Long-term Implications of Highway Quality and Length in the Growth of Indian Manufacturing Sector: A System Dynamics Analysis

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Received 12 October 2015; revised 16 April 2016; accepted 11 May 2016

India, with five million kilometers of length, has the world’s second largest road-network which is also the densest among the countries of similar size. Highways in the road-network play an important role in the development of a country’s economy. However, the highways in India are capacity constrained, slow, less safe, environmentally unfriendly, not maintained or non-maintainable and patchily administered. For the nation’s economic growth, the quality of roads and the length of its new-construction which facilitate the movement of tones of goods and market accessibility is a necessity. Improvement in transportation efficiency brings down the logistics cost, making the product more cost-competitive thereby encouraging economies-of-scale, which in turn provides the impetus to manufacturing growth. To understand the long-term implications of the quality of highways, the length of its new-construction and its related factors on the nation’s manufacturing growth, a System Dynamics approach has been used in the paper. The eight scenarios simulated in the model are expected to provide useful insights to the road-transport planners and the policy makers of the nation.

Keywords: Manufacturing growth, Road and National Highway (NH), Deterioration and Repair of highways, System Dynamics (SD), Causal Loop Diagram (CLD) and Stock and Flow Diagrams (SFD).

Introduction

A developed transportation infrastructure reduces the effect of distances, reduces lead-time, improves the flow of goods and people, integrates existing markets, creates new markets, facilitates labour-productivity, enhances people’s aspirations, smoothens the flow in export and import, improves inventory-turns, encourages potential investors to invest, and finally all these lead to enhanced manufacturing competitiveness. India has one of the largest and the densest road network9 amongst the countries of similar size in the world with a length of 4.9 million kilometres (kms). The huge road-asset base worth 10,300 billion INR12 and the increasing freight movement in terms of Billion Tonnes Kilometre (BTKM) demands attention. The National Highways of the country have a length of 96,214 Km8 and take up 40%4 of freight traffic. The logistics cost in India is 13-14% of the Gross Domestic Product (GDP), which is higher than 9-11% in Europe5 and US. Road transport related factors over a period of last fourteen years from Economic survey (Volume-II) 2014-15 and Mo RTH budget 2013-1410 indicated that the growth in total road and NH lengths have not been able to keep pace with the growth in manufacturing output and freight movement.

Causality between Infrastructural and Economic growth

Economic growth induces expansion in manufacturing sector which necessitates growth in the movement of goods measured in terms of BTKM, which in turn demands improved quality and length of highways. It is a demand-driven relationship. The increasing length in highways improve mobility and access to existing markets, create new towns, cities, newer consumer markets and increase the access to remote borders and rural areas. It facilitates people mobility from rural regions14 to cities creating skilled and productive labour over time and connecting competitive raw-material sources leading to improvement in economic growth. This is a supply-driven relationship. This relationship between infrastructural growth causing economic growth is a relatively weak linkage in India16. In conclusion, bidirectional causality exists between road transport growth and economic growth. Similar observations have also been made by another author4. According to the then Planning Commission study15, in India a 1.2% increase in road traffic adds a whole percentage...
point to the economic growth. A cross-sectional investigation on 98 countries has revealed that there is a significant association between economic development and road network density and its quality. Another research has brought out that regions closer to transportation-networks have higher levels of GDP.

Quality and Maintenance of Highways

The existing road network in India is under severe strain due to inferior road quality, high freight growth, over-loading of vehicles, inconsistent and severe weather conditions and government neglect in the past to provide funds for road maintenance. The master plan prepared by Ministry of Road Transport and Highways (Mo RTH) aims at developing the National expressway network to a length of about 18637 km and constructing the NH at the rate of 30 km/day. The five important distress factors which influence the performance of the roads are raveling, potholes, rutting, cracks and patching. The maintenance levels for highways have been categorized into three levels - Good, Average and Acceptable based on the distress factors. Poor and delayed maintenance cause major damage. The 270 million INR allocated for the year 2015-16 is just 50% of the requirement. As per the report the cause of poor management of NH is the lack of funds made available for maintenance as these do not exceed 60% of the requirements.

Impact of road-infrastructure on manufacturing

The average vehicle speed is 20-21 km/hour on the highways in India and a truck can cover only 250-400 km/day compared to 700-800 km in developed countries. A study indicates that 5% of the journey-time is wasted in the unwanted stoppages which include delays caused by the interstate check-posts. New construction of highways is a pre-requisite for further development as it permits and invites rather than compels other activities to follow suit. Road by itself is not sufficient for the development of a nation/region but it is a necessity in the development process. The regression function of the impact of Economic factors on the global competitiveness has indicated the presence of the variable-Infrastructure, which has a significant impact of Quality of roads.

Research Objectives

This paper has attempted to achieve the following four objectives:

- To identify the key elements in roads and highways, from the literature survey, having impact on growth of Indian manufacturing sector,
- To develop an exploratory model using System Dynamics to understand the deterioration and its maintenance behavior of the highways,
- To study the impact of the key endogenous variables on manufacturing output through simulation of various scenarios, and
- Make recommendations for improvement in the National Highways sector based on the scenarios simulated.

Research Methodology

The methodology adopted in the paper to study the behaviour of manufacturing growth with respect to the highway related factors is System Dynamics (SD) modelling. The rationale behind the choice of SD modelling to study the implications of the highway related variables on Manufacturing output is summarised as:

- It is based on a non-linear complex system consisting of the quality and length of highway linkage to manufacturing growth with multi-feedback (five) control loops,
- The highway is subjected to a round-the-clock usage with a growing BTKM leading to its dynamic deterioration and its subsequent repair and maintenance. To holistically understand this dynamic perspective of the system the use of SFD becomes relevant.
- Such complex system behaviours over long periods and with multi-scenario simulation runs are well understood by using the Stella software in SD to provide useful insights.

The SD model development, in the paper, basically consisted of five broad steps:

a) Developing the Causal Loop Diagram (CLD) and the Stock and Flow Diagram (SFD),
b) Building the SD scenario simulations with well-defined and realistic assumptions,
c) Understanding the dynamics of the Stocks and Flows in different scenarios,
d) Deriving conclusions from system behaviour trends of endogenous variables and stocks,
e) Making recommendations to the policy makers and strategic planners.

The CLD technique of SD has been employed for mapping the feedback loop structures of the system. A
causal relationship between Manufacturing output and the highway quality and the new construction of highways has been developed. The important feedback elements have been defined through the five reinforcing and the balancing loops. The authors have developed the SFD using the Stella software (V9.1.3) of SD to study the system behaviours for relevant scenarios.

**Application of the proposed model**

An exploratory SD model has been developed with the objective of understanding the long-term implications of the dynamics of quality and length of highways due to their deterioration and subsequent repair process on manufacturing output. A growing Manufacturing output of a nation would mean additional movement of goods on highways leading to higher road distress and ageing which call for responsive maintenance as well as construction of newer highways. Eight different scenarios with different combinations of the endogenous variables have been simulated using the proposed model. Three endogenous variables considered are different deterioration rates (different highway material), different highway repair rates and different new highway construction rates. The period of study considered is 25 years (25 x 4 = 100 quarters) as the Concrete highways have an average life of approximately 12 years and hence a two cycle study would be a logical representation.

**The Causal Loop and the Stock and Flow Diagrams**

The authors have attempted to map the impact of highway quality (quality-index) and magnitude (length) on the growth of Manufacturing output using the CLD which represents interdependencies and feedback processes of the model. There are five feedback loops comprising of three reinforcing (R) and two balancing (B) loops as shown in Fig. 1. The manufacturing growth would lead to larger movement of freight on the highways, measured in terms of BTKM, which would increase the road distress level leading to faster road deterioration, thereby lowering the highway surface quality. The natural ageing due to highway material and laying process is an additional factor of deterioration. The decrease in quality would slowdown the vehicle speed, increase the freight delivery lead-time, hold up material inventories causing increase in logistic cost, thereby reducing product competitiveness to adversely impact the Manufacturing output. This is indicated through the balancing loop B1 in the CLD. The deteriorating highway condition would call for increasing its repair and maintenance effort to improve the highway quality. This aspect of repair is shown through the reinforcing loop R1 in Fig. 1. The reinforcing loop R2 indicates the bidirectional causality between the highway distress level and its deterioration. By incorporating the highway repair the balancing loop B2 gets evolved. The growth in manufacturing brings in prosperity which encourages the construction of new highways (increase in length) causing

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*Fig. 1Δ CLD and SFD between the Highway quality and its length on manufacturing output.*
improvement in the accessibility to newer markets and resources, leading finally to improvement in manufacturing growth as shown through the reinforcing loop R3. The inputs from the experts from the Central Road Research Institute (CRRI), New Delhi, literature survey and academic experts have supported the logic developed in the CLD. As CLDs fail to capture the stock and flow structure of systems, the need for SFDs become important. Stocks are accumulations characterizing state of the system and generate the information upon which decisions and actions are based. The two critical stocks to be studied in the manufacturing growth and the highway system interaction are the quantum of Manufacturing output (accumulation in INR) and the highway lengths (accumulation in kms) as shown through the SFD developed in Fig. 1. The highway stock has been categorized into Good (G), Mediocre (M) and Bad (B) categories which have a defined deterioration rate (years) based on the technology and material used for the surface making. The dynamic deterioration of the highway calls for a dynamic repair for restoration to its desired quality level. The quality of the highway consisting of G, M and B categories of surface is defined by a Composite Road Quality Index (CRQI) evolved by the relationship of the proportion of the three categories. The SFD also indicates the relationships between the different endogenous variables in manufacturing growth, freight related BTKM, distress level of the highway, the deterioration rate, the repair rate, the CRQI and growth in new highway construction. The inputs to the development of the SFD were supported by the CRRI, industry and academic experts. The SD model was developed for simulation using the Stella software version V9.1.3.

**Assumptions made in the model**

To carry out the simulation of the scenarios the following realistic assumptions were made:

- Manufacturing growth leads to increased movement of freight and thereby increasing BTKM. In the 12 years period of 2000-01 to 2012-13 the ratio between the Manufacturing output to BKTM (Table 1) has been found to be

<table>
<thead>
<tr>
<th>Scenario no</th>
<th>Type of highway</th>
<th>New highway construction rate</th>
<th>Highway ageing/deterioration rate</th>
<th>Highway repair/maintenance rate</th>
<th>System behaviours under study</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Bitumen</td>
<td>Range from 500 to 1000 kms/q with inverted U trend.</td>
<td>G to M - 12 q, M to B - 4 q, 3rd order delay.</td>
<td>50% for B to G and M repaired in 2q period with 3rd order delay.</td>
<td>Study the trends of G, M, B categories of road lengths, CRQI and Manufacturing output.</td>
</tr>
<tr>
<td>S2</td>
<td>Concrete</td>
<td>Same as in S1 (normal)</td>
<td>G to M Í 48 q, M TO B Í 16 q, 3rd order delay.</td>
<td>Same as in S1 except repair period changed from 2q to 4q.</td>
<td>Study the trends of G, M and B categories of roads, CRQI and Manufacturing growth.</td>
</tr>
<tr>
<td>S3</td>
<td>Bitumen</td>
<td>Negligible (less than 50 kms / q) new construction.</td>
<td>Same as in S1</td>
<td>Same as in S1</td>
<td>Study the impact of negligible new construction on G, M and B roads, CRQI and Manufacturing output.</td>
</tr>
<tr>
<td>S4</td>
<td>Bitumen</td>
<td>High and uniform (1000 kms/q) new construction.</td>
<td>Same as in S1</td>
<td>Same as in S1</td>
<td>Study the trends of high new construction on G, M and B roads, CRQI and Manufacturing output.</td>
</tr>
<tr>
<td>S5</td>
<td>Bitumen</td>
<td>Same as in S1 (normal)</td>
<td>Same as in S1</td>
<td>100%, 75%, 50% &amp; 25% repair of B to G and M to G. Rest same as in S1</td>
<td>Study the impact of the 4 road repair rates on Manufacturing output.</td>
</tr>
<tr>
<td>S6</td>
<td>Bitumen vs Concrete</td>
<td>Same as in S1</td>
<td>Same as in S1 for Bitumen and S6 for Concrete.</td>
<td>Same as in S1 for Bitumen and S6 for Concrete.</td>
<td>Study the comparative trends of Manufacturing output.</td>
</tr>
<tr>
<td>S7</td>
<td>Bitumen</td>
<td>1000 kms/q</td>
<td>Same as in S1</td>
<td>100% repair rate and 25% repair rate</td>
<td>Study the impact of the 2 extreme cases on Manufacturing output.</td>
</tr>
<tr>
<td>S8</td>
<td>Concrete</td>
<td>Same as in S1.</td>
<td>Same as in S2</td>
<td>Same as in S7.</td>
<td>Study the impact of the 2 extreme cases on Manufacturing output.</td>
</tr>
</tbody>
</table>

q = Quarter of a year
varying over a small range between 1130 to 1251 each year. In the model it has been assumed to be 1157, an average during the period of simulation.

- It is assumed that initial ratio of G : M : B lengths is 1:2:4 with the highway length of 58000 Kms (NH length in the year 2001). Road deterioration takes place due to normal ageing of the road asset and the road-distress factor (BTKM / road length). However, road deterioration affect is mitigated by the dynamic repair and maintenance.

- Vehicle speed (Kms/hour) carrying manufactured goods in M and B category of roads are assumed to be 50% and 25% than that of G, respectively.

- Deterioration from G to M category and M to B for different materials of road have been assumed based on inputs from academia and CRRI experts. For Bitumen laid highways the G to M and M to B aging rates are 3 and 1 year, while for Cemented concrete highways it is 12 and 4 years respectively. Third-order-delay has been considered in the road ageing process.

- The road repair rates considered have been in terms of percentage repaired from M to G category and B to G category. From literature review, in India, government funds released are around 50% of the requirement. Third-order-delay has been assumed in the repairing process.

- The Composite Road Quality Index (CRQI) of a stretch is computed as \((1 \times \text{length of G} + 0.5 \times \text{length of M} + 0.25 \times \text{length of B}) / \text{(Total length of (G+M+B))}\) and varies between 0 and 1. It is assumed that the year on year manufacturing growth commences only after CRQI crosses a threshold figure of 0.5 and the maximum limit of 8.5%

- The least time unit considered in the Stella software is a quarter (q) of a year (3 months).

- Initially, with the increasing Manufacturing output the new highway construction rate is high then it diminishes. This is because the demand for goods movement, beyond a value, shifts from road to less expensive railways. The increase in the highway length impacts the manufacturing growth and follows an \(S\) shaped trend. Being a weak relationship, as indicated in the literature, a small year-on-year growth of 3.5% is assumed in manufacturing output.

- The composite impact in the year-on-year manufacturing growth is assumed to be the product of the growth factor due to CRQI and new-construction of highways to the preceding year's manufacturing output.

- The normal condition has been assumed when the new highway construction trend follows an inverted U-shape with minimum and maximum values of 500 and 1000 kms/quarter respectively, 50% of the deterioration is repaired every quarter and the distress level follows an increasing straight line pattern with increasing BTKM/road length.

### System Dynamics simulation scenarios

The eight simulation scenarios considered for study have been tabulated in Table 1.

### Analysis of System Behaviour due to various policy options

The SD model developed was run for a number of policy options to study the scenarios of system behavior on manufacturing output over a period of 25 years (100 quarters) by when the system reaches a near stable state. The two most prevalent surfaces of the highway considered are Bitumen-base and Concrete-base as the key policy options. Each of these highways has its deterioration / ageing rate as mentioned in the assumptions section. Another important policy option considered in the model is the repair rate of the deteriorated-highway which is varied from 100% to 25% level and which depends on the fund availability from the government. A yet another policy option considered in the SD simulation is the new highway construction (in terms of length) which is varied from a maximum rate of 1000 kms/quarter to a minimum rate of 50 kms/quarter and an intermediate normal condition (inverted U trend with minimum 500 kms/quarter to maximum of 1000 kms/quarter). The behavior trends of the three highway category lengths, CRQI and Manufacturing output, under different scenarios of normal conditions, with negligible (50 kms / quarter) and high new-construction (1000kms/quarter) are shown in Fig. 2. The comparative graphical trends of manufacturing output under different scenarios are shown in Fig. 3. The comparative trends of manufacturing output under two extreme situations of full repair with high new-construction and negligible repair with low new-construction for Bitumen and Concrete highways are also shown in Fig. 3.

### Model Validation

The SD model developed in the paper has been validated using six standard tests. In order to support the Boundary Adequacy and Structure Assessment
tests the choice of the endogenous variables, the
development of the CLD, evolving the SFD and
defining the equations used in the model were
incorporated after soliciting the opinion of experts
from research (CRRI) and industry (Automotive). The
equation developed for assessing the highway quality
(CRQI), defining the highway distress pattern,
highway deterioration rates, highway repair rates and
the manufacturing growth rate (based on quality and
length) were verified for Dimensional Consistency.
The parameter values were taken from the Indian
manufacturing sector and the NH context and hence
the Parameter Assessment test can be assumed to
have been done. The Extreme Condition tests using
the extreme values of 100% and 25% highway repair
rates, extreme values of new-construction (1000 and
50 kms/quarter) rates and two highway base materials
were done and the outcomes made sense with respect
to real-world. The Behavior Reproduction test can
be assumed to have been done as the model did show
trends which were consistent to the real industrial
world.

**Results and Discussions**

The SD model simulated 8 scenarios shown in
Figs. 2 and 3 were analyzed for policy implications
and managerial insights. These are summarized as
follows:

- The system behavior in the most prevalent
  practice of Bitumen based highway, with 50%
  repair rate and with a normal rate of new highway
  construction is shown in scenario-1 of Fig. 2.
  After initial volatility the slope of G (Good)
  category highway trend is significantly higher
  compared to M (Mediocre) and B (Bad)
  categories primarily because of new-construction
  factor and the 50% repair rate assumption. After
  the initial volatility, the CRQI stabilizes at a
  healthy figure of 95%. The growth in
  Manufacturing output is low initially only to pick
  up after a decade and finally grows quickly due to
  the double effect of quality improvement and the
  highway expansion.
- The system behavior for Concrete highway with
  50% repair rate and in normal new-construction
situation is shown in scenario-2 of Fig. 2. In the concrete highway scenario the Manufacturing output increases very steeply owing to the increased CRQI which nearly stabilizes at 98% and also due to new construction of highways. Owing to slow ageing and normal repair on concrete highways the M and B category stocks are exceedingly low and their levels remain flat.

- After the initial volatility, as seen in scenario-3 of Fig. 2, the three road stock trends of G, M and B categories are nearly flat. After the initial volatility the CRQI stabilizes at 94%. The growth in Manufacturing output is low initially only to pick up to finally grow quickly. Owing to the absence of new-construction of Bitumen highway the Manufacturing output growth trend is slightly flatter as compared to scenario-1 of Fig. 2.

- As evident from scenario-4 of Fig. 2, after the initial volatility the road stock trend of G category is seen to grow rather steeply when compared to that of M and B categories which is because of the high (1000 kms / quarter) new highway construction. After the initial volatility the CRQI gradually flattens to 94%. The growth in manufacturing output is quite rapid because of the creation of high new-construction of Bitumen highways.

- As expected, the increase in the highway repair rate would increase the Manufacturing output rate due to improved CRQI as observed in scenario-5 of Fig. 3. However, the increase in the Manufacturing output decreases with the increase in repair rate as seen in the graph. Therefore, it could be an optimal decision to operate with a repair rate of 75% of the requirement or more. This is quite different from the 50% or less actual funds availability for repair as currently practiced in the Indian context.

- The scenario-6 of Fig. 3 shows a comparative trend of the Manufacturing output under the two highway surface types- Bitumen vs Concrete. Under similar conditions, the Manufacturing
growth with Concrete highways moves up by almost 40% over a period of 25 years. It clearly confirms the expected results that the Concrete highways would deliver far superior results.

- The major difference in the manufacturing growth behaviour trends in two extreme situations of Bitumen based highways is evident in scenario-7 of Fig. 3. There is a three times growth, over 25 years, in Manufacturing output from the worst situation to the best situation.
- The major difference in manufacturing growth behaviour in two extreme situations of Concrete based highway is seen in scenario-8 of Fig. 3. There is a two-fold growth over 25 years in manufacturing output from the worst situation to the best situation. However, the graph has significantly shifted upwards when compared to that in scenario-7 of Fig. 3. This reinforces the proposition that there is need for constructing new highways mainly with the concrete base.

Recommendations
Based on the observations from the literature and insights obtained from the simulation analysis, six recommendations are made as follows;

- Develop a dynamic highway quality database and a sound maintenance strategy because this high-value asset has become an operating necessity in our manufacturing priority nation. Carry out the segmentation of the NH based on classes of road for repair and maintenance (including preventive maintenance) as the same level of maintenance is not needed for the entire length.
- Optimize the repair and maintenance of highways by providing sufficient governmental funds to operate at a minimum of 75% requirement.
- Ensure repair and maintenance completion within two quarter months of its generation for Bitumen surface and four quarter months for Concrete surface highway. Use of mechanized mobile units, superior material quality and updated technology for repair and maintenance would make a difference in improving the transport efficiency.
- Invest in Concrete highways for all future highway expansion. Based on funds availability from the government the gradual transition from the Bitumen to Concrete highways is recommended.
- In order to facilitate improvement in the average vehicle-speed, in addition to highway surface quality, the need for a singular Goods & Service Tax implementation is an operating necessity.
- Provide the Industry status to highway transportation to facilitate raising capital, facilitating it with the development of the continuous improvement culture, integrating the commonly used industry tools and techniques to improve quality, productivity and maintainability.

Scope for future research
There is scope for further enriching the exploratory model developed in this paper by incorporating variables and studying the effect of different combinations of Bitumen and Concrete based highway lengths on Manufacturing growth.

Conclusions
The SD model developed in this paper serves as a useful tool for a comprehensive understanding of the long-term dynamic implications of the policies for highway expansion and its repair and maintenance on the manufacturing growth of the country. The two important inferences one can derive from the policy experimentations have been, the need to effectively leverage the advantages of Concrete highways and setting a highway repair rate at 75% of the requirement. These two aspects will provide the requisite foundation to improve highway quality for an effective and efficient transport system. All new highway construction, henceforth, are recommended to be Concrete based and a gradual conversion of the existing Bitumen highways to Concrete base should be carried out. Construction of new highways to enhance manufacturing growth is a necessity but it is not a sufficient condition for ensuring manufacturing growth. Absence of it would have adverse effect but presence would weakly impact the growth for which many other enabling policy parameters are to be in place. The construction of new highways in the carefully chosen less accessible areas and villages will enable to explore new markets for growth. It should facilitate in integrating dispersed markets, creating new markets and improving accessibility to add to the manufacturing growth process.

Acknowledgement
The authors express their gratitude to Mr. B. M. Sharma, Chief Scientist, CRRI, New Delhi, for providing useful data and other inputs to the development of the SD model.
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