Strategic Management of Transportation Systems

G. Papageorgiou, Cyprus

Abstract: Traffic congestion is increasing world-wide as a result of increased motorization, urbanization, population growth and changes in population density. The problem of traffic congestion reduces utilization of the transportation infrastructure and increases travel time, fuel consumption, air pollution and greenhouse gas emissions. The aim of this paper is to examine the use of Systems Thinking and System Dynamics, whereby various solution scenarios are examined for the purpose of drawing sustainable urban development strategies.

Keywords: Transport, strategic management, traffic

Introduction

Transportation is directly influencing the quality of our lives. Countries all over the world, spend a considerable amount of their Gross National Product, on transportation most of which is given on road or highway transportation for both passenger and freight. Meanwhile, traffic congestion is continuously on the increase worldwide. In Cyprus, it is estimated that the cost of traffic congestion in urban centers approaches 50 million euros (a very large amount for a country of 750,000 population) per year as a result of traffic delays. There is an obvious need for effective transportation planning [1].

Car ownership increases all over the world and especially here in Cyprus as a result of economic growth and socio-cultural changes. In Cyprus we have more than half a million vehicles for a 750,000 population which constitutes almost 70 per hundred population (one of the highest in the world). These vehicles are driven an average of 10,000 kilometers per year for passenger cars and 30,000 kilometers per year for trucks on a road/highway system that comprises more than 12,000 kilometers.

The above indices may differ from country to country, but the importance of the transportation system, especially the urban and the highway component of it, is just the same or even greater. While car ownership in some countries may vary with respect to population, the available road and highway network capacity proves to be insufficient in most cases leading to severe congestion problems.

The work presented in this paper concerns the strategic management of transportation systems by the use of an effective analysis framework. The framework is supported by systems thinking principles and the system dynamics approach. The framework is applied for the case of the Cyprus traffic congestion problem.
Systems Thinking

With the tremendous change facing organisations and increasing complexity of the relationships in unstructured problems, policy makers need new tools and methods in managing complexity. Systems thinking [2] can play a significant role in strategy design, diagnosis and problem solving.

Systems thinking can help managers look at problems from a broader perspective and take a holistic view to help interpret patterns and events. It models the problem situation as a system that is an interdependent network of units forming a unified pattern.

Too often managers break down complexity by decomposing the system and dealing with its individual units separately. Thus, managers have focused on and scrutinised a particular part of the system (perhaps a poorly performing unit) before moving on to the next unit and so on. For example, we introduce road bumps in order to reduce vehicle speed in residential areas and thereby reduce accident frequency. But we fail to realise that such a remedy increases air pollution as a result of multiple vehicle decelerations and accelerations. Systems thinking reminds us that even if units can be 'perfected' by themselves this does not imply that they integrate well together. It encourages managers to diagnose problems by looking at the larger patterns of interaction within the transportation system, and the process interdependencies.

In short, Systems Thinking really means properly bounding the issue under consideration. This may sound trivial, but it can be difficult in practice. To analyze large problems more easily, we frequently use models. All too often, however, models that are oversimplified or incomplete lead to erroneous conclusions. This may derive from poor design, but more often, it comes from applying a model to a different system than that for which it was designed. For example, a traffic management policy that is suitable for the Swedish transportation system might not be necessarily suitable for application in Cyprus. Further, this can be quite insidious as a model which was appropriate in the past may become increasingly inadequate if the problem changes over time. For this reason, it is crucial to carefully consider the system(s) that is the group of elements that are connected or related in some way.

Managing Complexity

Everyone is familiar with systems. Consciously and without realizing it, people regularly ascribe events to all kinds of systems, real and imagined, and interpret them accordingly. But if this is so, couldn’t we use our mental models to analyse systems? The answer is no in most cases; because there is a large class of systems we have trouble understanding. We label these systems complex, and resign ourselves to only the most cursory explanations of their behaviour. Traffic congestion constitutes such a complex dynamical problem. It comprises of many complex processes, and incorporates many elements interacting with each other, such as vehicle-driver units, traffic control signals, lane changing rules, speed limits, road geometry and so on.
The terms complexity and complex systems [3] have a variety of definitions, but below, we will discuss three aspects of complexity, which can be thought of as generating three types of complex systems: Static complexity is associated with problems of complex structure. Dynamic complexity is associated with problems of complex behaviour. Analytical complexity associated with problems that are difficult to evaluate.

In the case of the traffic congestion problem we have all three aspects of complexity. Static Complexity with a large number of components involved. Behaviour complexity with dynamicity, coupling, feedback loops, non-linearity, chaos and adaptation. And evaluation complexity with trade offs between various objectives such as safety, quality of service and efficiency.

The question then becomes how can we analyse and understand complexity of the traffic congestion problem. The answer to this question is that mental models and intuition on their own cannot process all the necessary information to conceptualise the problem situation. So we resort to computer power and the use of an advanced modelling and simulation methodology as described in the next section.

**System Dynamics**

System dynamics [4] is an approach based on Systems Theory [5] and Systems Thinking to model the dynamics of complex systems such as population, ecological and economic systems, which usually interact strongly with each other. Systems Dynamics was founded in the early 1960s by Jay W. Forrester of the MIT Sloan School of Management with the establishment of the MIT System Dynamics Group. At that time, he began applying what he had learned about systems during his work in engineering to all kinds of systems. What makes using System Dynamics different from other approaches to studying complex systems, is the use of feedback loops. Stocks and flows are the basic building blocks of a System Dynamics model. They help describe how a system is connected by feedback loops which create the nonlinearity found so frequently in modern day problems. Computer software is used to simulate a System Dynamics model of the situation being studied. Running "what if" simulations to test certain policies on such a model can greatly aid in understanding how the system changes over time.

**Towards a Strategy Model for Transportation Planning**

The solution to the problem of traffic congestion, adopted in Cyprus as well as in most countries around the world, was to build more roads, which intuitively looks to be the right thing to do. But unfortunately building more roads does not solve the problem.

To start with analyzing the problem let us look at one significant measure of congestion that is travel time. Travel time depends on the balance between the capacity of the roads to handle traffic and the number of vehicles using the roads. As the number of vehicles on the roads increases the average trip will take longer. As the road capacity on the other hand increases the average travel time will fall. Road capacity may be altered by the construction of new roads or improvements to existing
roads such as adding lanes or changing the flow of traffic. Road construction projects though, take time to be completed so there is a significant delay between the project initiation and the increase in road capacity.

As we begin to realize the problem is not that simple. And using just words is difficult to describe the complexity of the problem. In order to make the problem more understandable and envision the various feedback loops and causes and effects involved in the traffic congestion problem, we utilize the stock and flow diagrams of the System Dynamics method and develop a System Dynamics model as shown in Fig. 1 below. The model is based on the causal loop assumptions of John Sterman [6].

Fig. 1. A System Dynamics Model for the Traffic Congestion Problem.

The model illustrates many of the concepts of System Dynamics such as levels, rates-of-flow and causal loops, discussed in the preceding paragraphs. Rectangles represent levels such as Road Capacity, Population, Vehicles in Region, Bus Network Investments and Bus Network Capacity. Rates-of-flow are represented by valve gauges which cause the levels to change such as vehicle purchasing (inflow) and vehicle discarding (outflows) causes the number of vehicles in use to increase or decrease. Circles represent auxiliary variables and arcs represent relationships that cause the rates of flow to change. For example, road construction rate depends on pressure to reduce congestion. Non-linear relationships may also be incorporated in the model.

Diamond shapes indicate variable types which contain fixed values such as desired travel time and initial number of vehicles in the region that are used in calculations of
auxiliary variables or flows. Diamonds can also be used as leverage points for policy formation. Arcs denote links that can be categorized as information links, delayed links, and initialization links that give information to auxiliary and level variables.

Clouds represent undefined sources or outlets for a flow to, or from a Level. Clouds denote that we are at one of the model's outer limits such as the cloud after vehicle discarding, which indicates the boundary between our traffic flow system and a vehicle disposal system.

As seen in Fig. 3 the model essentially depicts the relationships between attractiveness of driving, road capacity, bus network capacity and vehicles in the region all of which combine in multiple closed loops implying mutual causality. Despite its simplicity, the model possesses dynamic capability since it contains inertia elements, feedback loops, delays and non-linear relationships. These dynamic characteristics can produce totally different outcomes in a system’s behavior than what is intuitively expected, depending on relatively small changes in operating conditions.

The assumption held by most policy makers, city planners, and transportation officials is that traffic volume is exogenous in that traffic volume is growing as population grows and local economy develops. Building roads therefore should keep travel time at low levels but also can serve special interests of particular businesses which would be eager to satisfy the personal interest of the policy maker. However traffic volume is not exogenous, that is road building does not alleviate traffic congestion. The number of cars in a particular region is a major determinant of traffic volume.

Total traffic volume therefore equals to the number of vehicles in the region multiplied by the distance traveled of each vehicle per day. In turn the distance traveled per day for each vehicle is equal to the number of trips multiplied by the length of each trip. The number of trips per day and the average trip length are not constant but depend on the level of traffic congestion. People will take additional trips if the traffic is light while they would stick to the necessary trips when the traffic is heavy. Further, the number of vehicles in the region is not constant but varies with respect to the population multiplied by the number of cars per person. Furthermore the number of vehicles per person or business is not constant but depends on the attractiveness of driving, which depends on the level of traffic congestion.

Adding the above relationships to the model closes various negative feedback loops all of which act to increase congestion whenever new roads are built. Further, political pressure to reduce travel time grows and still more roads are built which increase congestion in a viscous circle. This situation does not only happen here in Cyprus. We can refer to many cases around the world to prove that building more roads does not solve the traffic congestion problem but makes it actually worse [7].
Conclusions

This paper provides an analysis to the highly complex problem of traffic congestion. As mental models prove to be inadequate for analyzing highly complex systems there is a need to incorporate more advanced methods and modeling techniques. Systems thinking and System Dynamics provide the necessary tools and techniques for analyzing complex systems such as traffic congestion case.

Using Systems Thinking and System Dynamics a holistic simulation model is developed for the traffic congestion problem situation in Cyprus. As revealed by the analysis of the traffic congestion problem the main causes are attributed to the reinforcing feedback loops that increase the number of cars per person and to the negative feedback loops associated with the use of the bus transport mode. Despite its limitations and omissions the model provides an explanation for the persisting failure of road building programs to solve the traffic congestion problem.

References