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Research Article

Robustness of Rural Road Networks: A Case Study of Gorkha, Nepal

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I N F O

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A B S T R A C T

Robustness is the ability of a system to continue operating efficiently under different operational conditions. It is observed in most road networks that they are becoming more vulnerable to various incidents and thus there is utmost need to make the road network robust. This research focused on the rural road network of Gorkha district of Nepal. This research addressed the question regarding the factor defining the robustness and indicator to quantify the robustness of the current road network of the study area. The research proposed a network structure that is efficient and robust enough to handle traffic movement in normal conditions and also accommodate the traffic in exceptional situations.

Keywords: Robustness, Redundancy, Connectivity, Node, Link

Introduction

Nepal having poverty-stricken rural countryside communities, rural development is one of the main agenda of development. The goal of rural development is attainment of sustainable livelihood and improved well- being of rural, people. Rural people's needs for sustainable livelihood and improved well-being are such that are they require better facilities to information, markets and opportunities; they need better access to health education and other goods and services.

Robustness is defined by (Gribble, 2001) as 'the ability of a system to continue to operate correctly under a wide range of operational conditions and to fail gracefully outside of that range'. Any disruption in a road network ultimately results in the changes of its supply (such as the link capacity) or/and its demand. The operation status of a road network is often evaluated with some indicators for its network-level performance, such as the average speed throughout the network. Thus, the study of road network robustness can be simply understood as the analysis of the performance of the road network under the situations with considerable changes in its supply or/and demand compared with its normal or desired performance. The main issue is connectivity of scattered areas rather than capacity in case of disruptions in the network. This is very important issue for policy makers for survival of the network and provides alternatives to supply goods and services during interruptions. This issue hasn't been dealt with in the context of rural hill areas which is found less addressed in literatures in the context of rural hill areas.

There is the construction of more than one alignment within the district, but the robustness of road network is not considered. In the absence of rational criteria and professional guidelines, road constructions are carried out in an adhoc manner leading to, wastage of limited resources country like Nepal. This research deals with the issue of robustness of rural road networks for investigation more focusing on connectivity of networks which is a pertinent issue in rural road network development and maintenance.

Research Objectives

The main objective of this research is investigation on robustness of rural road networks in Gorkha district of Gandaki province, Nepal.

Literature Review

Prevention, redundancy, compartmentalization, flexibility and resilience (Transportation Planning and Highway Engineering Kasteelpark Arenberg 40, B-3001 Heverlee, Belgium) are elements that make a network robust is supported by the fact that these elements are also found in other transport and non-transport network. Road network connectivity and land-cover dynamics, study uses graph theory-based concepts by employing alpha (α), beta (β) and gamma (γ) indices to determine road connectivity. (Lop Buri Provincial Office, 2008; Puri, 2006; Rojnkureesatien, 2006).

The alpha index (α) measures the circuitry of a network, or the degree to which it provides alternative paths for traveling from one node to another. The beta index (β) reflects the complexity and completeness of a network (Kansky, 1963; Morlok, 1967). The gamma index (γ) is a measure of the extent to which the nodes are connected, and is called connectivity (Kansky, 1963; Morlok, 1967). It yields the ratio between the links and nodes of a given network. Can also be used as a measure of redundancy or duplication in the road network (Kansky, 1963; Kofi, 2010). The index usually ranges from 0 to 1 but can be also expressed by percentage. The higher the value, the higher the connectivity of network.

$\alpha = (L-V+1)/(2V-5)$ .... (1)

$\beta = L/V$ .... (2)

$\gamma = L/(3*(V-2))$ .... (3)

Where,

L = the number of links

V = the number of nodes

Shortest Path

Finding the shortest path is an important task in many network and transportation related analyses. This problem arises as a main decision question or as a step in some situation. There are many variations, depending on the type of network and costs involved, and source/destination pairs of nodes for which we need solution (Rardin, 2003). The most in depth classification of shortest path problems is agreed to the Deo and Pang's taxonomy (1984) and most recently by Sniedovich (2005).

Shortest Path Algorithms

A variety of methods and algorithms are available for the solution of shortest path problems depending on the nature of the specific problem. There are of course, several ways to classify such algorithms like: i) dynamic programming inspired algorithms and linear programming inspired algorithms and ii) label setting algorithms and label correcting algorithms. The first classification scheme is very much OR/MS (operations research /management science) and methodologically oriented and the second classification scheme used both incomputer science and operations research literature (Bertsekas (1991); Evans & Minieka (1992); Sniedovich, 2005).

Floyd-Warshall Algorithm

The Floyd-Warshall algorithm is a dynamic programming algorithm to solve the all-pairs (or all-to-all) shortest path problem on a directed network. It can be used in a network to get the shortest distance.

Minimum Spanning Trees

A common problem in networks and design is that of connecting a set of nodes by a network of minimal total length. It assumed that the network is undirected. To minimize the length of the connecting networks, it never pays to have any cycles (since we could break any cycle without destroying connectivity and decrease the total length). Since the resulting connection graph is connected, undirected, and acyclic, it is a free tree. A Minimum Spanning Trees (MST) is a spanning tree of minimum weight.

Prism Algorithm

There are two well-known greedy algorithms for computing MST's: Prim's algorithm and Kruskal's algorithm (Lecture Notes CMSC 420. Lecture 6: Minimum Spanning Trees and Prim's Algorithm. Read: Section 9.5 in Weiss). Here, Prim's algorithm is used for computing Minimum Spanning trees. Prim's algorithm builds the tree up by adding leaves one at a time to the current tree (Lecture Notes CMSC 420. Lecture 6: Minimum Spanning Trees and Prim's Algorithm. Read: Section 9.5 in Weiss). It starts with a root vertex (it can be any vertex). At any time. The subset of edges forms a single tree.

District Transport Master Plan (DTMP)

In Nepal there is a DTMP Guidelines which assist in the preparation of a District Transport Master Plan (DTMP) for the conservation, improvement, and new construction of the District Road Core Network (DRCN) (DTMP guideline 2012). The DTMP is to be prepared every five years and provides a prioritized list of interventions for the DRCN that can be carried out with the estimated budget for the 5-year DTMP period. Each year the planned interventions are further detailed in the Annual Work Program of the DDC, adjusting the plan according to the actual budget and requirements. The conservation works are further detailed in the Annual Road Maintenance Plan (ARMP)

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that defines the maintenance interventions to be carried out in the DRCN and provides further detail to the general proposal included in the DTMP.

These DTMP Guidelines provide the following sequence of steps to be followed in the preparation of a DTMP in a specific district. These steps are carried out in this order, as each subsequent step depends on information obtained in the previous step. For each step, a few sub-steps are identified, and a description is given of the activities to be carried out, the items to be produced and the equipment and data required.

Step 1: Identification of the DRCN
Step 2: Collection of primary and secondary data
Step 3: Preparation of the DTMP

Specific objectives of preparing DTMP for a district

- Analyze accessibility situation in the district
- Identify and prioritize interventions based on the accessibility situation
- Prepare Indicative Developmental Potential Map (IDPM)
- Prepare District Inventory Map (DIM) of Rural Road networks
- Prepare Perspective Plan of transport services and facilities
- Prepare/update five years District Transport Master Plan (DTMP)
- Prepare a realistic physical and financial implementation plan of prioritized roads for the DTMP period

Methodology

Gorkha district which lies on Gandaki province of Nepal was selected as study area. There are 1019.29km lengths of roads in the district. Out of which Class A roads have length of 598.57 km and Class B roads have length of 420.72km. Major data collected for the research work includes the all the road network of Gorkha district is taken from the Google earth through the DTMP of Gorkha District. Data were collected from annual reports published by district level offices and consultation with stakeholders (such as DDC, DTO, local business entrepreneurs etc.).

Existing Network Connectivity

The main strategic road (Anbukhaireni - Gorkha Road) from the bridge of Marshandi to district headquarters. And the other road which exists in the district is taken for analysis purposes. For the data analysis firstly, the whole existing network is taken. And the removal of edge (link) is done by Prism Algorithm process by means of formation of minimum spanning tree. Networks analysis is done through the Floyd-Warshall algorithm method to form short path matrix. The existing level of connectivity of the network is calculated using alpha (α), beta (β), and gamma (γ) indexes and presented in table below.

The use of Floyd-Warshall algorithm the presentation of network diagram is shown in Figure 2.0

From the distance sheet obtained from the network diagram minimum spanning tree is obtained using the Prim's algorithm. While construction of minimum spanning tree some of the most valuable routes are not followed by the tree so some additions of nodes are done which is shown in the network diagram. The additional nodes in the network in the view of social-economic and its importance are respectively 81,82,83,84,85,86 and 87 respectively. The total length of road from minimum spanning tree is 488.244With the same coverage of road network is shows that the length of road networks is decreased more than fifty percent on minimum spanning tree. The MST is shown in Figure 3.0

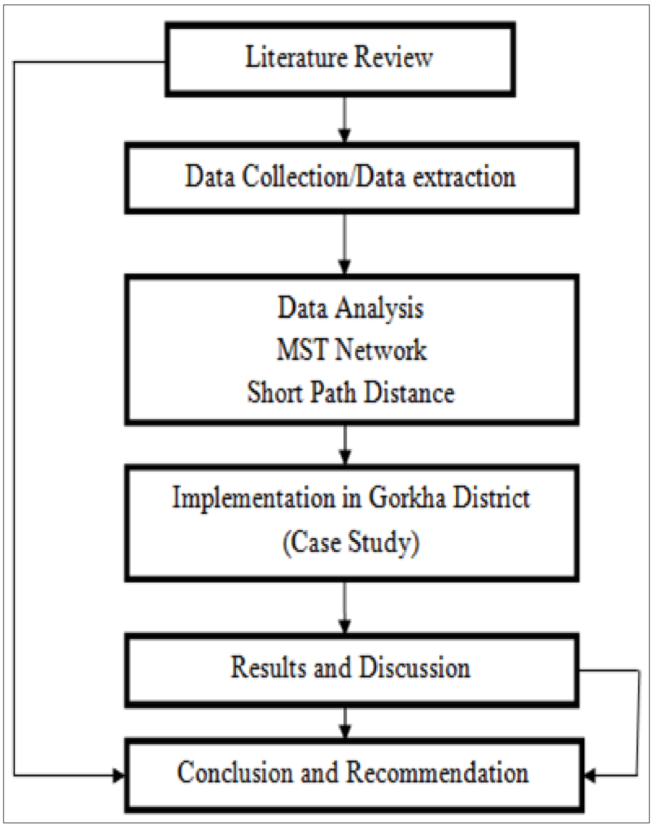

Figure 1.Flow Chart of Methodology

Table 1.The Existing Level of Connectivity

S.No.	Indicator	Existing Network
1.	Alpha	0.178
2.	Beta	1.333
3.	Gamma	0.455

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Figure 2.Network (Distance Diagram) between Nodes of Gorkha District

Construction of Short Path Network

After the construction of minimum span tree short path matrix of the network is calculate using Floyd-Warshall algorithm method. It is obvious that the robustness of the MST network is minimum. To improve the robustness of the network, we need to add additional links to the MST network. The short path matrix is the basis for the selection of the additional links in the study. The following steps were considered for the analysis of the new network after the addition of links to the previous network. The district headquarters is taken as a base for the analysis for the short path network. One link is added to MST from the list of unselected links and computed the short distance matrix. This process is repeated for the whole links. Among the links, the links which give the shortest distance are selected. A new network is being developed now. In the same way the second link is added to the new network. This process is repeated until a desired level of connectivity is achieved.

With the addition of all unselected links one by one on the MST network diagram the shortest distance is calculated taking Node 10 (i.e. district headquarters) as base. The shortest length among all unselected links is computed.

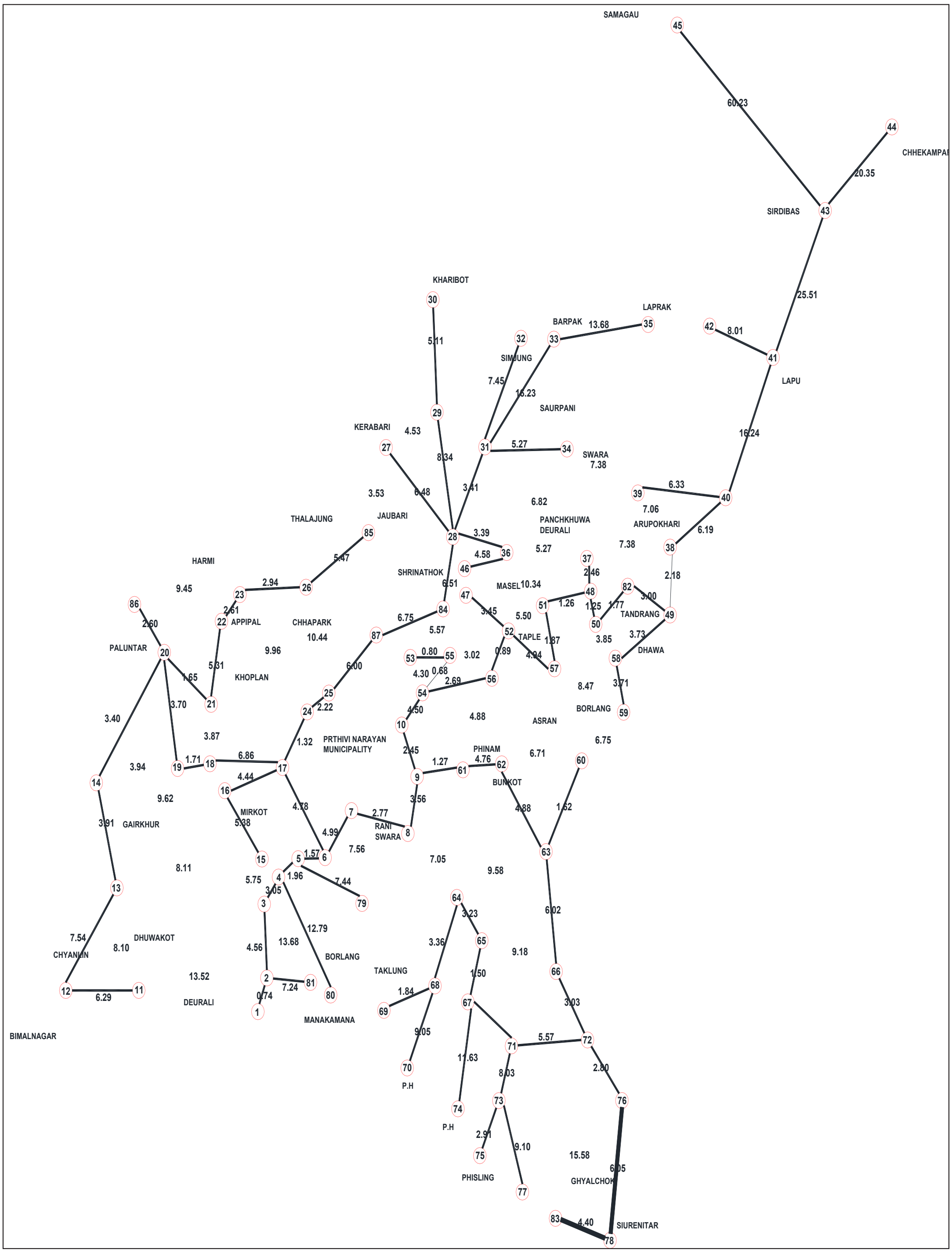

Figure 3.MST Diagram of Gorkha District under Research

Table 2.Aggregated form additional links

S.No.	Addition of Link	Short path length	α	Β	γ
1	(15-3)	5.75	0.006	1.000	0.341
2	(36-37)	5.27	0.012	1.011	0.345
3	(8-64)	7.05	0.018	1.023	0.349
4	(51-52)	5.50	0.024	1.034	0.353
5	(23-24)	9.96	0.030	1.046	0.357

6	(80-69)	1.81	0.036	1.057	0.361
7	(58-50)	3.85	0.041	1.069	0.365
8	(21-18)	3.87	0.047	1.080	0.369
9	(85-27)	3.53	0.053	1.092	x
10	(14-19)	3.94	0.059	1.103	0.376
11	(11-2)	13.52	0.065	1.115	0.380
12	(60-59)	6.75	0.071	1.126	0.384
13	(7-79)	7.56	0.077	1.138	0.388
14	(38-39	7.06	0.083	1.149	0.392
15	(34-36)	6.82	0.089	1.161	0.396
16	(13-15)	8.11	0.095	1.172	0.400
Total additional links length	100.35				

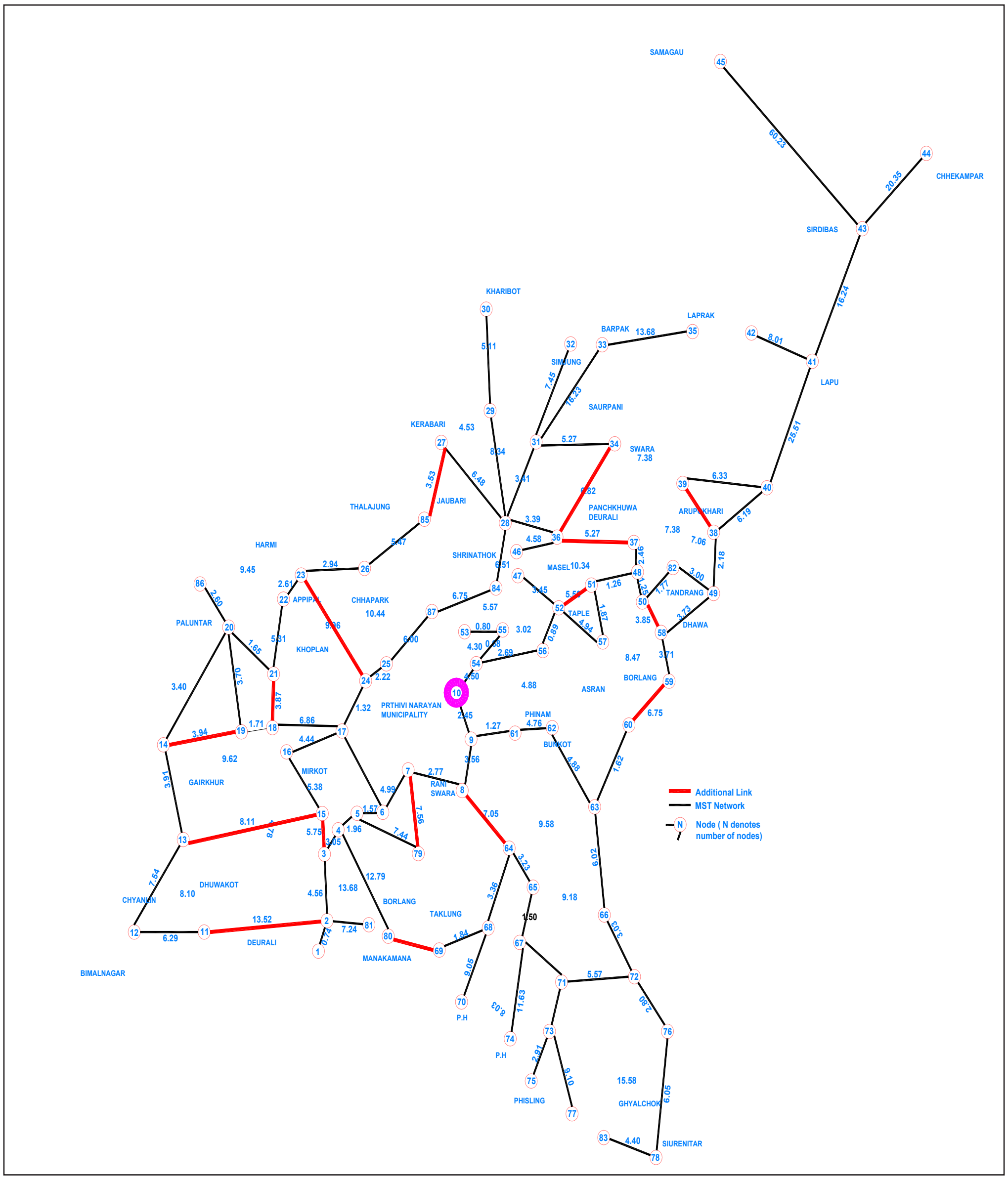

Figure 4.Final Network According to Robustness Concept

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Table 3.Alpha, Beta and Gamma Value of Road Network (Aurangabad Cities)

Indexes	Value
Alpha	0.0588-0.2
Beta	1.074-1.38
Gamma	0.376-0.468

Table 4.Comparisons of Alpha, Beta and Gamma Value of Rural Road Network (Gorkha)

S.No.	Indicator	Existing Network	MST Network	New Network
1.	Alpha	0.178	0.000	0.095
2.	Beta	1.333	0.989	1.172
3.	Gamma	0.455	0.337	0.400

Table 5.Result Comparisons

S. No.	Para-meter (Taken)	Existing Net-work	MST Net-work	New Net-work	Remarks
1.	number of links	116	86	102	Increase in link by 16 with increase in length of 100.35km
2.	number of nodes	87	87	87	
3.	Total Road network length	1019.29	488.24	588.59	42.30% decrease in road length

There are altogether116 links and 87 nodes on the existing networks. After the construction of minimum spanning tree, the total no of links is 86 whereas, the number of nodes is unchanged. There are all together 30 links which are not followed by MST network. So, network analysis is done by taking the 30 unselected links by MST networks. Analysis is done by taking all individual unselected links one after another for computing the short distance of the rural network. After computing the shortest distance among all the links, the shortest among the computing shortest distance link is added to the MST diagram and computing the shortest distance after adding the previous added link. And after computing all the shortest distance, the shortest among them is selected. The process is repeated until a desired level of connectivity is achieved.

Comparision With Relevant City

For the level of connectivity of the study area, the previous study research of Aurangabad city (a Capital of Marathwada Region of Maharashtra) was compared with the current study. From Table 2 and Table 3 it shows that the alpha (α), beta (β), and gamma (γ) indexes of the study rural road network (Gorkha) lies between the range of alpha (α), beta (β), and gamma (γ) indexes of rural road network of Aurangabad cities. This validates the road network of Gorkha district.

Robustness

From the indicator which is used for the analysis of robustness in the above Table 3 it shows that with decrease in link (i.e., Removing the links) it shows that the Alpha value is decreased the robustness of a networks increased in redundancy increase and decrease in redundancy decrease.

Conclusion

Analysis of robustness shows that with decrease in link (i.e. Removing the links) it shows that the Beta value is decreasing and due to increase of links (addition of links) it shows that Beta value is increased. Thus, it can be concluded that the completeness, value is increased while increasing the links number and decrease while decrease in links number. The robustness of networks increased in completeness increase and decrease in completeness decrease. From the indicator, which is used for the analysis of robustness, it shows that with decrease in link (i.e. Removing the links) it shows that the Gamma value is decreasing and due to increase of links (addition of links) it shows that Gamma value is increased. Thus, it is also concluded that the connectivity and value increase while increasing the links number and decrease while decrease in links number i.e. The robustness of networks increased in connectivity increase and decrease in connectivity decrease.

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