Quantifying Economic Benefits for Rail Infrastructure Projects

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16. Abstract: This project identifies metrics for measuring the benefit of rail infrastructure projects for key stakeholders. It is important that stakeholders with an interest in community economic development play an active role in the development of the rail network. Economic development activities in both rural and urban settings are essential if a nation is to realize growth and prosperity. Many communities have developed goals and visions to establish an economic development program, but they often fail to achieve their goals due to uncertainties during the project selection and planning process. Communities often select a project from a vast pool of ideas with only limited capital available for investment. Selecting the right project at the right time becomes imperative for economic and community development. This process is significantly hampered by limited methods for quantifying the economic benefit to key stakeholders. Four methodologies are used in this project to determine the most useful tools for quantifying benefit given the availability of data, relevant expertise, and other information.		
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Executive Summary

Determining the long-term benefits and costs of rail infrastructure projects is a complex process that involves addressing both economic and social factors that frequently change over the full lifecycle of these projects. Historically, and in current day practice, attempts to assess possible investment scenarios for such projects have relied upon benefit-cost analyses. It has been shown that these analytical frameworks are too limited to provide policymakers and decision-makers with adequate understandings of the tradeoffs that must be made across the multitude of social and economic factors of infrastructure investments that often have a lifecycle of 50 to 100 years. The reasons the traditional benefit-cost methods are inadequate is that these situations require multi-criteria decision making under conditions of uncertainty. In short, these types of investment decisions are not reducible to single rates of return or simple ratios derivable in traditional benefit-cost analyses. Thus, the purpose of this research project is to identify methods and tools that better address these tradeoffs such that Missouri policymakers and decision-makers can make better informed decisions regarding rail infrastructure investments in Missouri.

To this end, this research project uses sociotechnical roadmapping to identify methods and tools to better quantify the economic benefits of rail infrastructure projects in Missouri. The social and technical elements identified through socio-technical analysis are evaluated using three distinct models: Leontief, Bayesian and Systems Dynamics. These three model frameworks provide analytical tools for capturing complex interplays of multitudes of relevant social and economic factors impacting, and impacted by, railroad infrastructure investments. Further, the modeling frameworks offer a means for MoDOT to bring analytical rigor and stakeholder input into current statewide transportation planning and into the state rail planning processes.

The Leontief-based approach is the simplest of the three approaches if historical data of similar projects are available. Not only does it involve a simple system of linear equations, but it can easily be applied in the absence of reliable multipliers. Historical data on input and output variables can be used to arrive at fairly good multipliers that can be further used to calculate the project deliverables. One simplifying assumption used in this approach is that relationships between the various factors are linear. This method is fairly easy to use. The interdependencies among the various technical and non-technical elements can be studied using this framework.

In the Bayesian approach, social and technical factors are divided into three sets of variables, i.e., decision variables, evaluation criteria and objective variables. For this approach, it is very important to form a panel of experts and also conduct surveys to gather data for the approach. The major advantage of the Bayesian approach is that it is suitable for small data sets as the missing data can be filled using expert opinions. Also, due to the probabilistic nature of data, this technique allows for estimation of risk. Bayesian frameworks provide decision makers with a range of likelihoods of outcomes and also allow for improved estimates as more information becomes available as the investment process unfolds. Hence, decision makers can make adjustments in their decisions as additional information appears.

The third approach described in this report is the System Dynamics approach that takes into account all the socio-technical factors and the relationships between these factors. This approach provides a good framework to begin the analysis work, but the model quickly becomes quantitatively complex. Its greatest value rests with the ability to provide thorough qualitative information. The causal loop diagram provides a good framework to visually represent the

interactions between various elements. However, in the absence of good multipliers, the equations used to solve the dynamic model can be highly unreliable. The following table compares the three approaches used to model the socio-technical factors for rail infrastructure investment process.

Table: Model Comparisons

Criteria for comparison	**Leontief Approach**	**Bayesian Approach**	**System Dynamics Approach**
Data Availability	Historical data are required to solve the method	Can be used even when small data sets are available	Time-series data are required in this approach
Parameter Estimation	Estimated from historical data using regression analysis	Estimated after conducting expert interviews and surveys	Estimated from expert opinions, surveys and engineering data using regression analysis
Relevance to Railroad Infrastructure Investment	Highly relevant	Highly relevant	Highly relevant
Ease of Application	Straightforward method and easy to use	Easy to apply given the availability of expert opinions	Qualitative analysis is straightforward and easy, but quantitative analysis may get very complicated

The project team recommends in the near-term, if relevant historic data are readily available; use of Leontief models. These will provide the most robust solutions. However, as is likely to be the case, if these data are difficult to find or compile in useful formats, the Bayesian approach should be substituted for near-term analyses. Further, the development of Bayesian models for use in analyzing possible investment strategies associated with rail infrastructure in Missouri represents the first step in a long-term MoDOT program for systematic analyses for informing policy decision-making and programmatic direction. In addition to developing this capability, the development of mechanisms for regularly obtaining economic, demographic, attitudinal and other data should be initiated to create the option of developing Leontief models. Further, to establish the capability for addressing the long-term variability in socio-economic factors that impact railroad infrastructure and economic development, additional modeling efforts based upon both Bayesian network models and System Dynamic models should be undertaken, including the development of stakeholder panels and regularly obtaining and maintaining economic, demographic, attitudinal and other relevant data sets for use in these models. This latter recommendation is consistent with Federal requirements regarding statewide transportation plans and metropolitan transportation plans (MTP) at the MPO level. Both the Bayesian and System Dynamic models provide analytical “hooks” for the inclusion of stakeholder input on a regular and systematic basis.

Contents

1. Introduction 6

2. Socio-technical Analysis 9

2.1 Introduction 9

2.2 Methodology 9

2.2.1 System Analysis 9

2.2.2 Sustainability Analysis 10

2.2.3 Uncertainty Analysis 11

2.2.4 Socio-technical Roadmapping 12

2.3 Socio-technical Analysis Conclusions 15

3. Leontief-Based Approach 15

3.1 Literature Review 15

3.2 Model Description 17

3.3 Model Fitting 19

3.4 Numerical Example 20

4. Bayesian Approach 22

4.1 Bayesian Networks 22

4.2 Model Description 25

4.3 Model Fitting 28

4.4 Numerical Example 29

5. System Dynamics Approach 34

5.1 System Dynamics 34

5.2 Model Description 36

5.3 Model Fitting 39

5.4 Numerical Example 41

6. Conclusions 42

8.1 Appendix 1A: Possible Metrics for Railroad Infrastructure Investment 54

8.2 Appendix 2A: SAS Code for Leontief Approach 77

8.3 Appendix 3A: SAS Results 78

8.4 Appendix 4A: Excel sheet and instructions on how to use excel file for Leontief approach 92

8.5 Appendix 5A: Excel sheets and instructions on how to use excel file for the numerical example on Bayesian Approach 93

8.6 Appendix 6A: SAS Code for System Dynamics Approach 98
8.7 Appendix 7A: SAS Results for System Dynamics Approach 99

1. Introduction

Rail infrastructure contributes to the economic vitality of an economy. It moves both, the public and freight, and hence, in combination with the rest of the infrastructure industry, has a strong impact on society and private sectors. According to the US chamber of Commerce, $1 spent on infrastructure construction leads to approximately $1.92 direct and indirect economic output [1]. It has also been shown that for every one billion dollars of investment in infrastructure, as much as 20,000 new jobs can be created [1].

For a nation to realize growth and prosperity, economic development activities need to be carried out in both rural and urban settings. Transportation projects can be considered as complex systems as they are difficult to plan, design, build and operate. The involvement of the human element in the projects may cause the proposed infrastructure to fail to achieve the planned benefits due to the difficulty in measuring the non-quantifiable risks and uncertainties that come into picture along with the involvement of human elements [2],[3] and [4]. To account for the uncertainties and risks due to human elements, a social-technical analysis was done to identify the technical and social elements and to understand the interdependencies and relationships between these elements. For economic and community development selecting the right project at the right time is a must. This selection process is significantly hampered by limited methods to quantify the economic benefit to a stakeholder. This project attempts to quantify economic benefits realized from investment in rail infrastructure projects. The possible metrics for railroad investment projects are identified. These metrics are grouped into three categories, namely, economic development metrics, sustainability metrics and indices and user/customer metrics.

There are over a 100 economic development metrics identified in the extant literature (see for example, Isard 1956[5], 1959[6], 1960[7]; City of San Jose, CA 2013[8]; the California Association for Local Economic Development [10]; and Porter 2003[11]). Most of these measures aim at providing indicators of success/failure of government/non-governmental organization (NGO) Economic Development Organizations (EDOs). A strength of these metrics is that most are aligned with regularly collected data by governmental/NGO entities. The disadvantage of many of these metrics is that there is not an easy crosswalk between these measures and those that have been suggested as ways to measure Sustainability, as well as being able to clearly distinguish just what policy or investment by what entitity led to any given change in the value of a particular metric. Finally, the role of private sector investments in economic growth in any geographic area cannot be easily extracted from these measures. (See Appendix 8.1 for a listing of metrics and possible data sources.)

Since the inception of the concept of Sustainability, there has been an increasing focus on operationalizing or measuring sustainability, i.e., creating Sustainability Development Indicators (SDI). To date, there are almost 20 distinct sets of metrics and indices that have been developed and promulgated [12]. Of the many SDIs available, two may be directly relevant to railroad investments and economic development and capable of near-term implementation. (See Appendix 8.1 for a listing of metrics and possible data sources.)

Finally, it is important to address metrics for the users/customers of railroads – passengers, shippers and receivers. One of the challenges in devising metrics that are relevant for

users/customers is identifying indicators that can be readily collected and analyzed on a regular basis – that is, not requiring special studies that are episodic over time. The importance of this issue resides in the fact that socio-technical systems (railroads being one) have longer planning horizons and face greater uncertainities (risks) that only truly reveal themselves as time proceeds. Thus, user/customer evaluations and priorities are likely to change over time as more information becomes available. To make this more specific, consider the User Needs identified in Rangarajan and Long (2012) [3]. First, the user group needs to be identified, e.g., passengers, shippers, receivers, non-users, individually or corporately domiciled in the area of concern, etc. To illustrate the types of metrics that might be appropriate, consider the need for "Low Cost." First, does "Cost" mean monetary, time, lifecycle, etc.? There is evidence, for example, that, for passengers, travel time (a commonly used metric) is now losing its importance vis-à-vis "productivity of travel time" [13] and [14]. This illustrates how user/customer metrics may change over an infrastructure investment's lifetime. (See Appendix 8.1 for a listing of metrics and possible data sources.)

Communities often have to select a single or very few projects from a vast pool of ideas due to the limited funds available for investment. To avoid any uncertainties or fluctuations in the availability of funds, additional investment portfolios need to be created, and innovative approaches and public private partnerships should be encouraged. The increasing interest in integrating sustainable development[1] into decision-making processes requires the integration of social and technical parameters while quantifying benefits is essential. Also, similar to other developmental efforts, sustainable development strategies can change with time, so to account for the changes over time and approach sustainable development, the decision-making tools chosen must be flexible. For an integrated approach that involves both the economic and end-user factors, the process becomes a multi-objective decision making process – that is to say, in such decision processes, there will be the need to address multiple objectives simultaneously. These are complex decision processes. To address such complex decision processes, the economic and end-user factors can be divided into two categories: decision items and objective functions. Decision items are the factors over which the decision makers of a project have direct control. The objective functions are the ultimate goals to be achieved by a project. The objective variables together constitute all the benefits in the overall socio-economic framework. Thus, identifying the main stakeholder groups, the benefits to each stakeholder group and studying the interdependencies among them is vital to a thorough understanding of the impact of modifying or expanding existing rail road infrastructure. Based on the above discussion, this project proposes three possible methods to quantify the benefits of investing in railroad infrastructure.

Investment in railroad infrastructure will help support national freight and passenger capacity goals. With the development of the railroad infrastructure, the on-road traffic would also decrease. As mentioned earlier, it is essential to determine the viability of a railroad project from social and technical points of view. For this purpose, the main stakeholders in any railroad project are considered to be the community (residents) in which the project is situated, the

[1] Sustainable development refers to the type of development that improves the quality of life and leads to economic growth while preserving and enhancing the natural environment [15]. The idea of sustainable development was included in the new mandate of International Union for Conservation of Nature (IUCN) in 1969 and dates back more than 40 years [16]. Although, the idea of sustainability has been in existence for a long time, organizations focus on easy to measure goals and impacts [17] while ignoring difficult to measure social impacts and public acceptance [15].

governmental entities through which, or in which, the project is situated, the railroad, the railroad's customers, the suppliers and contractors to the railroad and other entities concerned with broader environmental impacts, as well as all parties that could be negatively impacted by the project. The benefits and costs associated with each of the stakeholder groups need to be evaluated and the interdependencies among them studied. These benefits and costs can further be classified as social or technical elements, depending on their characteristics.

To illustrate the concepts laid out in the preceding paragraph, we will use the construction of a new railroad bridge to particularize the constructs. A new railroad bridge will add to transportation options available to the general public as well as the shipping/freight industry and may help reduce on-road vehicular traffic and also reduce the GHG loads from trains sitting on the sidings along with other economic and non-economic benefits. Any change in travel cost, accessibility, and reduction in travel time due to this modification will affect the public sector. Therefore, these factors fall under the social elements category. Further, increases in the number of jobs, tax revenue, utility revenue, etc. are possible metrics that could affect government sector decision-making and policies. These objectives (benefits) contribute to the technical aspect of the impact of modification in rail infrastructure. Another technical factor involved in this system is the capacity of the rail corridor. Corridor capacity may be impacted by both infrastructure improvements and operating practice improvements. In this study, we focus on infrastructure investments that may improve corridor capacity. Improvements in corridor capacity may lead to reduced transit times, reduce costs, improved transit consistency, etc., all of which may beneficially impact private sector stakeholders, as well as the public and community sectors because of such things as reduced vehicular congestion, reduced GHG, etc.

Conventional decision-making processes in the infrastructure industry generally rely on cost-benefit analyses and impact assessments, and are thus, unable to address future transportation system challenges completely [18]. Therefore, it is imperative to adopt methods that are capable of acknowledging the diverse interests of all the stakeholder groups and evaluate both the social and technical elements involved. The evaluation methodologies to study an infrastructure project can be broadly divided into two categories - linear and non-linear. Whether to adopt a linear or non-linear methodology can only be determined after the identification of factors involved in the particular project has occurred, in addition to identifying the interdependencies among the factors. These interdependencies help in determining which possible evaluation methodologies are best suited to a project. In addition to the relationship between the factors, the availability of data and other resources and the time constraint for evaluation affect the decision on choosing an appropriate evaluation method.

This report outlines three methods to quantify rail benefits, namely Leontief input-output model, Bayesian approach and System Dynamics (SD) approach. These methodologies have previously been used in the field of construction and infrastructure projects, and are well understood in terms of strengths and limitations. The major advantage of using the above-mentioned approaches is that they incorporate qualitative factors along with the quantitative factors. These approaches have the ability to include factors related to all stakeholder groups and thereby would allow the policy makers to make a decision that would benefit the community as a whole. Details on the use of these methods in various industries are given in the following literature review-section. Following that are the procedures for each approach with a sample calculation. Concluding remarks and references can be found towards the end of the report.

2. Socio-technical Analysis

2.1 Introduction

To gauge the true effect of a system it is important to evaluate the system in terms of its social as well as technical elements. The performance of a system depends on the interactions between its social and technical elements. For a socio-technical analysis, the interactions between the social and technical elements need to be defined. These interactions contain linear cause and effect relationships, along with some non-linear ones. Systems are comprised of both linear and nonlinear relationships and in some instances unexpected outcomes and impacts are the result of nonlinear interactions that are not well understood [19]. The transportation system is also a socio-technical system, whose performance depends on the interactions between its social and technical factors. Socio-technical roadmapping can be used to provide a visual representation of the plan of action. Until now, most organizations have mainly focused on measuring those factors and impacts that can be easily measured [17]. Social factors such as public acceptance and other difficult to measure goals have been avoided in the decision making process [15]. Including sustainability in the organizational functioning and culture is very critical to realize the long-term objectives of any project [16] [20] [21]. Similar to other developmental efforts, sustainable development strategies also change over time, and to account for these changes a framework should be developed which allows flexible decision making. Such a framework must have the ability to study both the technical and social aspects of the system and evaluate the relationships between various elements of the system. The framework described here uses socio-technical roadmapping as a strategic tool to allow flexible decision making for sustainable development in transportation infrastructure projects. Designing such a framework includes four critical steps, (1) system analysis, (2) sustainability analysis, (3) uncertainty analysis and, (4) roadmapping.

2.2 Methodology

2.2.1 System Analysis

The first step, system analysis of a project, involves establishing the vision, goals and objectives of the project that also align with the organizational strategies. After this, the social and technical elements of the project are identified, interactions between various elements are studied and their effect on the project's performance analyzed. For the rail infrastructure project, a socio-technical analysis was done based on previous rail studies, reports and other documents identifying both proposed and planned Missouri rail infrastructure development alternatives and investments and other publicly available research reports, strategic studies and foresights at the national level. A comprehensive study of existing rail infrastructure in Missouri was done [22]. From a technical perspective, corridor characteristics such as average tonnage hauled, speed, train control systems, and number of trains per day were studied. Data for these characteristics were used to estimate corridor capacity which was represented in terms of level of service and demand for each rail corridor using the Association of American railroads [23] methodology. All the stakeholders and actors impacting the rail transportation infrastructure directly and indirectly were identified as part of analyzing the social elements. Also, other social factors directly affecting the transportation system were identified by conducting surveys, focus group interviews, public meetings, and studying existing reports and studies [22]. The socio-technical elements identified from system analysis are shown in Table 1 [22].

Table 1: Results from system analysis – Missouri rail transportation system [22]

Elements	Data Sources	Factors
Technical	Existing reports and studies AAR capacity analysis MoDOT database Railroad database Waybill data Commodity flow survey FAF data	Level of service Demand Corridor/track characteristics Tonnage hauled Forecasted growth data
Actors	Existing reports and studies MoDOT database	MoDOT Railroads Federal Railroad Administration Amtrak State government Elected officials City Land owners Conservationists Other freight modes Other passenger modes Freight users Passenger users
Social	Public meetings Focus group interviews Surveys Existing reports and studies	Quality of life Equality Economic considerations Accessibility Environmental concerns Cost Time Safety Affordability

2.2.2 Sustainability Analysis

The second step, sustainability analysis, includes classifying the project based on the project typology and analyzing the project's sustainability and sustainable development strategy. The interactions between various elements are then studied from a sustainability perspective and the associated instabilities and risks are determined. To study the interactions between various elements of the systems and the effects that these elements would have on each other and on the decision-making process, a thematic map is developed. This map helps the decision makers to understand the behavior of each stakeholder group and the influence that behavior has on the performance of the system. For the rail infrastructure project, the socio-technical factors identified in the system analysis phase were used as inputs in sustainability analysis. This project was classified as a strategic project after analyzing it from a sustainable development perspective

and aligning it with an economic development typology [3] as the project is capital intensive and involves high levels of risk.

Various focus group meetings and interviews were conducted with all railroad operators in Missouri to study the gap between the target customers and the governing agencies. Due to the private ownership of railroads in the US, railroad operators were reluctant to share information about capacity, demand, general rail corridor characteristics, scheduling, and operational and service characteristics. This caused a huge gap in transportation planning and sustainable development. After studying and analyzing the existing rail infrastructure for future growth, it was revealed that Class I railroads would run above their theoretical capacity and Class II regional railroads would run on their theoretical capacity if no tracks were added. The study suggested a lack of potential to sustain future growth. It was concluded that for future growth and maintaining existing service, infrastructure improvements are necessary. A thematic map as shown in Figure 1 was established to understand the railroad operations and services and to estimate the socio-technical instabilities to view the project from a sustainability perspective.

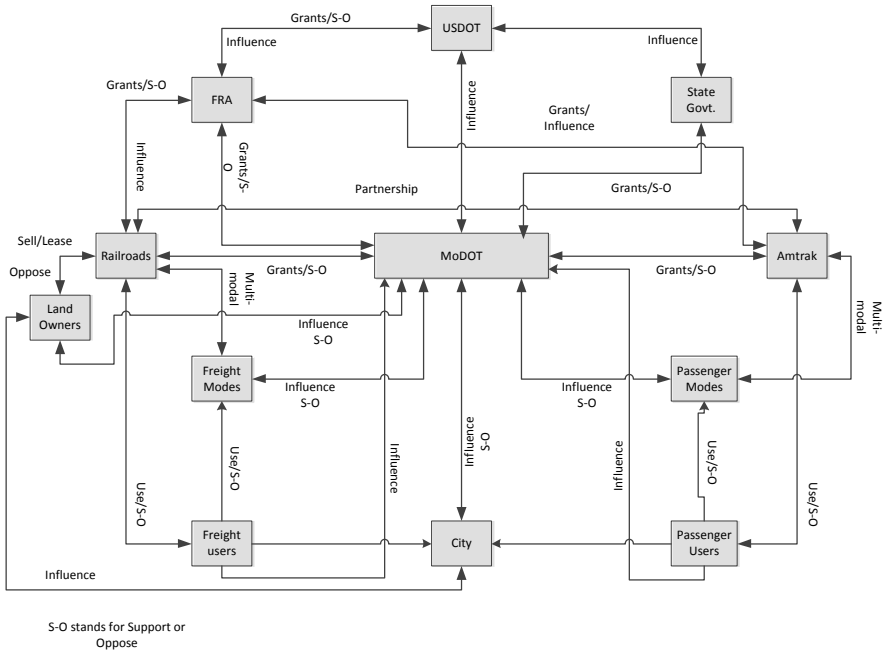

Figure1. Thematic stakeholder behavior/action map [22]

After analyzing the structure of investment and doing an economic impact analysis it was observed that, to maintain existing services and expand these services to other parts of the state additional funds and investment portfolios need to be created.

2.2.3 Uncertainty Analysis

The third step, uncertainty analysis, involves analyzing the instabilities and risks in the system. In this phase, those factors are identified which could impact the functioning of the system. For the rail infrastructure project, a stakeholder analysis was conducted to determine the effect of socio-technical instabilities on the sustainability of the transportation system. To identify and analyze the needs, priorities and issues of the region, public meetings and an informed survey

was conducted [22]. The results of the survey showed that stakeholders and general public have a notion that rail infrastructure development would lead to socio-economic benefits. This study also highlighted that an improvement in rail infrastructure is required, as well as the benefits that the existing rail service provides. The stakeholders had the view that new innovative ways to fund infrastructure efforts are required. Quality of life implications and public safety must also be considered while planning the project. Also, higher investment in other modes of transportation was perceived as an obstacle for improving rail in Missouri.

2.2.4 Socio-technical Roadmapping

The fourth step is socio-technical roadmapping for the project. Roadmaps are developed based on the results from the above three steps. For a rail infrastructure project, various factors along with the associated instabilities are shown in the table 2 [22].

Table 2: Socio-technical factors and instabilities in the rail transportation system [22]

Factors	Instabilities
Organizational	• Extent of interaction • Willingness to communicate • Willingness to cooperate • Public private partnership • Willingness to enter into contractual agreements
User Needs	• Low cost • Accessibility • Spatial coverage • Environmentally friendly • Efficient • Convenient • Quality of life • Alternate mode of transport
Technologies	• Train control system • Train technology • Scheduling technology • Alternate energy • Loading and unloading technology • Information and communication technology
Infrastructure	• Capacity • Life • Infrastructure characteristics • Sustain growth • Intermodal facilities • Stations • Docks and yards
Investment/Financial	• Existing methods • Future opportunities

	• Public private partnerships • Innovative approaches
Performance Measures	• Sustainability indicators • Performance evaluators

The roadmap should align the visions and goals of the project. A roadmap can be made by setting an endpoint for the project. Six factors, as shown in table 2, were identified based on the above three steps and a socio-technical roadmap was developed for Missouri rail infrastructure project as shown in Figure 2 [22].

Figure 2. Socio-technical roadmap for a Missouri rail infrastructure development [22]

2.3 Socio-technical Analysis Conclusions

To implement a socio-technical framework in a transportation infrastructure system, identifying the social elements, technical elements, actors and the interactions between them are critical to the approach [4]. The actors in a project are the people and the agencies that are directly or indirectly involved in or affected by the project. In regards to Missouri rail infrastructure projects, the actors include MoDOT, Railroads, Federal Railroad Administration, land-owners, freight users, passenger users, etc. Factors such as quality of life, equality, economic considerations, accessibility, environmental concerns, cost, time, safety, etc. comprise the social factors. From the technical perspective, factors such as corridor characteristics, level of service, demand, tonnage hauled, and forecasted growth data can be included. Also, with advances in technology, changes in society are inevitable. With societal changes, the factors and their impact are also bound to change. Therefore, it is essential for policy makers and stakeholders to use a framework that not only accounts for the social and the technical elements, but also the changes with time. Such a framework is also required in the light of sustainable development, as traditional methods like cost benefit analysis become inadequate due to their inability to consider a broader societal approach.

An expert panel with rotating membership from each stakeholder group should be created to identify the social and technical factors so as to incorporate all the factors relevant to each segment. The historical data relevant to the specific project and the identified factors need to be collected. The three approaches, Leontief approach, Bayesian network approach and System Dynamics approach used in the subsequent sections have the ability to incorporate both the technical and non-technical elements of the transportation infrastructure system. The aforementioned approaches as described in the subsequent sections consider the social and technical elements of the project and also help in understanding the interdependencies between these factors.

3. Leontief-Based Approach

3.1 Literature Review

The Leontief input-output model was developed by Professor Wassily Leontief in the 1930s [24]. The model, originally applied to economic systems was based on the assumption that each type of industry had two types of demands, the internal demand and the external demand. It was assumed that each industry makes a homogenous product, and the input ratio for the production of an output is fixed for an industry i.e., the amount of output from one industry that would be used as an input in another industry was fixed. Based on these assumptions the economy model was depicted as a set of differential linear equations [24]. The Leontief input-output model studies the interdependencies among the various industries involved. It shows how the output from one industry affects another industry by acting as an input to that industry. This approach was initially developed to study the interdependencies between different sectors of the economy. The Leontief model can tell us about the productivity of an economy, i.e., it is possible to get the production based on the demand levels of an economy. The model uses a system of linear equations to get the desired output variables. A simple system of linear equations can be solved using matrix algebra. The Leontief model is of two types, the open type and the closed type. A closed economy model assumes that no goods enter or leave the economy. On the other hand, in an open system, an economy has to meet demands outside of itself, i.e., goods may enter or leave

the economy. Based on this approach, Leontief represents the world economy as a system of interdependent processes. He uses the input-output model to elucidate the world economy. He explains that an output for one sub-system would require a particular amount of input, which could be the output of some other sub-system and so on. Leontief divided the world economy into two parts, i.e., developed and less developed regions and further divides these into sub-systems. Using the Leontief approach provides a framework to organize and assemble data needed to describe the structure of world economy, and finally use of this model predicts the behavior of the economy in the future [25]. Due to its simplicity and systematic approach, the Leontief input-output model can be applied to systems other than economy models, such as infrastructure, risk management, etc. Farooq et al. [26] make use of the Leontief input-output model to study the impact of intelligent transportation system (ITS) on the economy of the state of Michigan. They incorporate the effects of ITS in the transportation industry and designed a model to study its effects. They calculate the growth correlation factor for each industry using the Leontief approach and use it in a RIMS II input-output table to calculate the economic impact of ITS on other industries. Using their model they find that ITS will help to increase the number of jobs for all industries and the output per dollar [26]. Haimes and Jiang [27] develop a Leontief-based infrastructure output-input model to study the interdependency between various critical infrastructures as well as the interconnectedness within each critical infrastructure. Through this model they also captured the risk of inoperability of various critical infrastructures due to failure of one or more of the critical infrastructures or due to some kind of natural disaster. The Leontief input-output model can be further extended into an inoperability input-output model (IIM). Yakov et al. [28] studied the IIM to study interdependencies, initial disruptions, and the resulting ripple effects. Santos [29] uses the Inoperability Input-output Model (IIM) that is based on Leontief's input-output model to study the ripple effects of disruptions on interdependent systems. By using the IIM model, Santos analyzes the effects of 9/11 on the demand for air transportation and its ripple effects on other sectors. This paper provides a framework to identify the primary sector that is most affected due to a catastrophe such as 9/11 and the ripple effects that such an adverse event has on other sectors which are economically interdependent with the primary sector. The model proposed in this paper can be applied to study the effect of any adverse event on the economy of a system by understanding the underlying interdependencies [29].

Wang [30] uses the Leontief input-output model to construct a framework for analyzing the relationship between industrial and transport structure. Wang based this study on China where the industry is divided into three sectors namely, primary industry, secondary industry and tertiary industry. The primary industry includes agriculture, forestry, animal husbandry, fishery and farming and their services, secondary industry includes mining, manufacturing, electric power, gas and water production and supply industry and construction industry, and tertiary industry includes all other industries except those included in the primary and secondary industries. The five modes of transportation are described as railway, highway, water transport, air transport and pipeline transport. Wang uses the Leontief approach to conclude that as the three industry sectors would develop there would be rise in the demand of railway, highway and water transportation modes for the secondary and tertiary industries which would lead to the development of the national economy [30]. Lin et al. [31] study the impact of earthquakes on the industrial chain in Taiwan. They simulate two earthquakes and study their impact using the Leontief input-output model. After studying the correlation between various industries, the authors are able to use the Leontief model to find out the effect of an earthquake on the different

sectors of the industry. They find that the losses due to one of the earthquake are much greater than the other as the former happens in an area where the infrastructure for manufacturing is located. Hence, the output value and the repercussion effects for the former earthquake are much higher than in the latter.

In the above references, the Leontief approach has been used to identify and study the interdependencies among various variables. This demonstrates that the Leontief approach is a versatile one and can be applied to a variety of different systems. Therefore, it can also be extended and applied to a railroad infrastructure investment project. As illustrated in equations (3.1)-(3.3) below, the vector Y is the output matrix, or the deliverables, and the vector X represents the input matrix. A is the matrix of multipliers. The multipliers are an indication of if and how the input variables affect the deliverables. The Leontief input-output model can be applied to transport infrastructure projects. The matrix A needs to be determined from historical data using multivariate statistical analysis. Once an estimate for the multipliers is achieved, different sets of input values can be used to calculate the deliverables in each case.

3.2 Model Description

The Leontief input/output model is a quantitative technique that develops a systematic method to study the equilibrium behavior of an economy [27]. In this approach, the system is divided into a number of subsystems and the interdependencies between various subsystems are explained through this model. This method can be used to study the functionality or operability of various subsystems during the changes in some other subsystem. A similar approach can be used for this project where the resources, profit and project could be considered as the various subsystems and their interdependencies can be modeled.

For this project, we can use the following mathematical notation,

$$Y = XA + \mathcal{E} \qquad (3.1)$$

Here Y is a 1 by m matrix containing the desired m deliverables/outputs for a project, X is a 1 by (n+1) matrix containing n inputs for the project, A is an (n+1) by m matrix containing the economic multipliers required to calculate the output and $\mathcal{E}$ is the vector of error. In X, a one in the first column is a multiplier of a constant term that would be used later to fit the model. Hence, an artificial variable $X_{0i} = 1$ has to be added.

Applying the above equation to the metrics of the project we get the equation,

$$[Y_1 \quad Y_2 \quad Y_3 \quad Y_4 \quad Y_5 \quad Y_6 \quad Y_7 \quad Y_8 \quad Y_9 \quad Y_{10} \quad Y_{11}] = [1 \quad X_{11} \quad X_{12}] * \begin{bmatrix} A_{01} & A_{02} & A_{03} & A_{04} & A_{05} & A_{06} & A_{07} & A_{08} & A_{09} & A_{010} & A_{011} \\ A_{11} & A_{12} & A_{13} & A_{14} & A_{15} & A_{16} & A_{17} & A_{18} & A_{19} & A_{110} & A_{111} \\ A_{21} & A_{22} & A_{23} & A_{24} & A_{25} & A_{26} & A_{27} & A_{28} & A_{29} & A_{210} & A_{211} \end{bmatrix} + [\varepsilon_1 \quad \varepsilon_2 \quad \varepsilon_3 \quad \varepsilon_4 \quad \varepsilon_5 \quad \varepsilon_6 \quad \varepsilon_7 \quad \varepsilon_8 \quad \varepsilon_9 \quad \varepsilon_{10} \quad \varepsilon_{11}] \qquad (3.2)$$

Table 3: Lists all the different variables used in equation (3.2).

Matrix Y	Matrix A			Matrix X
Y_1 -Number of Jobs Created	A_{01} - number of jobs created due to other factors	A_{11} - number of jobs created per $ invested	A_{21} - number of jobs created per person hired	X_1 – Amount of Money invested
Y_2 - Increase in Tax Revenue ($)	A_{02} - increase in tax revenue due to other factors	A_{12} - increase in tax revenue per $ invested	A_{22} - increase in tax revenue per person hired	
Y_3 - Increase in Local Business Revenue ($)	A_{03} - increase in local business revenue due to other factors	A_{13} - increase in local business revenue per $ invested	A_{23} - increase in local business revenue per person hired	
Y_4 - Increase in Utility Revenue ($)	A_{04} - increase in utilities revenue due to other factors	A_{14} - increase in utilities revenue per $ invested	A_{24} - increase in utilities revenue per person hired	
Y_5 - Decrease in Passenger's Travel Time (minutes/passenger)	A_{05} - decrease in travel time due to other factors	A_{15} - decrease in travel time per $ invested	A_{25} - decrease in travel time per person hired	
Y_6 - Decrease in Travel Cost for the Passengers ($/passenger)	A_{06} - decrease in travel cost due to other factors	A_{16} - decrease in travel cost per $ invested	A_{26} - decrease in travel cost per person hired	X_2 – Number of workers hired
Y_7 - Decrease in Costs Accumulated by Shippers ($)	A_{07} - decrease in costs accumulated by shippers due to other factors	A_{17} - decrease in costs accumulated by shippers per $ invested	A_{27} - decrease in costs accumulated by shippers per person hired	
Y_8 - Decrease in Costs Accumulated by Receivers ($)	A_{08} - decrease in costs accumulated by receivers due to other factors	A_{18} - decrease in costs accumulated by receivers per $ invested	A_{28} - decrease in costs accumulated by receivers per person hired	
Y_9 – Increase in corridor capacity (%)	A_{09} – increase in corridor capacity due to other factors	A_{19} – increase in corridor capacity per $ invested	A_{29} - increase in corridor capacity per person hired	
Y_{10} – Increase in level of service (%)	A_{010} – increase in level of service due to other factors	A_{110} - increase in level of service per $ invested	A_{210} - increase in level of service per person hired	
Y_{11} – Increase in Accessibility (%)	A_{011} – increase in accessibility due to other factors	A_{111} - increase in accessibility per $ invested	A_{211} - increase in accessibility per person hired	

3.3 Model Fitting

To fit the model, historical data for X and Y are required from similar projects. Using these data we can calculate the values of elements of matrix A.

Table 4: Data for fitting Leontief model

Project ID	Independent Variables (Inputs), X						Dependent Variables (Outputs), Y					
	X_1	X_2	…	X_j	…	X_n	Y_1	Y_2	…	Y_i	…	Y_m
1												
2												
…												
p				X_j^p						Y_i^p		
…												
k												

For instance as shown in Table 4, from the historical data of k similar projects, we have information about the output and input variables in equation (3.1). For k projects, equation (3.2) can be written as:

$$\begin{bmatrix} Y_{11} & \cdots & Y_{1m} \\ \vdots & \ddots & \vdots \\ Y_{k1} & \cdots & Y_{km} \end{bmatrix} = \begin{bmatrix} 1X_{11} & \cdots & X_{1n} \\ : \vdots & \ddots & \vdots \\ 1X_{k1} & \cdots & X_{kn} \end{bmatrix} * A + \begin{bmatrix} \varepsilon_{11} & \cdots & \varepsilon_{1m} \\ \vdots & \ddots & \vdots \\ \varepsilon_{k1} & \cdots & \varepsilon_{km} \end{bmatrix} \qquad (3.3)$$

Here, Y_{11} is the number of jobs created from the first project and Y_{k1} is the number of jobs created from the kth project. Similarly, X_{11} is the amount of money invested in the first project and X_{k1} is the amount of money invested in k^{th} project.

Equation (3.3) is a multivariate regression model and can be rewritten as:

$$Y_{(k \times m)} = X_{(k \times (n+1))} A_{((n+1) \times m)} + \varepsilon_{(k \times m)} \qquad (3.4)$$

The above regression model has the following assumptions:

1) $E(\varepsilon_i) = 0$ and,2) $Cov(\varepsilon_p, \varepsilon_q) = \sigma_{pq} I$ for all p,q =1, 2,…, m

Since the values for Y and X are available, multivariate regression can be done and matrix A can be calculated as follows:

$$A_{(i)} = (X'X)^{-1} X' Y_{(i)} \qquad (3.5)$$

The value of the multipliers, i.e. A can also be calculated using statistical software such as SAS. These multipliers can be used to fit the model. After fitting the model, goodness of fit, r^2, can be calculated to see how well the model fits. This can also be done using the statistical software SAS.

3.4 Numerical Example

Assume that we collected data from 10 similar projects in the history, shown in Table 5. Variables are defined in Table 3.

Table 5: Data for numerical example

Projects	INPUTS		OUPUTS										
	X_1	X_2	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	Y_9	Y_10	Y_11
1	10,000,000	40	46	200,000	800,000	20,000	30	20	15,000	17,000	0.16	0.20	0.10
2	15,000,000	48	54	270,000	1,200,000	30,000	45	30	22,000	24,000	0.24	0.30	0.15
3	5,000,000	24	31	70,000	400,000	10,000	15	10	6,000	8,000	0.08	0.10	0.05
4	8,000,000	30	37	85,0000	650,000	16,000	24	16	9,000	11,000	0.10	0.16	0.08
5	3,000,000	14	19	50,000	250,000	6,000	8	6	2,000	4,000	0.03	0.06	0.03
6	22,000,000	60	74	500,000	1,800,000	44,000	65	44	37,000	41,000	0.35	0.44	0.22
7	17,000,000	55	63	350,000	1,400,000	34,000	53	35	33,000	36,000	0.29	0.34	0.17
8	12,000,000	44	52	250,000	1,000,000	24,000	36	25	18,000	23,000	0.19	0.24	0.12
9	9,000,000	35	42	180,000	750,000	18,000	27	18	12,000	15,000	0.13	0.18	0.09
10	6,000,000	28	34	77,000	500,000	13,000	18	14	8,000	10,000	0.11	0.12	0.06

Using SAS (Appendix 8.2), the model was fitted and the results were obtained as shown in Table 6.

Table 6: Model fitting results (Matrix A)

A01 = 6.982274447	A11= 0.000000934	A21= 0.746586559
A02 = -6845.913829	A12= 0.017725	A22= 930.941896
A03 = -1268.007701	A13= 0.081066	A23= 234.385949
A04 = 63.40038505	A14= 0.00194669	A24= 16.05848031
A05 = -2.372634933	A15= 0.000002630	A25= 0.167629290
A06 = -.6845913829	A16= 0.0000017725	A26= 0.0930941896
A07 = -6187.213702	A17= 0.001587	A27= 143.098984
A08 = -5024.297949	A18= 0.001595	A28= 181.338379
A09 = -.0378311093	A19 = 0.0000000119	A29 = 0.0020874549
A010 = -8.04912E-16	A110 = 2E-8	A210 = 6.134247E-17
A011 = -4.02456E-16	A111 = 1E-8	A211 = 3.067123E-17

This fitted model can now be applied in equation 3.2. To check the goodness of fit of the model, the value of R-square for the model can be seen in the SAS results.

Now, this fitted model can be used to find the output of the model. Suppose the inputs are as follows:

Amount of money invested = $28 million; Manpower hired = 235 people

Substituting the values of input in the fitted model, output is calculated as shown in the table below.

Table 7: Outputs for the numerical example

Y_1 -Number of Jobs Created	209
Y_2 - Increase in Tax Revenue ($)	708225.43
Y_3 - Increase in Local Business Revenue ($)	2323660.7
Y_4 - Increase in Utility Revenue ($)	58344.463
Y_5 - Decrease in Passenger's Travel Time (minutes/passenger)	110.66025
Y_6 - Decrease in Travel Cost for the Passengers ($/passenger)	70.822543
Y_7 - Decrease in Costs Accumulated by Shippers ($)	71877.048
Y_8 - Decrease in Costs Accumulated by Receivers ($)	82250.221
Y_9 – Increase in corridor capacity (%)	79%
Y_{10} – Increase in Level of Service (%)	56%
Y_{11} – Increase in Accessibility (%)	28%

So, in this hypothetical case, the railroad infrastructure investment of $28 million yielded 235 temporary jobs hired for the construction and 209 new jobs due solely to the project – which include jobs directly related to the project and secondary jobs that support those new jobs directly related to the project (note from Table 3 Matrix A that we distinguish between jobs created by other factors and jobs created by the project). These secondary jobs would not have occurred had the project not been completed and the direct jobs created. In addition, there is an increase in tax revenues of $708,225.43 due to this project and so on. Thus, from a policy-making perspective, this model could be used to analyze alternative investment scenarios to assist in deciding which projects yield the greatest return along the various outcome dimensions. Clearly, as with any tool, tradeoff judgments will still be required regarding which outcomes are more desired, e.g., increases in business revenue vs increases in accessibility because it is unlikely that any two or more projects will yield the same improvements for all dependent variables.

Hence, for the Leontief-based approach, historical data from similar projects are needed. Once the data have been collected and organized in the format discussed above, a multivariate regression analysis needs to be done to estimate the parameters. Parameter estimation can be done using statistical software such as SAS. The code needed to perform multivariate regression analysis for parameter estimation is mentioned in appendix 8.2. Once parameters are estimated, the only unknown variables that remain are the output variables (matrix Y). The value of parameters (matrix A) and the input variables (matrix X) can then be substituted in equation (3.2) and the output can be calculated. Equation (3.2) can be easily modeled in Microsoft Excel (Appendix 8.4) to calculate the output. Policy makers can use the results obtained from this model to support the decision making process.

4. Bayesian Approach

4.1 Bayesian Networks

A Bayesian network model is a probabilistic graphical model that represents the probabilistic relations between variables dependent on each other. It is a multi-objective evaluation method and is very useful when decision criteria are to be established. A Bayesian network is a decision network that systematically and logically joins the decision items to the objective functions via some evaluation criteria. They enable an effective representation and computation of the joint probability distribution (JPD) over a set of random variables [32]. Bayesian network models enable decision-makers to eliminate suboptimal solutions to arrive at the most profitable investment option in the socio-technical framework [33]. Correctly establishing a Bayesian network is critical to this method.

This approach finds applicability in the field of economics, engineering, and bioinformatics, etc. [34]. Bayesian network methods have also been applied to supply chain problems. According to Arasteh, Aliahmadi and Omran, [35] all businesses involve management of goods, funds and information that move through the supply chain. This makes the whole system complex and dynamic with interconnectedness among various parts of the business. The use of Bayesian network models can help identify strategies to reduce or eliminate the effect of disruptions that might occur in a business, thereby increasing overall reliability [35]. Luoto et al. [36] used Finnish data to study the effect of investment in infrastructure on the economy and conclude that investing in infrastructure has a strong positive effect on output growth over the long run. Xiaocong and Ling [37] established a risk management decision support system using a Bayesian network approach that is effective for intuitive and real time decision-making in risk management. They have used the Bayesian technique to identify the causes of risk and analyze the factors that cause the risk in a simple, probabilistic, independent and easily recognizable way. Their model helps study the effect on the project due to a sudden risk event and allows decisions to be taken to manage the risks. Zhu et al. [38] use Bayesian networks to construct an intersection safety evaluation index system. They make use of experts' opinions to quantify various qualitative variables involved. They ask for index values from different experts for a similar situation and then aggregate the experts' opinions using Bayesian network analysis. Zhu et al. divide the safety level of the intersection into five levels and test their model to diagnose and analyze the safety at an intersection even without the presence of any accident statistical data. They also develop a methodology to obtain indices for some other variables even without certain experts' opinion. Jha [39] makes use of the Bayesian approach to predict the likelihood of terrorist attacks at critical infrastructure facilities. Using dynamic Bayesian networks, Jha develops a reliable prediction model and analyzes the relevance of available intelligence to develop a terrorist attack prediction model. Cho et al. [40] develop a probabilistic model to predict infrastructure maintenance using Bayesian network analysis. This model helps to predict the damage that would occur and the maintenance budget that would be required for bridge components. Through this model they have developed a mechanism to predict the future performance of the infrastructure and the budget that would be required to maintain such complex infrastructures [40].

The Bayesian network is a directed acyclic graph that consists of two sets: set of nodes, and a set of directed edges. The edges represent direct dependencies between the nodes and are drawn by arrows between them [41]. The nodes are connected according to the reasoning direction of

decision makers [42]. The relationship between each pair of connected nodes is expressed in the form of probability distribution that encapsulates the decision makers' experience [42].

The nodes involved can further be divided into three sets: decision nodes, evaluation nodes and objective nodes, representing the decision items, evaluation criteria and objective functions, respectively. The decision items and objective functions are as defined previously in the introduction. Evaluation criteria are the connecting links between the decision items and objective functions. Evaluation criteria measure effectiveness of the decision in achieving the ultimate goal or objectives. The edges/arrows determine the parent nodes for each node. The parent node(s) for evaluation criteria will be from among the decision items, and the parent nodes for the objective functions from among the evaluation criteria. Figure 3, below shows a schematic Bayesian network diagram.

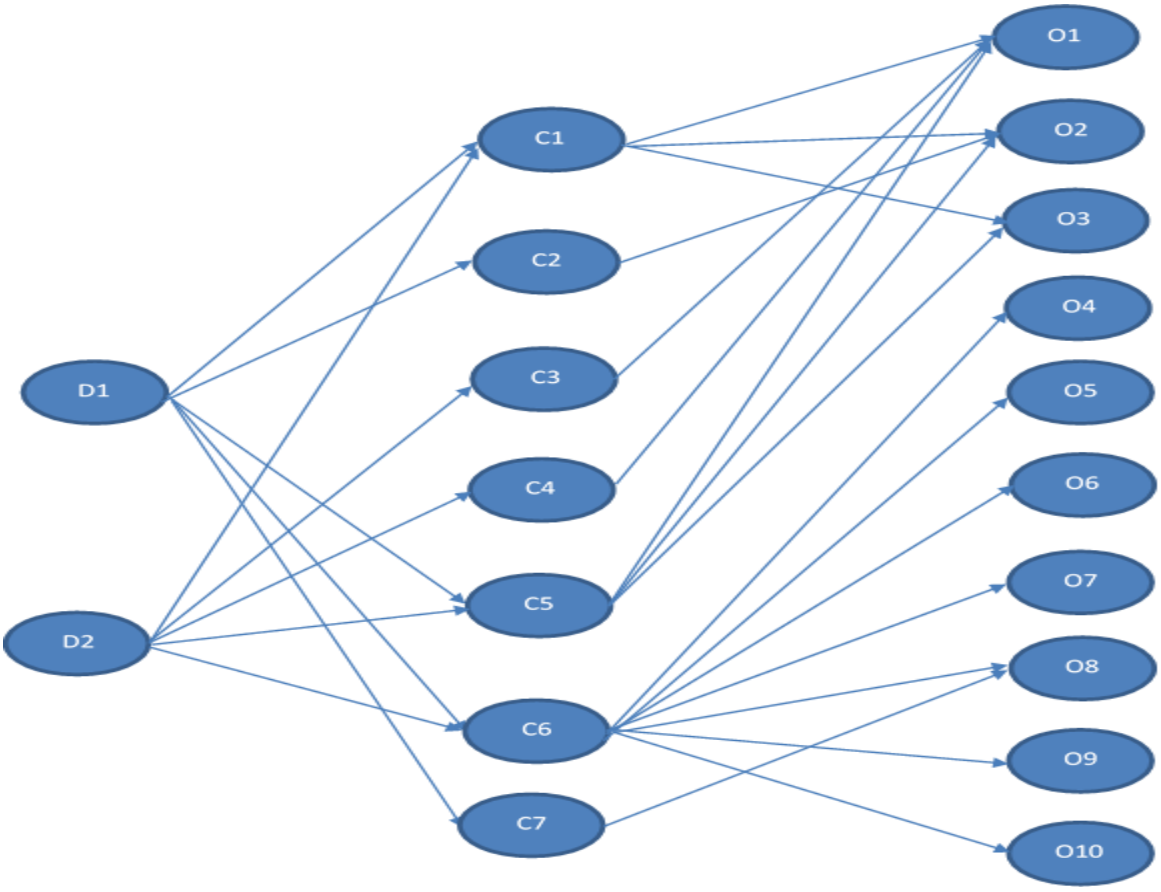

Figure 3: Bayesian network

The decision items are determined by the decision makers' experience or by conducting a survey among a panel of experts and selecting the highest rated items. The expert panel is chosen in a way so as to include knowledgeable experienced people from all the stakeholder groups affected by the project [47]. The expert panel must be carefully chosen to include people that acknowledge the diversity of the socio-technical elements involved. Following the decision items, evaluation criteria are also selected in a similar manner. The objective functions are then put together with the other nodes to complete the network. The next step is to determine a set of values for each decision item. The possible values for the decision items are decided based on

the decision makers' experience and the resources available. A similar set of values for the evaluation criteria is determined. This set of values is based on the possible outcomes of a project and the way it will determine the ability of the decision items to help achieve the desired goal. For the objective functions, a rating scale is established on which the success of the project can be determined. This has also been shown in [43], that multi-objective decision making processes involve simultaneously making decisions on various items, achieving a trade-off among probabilistically dependent items, and also to provide enough knowledge to build a realistic model. Beck and Katafygiotis [44] provide a Bayesian framework that can be used to update a model [44]. They argue that by using their proposed model more accurate response predictions can be made. According to them, a model containing a large number of data points with relatively small number of variables with uncertainty can be updated accurately using a Bayesian statistical technique. Predicting the deteriorating conditions of the bridge might not be accurate by just analyzing the inspection data as the methods used to measure data and the error in measurement are not taken into account [44]. Enright and Frangopol [45] predict the future of the bridges in a better way by making use of Bayesian techniques to incorporate engineering judgment along with the inspection data.

In figure 3 the arrow from D1 to C1 depicts the conditional probability (CPT) between the decision item d_1 and evaluation criteria c_1. The CPT relationship between each pair of connected nodes is expressed in the form of a probability distribution that contains the statistical information of the decision makers' experience [33]. The equations to calculate these conditional probabilities are given in equations (4.1) to (4.4), below. Finally a concluding decision can be made based on the optimum expected values of the objective variables [46]. Here, it is worth mentioning that the decision network varies according to the characteristics and requirements of each project and the associated objectives, and an expert panel and the decision network must be chosen accordingly [46].

Di Giorgio and Liberati [47] divide the Dynamic Bayesian Network in three levels, i.e., atomic events, propagation and services level, based on their relation with the various critical infrastructures. They also highlight three different types of analyses that can be performed on the resulting dynamic Bayesian network, i.e., reliability analysis, adverse events propagation analysis and failure prediction analysis. Xie and Ng [33] establish a framework to evaluate if the project is able to meet the interests of the key stakeholders. They make use of an example from a case study to determine which of the scenarios would be most suitable in a public-private partnership and identify and highlight the various factors that would be most critical for the success of the project and also to satisfy the stakeholders. Pang et al. [48] establish a framework on Economic Early Warning based on Bayesian network models to counter the effects of assumptions that are set, for example, the cause variable will only affect the effect variable and will not itself be affected by the effect variable. They use the Bayesian approach so as to consider the complex variables and the interdependencies between these variables to construct a cause and consequence diagram to overcome this problem. Dorner et al. [49] develop a multi-objective model using the Bayesian approach to analyze multiple objective functions using an already existing environmental model that has a single problem domain. This property of the Bayesian models is critical as most of the projects have multiple objective functions. All of these properties of Bayesian models lend themselves to analysis of transportation infrastructure investments, and more particularly, investments in railroad infrastructure, since as described previously in the discussion of the socio-technical framework, railroad infrastructure is clearly shown to have multiple stakeholders with multiple objectives.

4.2 Model Description

The Bayesian network model is a graphical method that makes use of probability to establish decision criteria. This approach helps to express the range of likelihood of outcomes and also as the investment process unfolds, improved estimates can be made. Thus, as more information becomes available decision-makers could make adjustments in their decisions. It can also help to study the extent to which a particular critical infrastructure could be affected through various factors and the effect on other critical infrastructures [47]. It helps to study three major aspects [47]:

- Reliability analysis – Helps to calculate the probability that a particular critical infrastructure will operate for a certain period of time without failure
- Adverse events propagation – Helps to evaluate the effect of adverse events on critical infrastructures. It also aims to control the situation and prevent further degradation
- Diagnosis – It helps establish a relationship between the failure of a specific critical infrastructure, its causes and its consequences

A similar approach can be used for this project to study the interdependencies by considering the metrics as various variables or nodes. The relationship between decision variables, evaluation criteria and the objective variables are depicted in the Bayesian network diagram (Figure 3).
The first step in this approach is to create a Bayesian Network. The variables selected in a Bayesian Network are mapped according to a certain criteria. Normally, there are three types of variables that are used to form a Bayesian Network. These are the decision items, evaluation criteria and the objective functions [33].

Decision items are the variables, mainly the inputs, on which a decision has to be taken, evaluation criteria are those variables that help to evaluate the decisions taken, and finally, the objective function consists of the variables that are the outputs or the expected deliverables from the project. Decision variables, evaluation criteria and objective variables are shown in the tables below. Evaluation criteria are the missing link between the decision variables and the objective functions. It is a way of analyzing the extent to which the decision variables are able to fulfill the desired objective functions. State policy regarding infrastructure can influence the amount of money being invested in a project. Favorable state and tax policies can encourage investment and give stakeholders more confidence in the project, thereby improving the chances of getting close to the acceptable/favorable values of the objective functions. Employment policy, population density and degree of urbanization play an important role in deciding the amount of money to be invested and the manpower hired. For instance, if the employment policy is favorable and if investing in infrastructure would lead to job creation, then the organization would be more inclined to invest in the region. Service requirement and accessibility are two criteria that would help investors decide if they would want to invest in a project or not. If investment in a project means increasing the level of service and accessibility, then more profits can be realized from such a project. The variables such as tax revenue generated and increase in local business revenue can be reclassified as satisfaction to the government sector. Decrease in shippers' and receivers' cost may be attributed to the satisfaction of the private sector and jobs created can be related to the satisfaction of the public sector.

The decision variables, evaluation criteria and objective variables are shown in the tables below.

Table 8: Decision variables

Node	Decision Variable	Decision State
D1	$ amount invested	Low: < 0.5 millions Moderate: 0.5~5millions High: > 5 millions
D2	# workers hired	Low: < 50 Moderate: 50 to 150 High: > 150

Table 9: Evaluation criteria

Node	Evaluation Criteria	Alternate States
C1	State policy regarding infrastructure investment	Favorable Unfavorable
C2	Tax policy	Favorable Unfavorable
C3	Employment policy	Favorable Unfavorable
C4	Population Density	Low Moderate High
C5	Degree of Urbanization	Low High
C6	Service Requirement	Low Moderate High
C7	Accessibility	Low Moderate High

Table 10: Objective variables

Node	Objective Variables	Alternate States
O1	#jobs created	Low Moderate High
O2	tax revenue generated	Low Moderate High
O3	Increase in utility revenue	Low Moderate High
O4	Decrease in passenger's travel time	Low High
O5	Decrease in shippers' cost	Low Moderate

		High
O6	Decrease in receivers' cost	Low Moderate High
O7	Local business revenue generated	Low Moderate High
O8	Decrease in travelling cost for passengers	Low Moderate High
O9	Level of Service	Low Moderate High
O10	Corridor Capacity	Low Moderate High

The next step is to decide on the alternate states for the decision items. These states need to be defined after completing expert surveys. For example, alternate states for the decision variables can be as follows:

Table 11: Alternate states for decision items*

Decision item	Alternate states
1. Amount of money invested (node D1)	Low: < $500,000 Moderate: $500,000 to $5,000,000 High: > $5,000,000
2. Number of workers hired (node D2)	Low: < 50 Moderate: 50 to 150 High: > 150

*The above values are arbitrary and are used just to provide an example. The value of the alternate states will differ from one organization to another.

Similarly, alternate states are set for the evaluation criteria and objective functions as well. A score is given to each state of the objective variable, as shown in Table 12.

Table 12: Alternate states of objective variable number of jobs created**

Objective variable	Alternate states	Score
Number of jobs created (node O1)	High: > 300 Moderate: 20-300 Low: < 20	10 5 1

**The values shown in table 12 are arbitrary and are used as an example. The value of the alternate states and the scores has to be decided after conducting an expert survey.

Conditional probability tables (CPT) can similarly be created for each pair of nodes.

Using the CPT, probability for a node X_o at a value x_o can be calculated as shown in equation 4.1

$$\Pr(x_0|x_p) = 1 - \prod_{i:Xi \in Xp}(1 - p_i) \qquad (4.1)$$

Where X_p are the parent nodes of node X_o, and p_i is the probability that X_o is true given that all the cause subset X_p is present.

For example, to calculate the conditional probability for node C1, for a given set of values for the input variables, D1 and D2, equation 4.1 can be used as:

$$\Pr(C_1=c_1|D_1=d_1; D_2=d_2) = 1-\{1-\Pr(C_1=c_1| D_1=d_1)\}* \{1-\Pr(C_1=c_1| D_2=d_2)\} \qquad (4.2)$$

Similarly, equation 4.1 can be used to calculate the conditional probabilities for the evaluation criteria variables and the objective variables. Once all the probabilities are calculated, the expected value of the objective function can be calculated. For example, for O_2 the objective value of the function can be calculated using the equation (4.3) and (4.4).

$$\Pr(O_2=o_2)= \sum_{c_1}\sum_{c_2} \Pr(O_2 = o_2|C_1 = c_1; C_2 = c_2) \qquad (4.3)$$

$$E(O_2) = \sum_{o_2} o_2 \Pr(O_2) \qquad (4.4)$$

The above procedure can be repeated to find the expected value of all the objective variables.

After calculating the objective values for different sets of values for the input variables, D1 and D2, solutions can be compared with each other to arrive at the best non-inferior solution.

4.3 Model Fitting

Once the alternate states for all the variables are defined, a conditional probability table, based on the expert poll, needs to be formulated for each pair of nodes. The survey/poll must be held among experts from all the stakeholder groups. For example, to assign conditional probabilities for the amount of money invested, node D1, and the state policy regarding investment in infrastructure and tax policy, node O1, a survey needs to be conducted and the experts should be asked for their opinions. The survey results from one such expert are as depicted in table 13.

Table 13: Rating of a decision item under a criterion

Decision Item	Evaluation criteria	
Amount of money to be invested (node D1)	State tax policy (node C1)	
	Unfavorable	Favorable
Low: < $500,000	x	
Moderate: $500,000 to $5,000,000		x
High: > $5,000,000		x

Once the opinion from the entire panel of experts is gathered, a conditional probability table is formulated. The table below shows an example of conditional probability table.

Table 14: Conditional probability table from node D1 to C1

Decision Item	Evaluation criteria	
Amount of money to be invested (node D1)	State tax policy (node C1)	
	Unfavorable	Favorable
Low: < $500,000	0.6	0.4
Moderate: $500,000 to $5,000,000	0.3	0.7
High: > $5,000,000	0	1

Table 14 shows that 60% people would invest a low amount if the tax policy is unfavorable and 40% people would invest a low amount of money only if the tax policy is favorable. For a moderate investment amount, 70% will invest only if the tax policies are favorable and only 30% would invest even if the tax policy is unfavorable and so on.

4.4 Numerical Example

Consider an example with two decision items, two evaluation criteria and two objective variables. Here the decision items are the amount of money invested and manpower hired. The variables for evaluation criteria are service quality and degree of urbanization, and the variables for objective function are number of jobs created and increase in tax revenue.

The amount of money that should be invested (node D1) can be evaluated based on the factors service requirement (node C1) and degree of urbanization (node C2). The number of workers to be hired (node D2) can be evaluated by the factor degree of urbanization (node C2). Further, depending upon the service requirement (node C1) achieved jobs (node O1) would be created and the tax revenue would increase (node O2). Also, degree of urbanization (node C2) would further have an impact on the number of jobs created (node O1). The above information is represented through a Bayesian network diagram.

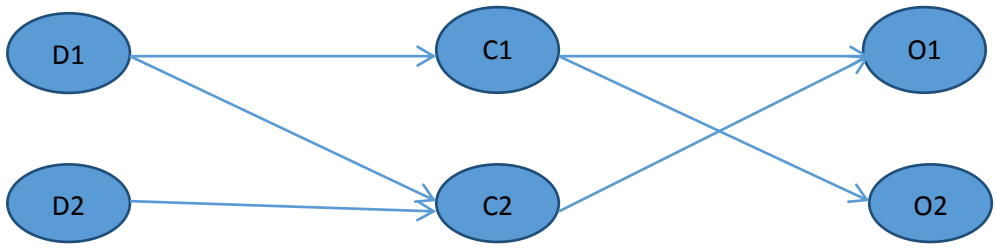

Figure 4: Bayesian network for the numerical example

The decision variables with their alternate states are described in the table below.

Table 15: Decision items

Decision items	Alternate states
1. Amount of money invested (Node D1)	Low: < $500,000 Moderate: $500,000 - $5,000,000 High: > $5,000,000
2. Manpower hired (Node D2)	Low: < 50 Moderate: 50 to 150 High: > 150

The evaluation criteria along with their alternate states are described in the table below.

Table 16: Evaluation criteria

Evaluation criteria	Alternate states
1. Service Requirement (Node C1)	Low Moderate High
2. Degree of urbanization (Node C2)	Low High

The objective variables with their alternate states are described in the table below.

Table 17: Objective variables

Objective variable	Alternate states
1. Number of jobs created (Node O1)	Low: < 50 Moderate: 50-250 High: > 250
2. Increase in tax revenue (Node O2)	Low Moderate High

After analyzing the alternate states for the variables, an expert survey has to be done to form the conditional probability tables (CPT). Suppose after conducting the survey and obtaining the results, the following CPT tables were obtained.

Table 18: CPT for amount of money invested and service requirement

Amount of Money Invested (node D1)	Service Requirement (node C1)		
	Low	Moderate	High
Low: < $500,000	0.9	0.1	0
Moderate: $500,000-$5,000,000	0.1	0.6	0.3
High: > $5,000,000	0	0.3	0.7

Table 19: CPT for amount of money invested and effect on degree of urbanization

Amount of Money Invested (node D1)	Degree of Urbanization (node C2)	
	Low	High
Low: < $500,000	0.9	0.1
Moderate: $500,000-$5,000,000	0.6	0.4
High: > $5,000,000	0.2	0.8

Table 20: CPT for manpower hired and degree of urbanization

Manpower Hired (node D2)	Degree of Urbanization (node C2)	
	Low	High
Low: < $500,000	0.9	0.1
Moderate: $500,000-$5,000,000	0.6	0.4
High: > $5,000,000	0.2	0.8

Table 21: CPT for service requirement and jobs created

Service Requirement (node C1)	Number of Jobs Created (node O1)		
	Low: < 50	Moderate: 50-250	High: > 250
Low	0.9	0.1	0
Moderate	0.2	0.6	0.2
High	0.1	0.1	0.8

Table 22: CPT for service requirement and increase in tax revenue

Service Requirement (node C1)	Increase in Tax Revenue (node O2)		
	Low	Moderate	High
Low	0.9	0.1	0
Moderate	0.1	0.6	0.3
High	0.1	0.7	0.2

Table 23: CPT for degree of urbanization and number of jobs created

Degree of Urbanization (node C2)	Number of Jobs Created (node O1)		
	Low: < 50	Moderate: 50-250	High: > 250
Low	0.8	0.2	0
High	0.1	0.3	0.6

Using the conditional probabilities, the probability for each variable depending on the states of the preceding variables can be calculated using the following formula:

$$\Pr(x_0|x_p) = 1 - \prod_{i:Xi \in Xp}(1 - p_i) \qquad (4.5)$$

Using the above formula, the probabilities are obtained as shown in the following tables.

Probability for the variable service quality (node C1) and increase in tax revenue (node O2) would be the same as their respective conditional probability tables as they have a single parent.

Table 24: Probability for degree of urbanization for all sets of decision items

Decision Items		Degree of Urbanization (node C2)	
Amount of Money Invested (node D1)	Manpower Hired (node D2)	Low	High
Low	Low	0.99	0.19
Low	Moderate	0.96	0.46
Low	High	0.92	0.82
Moderate	Low	0.96	0.46
Moderate	Moderate	0.84	0.64
Moderate	High	0.68	0.88
High	Low	0.92	0.82
High	Moderate	0.68	0.88
High	High	0.36	0.96

Table 25: Probability for number of jobs created for all sets of evaluation criteria variables

Evaluation Criteria		Number of Jobs Created node (O1)		
Service Requirement (node C1)	Degree of Urbanization (node C2)	Low: < 50	Moderate: 50-250	High: > 250
Low	Low	0.98	0.28	0
Low	High	0.91	0.37	0.6
Moderate	Low	0.84	0.68	0.2
Moderate	High	0.28	0.72	0.68
High	Low	0.82	0.28	0.8
High	High	0.19	0.37	0.92

Now, a rating scale is decided for the alternate states of the objective variables (ratings should be done by experts). The ratings for the alternate states of the objective function can be found in the following table.

Table 26: Rating scale for the objective variables

Objective variable	Alternate states	Rating Scale
1. Number of jobs created (node O1)	Low	1
	Moderate	5
	High	9
2. Increase in Tax Revenue (node O2)	Low	1
	Moderate	5
	High	9

After deciding the rating scales and calculating the combined probabilities for all decision states, the expected value for the objective function is calculated for each decision state. For instance, the expected value of the objective variable is calculated for the decision states when the inputs

are moderate amount of money invested and a high number of manpower hired. The expected value for the objective variables is calculated using equation (4.4).

E(Number of Jobs created) = Rating*Pr(Low Jobs Created) + Rating* Pr(Moderate Jobs Created) + Rating*(High Jobs Created)

Using the values from the conditional probability tables and the combined probability tables, the probabilities for each scenario can be found.

Pr(Low Jobs Created) = (0.98*0.68*0.1) + (0.91*0.88*0.1)+ (0.84*0.68*0.6) + (0.28*0.88*0.6)+ (0.82*0.68*0.3) + (0.19*0.88*0.3) = 0.855

Pr(Moderate Jobs Created) = (0.28*0.68*0.1) + (0.37*0.88*0.1)+ (0.68*0.68*0.6) + (0.72*0.88*0.6)+ (0.28*0.68*0.3) + (0.37*0.88*0.3) = 0.864

Pr(High Jobs Created) = (0.0*0.68*0.1) + (0.6*0.88*0.1)+ (0.2*0.68*0.6) + (0.68*0.88*0.6)+ (0.8*0.68*0.3) + (0.92*0.88*0.3) = 0.899

Hence, E(Number of Jobs Created) = 1*0.855 + 5*0.864 + 9*0.899 = 13.270

E(Increase in Tax Revenue) = Rating*Pr(Low Increase in Tax Revenue) + Rating* Pr(Moderate Increase in Tax Revenue) + Rating*(High Increase in Tax Revenue)

Pr(Low Increase in Tax Revenue) = (0.9*0.1) + (0.1*0.6) + (0.1*0.3) = 0.18

Pr(Moderate Increase in Tax Revenue) = (0.1*0.1) + (0.6*0.6) + (0.7*0.3) = 0.58

Pr(High Increase in Tax Revenue) = (0*0.1) + (0.3*0.6) + (0.2*0.3) = 0.24

Hence, E(Increase in Tax Revenue) = 1*0.18 + 5*0.58 + 9*0.24 = 5.24

So for the set of inputs, moderate amount of money invested and high manpower hired expected values for the objective variables are found as shown in the table below.

Table 27: Result for the numerical example

	Inputs		Expected value for the objective function	
	Amount of Money Invested (node D1)	Manpower Hired (node D2)	Number of Jobs Created (node O1)	Increase in Tax Revenue (node O2)
Alternate State	Moderate	High	13.270	5.24

Similarly, the expected value of the objective function can be calculated for each alternate state of the decision set. Based upon the expected values of the objective variables, a criterion is set by the experts and the best non-inferior solution is selected.

To summarize, quantitative results can be obtained using the above model that would help policy makers in their decision-making. This model, developed using Bayesian approach, can be used to quantify even qualitative variables. It is very crucial to form an appropriate panel of experts

consisting of members from each stakeholder group and conduct surveys. The results obtained from the surveys and interviews can then be used to calculate conditional probabilities for each set of decision states, and calculating the combined probabilities for each parent node. Expected values of objective variables for each combination of decision items can then be calculated. Microsoft Excel (Appendix 8.5) can be used to calculate the conditional probabilities and combined probabilities for each parent node, and finally calculating expected values for the objective variables. This methodology when modeled in MS Excel, acts as a tool to obtain direct results by just entering the data. Having gathered the data from the expert panel and using the gathered information in this model, policy makers can directly use the results obtained from this model to support the decision making process.

5. System Dynamics Approach

5.1 System Dynamics

System dynamics (SD) is a methodology to understand and analyze the dynamic nature of complex systems. This approach is normally used in systems where there are a large number of variables involved and there are complex relations between them. This approach makes use of qualitative and quantitative models to understand how the interdependent variables act in a system over time [50]. Feedback loops are used in a system dynamics model that makes this approach unique. A feedback loop is a loop connecting two or more variables such that a change in one variable would bring about a change in the other. Feedback loops are of two types, namely, positive and negative loops. Positive loops are also known as reinforcing loops which means that a change in the value of the variable in the loop would induce a similar change in the other variable, i.e., if one variable increases, then the other would also increase and vice-versa. In a negative loop, also known as a balancing loop, a change in one variable induces an opposite behavior in the other variable, i.e., if the value of one of the variable increases then the value of the other variable in the loop would decrease and vice-versa. The system dynamics approach can be divided into four stages [50]. The first stage, qualitative analysis, deals with recognizing the problem and identifying the metrics to study the problem. The second stage involves incorporating the identified metrics into a causal loop diagram (CLD). A causal loop diagram illustrates the relationship between the identified metrics or variables. A positive or negative sign is used on the arrowheads connecting the variables. A positive arrow means that a change in the variable at the tail of the arrow induces the same effect on the variable at the arrow head; a negative signs means a change in the variable at the tail of the arrow would induce an opposite effect on the variable at the head of the arrow. The third stage includes simulating the model and the fourth stage involves model testing. The system dynamics approach can be used to model simple linear systems as well as highly non-linear complex systems. This approach has a wide application in economic, ecological and population systems. One of the drawbacks of this model is that users tends to incorporate a lot of variables in the causal loop diagram, thus making it difficult to understand, difficult to metricize and computationally difficult.

According to Zhang et al. [51], any model can be divided into four subsystems or sectors, i.e. project, profit, resource and knowledge sectors. They also say that a project's success depends on its attribution to the strategic development of the enterprise, which can be predicted with the help of a system dynamics model. Due to the ease of applying this model to complex systems, system dynamics is widely used in economic, infrastructure, business processes and population systems

where a large number of interdependent variables are used. Causal loop diagrams are constructed to depict the relation between different variables. Alasad et al. [52] emphasize that for any project, the stakeholders are of paramount importance and expert knowledge and perceptions are key requirements to develop a realistic SD model. They provide a well-structured method to incorporate all the knowledge from the stakeholders for development of the stage.

According to Lyneis et al. [53], the highly non-linear nature of feedback systems involved in complex development projects is very difficult to manage using traditional tools such as critical path method (CPM) or program evaluation and review technique (PERT). But system dynamics models significantly improve the quality and performance of management on complex projects. An and Jeng [54] integrate the business process simulation model with the system dynamics approach which helps to evaluate and design the business process so as to optimize the process. They also point out that the business process simulation model can be used to study the deterministic behavior over a short span of time and the system dynamics model can be used to study the evolution of the business over a large time span. Zhu and Wang [55] have developed a system dynamics model which studies the different probable scenarios of economy-environment-resource system to find out the sustainability of the current development mode and substitution rate of technology for natural resources in Jiangxi, China. Such an approach can also be applied to transportation models to relate the economic and non-economic factors and study the overall effect of changes in infrastructure in a dynamic environment.

Sterman et al. [56] describe construction projects as extremely complex systems with multiple independent systems. They also explain that relationships between the sub-systems involved in such projects are highly non-linear and dynamic with multiple feedback processes involved requiring both quantitative and qualitative data. According to Sterman, the system dynamics approach is the best methodology to study such systems. Liu et al. [57] make use of the system dynamics approach to integrate transportation resources and increase the efficiency of capital use to promote economic development of the region [57]. They divide the system dynamics model into four subsystems: social-economic sub-system, demand sub-system, supply sub-system and investment sub-system. The gap between supply and demand is identified as the reason for the structural evolution of a transportation corridor. The supply/demand ratio is used to define the demand and supply of various demand nodes. They also identify that the growth in employment opportunities is affected by the degree of urbanization and investment in transportation infrastructure. They suggest that an increase in integrated transportation capacity and an increase in the urbanization ratio would lead to growth of the economy. Su et al. [58] use system dynamics as a supplement to discrete-event simulation to evaluate the unanticipated performance problems within the system of emergency medical services. They use a system dynamics model to account for the feedback effects caused due to human decisions. Also, a lot of complexity is involved while designing a simulation model for emergency response to a disaster and due to this complexity, a system dynamics model was used because of its ability to model complex systems effectively. Sha and Huang [59] study the complexity of the internal structure and operation mechanism of port operation system by developing a generic system dynamics model. They divide the whole subsystem into three subsystems namely time, quality and profit. They try to find effective solutions to solve the issues in a port operation system. Using system dynamics, they are able to study the changes that would occur if a certain factor is changed. They make use of the system dynamics model to guarantee the service time, improve quality time and reduce the cost of port service. Gui et al. [60] develop a system dynamics model to analyze an area logistics

system. They combine policy decisions with practical operations to provide a thorough understanding of the system mechanism. They emphasize the effectiveness of system dynamics methodology in modeling large complicated systems. They make use of the system dynamics model as this approach uses decision trees with cause and effect relationships that are very effective in analyzing social and economic systems. Sycamore and Collofello [61] integrate system dynamics modeling into a software tool for project management that would help to improve planning and tracking abilities of a project in terms of budget, schedule and rework hours. Here, the system dynamics model analyzes the dependencies among the project variables and the feedback loops that arise due to interdependencies among these variables. They conclude by saying that system dynamics modeling can be used to improve project management activities. Zheng et al. [62] study the interacting relations of aviation logistics and regional economy in Guangxi. These were addressed by China-ASEAN Free Trade Area Construction (CAFTA) through developing a system dynamics model. They argue that modern logistics plays an important role in developing a regional economy. A lot of factors, such as influence on infrastructure, foreign trade, regional logistics cost, growth rate of foreign trade, trade with other countries, etc., are involved in describing the relationship between logistics and economy and it is very difficult to explain these interdependencies and the cyclic nature of such factors using traditional methods. They make use of system dynamics to effectively describe the relation between these interacting factors to conclude that investment in aviation logistics and relevant industries is an effective way to promote the development of trade and economy. Zhao et al. [63] uses system dynamics approach to study the relationships between the main factors that influence the formation of logistics hubs. They divide the system into five subsystems namely, industry-policy subsystem, logistics park sub-system, population floating sub-system, logistics supply sub-system and logistics cost sub-system. Using the system dynamics approach, they identify the key factors that form the foundation of promoting regional logistics hubs formation. These works clearly demonstrate the wide application of system dynamics approach and the validity of the approach to address complex transportation infrastructure investment options.

5.2 Model Description

The system dynamics approach can be used to identify the major factors impacting project performance. According to this methodology, any system can be divided into four subsystems i.e., project, resources, profit and knowledge [55]. The subsystem - profit can be quantified using factors such as number of jobs created, increased revenues, etc. as metrics. To quantify resources, metrics such as investment amount, manpower and raw material required can be used. The last subsystem, i.e., knowledge, can be divided into implicit and tacit knowledge. The modeling process using the above approach can be divided into two parts, i.e., Qualitative System Dynamics and Quantitative System Dynamics [66]. The qualitative part, also known as model conceptualization, includes identifying the critical factors (metrics in this case), developing a framework of the model and finally creating Causal Loop Diagrams (CLD). After successfully identifying the metrics to be used in the model, a CLD was developed (Figure 5). The arrows specify the relation between variables, i.e., a change in the variable at the tail of the arrow will bring about a change in the variable at the arrowhead. The positive sign on the head of the arrow specifies that an increase in value of the variable at the tail of the arrow will cause an increase in the value of the variable at the arrowhead and vice-versa. A negative sign specifies that an increase in the value of the variable at the tail of the arrow will decrease the value of the variable at the arrowhead and vice-versa.

The causal loop diagram (CLD) in Figure 5 was made using the Vensim PLE software. The CLD shows that an increase in manpower hired would cause an increase in the number of jobs created, local business revenue, network efficiency, accessibility, service level and a decrease in the travel time. Also, increasing the manpower would cause a decrease in the costs accumulated by the shippers and the receivers. Investing more money would in turn increase the number of jobs, local business revenue, network efficiency, accessibility, service level, corridor capacity and a decrease in travel time and the shippers and receivers cost. An increase in the number of jobs would increase utility revenue and tax revenue. If utility revenue increases, this would lead to an increase in the tax revenue and local economic growth. An increase in the local business revenue would lead to an increase in the tax revenue and would also lead to local economic growth. More rail revenue would be generated if network efficiency, accessibility, service level, corridor capacity are increased and travel time and costs associated with shipping and receiving are reduced. Tax revenue would also be increased due to an increase in the rail revenue. Tax revenue and local economic growth form a reinforcing loop which means that an increase in tax revenue would lead to local economic growth and, local economic growth would lead to an increase in the tax revenue and so on. Local economic growth would attract more investments in the region and would generate new business opportunities that would further help in local economic growth. Local economic growth and national economic growth also form a reinforcing loop i.e., local economic growth would lead to national economic growth and national economic growth would in turn lead to local economic growth and so on. Depending on the type of the project and the variables involved, it might be the case that local economic growth does not lead to national economic growth and vice-versa, therefore, in such a case the multipliers/parameters that relate local and national economic growth may equal zero.

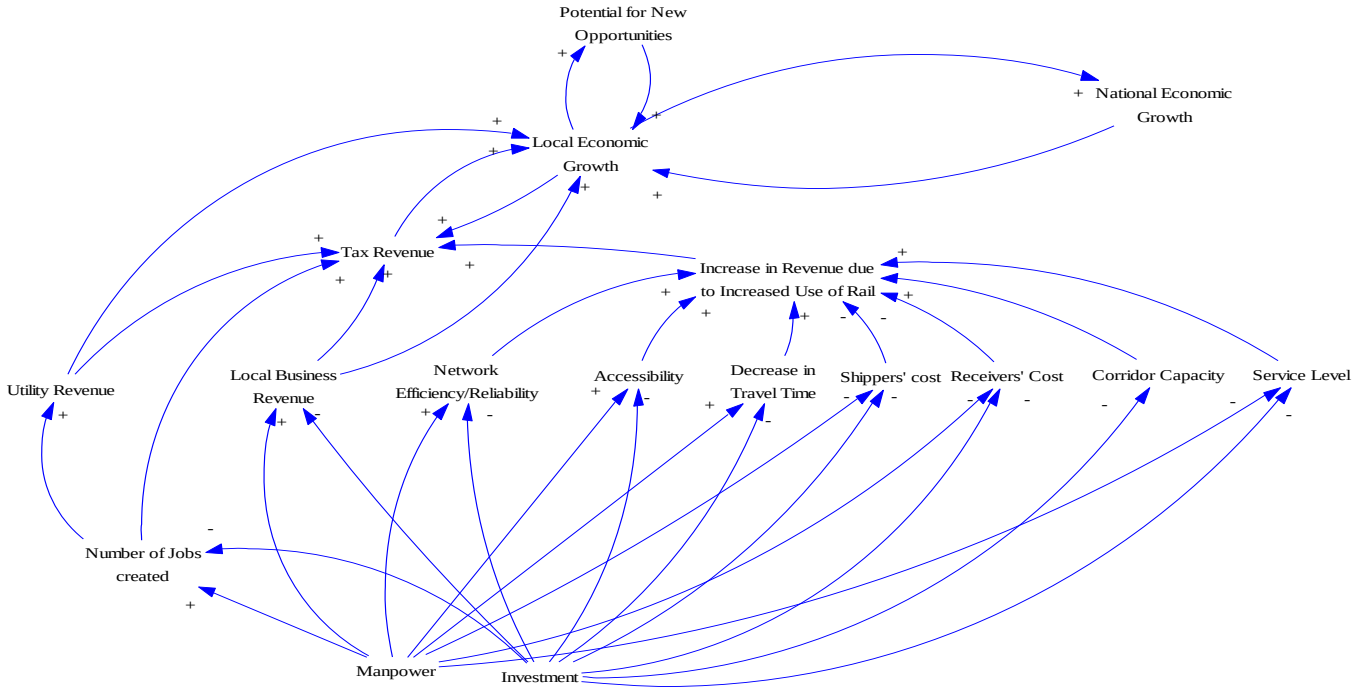

Figure 5: Causal loop diagram

After understanding the relation between various variables and putting those into a causal loop diagram, economic multipliers or parameter estimates are needed. These economic multipliers define the relation between two variables. Estimating the parameters is a controversial area and not easily accomplished. Extra care must be taken while estimating the parameters as experts might not agree with the parameters estimated using regression analysis or other techniques. The parameters must be estimated by incorporating the experts' opinions along with the historical data. The multipliers for this project are described in the table 27 below.

Table 28: Variables and multipliers used in the system dynamics approach

Relation Between	Parameter estimates
Money invested & Jobs created	Jobs created per $ invested (X1)
Manpower hired & Jobs created	Jobs created per person hired (X2)
Money invested &Local Business Revenue	Increase in local business revenue per $ invested (X3)
Manpower hired & Local Business Revenue	Increase in local business revenue per person hired (X4)
Money invested & Utility Revenue	Increase in utilities revenue per $ invested (X5)
Manpower hired & Utility Revenue	Increase in utilities revenue per person hired (X6)
Money invested & Network Efficiency	Increase in network efficiency per $ invested (X7)
Manpower hired & Network Efficiency	Increase in network efficiency per person hired (X8)
Money invested & Accessibility	Increase in accessibility per $ invested (X9)
Manpower hired & Accessibility	Increase in accessibility per person hired (X10)
Money invested & Decrease in Travel time	Decrease in Travel time per $ invested (X11)
Manpower hired & Decrease in Travel time	Decrease in Travel time per person hired (X12)
Money invested & Decrease in Shipping cost	Decrease in Shipping cost per $ invested (X13)
Manpower hired & Decrease in Shipping cost	Decrease in Shipping cost per person hired (X14)
Money invested & Decrease in Receiving cost	Decrease in Receiving cost per $ invested (X15)
Manpower hired & Decrease in Receiving cost	Decrease in Receivers' cost per person hired (X16)
Rail revenue & Network Efficiency	Increase in Rail revenue per % increase in Network Efficiency (X17)
Rail revenue & Accessibility	Increase in Rail revenue per % increase in Accessibility (X18)
Rail revenue & Decrease in Shipping Cost	Increase In Rail Revenue per $ decrease in Shipping cost (X19)
Rail revenue & Decrease in Receiving Cost	Increase In Rail Revenue per $ decrease in Receiving cost (X20)
Rail revenue & Decrease in Travel time	Increase in Rail revenue due to % decrease in travel time (X21)
Tax Revenue & Utility Revenue	Increase in Tax Revenue per $ increase in Utility Revenue (X22)
Tax Revenue & Local Business Revenue	Increase in Tax Revenue per $ increase in Local Business Revenue (X23)
Tax Revenue & Rail Revenue	Increase in Tax Revenue per $ increase in Rail Revenue (X24)
Local Economic Growth & Tax Revenue	Local Economic Growth per $ increase in Tax Revenue (X25)
Local Economic Growth & Local Business revenue	Local Economic Growth per $ increase in Local Business Revenue (X26)
Local Economic Growth & Rail Revenue	Local Economic Growth per $ increase in Rail Revenue (X27)
Local Economic Growth & Utility Revenue	Local Economic Growth per $ increase in Utility Revenue (X28)
New opportunities & Local Economy	New Opportunities per $ increase in Local Economy (X29)
National economy & Local Economy	National Economic Growth per $ Local Economic Growth (X30)
Money Invested & Corridor Capacity	Percentage increase in Corridor Capacity per $ invested (X31)
Money Invested & Service level	Percentage Increase in Service Level per $ invested (X32)
Manpower hired & Service Level	Percentage Increase in Service Level per person hired (X33)

5.3 Model Fitting

To estimate the parameters, data must be used from below the level of aggregation of the model, i.e., from expert surveys and interviews, engineering data and other sources that give a descriptive knowledge of the model rather than using the historical data that explain the aggregate behavior of the model [64]. As mentioned above, it is very important to incorporate expert's opinions along with the historical data for parameter estimation. To define the parameters for some of the variables, it might be best if experts estimate it based on their judgment and experience as historical data might yield some results that are not correct for the model. Also, the parameters estimated from historical data may not be valid for the project in hand depending upon the lifespan of the project, technological changes, etc. Therefore, a panel of experts must be set-up and results from surveys and interviews must be collected along with the historical data to get the right estimates. Once the parameters are estimated and the model is fitted, the goodness of fit of the model is calculated. The fitted model is now simulated over time beyond the period of fit. For good parameter estimation historical time-series data for the involved elements are required. These are important as system dynamics models are capable of predicting how the variables change over a period of time. The time period for which the data need to be collected depends upon the nature of the project and also on the nature of the variables involved.

Since this is a time-series model, parameter estimation can be done by using regression on fixed x's and lagged y's [53].

$$y_t + \alpha_1 y_{t-1} + \cdots + \alpha_p y_{t-p} = \beta_1 x_{1t} + \cdots + \beta_q x_{qt} + \varepsilon_t \quad (t = 1, \ldots, n) \qquad (5.1)$$

Where y_t is the output at time t, $\{x_{1t}\}$,…., $\{x_{qt}\}$ are the sequences of constants (inputs in this case), ε_t is the error term at time t, p is the time. Putting $y_{t-1} = x_{q+i,t}$ and $\alpha_i = -\beta_{q+I}$ (i=1,….,p) in equation (6.1), the model can be written as:

$$y_t = \beta_1 x_{1t} + \cdots + \beta_{q+p} x_{q+p,t} + \varepsilon_t \ (t = 1, \ldots, n) \qquad (5.2)$$

Equation (6.2) can be written in matrix notation as:

$$y = X\beta + \varepsilon \quad (5.3)$$

For every single dependent variable, linear regression can now be done to estimate the relationship between each set of a single dependent variable and one or more independent variables. For example, from the causal loop diagram (Figure 5), variable local business revenue is dependent upon investment and manpower. In equation (5.1), investment and manpower can act as inputs x_1 and x_2 respectively, and the variable local business revenue can act as an output, y_1, for these inputs. Now, x_1 and x_2 are constants and variable y_1 changes with time. Hence information for y_1 would be needed over a period of time and historical data for X and Y are required from similar projects. Using these data we can estimate the parameters β.

Table 29: Data for fitting system dynamics model

Project ID	Independent Variables (X)			Dependent variable at different times (Y_1)				
	X_1	……	X_1	Y_1 at t	Y_1 at t-1	….	…	Y_1 at t-p
1								
2								

…								
u								
…								
k								

Data for each sets of X and a single Y would be required and a linear regression analysis can be done to estimate the parameters. Data can be collected for each set of a single dependent variable and one or more independent variables and equation (5.3) can be rewritten as:

$$\begin{bmatrix} y_t^1 \\ \vdots \\ y_t^k \end{bmatrix} = \begin{bmatrix} 1 & x_{11} & \cdots & x_{1\,q+p} \\ \vdots & \vdots & \ddots & \vdots \\ 1 & x_{k1} & \cdots & x_{k\,q+p} \end{bmatrix} \begin{bmatrix} \beta_0 \\ \vdots \\ \beta_{q+p} \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \vdots \\ \varepsilon_n \end{bmatrix} \qquad (5.4)$$

Here y^k_t is the value of the dependent variable at time t from the kth project and X_{k1} is the value of the independent variable X_1 from the kth project.

Equation (5.3) is a classical linear regression model.

$$Y_{(k\times 1)} = X_{(k\times(q+p+1))}\beta_{((q+p+1)\times 1)} + \varepsilon_{(k\times 1)} \qquad (5.5)$$

The above regression model has the following assumptions:-

1. $E(\varepsilon) = 0$; and

2. $Cov(\varepsilon) = E(\varepsilon\,\varepsilon') = \boldsymbol{\sigma}^2 I$.

The values of X and Y can be used from the historical data and the parameter β can be estimated as follows:

$$\beta = (X'X)^{-1}X'y \qquad (5.6)$$

The parameters can also be estimated by using statistical software such as SAS. After fitting the model, goodness of fit can be tested by calculating coefficient of determination, r^2. This result is also obtained using statistical software.

5.4 Numerical Example

A part (highlighted in red) of the causal loop diagram (Figure 6) is used to illustrate model fitting.

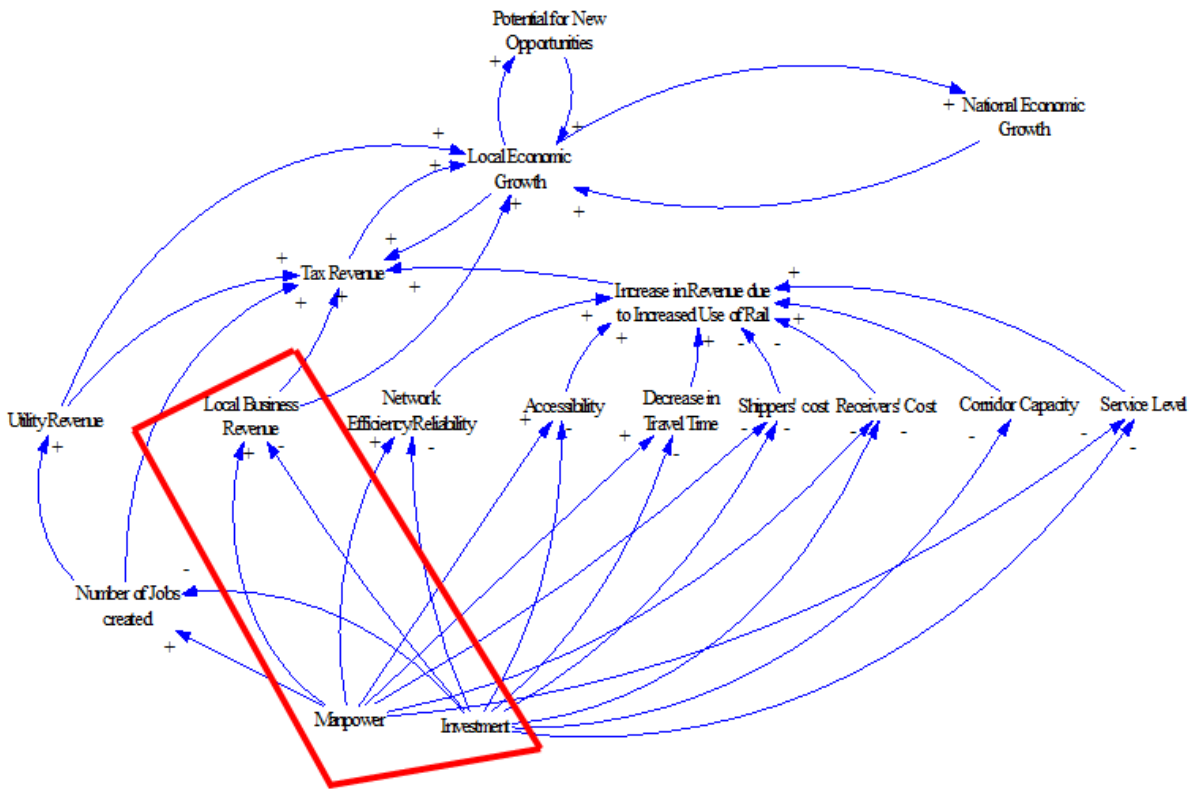

Figure 6: Causal loop diagram for numerical example

Assume that data were collected from 6 similar projects in history, shown in table 29. Here X_1 is the money invested, X_2 is the manpower hired and Y_1 is the increase in local business revenue at time t for 5 time periods. X_1 and X_2 are constants for each project and the output, Y is dynamic, i.e., keeps changing with time.

Table 30: Data for numerical example

Project ID	Independent Variable		Dependent variable at different times				
	X_1	X_2	Y_1 at t	Y_1 at t-1	Y_1 at t-2	Y_1 at t-3	Y_1 at t-4
1	10,000,000	40	300,000	265,000	215,000	145,000	100,000
2	15,000,000	48	400,000	350,000	275,000	225,000	175,000
3	5,000,000	24	180,000	140,000	110,000	80,000	55,000
4	8,000,000	30	250,000	210,000	175,000	115,000	90,000
5	17,000,000	55	450,000	385,000	325,000	260,000	210,000
6	22,000,000	60	700,000	650,000	585,000	520,000	475,000

Using the transformations from equation (5.1) and (5.2), the data from table 29 can be used in equation (5.3) as:

$$\begin{bmatrix} 300\,k \\ 400k \\ 180k \\ 250k \\ 450k \\ 700k \end{bmatrix} = \begin{bmatrix} 1 & 10{,}000k & 40 & 265\,k & 215k & 145k & 100k \\ 1 & 15{,}000k & 48 & 350\,k & 275k & 225k & 175k \\ 1 & 5{,}000k & 24 & 140\,k & 110k & 80k & 55k \\ 1 & 8{,}000k & 30 & 210\,k & 175k & 115k & 90k \\ 1 & 17{,}000k & 55 & 385\,k & 325k & 260k & 210k \\ 1 & 22{,}000k & 60 & 650\,k & 585k & 520k & 475k \end{bmatrix} \times \begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \\ \beta_3 \\ \beta_4 \\ \beta_5 \\ \beta_6 \end{bmatrix} + \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \\ \varepsilon_4 \\ \varepsilon_5 \\ \varepsilon_6 \end{bmatrix}$$

Using SAS (Appendix 8.6 and 8.7) the following results for the parameters can be obtained.

Table 31: Model fitting results (Matrix β)

$\beta_0 =$	50048
$\beta_1 =$	0.00805
$\beta_2 =$	149.07649
$\beta_3 =$	0.20684
$\beta_4 =$	0.32381
$\beta_5 =$	0.26919
$\beta_6 =$	0

The fitted model can now be applied to equation (5.3).

From SAS results (Appendix 8.7), coefficient determination, r-square is equal to 1, which means the fitted model explains all variability.

Finally, the model developed using system dynamics approach provides information about how the output would change with time. Historical data along with experts' opinions can be used to estimate the parameters for this model. Estimation of parameters can be done using statistical software SAS. Once the parameters are estimated, the above method can then be modeled in MS Excel or system dynamics software VENSIM and results for the outputs can be obtained. Policy makers can easily use these results to get information to support their decision-making.

6. Conclusions

Determining the long-term benefits and costs of rail infrastructure projects is a complex process that involves addressing both economic and social factors that frequently change over the full lifecycle of these projects. Historically, and in current day practice, attempts to assess possible investment scenarios for such projects have relied upon benefit-cost analyses. It has been shown that these analytical frameworks are too limited to provide policymakers and decision-makers with adequate understandings of the tradeoffs that must be made across the multitude of social and economic factors of infrastructure investments that often have a lifecycle of 50 to 100 years. The reasons the traditional benefit-cost methods are inadequate is that these situations require multi-criteria decision making under conditions of uncertainty. In short, these types of

investment decisions are not reducible to single rates of return or simple ratios derivable in traditional benefit-cost analyses. Thus, this research project identified methods and tools that better address these tradeoffs such that Missouri policymakers and decision-makers can make better informed decisions regarding rail infrastructure investments in Missouri.

Usually, any transportation project's performance is evaluated on the basis of technological elements. Non-technical elements are rarely studied to evaluate the system performance. It is very important to view any transportation infrastructure project from a technical as well as a non-technical viewpoint as the overall performance of the system is impacted by both social and technical elements.

To this end, this research project uses sociotechnical roadmapping to identify methods and tools to better quantify the economic benefits of rail infrastructure projects in Missouri. The social and technical elements identified through socio-technical analysis are evaluated using three distinct models: Leontief, Bayesian and Systems Dynamics. These three model frameworks provide analytical tools for capturing complex interplays of multitudes of relevant social and economic factors impacting, and impacted by, railroad infrastructure investments. Further, the modeling frameworks offer a means for MoDOT to bring analytical rigor and stakeholder input into current statewide transportation planning and into the state rail planning processes.

Going forward, MoDOT should adopt a socio-technical roadmapping approach to provide a visual framework that represents a plan of action for rail infrastructure projects. To use this approach, a socio-technical analysis is done to determine the technical and non-technical elements of the system. A socio-technical framework is developed to help decision makers understand the relationships and interactions between the various elements and encourage them to view the transportation infrastructure investment from a socio-technical viewpoint.

From the Missouri rail infrastructure project example, it is clear that the transportation infrastructure is a socio-technical system. It involves various stakeholders and actors who interact with the technical elements. The social elements consist of the actors and actor groups, and the interactions of actor and actor groups with other technical elements. The social and technical factors identified are shown in the table below. [22]

Table 32: Socio-technical factors [22]

Elements	Factors
Technical	Level of service Demand Corridor/track characteristics Tonnage hauled Forecasted growth data

Actors	MoDOT Railroads Federal Railroad Administration Amtrak State government Elected officials City Land owners Conservationists Other freight modes Other passenger modes Freight users Passenger users
Social	Quality of life Equality Economic considerations Accessibility Environmental concerns Cost Time Safety Affordability

Results from sustainability analysis show that the distance between the governing agencies and the target clientele represents a huge gap in the transportation planning and sustainable development. Also, improvement of rail infrastructure is necessary to maintain existing rail service and to promote future growth. From the uncertainty analysis conducted for previous work, as well as for this project, it is clear that the relationship between stakeholders and their willingness to cooperate and share information is very important to develop successful strategies for technology, infrastructure, and investment improvement and implementation. The

instabilities identified are used as a base to develop the roadmap for analysis of rail infrastructure projects. The results from the uncertainty analysis indicate that the gaps in the system were both from a technical as well as a planning perspective. The factors and instabilities identified were used to form a socio-technical roadmap. The roadmapping technique was used to develop the relationships between public and private entities while keeping other stakeholders and actors in mind to mitigate the instabilities and bridge the gaps between transportation planning and sustainable development. The roadmap also integrates the sustainable development practices in its framework. [22]

Building on the social and technical elements associated with Missouri rail infrastructure identified previously [22], this project identified three different approaches, namely Leontief approach, Bayesian approach and System Dynamics approach, to develop mathematical models for the system including the socio-technical elements.

The social and technical elements identified through socio-technical analysis were modeled using Leontief approach. The model was fitted via multivariate regression. The Leontief-based approach is the simplest of the three approaches if historical data of similar projects are available. Not only does it involve a simple system of linear equations, but it can easily be applied in the absence of reliable multipliers. Historical data on input and output variables can be used to arrive at fairly good multipliers that can be further used to calculate the project deliverables. One simplifying assumption used in this approach is that relationships between the various factors are linear. This method is fairly easy to use. The interdependencies among the various technical and non-technical elements can be studied using this framework.

In the Bayesian approach, social and technical factors are divided into three sets of variables, i.e., decision variables, evaluation criteria and objective variables. The framework developed here helps to understand the relationships between various socio-technical factors and studies the effects on the output variables when different sets of decision variables are considered. For this approach, it is very important to form a panel of experts and also conduct surveys to gather data for the approach. The expert panel must contain individuals from each stakeholder group. The entire data gathering approach, including the important design variables that affect the process, is subjective, and hence without careful consideration there is scope for large errors. Getting experts' opinion can be a tedious and expensive process and sometimes experts are not available for some stakeholder groups and there is a risk of gathering misleading data. It is extremely important to have the appropriate number of experts from all the different subsystems to have reliable data. If the data are unreliable, there may be significant variation, especially when applied to the future distributions of variables. Also, solving a Bayesian network can be complex and many decision-makers find it hard to use. The major advantage of Bayesian approach is that it is suitable for small data sets as the missing data can be filled using expert opinions. Also, due to the probabilistic nature of data, this technique allows for estimation of risk [67]. The Bayesian method provides a sophisticated approach to analyze the impact of modification in the rail infrastructure. It has the ability to combine prior knowledge based on causal forms and observed data to predict the impact. Even in the case of missing data, it can be used to study the causal relationships and gain a better understanding of different problem domains. Based on previous data values, a Bayesian network can be used to predict future events as well [65], [45]. Bayesian frameworks provide decision makers with a range of likelihoods of outcomes and also allow for improved estimates as more information becomes available as the investment process unfolds.

Hence, decision makers can make adjustments in their decisions as additional information appears.

The third approach described in this report is the System Dynamics approach that takes into account all the socio-technical factors and the relationships between these factors. This approach provides a good framework to begin with, but during the process of defining the equations and analyzing it quantitatively the model gets complex to solve. The causal loop diagram for Missouri rail project is represented in Figure 5 in this report. The CLD provides a good framework to visually represent the interactions between various elements. The correlation between various elements should not be confused with causality as this may lead to terrible misjudgments and policy errors [68]. Moreover, extra care must be taken while considering causal relationships in the model even if the correlation is strong or even if the coefficients in a regression are highly significant as this may lead to misleading results which is why incorporating the experts' opinions and the results from surveys are critical in understanding the causal relationship. The System Dynamics approach looks at the time series of each of the variables involved. However, in the absence of good multipliers, the equations used to solve the dynamic model can be highly unreliable. In the absence of numerical data, judgmental estimates can be made based on the available information and which can be later validated by doing a sensitivity analysis. To estimate the parameters in system dynamics approach, engineering data are required and expert interviews and surveys need to be done which might turn out to be a tedious and an expensive process. Finally it can be said that the system dynamics approach is a fairly straightforward and easy method for developing a visual framework to study the interactions and interdependencies between various elements, but quantitative analysis using this approach can become very complex.

The following table compares the three approaches used to model the socio-technical factors for rail infrastructure investment process.

Table 33: Model Comparisons

Criteria for comparison	Leontief Approach	Bayesian Approach	System Dynamics Approach
Data Availability	Historical data are required to solve the method	Can be used even when small data sets are available	Time-series data are required in this approach
Parameter Estimation	Estimated from historical data using regression analysis	Estimated after conducting expert interviews and surveys	Estimated from expert opinions, surveys and engineering data using regression analysis
Relevance to Railroad Infrastructure Investment	Highly relevant	Highly relevant	Highly relevant
Ease of Application	Straightforward method and easy to use	Easy to apply given the availability of expert opinions	Qualitative analysis is straightforward and easy, but quantitative analysis may get very complicated

In the near-term, if the relevant historic data are readily available; Leontief models will provide the most robust solutions. However, if these data are difficult to find or compile in useful formats, the Bayesian approach should be substituted for near-term analysis. The development of Bayesian models for use in analyzing possible investment strategies associated with rail infrastructure in Missouri represents the first step in a long-term MoDOT program for systematic analyses for informing policy decision-making and programmatic direction. In addition to developing this capability, the development of mechanisms for regularly obtaining economic, demographic, attitudinal and other data should be initiated to create the option of developing Leontief models. Further, to establish the capability for addressing the long-term variability in socio-economic factors that impact railroad infrastructure and economic development, additional modeling efforts based upon both Bayesian network models and System Dynamic models should be undertaken, including the development of stakeholder panels and regularly obtaining and maintaining economic, demographic, attitudinal and other relevant data sets for use in these models. This latter recommendation is consistent with Federal requirements regarding statewide transportation plans and metropolitan transportation plans (MTP) at the MPO level. Both the Bayesian and System Dynamic models provide analytical "hooks" for the inclusion of stakeholder input on a regular and systematic basis.

With regard to developing MoDOT data acquisition, storage, retrieval capabilities for undertaking systematic and ongoing analyses of infrastructure investment options, it is likely that data acquisition and sharing agreements will need to be developed with the various institutions in Missouri that currently gather and maintain some of the economic, demographic and other data on some sort of regular and systematic basis. These data sharing agreements represent an important component for MoDOT's future abilities to avail itself of the best in modeling and decision-making tools related to future transportation infrastructure investments.

Integral to the above approaches is the necessity to develop working partnerships with the railroad companies that operate in and through Missouri. One of the challenges that must be addressed in the formation of such partnerships is how to maintain the confidentiality of proprietary data while at the same time ensuring that the public welfare is at least protected and that long-term State policies and investments are beneficial to the citizens of Missouri.

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8 Appendices

8.1 Appendix 1A: Possible Metrics for Railroad Infrastructure Investment

BACKGROUND

As noted previously, existing U.S. railroad plans focus primarily on economic efficiency and are used for infrastructure assessments at a project level (Tuominen & Ahlqvist, 2010). While this assessment stresses the importance of economic impact and development, plans rarely include detailed analyses and metrics for conveying economic impact in meaningful ways to prospective stakeholders. A key part of this project is to identify possible metrics that can be incorporated into a socio-technical roadmapping process so as to convey, in stakeholder relevant terms, the economic impacts of investments in railroad infrastructure, equipment, communications and signals and real property (e.g., yards, shops, dispatch centers, etc.). Finally, it is important to identify metrics for which data are, or could be, readily and regularly acquired and analyzed.

To this last point, it is necessary to identify the likely data sources for both the investment side and the impact side (expected and actual impacts). In some instances, the data sources will be the same. In other cases, impact data will flow from quite different sources than investment data.

POTENTIAL INVESTMENT DATA SOURCES

Our focus in this project is on railroad infrastructure improvement investments, not maintenance investments, although the latter certainly have beneficial impacts in terms of maintaining safety, competitiveness, efficiency, etc. Railroad infrastructure investments are made by several different entitites, some private and some public, with an increasing role being played by public-private partnerships. On the private sector side, the most obvious and largest investors in railroad infrastructure are the railroads themselves. The Class I freight railroads far and away invest the greatest sums of money in railroad infrastructure (MoDOT recognizes six Class I railroads with a presence in Missouri). Short line and regional freight railroads also invest signifcantly in railroad infrastructure, although frequently there are public dollars flowing through these companies (MoDOT recognizes 13 Class II and III railroads in Missouri). On the passenger rail side, we distinguish between intercity service, provided by Amtrak, commuter rail service provided by transit authorities or contract operators (one in Missouri) and tourist train operations (four in Missouri). The latter are typically short line railroad companies that have tourist operations in conjunction with their freight operations. In the case of Amtrak, those infrastructure investment funds usually flow from public sources (typically federal and state, although occasionally local municipal funds may be directed toward some types of rail passenger infrastructure investments, e.g., station improvements). In some instances, public-private partnerships may be structured for rail passenger infrastructure improvements. Commuter rail operations are all publicly funded, although it could be possible to have public-private partnership investments in certain kinds of commuter facilities such as station improvements, etc.

The other set of investors in railroad infrastructure are industries that are significant users of rail freight service. These investments are typically associated with the provision of track, yard, loading and unloading facilities and equipment on the property of the particular enterprise. For smaller freight rail users, their investments will be sidetracks and appurtenances to bring rail

service to the property. With the exception of the switch and track on the serving railroad right-of-way, these improvements belong to the industry and must be maintained by them. In some instances, state DOT or local Economic Development Corporation (EDC) monies may be provided to the industry for these improvements as an incentive for the company to locate or expand facilities in that location.

Thus, in analyzing the total investments in railroad infrastructure improvements in any geographic area, all sources need to be identified and the monies for each type of improvement separated to ensure that appropriate relationships are identified with regard to expected impact and benefit streams.

POTENTIAL IMPACT DATA SOURCES

As mentioned previously, the data sources for the expected and actual impacts of railroad infrastructure investments may be the same sources as those having the investment data, both expected and actual. However, frequently, other data sources may be the best provider of actual impact data, particularly with regard to obtaining baseline data for determining the difference between exogenous impacts not directly attributable to the railroad investments and those attributable to the railroad investments. Regardless of the source, it is important the data are regularly collected and reported, the type of data collected and reported are consistent over time (very important in terms of ensuring that comparisons are meaningful) and the ease with which the data can be obtained remains non-burdensome both in terms of time and monetary resources. Ideally, the data releases are, or can be, automated. As will be discussed subsequently, all of the conditions are not currently met in terms of investment or impact data.

Class I railroads routinely announce the expected impacts of their infrastructure investments. Typically these are announced in an aggregate form, i.e., system-wide, but may also be available on a statewide level. If there are particularly large projects, such as large bridge improvements/replacements, large yard improvements/or additions, such as new intermodal facilities, fueling stations, etc., these projects and the expected impacts will be announced individually. The challenge will be in obtaining investment data on a sufficiently disaggregated level so as to be able to identify specific projects and specific expected benefits. To the extent Class I investments in infrastructure are directly related to economic development (each Class I has a department expressly devoted to bringing new freight traffic to the company through industry expansion or location), the type of investment and the expected number of jobs (direct, indirect, temporary and permanent) will be reported, frequently in press releases and through the local EDCs and sometimes through local political channels. These data reside within the appropriate Class I departments (typically labeled Industrial Development, Economic Development or Market Development) as well as within the Corporate Communications departments.

Short line and regional railroads generally do not have separate departments for the purpose of economic development. However, they do represent a significant part of the inbound and outbound rail freight traffic in the US (approximately 30%) and frequently are the actual railroad connection to new/expanding industries. To the extent that a Class I partnered with the short line or regional railroad, those projects will be reported by the Class I and possibly the short line or regional railroad. It is also common for state or local EDC monies to be expended for short line or regional railroad economic development projects. Thus, it is necessary to be sure the

investment and impact data are correctly identified and not duplicated. Again, the data will typically include expected jobs (direct, indirect, temporary and permanent) and dollars to be expended on the project.

Industry announcements regarding expanding or new facilities typically identify the proposed gross dollar investment and expected economic benefits to the community in terms of temporary and permanent new jobs, increased tax base and sometimes the multiplier effect of the project dollars in the community in terms of services and additional purchases made during construction. However, these announcements do not usually identify the railroad investment separate from the other investments. Whether these data can be obtained from an industry is likely to be on a case-by-case basis. Further, for larger industries and employers, in today's environment, there are almost always state and local Economic Development incentives that are proffered. These are sometimes in the form of tax rebate incentives, sometimes in the form of direct facility investment, for example, track and switch installation, or some other financial "carrot" such as training, etc. While these data are available from the state and local Economic Development agencies, they may not be in a form that is easily convertible into metrics that can be used to assess forecast and actualized benefits. However, over time, it should be feasible to develop reporting protocols such that relevant data from these agencies are captured and exported electronically.

State DOTs and MPOs frequently maintain databases regarding all infrastructure investments within their territories. Some DOTs and MPOs only track infrastructure investments that flow through the respective agency. Other DOTs and MPOs attempt to capture all proposed infrastructure investments. The level of disaggregation of the data is likely to vary depending upon the agency. In terms of pre- and post-investment data, the amount and quality of post-project impact data these agencies collect and report can vary quite substantially. It is probably safe to say that announced investment and impact data are significantly more likely to be captured and reported than post-investment impact data. This is particularly true with regard to baseline data pre- and post- project such that exogenous factors are filtered out of the data sets.

An example of the combination of investment sources and the expected outcomes is the announcement in 2011 of a major new facility being built outside of Topeka, KS for the Mars Chocolate North America Facility. This facility, which is now open and operating, had financial investments from Mars, the State of Kansas, the local Economic Development entity (Go Topeka) and BNSF. Of the $270 million for the facility, roughly $1.3 million was for rail yard construction and connection the BNSF line. However, it is also asserted that having direct rail access was essential for inbound materials for this facility – in short, while the rail investment was a small portion of the total project cost, it was deemed "essential" and thus arguably of greater importance than the investment would appear to represent (see, http://cjonline.com/news/2011-06-29/mars-chocolate-build-250m-plant-topeka). From an analysis perspective, this example offers several insights. First, did the project actually cost what was reported? Second, did the hiring achieve the stated new employees? Third, did the tax receipts total what was expected? And so on. Thus, to unravel the benefit stream from this railroad infrastructure investment, it will be necessary to obtain data from Mars – number of new hires, payroll, etc.; from the State tax department – tax receipts from Mars, but also from employees; from the local taxing authorities, e.g., school districts, etc., what was the attributable increase in tax revenues; from BNSF the number of new carloads of traffic (there is little

likelihood they will reveal revenues attached to those carloads), etc. Of course, all of these data need to be compared to what else was happening in Topeka and Shawnee County prior to the announcement and what else has happened since – e.g., collateral development that could be considered a result of this new chocolate factory development. Thus, this single project illustrates the multiple input and outcome data sources that may need to be exercised to assess the economic benefit of the rail infrastructure investment in the project.

More generally, baseline data for determining infrastructure investment impacts are most likely to be found in government databases, such as those within the Missouri Economic Research and Information Center (MERIC), part of the Missouri Department of Economic Development. For example, MERIC has 14 basic baseline economic indicators of Missouri's economy that are regularly updated. In addition, MERIC maintains regional workforce data for the 10 regions within the State. There are also comparable databases at the federal level, for example the regional economic database at the St. Louis Fed's consortium known as the Eighth District Business and Economics Research Group (BERG). BERG is composed of CRE8 - Center for Regional Economics 8th District (Missouri) and university-based centers for business and economics research in the states of the Eighth District. In addition, there are centers within the various institutions of higher learning that focus on economic development, such as Business and Economic Development at Missouri State University in Springfield, MO and Center for Economic & Business Research at Southeast Missouri State University, Cape Girardeau, Mo. All of these institutions house baseline databases for use in comparative analyses of railroad infrastructure investment and concomitant economic benefits. In general, the underlying data for the studies conducted by these units will be electronically retrievable and can lend themselves to providing baseline estimates along any railroad service corridor within Missouri.

POTENTIAL METRICS

The project team has identified three categories of metrics to be considered:

- ECONOMIC DEVELOPMENT METRICS
- SUSTAINABILITY METRICS AND INDICES, and
- USER/CUSTOMER METRICS

The following discussion identifies metrics that are now, or could be, collected on a consistent basis and in a mostly uniform manner. As was noted previously, some metrics are simple, single outcome measures and some are composite outcome indices. Regardless, the metrics provide indicators for each of the three categories that have been found to be important ways of assessing the benefit stream of infrastructure investments.

ECONOMIC DEVELOPMENT METRICS

As previously reported, over 100 Economic Development metrics have been identified in the extant literature (see for example, Isard 1956, 1959, 1960; City of San Jose, CA 2013; http://icma.org/en/icma/knowledge_network/questions/question/22010; http://economicdevelopment.caled.org/resources/economic-development-performance-measures; and Porter 2003). A strength of these metrics is that most are aligned with regularly collected data by governmental/NGO entities. The disadvantage of many of these metrics is that there is not an easy crosswalk between these measures and those that have been suggested as ways to measure Sustainability, as well as being able to clearly distinguish just what policy or investment

by what entitity led to any given change in the value of a particular metric. Finally, the role of private sector investments in economic growth in any geographic area cannot be easily extracted from these measures.

Typical and generally collected data regarding economic costs and benefits of railroad investments are shown in Table 1. These are listed first as investments or inputs and benefits or outputs second.

TABLE 1: ECONOMIC METRICS

INVESTMENT/COST	DATA SOURCES
• DIRECT RAILROAD INVESTMENT $$	• RAILROAD COMPANY
• DIRECT INDUSTRY INVESTMENT $$	• INDUSTRY (MAY ALSO BE AVAILABLE THROUGH LOCAL EDC)
• DIRECT STATE INVESTMENT $$ ○ DOT $$ ▪ RAIL ▪ HIGHWAY ▪ OTHER ○ ECONOMIC DEVELOPMENT $$ ○ OTHER STATE AGENCY $$	• STATE AGENCIES (MAY ALSO BE AVAILABLE THROUGH LOCAL EDC)
• DIRECT LOCAL EDC INVESTMENT $$	• LOCAL EDC
• DIRECT LOCAL COMMUNITY INVESTMENT $$ ○ ROAD IMPROVEMENTS ○ OTHER	• LOCAL MUNICIPALITIES (MAY ALSO BE AVAILABLE THROUGH LOCAL EDC)
• INDIRECT RAILROAD INVESTMENT ○ PAYMENT IN LIEU OF TAXES – PILT – $$ VALUE ○ TRAINING PROGRAM SUPPORT – $$ VALUE ○ OTHER	• RAILROAD COMPANY
• INDIRECT INDUSTRY INVESTMENT ○ PAYMENT IN LIEU OF TAXES – PILT – $$ VALUE ○ OTHER	• INDUSTRY (MAY ALSO BE AVAILABLE THROUGH LOCAL EDC)
• INDIRECT STATE INVESTMENT ○ TAX RELIEF – $$ VALUE ▪ CORPORATE INCOME/SALES TAX ▪ OTHER ○ TRAINING SUPPORT – $$ VALUE ○ OTHER – $$ VALUE	• STATE AGENCIES – TAX DEPARTMENT, ECONOMIC DEVELOPMENT, ETC. (MAY ALSO BE AVAILABLE THROUGH LOCAL EDC)
• INDIRECT LOCAL INVESTMENT ○ PROPERTY TAX RELIEF – $$ VALUE	• LOCAL MUNICIPALITIES – TAX DEPARTMENT,

○ Utility Cost Relief – $$ value ▪ Water ▪ Sewer/Waste Disposal • Other Investments $$	Utility Company, etc. (may also be available through local EDC) • Other entities contributing to project (may also be available through local EDC)
Benefits	
• Jobs # ○ Short-term construction, etc. ○ Long-term permanent ○ Multiplier effect • Jobs $$ ○ Median/Mean short-term wages x number of jobs ○ Median/Mean long-term wages x number of jobs ○ Median/Mean increased purchases due to new jobs	• Railroad & Industry (Also available through USDOC BEA, local EDC, Missouri Economic Research & Information Center (MERIC), Eighth District Business & Economics Research Group (BERG), Business & Economic Development, Missouri State University, Springfield, MO & Center for Economic & Business Research, Southeast Missouri State University, Cape Girardeau, MO) • Railroad & Industry (Also available through USDOC BEA, local EDC, Missouri Economic Research & Information Center (MERIC), Eighth District Business & Economics Research Group (BERG), Business & Economic Development,

	Missouri State University, Springfield, MO & Center for Economic & Business Research, Southeast Missouri State University, Cape Girardeau, MO)
• Tax revenues $$ ○ Industry Gross Receipts/Sales Taxes ○ State Business Income Taxes ○ Real Estate Taxes ○ School Taxes ○ Personal Income Taxes ○ Sales Taxes due to Increased Purchases ○ PILT	• State and Local Tax departments (Also available through USDOC BEA, local EDC, Missouri Economic Research & Information Center (MERIC), Eighth District Business & Economics Research Group (BERG), Business & Economic Development, Missouri State University, Springfield, MO & Center for Economic & Business Research, Southeast Missouri State University, Cape Girardeau, MO)
• Increased local business revenues $$ ○ Direct Sales due to construction ○ Direct Sales due to ongoing operations ○ Indirect multiplier sales	• Railroad & Industry (Also available through USDOC BEA, local EDC, Missouri Economic Research & Information Center (MERIC), Eighth District Business & Economics Research Group (BERG), Business & Economic Development, Missouri State University, Springfield, MO &

	Center for Economic & Business Research, Southeast Missouri State University, Cape Girardeau, MO)

• Increased Utility Revenues $$
  ○ Water
  ○ Electric
  ○ Waste
• Other $$
  ○ Contributions to local charities
  ○ Contributions to local cultural institutions
  ○ Other
	• Local Utilities (Also available through local EDC)
	
	• Railroad & Industry (Also available through local EDC, Missouri Economic Research & Information Center (MERIC), Eighth District Business & Economics Research Group (BERG), Business & Economic Development, Missouri State University, Springfield, MO & Center for Economic & Business Research, Southeast Missouri State University, Cape Girardeau, MO)

Sustainability Metrics and Indices

As previously reported, over the last ten years or so there has been an expansion of interest in Sustainability Development Indicators (SDI) systems. To date, there are almost 20 distinct sets of metrics and indices that have been developed and, to some extent, promulgated. More recently, there have been further refinements related to the introduction of sustainability metrics into the bottom line of companies, specifically with regard to the supply chain, but also more generally in terms of the overall business practices. Today, with the advances in network-based information technology, the most environmentally conscious companies recognize "there are thousands of things that you can do that are sustainable practices and good for the environment, and that are also good for your company," including some things that involve collaboration with other shippers (Field 2014).

In considering using possible SDI, we distinguish between three types of sustainability:

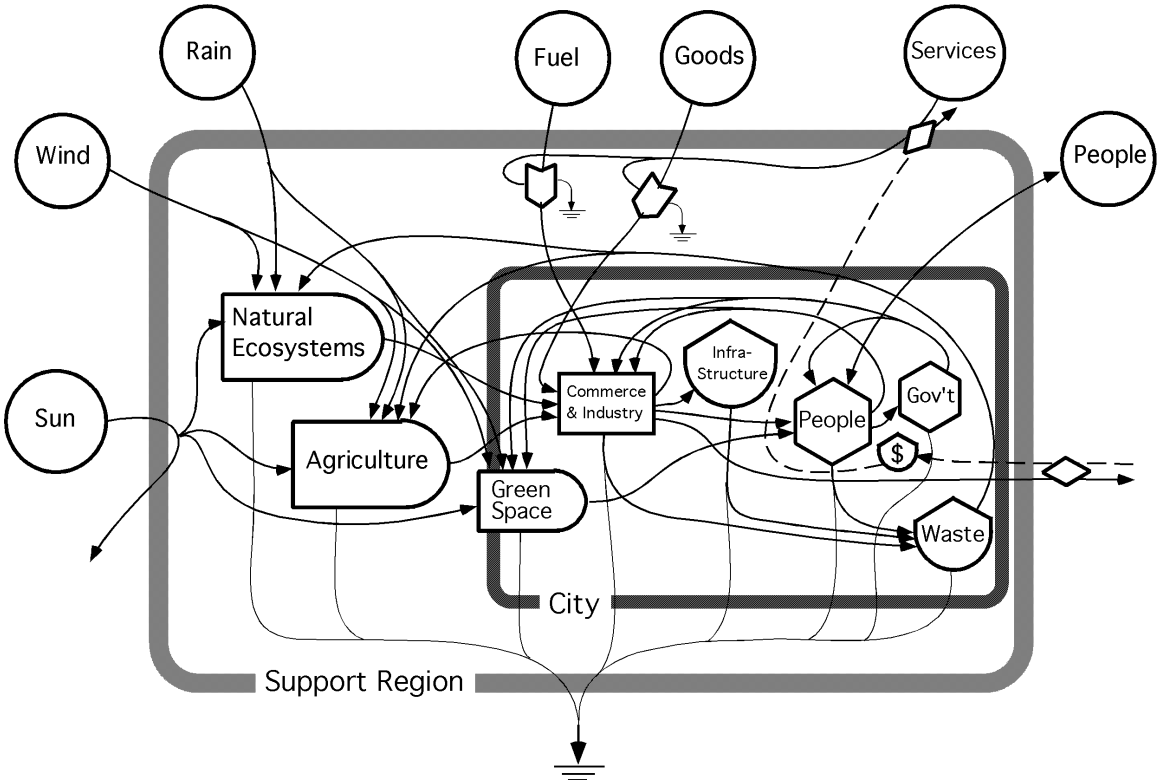
- Sustainability of a culture (human system) within its resources and environment;
- Sustainability of a specific stream of benefits or productivity (usually an economic measure); and
- Sustainability of a particular institution or project without additional assistance (institutionalization of an input).

Figure 1 illustrates how the three factors interact within a community and its environment.

In the context of railroads as socio-technical systems, all three of these factors come into play. Historically however, the focus on railroad investments and economic development relates largely to the latter two sustainability concerns. We address all three below (Table 2), but recognize that metrics covering the human system are less well defined and less well measured in regularly collected data and analytics.

As reported earlier, there are two composite sustainability indices that can be calculated with currently available data, although these data may not be regularly collected or reported in easily accessible formats for local or regional analyses. However, there are national and international databases that can be utilized for undertaking such analyses (as noted in Table 2). (For a brief summary of these indices, see http://en.wikipedia.org/wiki/Sustainability_metrics_and_indices.)

FIGURE 1: INTERACTION OF SUSTAINABILITY FACTORS IN A CITY AND ITS ENVIRONMENT (LECTURE 11, CEP, UNIVERSITY OF FLORIDA, HTTP://WWW.CEP.EES.UFL.EDU/EMERGY/RESOURCES/PRESENTATIONS.SHTML)



These indices are:

- Energy, Emergy and Sustainability Index (SI), and
- Life-cycle Assessment.

Table 2 describes these indices and some of their measureable components.

TABLE 2: SUSTAINABILITY METRICS AND INDICES	
ENERGY, EMERGY AND SUSTAINABILITY INDEX (SI)	**DATA SOURCES**
• SI = $\frac{\text{EMERGY YIELD RATIO}}{\text{ENVIRONMENTAL LOADING RATIO}} = \frac{EYR}{ELR}$ **NOTE:** THE NUMERATOR IS CALLED "EMERGY" AND IS SPELLED WITH AN "M". IT	• UNIVERSITY OF BATH *EMBODIED ENERGY & CARBON MATERIAL INVENTORY*; OR UNIVERSITY OF FLORIDA, CENTER FOR ENVIRONMENTAL

IS AN ABBREVIATION OF THE TERM, "EMBODIED ENERGY".[2] THE NUMERATOR IS NOT "ENERGY YIELD RATIO", WHICH IS A DIFFERENT CONCEPT	POLICY *Emergy Evaluation Folios*
• EYR METRIC COMPONENTS ○ MJ/KG (MEGAJOULES OF ENERGY NEEDED TO MAKE A KILOGRAM OF PRODUCT) ○ TCO_2 (TONS OF CARBON DIOXIDE CREATED BY THE ENERGY NEEDED TO MAKE A KILOGRAM OF PRODUCT)	• UNIVERSITY OF BATH *EMBODIED ENERGY & CARBON MATERIAL INVENTORY*; OR UNIVERSITY OF FLORIDA, CENTER FOR ENVIRONMENTAL POLICY *Emergy Evaluation Folios*
• ELR METRIC COMPONENTS ○ THE RATIO OF NONRENEWABLE AND IMPORTED EMERGY USE TO RENEWABLE EMERGY USE. IT IS AN INDICATOR OF THE PRESSURE OF A TRANSFORMATION PROCESS ON THE ENVIRONMENT AND CAN BE CONSIDERED A MEASURE OF ECOSYSTEM STRESS DUE TO A PRODUCTION (TRANSFORMATION ACTIVITY).	• UNIVERSITY OF BATH *EMBODIED ENERGY & CARBON MATERIAL INVENTORY*; OR UNIVERSITY OF FLORIDA, CENTER FOR ENVIRONMENTAL POLICY *Emergy Evaluation Folios*

[2] Embodied energy is an accounting method which aims to find the sum total of the energy necessary for an entire product lifecycle. Determining what constitutes this lifecycle includes assessing the relevance and extent of energy into raw material extraction, transport, manufacture, assembly, installation, disassembly, deconstruction and/or decomposition as well as human and secondary resources. Different methodologies produce different understandings of the scale and scope of application and the type of energy embodied.

• EYR Calculation Example ○ Converting MJ to tCO_2 is not straightforward because different types of energy (oil, wind, solar, nuclear and so on) emit different amounts of carbon dioxide, so the actual amount of carbon dioxide emitted when a product is made will depend on the type of energy used in the manufacturing process. EYR= U/(F+S)[3] ▪ Comparative lists (for an example, see the University of Bath *Embodied Energy & Carbon Material Inventory*; or University of Florida, Center for Environmental Policy *Emergy Evaluation Folios*) contain average absolute values, and explain the factors that have been taken into account when compiling the lists.[4]	• University of Bath *Embodied Energy & Carbon Material Inventory*; or University of Florida, Center for Environmental Policy *Emergy Evaluation Folios*
• ELR Calculation Example ○ Total nonrenewable and imported emergy released per unit of local renewable resource – ELR= (N+F+S)/R (See Figure 2)	• University of Bath *Embodied Energy & Carbon Material Inventory*; or University of Florida, Center for Environmental Policy *Emergy Evaluation Folios*
Life-cycle Assessment	
• Life-cycle Assessment: a "composite measure of sustainability." It analyzes the environmental performance of products and services through all phases of their life cycle, which include: ○ Extracting and processing raw materials	• The National Institute of Standards & Technology (NIST) - *Life Cycle Costing Manual* for the Federal Energy

[3] Where U = Used Energy (see Lecture 3, CEP, University of Florida, http://www.cep.ees.ufl.edu/emergy/resources/presentations.shtml

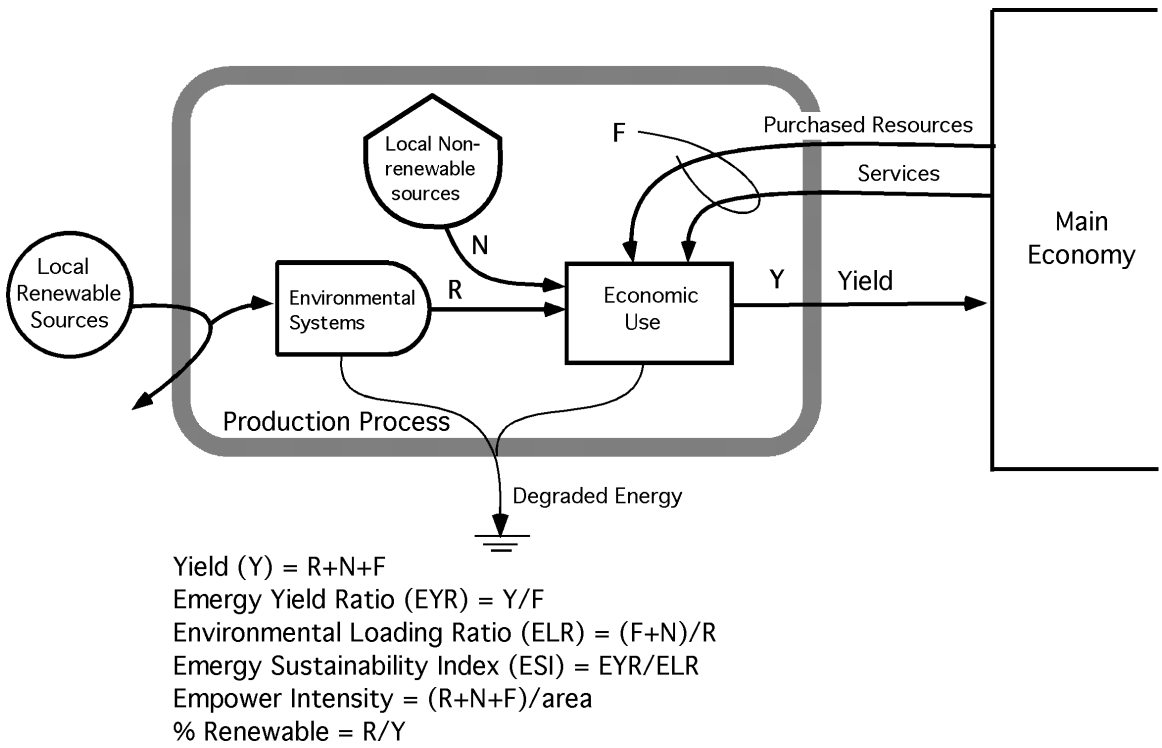
[4] G. P. Hammond and C. I. Jones (2006) *Inventory of (Embodied) Carbon & Energy (ICE)*, Department of Mechanical Engineering, University of Bath, United Kingdom; Various authors (2000-2002) *Emergy Evaluation Folios*, Center for Environmental Policy, University of Florida, http://www.cep.ees.ufl.edu/emergy/publications/folios.shtml.

	○ Manufacturing, transportation and distribution ○ Use, re-use and maintenance ○ Recycling and final disposal	Management Program (NIST Handbook 135) & *Building Life Cycle Cost* (BLCC) Annual Supplement to Handbook 135 (ASHB 135), *Energy Price Indices and Discount Factors for Life Cycle Cost Analysis*.) • Centre for Life Cycle Inventories, Swiss Federal Institute of Technology Zürich (ETH Zurich) & Lausanne (EPF Lausanne), the Paul Scherrer Institute (PSI), the Swiss Federal Laboratories for Materials Testing & Research (Empa), & the Swiss Federal Research Station Agroscope Reckenholz-Tänikon (ART) – several thousand Life Cycle Inventory (LCI) datasets - agriculture, energy supply, transport, biofuels & biomaterials, bulk & speciality chemicals, construction materials, packaging materials, basic & precious metals, metals processing, ICT & electronics as well as waste treatment.

- Calculators – examples
  - The National Institute of Standards and Technology (NIST) - *Life Cycle Costing Manual* for the Federal Energy Management Program (NIST Handbook 135) & *Building Life Cycle Cost* (BLCC) (Annual Supplement to Handbook 135 (ASHB 135), *Energy Price Indices and Discount Factors for Life Cycle Cost Analysis*.)
  - ecoinvent, the Centre for Life Cycle Inventories, is a Competence Centre of the Swiss Federal Institute of Technology Zürich (ETH Zurich) and Lausanne (EPF Lausanne), the Paul Scherrer Institute (PSI), the Swiss Federal Laboratories for Materials Testing and Research (Empa), and the Swiss Federal Research Station Agroscope Reckenholz-Tänikon (ART) -- several thousand Life Cycle Inventory (LCI) datasets in the areas of agriculture, energy supply, transport, biofuels and biomaterials, bulk and speciality chemicals, construction materials, packaging materials, basic and precious metals, metals processing, ICT and electronics as well as waste treatment.
  - FHWA Office of Asset Management has initiated an LCCA approach for state, regional and local transportation agencies with an initial focus on Pavement Design Alternatives.

- FHWA Office of Asset Management
- The National Institute of Standards and Technology (NIST)
- Swiss Federal Institute of Technology Zürich (ETH Zurich) and Lausanne (EPF Lausanne)
- Paul Scherrer Institute (PSI)
- Swiss Federal Laboratories for Materials Testing and Research (Empa)
- Swiss Federal Research Station Agroscope Reckenholz-Tänikon (ART)
- FHWA Office of Asset Management

FIGURE 2: SUSTAINABILITY INDEX COMPONENTS (LECTURE 11, CEP, UNIVERSITY OF FLORIDA, HTTP://WWW.CEP.EES.UFL.EDU/EMERGY/RESOURCES/PRESENTATIONS.SHTML)



Yield (Y) = R+N+F
Emergy Yield Ratio (EYR) = Y/F
Environmental Loading Ratio (ELR) = (F+N)/R
Emergy Sustainability Index (ESI) = EYR/ELR
Empower Intensity = (R+N+F)/area
% Renewable = R/Y

To illustrate a life cycle costing analysis, we use a generic dump truck example drawn from an online LCC calculator (Figure 3, drawn from iSolutions Pty Ltd. 2007). In this example, a 20-year life is used to illustrate how the various cost components are integrated into life cycle cost analysis. The process is the same for other types of long-term capital investments.

FIGURE 3: EQUIPMENT LIFE COST CALCULATOR (ISOLUTIONS PTY LTD. 2007, HTTP://ISIPL.COM)

Equipment Life Cycle Cost Calculator

iSolutions www.isipl.com

Equipment Description: Generic Dump Truck

Input Table	
Purchase Price	1,200,000
Equipment Life in Hours	28,000
Residual Value (%)	15%
Interest Rate (%)	8%
Annual Usage	4,000
Insurance %	1.10%
Annual Major Cost	145,000
Annual Servicing Cost	80,000
Labour to Hours Ratio	0.35
Labour Rate per Hour	60.00
Unassigned Cost Ratio	15%
Fuel Cost (Litre)	1.00
Fuel Consumption (L/hr)	28
Cost of Tyres / Tracks	38,000
Life of Tyres / Tracks	4,500
Cost of Bucket / Blade / Body	55,000
Life of Bucket / Blade / Body	20,000
Operator Cost per Hour	55.00

Ownership Cost per Hour	
Depreciation	36.43
Interest	13.80
Insurance	3.30
Total Ownership	53.53

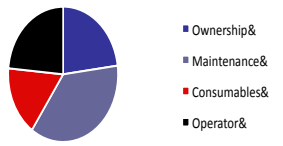
Maintenance Cost per Hour	
Major Components	36.25
Service and Repair	20.00
Labour	21.00
Unassigned Cost	8.44
Total Maintenance	85.69

Consumables	
Fuel	28.00
Tyres / Tracks	8.44
Bucket / Blade / Body	2.75
Total Consumables	39.19

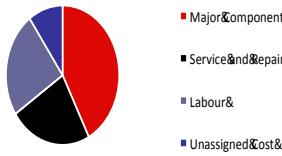
Operator	
Operator	55.00

Total Cost per Hour	
Ownership	53.53
Maintenance	85.69
Consumables	39.19
Operator	55.00
Total Hourly Cost	233.41

Life Cycle Cost Breakdown



Maintenance Cost Breakdown



Disclaimer:

iSolutions International Pty Ltd does not warrant the cost data or calculations contained within this Equipment Life Cycle Cost Calculator Spreadsheet. In no event shall iSolutions be liable to any party for any indirect, incidental, consequential, or special damages, including without limitation, lost revenues or profits.

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USER/CUSTOMER METRICS

As described earlier, it is important to address metrics for the users/customers of railroads – passengers, shippers and receivers. One of the challenges in devising metrics that are relevant for users/customers is identifying indicators that can be readily collected and analyzed on a regular basis – that is, not requiring special studies that are episodic over time. The importance of this issue resides in the fact that socio-technical systems (railroads and large-scale industrial facilities being two such systems) have longer planning horizons and face greater uncertainities (risks)

that only truly reveal themselves as time proceeds. Thus, user/customer evaluations and priorities are likely to change over time as more information becomes available. For example, today, some Class I freight railroads now have GHG calculators on their websites to allow customers or potential customers to determine the GHG contributions associated with receving/shipping product by rail versus truck. Should the shipper choose to receive/ship by rail, these calculators can then be used by the industry to derive its total GHG footprint in its product production and distribution (see, for example, http://www.csx.com/index.cfm/customers/tools/carbon-calculator-v2/ and http://www.cn.ca/en/repository/popups/ghg/ghgcalculatortool). Thus, for a company that markets itself as a "Green" company, it is possible for it to demonstrate how it practices "Green" processes in its entire inbound logistics, production and outbound logistics chain. The interest in demonstrating such "Green" behavior is a relatively recent phenomenon having arisen within the last decade since the buying public and public policy began to push toward more environmentally friendly practices and products (see, for example, GfK Roper Consulting 2011). Further, there is evidence that, for passengers, travel time (a commonly used metric) is now losing its importance vis-à-vis "productivity of travel time" (Schwieterman, Fischer and Schulz 2012a & b). This illustrates how user/customer metrics may change over the time of the life of an infrastructure investment.

Table 3 illustrates types of possible metrics that may be considered by passengers, shippers and receivers.

TABLE 3: USER/CUSTOMER METRICS	
PASSENGERS	**DATA SOURCES**

• TRAVEL TIME
  ○ TOTAL TRIP TRAVEL TIME – DOOR-TO-DOOR
  ○ TRIP SEGMENT TRAVEL TIME
  ○ OTHER
	• FHWA, MODOT, MPOS, SPECIAL STUDIES (O-D STUDIES, TRANSIT, ETC.)

• TRAVEL COST $$
  ○ OUT-OF-POCKET OPERATING/FARE COSTS
  ○ TOTAL COST – INCLUDING PARKING, TOLLS, VEHICULAR COSTS (FUEL, ANNUALIZED MAINGTENANCE, ETC.), FARES, ETC.
	• FHWA, MODOT, MPOS, SPECIAL STUDIES (O-D STUDIES, TRANSIT, ETC.)

• ACCESSIBILITY/CONVENIENCE/FLEXIBILITY
  ○ NUMBER OF TRIP LINKS (TRANSFERS)
  ○ NUMBER OF MODE CHANGES
  ○ TRANSFER DWELL TIME – AVERAGE WAIT TIME
  ○ TRANSFER DELAYS
  ▪ TOTAL – GROSS LOST TIME
  ▪ FREQUENCY – STATISTICAL LIKELIHOOD OF DELAY IN ANY GIVEN LINK/NODE
  ▪ TYPE – WEATHER, EQUIPMENT FAILURE, ACCIDENTS, ETC.
  ○ DOOR-TO-DOOR
	• FHWA, MODOT, MPOS, SPECIAL STUDIES (O-D STUDIES, TRANSIT, ETC.) (ALSO RESEARCH REPORTS SUCH AS, SCHWIETERMAN, FISCHER & SCHULZ 2012A & B)

▪ Total time ▪ Time/Distance to Nearest Link ○ Ability to Use Travel Time for other activities ▪ Read ▪ Work ▪ Sleep ▪ Socialize ▪ Other ○ Ease of Changing Travel Arrangements ○ Other	
• Safety/Security ○ Perceived Likelihood of Accident/Incident ○ Statistical Likelihood of Accident/Incident ○ Annualized number of accidents/incidents ○ Severity of accidents/incidents ▪ Fatalities – by link ▪ Severe Injuries – by link ▪ Moderate Injuries – by link ▪ Non-injury – by link ○ Sense of Privacy ○ Cleanliness ○ Apparent Maintenance ○ Other	• FHWA, MoDOT, MPOs, Special Studies (O-D Studies, Transit, etc.) (Also research reports such as, Schwieterman, Fischer & Schulz 2012a & b)
• Spatial Coverage ○ Network Density ○ Network Availability – Likelihood any link/node in nework will fail ○ Proximity to nearest link – time/distance ○ Other	• MoDOT & MPOs
• Network Efficiency/Reliability ○ Overall Congestion ○ Number of Choke Points ○ Total Travel Delay Time – link and node ○ Mean/Median Delay Time – link and node ○ Likelihood of Delay – day/week/month ○ Network Recovery ○ Network Resilience ○ Other	• MoDOT & MPOs
• Environmental Impact ○ GHG Footprint ○ Litter, debris, etc. ○ Visual Impact ○ Ride-Sharing Availability ○ Other	• DOE, MoDOT, MPOs, State Environmental Agency
• Quality of Life	• MoDOT, MPOs

○ Ease of Use of Digital Devices ▪ Real-time Updates ▪ WiFi/3G/4G available ▪ Use of Digital Devices for Connecting to Community Amenities ▪ Smartphone Fare Payment ▪ Other ○ Community Values re Transportation ○ Other	Special studies (Also research reports such as, Schwieterman, Fischer & Schulz 2012a & b)
• Alternative Mode Availability ○ Number ○ Type ○ Ease of Use ▪ Proximity ▪ Cost Parity ▪ Handicap Accessible ▪ Other	• MoDOT, MPOs & Transit Authorities
• Other	• MoDOT, MPOs & Special Studies
Shippers	
• Cost $$ ○ Total supply-chain cost/SKU ○ Carrying cost of inventory/SKU ○ Fleet life-cycle cost ○ Logistics staff cost ○ Other	• Industry, Industry Associations
• Network Efficiency/Reliability ○ Total Shipment Delay Time – link and node ○ Mean/Median Delay Time – link and node ○ Likelihood of Delay – day/week/month ○ Network Recovery ○ Network Resilience ○ Other	• Industry, MoDOT & MPOs
• Safety/Security ○ Perceived Likelihood of Accident/Incident ○ Statistical Likelihood of Accident/Incident ○ Annualized number of accidents/incidents ○ Severity of accidents/incidents ▪ Equipment damage/loss – by link ▪ Materials/products damage/loss – by link ▪ Delay due to accident/incident – by link ▪ Other	• Industry, MoDOT & MPOs

○ Materials/Products Cleanliness/Contamination ○ Other	
• Alternative Mode Availability ○ Number ○ Type ○ Ease of Use ▪ Proximity ▪ Cost Parity ▪ Conversion Cost/Time ○ Other	• Industry, MoDOT & MPOs
• Environmental Impact ○ Enterprise GHG Calculation Impacts ○ Consistent w/Enterprise "Green Image" ○ Possible to Collaborate w/Other Enterprises to Consolidate Shipments ○ Possible "Goods-in-Transit" Consolidation Hubs ○ Fleet Utilization Improvement Impacts ○ Other	• Industry, DOE, MoDOT, MPOs, State Environmental Agency
• Spatial Coverage ○ Network Density ○ Network Availability – Likelihood any link/node in nework will fail ○ Proximity to nearest link – time/distance ○ Proximity to Receivers – time/distance/type of receipt (direct/transload/intermodal) ○ Other	• Industry, MoDOT & MPOs
• Other	• Industry, Industry Associations, MoDOT & MPOs
Receivers	
• Cost $$ ○ Total supply-chain cost/SKU ○ Carrying cost of inventory/SKU ○ Fleet life-cycle cost ○ Logistics staff cost ○ Other	• Industry, Industry Associations
• Network Efficiency/Reliability ○ Total Shipment Delay Time – link and node ○ Mean/Median Delay Time – link and node ○ Likelihood of Delay – day/week/month ○ Network Recovery ○ Network Resilience	• Industry, MoDOT & MPOs

○ Other	
• Safety/Security ○ Perceived Likelihood of Accident/Incident ○ Statistical Likelihood of Accident/Incident ○ Annualized number of accidents/incidents ○ Severity of accidents/incidents ▪ Equipment damage/loss – by link ▪ Materials/products damage/loss – by link ▪ Delay due to accident/incident – by link ▪ Other ○ Materials/Product Cleanliness/Contamination ○ Other	• Industry, MoDOT & MPOs
• Alternative Mode Availability ○ Number ○ Type ○ Ease of Use ▪ Proximity ▪ Cost Parity ▪ Conversion Cost/Time ▪ Other	• Industry, MoDOT & MPOs
• Environmental Impact ○ Enterprise GHG Calculation Impacts ○ Consistent w/Enterprise "Green Image" ○ Possible to Collaborate w/Other Enterprises to Consolidate Shipments ○ Possible "Goods-in-Transit" Consolidation Hubs ○ Fleet Utilization Improvement Impacts ○ Other	• Industry, DOE, MoDOT, MPOs, State Environmental Agency
• Spatial Coverage ○ Network Density ○ Network Availability – Likelihood any link/node in nework will fail ○ Proximity to nearest link – time/distance ○ Proximity to Receivers – time/distance/type of receipt (direct/transload/intermodal) ○ Other	• Industry, MoDOT & MPOs
○ Other	• Industry, Industry Associations, MoDOT & MPOs

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8.2 Appendix 2A: SAS Code for Leontief Approach

The SAS code used for fitting the model using Leontief approach is given below:

```
data mra;
input x1 x2 y1 y2 y3 y4 y5 y6 y7 y8 y9 y10 y11;
datalines;
10000000 40 46 200000 800000 20000 30 20 15000 17000 0.16 0.20 0.1
15000000 48 54 300000 1200000 30000 45 30 22000 24000 0.24 0.30 0.15
5000000 24 31 100000 400000 10000 15 10 6000 8000 0.08 0.10 0.05
8000000 30 37 160000 650000 16000 24 16 9000 11000 0.10 0.16 0.08
3000000 14 19 60000 250000 6000 8 6 2000 4000 0.03 0.06 0.03
22000000 60 74 440000 1800000 44000 65 44 37000 41000 0.35 0.44 0.22
17000000 55 63 350000 1400000 34000 53 35 33000 36000 0.29 0.34 0.17
12000000 44 52 250000 1000000 24000 36 25 18000 23000 0.19 0.24 0.12
9000000 35 42 180000 750000 18000 27 18 12000 15000 0.13 0.18 0.09
6000000 28 34 140000 500000 13000 18 14 8000 10000 0.11 0.12 0.06
proc glm data = mra;
model y1 y2 y3 y4 y5 y6 y7 y8 y9 y10 y11= x1 x2 /ss3;
manova h = x1/printe;
manova h = x2/printe;
run;
```

8.3 Appendix 3A: SAS Results

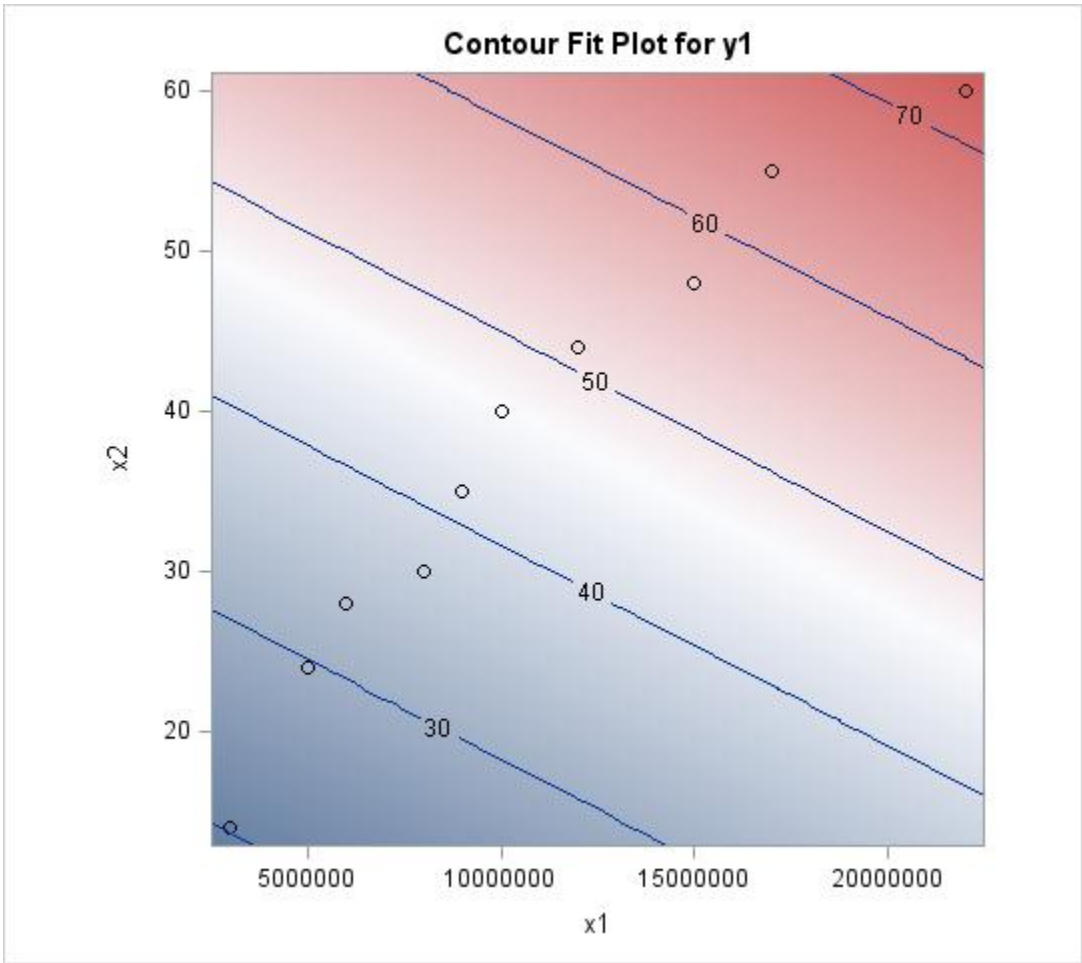
The following results were obtained using SAS and the parameter estimates for each variable are highlighted in yellow.

The SAS System

The GLM Procedure

Dependent Variable: y1

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	6.982274447	2.29704132	3.04	0.0189
x1	0.000000934	0.00000040	2.31	0.0541
x2	0.746586559	0.16569921	4.51	0.0028

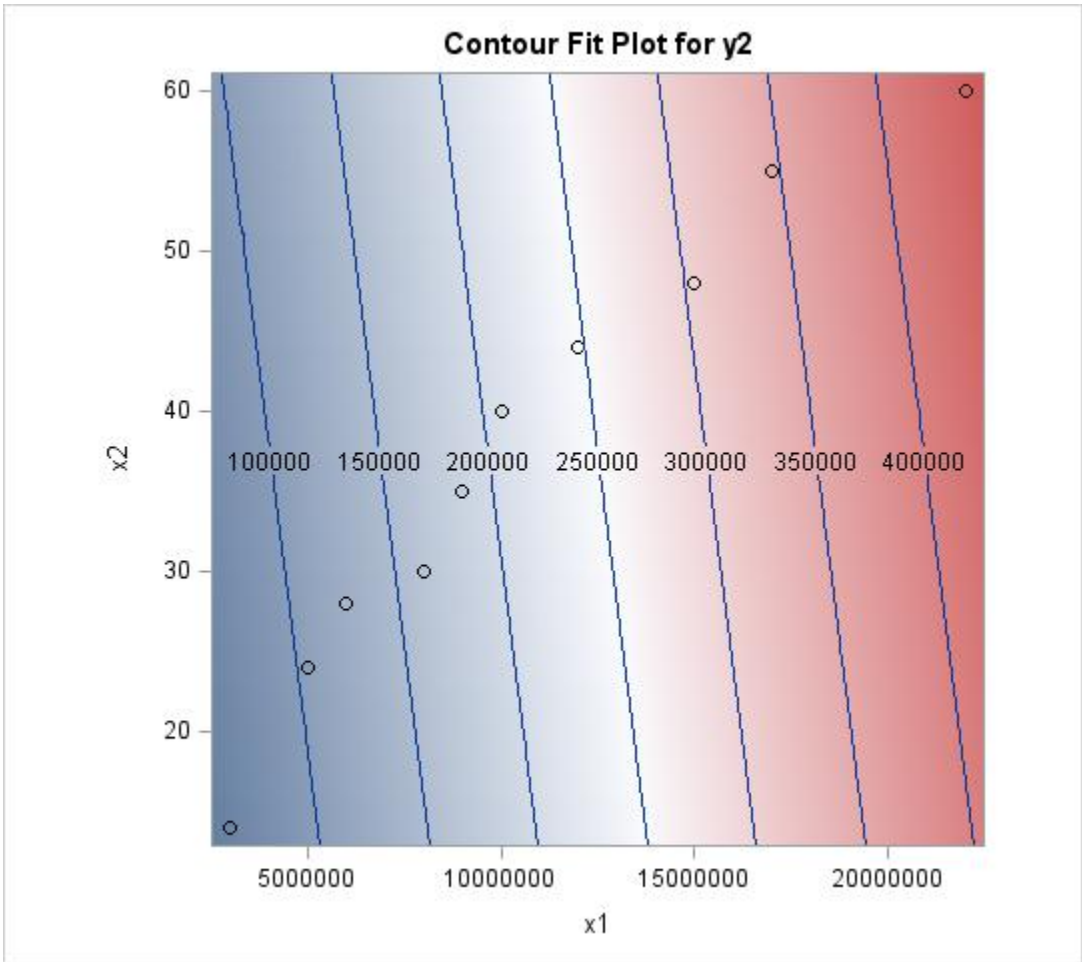


The SAS System

The GLM Procedure

Dependent Variable: y2

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-6845.913829	10720.35855	-0.64	0.5434
x1	0.017725	0.00189	9.39	<.0001
x2	930.941896	773.32300	1.20	0.2678

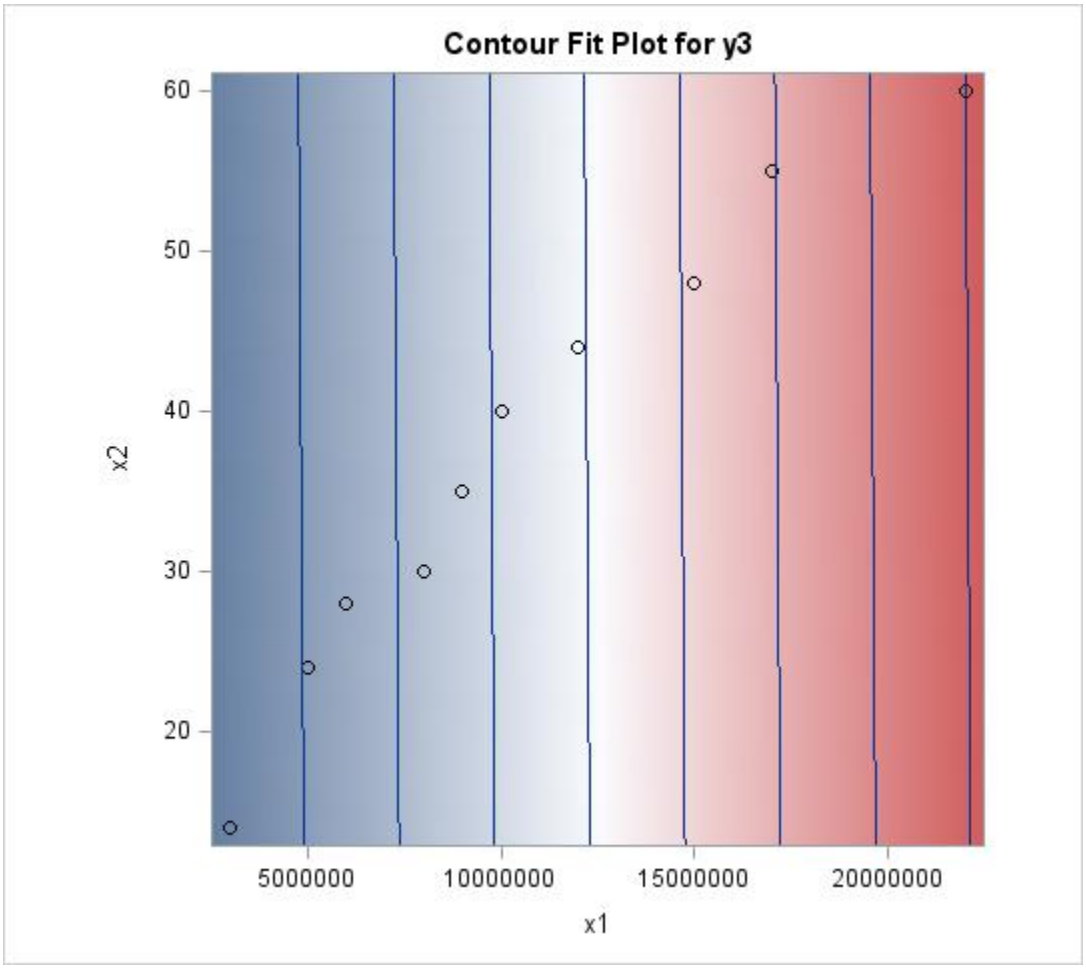


The SAS System

The GLM Procedure

Dependent Variable: y3

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-1268.007701	24254.89243	-0.05	0.9598
x1	0.081066	0.00427	18.99	<.0001
x2	234.385949	1749.64916	0.13	0.8972

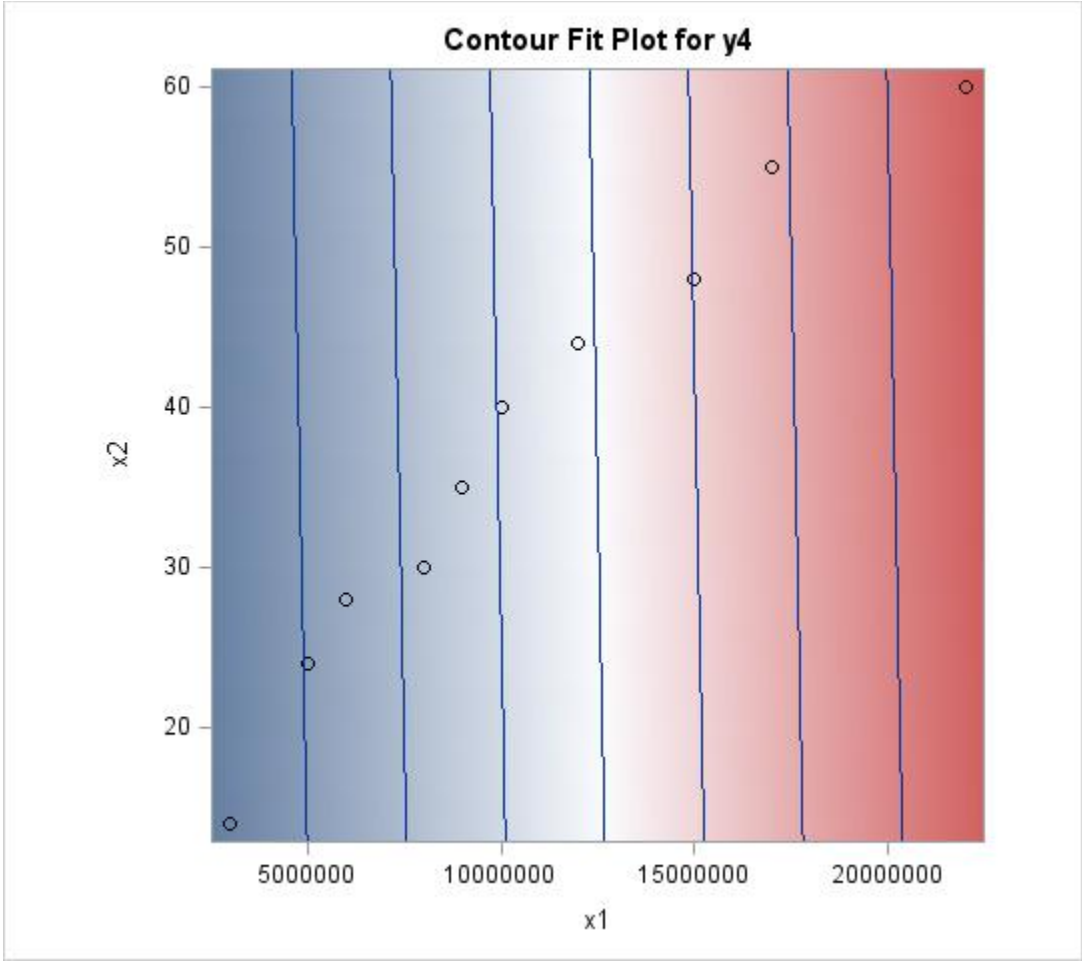


The SAS System

The GLM Procedure

Dependent Variable: y4

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	63.40038505	504.9428785	0.13	0.9036
x1	0.00194669	0.0000889	21.91	<.0001
x2	16.05848031	36.4245227	0.44	0.6726

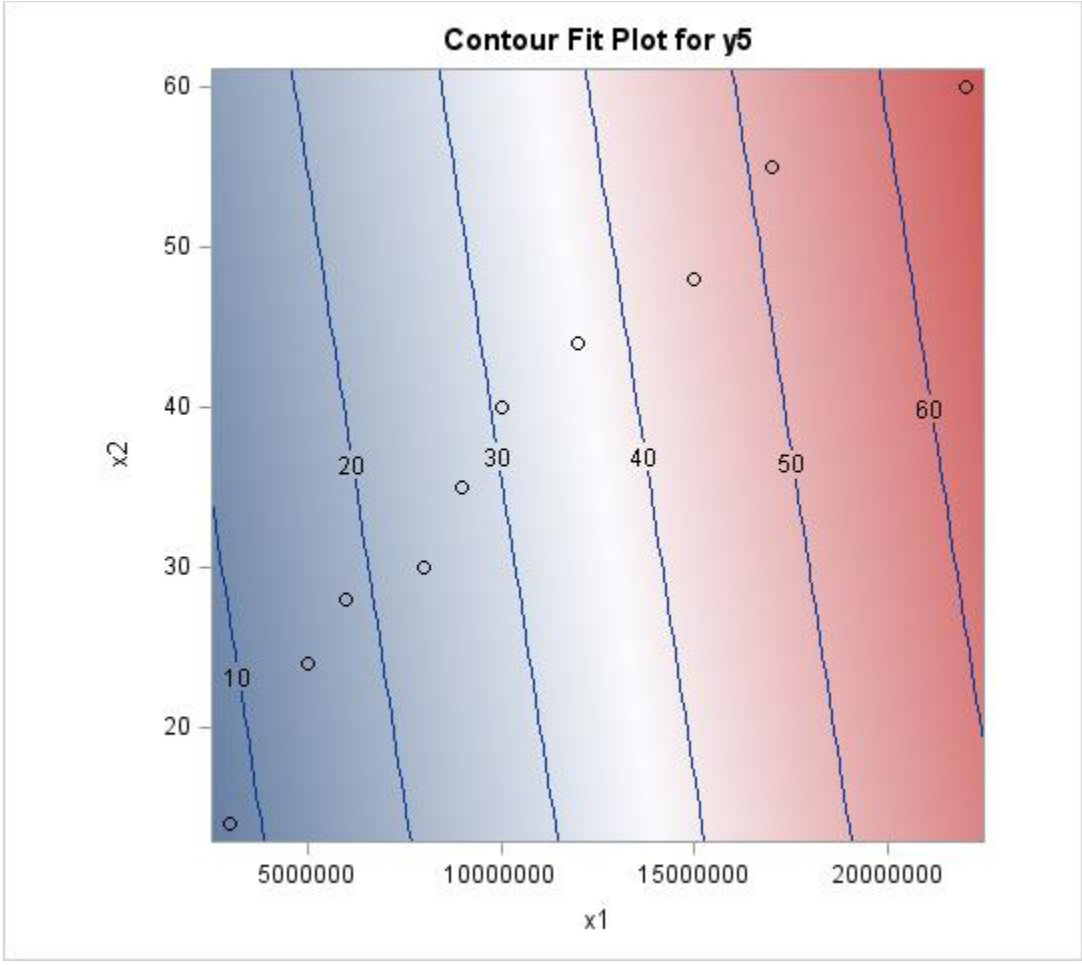


The SAS System

The GLM Procedure

Dependent Variable: y5

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-2.372634933	1.02109929	-2.32	0.0531
x1	0.000002630	0.00000018	14.63	<.0001
x2	0.167629290	0.07365794	2.28	0.0570

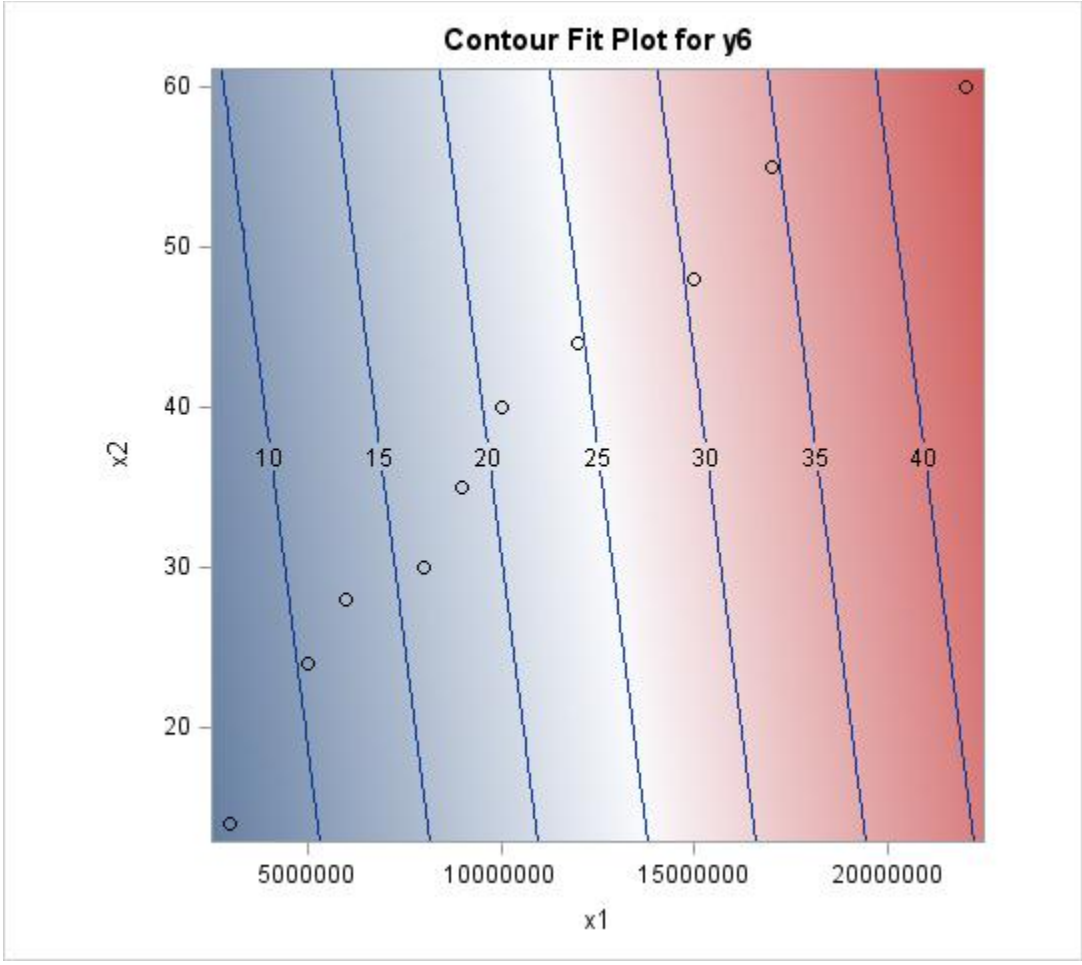


The SAS System

The GLM Procedure

Dependent Variable: y6

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-.6845913829	1.07203586	-0.64	0.5434
x1	0.0000017725	0.00000019	9.39	<.0001
x2	0.0930941896	0.07733230	1.20	0.2678

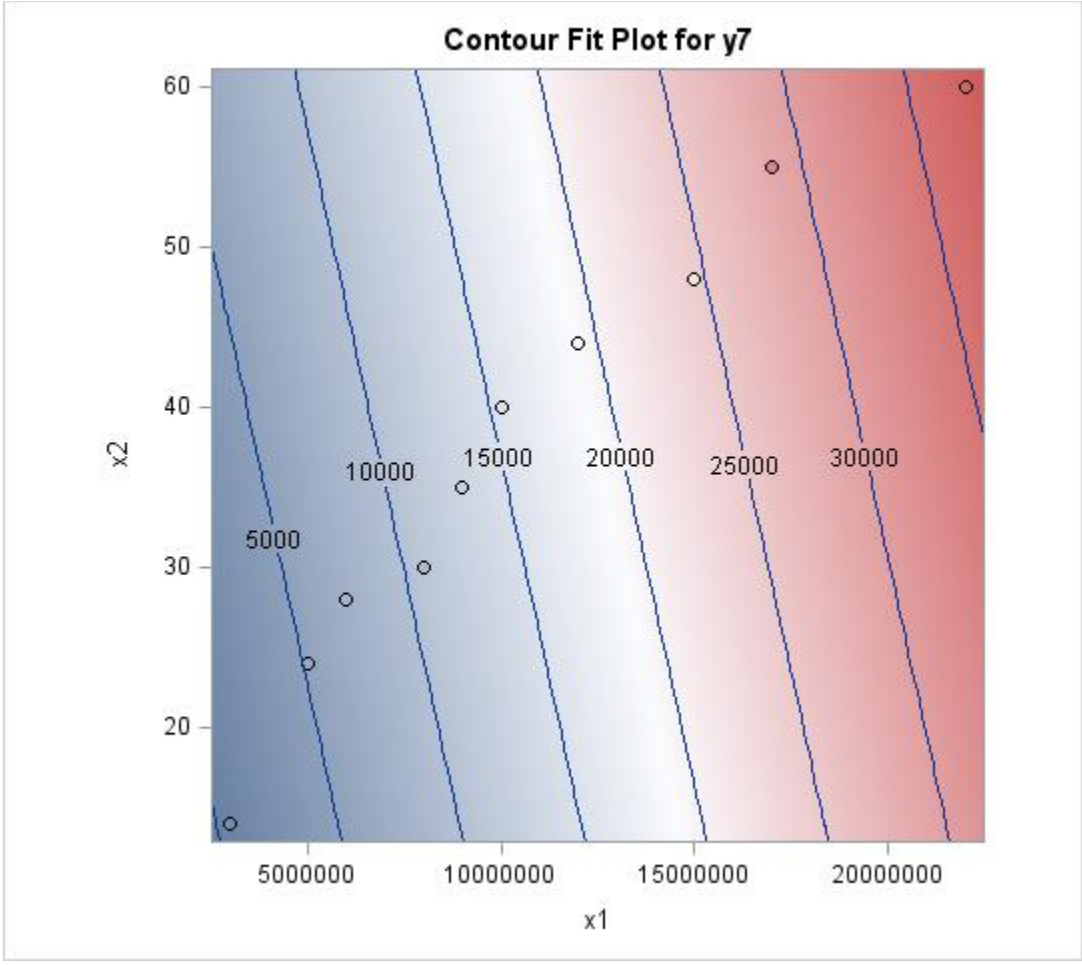


The SAS System

The GLM Procedure

Dependent Variable: y7

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-6187.213702	3286.767849	-1.88	0.1018
x1	0.001587	0.000578	2.74	0.0288
x2	143.098984	237.094046	0.60	0.5652

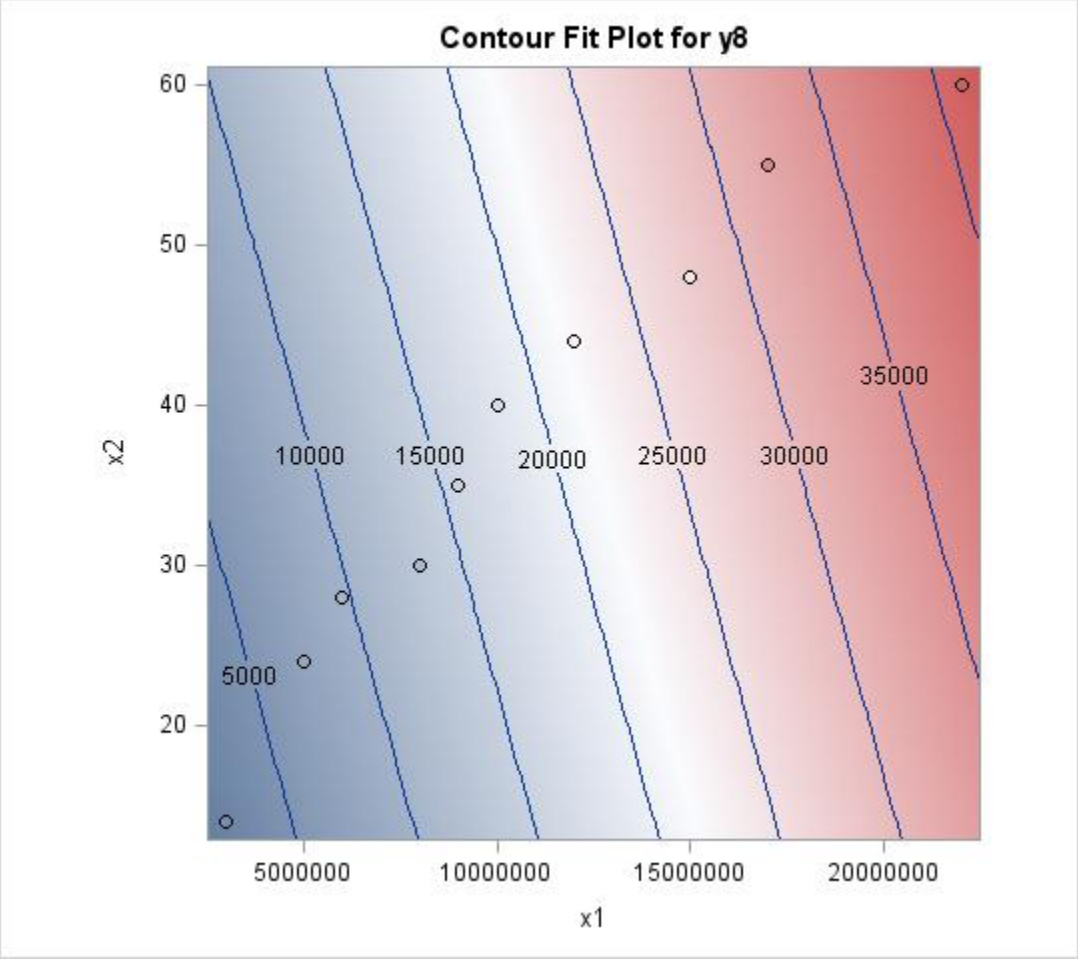


The SAS System

The GLM Procedure

Dependent Variable: y8

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-5024.297949	3529.126520	-1.42	0.1976
x1	0.001595	0.000621	2.57	0.0371
x2	181.338379	254.576814	0.71	0.4993

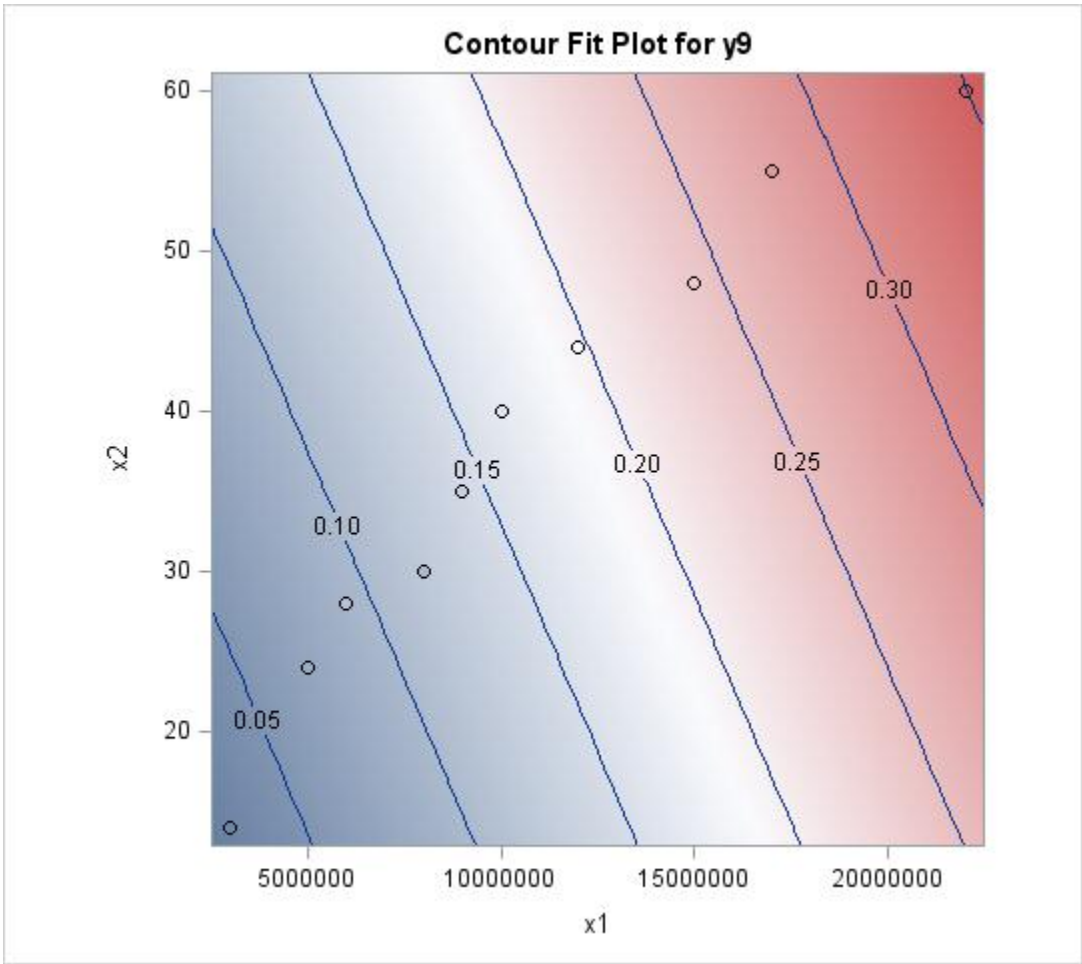


The SAS System

The GLM Procedure

Dependent Variable: y9

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-.0378311093	0.01892865	-2.00	0.0858
x1	0.0000000119	0.00000000	3.56	0.0092
x2	0.0020874549	0.00136544	1.53	0.1702

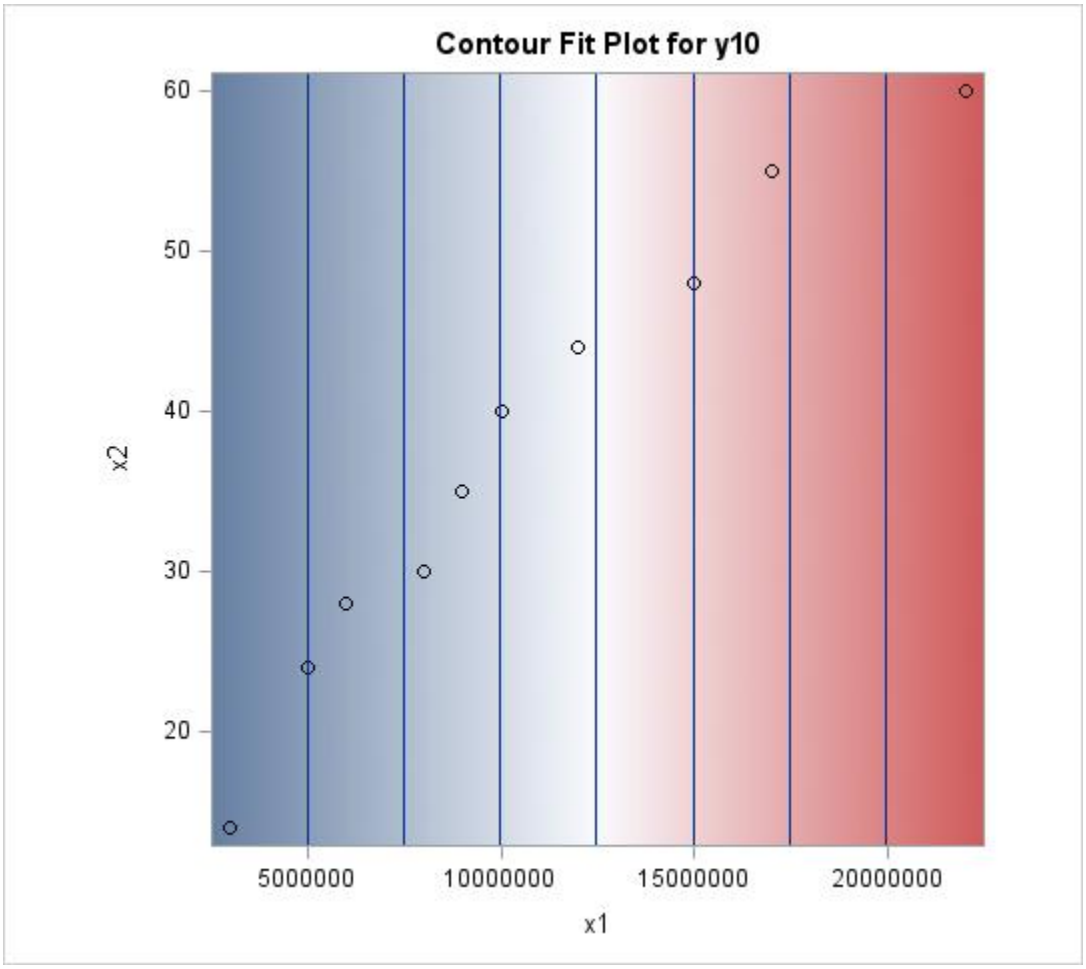


The SAS System

The GLM Procedure

Dependent Variable: y10

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-8.04912E-16	0	-Infty	<.0001
x1	2E-8	0	Infty	<.0001
x2	6.134247E-17	0	Infty	<.0001

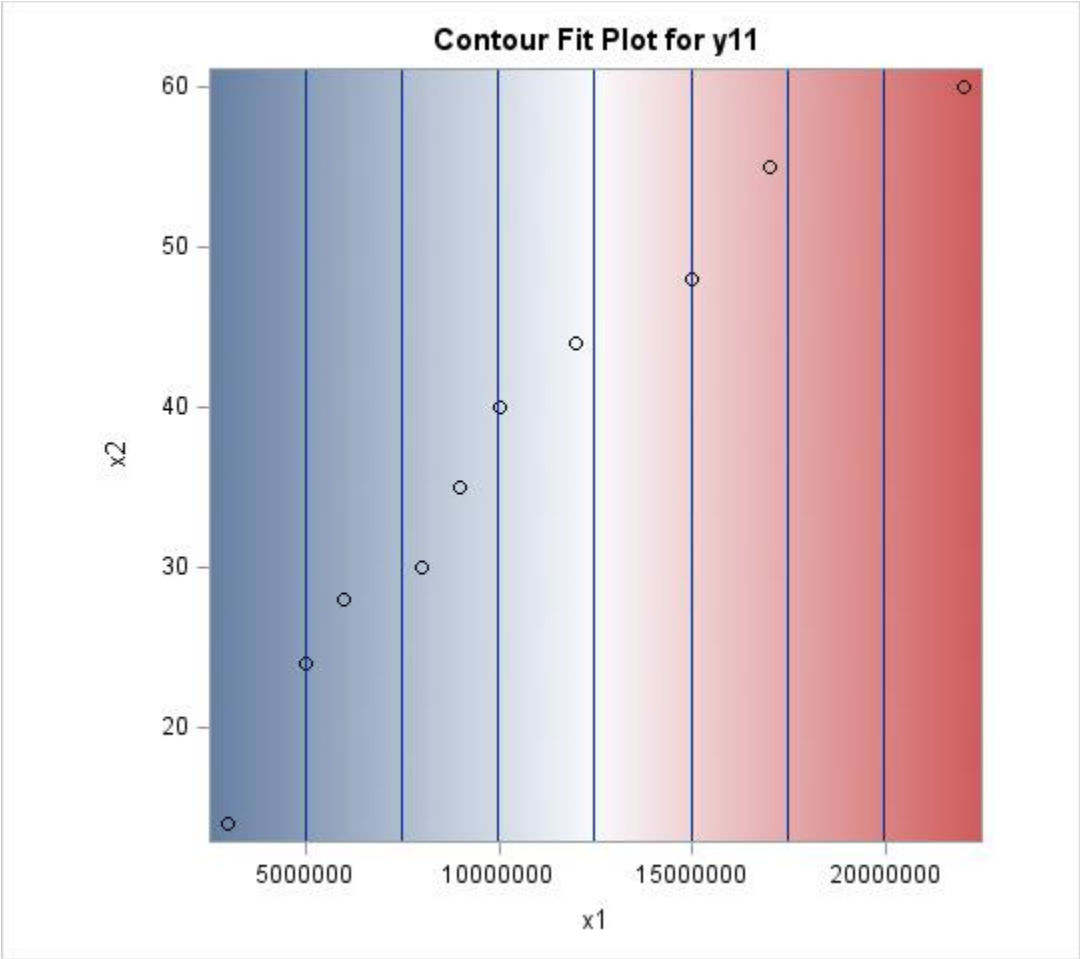


The SAS System

The GLM Procedure

Dependent Variable: y11

Parameter	Estimate	Standard Error	t Value	Pr > |t|
Intercept	-4.02456E-16	0	-Infty	<.0001
x1	1E-8	0	Infty	<.0001
x2	3.067123E-17	0	Infty	<.0001



The GLM Procedure
Multivariate Analysis of Variance

E = Error SSCP Matrix

	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	y11
y1	16.69664077 5	10446.67950 2	81513.75334 7	507.6456659 8	-2.285600478	1.0446 67950 2	423.32 20474	6181.5 37542 3	-0.0033 49266	-7.5313 3E-15	-3.7656 6E-15
y2	10446.67950 2	36367 2206.3 6	45028 4730.0 6	14430 207.94 1	6962.0 92544 6	36367.22063 6	45123 481.37 8	55824 536.94 5	414.19 59326 4	-3.4064 9E-11	-1.7032 4E-11
y3	81513.75334 7	45028 4730.0 6	18616 16396.3	83080 69.072 9	11966.40775 4	45028.47300 6	91799 442.34 2	17749 9502.0 9	102.48 06922	-1.1766 4E-10	-5.8832 2E-11
y4	507.6456659 8	14430 207.94 1	83080 69.072 9	80681 8.7685 8	-98.320 38771	1443.0 20794 1	66002 7.8828 9	37502 4.8954 4	18.209 29872 3	-1.9045 7E-12	-9.5228 3E-13
y5	-2.285600478	6962.0 92544 6	11966.40775 4	-98.320 38771	3.2993 42760 4	0.6962 09254 5	7567.8 15176 3	6114.1 20693 1	0.0180 92013 5	-4.4460 2E-15	-2.2230 1E-15
y6	1.0446 67950 2	36367.22063 6	45028.47300 6	1443.0 20794 1	0.6962 09254 5	3.6367 22063 6	4512.3 48137 8	5582.4 53694 5	0.0414 19593 3	-4.0488 2E-15	-2.0244 1E-15
y7	423.32 20474	45123 481.37 8	91799 442.34 2	66002 7.8828 9	7567.8 15176 3	4512.3 48137 8	34184 524.99 5	33361 183.03 1	130.50 58753 2	-2.5815 7E-12	-1.2907 9E-12
y8	6181.5 37542 3	55824 536.94 5	17749 9502.0 9	37502 4.8954 4	6114.1 20693 1	5582.4 53694 5	33361 183.03 1	39411 770.56 4	114.02 31029 7	-2.7853 5E-12	-1.3926 8E-12
y9	-0.0033 49266	414.19 59326 4	102.48 06922	18.209 29872 3	0.0180 92013 5	0.0414 19593 3	130.50 58753 2	114.02 31029 7	0.0011 33784 8	-2.5002 E-17	-1.2501 E-17
y10	-7.5313 3E-15	-3.4064 9E-11	-1.1766 4E-10	-1.9045 7E-12	-4.4460 2E-15	-4.0488 2E-15	-2.5815 7E-12	-2.7853 5E-12	-2.5002 E-17	0	-1.3877 8E-17
y11	-3.7656 6E-15	-1.7032 4E-11	-5.8832 2E-11	-9.5228 3E-13	-2.2230 1E-15	-2.0244 1E-15	-1.2907 9E-12	-1.3926 8E-12	-1.2501 E-17	-1.3877 8E-17	0

Partial Correlation Coefficients from the Error SSCP Matrix / Prob > |r|

DF = 7	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	y11
y1	1.000000	0.134063 0.7516	0.462350 0.2487	0.138311 0.7440	-0.307944 0.4581	0.134063 0.7516	0.017719 0.9668	0.240973 0.5654	-0.024343 0.9544	0.000000 .	0.000000 .
y2	0.134063 0.7516	1.000000	0.547252 0.1604	0.842422 0.0087	0.200988 0.6332	1.000000 <.0001	0.404700 0.3200	0.466291 0.2442	0.645038 0.0842	0.000000 .	0.000000 .
y3	0.462350 0.2487	0.547252 0.1604	1.000000	0.214371 0.6102	0.152688 0.7181	0.547252 0.1604	0.363898 0.3755	0.655298 0.0777	0.070539 0.8682	0.000000 .	0.000000 .
y4	0.138311 0.7440	0.842422 0.0087	0.214371 0.6102	1.000000	-0.060262 0.8873	0.842422 0.0087	0.125678 0.7668	0.066506 0.8757	0.602060 0.1143	0.000000 .	0.000000 .
y5	-0.307944 0.4581	0.200988 0.6332	0.152688 0.7181	-0.060262 0.8873	1.000000	0.200988 0.6332	0.712594 0.0473	0.536176 0.1707	0.295807 0.4769	0.000000 .	0.000000 .
y6	0.134063 0.7516	1.000000 <.0001	0.547252 0.1604	0.842422 0.0087	0.200988 0.6332	1.000000	0.404700 0.3200	0.466291 0.2442	0.645038 0.0842	0.000000 .	0.000000 .
y7	0.017719 0.966	0.404700 0.32	0.363898 0.37	0.125678 0.766	0.712594 0.047	0.404700 0.32	1.000000	0.908895 0.00	0.662903 0.073	0.000000 .	0.000000 .

Partial Correlation Coefficients from the Error SSCP Matrix / Prob > |r|

DF = 7	y1	y2	y3	y4	y5	y6	y7	y8	y9	y10	y11
	8	00	55	8	3	00		18	2		
y8	0.240973	0.466291	0.655298	0.066506	0.536176	0.466291	0.908895	1.000000	0.539405	0.000000	0.000000
	0.5654	0.2442	0.0777	0.8757	0.1707	0.2442	0.0018		0.1677	.	.
y9	-0.024343	0.645038	0.070539	0.602060	0.295807	0.645038	0.662903	0.539405	1.000000	0.000000	0.000000
	0.9544	0.0842	0.8682	0.1143	0.4769	0.0842	0.0732	0.1677		.	.
y10	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	.	.	.	.	.	.	.	.	.		.
y11	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
	.	.	.	.	.	.	.	.	.	.	

8.4 Appendix 4A: Excel sheet and instructions on how to use excel file for Leontief approach

Excel Sheet: Leontief Approach

Numerical Example for Leontief Model

Y= A * X

Inputs		
Matrix X		
1	28,000,000	235

Insert amount of money invested

Input the number of manpower hired

Matrix A - Parameter Estimates

6.98227445	-6845.91383	-1268.0077	63.400385	-2.3726349	-0.6845914	-6187.2137	-5024.2979	-0.03783111	-8.05E-16	-4.02E-16
9.34E-07	0.017725	0.081066	0.0019467	2.63E-06	1.7725E-06	0.001587	0.001595	1.19E-08	2.00E-08	1.00E-08
0.74658656	930.941896	234.385949	16.05848	0.1676293	0.09309419	143.098984	181.33838	0.002087455	6.13E-17	3.07E-17

How to use:
1. Collect historical data from similar projects in the format as shown in Table 4: Data for fitiing Leontief model.
2. Input historical data in SAS code (Appendix 8.2) to estimate the parameters.
3. From SAS results, use the value of parameters estimated and input them in Matrix A in the MS Excel file. The value of parameters should be input in Matrix A in the form :

$$\begin{bmatrix} A_{01} & A_{02} & A_{03} & A_{04} & A_{05} & A_{06} & A_{07} & A_{08} & A_{09} & A_{010} & A_{011} \\ A_{11} & A_{12} & A_{13} & A_{14} & A_{15} & A_{16} & A_{17} & A_{18} & A_{19} & A_{110} & A_{111} \\ A_{21} & A_{22} & A_{23} & A_{24} & A_{25} & A_{26} & A_{27} & A_{28} & A_{29} & A_{210} & A_{211} \end{bmatrix}$$

4. Input the value for the input variables – amount of money invested and number of manpower hired in the MS Excel file.
5. The results for the output variables are thus obtained.

Outputs	
Y_1 -Number of Jobs Created =	208.58212
Y_2 - Increase in Tax Revenue ($) =	708225.43
Y_3 - Increase in Local Business Revenue ($) =	2323660.7
Y_4 - Increase in Utility Revenue ($) =	58344.463
Y_5 - Decrease in Passenger's Travel Time (minutes/passenger) =	110.66025
Y_6 - Decrease in Travel Cost for the Passengers ($/passenger) =	70.822543
Y_7 - Decrease in Costs Accumulated by Shippers ($) =	71877.048
Y_8 - Decrease in Costs Accumulated by Receivers ($) =	82250.221
Y_9 – Increase in corridor capacity (%) =	79%
Y_{10} – Increase in level of service (%) =	56%
Y_{11} – Increase in Accessibility (%) =	28%

Outputs

How to use the excel file:

1. Collect historical data from similar projects in the format as shown in Table 4: Data for fitting Leontief model.
2. Input historical data in SAS code (Appendix 8.2) to estimate the parameters.
3. From SAS results, use the value of parameters estimated and input them in Matrix A in the MS Excel file. The value of parameters should be input in Matrix A in the form:

$$\begin{bmatrix} A_{01} & A_{02} & A_{03} & A_{04} & A_{05} & A_{06} & A_{07} & A_{08} & A_{09} & A_{010} & A_{011} \\ A_{11} & A_{12} & A_{13} & A_{14} & A_{15} & A_{16} & A_{17} & A_{18} & A_{19} & A_{110} & A_{111} \\ A_{21} & A_{22} & A_{23} & A_{24} & A_{25} & A_{26} & A_{27} & A_{28} & A_{29} & A_{210} & A_{211} \end{bmatrix}$$

4. Input the value for the input variables – amount of money invested and number of manpower hired in the MS Excel file.
5. The results for the output variables are thus obtained.

8.5 Appendix 5A: Excel sheets and instructions on how to use excel file for the numerical example on Bayesian Approach

Excel Sheet: Bayesian Approach- Expert Survey Data

Bayesian Approach- Expert Survey Data

Conditional Probability Tables(CPT) from Obtained From Experts' Surveys

Insert the conditional probabilities collected from expert interviews and surveys for the respective combinations in the boxes highlighted yellow.

Table 1: Amount of Money Invested and Service Requirement

Amount of Money Invested (node D1)	Service Requirement (node C1)		
	Low	Moderate	High
Low: < $500,000	0.9	0.1	0
Moderate: $500,000-$5,000,000	0.1	0.6	0.3
High: >$5,000,000	0	0.3	0.7

Table 2: Amount of Money Invested and Effect on Degree of Urbanization

Amount of Money Invested (node D1)	Degree of Urbanization (node C2)	
	Low	High
Low: < $500,000	0.9	0.1
Moderate: $500,000-$5,000,000	0.6	0.4
High: >$5,000,000	0.2	0.8

Insert the conditional probabilities collected from expert interviews and surveys for the respective combinations in the boxes highlighted yellow.

Table 3: Manpower Hired and Degree of Urbanization

Manpower Hired (node D2)	Degree of Urbanization (node C2)	
	Low	High
Low: < $500,000	0.9	0.1
Moderate: $500,000-$5,000,000	0.6	0.4
High: >$5,000,000	0.2	0.8

Table 4: Service Requirement and Jobs Created

Service Requirement (node C1)	Number of Jobs Created (node O1)		
	Low: <50	Moderate : 50-250	High: >250
Low	0.9	0.1	0
Moderate	0.2	0.6	0.2
High	0.1	0.1	0.8

Table 5: Service Requirement and Increase in Tax revenue

Service Requirement (node C1)	Increase in Tax Revenue (node O2)		
	Low	Moderate	High
Low	0.9	0.1	0
Moderate	0.1	0.6	0.3
High	0.1	0.7	0.2

Table 6: Degree of Urbanization and Number of Jobs Created

Degree of Urbanization (node C2)	Number of Jobs Created (node O1)		
	Low: <50	Moderate : 50-250	High: >250
Low	0.8	0.2	0
High	0.1	0.3	0.6

Excel Sheet: Bayesian Approach: Calculations (Part 1)

Bayesian Approach - Calculations

Decision Items		Degree of Urbanization (node C2)	
Amount of Money Invested (node D1)	Manpower Hired (node D2)	Low	High
Low	Low	0.99	0.19
Low	Moderate	0.96	0.46
Low	High	0.92	0.82
Moderate	Low	0.96	0.46
Moderate	Moderate	0.84	0.64
Moderate	High	0.68	0.88
High	Low	0.92	0.82
High	Moderate	0.68	0.88
High	High	0.36	0.96

Evaluation Criteria		Number of Jobs Created node (O1)		
Service Requirement (node C1)	Degree of Urbanization (node C2)	Low: <50	Moderate: 50-250	High: >250
Low	Low	0.98	0.28	0
Low	High	0.91	0.37	0.6
Moderate	Low	0.84	0.68	0.2
Moderate	High	0.28	0.72	0.68
High	Low	0.82	0.28	0.8
High	High	0.19	0.37	0.92

Objective variable	Alternate states	Rating Scale
1. Number of jobs created (node O1)	Low	1
	Moderate	5
	High	9
2. Increase in Tax Revenue (node O2)	Low	1
	Moderate	5
	High	9

Excel Sheet: Bayesian Approach- Calculations (Part 2)

For Decision State: - "Moderate" Amount of Money Invested and "High" Manpowered Hired

Pr (Low Jobs Created) =	(Pr("Low" C1)*Pr("Low" C2)*Pr("Low"O1)) + (Pr("Medium" C1)*Pr("Low" C2)*Pr("Low"O1)) + (Pr("High" C1)*Pr("Low" C2)*Pr("Low"O1)) +(Pr("Low" C1)*Pr("High" C2)*Pr("Low"O1)) +(Pr("Moderate" C1)*Pr("High" C2)*Pr("Low"O1)) +(Pr("High" C1)*Pr("High" C2)*Pr("Low"O1))
Pr (Low Jobs Created) =	0.85472
Pr (Moderate Jobs Created) =	(Pr("Low" C1)*Pr("Low" C2)*Pr("Moderate"O1)) + (Pr("Medium" C1)*Pr("Low" C2)*Pr("Moderate"O1)) + (Pr("High" C1)*Pr("Low" C2)*Pr("Moderate"O1)) +(Pr("Low" C1)*Pr("High" C2)*Pr("Moderate"O1)) +(Pr("Moderate" C1)*Pr("High" C2)*Pr("Moderate"O1)) +(Pr("High" C1)*Pr("High" C2)*Pr("Moderate"O1))
Pr (Moderate Jobs Created) =	0.864
Pr (High Jobs Created) =	(Pr("Low" C1)*Pr("Low" C2)*Pr("High"O1)) + (Pr("Medium" C1)*Pr("Low" C2)*Pr("High"O1)) + (Pr("High" C1)*Pr("Low" C2)*Pr("High"O1)) +(Pr("Low" C1)*Pr("High" C2)*Pr("High"O1)) +(Pr("Moderate" C1)*Pr("High" C2)*Pr("High"O1)) +(Pr("High" C1)*Pr("High" C2)*Pr("High"O1))
Pr (High Jobs Created) =	0.89952
Pr(Low Increase in Tax Revenue) =	(Pr("Low" C1* "Low" O2))+(Pr("Moderate"C1)*Pr("Low" O2))+(Pr("High"C1)*Pr("Low"O2))
Pr(Low Increase in Tax Revenue) =	0.18
Pr(Moderate Increase in Tax Revenue) =	(Pr("Low" C1* "Moderate" O2))+(Pr("Moderate"C1)*Pr("Moderate" O2))+(Pr("High"C1)*Pr("Moderate"O2))
Pr(Moderate Increase in Tax Revenue) =	0.58
Pr(High Increase in Tax Revenue) =	(Pr("Low" C1* "High" O2))+(Pr("Moderate"C1)*Pr("High" O2))+(Pr("High"C1)*Pr("High"O2))
Pr(High Increase in Tax Revenue) =	0.24

E(Number of Jobs created) = Rating*Pr(Low Jobs Created) + Rating* Pr(Moderate Jobs Created) + Rating*(High Jobs Created)

Amount of Money Invested	Manpower Hired	Expected value of objective functions	
		Jobs Created	Increase in Tax Revenue
Moderate	High	13.2704	5.24

Output for the decision combination "moderate" amount of money invested and "high" number of manpower hired

How to use the excel file for the numerical example in Bayesian approach:

1. Collect the data for conditional probability values from expert interviews and surveys.

2. Form conditional probability tables as shown in the MS Excel sheet "Bayesian Approach- Expert Survey Data". A conditional probability table is formed between the alternate states of two variables that are interconnected.

3. Once the conditional probability tables are formed, combined probability tables are constructed. Combined probability tables are made for the child nodes with all its parent nodes form the Bayesian network diagram (Figure 4).

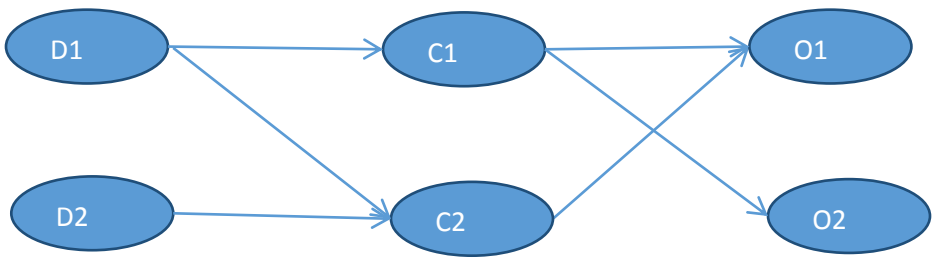


Figure 4: Bayesian network for the numerical example

Parent nodes are connected to the child nodes with an arrow. The node at the arrowhead is the child node and the node at the tail of the arrow is the parent node. For example in the diagram above, D1 and D2 are the parent nodes for C2, D1 is also the parent node for C1. Similarly, for node O1 (child node), node C1 and C2 are the parent nodes and for child node O2, C1 is the parent node.

4. Enter the values for conditional probability in the excel sheet "Bayesian Approach- Expert Survey Data".

5. Values for the combined probability tables will be calculated in the excel sheet "Bayesian Approach-Calculations".

The formula used to calculate the probabilities in combined probability table is:

$$\Pr(x_0|x_p) = 1 - \prod_{i:Xi \in Xp} (1 - p_i)$$

Where x_0 is the child node, x_p is the parent nodes.

6. After entering the data, the expected value of the objective function will be calculated for a combination of the decision items. The expected values for the objective function for each combination of the alternate states of the decision items are calculated using the formula:

$$E(O_a) = \sum_{o_a} o_a \Pr(O_a)$$

Where O_a is the objective function for one combination of decision items, and o_a is the rating or score given to the objective functions by the experts.

The above steps can be followed to calculate the objective function for each combination of decision items.

Note: This is an excel model for the numerical example for Bayesian approach (Section 5.4). As more variables would be included, additional conditional probability tables would be needed to capture the relationship between each interconnected variables and hence more combined probability tables will need to be created.

8.6 Appendix 6A: SAS Code for System Dynamics Approach

```
data railroad;
input x1 x2 y1 y2 y3 y4 yt;
datalines;
10000000 40 265000 215000 145000 100000 300000
15000000 48 350000 275000 225000 175000 400000
5000000 24 140000 110000 80000 55000 180000
8000000 30 210000 175000 115000 90000 250000
17000000 55 385000 325000 260000 210000 450000
22000000 60 650000 585000 520000 475000 700000
proc reg data = railroad;
model yt = x1 x2 y1 y2 y3 y4;
run;
```

8.7 Appendix 7A: SAS Results for System Dynamics Approach

The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: yt

Number of Observations Read	6
Number of Observations Used	6

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	1.71E11	34200000000	.	.
Error	0	0	.		
Corrected Total	5	1.71E11			

Root MSE	.	**R-Square**	1.0000
Dependent Mean	380000	**Adj R-Sq**	.
Coeff Var	.		

Note: Model is not full rank. Least-squares solutions for the parameters are not unique. Some statistics will be misleading. A reported DF of 0 or B means that the estimate is biased.

Note: The following parameters have been set to 0, since the variables are a linear combination of other variables as shown.

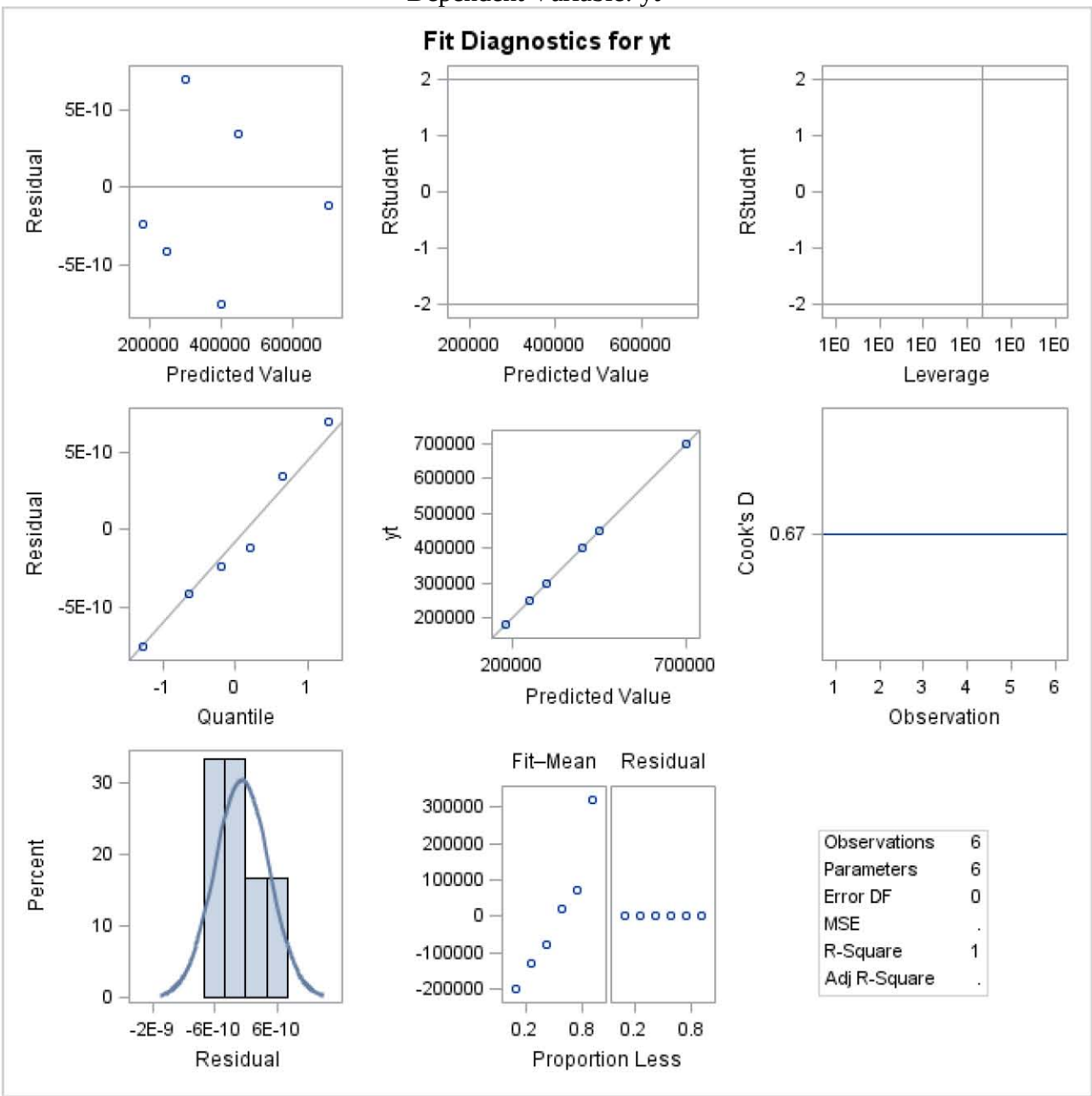
y4 = 19421.5 * Intercept + 0.00568 * x1 - 2418.94 * x2 - 0.42594 * y1 + 0.45416 * y2 + 0.93655 * y3

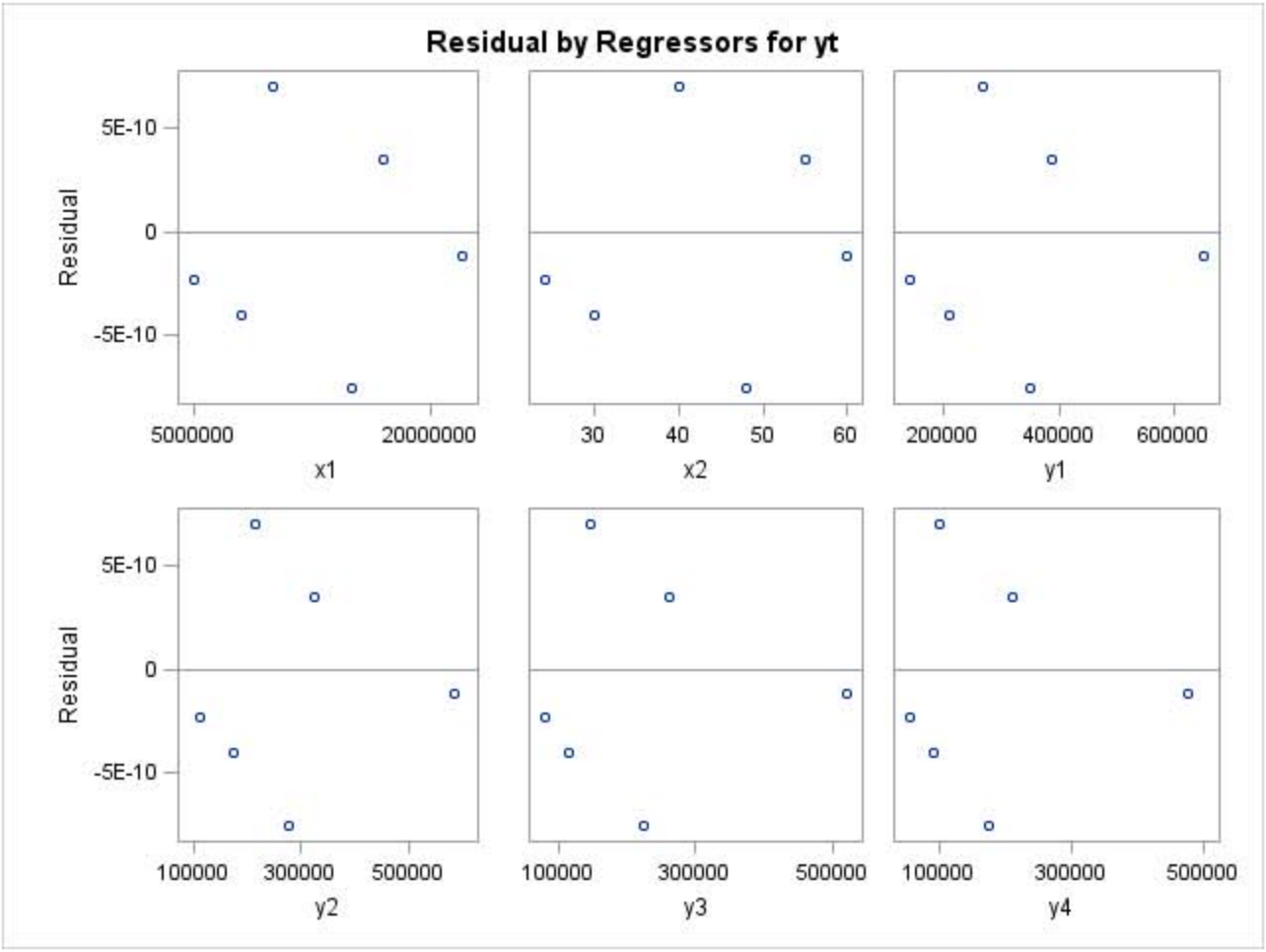
Parameter Estimates

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	**B**	50048	.	.	.
x1	**B**	0.00805	.	.	.

Parameter Estimates					
Variable	**DF**	**Parameter Estimate**	**Standard Error**	**t Value**	**Pr > |t|**
x2	**B**	149.07649	.	.	.
y1	**B**	0.20684	.	.	.
y2	**B**	0.32381	.	.	.
y3	**B**	0.26919	.	.	.
y4	**0**	0	.	.	.

The REG Procedure
Model: MODEL1
Dependent Variable: yt




Residual by Regressors for yt
Residual
5E-10
0
-5E-10
5000000
20000000
x1
30
40
50
60
x2
200000
400000
600000
y1
100000
300000
500000
y2
y3
y4