ISSN 2229-5518

A Discrete-Event Coordinates Methodology for A Composite Curve

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ABSTRACT - This paper gives information about the results of investigation on a discrete-event simulation methodology to compute coordinates of a composite curve through Information and Communication Technology (ICT) system. Tangible modelling and simulation validity was done using general purpose application programs that is readily available rather than costly and tedious conventional hand method. In the methodology, deflection angle, tangential angles for the two transition curves and central circular arc, together with deviation angle computations, were successful modelled and simulated via ICT approach. Coordinates produced as the result of the process are useful set of numbers in Eastings and Northings to defining the entry transition curve, central circular arc and the exit transition curve of a highway or railroad composite curve at site. The conclusion in this study is that a discrete-event simulation is a suitable methodology for computing useful coordinates for setting out of a composite curve meant for a safe highway or railroad.

Index Terms – Coordinates, Composite, Discrete, Safe, Simulation, Tangential, Transition

1 INTRODUCTION

Discrete-event simulation could practically be done by hand calculations whereas for the amount of data that must be stored and manipulated for most real-world systems dictates that same is better done on a digital computer, Schriber and Brunner [1], Law and Kelton [2]. Discrete-event simulation goal in this paper is concerned with the modelling of a composite curve for highway or railroad in Information and Communication Technology (ICT) environment rather than traditional hand approach. According to Law and Kelton [2], discrete-event simulation concerns the modelling of a system by a representation in which the state variables change instantaneously at separate points. Simulation is a powerful tool for the evaluation and analysis of new system designs, modifications to existing systems and proposed changes to control systems and operating rules. Carson [3] claimed that conducting a valid simulation is both an art and a science. Adedimila and Akiije [4], Akiije [5], Akiije [6] considered simulation as the representation of physical systems and phenomena by computers, models and other equipment.

Simulation of coordinates for a composite curve by employing computer is the focus of this study. Coordinates are ordered set of numbers which specified the position or orientation of a point or geometric configuration relative to a set of axes in Eastings and Northings as claimed by Akiije [7].

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According to Tiberius [8], McDonald [9], coordinates may be obtained from the record of some accurately located points of the framework of geodetic surveys or global positioning system (GPS).

Composite curve consists of entry transition curve, central circular arc and the exit transition curve. Types of transition curve in use for composite curve include clothoid or spiral, Bernoulli's Leminscate, cubic parabola, cubical spiral and S.Shaped. The need for transition curve paves in where a vehicle travelling on a straight course enters a curve of finite radius. At this juncture, Andrzej [10] claimed that such vehicle will be subjected to a sudden centrifugal force that will cause shock and sway. In order to avoid this centrifugal force, it is customary to provide a transition curve at the beginning and at the end of a circular curve.

A transition curve has a radius equal to infinity at the end of the straight and gradually reducing the radius to the radius of the circular curve where the later begins. Incidentally, the transition portion is useful for building up the centrifugal force gradually. Also, it provides a more aesthetically pleasing alignment and gradual application of the superelevation. Superelevation is the desirable raising of one edge of a roadway or a rail higher than the other along curve of a road or railway. The reason is to counteract centrifugal forces on passengers and vehicles or trains. The action brings comfort and safety to passengers and also prevents vehicles from overturning or sliding off the highway.

The objectives of this paper therefore is to provide a desirable automation platform for highway engineers to define coordinates as set of numbers in Eastings and Northings that are useful in an electronics environment for the design of a composite curve. Significantly with this study knowledge, computation of any segment of the composite

ISSN 2229-5518

curve can be modelled in a particular module and be simulated. Also, this study can be appreciated for where local computation modification is to be made in the modelling module; it is always made at ease. At this facet, by selection of an existing value and replacement of same by a new one, the required results are generated automatically. This technique is a powerful tool for geometric modelling and simulation of a composite curve coordinates. The justification for this study is that the use of digital computer is a most common computing device and a cheaper means of computation rather than conventional hand approach. In this study, digital computer performs operations on data represented in digital or number form with continuity and reusability capability for further necessary computation coordinates.

It is worthy of note that, the process of minimization and elimination of errors caused by instrumental imperfections or human operation by manual approach is a tedious work in order to accurately determine coordinates of points of a composite curve. However, GPS receiver can locate points in coordinates to an accuracy of ± 0.02 m as claimed by Uren and Price [11]. Therefore it is a useful instrument for defining coordinates points developed by the discrete-event methodology for a composite curve. GPS consists of three segments called the space segment, control segment and user segment. The use of GPS is advanced in this study at user segment level to capture coordinates of field stations and intersection points as data to compute coordinates for chainage points to define composite curve at the highway site. Also, Microsoft Excel a general purpose application program has been used to generate necessary chainage points coordinates for composite curve through computation via simulation modelling in an electronics office.

2 CONCEPTUAL FRAMEWORK

Transition curve chosen in this study is the cubic parabola simply because its formulae and calculations are easier to show in written form as claimed by Uren and Price [11]. Figure 1 is showing a typical framework of composite curve. The deflection angle is θ as measured on site or in the office by ICT methods rather than conventional hand method of using protractor. The radius R of the composite curve as required by the design speed V based upon design standards is possible by using Equation 1. The rate of change of radial acceleration c is defined by equation 2. Transition curve length L_T = $TT_1 = T_2U$ as defined by Equation 3.

In Figure 2, the shift at YG or WK is bisected by the transition curve and the transition curve is bisected by the shift. The shift S is defined by Equation 4. The tangent length IT = IU is defined by Equation 5. The maximum deviation angle $\phi_{\max}$ at the common tangent between the transition and the circular curve is defined by Equation 6. The length of the circular arc T_1T_2 is defined by Equation 7. The total length of the composite curve L_{total} is defined by Equation 8.

Figure 3 is showing the relationship between deviation angle ϕ and tangential angle δ. Deviation angle ϕ is defined by Equation 9. The formula showing the relationship between deviation angle ϕ and tangential angle δ is in Equation 10. The tangential angle δ for transitional curves is represented by Equations 11 and 12. The tangential angle α of the central circular arc is defined by Equations 13 and 14. Superelevation is calculated using Equation 15.

A technique of establishing a composite curve relies extensively on the use of transparent templates by conventional hand methodology. Pre-computed data from template are compiled into a design table that can be used as an input for the computation of the composite curve referenced completely to a coordinate system. The use of templates and design table relieves the design engineer of much computation and ensures more standardization and higher design standards. Although the conventional hand approach is a standard approach, it is tedious and it is not made in an electronic environment. In recent time, individual engineer's productivity has been increased by the use of automated procedures that rely extensively on electronic computer. Automated computation of coordinates to readily generate a composite curve is the focus of this study.

Design and setting out of the composite curve on site using coordinates methodology require the use of both rectangular and polar coordinates as claimed by Akiije [6]. The methodology requires the determination of eastings, northings and whole circular bearing of each chainage point along the alignment centre line as found in Equations 16 and 17. The variables for Equations 16 and 17 are in Figures 4 and 5. These variables include: E_A is Easting of A; E_B is Easting of B; N_A is Northing of A; N_B is Northing of B; ΔE_{AB} is eastings difference from A to B; ΔN_{AB} is northings difference from A to B; D_{AB} is horizontal length of AB; θ_{AB} is whole-circle bearing of line AB.

Hence, in this study, an innovative coordinates methodology of using GPS together with Microsoft Excel is introduced for appropriate cheaper technology of computing coordinates for designing and setting out of a composite curve at a site. In this new methodology, the use of horizontal control points supposedly established by surveyor near the alignment that may not be readily found is not necessary since

GPS could be used to capture coordinates of essential points that are required.

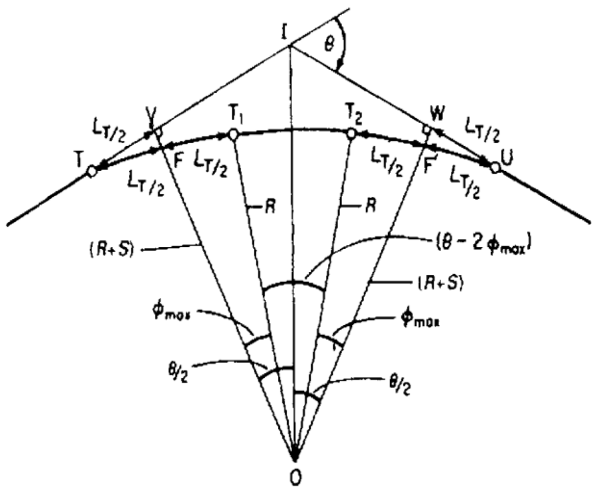

Figure 1: Tangent and Curve Length of Cubic Parabola
Source: Uren and Price [11]

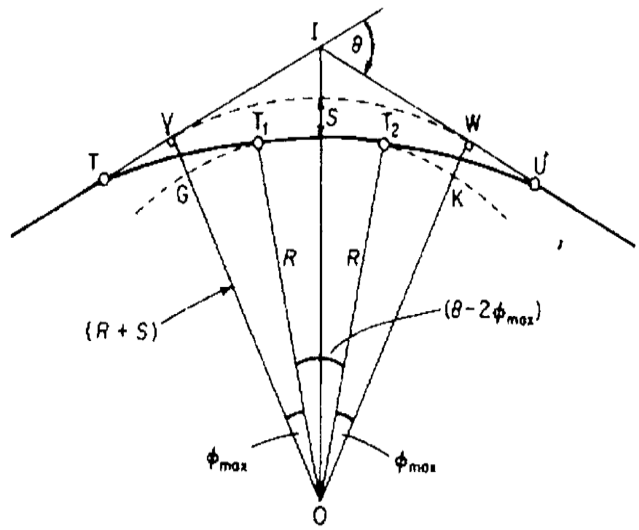

Figure 2: The Shift of a Cubic Parabola
Source: Uren and Price [11]

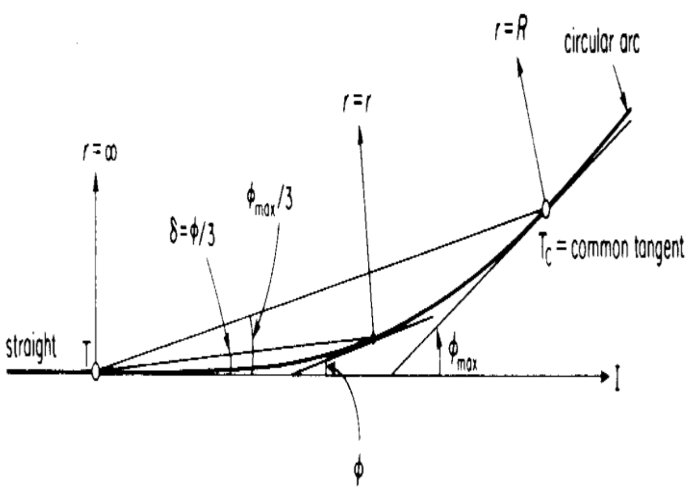

Figure 3: Relationship Between ϕ and δ
Source: Uren and Price [11]

TABLE 1: VARIABLE EQUATIONS FOR A COMPOSITE CURVE

$\frac{V^2}{R} = 14.14$ for V = 100 km/h	(1)	$c \le 0.3\, m/s^2$	(2)
$L_T = \frac{V^3}{3.6^3 cR}$	(3)	$S = \frac{L_T^2}{24R}$ m	(4)
$IT = IU = (R+S)\tan\left(\frac{\theta}{2}\right) + \frac{L_T}{2}$ m	(5)	$\phi_{max} = \frac{L_T}{2R}$ radians	(6)
$L_{circular\ arc} = T_1T_2 = R(\theta - 2\phi_{max})\ m$	(7)	$L_{total} = TT_1 + T_1T_2 + T_2U$ $= L_T + R(\theta - 2\phi_{max}) + L_T\ m$	(8)
$\phi = \frac{l^2}{2RL_T}$ radians	(9)	$\delta_{max} = \frac{\phi_{max}}{3}$ radians	(10)
$\delta = \frac{l^2}{6RL_T}$ radians	(11)	$\delta = \frac{l^2}{6RL_T} \times \frac{180}{\pi}$ degrees	(12)
$\alpha = \frac{l}{R}$ radians	(13)	$\alpha = \frac{180 \times l}{2\pi R}$	(14)
$e\% = \frac{V^2}{2.828R}$	(15)	$E_B = E_A + \Delta E_{AB} = E_A + D_{AB}\sin\theta_{AB}$	(16)
$N_B = N_A + \Delta N_{AB} = N_A + D_{AB}\cos\theta_{AB}$	(17)		

ISSN 2229-5518

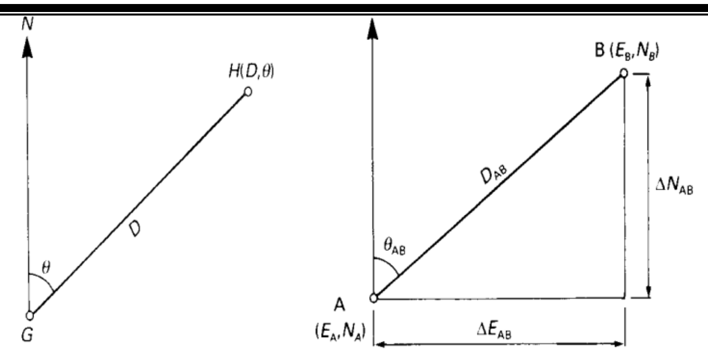

Figure 4: Coordinates Systems
Source : Uren and Price [11]

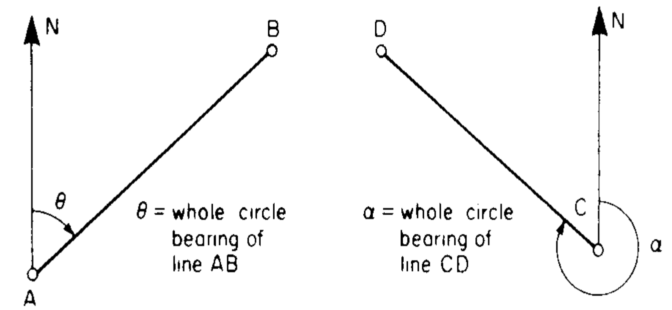

Figure 5: Whole-Circle Bearings
Source : Uren and Price [11]

3 MATERIALS AND METHODOLOGY

Data capturing and setting out materials for this study include GPS receiver. GPS receiver was able to connect with more than four satellites before coordinates readings and bookings. Computer workstation materials used to design the composite curve being study in this paper comprise the hardware and software components. The hardware components include systems board, central processing unit, memory, disks, a monitor, keyboard as an input device and printer as an output device. The software components used is the Microsoft Excel. Microsoft Excel is a spreadsheet with a table of cells with unique addresses for each cell. The important thing about the table is that data were entered into cells as labels and formulas written for the manipulation of same as modelling. Data modelled gave numerical results as simulation.

In this paper, a road leading to a fruit processing plant is used as a case study. A GPS receiver was used to capture coordinates (Table 2) of the beacons at the beginning $(E_{B,} N_B)$, at an intersection point $(E_{I,} N_I)$ and at the point where the road to the factory stops $(E_{S,} N_S)$. The deflection angle of the connected two straights was determined within spreadsheet using Table 2. Based on the design speed of 85 km/h, the length of the transition curve and the tangent lengths were determined in Table 3. Also in Table 3, the determination of the through chainage of the beginning of entry transition curve T and the through chainage of the end of entry transition T_1 was defined. Table 4 is the modelling module of tangential angles for through chainages of the entry transition curve. Table 5 is the modelling module for the central circular arc of the composite curve. Table 6 is the modelling module of chord lengths tangential angles for through chainage of the central circular curve. Table 7 is the modelling module for exit transition curve. Table 8 is the modelling module of chord lengths tangential angles for through chainage of the exit transition curve. Table 9 is the modelling module for coordinates of tangent point T, of entry transition curve, chainage 1537.088. Table 10 is the modelling module for coordinates of the initial sub-chord length for point C_1, of the entry transition curve at chainage 1550.000.

Table 11 is the modelling module for coordinates first general chord length C_2, of the entry transition curve at chainage 1575.000. Table 12 is the modelling module for coordinates the second general chord length C_3, for the entry transition curve at chainage 1600.000. Table 13 is the modelling module for coordinates of the final sub-chord length for point T_1, of the entry transition curve at chainage 1610.214. Table 14 is the modelling module for coordinates of initial sub-chord length end point C_4, of circular arc, chainage 1625.000 m.

Table 15 is the modelling module for coordinates of the final sub-chord length end point T_2, of the circular arc, chainage 1646.833 m. Table 16 is the modelling module for coordinates of tangent point U, of exit transition curve, chainage 1719.960 m. Table 17 is the modelling module for coordinates of the initial sub-chord length for point C_7, of the exit transition curve, chainage 1700.000 m. Table 18 is the modelling module for coordinates first general chord length point C_6, of exit transition curve, chainage 1675.000 m. Table 19 is the modelling module for coordinates for the second general chord length point C_5, of exit transition curve, at chainage 1650.000 m.

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TABLE 2: THE MODELLING MODULE FOR DEFLECTION ANGLE DETERMINATION

	C	D	E	F	G	H
2	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
3	E_B =	971695.890	m	Distance D_{BI} = (ΔE_{BI}^2 + ΔN_{BI}^2)^0.5 =	=(D9^2+D10^2)^0.5	m
4	N_B =	678164.460	m	Distance D_{IS} = (ΔE_{IS}^2 + ΔN_{IS}^2)^0.5 =	=(D11^2+D12^2)^0.5	m
5	E_I =	972796.670	m	Bearing $\theta_{BI} = \tan^{-1}$ ($\Delta E_{BI}/\Delta N_{BI}$) =	=ATAN(D9/D10)	radians
6	N_I =	679364.870	m	Bearing θ_{BI} =	=G5*180/22*7	degrees
7	E_S =	974123.000	m	Bearing $\theta_{IS} = \tan^{-1}$ ($\Delta E_{IS}/\Delta N_{IS}$) =	=ATAN(D11/D12)	radians
8	N_S =	680364.300	m	Bearing θ_{IS} =	=G7*180/22*7	degrees
9	$\Delta E_{BI} = E_I - E_B$ =	=D5-D3	m	Deflection angle θ = Bearing θ_{TI} - Bearing θ_{IS} =	=G7-G5	radians
10	$\Delta N_{BI} = N_I - N_B$ =	=D6-D4	m	Deflection angle θ =	=G8-G6	degrees
11	$\Delta E_{IS} = E_S - E_I$ =	=D7-D5	m	Deflection angle θ =	10° 29' 06"	dms
12	$\Delta N_{IS} = N_S - N_I$ =	=D8-D6	m			

TABLE 4: THE MODELLING MODULE OF TANGENTIAL ANGLES FOR THROUGH CHAINAGES OF THE ENTRY TRANSITION CURVE

	B	C	D	E	F	G
32	LABEL		MODELLING			LABEL
33–34	Chainage	Chainage Identification	Chord Length	Cumulative Length	Cumulative Clockwise Tangential Angle From T Relative To TI, $\Delta = L^2/6RL_T$	Tangential Angles Identification
35	(m)		(m)	(m)	radians	
36	=G21	T	0	0	=E36^2/(6*$D$25*$D$26)	
37	=B36+D37	C_1	=G26	=D37	=E37^2/(6*$D$25*$D$26)	δ_1
38	=B37+D38	C_2	=G27	=E37+D38	=E38^2/(6*$D$25*$D$26)	δ_2
39	=B38+D39	C_3	=G27	=E38+D39	=E39^2/(6*$D$25*$D$26)	δ_3
40	=B39+D40	T_1	=G28	=E39+D40	=E40^2/(6*$D$25*$D$26)	δ_{max}
41	SUM =		=SUM(D36:D40)	(checks)	=D26/2/D25/3	ϕ max/3 = L_T/6R/3

TABLE 3: THE MODELLING MODULE FOR ENTRY TRANSITION CURVE

	C	D	E	F	G	H
19	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
20	Design speed, V =	85	Km/h	Chainge of Intersection point, CH.I =	=G3	
21	Rate of change of radial acceleration, c =	0.3		Through chainage of T = CH.I - IT =	=G20-D28	m
22	Superelevation, e% =	0.025	m/s^3	Through chainage of T_1 = CH.I - IT + L_T =	=G21+D26	m
23	Side friction factor, f =	0.07		Through chainage multiple interval value =	25	m
24	Radius, R = $V^2/(127(e\%+f))$ =	=D20^2/(127*(D22+D23))	m	Next multiple of 25 m for chainage after T =	1550	m
25	Design Radius =	600	m	Last multiple of 25 m for chainage before T_1 =	1600	m
26	Length of transition curve L_T= V^3/(3.6^3*c*R) =	=D20^3/((3.6^3)*D21*D25)	m	Length of initial sub cord =	=G24-G21	m
27	Shift = $L_T^2/24R$ =	=D26^2/24/D25	m	Length of general chord =	25	m
28	Tangent length, IT = (R + S) tan θ/2 + LT/2 =	=(D25+D27)*TAN(G9/2)+D26/2	m	Length of final sub-chord =	=G22-G25	m
29	Tangent length, IU = IT =	=D28	m			

TABLE 5: THE MODELLING MODULE FOR THE CENTRAL CIRCULAR ARC

	C	D	E	F	G	H
45	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
46	Maximum Deviation Angle $\phi_{max} = L_T/(2R)$ =	=D26/(2*D25)	radians	Last multiple of 25 m for chainage before T_2 =	1625	m
47	Length of circular arc $L_C = R(\theta - 2\phi max)$ =	=D25*(G9-2*D46)	m	Length of initial sub chord =	=D49-G22	m
48	Through chainage of T_2 = CH.T_1 + L_C =	=G22+D47	m	Length of general chord =	0	m
49	Next multiple of 25 m for chainage after T_1 =	1625	m	Length of final sub-chord =	=D48-G46	m

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TABLE 6: THE MODELLING MODULE OF CHORD LENGTHS TANGENTIAL ANGLES FOR THROUGH CHAINAGE OF THE CENTRAL CIRCULAR CURVE

	B	C	D	E	F	G
52	LABEL		MODELLING			LABEL
53 54	Chainage	Chainage Identification	Chord Length	Tangential Angle for Each Chord α = l/2R	Cumulative Clockwise Tangential Angle From T Relative to the Common Tangent	Tangential Angles Identification
55	(m)		(m)	radians	radians	
56	=G22	T_1	0	=D56/2/$D$25	=E56	
57	=B56+D57	C_4	=G47	=D57/2/$D$25	=F56+E57	α_1
58	=B57+D58	T_2	=G49	=D58/2/$D$25	=F57+E58	α_2
59	SUM =		=SUM(D56:D58)	(checks)	=D47/D25/2	$(\theta - 2\phi max)/2$

TABLE 7: THE MODELLING MODULE FOR EXIT TRANSITION CURVE

	C	D	E	F	G	H
63	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
64	Through Chainage of T_2 =	=D48	m	Last Multiple of 25m for Chainage Before U =	1700	m
65	Length of Exit Transition Curve =	=D26		Initial Sub-Chord Length from U =	=D66-G64	m
66	Through Chainage of U =	=SUM(D64:D65)		Length of General Chord =	25	m
67	First Multiple of 25m for Chainage After T_2 =	1650	m	Final Sub-Chord Length to T_2 =	=D67-D64	m

TABLE 8: THE MODELLING MODULE OF CHORD LENGTHS TANGENTIAL ANGLES FOR THROUGH CHAINAGE OF THE EXIT TRANSITION CURVE

	B	C	D	E	F	G
70	LABEL		MODELLING			LABEL
71 72	Chainage	Chainage Identification	Chord Length	Cumulative Length	Cumulative Clockwise Tangential Angle From U Relative To UI, Δ = L^2/6RLT	Tangential Angles Identification
73	(m)		(m)	(m)	radians	
74	=D66	U	0	0	=E74^2/(6*$D$25*$D$26)	
75	=B74-D75	C_7	=G65	=D75	=E75^2/(6*$D$25*$D$26)	δ_7
76	=B75-D76	C_6	=G66	=E75+D76	=E76^2/(6*$D$25*$D$26)	δ_6
77	=B76-D77	C_5	=G66	=E76+D77	=E77^2/(6*$D$25*$D$26)	δ_5
78	=B77-D78	T_2	=G67	=E77+D78	=E78^2/(6*$D$25*$D$26)	δ_{max}
79	SUM =		=SUM(D74:D78)	(checks)	=F41	ϕ max/3 = $L_T/6R/3$

TABLE 9: THE MODELLING MODULE FOR COORDINATES TANGENT POINT T, OF ENTRY TRANSITION CURVE, CHAINAGE 1537.088 M

	C	D	E	F	G	H
83	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
84	Length of TI =	=D29	m	Cos Bearing of TI =	=COS(D87)	radians
85	E_I=	=D5	m	$\Delta_{EI} = D_{TI}$ x Sin Bearing of TI =	=D84*D88	m
86	N_I=	=D6	m	$\Delta_{NI} = D_{TI}$ x Cos Bearing of TI =	=D84*G84	m
87	Bearing of TI =	=G5	m	$E_T = E_I - \Delta_{EI}$ =	=D85-G85	m
88	Sin Bearing of TI =	=SIN(D87)	radians	$N_T = N_I - \Delta_{NI}$ =	=D86-G86	m

TABLE 10: THE MODELLING MODULE FOR COORDINATES INITIAL SUB-CHORD LENGTH C_1, OF ENTRY TRANSITION CURVE, CHAINAGE 1550.000 M

	C	D	E	F	G	H
93	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
94	Length of TC_1 =	=D37	m	ΔN_{TI} =	=D97-D99	m
95	δ_1=	=F37	radians	Bearing of TI = arc Tan ($\Delta E_{TI}/\Delta N_{TI}$) =	=ATAN(D100/G94)	radians
96	E_I=	=D85	m	Bearing of TC_1 = Bearing of TI + δ_1 =	=G95+D95	radians
97	N_I=	=D86	m	$\Delta E_{TC1} = TC_1$ Sin bearing of TC_1 =	=D94*SIN(G96)	m
98	E_T=	=G87	m	$\Delta N_{TC1} = TC_1$ Cos bearing of TC_1 =	=D94*COS(G96)	m
99	N_T=	=G88	m	$E_{C1} = E_T + \Delta E_{TC1}$ =	=D98+G97	m
100	ΔE_{TI}=	=D96-D98	m	$N_{C1} = N_T + \Delta N_{TC1}$ =	=D99+G98	m

TABLE 11: THE MODELLING MODULE FOR COORDINATES FIRST GENERAL CHORD LENGTH C_2, OF ENTRY TRANSITION CURVE, CHAINAGE 1575.000 M

	C	D	E	F	G	H
104	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
105	LENGTH OF TC_1 =	=D37	m	bearing C_1C_2 = bearing TC_1 + Υ =	=G96+D111	radians
106	LENGTH OF C_1C_2 =	=D38	m	$\Delta E_{C1C2} = C_1C_2$ SIN BEARING OF C_1C_2 =	=D106*SIN(G105)	m
107	δ_1=	=F37	radians	$\Delta N_{C1C2} = C_1C_2$ COS BEARING OF C_1C_2 =	=D106*COS(G105)	m
108	δ_2=	=F38	radians	E_{C1}=	=G99	m
109	$\sin\beta_1 = (TC_1/C_1C_2) * \sin(\delta_2 - \delta_1)$ =	=(D105/D106)*Sin(D108-D107)	radians	N_{C1}=	=G100	m
110	β1 =	=ASIN(D109)	radians	$E_{C2} = E_{C1} + \Delta E_{C1C2}$=	=G108+G106	m
111	Υ = β1 + ($\delta_2 - \delta_1$) =	=D110+D108-D107	radians	$N_{C2} = N_{C1} + \Delta N_{C1C2}$ =	=G109+G107	m

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TABLE 12: THE MODELLING MODULE FOR COORDINATES SECOND GENERAL CHORD LENGTH C_3, OF ENTRY TRANSITION CURVE, CHAINAGE 1600.000 M

	C	D	E	F	G	H
115	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
116	Length of TC_1 =	=D37	m	$Y = \beta_2 + (\delta 3 - \delta 2)$ =	=D123+D121-D120	radians
117	Length of C_1C_2 =	=D38	m	bearing C_2C_3 = bearing $C_1C_2 + Y$ =	=G105+G116	radians
118	Length of TC_2 = $TC_1 + C_1C_2$ =	=D116+D117	m	$\Delta E_{C2C3} = C_2C_3$ Sin bearing of C_2C_3 =	=D119*Sin(G117)	radians
119	Length of C_2C_3 =	=D39	m	$\Delta N_{C2C3} = C_2C_3$ Cos bearing of C_2C_3 =	=D119*Cos(G117)	m
120	δ_2=	=F38	radians	E_{C2}=	=G110	m
121	δ_3=	=F39	radians	N_{C2}=	=G111	m
122	$\sin\beta_2$ = $(TC_2/C_2C_3)*\sin(\delta_3 - \delta_2)$ =	=(D118/D119)*SIN(D121-D120)	radians	$E_{C3} = E_{C2} + \Delta E_{C2C3}$=	=G120+G118	m
123	β_2 =	=ASIN(D122)	radians	$N_{C3} = N_{C2} + \Delta N_{C2C3}$ =	=G121+G119	m

TABLE 13: THE MODELLING MODULE FOR COORDINATES OF THE FINAL SUB-CHORD LENGTH FOR POINT T_1, CHAINAGE 1610.214 M

	C	D	E	F	G	H
127	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
128	Length of TC_2 =	=D118	m	$Y = \beta_3 + (\delta_{max} - \delta_3)$ =	=D135+(D133-D132)	radians
129	Length of C_2C_3 =	=D39	m	bearing C_3T_1 = bearing $C_2C_3 + Y$ =	=G117+G128	radians
130	Length of TC_3 = $TC_2 + C_2C_3$ =	=D128+D129	m	$\Delta E_{C3T1} = C_3T_1$SIN bearing of C_3T_1 =	=D131*SIN(G129)	m
131	Length of C_3T_1=	=D40	m	$\Delta N_{C3T1} = C_3T_1$ COS bearing of C_3T_1 =	=D131*COS(G129)	m
132	δ_3=	=F39	radians	E_{C3}=	=G122	m
133	δ_{max}=	=F40	radians	N_{C3}=	=G123	m
134	$\sin\beta_3 = (TC_3/C_3T_1)$ $*\sin(\delta_{max} - \delta_3)$=	=(D130/D131)*Sin(D133-D132)	radians	$E_{T1} = E_{C3} + \Delta E_{C3T1}$=	=G132+G130	m
135	β_3 =	=ASIN(D134)	radians	$N_{T1} = N_{C3} + \Delta N_{C3T1}$ =	=G133+G131	m

TABLE 14: THE MODELLING MODULE FOR COORDINATES INITIAL SUB-CHORD LENGTH END POINT C_4, OF CIRCULAR ARC, CHAINAGE 1625.000 M

	C	D	E	F	G	H
139	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
140	ϕ_{max} =	=D46	radians	ΔE_{T1C4} = Length T_1C_4 x Sin Bearing T_1C_4 =	=D145*SIN(D144)	m
141	Bearing TI =	=G95	radians	ΔN_{T1C4} = Length T_1C_4 x Cos Bearing T_1C_4 =	=D145*COS(D144)	m
142	Bearing T_1Z = Bearing TI + ϕ_{max} =	=SUM(D140:D141)	radians	E_{T1} =	=G134	m
143	α_1 =	=F57	radians	N_{T1} =	=G135	m
144	Bearing T_1C_4= Bearing $T_1Z + \alpha_1$ =	=SUM(D142:D143)	radians	$E_{C4} = E_{T1} + \Delta E_{T1C4}$=	=G142+G140	m
145	Length T_1C_4 =	=D57	m	$N_{C4} = N_{T1} + \Delta N_{T1C4}$=	=G143+G141	m

TABLE 15: THE MODELLING MODULE FOR COORDINATES OF THE FINAL SUB- CHORD LENGTH END POINT T_2, OF THE CIRCULAR ARC, CHAINAGE 1646.833 M

	C	D	E	F	G	H
149	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
150	α_1 =	=F57	radians	ΔE_{C4T2} = Length C_4T_2x Sin Bearing C_4T_2 =	=D155*SIN(D154)	m
151	α_2 =	=F58	radians	ΔN_{C4T2} = Length C_4T_2x Cos Bearing C_4T_2 =	=D155*COS(D154)	m
152	$\lambda = (\alpha_1 + \alpha_2)$ =	=SUM(D150:D151)	radians	E_{C4} =	=G144	m
153	Bearing T_1C_4 =	=D144	radians	N_{C4} =	=G145	m
154	Bearing C_4T_2 = Bearing $T_1C_4 + \lambda$ =	=SUM(D152:D153)	radians	$E_{T2} = E_{C4} + \Delta E_{C4T2}$ =	=G152+G150	m
155	Length C_4T_2 =	=D58	m	$N_{T2} = N_{C4} + \Delta N_{C4T2}$ =	=G153+G151	m

TABLE 16: THE MODELLING MODULE FOR COORDINATES TANGENT POINT U, OF EXIT TRANSITION CURVE, CHAINAGE 1719.960 M

	C	D	E	F	G	H
159	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
160	θ =	=G9	radians	ΔN_{IU} = Length IU x Cos Bearing IU =	=D163*COS(D162)	m
161	Bearing TI =	=G95	radians	E_I =	=D5	m
162	Bearing IU = Bearing TI + θ =	=SUM(D160:D161)	radians	N_I =	=D6	m
163	Tangent length IU =	=D29	m	$E_U = E_I + \Delta E_{IU}$ =	=G161+D164	m
164	ΔE_{IU} = Length IU x Sin Bearing IU =	=D163*SIN(D162)	m	$N_U = N_I + \Delta N_{IU}$ =	=G162+G160	m

TABLE 17: THE MODELLING MODULE FOR COORDINATES OF THE INITIAL SUB- CHORD LENGTH FOR POINT C_7, OF THE EXIT TRANSITION CURVE, CHAINAGE 1700.000 M

	C	D	E	F	G	H
168	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
169	Length of UC_7 =	=D75	m	ΔN_{UI} =	=D172-D174	m
170	δ_7 =	=F75	radians	Bearing of UI = Arc Tan ($\Delta E_{UI}/\Delta N_{UI}$) =	=ATAN(D175/G169)	radians
171	E_U =	=G163	m	Bearing of UC_7 = bearing of UI - δ_7 =	=G170-D170	radians
172	N_U =	=G164	m	ΔE_{UC7} = UC_7 Sin bearing of UC_7 =	=D169*SIN(G171)	m
173	E_I =	=D5	m	ΔN_{UC7} = UC_7 Cos bearing of UC_7 =	=D169*COS(G171)	m
174	N_I =	=D6	m	$E_{C7} = E_U - \Delta E_{UC7}$ =	=D171-G172	m
175	ΔE_{UI} =	=D171-D173	m	$N_{C7} = N_U - \Delta N_{UC7}$ =	=D172-G173	m

TABLE 18: THE MODELLING MODULE FOR COORDINATES FIRST GENERAL CHORD LENGTH POINT C_6, OF EXIT TRANSITION CURVE, CHAINAGE 1675.000 M

	C	D	E	F	G	H
179	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
180	Length of UC_7=	=D169	m	bearing C_7C_6 = bearing UC_7 - Υ =	=G171-D186	m
181	Length of C_7C_6 =	25	m	ΔE_{C7C6}= C_7C_6 Sin bearing of C_7C_6 =	=D181*SIN (G180)	m
182	δ_7=	=F75	radians	ΔN_{C7C6} = C_7C_6 Cos bearing of C_7C_6 =	=D181*COS (G180)	m
183	δ_6=	=F76	radians	E_{C7}=	=G174	m
184	Sinβ_7 = (UC_7/C_7C_6) *Sin(δ6 - δ7) =	=(D180/D181)* Sin(D183-D182)	radians	N_{C7}=	=G175	m
185	β7 =	=ASIN(D184)	radians	E_{C6}= E_{C7} - ΔE_{C7C6}=	=G183-G181	m
186	Υ = β7 + (δ6 - δ7) =	=D185+D183-D182	radians	N_{C6}= N_{C7} . ΔN_{C7C6} =	=G184-G182	m

TABLE 19: THE MODELLING MODULE FOR COORDINATES FOR THE SECOND GENERAL CHORD LENGTH POINT C_5, OF EXIT TRANSITION CURVE, CHAINAGE 1650.000 M

	C	D	E	F	G	H
190	LABEL	MODELLING	UNIT	LABEL	MODELLING	UNIT
191	Length of UC_7 =	=D180	m	Υ = β6 + (δ5 - δ6) =	=D198+D196-D195	radians
192	Length of C_7C_6 =	=D181	m	bearing C_6C_5 = bearing C_7C_6 - Υ =	=G180-G191	radians
193	Length of UC_6 = $UC_7 + C_7C_6$ =	=D191+D192	m	ΔE_{C6C5}= C_6C_5Sin bearing of C_6C_5 =	=D194*Sin (G192)	radians
194	Length of C_6C_5=	25	m	ΔN_{C6C5} = C_6C_5 COS bearing of C_6C_5=	=D194*COS (G192)	m
195	δ_6=	=F76	radians	E_{C6}=	=G185	m
196	δ_5=	=F77	radians	N_{C5}=	=G186	m
197	Sinβ_6 = (UC_6/C_6C_5) *Sin($\delta_5 - \delta_6$)	=(D193/D194)* SIN(D196-D195)	radians	E_{C5}= E_{C6} - ΔE_{C6C5}=	=G195-G193	m
198	β6 =	=ASIN(D197)	radians	$N_{C5} = N_{C6} - \Delta N_{C6C5}$=	=G196-G194	m

4 RESULTS AND DISCUSSION

The summary of the modelling that processed the coordinates of points to define the composite curve is shown in Table 20. Table 21 is showing the summary of the simulation of coordinates for the design and setting out of the composite curve on site. Modelling modules of Table 2 through Table 19 allow iteration process by engineers to automate design variables through a discrete-event simulation design process to develop coordinates for a composite curve. This is accomplished through an integrated ICT design environment that links design activities of entry transition curve, circular arc and exit transition curve to produce coordinates for a composite curve.

Numerous design iterations for the purpose of improving and refining the coordinates to develop a composite curve without expending a large amount of time or effort are possible using the modelling tables. The developed modelling tables within spreadsheet environment are valuable features with the ability to view the resulting effect of the computation of coordinates and modifications. Hence, coordinates for a composite curve are automatically carried out via a discrete-event methodology without the need to conduct the numerous intermediate steps that have been associated with the conventional manual design method. The method developed here does not need the involvement of vendors to complement design activities as in the case of specific purpose application programs and the system operation is not under license.

5 CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations are derived from the investigation carried out in this study.

5.1 CONCLUSIONS

1. A new methodology of computing coordinates for designing a composite curve via a discrete-event simulation approach in an ICT environment has been vividly carried successfully.
2. This novel methodology has been successfully carried out by making use of coordinates generated by GPS on site and advancing same in Microsoft Excel to compute coordinate to design a composite curve.
3. The process allows coordinates to be computed for a composite curve by using various related variables that change instantaneously at separate points in different modelling module tables while making use of a readily available general purpose application program.
4. The result is similar to the conventional hand method of computation but this novel methodology is in an electronics environment.
5. The methodology is amenable to intranet and internet and allows various engineers to work on a composite curve for improvement optimally.
6. The process has the ability to enhance the productivity of highway engineers to conduct numerous iteration of computations for a composite curve coordinates for the purpose of improving and refining without expending a large amount of time or effort.

5.2 RECOMMENDATIONS

1. The methodology is highly recommended as a better alternative to the use of programming software, specific purpose application programs and conventional hand method in the computation of coordinates for design of road or rail composite curve.
2. The methodology is also highly recommended as a better alternative while setting out of road or rail composite curve.

TABLE 20: MODELLING MODULE SUMMARY OF THE COMPOSITE CURVE COORDINATES

	J	K	L	M
215	LABEL		MODELLING	
216	Point	Through Chainage	Coordinates	
217		m	mE	mN
218	T	1537.088	=G87	=G88
219	C_1	1550	=G99	=G100
220	C_2	1575	=G110	=G111
221	C_3	1600	=G122	=G123
222	T_1	1610.214	=G134	=G135
223	C_4	1625	=G144	=G145
224	T_2	1646.833	=G154	=G155
225	C_5	1650	=G197	=G198
226	C_6	1675	=G185	=G186
227	C_7	1700	=G174	=G175
228	U	1719.96	=G163	=G164

TABLE 21: SUMMARY OF THE COMPOSITE CURVE COORDINATES SIMULATION MODULE

	J	K	L	M
215	LABEL		SIMULATION	
216	Point	Through Chainage	Coordinates	
217		m	mE	mN
218	T	1537.088	972734.745	679297.340
219	C_1	1550.000	972743.478	679306.852
220	C_2	1575.000	972760.521	679325.143
221	C_3	1600.000	972777.999	679343.017
222	T_1	1610.214	972785.411	679350.046
223	C_4	1625.000	972796.175	679360.182
224	T_2	1646.833	972812.696	679374.457
225	C_5	1650.000	972814.848	679376.786
226	C_6	1675.000	972834.147	679392.678
227	C_7	1700.000	972853.922	679407.973
228	U	1719.960	972869.845	679420.009

ISSN 2229-5518

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