DEVELOPMENT OF MODELLING SYSTEMS FOR AN EFFECTIVE HUMANITARIAN SUPPLY CHAIN FOR DISASTER RELIEF OPERATIONS IN THE SOUTHERN AFRICAN REGION

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ABSTRACT

The Southern African Development community (SADC) has seen both man-made and natural disasters killing over 68,000 people and affecting millions in the past 33 years. Most of these deaths are results of lack of infrastructure and preparedness. With consideration to the challenges faced by the region, this paper has emphases more on the last mile transportation of resources, victims, emergency supplies. The aim of this study is to optimize the effectiveness (quick-response) and efficiency (low-cost) of logistics activities including humanitarian supply chain. Historical data from reviewed literature was utilized for data collection. The literature review also helped determine the impact of disaster relief chains and led to the development of a mathematical model to equip the region with mechanisms for response and recovery operations.

1. INTRODUCTION

1.1 Background

Statistics has proven that many thousands of people perish annually as a result of man-made and natural disasters. The centre of research on the Epidemiology of Disasters (CRED) has published that Earthquakes, floods, landslides, and extreme weather conditions made 2010 the deadliest year in the past two decades. Some 373 natural disasters killed almost 300,000 people in 2010, affecting nearly 207 million others, and costing nearly US$10billion in economic losses" (lancet, 2010). From the creation of the Southern African Development community (SADC) in April 1980, CRED has reported that the region has seen disaster (Man-Made and Natural) killing over 68,000 people and affecting millions (Van Wyk et al, 2011, CRED, 2013).

1.2 Problem Statement

The problems that arise during disaster relief operations may differ depending on various factors, such as the type, impact, and location of the disaster, and local conditions in the affected regions (Balcik et al., 2008). Haimes and Longstaff (2002) argue that there is disconnection among the organizations that plan, design, construct, operate, maintain, and manage complex infrastructures. CRED believe that lack of infrastructure is the main reason of such high number of victims perishing in the SADC region during and after disaster (CRED, 2013). The insufficient infrastructure has caused transportation of first aid material, food, equipment, and rescue personnel impracticable.

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1.3 Research aim

This study is aiming to assist disaster organizations in optimizing relief's transportations with the purpose minimizing human suffering and death. Looking at the future menace and at the immense challenges the SADC regions are facing; the success of this study will be determine by the researcher finding a fast and cost effective way to supply reliefs in affected areas. The developed model aim to identify alternative routes for effective and efficient goods transportation within SADC constituency.

1.4 Research Scope

The findings from this study will improve SADC capacity of reaction and preparedness to disaster eventuality. First step toward reaching the required objective is to identify areas with the highest risk of disaster, then investigate current infrastructure and transportation facility's conditions across the region in order to select the cost-effective routing. The minimization of cost and optimization of time were reach using In order to optimize time and cost of transportation, the researcher has developed a genetic algorithm theory focussing on prüfer number.

2. LITERATURE REVIEW

2.1 Humanitarian logistics

With the global increase on disasters activities, the use of supply chain management can assist communities' for pre or post-disaster. (Tatham and Houghton, 2011). Many SADC countries has been pro-active, in numerous areas the locals has been train on supply chain management. Such move reduce the dependency on foreign assistance and upsurge confidence.

2.2 SADC most affected Area

The SADC is constituted of 15 countries, all the countries in the region considered as third world nations. Benson et al, (2001) argue that disasters affect poorer countries disproportionately and, furthermore, that the poorer sections of the population are, typically, the most severely affected. Likewise, Samii (2008) suggested that 90% of those affected by natural disasters are in countries of medium human development, and that two thirds of those killed are from countries of low human development (Peter Tatham, 2009).

2.1.1 Natural Disaster

From its existence, SADC region has been affected mostly by famines, earthquakes or floods. Although some catastrophe could have avoid, unfortunately the dearth on infrastructures and lack of connectivity (Long & Wood, 1995) between countries has made the disaster zones nearly unreachable.

2.1.2 Man Made Disaster

According to CRED database, South Africa is the country with the most number of disaster events in the region (with about 160 events since the creation of SADC in 1980), while Mozambique is the country with the most number of affected population (with about 60000 from SADC creation in 1980) (CRED, 2013).

2.3 Transportation Model

To build the model, the researcher has utilized the Genetic Algorithm model in order to optimize the time and the cost of humanitarian transportation.

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3. DEVELOPMENT OF MODEL

3.1. Genetic Algorithms

According to Vignaux and Michalewicz (1990), transportation problem seeks to determine the minimal cost of supplying a single commodity from a number of sources to a number of destinations. In line with all these properties, a multi-objective genetic algorithm was developed. This research has made use of all historical data collected by reviewing all publish work on this topics. Bryant (2000) describe Genetic Algorithm as a 'new optimization techniques which can be applied to various problems, including those that are NP-hard (non-deterministic polynomial-time hard).' For Bryant (2000), Genetic algorithms (GA) are an optimization technique based on natural evolution. To develop this model, information needed are the following (1) A list of the origins. (2) A list of destinations and each one's demand per period. (3) The unit cost of shipping items from each origin to each destination.

Constraint Conditions

With allocated supply quantity, the study assume that a disaster agency operating in the region supply relief to affected areas in SADC countries. This research effort is to identify shortest routes for relief supplies. Knowing that the quantity of relief to be is proportional to the demand on the ground, it is assumed that each city on the region owns warehouses with sufficient storage capacity reliefs supplies and not border checking required.

The following are areas of highest disaster risk in each country on the region: Angola (Luanda & Cabinda), Botswana (Gaborone & Kgwakgwe), Democratic Republic of Congo (Lubumbashi & Bukavu), Lesotho (Theba-Tseka & Maseru), Madagascar (Antananarivo & Amparafaravola), Malawi (Blantyre & Lilongwe), Mauritius (Port Louis & Goodland), Mozambique (Xai-Xai & Zambezi delta), Namibia (Ohangwena & Windhoek), Seychelles (Mahe & Anse La Mouche), South Africa (Durban & Limpopo), Swaziland (Matsapha & Mbabane), Tanzania (Tanga & Dar es Salam), Zambia (Chongwe & Lusaka), and Zimbabwe (Matabeleland & Harare). Those countries supply quantities are represented respectively by the following symbols: $S1$, $S2$, $S3$, $S4$, $S5$, $S6$, $S7$, $S8$, $S9$, $S10$, $S11$, $S12$, $S13$, $S14$ and $S15$. The Quantities of the reliefs supply to those nations are assumed based on based on their superficial representation and their vulnerability (Table 1).

Table 1: Supply Quantities of Suppliers

SC	$S1$	$S2$	$S3$	$S4$	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
SQ	200	90	300	30	190	50	110	250	150	30	80	40	160	120	140

SC: Supplier code, SQ: Supply quantity (piece/day, N.B: Value are in Batches), One Batch of supply = a Tonne. (Xiangyu et al, 2012)

The demand for each country is represented respectively by the following symbols: D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D13, D14 and D15. Each variable relate to those following countries: Angola (S1, D1), Botswana (S2, D2), Democratic Republic of Congo (S3, D3), Lesotho (S4, D4), Madagascar (S5,D5), Malawi (S6, D6), Mauritius (S7, D7), Mozambique (S8, D8), Namibia(S9, D9), Seychelles (S10, D10), South Africa (S11, D11), Swaziland (S12, S12), Tanzania (S13, D13), Zambia (S14, D14), and Zimbabwe (S15, D15). The quantities demanded by each country are assumed based on their population and their vulnerability to disaster occurrence (Table 2).

Table 2: Demand Quantities of Sale Departments

SC	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
DQ	220	50	350	30	190	50	90	230	150	45	80	35	200	120	160

SC: Supplier code, DQ: Demand quantity (piece/day, N.B: Value are in Batches）, One Batch of Maize = a Tonne. Source: (Xiangyu et al, 2012)

In order to accurately identify the average transportation cost and time using Xiangyu et al (2012) model, this research assume that no delays are experienced at border gates or airport customs. To optimize the disaster relief plan, disaster reactions time need to be reduced. The reduction of time may not necessarily reduce the cost of transportation, but will increase the supply pool and augment the number of survival. Table 3 provides details on the average transportation time C_{ij}^2 (hour/piece) and the average transportation cost C_{ij}^1 (US Dollar/piece) for each country within SADC region.

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Table 3: Average transportation cost & Average transportation time
Source: (Xiangyu et al, 2012)

Supplier Code	Average transportation cost C_{ij}^1 (US Dollar/piece) Air Transportation: Between 4 \$ to 6 \$ (10^3) Route Transportation: Between 12 \$ to 28 \$ (10)															Supply Quantity a_i (piece)
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D12	D14	D15	
S1	5	28	28	28	6	28	8	23	20	7	27	28	28	25	24	200
S2	25	12	27	12	5	24	5	14	24	5	12	12	27	22	12	90
S3	26	27	12	25	5	24	6	18	21	5	18	28	22	12	21	300
S4	20	12	18	12	3	20	5	16	22	6	12	12	28	27	16	30
S5	6	6	5	3	3	3	5	4	4	5	5	4	4	5	5	190
S6	28	24	24	28	3	12	4	20	19	4	19	25	24	14	16	50
S7	6	5	5	5	4	4	2	6	3	3	4	4	4	4	4	110
S8	28	16	17	16	5	20	4	12	25	5	12	12	28	25	15	250
S9	20	24	13	17	4	16	6	20	12	6	20	27	28	22	24	150
S10	5	5	5	6	5	4	4	18	23	12	6	5	4	5	4	30
S11	28	12	17	19	4	15	4	12	33	6	12	12	28	27	16	80
S12	28	12	16	11	5	25	4	12	25	5	12	12	27	24	12	40
S13	27	26	22	28	4	24	4	27	28	3	28	26	12	28	28	160
S14	20	22	12	27	4	14	4	25	15	5	27	24	28	12	14	120
S15	21	13	16	16	4	16	4	15	24	4	16	15	15	14	12	140

	Average transportation time C_{ij}^2 (hour/piece)															
	D1	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12	D12	D14	D15	
S1	1	40	44	51	6	49	8	53	20	7	52	48	57	38	43	200
S2	40	5	27	12	3	24	5	16	24	5	12	10	46	22	10	90
S3	44	27	22	35	5	24	7	31	29	5	33	30	22	10	21	300
S4	51	12	35	3	3	30	5	16	34	6	6	11	54	27	16	30
S5	6	3	5	3	1	3	1	2	4	3	3	3	3	3	3	190
S6	49	24	24	30	3	5	4	20	35	4	30	25	24	14	16	50
S7	8	5	7	5	1	4	1	6	3	3	4	4	4	4	4	110
S8	53	16	31	16	2	20	4	18	30	5	11	6	43	25	15	250
S9	20	24	29	34	4	35	6	30	11	6	33	48	54	30	24	150
S10	7	5	5	6	3	4	3	5	6	1	6	5	3	5	4	30
S11	52	12	33	6	3	30	4	11	33	6	10	7	54	27	16	80
S12	48	10	30	11	3	25	4	6	48	5	7	2	48	24	11	40
S13	57	46	22	54	3	24	4	43	54	3	54	48	5	28	39	160
S14	38	22	10	27	3	14	4	25	30	5	27	24	28	3	14	120
S15	43	10	21	16	3	16	4	15	24	4	16	11	39	14	8	140
Demand Quantity b_j (piece)	220	50	350	30	190	50	90	230	150	45	80	35	200	95	135	1975

The cost of transportation of goods on road are often determine by distance from origin to destinations. While the airport and marine ports transportations utilize different measure such as the weight or the time to estimate the cost. 'Transportation of goods using trucks in the SADC region cost between \$120 and \$280 per tonne, while air transportation varies between \$4000 and \$6000 per tonne' (Rupa Ranganathan V. F, 2011). The transportation time and distance was obtained using google map.

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3.2 Model Application

Prasad (1993) expressed the transportation problem in the mathematical language. With $C_{ij}(t)$ as the unit cost of transportation from supply point m, $i(i = 1,2,\dots,m)$ to demand point n, $j(j = 1,2,\dots,n)$ when the duration allowed for the transportation is t units. Now, setting X_{ij} to be the variable denoting the amount transported from supply point i to demand point j, let a_i be the availability at source points i and b_j the demand at demand point j. The mathematical language is the following:

$$\min z_q = \sum_{i=1}^{m}\sum_{j=1}^{n} C_{ij}^q X_{ij}, q = 1,2 \quad 1$$

$$s.t. \sum_{j=1}^{n} X_{ij} = a_i, i = 1,2,3,4,5,6,7,\dots,m \quad 2$$

$$\sum_{i=1}^{m} X_{ij} = b_j, j = 1,2,3,4,5,6,7,\dots,n \quad 3$$

$$X_{ij} \geq 0, \forall i,j \quad 4$$

The application of the above mathematical language to the problem at hand leads to the following:

$$\min z_q = \sum_{i=1}^{15}\sum_{j=1}^{15} C_{ij}^q X_{ij}, q = 1,2 \quad 5$$

$$s.t. \sum_{j=1}^{15} X_{ij} = a_i, i = 1,2,3,4,5,6,7,\dots,15 \quad 6 \quad \sum_{i=1}^{15} X_{ij} = b_j, j = 1,2,3,4,5,6,7,\dots,15 \quad 7$$

$$X_{ij} \geq 0, \forall i,j \quad 8$$

A. Genetic Algorithm Program Flow

In order to solve the problem, Xiangyu et al (2012) utilised a coding method based on prüfer numbers of spanning tree. The main program flow chart can be seen in Figure 1.

Figure 1: Genetic algorithm program flow chart

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B. Method Based on Spanning Tree

The genetic algorithm uses a prüfer numbers coding based on the spanning tree. During the solving of the transportation problem, Li and Gen (1999) revealed that the spanning tree-based Genetic Algorithm (GA) has an edge over the matrix-based Genetic Algorithm (GA) on two properties: 1) it save more computational time than the matrix-based Genetic Algorithm (GA) and 2) it has a higher solution quality. In order to find the optimal solutions or the approximate optimal solutions of transportation problem, the genetic algorithm based on the spanning tree will be highly considered.

To apply Li and Gen (1999) model to the SADC context, spanning tree is represented on the following: supply quantities l, 2, 3, ..., m as the components of the set of origins $S = \{1,2, 3, ..., m \}$ and demands quantities 1,2, 3, 4, ..., n as the components of the set of destinations $D = \{m + 1, ..., m + n\}$.

For instance, SADC countries suppliers is represented such as: S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14, and S15. They are defined as elements of the set S ={1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15}; SADC countries demands is represented such as: D1, D2, D3, D4, D5, D6, D7, D8, D9, D10, D11, D12, D13, D14 and D15. They are will defined as elements of the set D={15+1,15+2,15+3,15+4,15+5,15+6, 15+7, 15+8, 15+9, 15+10, 15+11, 15+12, 15+13, 15+14, 15+15}= {16,17,18,19,20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30}. The transportation problem has 15x15= 225 nodes in its spanning tree. It may have 15×15=225 different edges. For a complete graph of p nodes, it may have pp-2 trees of different node label permutations. The node that only connects one edge is called leaf of the tree. Any tree has at least 2 leaves.

C. Matrix Representation

Matrix is the most natural representation of a solution for a transportation problem. The transportation problem matrix are written as the following:

$$X_p = \begin{bmatrix} x11 & x12 & x13 & \cdots & x1n \\ x21 & x22 & x23 & ... & x2n \\ ... & ... & ... & ... & ... \\ xm1 & xm2 & xm3 & ... & xmn \end{bmatrix}$$

Where X_p denotes the pth chromosome (solution) and X_{ij}, is the corresponding decision variable.

D. Coding Method

Transportation tree can be represented as a spanning tree with prüfer number. To complete the construction of the prüfer numbers $P(T)$, Xiangyu et al (2012) suggested a gradual process. To code the transportation tree, first it is needed to record a non-leaf node that directly connects a minimum leaf node, and then remove the minimum leaf node from the transportation tree. The process need to be done until only two nodes are left in the tree. Overall process of constructing prüfer numbers is shown as follow: With demand quantities from Table 1 and 2 given, the study select the following for the sack of this exercise: D2, D8, D10, D15 to be supply to respective countries Botswana (D2, S2), Mozambique (D8, S8), Seychelles (D10, S10) and Zimbabwe (D15, S15). Suppliers S1, S7, S9 are defined as elements of the set S ={1, 2, 3}; sale or use departments D2, D8, D10, D15 are defined as elements of the set D={3+1,3+2,3+3,3+4}={4, 5, 6, 7}. To find an initial transportation solution, North West Corner rule in the Tableau below:
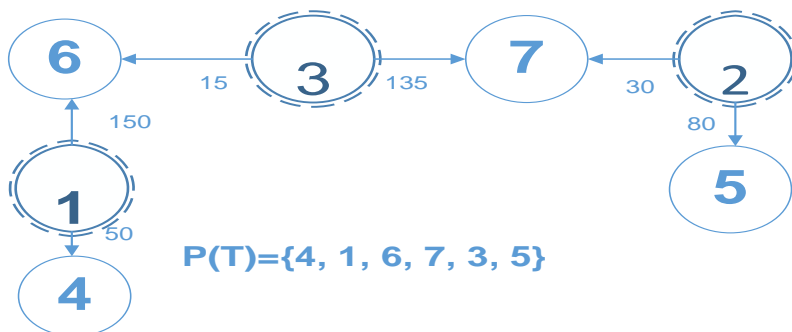
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Table 4: Transportation tableau

From To	D2	D8	D10	D15	Supply
S1	50	150	x	X	200
S7	x	80	30	X	110
S9	x	x	15	135	150
Demand	50	230	45	135	460 460

Figure below is a graphical representation of the transportation tableau:
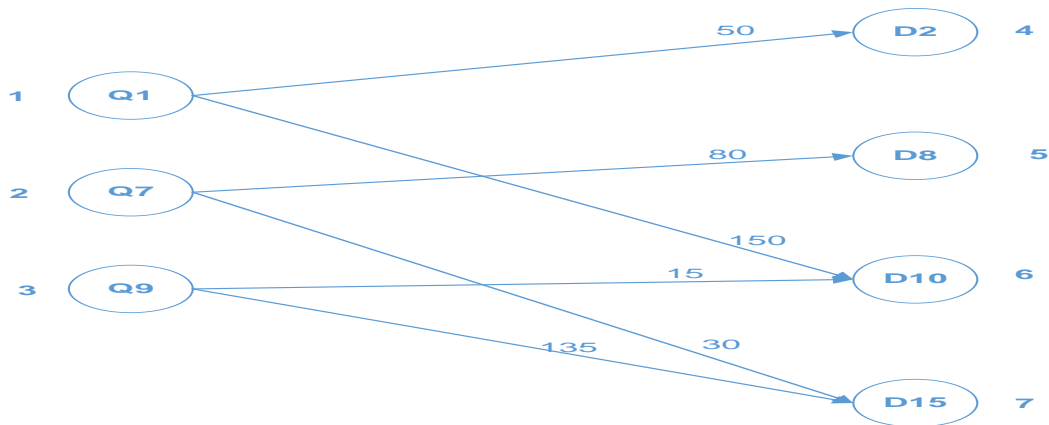
Figure 2: Transportation graph

The Figure below is a spanning tree and its prüfer number describe in detail the transportation graph:

P(T)={4, 1, 6, 7, 3, 5}

Figure 3: A spanning tree and its prüfer number

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Prüfer number could as well be found using a gradual process as shown below:
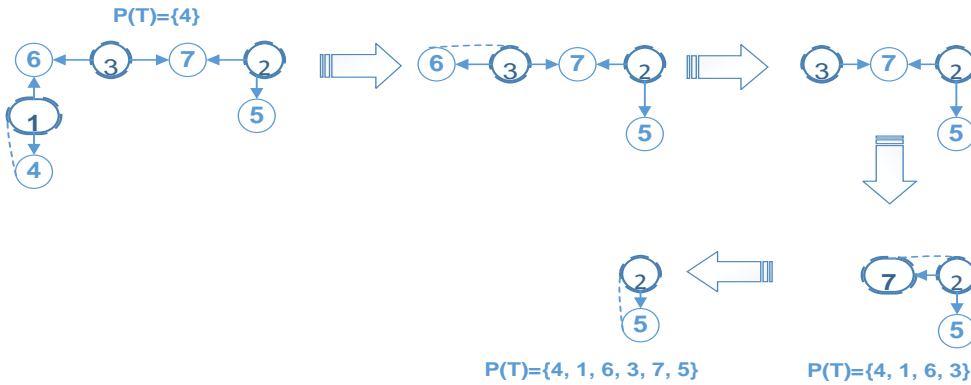

Figure 4: Process of constructing prüfer numbers

F. Decoding Method

The first step in Xiangyu et al (2012) decoding method is to connect the minimum considering node in the set $\bar{P}(\text{T}) = S \cup D - P(T)$ to the leftmost number of $P(T)$, and then remove the leftmost number of $P(T)$. This process need to be gradually done every time to construct the transportation tree. In the spanning tree below, the numbers underlined in $P(T)$ are the nodes that have been added to the tree. When $P(T) = \emptyset$, directly connect two considering nodes in $P(T)$ to complete the construction of transportation tree. Considering the demand quantities D2, D8, D10, D15, represented as D= {4, 5, 6, and 7} and the Suppliers S1, S7, S9, represented as S = {1, 2, and 3}; the process of converting prüfer numbers into transportation tree will be as follows:
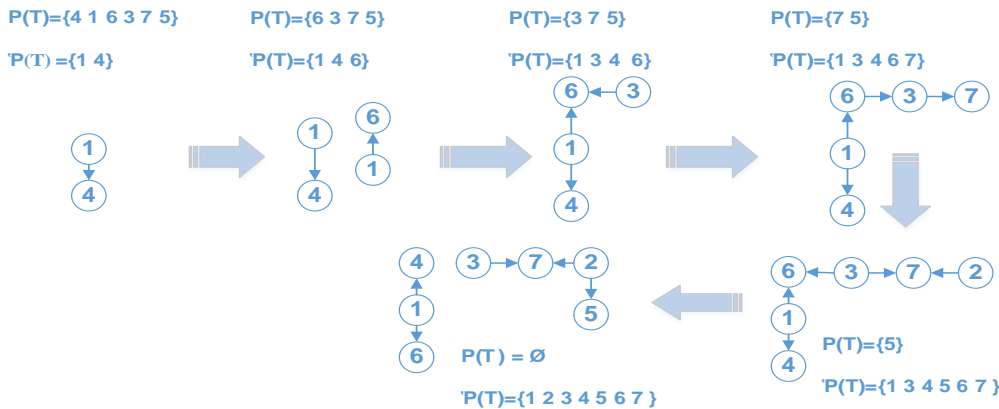

Figure 5: Process of converting prüfer numbers to transportation tree

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4. CONCLUSION

A spanning tree and its prüfer number coding has assisted the research in identifying the best routing decision from the transportation graph. The process of constructing prüfer numbers and the one of converting them to transportation tree is a manual process design for a limited number of demands. With this model, the disaster organization has the power of selecting the best possible decision for transportation and optimize the region's supply time, quantity and cost, taking into consideration the given the given demand. This model can be applied into various sector, situation and environment.

With SADC compelled to react upon the disaster risks faced by the region, it is of great necessity that more researches and actions being taken in order to assure that the region is prepared. The review of this study has proven that the increase on disaster victim rate is a result of poor infrastructures and unstructured transportation system.

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