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Road Resources Distribution and Evolution Analysis Using a Species Competition Model for Improving Road Equity*

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Abstract: The paper analyzes the equity of road resources distribution in urban areas by modeling the competitive relationship among different road users. A logistic model is used to describe the development of different traffic modes in the transportation network. The system is similar to the species competition model, so a two-species model is used to analyze the relationship between users based on the stability of the equilibrium points. The Lotka-Volterra model is then used to describe the multi-species cases with numerical examples, showing that this model can describe the effects of the road space distribution on the competitive user relationships. Policy makers must ensure the equity of road resources distribution so that each urban transportation mode is properly developed for sustainable social development.

Key words: equity; competition model; resource distribution; Lotka-Volterra model

Introduction

Equity is one of the most important concepts in sustainable transportation development, but its meaning is quite abstract. Equity can be simply described as “fairness or justice”, but it is difficult to evaluate; thus there has been little research on transportation equity. However, the principle of equity has been considered by numerous economists for centuries. Many theories such as the Gini coefficient, the different functions of social welfare[1], and Rawls’s typical theory of justice[2] were developed to describe various equities in the economic world.

Equity is closely related to distribution, and the key problem of equity is how to distribute resources fairly, where distribution here includes both opportunities and benefits. According to Rawls’s theory of justice, people who are equally talented and motivated must have equal chances to attain desirable positions. In other words, the distribution of opportunities is “fairer” than that of benefits.

A vague concept of transportation equity can be traced to the 1770s, when the founder of market economics, Adam Smith, subconsciously mentioned the equity of transportation pricing. The European Union Transport Research Fourth Framework Program utilizes two dimensions of equity with horizontal equity associated with the principle of equality of opportunities and longitudinal equity associated with a comparison of conditions between the present and the past, for each individual citizen and for social groups. The National Cooperative Highway Research project defines equity as the equitable distribution problem of costs and benefits among people of different incomes[3]. Later, Litman classified transportation equity into horizontal and vertical types[4,5]. These concepts of equity refer to a reasonable allocation of benefits among various social groups or individuals, but do not consider the problem of distribution of opportunities.

Yang et al.[6,7] analyzed the equity of investment choices in different parts of China in transportation

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policies. They used the Wilson Entropy Model to evaluate the equity of different infrastructure investments in different regions. In urban transportation problem, policymakers focus more on different transportation modes rather than the infrastructure because in most cases, road resources are more limited than investment resources. Therefore a new road resource distribution model should be developed that is applicable to urban settings. Then the term "resources" is related to "opportunities" rather than "benefits", which provides a more interesting research topic.

Road resources have many different types such as spatial and environmental resources; however, the most important resource is space. Different road users compete for limited road space according to the laws and sometimes even ignore these rules. The distribution of road space resources depends mostly on the traffic laws made by the government and road designers, but the effect of new policies or designs on the competition for resources and the promotion of equity is difficult to judge. For example, the regulators need to decide how much space to give to buses, cars, and bicycles to maintain a sustainable transportation development. In addition, the space resource must be distributed with reasonable transportation equity. This paper presents a model describing the competitive relationships among different road users based on the species competition model to analyze these problems.

1 Problem Description

In an urban area, different transportation modes (such as private cars and buses) have their own groups of users, which in this model are called road users, because road resources are consumed by whichever transportation mode they use. In this paper, the road resource is related to the road space which is the key resource that limits development. The road space resource is considered to be finite and the number of each type of road user depends on the amount of space. The analysis models the competitive relationships among these different road users which are used to define the equity for such competition.

The system can be an urban area, several roads, or a whole city. A normal assumption is that the system space resources do not change within a certain period of time. The space resources are divided into a common space resource which is available to all users or to at least two of them and a special resource which can only be used by one road user. The users must compete for only the common space (for example, cars cannot enter the bus lane), and the coefficient of competition between the two types, which will be defined later, depends on the ratio of the common space to the total space.

The number of trips generated by different types of users will increase with economic growth or population growth, among other reasons, as long as there is still a surplus of road resources. The growth of each type of trip depends on a common natural growth rate and the surplus of resources for this type of user.

2 Analogy with the Species Competition Model

The species competition model has been widely used in mathematics. Different species have relationships such as coexistence[8], competition[9], and predator-prey relationships[10]. As in the species competition model, this road resource problem can be described by a competitive relationship with different types of road users being competitive species, which compete with each other for the space resources. The number of individuals in each species is the number of trips generated by the road users. The number of trips increases with time if there are enough resources because of population and economic growth, just as each species will experience a natural growth rate.

As in the one-species competition model, there is only one transportation mode in the system and there is no resource limit, then the growth speed is equal to the natural growth rate. Therefore, the number of the trips (N) generated is as follows:

$$\frac{\mathrm{d}N}{\mathrm{d}t} = rN \quad \text{and} \quad N(t) = N_0 \mathrm{e}^{r(t-t_0)} \tag{1}$$

where r is the natural growth rate of the transportation trips, which depends on the population growth rate and the economic growth rate in the area. To simplify the problem, the growth rate is assumed not to change with time.

3 Logistic Model for Trip Increase

The logistic model is widely used to describe the increase in the number of individuals of a species when resources are limited[11]. The model is often used in urban and economic development studies[12]. Assuming that the number of trips depends linearly on the population and economic development, with limited resources, the number of trips can be described by the logistic model as

$$\frac{\mathrm{d}N}{\mathrm{d}t}=r\left(1-\frac{kN}{R}\right)N \tag{2}$$

where R is the critical limited resource for the user and k is the amount of that resource used by each trip (resource occupation rate). The equation also assumes that the growth speed is linearly related to the resource surplus, which means that when the critical resource is 50% occupied, the growth rate will decrease by 50%. Integrating Eq. (2) gives

$$N(t)=\frac{R}{k+\left(\frac{R}{N_0}-k\right)\mathrm{e}^{-rt}} \tag{3}$$

The meaning of the critical resource R can be clearly seen in Eq. (3). If the space resource occupied by the users exceeds the limit, the development rate becomes negative, which means that the number of trips begins to decline. If the initial condition is below the critical threshold, then the development curve has an inflexion point as shown in Fig. 1. The maximum road space resource is easy to determine since it depends on the road geometry, and the critical resource, R, should not be larger than the maximum. If the road usage is less than the critical resource level, then the number of trips can increase, but if the road space becomes more crowded than the critical level, people will no longer choose this transportation mode and the usage will decrease. For private cars, the critical value should give a service level slightly less than the maximum road capacity, normally 70% to 90% of the maximum road space. For buses, which are less maneuverable in congested traffic, the critical value is normally smaller than for cars.

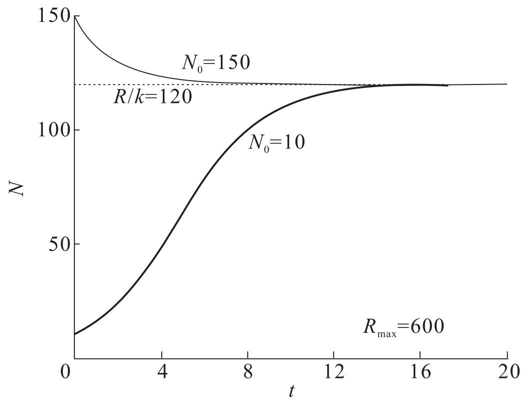


Fig. 1 Logistic model with *r*=0.5, *k*=4, *R*=480, and two initial conditions of N_0=150 and N_0=10

For example in Fig. 1, the maximum system resource is 600, with the critical resource level set at 80% of the maximum. Users may use more than 480 units of space but will never exceed 600. The upper line shows the decrease in the number of trips when the initial usage is equal to the maximum. The lower line shows the inflexion shape converging to the critical trip usage R/k.

4 Two-Species Competition Model

Now, consider two types of road users in the system with the number of users being N_1 and N_2. The total resources available to species 1 is R_1 and that for species 2 is R_2. The common resource for both species is R_{12}. The resource occupation rates for these two species are k_{11} and k_{22}. The percentages of the critical resource of the maximum resource for the two species are p_1 and p_2.

The presence of species 2 which occupies some of the common resource reduces the total resources available for species 1, which creates a competitive relationship. However, the effect of species 2 on species 1 is not simply k_{22} because not all of species 2 will occupy the common resource, but only a percentage which is assumed to be R_{12}/R_2 will use the common resource. In the same way not all the resources available for species 1 will be used by species 2. The coefficient of competition between species 1 and 2 can then be defined as: $c_{12}=R_{12}^2/(R_1R_2)$ as shown in Fig. 2,

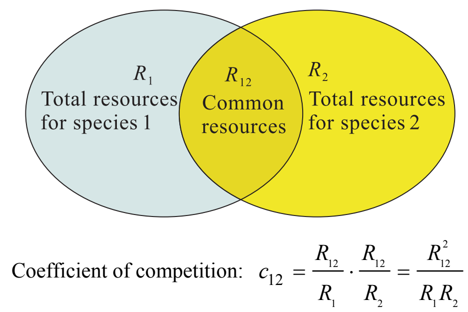


Fig. 2 Meaning of the coefficient of competition

Thus, the effect on species 1 of species 2, k_{12}, is the product of the coefficient of competition between the two species and the resource occupation rate of species 2:

$k_{12}=\frac{R_{12}^2}{R_1R_2}\cdot k_{22}$ and in the same way $k_{21}=\frac{R_{12}^2}{R_1R_2}\cdot k_{11}$.

Then, the growth rate for each type is

$$\begin{cases}\dfrac{dN_1}{dt}=r\left(1-\dfrac{k_{11}N_1+k_{12}N_2}{p_1R_1}\right)N_1, \\ \dfrac{dN_2}{dt}=r\left(1-\dfrac{k_{21}N_1+k_{22}N_2}{p_2R_2}\right)N_2\end{cases} \tag{4}$$

with

$$b_{ij}=\frac{k_{ij}}{p_iR_i},\quad i,\ j=1,2 \tag{5}$$

Equation (4) can be rewritten as

$$\begin{cases}\dfrac{dN_1}{dt}=f_1(N_1,N_2)=rN_1(1-b_{11}N_1-b_{12}N_2), \\ \dfrac{dN_2}{dt}=f_2(N_1,N_2)=rN_2(1-b_{21}N_1-b_{22}N_2)\end{cases} \tag{6}$$

With the initial conditions $N_1(0)$ and $N_2(0)$, the equations describe the competitive development between the two species. The solutions of these equations should be non-negative.

Equilibrium is reached when the growth rates of the two species are both zero. The three equilibrium points besides (0, 0) are

$$P_1=\left(0,\frac{1}{b_{22}}\right),\ P_2=\left(\frac{1}{b_{11}},0\right),$$
$$P_3=\left(\frac{b_{22}-b_{12}}{b_{11}b_{22}-b_{12}b_{21}},\frac{b_{11}-b_{21}}{b_{11}b_{22}-b_{12}b_{21}}\right) \tag{7}$$

These equilibrium points have clear meanings: P_1 means that species 1 is extinct, P_2 means that species 2 is extinct, and P_3 means that the two types coexist. However, in some cases, P_3 may not be positive, which means that only P_1 and P_2 can occur and one of the species must die out in the competition.

The extinction of one species in the biological world is sometimes considered as a catastrophe. Many rare species have become disadvantaged because of competition for resources. They disappear simply due to the presence of humans and an inequitable distribution of natural resources. Urban transportation systems can experience the same problem. Each mode of transportation has its own reason for existing. Cars take more resources, but they bring more comfort, convenience, and freedom, while public transportation saves more energy and has fewer emissions. As such, if an unreasonable distribution of road space leads to the extinction of one mode, it cannot be considered to be equitable. Therefore, the basic equity of the distribution of the road space resource can be defined as a reasonable distribution of road space which assures that none of the various road users will become extinct.

The equations can be linearized to check the stability of each equilibrium point, using the eigen values of the coefficient matrix.

For equilibrium point 1, linearization of Eq. (6) near $(0, 1/b_{22})$ gives

$$\begin{cases}\dfrac{dN_1}{dt}=\dfrac{\partial f_1}{\partial N_1}\left(0,\dfrac{1}{b_{22}}\right)(N_1-0)+\dfrac{\partial f_1}{\partial N_2}\left(0,\dfrac{1}{b_{22}}\right)\left(N_2-\dfrac{1}{b_{22}}\right)= \\ \qquad rN_1\left(1-\dfrac{b_{12}}{b_{22}}\right), \\ \dfrac{d\left(N_2-\dfrac{1}{b_{22}}\right)}{dt}=\dfrac{\partial f_2}{\partial N_1}\left(0,\dfrac{1}{b_{22}}\right)(N_1-0)+\dfrac{\partial f_2}{\partial N_2}\left(0,\dfrac{1}{b_{22}}\right)\cdot \\ \qquad \left(N_2-\dfrac{1}{b_{22}}\right)=-r\dfrac{b_{21}}{b_{22}}N_1-r\left(N_2-\dfrac{1}{b_{22}}\right)\end{cases} \tag{8}$$

The coefficient matrix and its eigenvalues are

$$\begin{bmatrix} r-\dfrac{b_{12}}{b_{22}} & 0 \\ -r\dfrac{b_{21}}{b_{22}} & r\end{bmatrix}\to\lambda_1=1-\frac{b_{12}}{b_{22}},\quad \lambda_2=-r<0 \tag{9}$$

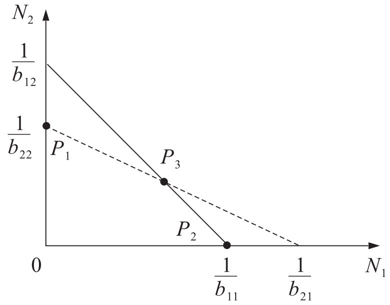
The stability analysis results are listed in Table 1. According to Perron's theorem[13], the equilibrium point is stable if all the eigenvalues are negative. Hence, if $b_{12}>b_{22}$, P_1 is stable. In the same way, the

Table 1 Equilibrium and stability analysis result

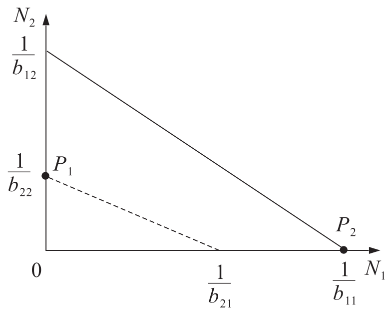
Case No.	Condition	Stability of balance point			Physical meaning
		P_1	P_2	P_3	
1	$b_{11}>b_{21}$ and $b_{22}>b_{12}$	Unstable	Unstable	Stable	Coexist
2	$b_{11}<b_{21}$ and $b_{22}>b_{12}$	Unstable	Stable	Non-positive	2nd extinct
3	$b_{11}>b_{21}$ and $b_{22}<b_{12}$	Stable	Unstable	Non-positive	1st extinct
4	$b_{11}<b_{21}$ and $b_{22}<b_{12}$	Stable	Stable	Instable	Both possible

similar result for P_2 is that if $b_{21}>b_{11}$, P_2 is stable. The eigenvalues for P_3 lead to the conclusion that if $b_{11}>b_{21}$ and $b_{22}>b_{12}$, then P_3 is stable.

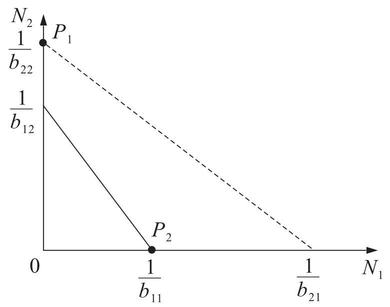
In case 4, either type may became extinct depending on the initial conditions. The positions of the equilibrium points for these four cases are shown in Fig. 3.



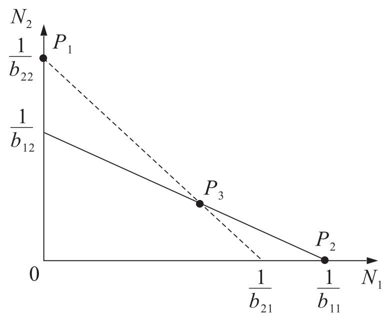
(a) Case 1



(b) Case 2



(b) Case 3



(b) Case 4

Fig. 3 Position of the equilibrium points of the four cases

5 Numerical Example for the Two-Species Model

Consider an urban area where all the roads have the same design as shown in Fig. 4 with three lanes in each direction and a bus stop by the side of the road. Since all the roads are the same, the competition can be simply analyzed for one road.

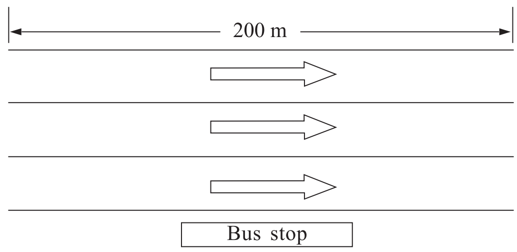


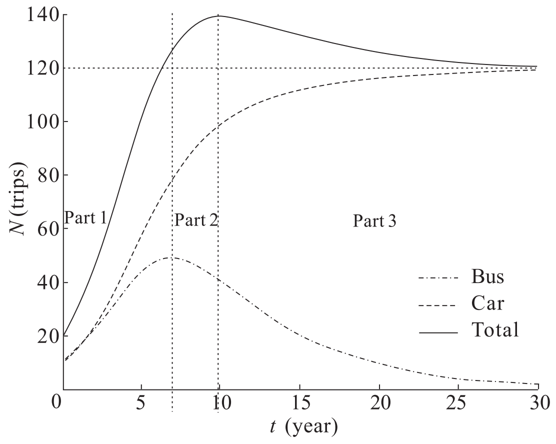
Fig. 4 Road design 1 for two species

The width of each lane is normalized to one unit for simplification. The total space resource for buses and cars is then 600 units. Species 1, the buses, encounter a more difficult situation since they have to accelerate and decelerate and also change lanes near the bus stop. Thus, assume that p_1 is 60%, which means that if the road is more than 60% occupied (360 units of space), the buses have a serious problem operating and the passengers complain more and more about the bus service. Then number of bus trips will decrease. Assume that p_2 is 80%. Since $R_1=R_2$, the coefficient of competition is 1. Further assume that each bus trip takes one unit of space while that of a car takes four units and r is 0.5, then

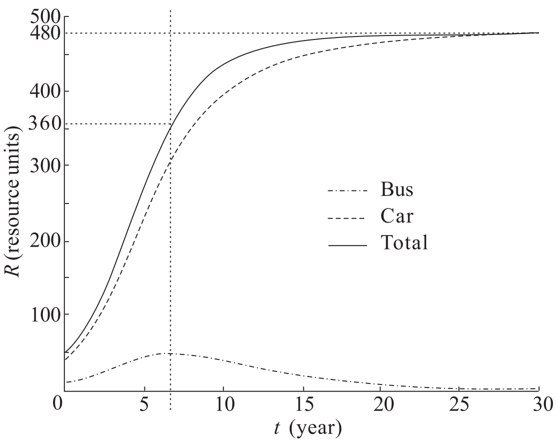
$$\begin{cases} \dfrac{\mathrm{d}N_1}{\mathrm{d}t}=0.5N_1\left(1-\dfrac{1}{360}N_1-\dfrac{4}{360}N_2\right) \\ \dfrac{\mathrm{d}N_2}{\mathrm{d}t}=0.5N_2\left(1-\dfrac{1}{480}N_1-\dfrac{4}{480}N_2\right) \end{cases} \tag{10}$$

According to Table 1, since $b_{11}>b_{21}$ and $b_{22}<b_{12}$, the buses will became extinct as shown in Fig. 5 for the initial condition (10, 10).

Figure 5a shows how the number of trips changes with time, while Fig. 5b shows how the resource occupied by each species changes with time. The total number of trips is also given because it is a good indicator of the economic level. The process in Fig. 5 can be divided into three parts. At the beginning, the resource limit is not a problem so both species increase



(a)



(b)

Fig. 5 Competitive development of the number of trips for buses and cars

very fast until part 2. At the beginning of part 2, the critical resource is exceeded for the buses, which in Fig. 5b is at the point when R=360, so the number of bus trips begins to decrease as the number of car trips still increases so fast that the total resource usage keeps rising as the number of bus trips is forced to decrease. In part 2, the citizens feel more and more uncomfortable taking buses because of the difficulties of the bus operation in a very crowded environment. As a result, passengers choose cars instead, or just avoid traveling by bus. In part 3, the traffic becomes worse and the total number of trips begins to decrease, which will have a negative effect on economic growth. The negative economic growth is the result of the extinction of buses due to the lack of equity in the road space resource distribution.

Now, assume that the government decides to set up a bus lane in the middle of each road, as shown in Fig. 6. Cars cannot use the bus lane, while buses can use all three lanes. Thus, R_1=600, R_2=600, and R_{12}=400.

$$\boldsymbol{K}=\begin{bmatrix} k_{11} & k_{12} \\ k_{21} & k_{22} \end{bmatrix}=\begin{bmatrix} 1 & \dfrac{8}{3} \\ \dfrac{2}{3} & 4 \end{bmatrix}, \boldsymbol{B}=\begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}=\begin{bmatrix} \dfrac{1}{360} & \dfrac{1}{135} \\ \dfrac{1}{480} & \dfrac{1}{80} \end{bmatrix} \tag{11}$$

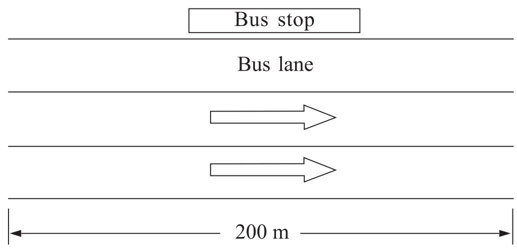


Fig. 6 Road design 2 with a bus lane for two species

This scenario results in coexistence as shown in Fig. 7. The equilibrium point is $(264, 36)^{\mathrm{T}}$, with the total trips in the area converging to 300, which is much more than without a bus lane. Hence, the system has a better traffic flow for improved economic development and the percentage of public transportation is higher than 80%. Compared with the first case, the maximum road service level is reached after a longer period of time with more trips, which provides for population and economic growth needs, as well as sustainable development. Thus, road space resource distribution is more equitable.

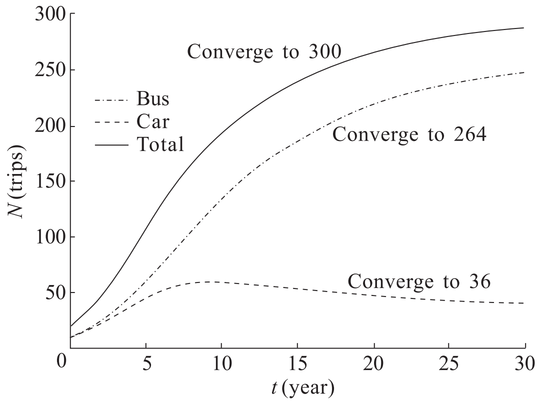


Fig. 7 Coexistence with a bus lane

6 Multi-Species Competition Model

In most actual cases, the competition for road resources is not just between two species. In China as an example, in many cities, cars, buses, trucks, bicycles, and even pedestrians are crowded into the common space. Hence, effective policies are needed to meet the equity in today's China and to make transportation development more sustainable. A multi-species competition model is needed to address these issues. Consider a multi-species (m species) competition model similar to the two-species model: N_i is the number of trips by species i; R_i is the total resource used by species i; p_i is the critical resource percentage for species i; R_{ij} is the common resource available to both i and j; $c_{ij}=R_{ij}^2/(R_iR_j)$ are the coefficients of competition; k_{ii} is the resource occupation rate of species i; $k_{ij}=(R_{ij}^2/(R_iR_j))\,k_{ii}$; and $b_{ij}=k_{ij}/(p_iR_i)$. The rate equations are then

$$\frac{\mathrm{d}N_i}{\mathrm{d}t}=r\left(1-\frac{\sum_j k_{ij}N_i}{p_iR_i}\right)N_i=r(1-\sum_j b_{ij}N_i)N_i,\ i=1,2,\ldots,m \tag{12}$$

which can be written in vector form as

$$\frac{\partial \boldsymbol{N}}{\partial t}=\mathrm{LV}(r,\boldsymbol{B},\boldsymbol{N}) \tag{13}$$

where LV indicates the "Lotka-Volterra" model. The equilibrium points then have the following types:

(1) Origin (0, 0);

(2) Supposing M' is any subset of $[0,1,\ldots,m]$ and for $k\in M'$, $N_k=0$, then the other N_i are the positive solution of

$$\sum_j b_{ij}N_i=1,\quad i,j\notin M' \tag{14}$$

(3) The positive solution of $\boldsymbol{BN}=\boldsymbol{I}$, where $\boldsymbol{N}$ is $(N_1,\ldots,N_m)^{\mathrm{T}}$, $\boldsymbol{B}$ is the matrix of b_{ij}, $i,j=1,2,\ldots,m$, $\boldsymbol{I}=(1,\ldots,1)^{\mathrm{T}}$.

The first and third types are just special cases of the second type. Only the third type of equilibrium assures that all the species exist after a long period of time.

The stability of the equilibrium points becomes quite complicated for dimensions larger than two. For example, the competition between three species involves 46 different conditions[14]. Thus, the problem must be analyzed numerically.

7 Numerical Example of Three-Species Competition

In China, the three dominant modes of transportation are bicycles, buses, and cars (including taxis). In Beijing for example, the percentage of bicycles used 20 years ago was much higher than today as more and more citizens choose to use private cars or taxis. At the same time, road space distribution policies have changed. The wide bicycle lanes are becoming narrower and narrower, and the pedestrian space is being reduced. In addition, some bicycle lanes are now used for parking, while others are being redesigned as right-turn lanes for cars. Therefore, consider the scenario in Fig. 8 which is typical of Beijing's newly designed roads.

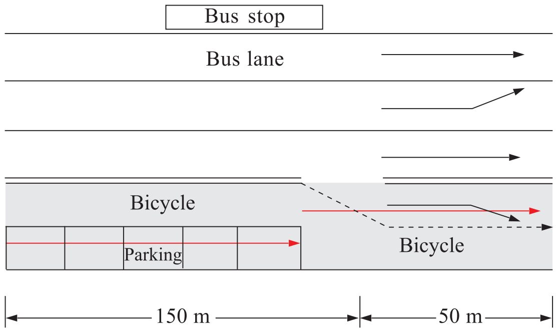


Fig. 8 Road design for the three-species competition

In Fig. 8, the dotted area was once a bicycle lane but is now partly occupied by both parking space and a right-turn lane. Since the competition between bicycles and automobiles (including buses and cars together) is quite complicated in China, it is assumed that all the bicyclists ignore the right-turn lane and the parking, and use all of the dotted area not occupied by automobiles, including the right-turn lane. Hence, the parking area and the right-turn lane are common spaces for both bicycles and automobiles. The lane width is again normalized to one unit. Meanwhile, the percentages of the critical resources are assumed as p_1(bus)=60%, p_2(car)=80%, and p_3(bicycle)=80%.

With this design R_1=600 for buses, R_2=600 for cars, and R_3=400 for bicycles, R_{12}=400, R_{13}=0, and R_{23}=50+150=200.

With the original design when the dotted region was only for bicycles: R_1'=600 for buses, R_2'=400 for cars, and R_3'=400 for bicycles, R_{12}'=400, R_{13}'=0, and R_{23}'=0.

Then, $\boldsymbol{K}$ and $\boldsymbol{K}'$ are

$$\boldsymbol{K}=\begin{bmatrix}1 & \frac{16}{9} & 0\\ \frac{4}{9} & 4 & \frac{1}{6}\\ 0 & \frac{2}{3} & 1\end{bmatrix},\quad \boldsymbol{K}'=\begin{bmatrix}1 & \frac{8}{3} & 0\\ \frac{2}{3} & 4 & 0\\ 0 & 0 & 1\end{bmatrix} \tag{13}$$

These matrixes show that the competitive relationship between cars and bicycles becomes more pronounced with the new road design. The bicycles and the automobiles were originally independent as shown by $\boldsymbol{K}'$.

The process of development of each species is then analyzed numerically. The first 30 years used the original design, with the next 30 years using the new design. The initial condition is $[100, 5, 100]^{\mathrm{T}}$. The calculational results are shown in Fig. 9.

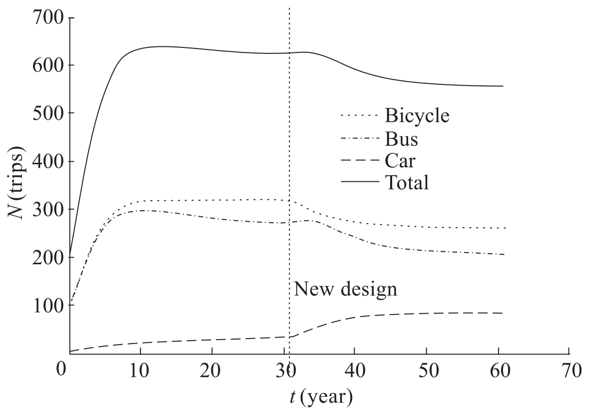


Fig. 9 Development of bicycle, bus, and car traffic before and after road design changes

In the first 30 years, the bicycle develops independently of the other two species and the equilibrium point is [264, 36, 320]. After the 31st year, the road design change creates competitive relationships between the three species. The cars compete with the bicycles for parking and right turns. The number of bicycle trips begins to decline while the percentage of car trips increases quickly. With the improved car traffic flow, there is less competition between buses and cars. Thus the number of bus trips increases as the number of car trips increase at the beginning. However, two or three years later, the number of bus trips begins to decrease. This demonstrates the very interesting phenomenon that the real effect of a new design does not always emerge immediately.

8 Conclusions

The traffic competition model presented in this paper, which is analogous to the species competition model, describes the competitive relationship and the development process of different types of road users in urban areas as functions of the road geometry and traffic policies concerning road space distribution. The model can be used to evaluate transportation equity and the effect of policy changes.

This study transfers species competition theory from biology to evaluate transportation equity, with several assumptions. The advantage of this model is that most of the data needed for the calculations is geometric and easily obtained. The remaining inputs, such as the natural growth rate for traffic trips, can be obtained using statistical analysis of population and economic growth data. The analysis shows the traffic conditions for the entire development process. The results provide guidelines for evaluating the equity of road design and transportation policies, such as the percentage of each transportation mode needed for economic development and environmental protection.

Future models should relax the assumptions that are not realistic. For example, the natural growth rate is assumed to depend only on population and economic growth. In the real world, however, the growth rate is also affected by new technologies and other effects. For example, the fast development of the car industry will cause faster growth of cars than other species. Thus, the natural growth rate, r, is not the same for all species and the model is more complicated.

Another assumption is that road designs do not change over time, which makes the resource distribution matrixes $\boldsymbol{R}$, $\boldsymbol{C}$, $\boldsymbol{K}$, and $\boldsymbol{B}$ independent of time. The three-species example shows how these constants can change with time.

The road resource is defined as a spatial resource because space is the key resource which is most limited. However, other resources may affect the competition even if the effects appear to be very small.

Because of the many assumptions in this model, the numerical examples use only simplified data. However, the numerical results still show many interesting phenomena and explain some important problems. Future work should include further improvements and a more practical scenario to improve this model.

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Professor Andrew Chi Chih Yao Speaks at Tsinghua Forum

Tsinghua Professor and Turing Award Winner Andrew Chi-chih Yao delivered a speech on July 7, 2008, to the Tsinghua Forum entitled “China’s Road toward the Turing Award”.

During his talk, Professor Yao emphasized the importance of developing world-class disciplines in building a world-class university. “A world-class university should cultivate top graduates and do first-class research,” said Professor Yao. He analyzed the development of computer science in China, especially at Tsinghua University, noting the important role of making innovations in computer science research.

Professor Yao has been on the faculty at MIT, Stanford, UC Berkeley, and Princeton University. In 2004 he left Princeton to become a Professor of Computer Science at Tsinghua University. He was the recipient of the prestigious A.M. Turing Award in 2000 for his “fundamental contributions to the theory of computation, including the complexity-based theory of pseudorandom number generation, cryptography, and communication complexity.”

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