System Dynamics '90

Volume 1: Abbas – Henderson

Proceedings of the
1990 International System Dynamics Conference

Chestnut Hill, Massachusetts
July 10 through 13, 1990

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The System Dynamics Society
Massachusetts Institute of Technology, E40-294
Cambridge, Massachusetts 02139
and
Nelson A. Rockefeller Institute of Government
State University of New York
411 State Street, Albany, NY 12203
Conference Sponsors

ISBN: 0-914341-16-2 (3-volume set)

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VOLUME 1

The Use of System Dynamics in Modelling Transportation Systems With Respect to New Cities in Egypt

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ABSTRACT

Since the development of System Dynamics, it has been applied successfully to a range of complex problems in different areas. However, relatively little use of the methodology has been made in the field of transportation. This paper attempts to review and evaluate the utility of the System Dynamics methodology for transportation studies, showing that it is well suited to the needs of various analytical problems in transportation. In fact, System Dynamics offers a potential way forward for transportation planning in general. The focus of this paper is on appreciating the strengths and weaknesses of the methodology of System Dynamics as an aid to reach a better understanding and appreciation of the dynamic, feedback relationships between the transport system and the other major sectors contributing to the development of a new city in the Egyptian desert.

INTRODUCTION

Located at the world's crossroads between east and west, Africa and Asia, Egypt presents a unique combination of many conditions prevalent in the developing world. Egypt is a land of contrasts, with its topography dominated by the River Nile, that cuts its way through bare desert.

According to the latest official census of 1986, Egypt's population is about 48.2 million. Over 97% of the population is concentrated in the Delta region and the Nile valley which constitutes only 4% of Egypt's land area. Egypt is an under-populated country with a problem of over-population.

Overcrowding in Egypt's urban areas has created severe problems, economic as well as social. The densities in the already overcrowded areas have reached the level where gross inefficiencies exist. Existing urban areas cannot absorb the population increase and this causes uncontrolled encroachment into surrounding fertile, agricultural areas, subdivision of holdings, high stresses on public service utilities, high rates of unemployment and under-employment, etc.

In contrast, the desert areas suffer from lack of population and development. The main problem in Egypt is not the size of the population, it is the imbalance of the distribution of population over the land area.

THE DESERT ..... THE EGYPTIAN CHOICE

In nearly all countries, developed and developing, decentralisation has been almost the only strategy on offer, in terms of territorial national planning, to cope with the pressures on the major cities as more and more dwellers move to the cities in anticipation of a better life.

Land, people and the Nile remain the main sources of Egypt's natural wealth. Since 1978 the Egyptian Government has embarked on a spatial planning policy based on development into the desert areas away from the Nile and the main cities of the Delta. A national strategy for developing satellite towns and medium-sized cities has been produced. Some of the new developments, e.g. El-Obour, El-Salam and 15th of May, are intended mainly as satellite towns, close to the capital city, Cairo, to relieve some of the pressures of overpopulation. Others, notably 10th of Ramadan, Sadat and 6th of October cities are developed to stand alone in the desert and away from the Delta and Nile valley.

PLANNING OF NEW CITIES DEVELOPMENT

It is of great importance to adopt a wise policy in the construction of the new cities, to set goals, base decisions and evaluate results according to realistic, national, socio-economic parameters.

The national and regional, socio-economic plans should be based according to the strategy of the state, taking into account the existing economic realities and the constraints on the development process. The most important constraint is the inability to allocate the full, required rates of investments to the new cities.

To date, due to ad-hoc investment policies, and lack of coordination and planning, a waste of resources has, almost inevitably, taken place. The most effective use of scarce resources is needed. This could be achieved through the parallel coordination,, (between the planning and provision), of main infrastructural facilities, industrial enterprises and housing to achieve a balanced growth of a new city. Sectors should grow closely linked to each other ensuring the optimum utilisation of resources, thereby avoiding any idle investment of scarce funds.

Unless new cities attract users in sufficient numbers they certainly will not survive in a positive, contributory way. The scope for dispersl of population to new cities depends largely on the ability to create employment opportunities and to provide adequate housing.

The industrial sector is the prime determinant of the growth of new cities. Locating new industries will require substantial investment to overcome the economic development constraints of the desert regions. It follows that the provision of locational incentives stimulates the development process in new cities. Accessibility and mobility are two of the key elements that encourage industry, and hence population, to relocate, settle and use the available land area in the desert.

THE ROLE OF TRANSPORT IN ACHIEVING DEVELOPMENT GOALS OF NEW CITIES

Investments in transportation are expected partly to pave the way for the development of new cities. The significance of transport lies not only in the services it renders, but even more in the stimulating influences it exerts on economic activities. In newly developing regions, causal, dynamic, feedback relationships exist between elements of development, i.e. transportation, population, housing, the economy. For new cities particularly, the provision of transport and its infrastructure, have a significant influence on attracting industry, resettlement of people and the availability of labour.

There are two concepts pertaining to the exact role that transport plays in development. The first suggests: transport plays the major role in the development of land and resources; it is a prerequisite that automatically leads to development. The second suggests: transport is considered to be but one of the necessary catalysts, amongst others, for promoting development and not necessarily the major catalyst.

The first concept may result in an over-investment in transport, consuming scarce capital resources thus reducing the potential to support other needed catalytic investments. If no coordination exist between investments in different sectors, including transport, the second concept may result in an under-investment in transport leading to bottleneck situations and adversely retarding the progress in other sectors. So, a balanced strategy is needed. A strategy that views the development process in a holistic, coordinated way.

An integrated system of development, that considers within a comprehensive framework the main factors contributing to the development process, should be pursued. This requires extensive time, data, human and capital resources which is outside the scope of the study.

In this study, an attempt is being made to consider some of the following main, developmental elements within a systems approach framework:

(i) the transport element;
(ii) the industrial element;
(iii) the population element; and
(iv) the housing element.

The main emphasis will be on the transport element including both the provision of transport infrastructure and transportation facilities. Figure 1 shows the suggested, hypothetical, feedback linkages between the four submodels.

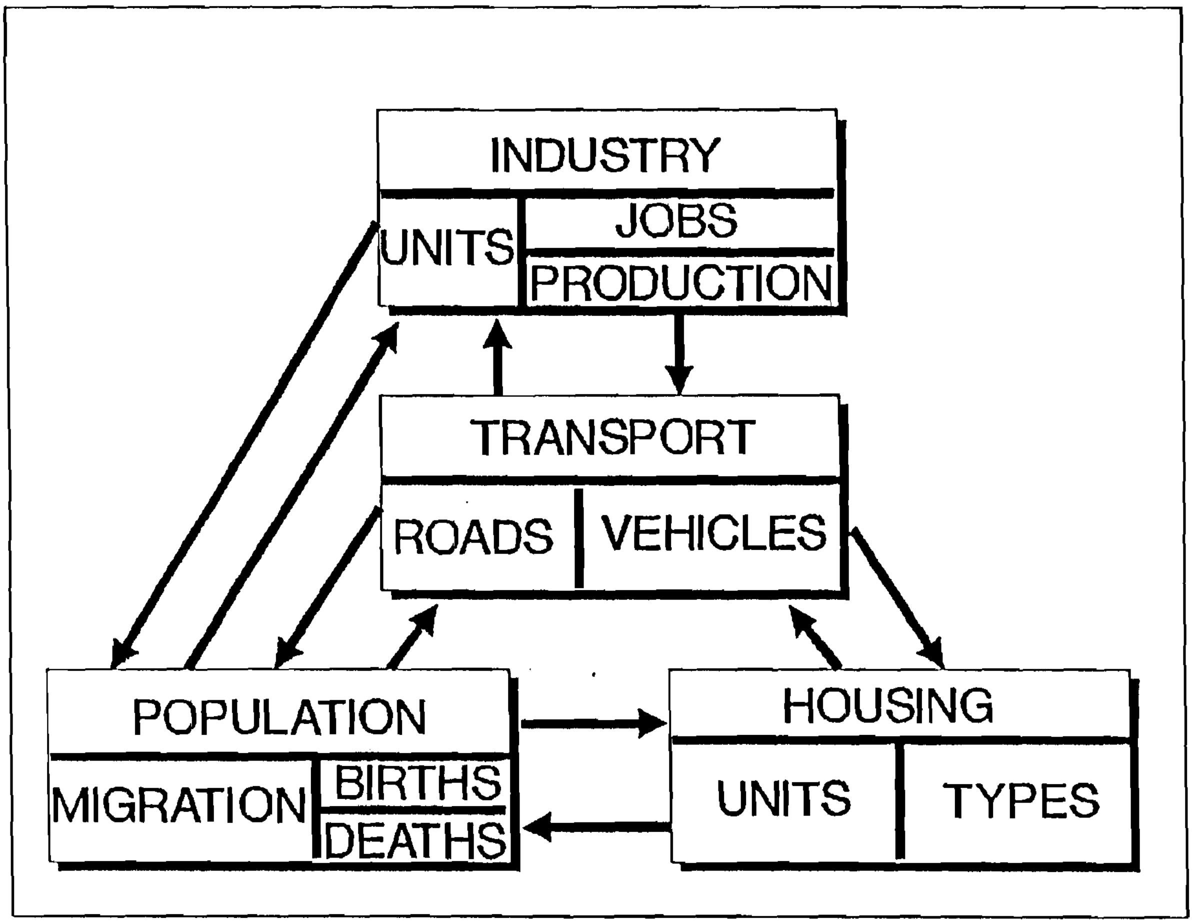

Fig. 1: Feedback Linkages Between the Development Elements in New Cities

THE SYSTEMS APPROACH

The systems approach can be defined as an organised, efficient procedure for representing, analysing and planning complex systems. It is a comprehensive, problem-solving methodology that involves two main steps:

(1) the rational structuring of both quantitative and qualitative knowledge, mainly in the form of models, to represent problems; and
(2) the development of analytical techniques through which the problem can be analysed and solved.

In complex, large-scale systems, like transport, the true problems are rooted in the basic structure of the system. Actions taken to deal with one problem may create difficulties elsewhere. System analysis is needed in order to treat problems in a comprehensive manner: some form of systematic approach is necessary.

System Dynamics (S.D.), pioneered the use of system concepts and computer simulation for the analysis of complex problems in business and management. S.D. is a methodology of wide applicability. It has become an appealing modelling style used by many different disciplines.

Before making the decision to apply the S.D. methodology to model the transport and socio-economic developments of new cities in Egypt, the applicability of S.D. methodology to modelling and solving transportation problems is thoroughly reviewed in this paper. This review covers the following topics:

- the contemporary requirements for modelling transportation problems;
- broader evaluation in transportation ... why?;
- what System Dynamics offers in a general context;
- how System Dynamics might contribute to transportation modelling; and
- the limitations of System Dynamics with respect to transportation modelling.

CONTEMPORARY REQUIREMENTS FOR MODELLING TRANSPORTATION PROBLEMS

The nature of transport problems has evolved over the years, and so did the modelling requirements. Some of the main contemporary requirements for a better modelling of transportation problems are listed below.

1. The various elements of transportation-related problems call for coordinated approaches for examining and solving problems. Comprehensive models are needed to account for the total impacts of transportation systems.
2. Before any data collection effort, models should be built on an a priori knowledge of the transport system.
3. Explicit consideration of the dynamism of the transport system components.
4. Planning models are required that generate insight and help in enhancing our understanding of the complex, long term intra-relations and inter-relations of the transport and other sectors.
5. The feedback between transportation supply of facilities and demand for services should be explicity accounted for.
6. Acceptance that transport planning is a long term task, that is subject to risk and uncertainties, and therefore requires the integration of both deterministic and stochastic modelling efforts.
7. Simplified, creative, user oriented techniques for modelling transportation systems should be fully pursued.
8. Policy oriented planning techniques that can generate and test a variety of alternatives without the need to collect and analyse huge volumes of data. These are intended to ease the dilemma faced by transportation decision-makers when attempting to reach rational, informed decisions.
9. Evaluation of transportation policies should be based both on long and short term impacts.
10. Reorientation in transport planning, particularly in developing countries, from the traditional project-by-project approach to the comprehensive system approach.

BROADER EVALUATION IN TRANSPORTATION ... WHY?

Existing transport evaluation procedures are not effective in assessing the overall, as well as the specific, consequences of a broad range of transport policies. Evaluation must take into account the degree to which the impacts of transport satisfy socio-economic goals and objectives. The need for such an evaluation procedure arises more in developing countries for the following reasons:

1. transportation investments constitute a high percentage of public expenditure, and are known for their 'lumpiness';
2. transportation investments may involve a high proportion of foreign exchange, and there is usually a scarcity of foreign exchange, as well as of national capital resources;
3. transport is considered to play a strategic role in the country's developmental projects;
4. many transport projects are financed by foreign loans, lenders often requiring as complete an evaluation as possible; and
5. there is the need for optimum allocation of resources as waste resulting from random actions may have negative, long term effects.

WHAT SYSTEM DYNAMICS OFFERS IN A GENERAL CONTEXT

The following respresents a comprehensive list of the advantages of using S.D. as a modelling technique.

1. S.D. provides a logical, systematic and detailed procedure through which complicated systems can be easily represented.
2. It permits the analysis of the behaviour of complex systems in terms of their structure and policies.
3. In S.D., the main structural relationships describing a system are of the causal, dynamic, feedback form. S.D. models are derived from mental and descriptive models. In other words, it comes from direct observations of the real world.
4. Simplicity of model building; the modeller can build explicit, comprehensive, realistic, easy to manipulate models from simple concepts.
5. S.D. provides a conceptual framework which makes the maximum use of the modeller's mental and modelling agility, that is one which is formulated as much as possible in diagrammatic and graphical forms, as well as in the algebraic form, and is closely related to the manipulative framework within which the computer operates i.e. the DYNAMO, and alike, family of computer simulation languages. S.D. diagrams are very helpful for thinking, overview, discussions, and documentation.
6. S.D. models utilises data which is readily available; data may be used at an aggregate level.
7. S.D. has a capability of incorporating alternative structural assumptions, input data or empirical parameters.
8. A means through which hypothesised structures can be formulated, analysed and tested is provided by using S.D.
9. A better insight and understanding of the behaviour of a system's structure is one of the main strengths of S.D. modelling.

10. S.D. is a policy-oriented technique, where alternative policies and scenarios can be easily tested. Quick and efficient responses to the various questions posed by decision makers are possible through S.D.
11. S.D. gives flexibility in tracing the behaviour of a system over time, allowing for timely inspection and modification of the system. This capability is helpful in identifying critical issues and likely future problems. It also points to areas in which there is potential for significant improvements. S.D. is a very well suited technique for the effective management and control of complex systems.
12. S.D. models provide a media for instigating the creativity of modellers and users to design and formulate a variety of structures, policies and scenarios.
13. As an evaluation technique, S.D. provides us with a flexible framework for comparing a wide variety of options, which will eventually lead to the improvement of future system courses.
14. S.D. models provide a solid common platform for interdisciplinary communication between people of various fields of interests.
15. Delays and non-linearities can be easily modelled using S.D.
16. Feasibility and cost effectiveness, (both in terms of time and money), in constructing and running S.D. models.
17. S.D. models are applicable to long-term analysis.
18. They operate in a simultaneous fashion, as opposed to the sequential mode.
19. S.D. models are easily adapted to different environments and different levels of aggregation.

HOW SYSTEM DYNAMICS MIGHT CONTRIBUTE TO TRANSPORTATION MODELLING

S.D. is well suited to modelling transportation systems. S.D. can contribute to solving transportation problems in many different ways, some of these are discussed below.

1. S.D. provides us with a structured framework through which large scale systems, such as transportation systems, can be easily accommodated i.e. modelled, analysed and tested.
2. Conventional transport modelling methodologies are oriented towards achieving a supply/demand equilibrium. This requires heavy assumptions that are quite difficult to satisfy in reality. In S.D. the main, dynamic, feedback interactions between supply and demand in transportation systems are easily and explicitly accounted for.
3. In most transportation studies, the socio-economic and demographic forecasts are obtained using separate modelling techniques. These are then used as external inputs into the transportation models, which may ultimately result in inconsistencies and incompatibilities. S.D. methodology provides a framework through which socio-economic, demographic and transportation systems can be modelled using the same methodological procedures.
4. In general, transport planning lacks the comprehensive, holistic view, where feedbacks between transport and other sectors are considered. This ignores the totality of impacts that transportation systems may have on their environments. As mentioned in (3) the S.D. approach can act as a common platform for modelling transport and other related sectors.

5. S.D. models utilise easily available data. Data is mainly required to initialise the model for the simulation run. Data may be later collected to fill gaps in the constructed models. In fact a S.D. transport model acts as a means for assessing the appropriate data needed for future enhancement of the model. This avoids collection of extensive volumes of unnecessary data and the waste of resources.
6. Using S.D. for transportation modelling, the way in which the traditional submodels are linked to each other and to other subsystems occurs simultaneously, rather than step by step.
7. Results of S.D. transport models are arrived at through the dynamic, causal, feedback interactions of the structural components of the model, a situation existing in reality. Non-linearities and time delays are explicitly accommodated.
8. S.D. methodology can be used as a basis for constructing and testing, a priori, hypothetical models of different transportation problems.
9. S.D. conceptualisation procedure provides a rich, common media for communication and understanding between the various parties that have interest in the transportation system. S.D. models can be used as training tools to help familiarise transport personnel with the different transportation problems.
10. S.D. assist in developing experimental tools. These tools are meant to provide a great flexibility to design, analyse and test a wide variety of transport policy options and scenarios.
11. Through S.D. simulation, short-term and long-term behaviour of a transport system is well traced. This provides a thorough insight into the precise nature of the transport problem, thus allowing for timely adjustments to be made, if required.
12. In a few seconds of computer time, S.D. simulation models can quickly analyse a large number of alternative policy options and scenarios.
13. S.D. methodology lays for us a very deep foundation for structuring our thoughts and building a better understanding of the complex transportation system problems. This supports transport decision-makers to make rational decisions, rather than completely relying on rule-of-thumb and intuition, which involves considerable risk.
14. Low cost, less time and computing requirements, transparency, transferability and ease of updating are characteristics that recommend S.D. to be applied to solving transportation problems.

LIMITATIONS OF SYSTEM DYNAMICS WITH RESPECT TO TRANSPORTATION MODELLING

There are of course limitations to modelling using the S.D. approach. Some of these limitations could be looked upon in a general context, while others are specific to the modelling of transportation systems.

1. S.D., being a simulation technique, works mainly through the time dimension. Spatial aspects and distribution effects are not easily accounted for.
2. In general, modelling involves assumptions about behaviour in the real world, and thus cannot represent reality in a complete fashion, but it can attempt to approach reality.
3. S.D. models are relatively complex models. There is always a tendency by S.D. model builders to include a clutter of causal relations that

might be irrelevant. This may result in complex, incomprehensible models, that might be deficient in scope and focus.

4. Most S.D. models are aggregate models intended to show policy impacts in terms of approximate magnitudes and direction of change. Emphasis in S.D. is on aggregate simplicity. However, S.D. models could be further refined to describe the system in a more accurate way, thus providing numerically accurate output.
5. Some of the relations used in S.D. modelling are purely heuristic. They lack scientific evidence to support them, but in some cases this is the only way to model socio-behavioural relations.
6. In many situations, the way in which a S.D. model is decomposed and its variables defined, is synthetic.
7. Generally, S.D. models are deterministic in nature, yet randomness and stochasticity can be easily incorporated.
8. S.D. models are recursive. This assumption is intended to simplify the modelling effort by avoiding the solution of simultaneous equations. Recursiveness, though useful, may restrict the determination of various parameters that take place simultaneously in reality. This limitation could be overcome by using a general-purpose computer language, such as FORTRAN.
9. The ultimate aim of a S.D. model is to aid policy-makers in reaching an optimum design policy. In complex systems, heuristic optimisation becomes a very difficult task. Computerised optimisation approaches have been developed, and they should be more usable.
10. The validity of S.D. models has been the subject of strong, heated debates throughout the past years. In S.D., validity is interpretated as 'model usefulness', rather than 'numerical exactness'. The S.D. literature includes a wide range of both qualitative and quantitative validity tests. These tests are meant to increase our confidence in S.D. models, as well as to withstand any criticisms. Some of these tests are available in software form, yet further efforts to automate and facilitate the use of these tests should be pursued.

SUMMARY AND CONCLUSION

The paper is divided into two distinct sections. The first, introduces new cities in Egypt and discusses the role that transport might play in achieving the developmental goals of new cities. This section ends with the conclusion that we need a form of systems approach to represent the transport system within a coordinated, comprehensive framework, and the methodology of S.D. is proposed as a modelling technique that meets the requirements. The paper, then, moves to the second section, where the utility of S.D. methodology as regards its suitability for application to modelling transportation systems is critically reviewed. This methodological review is performed mainly to support the intention of using S.D. to model transportation and socio-economic developmental patterns of new cities in Egypt.

While the S.D. modelling concept has its limitations, the motivations for pursuing the concept for solving transport problems are overwhelming. A comprehensive, analytical approach is an effective aid in identifying and appraising alternatives to change the policy for the future course, but it is only an aid. A S.D. model does not set or evaluate the criteria for improved system behaviour. It may illustrate trade-offs, but it cannot determine what is a desirable scenario: decision-makers make the value judgements. A quantitative model merely adds to their information in weighting alternatives. Although computer simulation models cannot guarantee better decisions, they give decision-makers more information more quickly, leading to more informed decisions.

In concluding this paper the author would like to quote from two different studies. The first is from the (OECD 1974) thorough review on possibilities for simplification of urban transport models where transport models were mainly divided into three categories:

1. four-step models;
2. demand models; and
3. urban dynamic development models.

In discussing the urban dynamic development models, the report states 'A third group consists of models structured by methods of systems analysis. This is the most promising group, though they are in the moment only global models. The basis of these models is the Forrester model, mentioned in Urban Dynamics.' The second quotation is by (Hazel 1989), where he recommends S.D. to be used for transportation studies, 'Indeed, S.D. offers a potential way forward for transportation planning in general, which seems to be becalmed between disbelief in the traditional four-stage model and a lack of a credible alternative.'

An extensive review of transport studies which have used S.D. has been carried out by the author. The main point to be stated is that most of these studies have tended towards using parameters at the macro, rather than the micro scale. As a result of the review, the author feels that there is scope for extending the applicability of S.D. thinking in the direction of developing micro, analytic models for various transportation issues. Such models, when combined togther should provide much more specific answers to the problems of transport. There follows, an extensive bibliography that includes most of the applications of S.D. in the field of transportation.

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