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**Multi-Objective Approach to Road Network Optimization:  
A Case of Freight Route in Nepal**

**by:**

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A THESIS

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## ABSTRACT

Transportation cost of freight associated with import and export imposes high level impact on consumer end in case of land locked countries like ours. Basically, the pre-haul and end-haul are prone to higher unit cost of transport characterised by uncertain situations during the haulage process. This result in additional cost to the consumer of the freight, for which they do not enjoy benefit. Capacity reliability is the function of driver's preference to choose the path of travel and a multiplier set to adjust the reserve capacity of the network. Hence the increase in reserve capacity of the road increases the capacity reliability of the road network.

Transportation authorities want the capacity reliability benefits derived from the improvement of road networks to be fairly distributed across the different parts of a country or a region because uneven welfare gains are not desired due to sustainable development objectives of public sectors.

This is why decision maker (DM) gets interested in maximizing the reserve capacity of road network. Contrary to this, emphasis is placed by decision makers to minimize the construction cost for the upgrading inventory. These two objectives are not compatible among themselves and thus require multi-objective analysis for simultaneous optimization. Multi objective decision problems have been of increasing interest to management scientists, due to the realization that many problems, particularly those of strategic nature and more particularly those in public sector, most explicitly consider multiple criteria if they are to be resolved with truly good decisions.

A non-dominated solution is a vector of solution for which none of the objective functions can be optimised without degrading some other objectives. In case if solutions are free from additional subjective preference, all non-dominated solutions are considered equally good. Multi-objective optimization problems are studied from different viewpoints in different researches and, there exist different solution philosophies while solving them. This work aims in finding a set of Pareto optimal (Non-dominated) solutions, and discuss the trade-offs between the different objectives,

and hence clarify the optimal solution strategy might meet the subjective preferences decision maker (DM).

Here the non-dominated solutions are worked out to present multi-objective decision technique to suggest network optimization solutions at two contrasting objective functions. (i.e. maximizing reserve capacity of network, minimizing construction (upgrading) cost).

***Keywords:*** *Non-dominated solutions, Reserve capacity, Freight Network, Multi-objective optimization.*

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## LIST ACRONYMS AND ABBREVIATIONS

AD	Anno Domini
BS	Bikram Sambat
CBS	Central Bureau of Statistics (Nepal)
DM	Decision Maker
DOLIDAR	Department of Local Infrastructure and Agricultural Roads (Nepal)
DOR	Department of Roads (Nepal)
DoTM	Department of Transport Management, (Nepal)
E.g.	Example
et al.	et alii (and others)
etc.	Et cetera (and other things / and so forth)
GAs	Genetic Algorithms
GON	Government of Nepal
i.e.	id est (that is), further explanation
ICD	Inland Clearance Depot
IOE	Institute of Engineering
JIT	Just in Time
KM	Kilo meter
LRN	Local Road Network
MOIP	Multiobjective Integer Programming
MOMIP	Multiobjective mixed-integer Programming
MOP	Multi Objective problems
MOPIT	Ministry of Physical Infrastructure and Transport (Nepal)
NDP	Network Design Problem
OD	Origin – Destination
OECD	Organisation for Economic Co-operation and Development
OR	Operation Research
ROW	Right of Way
SRN	Strategic Road Network
TU	Tribhuvan University
viz.	videlicet (namely / that is to say / as follows)

# CHAPTER ONE: INTRODUCTION

## 1.1 Problem Description

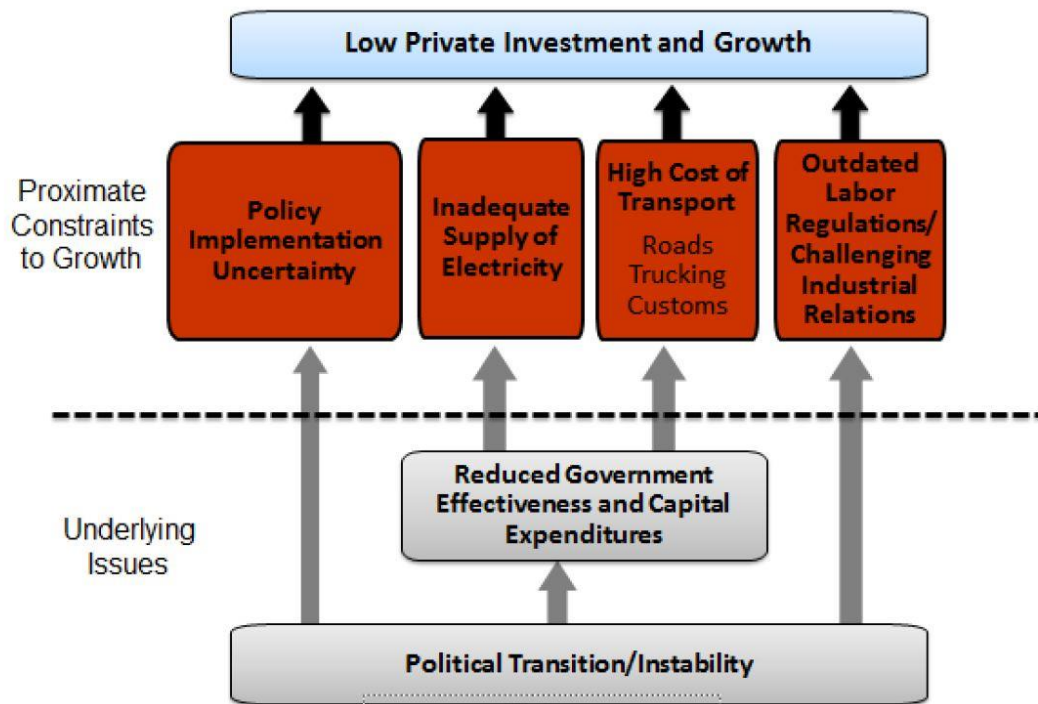
Transportation cost of freight associated with import and export imposes high level impact on consumer end in case of land locked countries like ours. The freight transportation market has undergone several changes in trends in search of economic haul in world scenario. A freight transportation is presently carried as a bundle of tasks, rather than a single job. The transportation chain is basically partitioned in three segments: (i) *pre-haul* – first mile for the pickup process, (ii) *long-haul* – transit of freight units, and (iii) *end-haul* – last mile for the delivery process. In most cases, the pre-haul and end-haul is carried out via road, while road, rail, air and water modes are considered for the long-haul. It is hence the transportation chain completes through combination of different modes, conventionally termed as multimodal transport. Basically, the pre-haul and end-haul are prone to higher unit cost of transport characterised by uncertain situations during the haulage process. Smaller scale of goods is also one of the factor to contribute for higher cost in this stage of multimodal transport.

In case of developing countries, the problem of uncertainties of freight transport associated with loss in connectivity, congestion and other kind of disruptions are often faced. Unlike, passenger transport which enjoys higher level of priority in road movement, freight movement frequently suffers from delays due to such uncertainties. This result in additional cost to the consumer of the freight, for which they do not enjoy benefit. Doing Business Report by the World Bank cites high level of uncertainty in case of freight transportation is one among the hindrance for efficient business environment in Nepal.

*MCC et al., 2014* identifies growth syndrome in context of Nepal that describes the overarching nature of the failure of the government that results in constraints to growth. The results of the growth diagnostic study highlight the foundational role of government instability in Nepal's economy. Instability has led to reductions in the

quantity and quality of capital expenditures on infrastructure, which contributes to constraints in electricity and transportation.

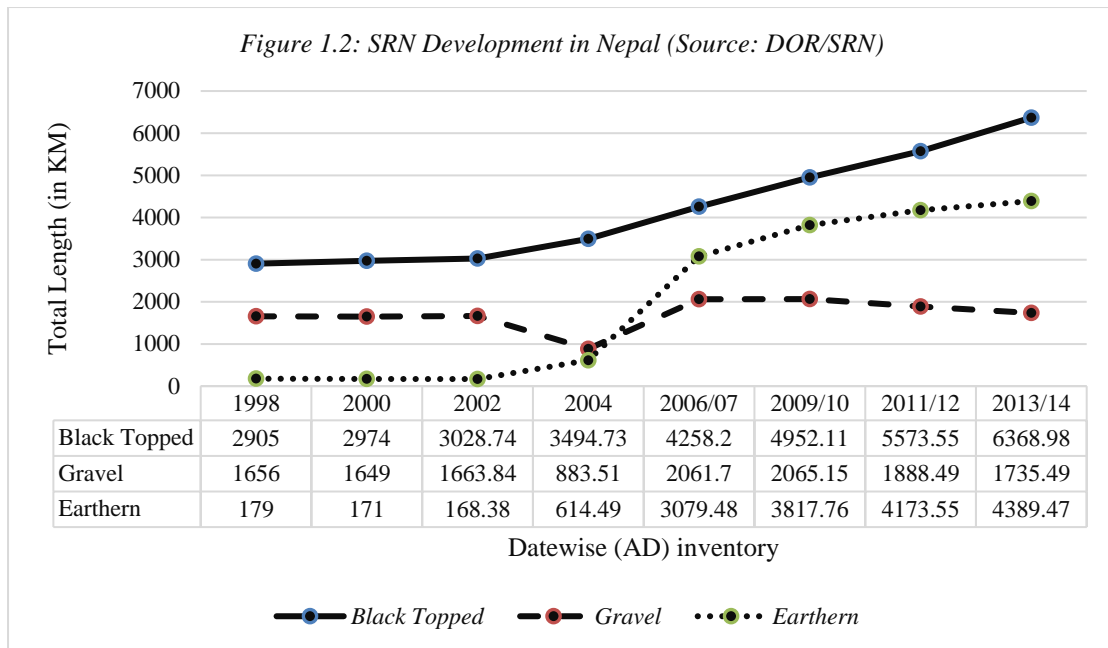
Figure 1.1: Nepal's Growth Constraints and Syndrome (Source: MCC et al., 2014)



Highway expansion has been a focus of efforts to accommodate increasing passenger in urban areas however expansion of highways because of freight demand is overlooked most often. Limited highway capacities which must simultaneously serve the needs of goods movement and passenger transportation eventually cause problems in transportation system. From the trucking industry perspective, congestion problems have five primary aspects. These are slow average speeds, unreliable travel times, increased driver frustration and accompanying lower morale, higher fuel and maintenance costs, and higher costs due to accidents and insurance. The most problematic aspect among these five is the reliability of travel times followed by driver frustration and morale, then by slow average speeds (Golob and Regan, 2001). Additionally, congestion causes increase in accidents and externalities such as air and noise pollution and, in today's climate, one of the most important externalities is the fuel consumption. More interestingly, marginal cost of delay is much high in case of freight traffic when compared to passenger traffic.

A transportation system should maintain an acceptable level of service in spite of the deterioration of certain roadways in the network. The stability in the transportation system reflects the quality of service it would normally provide. A stable transportation system would provide a competitive edge in the global economy. (*Chen et al., 2002*). Moreover, the studies on reliability are concentrated either on *Connectivity reliability* or on *Travel time reliability*. However, none of the above measures addresses the issue of adequacy of network capacity to accommodate demand (*Chen et al., 1999*). Recently in 1999, *Chen et al.* introduced capacity reliability as a new performance measure to evaluate the performance of a network. Capacity reliability is defined as the probability that a network can accommodate a certain traffic demand at a required Level of service. The study considers the capacity reliability as the function of driver's preference to choose the path of travel and a multiplier set to adjust the reserve capacity of the network. We hereby can conclude that the increase in reserve capacity of the road increases the capacity reliability of the road network.

In context of Nepal, continuous efforts are being made for strengthening of roadway connectivity. Figure below shows development of Strategic road network in terms of KM that reflects such effort. However, such improvement posed for betterment eventually gets misguided due to improper tools utilized for its planning. Likewise, problems are often faced due to fluctuation of resources allocated during the time of planning. To mention one among many others, the annual budget allocated at the beginning of the fiscal year often gets changed in each of trimesters. Such fluctuations in resource allocation requires higher effort to update the plans to cope with the fluctuations. Unless an effective tool is in place for updating of the planning the ultimate aim of the improvement gets distorted due to subjectivism imposed during the updating. Such situations seen at stages of planning seeks overwhelming need of an objective modal to scrutinise the change scenario to come up with new plans that always sticks with the optimal solutions.



## 1.2 Reserve capacity of network

Transport networks forms a bloodline for a nation’s good supply. Occasional disruption seen in these networks incurs significant resource consumption for being recovered. Potential sources of disruption to transportation networks are numerous, ranging from major exceptional events (e.g. natural or man-made disasters) to minor regular events (e.g. daily recurrent congestion). The scale, impact, frequency, and predictability of these abnormal events also vary enormously. Network reliability is the ability of entire transport network system to withstand disruptions that can cause significant reduction in network services.

With increasing demands for better and more reliable services, many systems (E.g. electric power systems, water distribution systems, communication networks etc.) have incorporated reliability analysis as an integral part in their planning, design, and operation. However, reliability analysis has not received sufficient attention in the study of road networks in spite of its importance. Moreover, existing reliability studies are mainly limited to connectivity and travel time reliability. These reliability measures are useful for assessing different factors related to the performance of transportation network. However, none of the above measures address the issue of adequacy of network capacity to accommodate demand. That is, whether the available network

capacity relative to the required demand is sufficient (*Chen et al., 2002*). Capacity reliability provides important information for efficient flow control, capacity expansion, and other relevant works to enhance the reliability of road network. Capacity reliability is a function of network reserve capacity, details in *Wong et al., 1997*.

The concept of reserve capacity has been used extensively for performance measure and timing design of individual signal-controlled intersections. It was originally proposed by *Webster et al., 1966* to analyse a simple, isolated signal-controlled intersection. Recently, *Wong et al., 1997* further extended the concept of reserve capacity for a general road network to estimate the maximum network capacity under a route choice model. *Wong et al., 1997* measured the reserve capacity for a road network by how large a common multiplier can be applied to an existing origin destination (O-D) matrix subject to the flow on each link not exceeding a prescribed degree of saturation. When the demand of the network is increased to an amount close to its full capacity, traffic congestion will have substantial effects on the distribution of flow over the network. This would result in a change in traffic-flow pattern and hence a different value of the reserve capacity.

Reserve capacity is thus defined as the largest multiplier applied to a given existing (or basic) OD matrix that can be allocated to a network without violating the arc capacities. Namely, the maximum OD matrix multiplier is sought subject to the arc flows resulting from the network equilibrium problem not exceeding the arc capacities. Through this interrelation it can be inferred that the decision maker (DM) gets interested in *maximizing the reserve capacity* of road network.

### **1.3 Construction cost of road**

As stated earlier the reserve capacity in a network can be increased by increasing the arc capacities. This can be achieved through addition of lane or through traffic operational optimization. Since, the freight network is not an urban roadway, so they are not often bottle necked by intersections. Freight transportation link forms a part of an intercity highway, hence the increase in lane helps to enhance the road reserve

capacity through addition of inventory. However, emphasis is placed by decision makers to *minimize the construction cost* for upgrading the road inventory.

Construction cost associated in increasing reserve capacity through addition of lane is of interest in the study. Road inventory consists of different cost factors, viz. ROW Land cost, Route opening cost, Soil stabilization cost, Traffic lane construction cost, Structural cost, Roadway furniture cost, etc. This study more concentrated with the expansion cost which basically focuses the traffic lane construction cost and some of other costs to some extent. Such cost can be adopted through sample survey of ongoing expansion projects, cost excluding the structural costs. Practically, cost of expansion in different section within the network varies. For rigorous exercise, different costing scenario can be exercised. In spite of this, such variation can be addressed statistically through average of costs in different locations and terrains as a simplification.

#### **1.4 Multi-objective analysis**

As discussed in earlier paragraphs, it can be seen that the decision may have multiple natured objectives to fulfil their search for optimal solutions. The Network Design Problem (NDP) involves the optimal decision on the expansion of a street and highway system in response to a growing demand for travel. It has emerged as an important area for progress in handling effective transport planning, because the demand for travel on the roads is growing at a rate faster than our urban transport systems can ever hope to accommodate, while resources available for expanding the system capacity remain limited (*Yang et al., 1998*). Pareto optimal solutions allow the DM to choose, from a set of significant alternatives, the solution(s) which better reflects aspects (possibly not considered in the mathematical model) of the real-world scenario (*Shrestha et al., 2013*).

A solution set of Multiobjective function for two arbitrary solutions are related to each other in two possible ways: in the first way is optimal solution in first objective dominates the objective of the second; in other way neither of the objective function dominates each other (*Zitzler et al., 2000*).

To understand the concept of non-dominated solution, let us consider a multiobjective minimization problem with  $\mathbf{m}$  decision variables (parameters) and  $\mathbf{n}$  objectives:

$$\text{Minimize } \mathbf{y} = f(\mathbf{x}) = (f_1(\mathbf{x}), f_2(\mathbf{x}), \dots, f_n(\mathbf{x}))$$

$$\text{Where } \mathbf{x} = (x_1, x_2, \dots, x_m) \in \mathbf{X}$$

$$\mathbf{y} = (y_1, y_2, \dots, y_n) \in \mathbf{Y}$$

Here,  $\mathbf{x}$  is the decision vector,  $\mathbf{X}$  parameter space,  $\mathbf{y}$  objective vector, and  $\mathbf{Y}$  objective space. In such case, a decision vector  $\mathbf{a} \in \mathbf{X}$  is said to dominate a decision vector  $\mathbf{b} \in \mathbf{X}$ , (commonly expressed as  $\mathbf{a} < \mathbf{b}$ ) if and only if;

$$\forall i \in \{1, \dots, n\} : f_i(\mathbf{a}) \leq f_i(\mathbf{b}) \wedge$$

$$\exists j \in \{1, \dots, n\} : f_j(\mathbf{a}) < f_j(\mathbf{b})$$

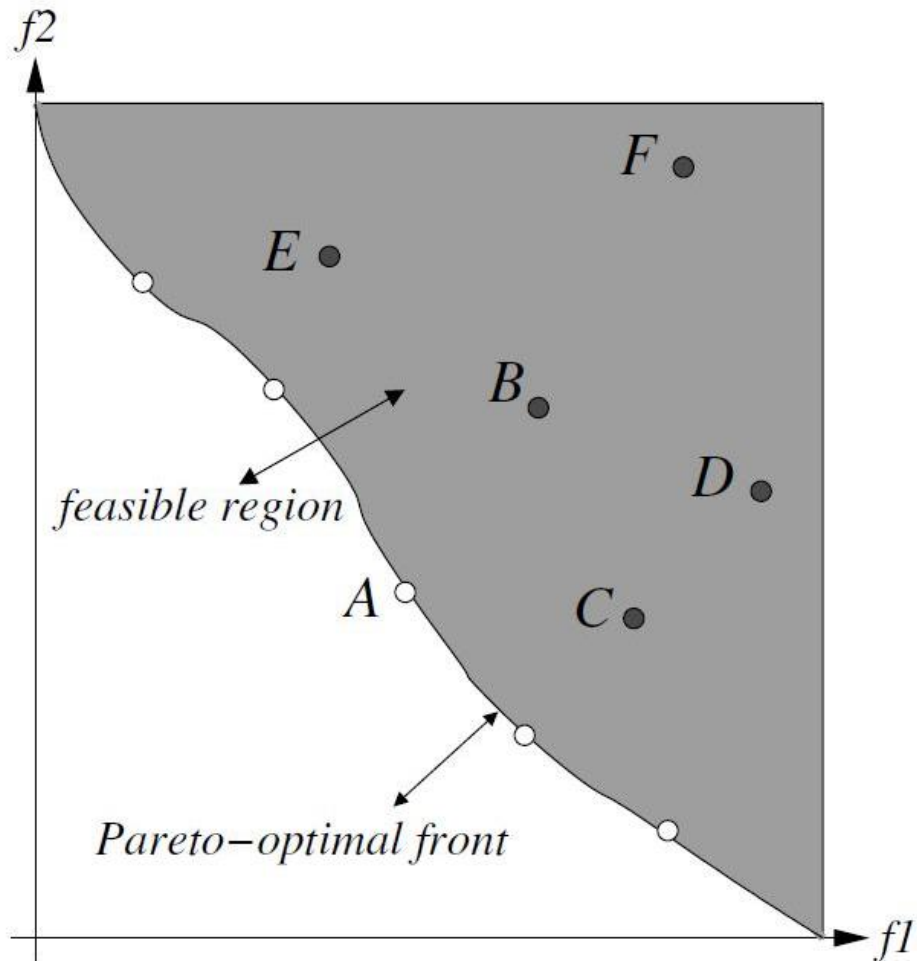
Again based on the above relation, the decision vector  $\mathbf{a}$  is said to be nondominated regarding a set  $\mathbf{X}' \subseteq \mathbf{X}$  if and only if there is no vector in  $\mathbf{X}'$  which dominates  $\mathbf{a}$ ; expressed as;

$$\nexists \mathbf{a}' \in \mathbf{X}' : \mathbf{a}' < \mathbf{a}$$

The decision vector  $\mathbf{a}$  is Pareto-optimal if and only if  $\mathbf{a}$  is nondominated regarding  $\mathbf{X}$ .

Pareto-optimal decision vectors cannot be improved in any objective without causing a degradation in at least one other objective; in other words, they represent globally optimal solutions. However, analogous to single-objective optimization problems, there may also be local optima which constitute a nondominated set within a certain neighbourhood. Details on concept of global and local Pareto-optimal sets is introduced and explained in *Deb, 1999*.

Figure 1.3: Graphical interpretation of pareto dominance



Multi objective decision problems have been of increasing interest to management scientists, due to the realization that many problems, particularly those of strategic nature and more particularly those in public sector, most explicitly consider multiple criteria if they are to be resolved with truly good decisions. At the same time, some progress has been made on the theoretical and computational sides, and a number of different techniques are presently available to help decision makers handle multiple decision problems.

## 1.5 Objectives

The primary goal of this study is to adopt a multiobjective optimization techniques to resolve problems under variable resources and limited database for its prediction. To reach the goal set forth, following objectives have been marked. This study utilizes

multiobjective solution approach using weighted sum program suggested by *Soland et al., 1979* to reach the objectives:

- To develop a multi-objective decision tool (model) for road network optimization problem at two contrasting objective functions. (i.e. maximizing reserve capacity of network, minimizing construction cost of upgradation)
- To present network optimization problems using the developed decision model in case study of freight route in Nepal.

## **1.6 Study Area and Limitations**

Operation research techniques are interestingly useful in making optimal decisions in the field of both management and science. Multiobjective approach to a problem having conflicting objective functions can easily be dealt using OR techniques. This study attempts in making effort to propose a decision tool using multiobjective optimization approach. Portion of road network in Nepal, which are of importance to freight movement is considered for case study of the model. The candidate network is selected based on present day utilization of routes by the freight traffic.

Because of different rational constraints in spite of which the study has been made, this thesis is bound to following limitations:

- Probabilistic approach to route choice model within capacity reliability has been kept constant to control the scope of study within scope of network planning. Introduction of route choice model to define capacity reliability is more associated to complex probabilistic modelling.
- The cost for upgradation is generalised for both Terai and hilly region to control the scope of study.
- Distorted samples are likely to incur due to probable unusual traffic scenario because of recent incidents. i.e. massive earthquake, political movement in Terai.
- Small inland points of entry are assumed to be represented by nearest larger entry point.

- Historical data for Rasuwa ICD is different due to breakdown of road network to Tatopani.
- Data adopted through secondary sources reflect the limitations of respective sources.

## **1.7 Organization of the report**

The report is organized in five chapters. The present chapter i.e. chapter one deals with the descriptive introduction, statement of problem and objectives associated with this thesis. Relevant definitions, introduction and rationale of the study is discussed in this chapter.

Second chapter in this report encompasses literature review. This chapter presents the studies in different aspects of topic of interest that exist in existing body of knowledge. A general perspective of studies in this sector are discussed under this heading. Multiobjective optimization techniques that prevails in management science are included to significant depth and analytics. Likewise, the construction (upgrading) cost minimization and reserve capacity maximization function are discussed in relation with previous studies.

Based on ideas gained through literatures, objective of this thesis is formulated into a model in third chapter considering practical knowhow of the parameters of interest. It discusses the multi objective problem for the case of maximizing the reserve capacity of the road and minimizing the construction (upgrading) cost for additional improvement of the network.

Chapter four covers the methodology adopted for the study. The chapter simultaneously highlights the methodology along with summary of analysed raw data to more clearly explain the method followed.

Fifth chapter is a presentation of outputs being analysed and discussed in connection with the theoretical aspect of the parameters under consideration.

The sixth chapter provides conclusion of the study.

## **CHAPTER TWO: LITERATURE REVIEW**

In this chapter, the concept of relevant research in the domain of objective under consideration is drawn through review of literatures. The literature related to multi objective decision making, reliability and reserve capacity and costing of transport system are dealt with major emphasis. Likewise, freight transportation related literatures in context of Nepal and similar developing nations are reviewed with special interest. Seeking the clarity in the research question, the review of different topic is illustrated in the following section. The sequence of review theme is; multi objective optimization, Reliability studies and Reserve capacity, cost in road sector, and network scenario in this research context.

### **2.1 Multi objective optimization Problems**

Issues on freight transportation in developing and land locked countries cannot be addressed only through transport engineering and management. Many other prominent sector leaves impact on the freight transport. However, transportation engineering and infrastructures are core factors to improve the trade economy, as improvement of freight transport condition imparts tremendous impact upon the goods price. From transportation planning point of view, main two categories of research are involved in this issue: Network planning, infrastructure development. In network planning sector, most of the research deals with topologies using operation research techniques while others deal with transport management involving traffic engineering. Below presented are few research which are aimed at optimization of transportation system through multiobjective approaches.

Network Design Problem (NDP) addresses how to construct a network that optimizes the objective efficiency criteria while considering limitations which can come from resource constraints or specific problem requirements. Although there are many different network design studies, they can be classified into two main groups by their different primary goals. The first goal mainly belongs to the public sector which intends to improve transportation infrastructure for social benefits. Traffic movements and

traffic problems that surround the infrastructure are the main concerns. In this network design problem, the network representation shows the physical characteristics of the infrastructure including the geographic locations and the capabilities of transportation links and facilities. The solutions are directly applied to this physical network. This work is aligned to the physical network design problem. In the other hand, the second goal belongs to the private sector companies which intend to use the infrastructure in order to fulfil their needs. These problems are vehicle routing problems or scheduling problems which can be represented by network schemes. The traffic congestion on links usually is not considered. The travel time used to compute the shortest paths is the average travel time. The service NDP is studied extensively in the package delivery industry such as aircraft fleet and routing, (*Armacost et al., 2004*) and truck routing, (*Lin and Chen, 2004*).

Many methods scalarize the objective vector into a single objective while solving the multiobjective problems. In such cases, the obtained solution is highly sensitive to the weight vector used in the scalarization process and demands that the user have knowledge about the underlying problem. Moreover, in solving multiobjective problems, designers may be interested in a set of Pareto-optimal points, instead of a single point. *Srinivas and Deb, 1995* investigate nondominated sorting in Genetic Algorithms (GAs) to find multiple Pareto-optimal points simultaneously.

*Santos et al., 2009* presents a multiobjective approach to long-term interurban multilevel road network planning. In addition to the efficiency objectives dealt with in most of the literature where the subject is addressed, their approach takes into account robustness and equity objectives. To fulfil the set objectives of their research, they consider that two types of action can be performed: the construction of a new road of a given level; and the upgrading of an existing road to a higher level. The application of their approach is illustrated for a case study involving the main road network of Poland in the same work.

*Miandoabchi et al., 2011* investigates a bimodal discrete urban road network design problem with bus and car modes. The problem consists of decision making for lane addition to the existing streets and new street constructions among others. They consider following two objectives in the problem: maximization of consumer surplus, and maximization of the demand share of the bus mode. The work mainly contributes

for proposing a new network design problem that combines the road network design decisions with the decision making for bus networks. The problem is formulated as a mathematical program with equilibrium constraints. Through the paper, they propose three different multiobjective algorithms in which they incorporate simulated annealing approach to reach the best decision. Those algorithms use a distance-based fitness evaluation method to capture the multi-objectivity of the problem and generate a set of Pareto-optimal solutions.

*Magnanti and Wong, 1984* introduces the equilibrium network design problem in a single level optimization, which can be viewed as a bi-level problem. Not only does the bi-level form of the problem clearly explain the model's behaviours, it also inspires many solution algorithms. *Friesz, 1985* and *Yang and Bell, 1998* survey the network design studies focusing on the equilibrium network design. They presented an interesting generic framework for network design models.

Beside these, various contributions can be found for Multi objective optimization in Engineering and Management sector. *Alves and Joao, 2006* makes a review of interactive methods devoted to multiobjective integer and mixed-integer programming (MOIP/MOMIP) problems. In the paper the authors have tried to draw out some contrasts and similarities of the different types of methods.

## **2.2 Reliability studies and reserve capacity**

Reliability is unanimously regarded as a desirable transport network attribute. However, Literatures on transport reliability, defines transport reliability in number of different ways. The choice of definition differs based upon the approach adopted to perceive the term and its context of use.

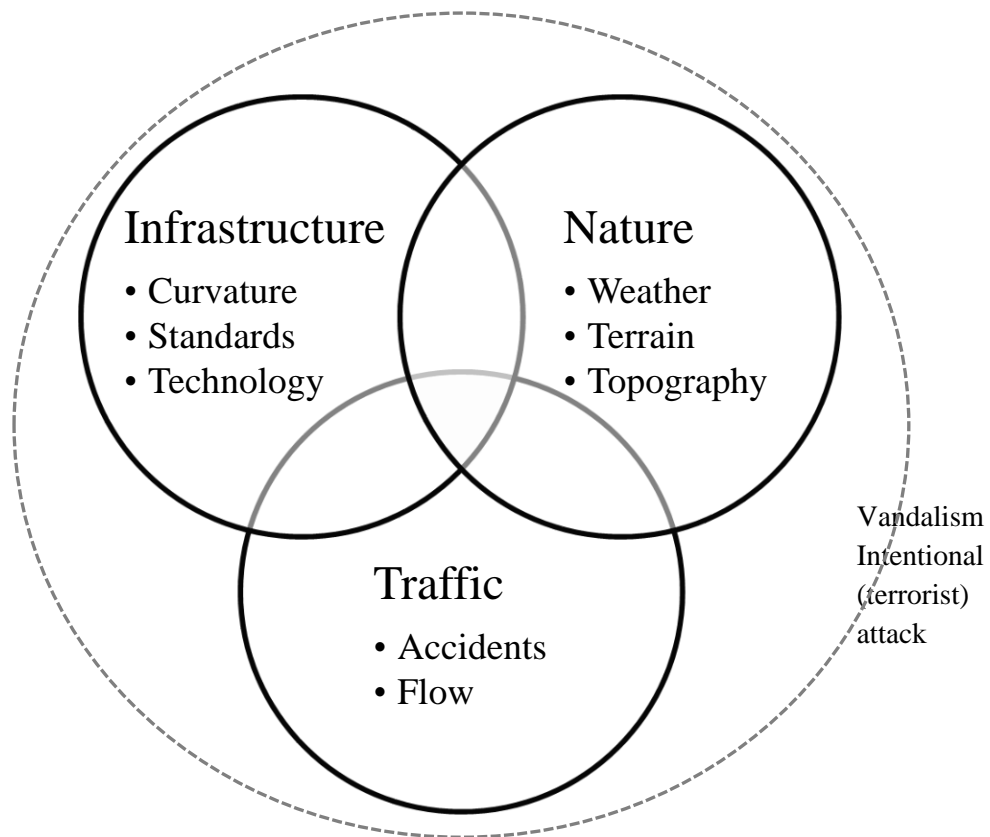
*OECD, 2010* defines reliability as follows:

*The ability of the transport system to provide the expected level of service quality, upon which users have organised their activities.*

On analysing the above definition, it can be seen that network reliability performance depends on the occurrence of traffic, nature, and infrastructure events; the impact of

incidents is lowered or raised by prevailing infrastructure management and traffic levels. For the Decision Makers in transport sector it is crucial that the sources of unreliability are well identified along with the interrelationships among the sources. So that the decision is made on the least cost option to enhance the reliability of the network. The figure below illustrates the sources of unreliability and their interrelationship.

Figure 2.1: Primary sources of unreliability and their interrelationships (Source: Husdal, J., 2004)



As mentioned earlier, it is important to note that “reliability” will mean different things to each of the parties involved. *OECD, 2010* clearly distinguishes the network provider perspective and the user-perspective and the differences is seen in among the parties in terms of their will and need to use different indicators representing reliability for their purposes.

For a network provider or operator, the focus is on:

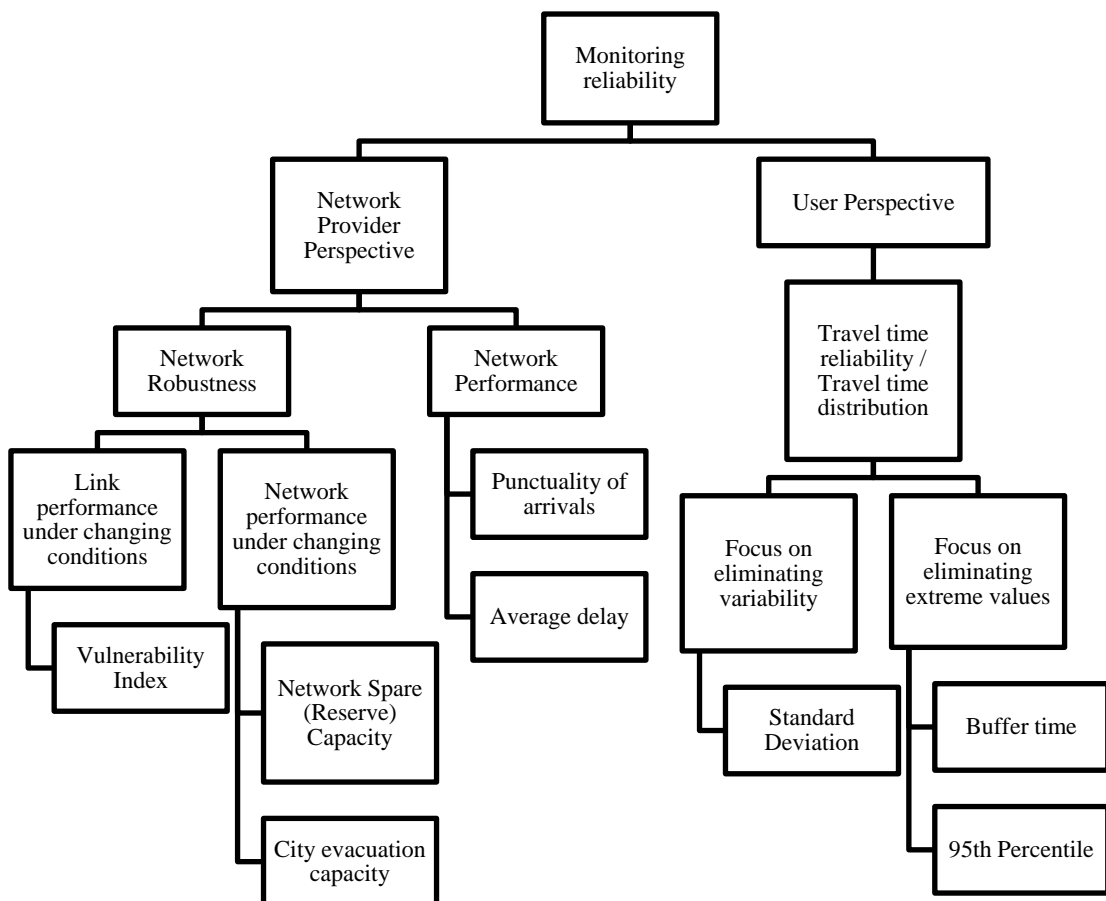
- System robustness/vulnerability. Here, a further distinction is made between link and network performance indicators, under changing conditions.

- System operating performance. Here, the focus is on indicators to describe the performance of a system in terms of deviations from expected, or agreed, levels of service.

For a network user, the focus is on

- The variability of travel times experienced by the user. This can provide useful travel planning information. A further distinction is made between indicators to describe issues regarding general variability of travel times, and issues regarding the elimination of extreme, unexpected, travel times.

Figure 2.2: Network and User perspective of reliability (Source: OECD, 2010)



There are wide range of instrument available for managing the transport system reliability. *OECD, 2010* presents the available instruments into four principal options:

- Increasing the physical capacity of infrastructure, either through supplying extra capacity or improving the quality of existing capacity. Capacity enhancements are generally costly, time consuming and often politically difficult. Setting appropriate network standards and improving the robustness of infrastructure (for instance, durability of material) also influences reliability.
- Better management of existing capacity can facilitate reliability; just as poor management can increase unreliability. Infrastructure managers can improve reliability through better incident management and appropriate scheduling and publicising of maintenance. The core management skills can be supplemented by pro-active network oversight.
- Where feasible, charging directly for reliability could be used to achieve more efficient levels of reliability. However, it is often difficult to provide different levels of reliability according to the value different users place on reliability, and equally difficult to extract different charges for differential performance.
- Information can be provided to users enabling them to mitigate the adverse effects of poor reliability. This may be a cost-effective way to reduce both unreliability and the impacts of traffic incidents on subsequent business and personal schedules.

*Chen et al., 1999* for the first time introduced capacity related reliability for transportation networks with random link capacity. In his research, the capacity reliability is defined as the probability that the road network can accommodate a certain level of traffic demand, and is built on the concept of network reserve capacity. Network reserve capacity is defined as the largest multiplier applied to an existing origin-destination demand matrix that can be allocated to a transportation network in a user-optimal way without violating the link capacities.

Reliability studies are most often confined to: (1) connectivity reliability, (2) travel time reliability. Travel time reliability deals from the user perspective, that is out of scope of this study. When talking about the connectivity reliability, it is concerned with the probability that the network nodes remain connected. For each given node pair, the network is considered successful if at least one of the paths is operational. A path consists of a set of components (e.g. roadways or links) which are characterized by zero-one variables to denote state of each link: operating or failed. When a path is

operational, it assumes that any required amount of flow can pass through it. Capacity constraints on the links are not accounted for when finding the connectivity reliability. This assumption often leads to over-estimation of the reliability and under-estimation of the potential risk for the overall network. In simple words, the deficiency of the connectivity reliability is that it only allows for two operating states: operating at full capacity or completely failed with zero capacity. This binary state approach limits the application to handle everyday situations where links are operating in-between, complete fail or full efficient flow.

In case of urban networks, where additional infrastructure is not principal choice and decision makers prioritise management approach to enhance the network performance, reserve capacity can be enhanced through signal timing management. This approach is more related to concept of reserve capacity for performance measure and timing design of individual signal-controlled intersections. This concept was extended to general signal controlled urban road network by *Wong and Yang, 1997* Where assumption are made that the whole capacity of a road network is controlled by intersections whose capacity depends on traffic signal settings. However, in case of intercity roadway intersection constraints are rare, and capacities are more associated with the scale of infrastructure available. This study deals with the addition of road facility through addition of lanes to increase the reserve capacity of the roadway to increase the capacity reliability of the entire network.

### **2.3 Roadway costing**

As all infrastructural improvement come with a price tag, Costing always becomes a prime focus to Decision makers when working at limited resources. And same applies to the transportation system, moreover in developing countries like ours, decision makers always aim for least cost option to cope with the available resources. Researcher have made significant work keeping the cost minimization as one of the objective in transport system optimization.

*Friesz et al., 1993* formulates a single level mathematical program to solve the multi-objective problem under equilibrium conditions. The objectives are minimizing total

user transport costs, total construction costs, and total vehicle miles travelled. In the research work they modelled the transportation minimization function as follow:

Consider any link of road for which four objectives are set by *Friesz et al., 1993*. Construction cost is considered to be one among the objective of the optimization problem. Minimization of construction cost ( $z_2$ ) is modelled in terms of;

$$z_2 = \sum_a g_a(y_a)$$

The study also includes the cost of displacement and relocation of individuals residing near links of the network that are to be enhanced. Hence, the construction cost function is further appended to include such cost of such dwelling units.

$$z'_2 = \sum_a \alpha_a y_a^2$$

Where,

$z_2$  and  $z'_2$  = Construction (Improvement) Cost function;

$a$  = An index denoting an arc in the network,  $a \in A$ ;

$y_a$  = The magnitude of the improvement to link  $a$ , i.e. the increase in the effective capacity of link  $a$  (for specific purpose of study)

$g_a(y_a)$  = The cost of making an improvement of magnitude  $y_a$  on link  $a$ . For which  $\alpha_a$  is modified factor considering displacement of dwelling units in ROW.

Review of literatures on road improvement costing can be found in *Yang and Bell, 1998*. Where they report that the multi-objective equilibrium network design problem was first put forward by *Friesz, 1981* and *Friesz and Harker, 1983* with many other studies later including *Current and Min, 1986*, *Friesz et al., 1993* and *Tzeng and Tsaur, 1997*. They also conclude that most network design problems have three dominant objective functions which are total user transport costs, total construction

costs, and total vehicle miles travelled which could be considered as a surrogate for air pollution.

For obtaining the sample data in upgradation cost of road network in context of area of study. Relevant project report including engineers estimate for the improvement is referred. Statistical tools are used in taking the generalised cost of improvement. Such improvement cost can be specialised in employing the model based on the locality and context of its application in decision specific purpose by the decision maker from one to one basis.

## **2.4 Network planning and Inventory in Nepal**

Optimal tool in planning of Road network in dynamic scenario of resource allocation is often said to be lacking in context of developing countries like Nepal. Planning of networks are often guided by socio-political influence or by strategic perspective to some extent. Uncertainties however are rather higher in lower economies due to unstable political framework and dependent economic planning. In such context, handy decision tool to cope with dynamism of economy and resource has elevated importance.

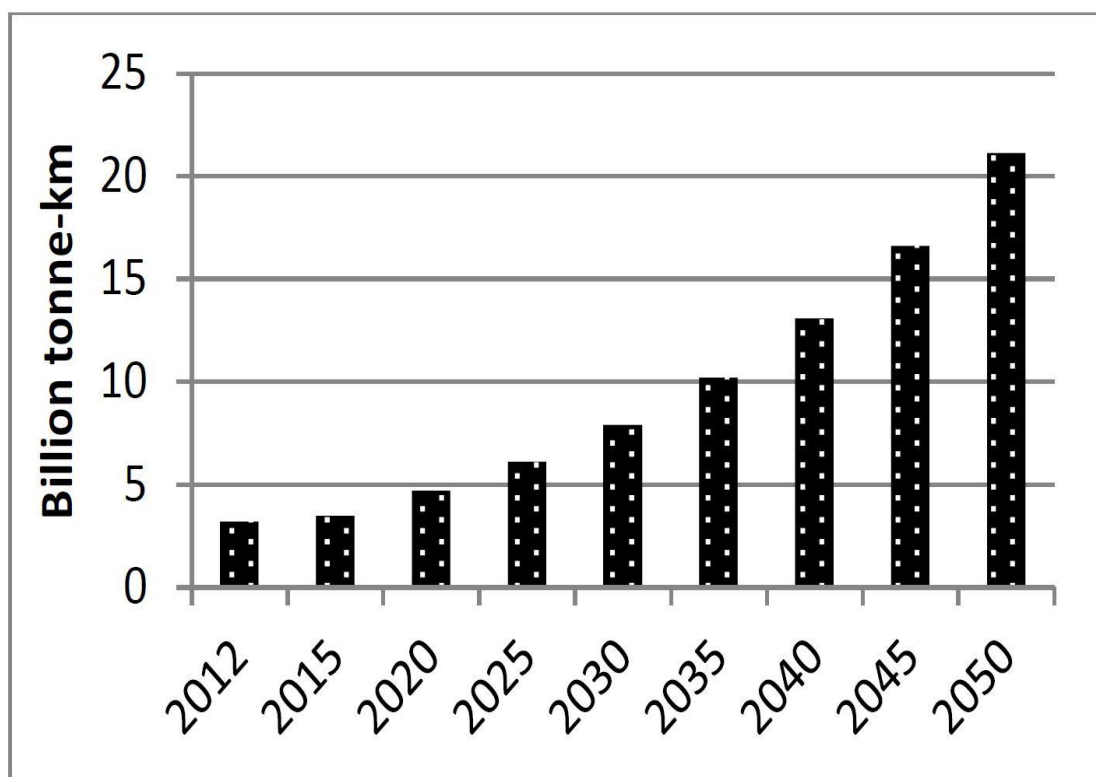
*Shrestha et al., 2014* analysed a multi-objective optimization model for upgradation of rural road network using weighted sum program. The model aims to support decision-makers in the choice of roads to upgrade in the hilly regions of Nepal. The multiobjective optimization model considers two objectives: minimization of user operation costs and maximization of population covered. The validation of the methodology proposed by *Shrestha et al., 2014* is tested for a hilly region in the Gorkha district of Nepal within the work. The research concludes suggesting the applicability of proposed approach to real-world rural road network decision problems in hilly regions of Nepal, allowing the use of the limited available resources efficiently.

According to National Census 2011 by CBS Nepal has a population of about 26.6 million, of which 17% lived in the urban area. Population growth rate in urban area is 3.97%, which is over 3 times that of the national population growth rate during the same census. This has resulted in higher demand of transport facilities with exponential increase rate. The average annual growth rate of passenger transport vehicles in the

country is found to be above 13.7 % during 1990–2012, while that of freight transport vehicles is found to be 7.3% (DoTM, 2012).

In a study related to vehicle emission by *Dhital and Shakya, 2014* the freight demand is projected for Kathmandu Valley which is illustrated in figure below:

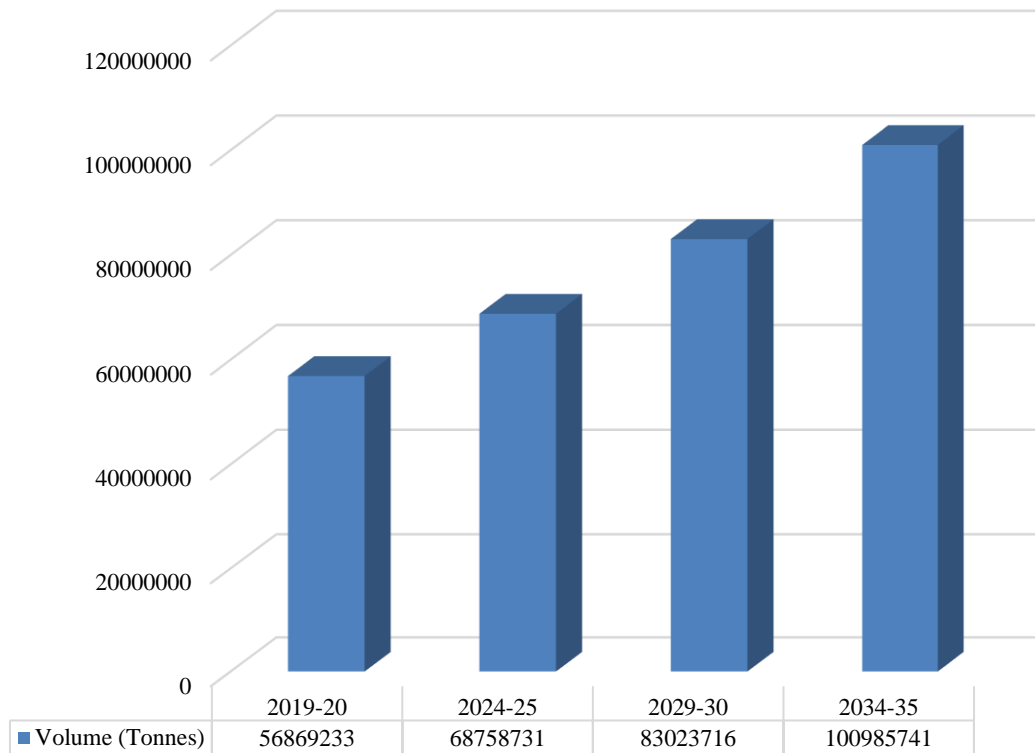
Figure 2.3: Freight travel demand of Kathmandu (Source: Dhital and Shakya, 2014)



In addition to this, Nepal has already adopted movement of freight in the main stream of its strategic planning by considering multimodal volumes for different projects of nation’s pride. To mention one; freight volume has remarkable contribution in traffic consideration of Mechi – Mahakali Electric Railway Project in its feasibility study. Freight volume from 1646 industries, 11 industrial estates and 4 special economic zones is envisaged and dominantly considered for the sustainability of the project.

The study considers growth rate of 3%, 8%, 4% and 10% for manufacturing goods, automobiles, construction related commodities and POL respectively for a period till 2019/20. However, proper recommendation to achieve this traffic is not included in the study. Following figure shows the freight traffic projection in the study.

Figure 2.4: Projected freight traffic, Mechi – Mahakali Electric Railway (Source: RITES et al., 2010)



To discuss on inventory side of road network in Nepal, approximately half the strategic network and less than 5% of the rural road network is paved, with most of the network consisting of fair weather roads that, combined with a lack of bridges, make many areas poorly accessible during the rainy season. There is very little planned maintenance, reducing the effective life of the road network and further reducing the reliability of connectivity.

When we focus on planning and prioritization in the road sector, a finding of *The World Bank et al., 2013* more or less reflects the existing scenario. According to the study, the planning and prioritization tends to be strongly influenced by political priorities rather than based on objective prioritization criteria and planning procedures. This has reduced the effectiveness and efficiency of road sector investments. The expenditure rate of SRN funding is quite high, averaging 83% over the past 5 years (as on 2013). However, efficiency and effectiveness are considered quite low, as funding is not focused on priority roads as identified in several policy documents such as the Priority Investment Plan, 2007. This is evident from the fact that the SRN road length has

already exceeded the targets set in these policy documents, while the priority roads have yet to be completed. To a large extent this is due to political influence, with funding distributed in an ad hoc manner based on political interests rather than on agreed priorities. The expenditure rate is more miserable in case of LRN where the expenditure rate 70-80% and efficiency and effectiveness are considered to be very poor.

## CHAPTER THREE: PROBLEM FORMULATION

Road network design in case of developing countries like Nepal considers passenger transport as major objective. However, along selected routes, freight movement contributes significant traffic in comparison to the passenger movement. Road network upgradation may be necessary in many cases in considering the freight movement. Taking into account the traffic share of freight movement, the problem is formulated for development of the model with multiple optimization objectives.

### 3.1 Decision Variables

As discussed in section 2.2 earlier, to improve the capacity reliability of road segment it is necessary to increase the reserve capacity, under deterministic approach. Higher reserve capacity of network in case of non-urban networks doesn't involve intersections as bottle neck, they rather face bottlenecks in the arcs with higher discharge (inflow/outflow). This can be achieved through additional road lanes in such segments. Now, it is crucial for decision makers whether to widen a road segment or not. To answer this question on selection of width of road segment we select two-lane, four-lane and six-lane as decision variable set for DM. Let us represent the decision variable set by  $V$ .

We now formulate the variable discussed earlier as, a multi-objective road network problem in terms of vector  $(N, L)$ , where  $N$  is set of Nodes and  $L$  is a set of Link in the network. The model is developed with two-lane, four-lane and six-lane link as discrete decision variable to address additional reserve capacity in the link. This is represented in following decision set:

$$V = \{v1, v2, v3\} \quad (3.1)$$

Where,  $v1$ ,  $v2$ , and  $v3$  represents two lanes, four lanes and six lanes links respectively.

### 3.2 Objective Functions

Now, the when decision maker (DM) aims in increasing the reserve capacity of the road network, he simultaneously aims in making such improvement at minimum cost possible. So, his objective will be to minimize the upgradation cost.

Let,  $L_{ij}$  and  $C_{ij}$  be distance and cost of upgradation of the link to type  $V$ .  $x_{ij}^V$  is introduced as a binary discrete decision variable (0,1) taking the value 1 when link (i, j) is developed to the type  $V$ , and takes value 0 when the upgradation is not done.

$$\text{Minimize: } Z_1 = \sum_{v=1}^3 \sum_{(i,j) \in L, i < j} C_{ij}^v x_{ij}^v \quad (3.2)$$

Likewise, the other objective of the decision maker (DM) to increase reserve capacity through addition of lanes can be formulated as below. In this objective, it is necessary to introduce Usefulness coefficient ( $U_{ij}$ ) to account for the level of inflow and outflow to the Link. So, that the link with the higher usefulness gets prioritised first in the hierarchy.

$$\text{Maximize: } Z_2 = \sum_{v=1}^3 \sum_{(i,j) \in L, i < j} U_{ij} L_{ij} x_{ij}^v \quad (3.3)$$

According to Handbook of Global Logistics by *Hillier, 2013* the importance of inland transportation of goods is defined by the multimodal significance defined on each segment of railway or roadway that is a function of economic share of inland port of entry and the portion of domestic economy the segment serves. *Janic, 2007* uses the term usefulness coefficient in synonymous to multimodal significance, where it is defined as below:

$$U_{ij} = \frac{\alpha_i}{\sum_i \alpha} * \frac{\sum_j \beta_j}{\sum_i \sum_j \beta}$$

Where,

$\alpha_i$  = Proportion of economy shared by inland port of entry associated with  $i$ .

$\beta_j$  = Proportion of domestic economy catered by the node  $j$ .

Usefulness coefficient ( $U_{ij}$ ) is assigned to each link in the network, the coefficient prioritises the arcs of higher usefulness value. In addition to this the model can also include socioeconomic preference where necessary, this can be done through introduction of weightages in the model. For this study, no weightage has been imposed, i.e. all arcs are assumed to be equally important from socio economic point of view.

### 3.3 Constraints

Budgetary constraint:

$$\sum_{v=1}^3 \sum_{(i,j) \in L, i < j} C_{ij}^v x_{ij}^v \leq B \quad (3.4)$$

Non-Exclusivity Constraint:

$$\sum_{v=1}^3 x_{ij}^v = 1 \quad \forall (i,j) \in L, i < j \quad (3.5)$$

Binary (discreteness):

$$x_{ij}^v \in (0, 1) \quad \forall (i,j) \in L, \forall v \in V \quad (3.6)$$

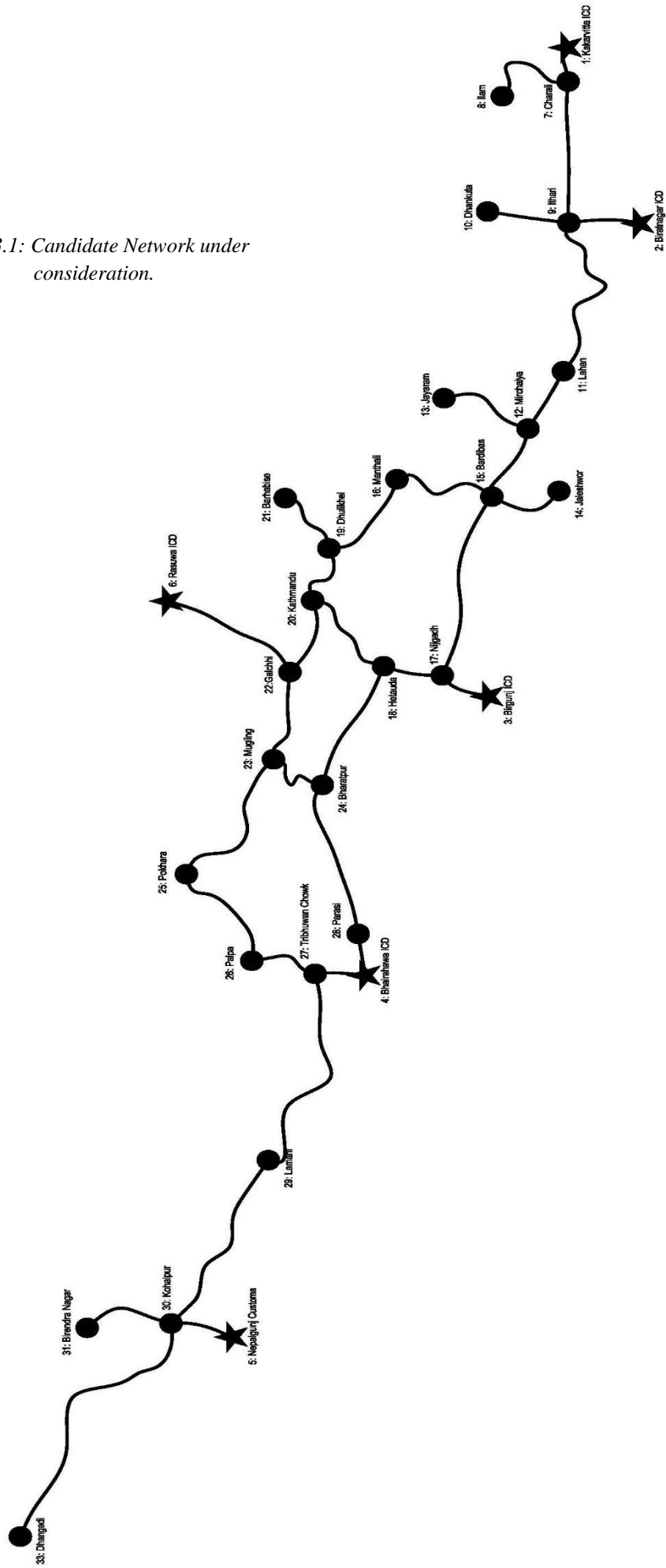
In case of more constraints specific to the decision, higher number of constraints can be modelled in the problem.

### 3.4 Application

The proposed multiobjective model is checked for its applicability by a case of prominent freight route in Nepal. The network is identified through a 7-day survey of Customs clearance document in each custom point that contains the destination for the freight. The days were selected at random, it includes continuously a week-long data.

Figure below shows the network under consideration.

Figure 3.1: Candidate Network under consideration.



The network presented above is obtained through lumping of small destinations that were found in the customs delivery order. Likewise, major customs point is only considered, which results in flow through small entry points are negligible and are incorporated as they pass through the nearby major inland port of entry.

*Table 3.1: Summary of Network under consideration*

<b>Link Description</b>	<b>Link ID</b>	<b>Link Length (km)</b>
Kakarvitta ICD – Charali	1-7	11.25
Charali – Ilam	7-8	64.92
Charali – Ithari	7-9	81.14
Ithari – Dhankuta	9-10	63.5
Ithari – Biratnagar ICD	9-2	29.65
Ithari – Lahan	9-11	106.71
Lahan – Mirchaiya	11-12	24.81
Mirchaiya – Bardibas	12-15	43.79
Bardibas – Nijgadh	15-17	86.21
Nijgadh – Hetauda	17-18	29.07
Hetauda – Bharatpur	18-24	73.14
Bharatpur – Parasi	24-28	96.29
Parasi – Bhairahawa ICD	28-4	22.15
Bhairahawa ICD – Tribhuvan Chowk	4-27	24.1
Tribhuvan Chowk – Lamahi	27-29	128.28
Lamahi – Kohalpur	29-30	108.73
Kohalpur – Dodhara	30-32	159.07
Bardibas – Jaleswor	15-14	42.00
Hetauda – Kathmandu	18-20	50.2
Kohalpur – Birendra Nagar	30-31	83.76
Kohalpur – Nepalgunj Customs	30-5	16.91
Mirchaiya – Jayaram	12-13	45.25
Bardibas – Manthali	15-16	52.15
Manthali – Dhulikhel	16-19	72
Dhulikhel – Kathmandu	19-20	23
Dhulikhel – Barhabise	19-21	47.50
Kathmandu – Galchi	20-22	37.8
Galchi – Rasuwa ICD	22-6	76.7
Galchi – Mugling	22-23	49.7
Mugling – Bharatpur	23-24	44.5
Mugling – Pokhara	23-25	80.8
Pokhara – Palpa	25-26	56.1
Palpa – Tribhuvan Chowk	26-27	29.5
Nijgadh – Birgunj ICD	17-3	22.5



In decision theory, the weighted sum model (WSM) is the best known and simplest multi-criteria decision analysis (MCDA) / multi-criteria decision making method for evaluating a number of alternatives in terms of a number of decision criteria. It is very important to state here that it is applicable only when all the data are expressed in exactly the same unit.

In general, suppose that a given MCDA problem is defined on  $m$  alternatives and  $n$  decision criteria. Furthermore, let us assume that all the criteria are benefit criteria, that is, the higher the values are, the better it is. Next suppose that  $W_j$  denotes the relative weight of importance of the criterion  $C_j$  and  $a_{ij}$  is the performance value of alternative  $A_i$  when it is evaluated in terms of criterion  $C_j$ . Then, the total (i.e., when all the criteria are considered simultaneously) importance of alternative  $A_i$ , is defined as follows:

$$A_i^{WSM-Score} = \sum_{j=1}^n w_j a_{ij}, \text{ for } i = 1, 2, 3, \dots, m.$$

*Soland, 1979* defines pareto optimal, non-dominated, or efficient solution in the context of deterministic multicriteria maximization, as a feasible solution for which an increase in value of any one criterion can only be achieved at the expense of a decrease in value of at least one other criterion. Without restrictions of convexity or continuity, it is shown that a solution is efficient if and only if it solves an optimization problem that bounds the various criteria values from below and maximizes a strictly increasing function of these several criteria values. In the paper the author claims the weighted sum approach as an interactive technique for multicriteria optimization which is both robust and not unduly demanding of the DM.

## 4.2 Primary data for application

As an input to the solver, following distance Matrix ( $L_{ij}$ ) is developed for input to the modelling language.

Table 4.1: Distance Matrix ( $L_{ij}$ ) for the network under consideration.

$(L_{ij})$	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
1	0	0	0	0	0	0	11.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	24.1	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	64.9	81.1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	29.6	0	0	0	0	0	0	0	63.5	106.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	24.8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	45.2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	42.0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	72	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	22.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	29.0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50.2	0	0	0	0	0	0	0	0	0	0	0
19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	23	47.5	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	37.8	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0



Table below shows the coefficient considered for each of the links for the purpose of analysis.

Table 4.2: Link length ( $L_{ij}$ ) and Usefulness coefficient for the links in network.

<b>Link</b>	<b>Link Length (km)</b>	<b>Usefulness Coefficient (<math>U_{ij}</math>)</b>
1-7	11.25	0.164
7-8	64.92	0.063
7-9	81.14	0.124
9-10	63.5	0.107
9-2	29.65	0.222
9-11	106.71	0.158
11-12	24.81	0.120
12-15	43.79	0.121
15-17	86.21	0.234
17-18	29.07	0.238
18-24	73.14	0.205
24-28	96.29	0.126
28-4	22.15	0.249
4-27	24.1	0.262
27-29	128.28	0.101
29-30	108.73	0.068
30-32	159.07	0.187
15-14	42.00	0.041
18-20	50.2	0.151
30-31	83.76	0.096
30-5	16.91	0.125
12-13	45.25	0.062
15-16	52.15	0.122
16-19	72	0.031
19-20	23	0.108
19-21	47.50	0.082
20-22	37.8	0.120
22-6	76.7	0.154
22-23	49.7	0.118
23-24	44.5	0.129
23-25	80.8	0.133
25-26	56.1	0.076
26-27	29.5	0.146
17-3	22.5	0.283

### **4.3 Additional data for application**

Following are the values obtained through survey of secondary sources for testing the model. Values are adopted to best match the practical scenario in majority of the cases.

The test network consists of 32 nodes and 34 links. The budget constraint for upgradation is taken to be NRs. 36,000 million for the test instance (which is 75% of budget expenditure of budget allocated for MoPIT in F/Y 2015/16). Likewise, per kilometre upgradation cost for two lanes, four lanes and six lanes link is taken to be NRs. 10.24 Million, NRs 24.62 Million and NRs 46.07 Million respectively. The value is obtained through survey of few ongoing upgradation projects. Projects under department of roads including Trade Route Improvement Project, Nepal-India Regional Trade and transport project are surveyed for obtaining this value.

Likewise, the import and export history of each of the customs point is collected from respective custom offices and the raw data was analysed to obtain the total value of import and export from each of the customs point this values are used in determining the usefulness coefficient.

The value addition by industrial establishment in each of the district is lumped to each of the nodes. Likewise, population of the area is also lumped to nodes to indicate consumption at each node.

## CHAPTER FIVE: ANALYSIS AND OUTPUTS

### 5.1 Analysis of the case

The transportation system and the transport has been playing strong role to increase the economic development of a country. Development of transport also traces with public and private investors because the potentiality of the transport. Beside some exception transportation has been a highly regarded factor for a country's economic development. Road network planning can be done through handy decision tools using similar cases at the area of interest.

The test network under consideration is mainly the portion of strategic road network that has freight importance. The road length and inventory information are obtained from SRN 2014 published by Department of Roads. Total length of road in the case is 1983.18 KM. Majority of the links lies in plain terrain while few are in hilly and rolling terrain. All road links at present are considered to be of two lanes, however short stretch vary at urban regions.

### 5.2 Output of case study

Analysis can be conducted at desired budget constraint, however for this study a constraint of NRs 36,000 million is considered.

#### ***TEST OUTPUT (S1):***

Z1 = **33,470** Million Nepalese Rupees

Z2 = **5,702.04** lane-km

#### ***TEST OUTPUT (S2):***

Z1 = **33,260** Million Nepalese Rupees

Z2 = **5,674.5** lane-km

#### ***TEST OUTPUT (S3):***

Z1 = **32,945** Million Nepalese Rupees

Z2 = **5,532.6** lane-km

***TEST OUTPUT (S4):***

Z1 = **32,314** Million Nepalese Rupees

Z2 = **5,132.4** lane-km

***TEST OUTPUT (S5):***

Z1 = **32,050** Million Nepalese Rupees

Z2 = **4,964** lane-km

Graphical representation of the result in case output (s1) is presented below.

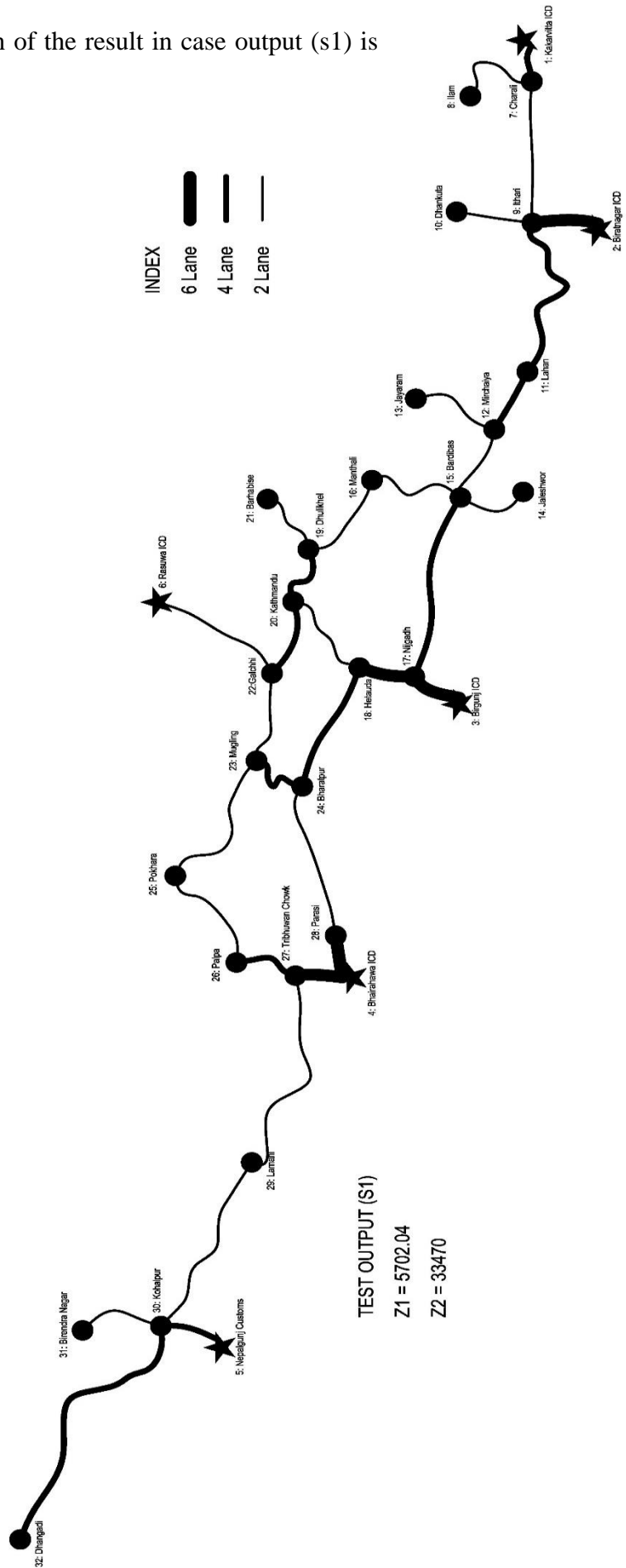


Figure 5.1: Graphical Representation of test results (s1)

## CHAPTER SIX: CONCLUSION

### 6.1 Pareto front

Pareto frontier for the test budget is shown in the figure below. The front can be used by DM to judge the investment level based on the available scale of resources. Upon any variation in the resource, the DM can move along the front such that none of the objective will be beyond optimum. This figure can be used to find the level of investment at which reserve capacity changes abruptly.

The beauty of pareto frontier is that it clearly demonstrates the decision maker (DM) about how much to compromise on one objective to achieve more from the other. Even when the decision maker changes the investment level, same graph can be obtained at each scale of investment so that optimum values can be visualised promptly.

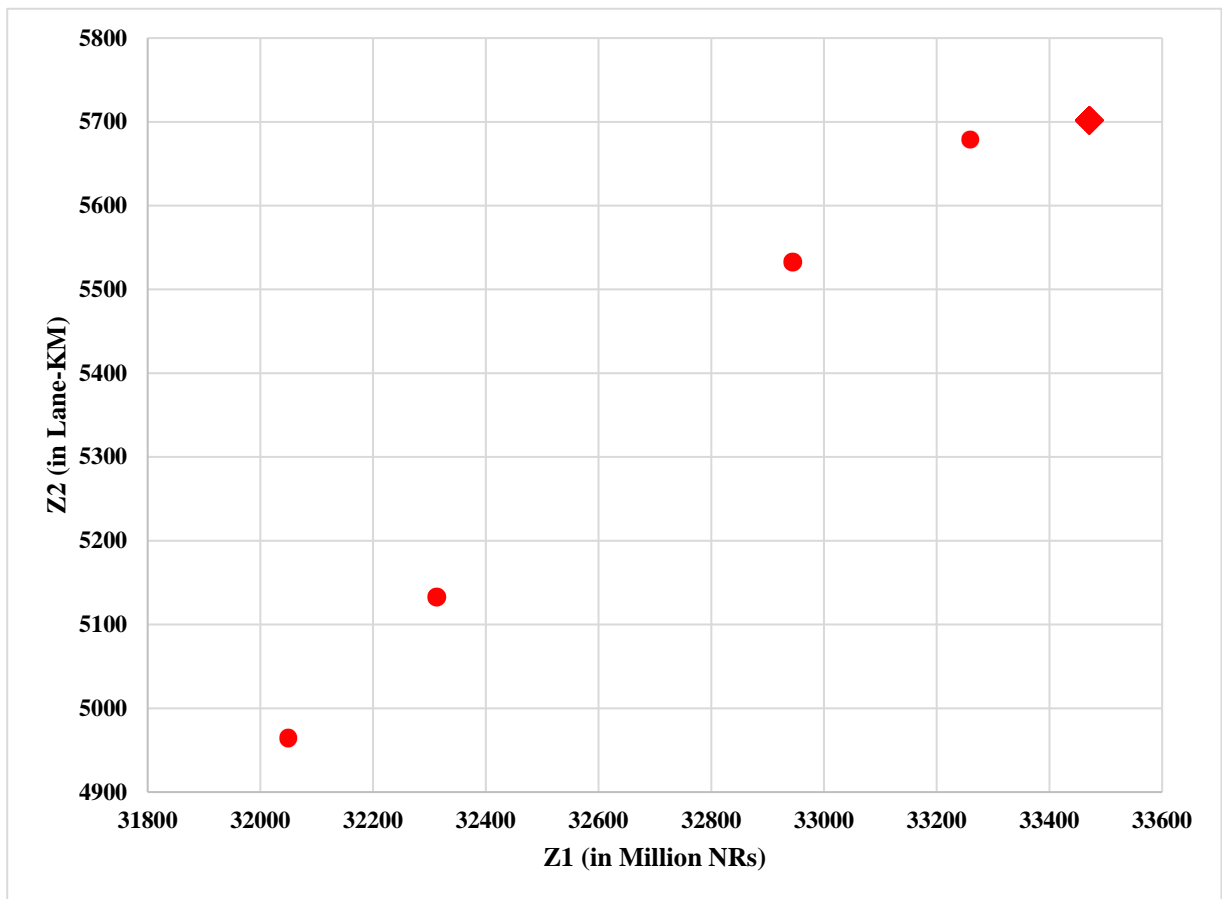


Figure 6.1: Pareto frontier of Z1 and Z2 at test budget

## 6.2 Conclusion and future research

The thesis proposes a multiobjective model to maximize the reserve capacity of road network through additional lane for intercity road network. Two objectives, (1) reserve capacity, and (2) upgradation cost were adopted for multi-objective model. For the objectives under consideration, Pareto optimal solutions were obtained, such that the optimal solutions can be graphically visualised.

The proposed model was tested in Nepal's road network having freight movement significance. Result of this application shows that the model is applicable in decision making with nondominated optimization of the objectives. In addition, it is also helpful to judge the scale of resource (cost) variation in case of changed availability during implementation for more preferable unit rate of change of objectives under consideration. In other words, with the help of the outcome Decision Maker can judge better investment limit in case of resource change. For E.g., it is clear from the pareto graph that decision of moving from S3 to S2 is more cost effective than from s2 to S1.

Further to this work, consideration of road user cost minimization objective will add significant value in the subject of interest and is considered for future studies. This work can also be extended to three dimensional optimization by adding third objective function that is of keen interest to decision makers.

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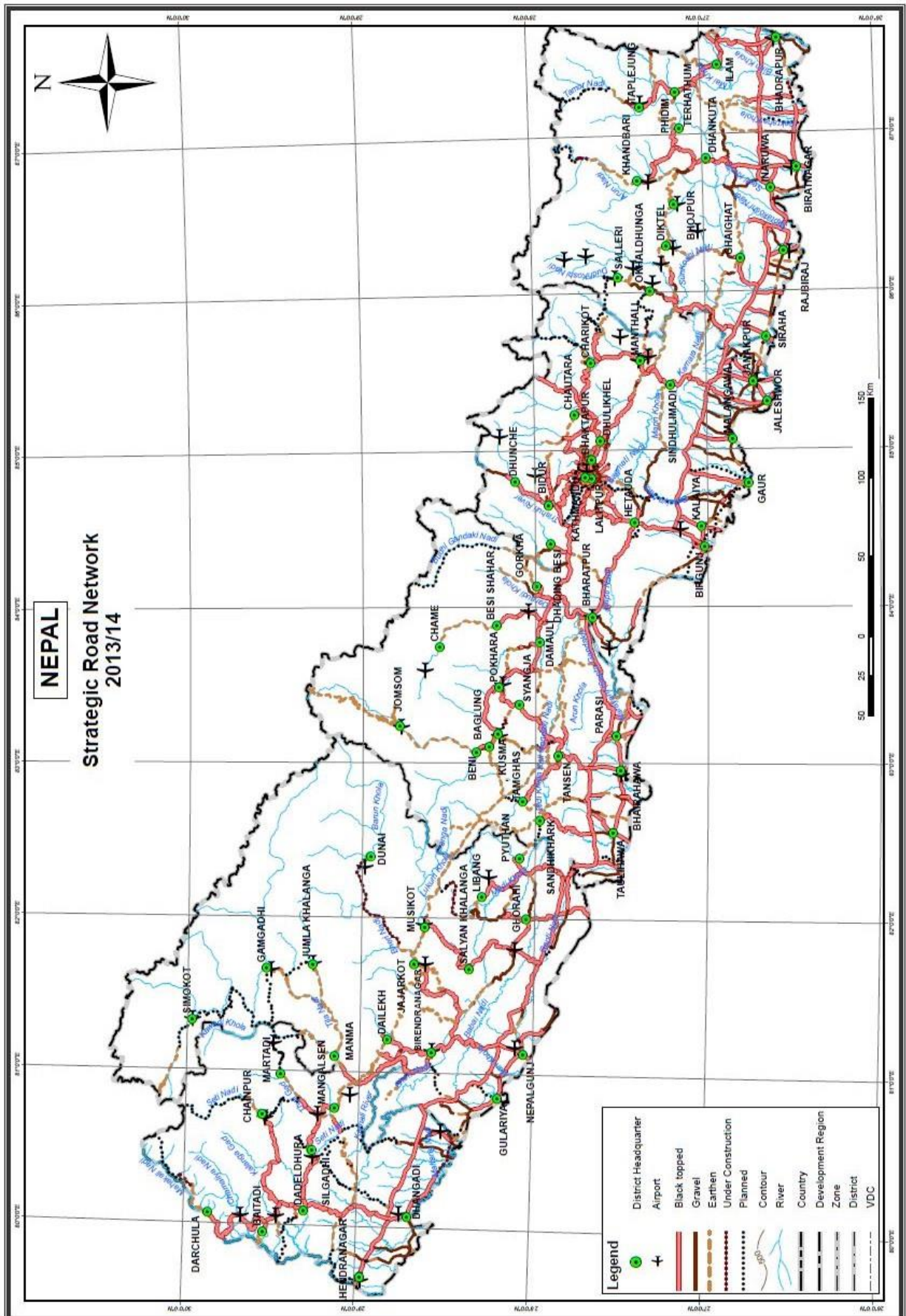
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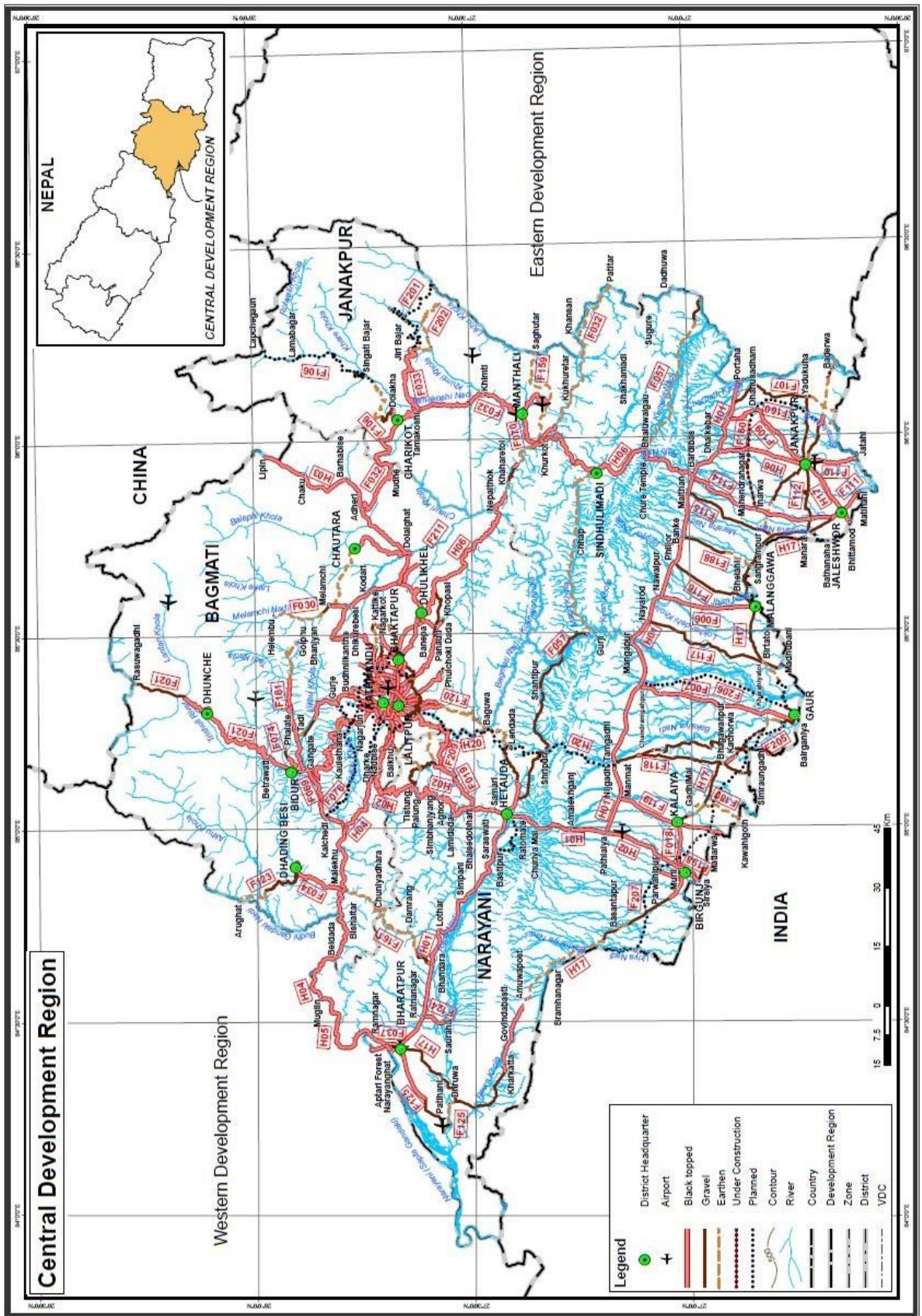
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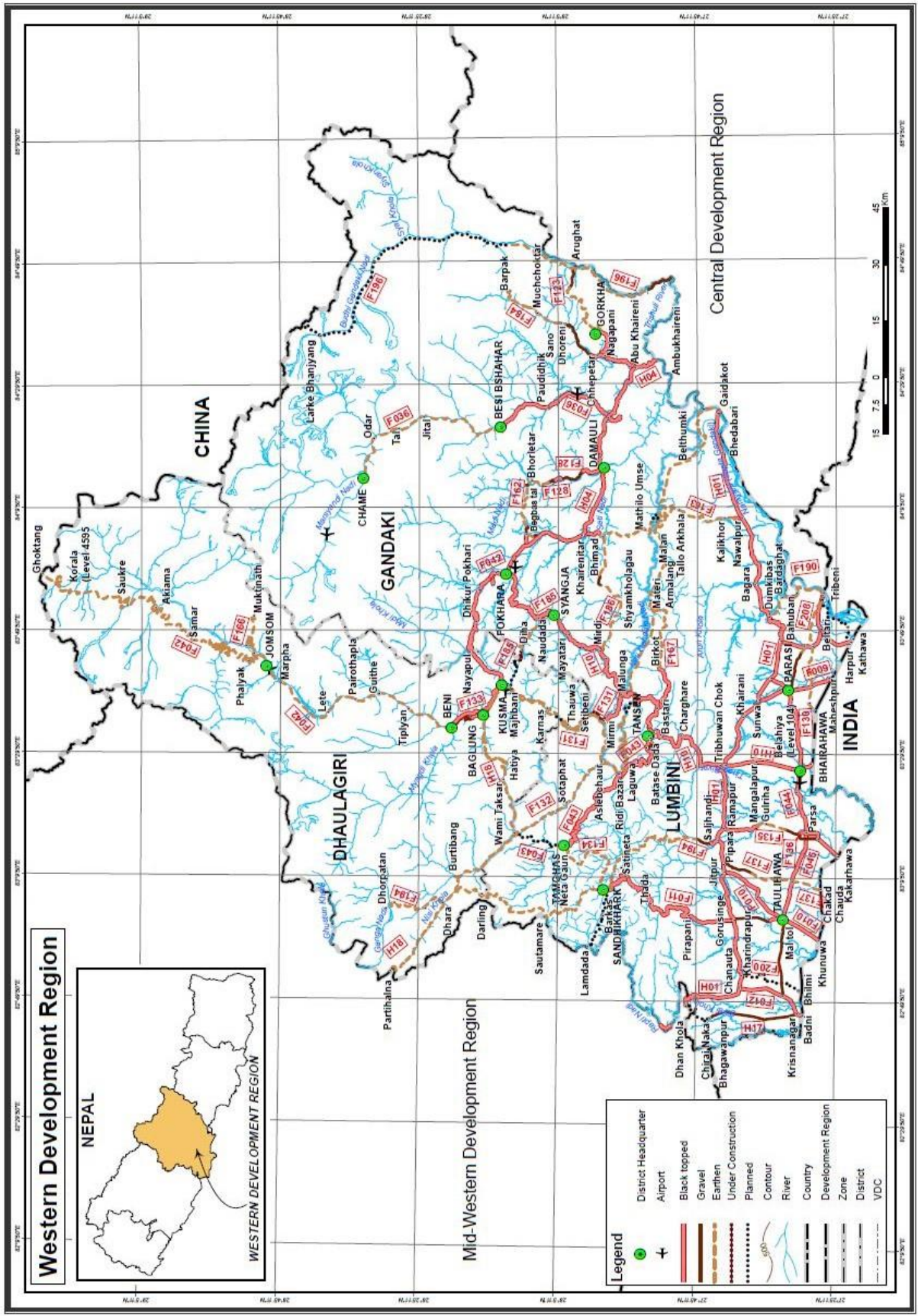
## **ANNEX**

# ANNEX 1: Strategic Road Network 2013/14













## ANNEX 2: Sample SRN statistics

DISTRICT: JHAPA  
 ZONE: MECHI  
 REGION: EASTERN

S.N	Name of Road	Class	Ref No	Link Code	BT	GR	ER	Total	UC	PL
1	Kakarbhitta-Charali	NH	H01	H0101	11.25	0.00	0.00	11.25	0.00	0.00
2	Charali-Birtamod	NH	H01	H0102	6.27	0.00	0.00	6.27	0.00	0.00
3	Birtamod-Padajogi (Damak)	NH	H01	H0103	29.51	0.00	0.00	29.51	0.00	0.00
4	Padajogi (Damak)-Ratuwa	NH	H01	H0104	0.96	0.00	0.00	0.96	0.00	0.00
5	Ratuwa-Mawa	NH	H01	H0105	6.76	0.00	0.00	6.76	0.00	0.00
6	Kechna (IB)-Kechna village	NH	H07	H0701	0.00	3.00	0.00	3.00	0.00	0.00
7	Kechna village-Jhapa Chok	NH	H07	H0702	0.00	21.68	0.00	21.68	0.00	0.00
8	Jhapa Chok-Bhaire Chok	NH	H07	H0703	4.17	0.00	0.00	4.17	0.00	0.00
9	Bhaire Chok-Charali	NH	H07	H0704	10.37	0.00	0.00	10.37	0.00	0.00
10	Charali-Chihanedanda	NH	H07	H0705	16.78	0.00	0.00	16.78	0.00	0.00
11	Birtamod (MRM)-Chandragadhi	FRN	F001	F00101	12.53	0.00	0.00	12.53	0.00	0.00
12	Damak-Gauradaha Dipu	FRN	F002	F00201	10.56	0.00	0.00	10.56	0.00	0.00
13	Gauradaha Dipu-Gaurigunj	FRN	F002	F00202	11.40	0.00	0.00	11.40	0.00	0.00
14	Birtamod (MRM)-Sanishare-Budhbare	FRN	F059	F05901	12.86	0.00	0.00	12.86	0.00	0.00
15	Damak (MRM)-Refugee Camp	FRN	F158	F15801	6.50	0.00	0.00	6.50	0.00	0.00
16	Bhadrapur-Ratuwa(Postal)	PR	H17	H1701	0.00	15.00	17.00	32.00	10.00	6.00
<b>Total</b>					<b>139.92</b>	<b>39.68</b>	<b>17.00</b>	<b>196.60</b>	<b>10.00</b>	<b>6.00</b>

### ANNEX 3: Sample Export/Import Data

From Date: July 2009 To Date: June 2010

Export side

Node Number	Customs	Value(NRS)	% Value
2	Biratnagar	17680232246	28.90%
3	Birgunj	16870920061	27.58%
1	Kakarvitta	9505183778	15.54%
4	Bhairahawa	3301569135	5.40%
5	Nepalgunj	1336694851	2.19%
6	Rasuwa	69038769	0.11%
		<b>48763638840</b>	
		0.797166413	
	Country's Total Export	<b>61171215979</b>	

From Date: July 2009 To Date: June 2010

Import

Node Number	Customs	Value(NRS)	% Value
3	Birgunj	186683396385	51.16%
4	Bhairahawa	37460884814	10.27%
2	Biratnagar	27844493808	7.63%
1	Mechi	7798136628	2.14%
5	Nepalgunj	7725925790	2.12%
6	Rasuwa	166896473	0.05%
		267679733898	
		0.733525974	73.35%
	Total Import	364921957115.00	

From Date: July 2010 To Date: June 2011

Export Side

Node Number	Customs	Value(NRS)	% Value
2	Biratnagar	23,153,877,684	36.20%
3	Birgunj	15,227,914,106	23.81%
1	Mechi	7,632,362,187	11.93%
4	Bhairahawa	2,685,586,713	4.20%
5	Nepalgunj	1,446,248,341	2.26%
6	Rasuwa	423,319,739	0.66%
		<b>50,569,308,770</b>	
		79.06%	79.06%
	Country's Total Export	<b>63,962,903,200</b>	

From Date: July 2010 To Date: June 2011

Import Side

Node Number	Customs	Value(NRS)	% Value
3	Birgunj	220,707,535,691	54.28%
2	Biratnagar	50,378,351,049	12.39%
4	Bhairahawa	50,258,379,417	12.36%
6	Rasuwa	13,473,275,764	3.31%
5	Nepalgunj	9,438,860,284	2.32%
1	Mechi	8,299,628,544	2.04%
		<b>352,556,030,749</b>	
		86.71%	86.71%
	Country's Total Import	<b>406,587,321,023</b>	

From Date: July 2011 To Date: June 2012

Export Side

Node Number	Customs	Value(NRS)	% Value
2	Biratnagar	26,649,226,611	35.63%
3	Birgunj	20,104,777,167	26.88%
1	Mechi	6,301,351,422	8.42%
4	Bhairahawa	4,242,465,077	5.67%
5	Nepalgunj	1,657,347,040	2.22%
6	Rasuwa	716,418,576	0.96%
		<b>59,671,585,893</b>	
		79.78%	79.78%
	Country's Total Export	74,797,104,522	

From Date: July 2011 To Date: June 2012

Import Side

Node Number	Customs	Value(NRS)	% Value
3	Birgunj	254,350,235,595	51.69%
2	Biratnagar	64,112,135,528	13.03%
4	Bhairahawa	62,215,070,637	12.64%
6	Rasuwa	12,981,325,324	2.64%
5	Mechi	12,815,597,650	2.60%
1	Nepalgunj	12,631,351,090	2.57%
		<b>419,105,715,824</b>	
		85.17%	85.17%
	Country's Total Import	492,092,788,829	

From Date: July 2012 To Date: June 2013

Export Side

Node Number	Customs	Value(NRS)	% Value
2	Biratnagar	24,324,964,807	31.65%
3	Birgunj	22,390,192,514	29.13%
1	Mechi	7,606,109,119	9.90%
4	Bhairahawa	4,165,058,009	5.42%
5	Nepalgunj	1,567,800,233	2.04%
6	Rasuwa	1,464,513,506	1.91%
		<b>61,518,638,188</b>	
		80.04%	80.04%
	Country's Total Export	76,863,763,483	

From Date: July 2012 To Date: June 2013

Import Side

Node Number	Customs	Value(NRS)	% Value
3	Birgunj	310,223,953,195	51.53%
4	Bhairahawa	84,022,125,381	13.96%
2	Biratnagar	73,580,377,062	12.22%
6	Rasuwa	15,866,355,893	2.64%
1	Mechi	15,493,046,538	2.57%
5	Nepalgunj	14,118,744,044	2.35%
		<b>513,304,602,113</b>	
		85.27%	85.27%
	Country's Total Import	602,003,273,778	

From Date: July 2013 To Date: June 2014

Export Side

Node Number	Customs	Value(NRS)	% Value
2	Biratnagar	30,920,276,693	34.26%
3	Birgunj	22,874,383,934	25.34%
1	Mechi	6,468,785,896	7.17%
4	Bhairahawa	4,465,383,901	4.95%
6	Rasuwa	1,934,694,489	2.14%
5	Nepalgunj	1,453,359,945	1.61%
		<b>68,116,884,858</b>	
		75.47%	75.47%
	Country's Total Export	90,255,752,196	

From Date: July 2013 To Date: June 2014

Import Side

Node Number	Customs	Value(NRS)	% Value
3	Birgunj	358,349,771,345	50.26%
4	Bhairahawa	106,804,491,256	14.98%
2	Biratnagar	88,150,011,094	12.36%
1	Mechi	23,846,875,874	3.34%
6	Rasuwa	19,031,370,955	2.67%
5	Nepalgunj	18,735,423,208	2.63%
		<b>614,917,943,732</b>	
		86.25%	86.25%
	Country's Total Import	712,978,893,718	

From Date: July 2014 To Date: June 2015

Export Side

Node Number	Customs	Value(NRS)	% Value
2	Biratnagar	26,734,815,645	30.52%
3	Birgunj	23,889,415,489	27.27%
1	Mechi	6,609,909,349	7.55%
4	Bhairahawa	4,176,027,060	4.77%
5	Nepalgunj	2,359,844,204	2.69%
6	Rasuwa	1,345,836,284	1.54%
		<b>65,115,848,031</b>	
		74.33%	74.33%
	Country's Total Export	87,602,142,232	

From Date: July 2014 To Date: June 2015

Import Side

Node Number	Customs	Value(NRS)	% Value
3	Birgunj	403,049,651,834	51.81%
4	Bhairahawa	108,744,434,473	13.98%
2	Biratnagar	88,034,884,209	11.32%
1	Mechi	23,594,418,347	3.03%
5	Nepalgunj	20,651,990,109	2.65%
6	Rasuwa	11,254,957,099	1.45%
		<b>655,330,336,071</b>	
		84.24%	84.24%
	Country's Total Import	777,909,740,865	

From Date: July 2015 To Date: June 2016

Export Side

Node Number	Customs	Value(NRS)	% Value
2	Biratnagar	21,136,772,365	29.58%
3	Birgunj	13,416,597,314	18.78%
1	Mechi	5,471,413,312	7.66%
4	Bhairahawa	4,344,603,580	6.08%
5	Nepalgunj	2,014,404,411	2.82%
6	Rasuwa	584,597,258	0.82%
		<b>46,968,388,240</b>	
		65.73%	65.73%
	Country's Total Export	71,453,010,793	

From Date: July 2015 To Date: June 2016

Import Side

Node Number	Customs	Value(NRS)	% Value
4	Bhairahawa	184,607,724,654	23.57%
3	Birgunj	276,772,884,130	35.34%
2	Biratnagar	117,207,851,354	14.97%
1	Mechi	30,216,208,914	3.86%
5	Nepalgunj	26,200,697,789	3.35%
6	Rasuwa	9,792,159,828	1.25%
		<b>644,797,526,669</b>	
		82.33%	82.33%
	Country's Total Import	783,154,503,582	

## ANNEX 4: Districtwise economic value addition

Table No 1.: Principal indicators, 2011/12.

NSIC code	NSIC	No. of estbs.	No. of persons engaged	No. of emps.	Wages, salaries & other benefits	Change in stocks at the end of the year	Gross addition to fixed assets	Gross fixed assets at the end of the year	Value of output	Value of input	Total value added
Nepal		4,076	204,360	194,989	16,440,763	12,765,817	6,161,980	119,728,060	322,551,699	241,767,640	80,784,059
Taplejung		6	67	56	6,300	116	366	14,419	15,122	5,625	9,497
17	Manufacture of paper and paper products	3	35	29	2,530	-4	52	310	5,909	2,088	3,821
31	Manufacture of furniture	3	32	27	3,770	120	314	14,109	9,213	3,537	5,676
Panchthar		6	262	246	13,442	1,741	3,069	151,391	38,665	20,239	18,426
10	Manufacture of food products	1									
13	Manufacture of textiles	2									
16	Manufacture of wood and of products of wood and cork, except furniture	2									
23	Manufacture of other non-metallic mineral products	1									
Ilam		12	622	595	38,975	1,067	4,712	516,872	466,285	327,511	138,774
10	Manufacture of food products	10	531	504	29,952	677	4,712	506,427	437,602	320,962	116,640
16	Manufacture of wood and of products of wood and cork, except furniture	2									
Jhapa		176	5,926	5,519	406,126	331,751	91,068	2,725,989	5,465,705	4,289,002	1,176,703
10	Manufacture of food products	68	2,265	2,086	169,492	214,099	54,002	1,760,951	2,756,177	2,210,916	545,261
11	Manufacture of beverages	3	33	26	3,954	-18	450	11,080	15,305	11,744	3,561
12	Manufacture of tobacco products	1									
15	Manufacture of leather and related products	1									
16	Manufacture of wood and of products of wood and cork, except furniture	29	887	843	55,406	52,269	18,763	255,531	981,024	837,178	143,846
18	Printing and reproduction of recorded media	9	221	198	10,779	106	187	14,814	30,114	15,001	15,113
20	Manufacture of chemicals and chemical products	3	48	39	5,221	2,537	18	6,625	54,099	45,783	8,316
22	Manufacture of rubber and plastics products	1									
23	Manufacture of other non-metallic mineral products	27	1,721	1,654	102,866	40,217	12,760	547,324	1,335,075	981,586	353,489
25	Manufacture of fabricated metal products, except machinery and equipment	2									
31	Manufacture of furniture	32	608	539	45,138	17,578	888	79,817	214,430	138,341	76,089

## ANNEX 5: Districtwise Population (sample)

Table 1: Households by ownership of house/housing unit in use.

Area	Total	Ownership of house/housing unit			
		Owned	Rented	Institutional	Others
Lalitpur	109,505	62,419	44,806	1,121	1,159
Bhaktapur	68,557	44,988	22,349	372	848
Kathmandu	435,544	171,828	255,444	4,675	3,597
Nuwakot	59,194	55,981	2,195	394	624
Rasuwa	9,741	8,747	704	165	125
Dhading	73,842	67,706	5,224	235	677
Makwanpur	86,045	75,155	8,561	1,109	1,220
Rautahat	106,652	104,995	1,069	125	463
Bara	108,600	104,352	2,955	551	742
Parsa	95,516	86,655	7,751	650	460
Chitawan	132,345	99,107	22,589	1,704	8,945
Gorkha	66,458	60,591	4,941	257	669
Lamjung	42,048	35,760	5,438	243	607
Tanahu	78,286	66,323	10,344	488	1,131
Syangja	68,856	61,462	6,317	262	815
Kaski	125,459	76,599	44,192	1,656	3,012
Manang	1,448	904	329	36	179
Mustang	3,305	2,278	706	182	139
Myagdi	27,727	23,310	3,072	244	1,101
Parbat	35,698	31,090	3,621	186	801
Baglung	61,482	54,549	5,947	151	835
Gulmi	64,887	58,924	4,912	232	819
Palpa	59,260	51,704	6,510	400	646
Nawalparasi	128,760	117,806	9,358	569	1,027
Rupandehi	163,835	137,116	24,172	1,219	1,328
Kapilbastu	91,264	87,462	3,199	179	424
Arghakhanchi	46,826	43,895	2,512	160	259
Pyuthan	47,716	45,538	1,706	185	287
Rolpa	43,735	41,188	2,204	118	225
Rukum	41,837	39,579	1,918	46	294
Salyan	46,524	44,660	1,547	126	191
Dang	116,347	103,762	10,724	418	1,443
Banke	94,693	83,430	9,911	713	639
Bardiya	83,147	80,076	2,072	238	761
Surkhet	72,830	66,131	5,681	156	862
Dailekh	48,915	46,899	1,604	79	333
Jajarkot	30,468	29,720	578	14	156
Dolpa	7,466	6,961	327	120	58
Jumla	19,291	18,394	664	80	153
Kalikot	23,008	21,983	850	48	127
Mugu	9,600	9,303	209	33	55
Humla	9,437	8,574	526	197	140
Bajura	24,888	23,506	1,045	138	199
Bajhang	33,773	32,904	560	110	199
Achham	48,318	46,812	1,023	163	320
Doti	41,383	39,152	1,321	360	550
Kailali	142,412	122,025	7,861	462	1,164