by PROC 2; PROC 1 produced for 652,18 linkGA, HV = 750 mm for 30/70 %. The triangle method to obtain the virtual point V considered the CG or implement load action theactual tractor CG.

To transfer the loads from C to V, involved six independents equations for six unknowns. The line of pull FV, from C to V, added weight to the tractor wheel base. The C loads transferred to V with a couple. The reactions determined by applying statics equations inversely. The center of resistance coordinates assumed 2/3 of the operation depth following the implement centerline. Kumar *et al*. (2018) found 2/3 mm for the optimum depth operation.

The forces transferred to V produced reaction in the tractor: IW added load to the tractor rear axle; P was the minimum force required by the tractor to pull the implement, the soil thrust force T, produced by the implement, forces the tractor to left, or the rudder takes cares of it. The M_Y moment effect causing to pull the tractor to the right, M_X the moment effect turning the tractor to left overcame by the tractor-implement weight, and the result of both M_Z moments. The reactions on the wheelbase were determined by applying static equations.

According to Macmillan (2017), V is termed the virtual or effective hitch point; at that instant, the implement behaved as attached to the tractor at that point. Generally, the dynamic rear wheel load possibly controlled and increased by wheel weights, tire ballast, weight transfer from front wheels to the rears and from implements (Naderi *et al*. 2008). The CG analysis presented in Figures 7, 8, 9 and 10 exposed that all CG coincided at the same location when the weight wheelbase had a percentage distribution (30/70). On observe in Figures 7, 8, 9 and 10 that the implement transferred 750 kg to the rear axle and 240 kg to the front, and the tractor 1750 kg to the rear and 560 to the front. If the tractor-implement unit weighted 3300 kg, the rear axle supported 2310 kg; indicating that the CG have to be in the same location, V, proved considering the following procedure: (3300 – 2310) * (2500 - XCG) = 2310 * XCG; then 990*2500 – 990*XCG = 2310*XCG, or XCG = 750 mm.

CONCLUSIONS

The program resulted flexible, adaptable and amendable. The virtual hitch point received all the loads or rotation due to the action of the center of load C and the weight of the implement. To define the three triangles with eight identified variables, twenty-three unknowns and twenty-three linear trigonometric and quadratic equations were obtained. The analysis, applying the three triangles procedure engendered a set of equations, that permitted a complete result of the virtual hitch point and a set of gravity center locations that coincided at the same distance with regard towhee base percentage. The same results occurred changing only the tractor and implement loads. The virtual point rose overlaps with the tractor-implement gravity center at optimal upper link length.

ACKNOWLEDGEMENTS

This work was financially and logistical supported by the University of Oriente.

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