

## **Evaluation of Feeder Port Benefits Using Analytic Hierarchy Process Method with Quantitative and Qualitative Criteria: Case Study of Sapudi Port - Indonesia**

**Rutma Pujiwat<sup>1</sup>, Sucipto<sup>1</sup>, Dwi Phalita Upahita<sup>1</sup>, Djoko Prijo Utomo<sup>1</sup>, Maharani Almira Salsabila<sup>1</sup>**

<sup>1</sup>Research Center for Transportation Technology, National Research and Innovation Agency, Indonesia

### **Abstract**

Class III/feeder ports are built to drive the hinterland area's economic growth. This study will evaluate Port benefits during operation using the analytical hierarchy process (AHP) method with quantitative and qualitative criteria arranged in a criteria tree. This study took the case of the Port of Sapudi-Sumenep regency - East Java Province-Indonesia. The results show that the value of the benefits is quite high. Therefore, this study suggests that the feeder port is significant to be maintained as a driver of community economic activity.

**Keywords:** *Analytic Hierarchy Process, qualitative criteria, quantitative criteria, criteria tree, value of benefits*



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### **INTRODUCTION**

Sapudi is a port under the Directorate General of Sea Transportation, Ministry of Transportation. The port belongs to Class III ports and is a regional feeder port (Ministry of Transportation Republic of Indonesia, 2022). This port is in Gayam District, Sumenep regency, East Java province. Geographically Sapudi island is located at 70 05" 20" north latitude and 1140 25' 45 " east longitude. It has three docks: Pier 1 is in a non-functioning condition, Pier 2 is 20 x 10 meters, and Pier 3 is 44 x 7.5 meters. The depth of the harbor pool is stretched from -5 to -10 meters. There are three trestles; trestle 1 has a size of 144 x 8 meters, trestle 2 is 370 x 3.5 meters, and trestle three is not used.

The type of vessel that serves shipping from/to Sapudi port regularly is a ship with a capacity of 100 passengers and 20 tons of goods. The ships serve the Sapudi – Jangkar (round trip) route once a week on Saturday and the Sapudi – Kalbut (round trip) route on Monday, Tuesday, Wednesday, Thursday, and Sunday. In addition to this type of ship, Pioneer ships stop at the Port of Sapudi every two weeks. As for the unscheduled routes, the service area covers trips from Sapudi to Kalianget, Kalbut, Jangkar, Kangean, Saronggi, Pasuruhan, Dungkek, Tanjung Wangi, Pagerungan and Probolinggo Port.

Ports play an essential role not only in traffic and transportation activities but also in a wide range of economic activities, ranging from industries that use mostly raw materials imported by sea and whose transportation costs by land are too high (Benacchio et al., 2000). This paper focuses

on analyzing Sapudi port's benefits as an evaluation for the improvement of sustainability, policy, and management of the port in the future. This paper is organized as follows: Section 2 presents the literature review. Section 3 describes the methodology for evaluating Port benefits. Section 4 discusses numerical results. Finally, the conclusions and directions of future research are presented in section 5.

## **LITERATURE REVIEW**

Indonesia is an archipelagic country that demands connectivity and affordability between its regions so that ports become one of the links or node points between land, sea, river, lake, and crossing transportation. A feeder port is a port whose primary function is to serve domestic sea freight activities, transfer the cargo of domestic sea freight in limited quantities, is a feeder for the main port and collecting port and as a place of origin for passengers and/or goods and crossing transportation with a range of services in the province (regional feeder) or the Regency (local feeder) (Indonesia Ministry of Transportation, 2017). Technical criteria for local feeder ports based on the Ministry of Transportation is to have (a). A minimum distance of 5-20 miles from other local feeder ports on the same coastline; (b). Maximum Basin depth five m-low Spring; (c). Maximum berth capacity 1000 deadweight tonnage; (d). Maximum berth length 80 m; (e). The maximum land area of one hectare; and (f). loading and unloading equipment according to the type of goods transported. In comparison, the main port serving the hub of the Indonesian port system has a berth capacity of 10,000 deadweight tonnage with a minimum berth length of 350 m which can accommodate a container capacity of at least 100,000 units equivalent to twenty feet/year.

Transportation infrastructure is essential to public policies, regulations, and operating systems, so it needs to be evaluated continuously. Several studies have been conducted extensively that discuss the evaluation and impact of ports from various aspects. Maritime transport has historically played an essential role in the formation and development of cities. In the Indonesian context, port infrastructure plays one of the most fundamental roles in shaping the national economy. Close proximity to major ports positively affects GDP per capita, labor productivity, poverty levels, and poverty disparities (Maryaningsih et al., 2014). It is in line with another research about seaport benefits by Woo et al. (2011); the presence of the port not only plays an essential role in the port area itself but also in the adjacent territory. In addition, this infrastructure also provides more connectivity and access to other regions and boosts export–import activities (regional and international) (Yudhistira & Sofiyandi, 2018). Developing countries need to continue improving the quality of port infrastructure because it contributes to better logistics performance, which leads to higher cross-sea trade, resulting in higher economic growth (Munim & Schramm, 2018). In addition, the study in Indonesia showed that the development of small ports increased local economic activity by 1.8 percent (Karimah & Yudhistira, 2020).

From the aspect of methods, several methods have been used for policy evaluation, including (1) cost-benefit analysis that rests on unidimensional measurement and ranking, (2) multi-criteria decision analysis that applies multi-dimensional measurement but unidimensional ranking, and (3) non-aggregate indicator systems that operate with multi-dimensional measurement and sometimes also multi-dimensional ranking. The most simple method is Multi-Criteria Decision Analysis (MCDA) (Hadorn, 2022).

The Analytical Hierarchy Process (AHP), as one of the MCDA methods, has been widely used in weighting criteria and alternative selection. AHP is a decision support model first developed by Thomas L. Saaty. This decision-support Model will decompose complex multi-factor or multi-criteria problems into a hierarchy (Saaty, 2003). The Top Level is the system's goal; level 2 is the criteria of the subsystem; level 3 sub-criteria of the sub-subsystem, and so on, until the lowest level is referred to as indicators, hereinafter referred to as a decision tree in a hierarchical structure. Frequently used indicators for port performance are traffic (vessel traffic, cargo throughput, container traffic); productivity (ship turnaround time, dock occupancy, ship productivity, cargo stay time); quality (port community system, user satisfaction, maritime connectivity) (McGovern, 1988)

From the literature review mentioned earlier, it can be summarized that the following points need to be considered besides direct benefits in evaluating the port so that it can provide a basis for planners, governments, users, and other relevant stakeholders in planning and determining policies. Some important things are as follows:

- Indirect economic benefits: commodity GDP and the trend of rising land prices around the port area
- Indirect benefits from aspects of the social criteria of population: trend changes in income outside the port zone, the cumulative number of migrations, and the Human Development Growth Index in the area where the port is located.
- Indirect benefits from aspects of territorial criteria consist of the suitability of spatial patterns and trends in land use utilization changes.
- Indirect benefits from environmental aspects of assessing the completeness of facilities available in the port environment.

## RESEARCH METHOD

The analytical hierarchy process (AHP) method was used to assess the port's benefit in backward and forward analysis, so it is useful for improving future planning to increase the benefit value of the port. The research flow Diagram is illustrated in Figure 1 below.

- Define the goal/objectives  
The Goal of this study is to assess the benefits of the Port of Sapudi after operating for several years as the top level in the criteria tree.
- Pairwise comparison & Weights of criteria calculation  
Determination of weight is done by comparing between criteria in pairs at the same hierarchy and sub-system levels presented as a comparison matrix. Suppose A is the comparison matrix  $n \times n$ , as follows

$$= [a_{ij}] = \begin{bmatrix} 1 & a_{12} & a_{13} & \dots & a_{1n} \\ 1/a_{21} & & & & a_{2n} \\ 1/a_{31} & & \ddots & & a_{3n} \\ \vdots & & & & \vdots \\ 1/a_{n1} & 1/a_{n2} & 1/a_{n3} & \dots & 1 \end{bmatrix} \quad (1)$$

$$a_{ij}, i = 1, 2, \dots, n, j = 1, 2, \dots, n \text{ where } a_{ij} = 1 \text{ for } i = j \text{ and } a_{ij} > 0, i \neq j$$

In order to make a contrast about the degree to which one criterion is more important than another, the original 1 – 9 scale by Saaty (1980) is used. Comparison of criteria is presented in Table 1.

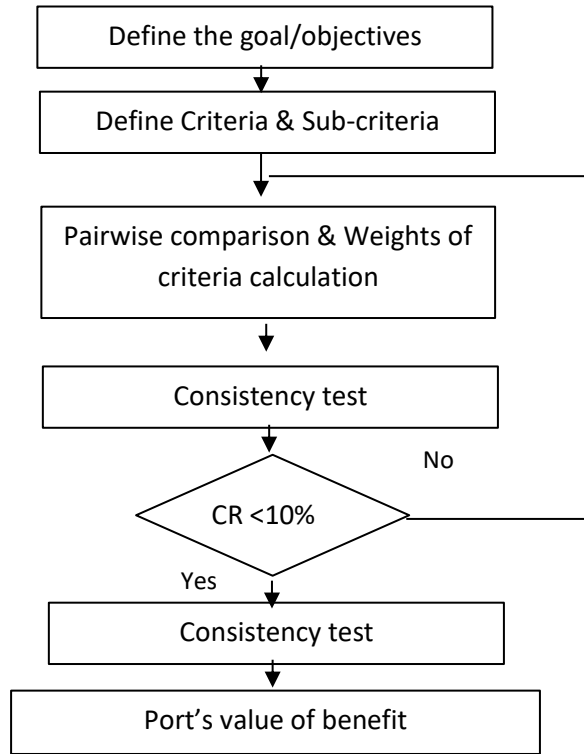


Figure 1. Methodology Diagram

Table 1. Criterion Comparison Scale

Scale	Definition
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate value

Normalized matrix  $A = [a_{ij}]$  is  $A^1 = \left[ \frac{a_{ij}}{\sum_{i=1}^n a_{ij}} \right], i = 1,2,3 \dots n$  for  $j = 1,2,3 \dots n$

$$A^1 = \begin{bmatrix} a_{11}^1 & \dots & a_{1n}^1 \\ \vdots & \ddots & \vdots \\ a_{n1}^1 & \dots & a_{nn}^1 \end{bmatrix},$$

next criteria weight,  $W_i = \frac{1}{n} \sum_{j=1}^n a_{ij}^1, j = 1,2,3 \dots n$  untuk  $i = 1,2,3 \dots n$

$$\text{So, } W_i = \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix}, i = 1,2,3 \dots n \tag{2}$$

- Consistency test  
Priority assignment is acceptable if the comparison matrix of Equation (1) is expressed as consistent or close to consistent by calculating its eigenvectors. The Eigenvector is obtained from the maximum value of the eigenvalue ( $\lambda_{max}$ ). Consistency value approach can be calculated by following formula (Saaty, 1987):

$$CR = \frac{CI}{RI} \tag{3}$$

Where,

CR = Consistency Ratio

CI = Consistency Index

RI = Random Index for the matrix size, n

A matrix is called consistent if the value of  $CR < 0.1$ . The value of *RI* depends on number of attributes under comparison (Saaty, 1987)

**Table 2.** value of *RI*

<i>n</i>	1	2	3	4	5	6	7	8	9	10
<i>RI</i>	0	0	0,58	0,90	1,12	1,24	1,32	1,41	1,45	1,49

The index consistency value is calculated using the formula:

$$CI = \frac{\lambda_{max} - n}{n - 1} \tag{4}$$

$\lambda_{max}$  calculated by formula:

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^n \frac{W_i^1}{W_i}, i = 1, 2, 3 \dots \dots \dots n \tag{5}$$

Where  $W_i^1$  is the product of the comparison matrix A of Equation (1) with the weight value  $W_i$  of Equation (2):

$$W_i^1 = AxW_i = \begin{bmatrix} 1 & a_{12} & a_{13} & \dots & a_{1n} \\ 1/a_{21} & 1/a_{22} & 1/a_{23} & \dots & a_{2n} \\ 1/a_{31} & 1/a_{32} & 1/a_{33} & \dots & a_{3n} \\ \dots & \dots & \dots & \dots & \dots \\ 1/a_{n1} & 1/a_{n2} & 1/a_{n3} & \dots & 1 \end{bmatrix} \times \begin{bmatrix} W_1 \\ W_2 \\ \vdots \\ W_n \end{bmatrix} = \begin{bmatrix} W_1^1 \\ W_2^1 \\ \vdots \\ W_n^1 \end{bmatrix} \tag{6}$$

The use of the formula for calculating the number of samples is distinguished if the number of populations is known and if the number of populations is unknown, respectively, there are several formulas that can be used. In this study, the population is unknown, so the authors use the formulation of:

- Roscoe, determine at least 30 or between 30 to 500 samples there is also a determine the number of variables x 10
- Lameshow =  $n = \frac{Z^2 \cdot \frac{\alpha P(1-P)}{1-\frac{\alpha}{2}}}{d^2}$
- Isaac and Michael table: n unknown with sampling error 1% then n = 664, if error = 5% then n = 349 and if error = 10% then n = 272
- Multivariate, rule of thumb (n+1) x 10 where n is the number of independent variables.

Based on these references, the number of samples in this study is in the range of 30-100 respondents.

**FINDINGS AND DISCUSSION**

Weighting criteria were obtained from the results of comparing between criteria by experts who were selected as respondents. Experts in this study are grouped from the local Department of transportation and regional planning as government representatives, port operators, and transportation system experts. Quantitative Data were collected from the port operator, the Sumenep regency Transportation Office, the Ministry of Transportation, the Sumenep regency local government and the Central Statistics Agency of Sumenep regency, and the Central Statistics Agency of East Java province. Qualitative Data were obtained by surveying port users and communities in the hinterland of Sapudi port. A qualitative data assessment survey was conducted by direct interviews with a random survey of respondents. Evaluation of qualitative criteria using a Likert scale of 1 – 5 with a value of 0-100. Very bad (1) value 0 – 20, Bad (2) Value 21 – 40, enough (3) value 41 – 60, Good (4) value 61 – 80, and very good (5) value 81 – 100. Respondents were asked to choose a rating between 1 – 5 and give a rating in the appropriate range. Sapudi Class III Port production Data for 2013 – 2016 are presented in Table 3.

**Table 3.** Production data Sapudi Port (2013 - 2016)

Rated elements	Unit	Operational Data			
		2013	2014	2015	2016
1. Vessel Arrival					
a. Number Of Ships		901	1.033	1.129	935
b. Gross Tonnage	GT	87.297	103.658	96.335	106.335
2. Commodity					
a. Cargo	Ton	10.312	9.376	15.864	13.815
b. Livestock		2.910	3.442	3.056	2.075
3. Passenger	pax	11.759	10.443	12.399	13.025

UPP Class III Sapudi, 2017

The growth of loading and unloading goods at the Port of Sapudi on average per year amounted to 15.7% in 2013 – 2016. Types of goods include building materials, mixed goods, agricultural products, and merchandise. While the development of arriving and departing passengers in 2013-2016 amounted to 4.2% per year. The total population of the Sumenep regency in 2015 was 1,072,113 people, with an average annual growth rate of 0.564% for 2011 – 2015. Economic growth in Sumenep regency grew by 6.2% per year from 2011 – 2015, as indicated in Table 5.

**Table 4.** Sumenep Regency Population Growth 2011-2015

Description	Unit	2011	2012	2013	2014	2015
Area	km <sup>2</sup>	2.093,47	2.093,47	2.093,47	2.093,47	2.093,47
<b>Population</b>						
- B P S	people	1.048.177	1.053.640	1.061.211	1.067.202	1.072.113
<b>Population Growth</b>						
- B P S	%	0,56	0,52	0,72	0,56	0.46
<b>Population Density</b>						
- BPS	people /km <sup>2</sup>	501	503	507	510	512

BPS, Sumenep regency in Figures (2016)

**Table 5.** Economic Growth of Sumenep Regency 2011 -2015

Description	Unit	2011	2012	2013	2014	2015
Economic growth	%	6,05	6,51	6,64	5,70	6,23

BPS, Sumenep regency in Figures (2016)

**Table 6.** Development of GDP by field of business - Sumenep 2011 – 2015

No	Desc.	Unit	2011	2012	2013	2014	2015	r (%)
1	GDP (ADHB)	Billion Rp	17.457,07	20.079,70	25.360,04	28.312,66	28.998,01	13,5
2	GDP (ADHK)	Billion Rp	16.064,77	17.665,02	20.218,07	21.476,77	21.750,48	7,9

BPS, Sumenep regency in Figures (2016)

The study aims to assess the benefit of Sapudi Port, where the benefits are divided into direct and indirect benefits. Direct benefits are benefits directly related to the port's performance, while indirect benefits are the impact of the operation of the port of Sapudi. Direct benefits include encouraging the economic growth indicated by the passenger number growth rate and the amount of loading and unloading of goods. Another aspect of direct benefit is transportation benefits indicated by goods handling time and the amount of handling costs. The Port labor income indicates benefits to the social population. Port service quality was assessed by safety, security, order,

smoothness, comfort, and convenience. Meanwhile, the financial aspects are assessed with Port revenue as the indicator.

The impact of the existence of Sapudi port on the economy of Sumenep regency is assessed by indicators such as total GDP, commodity GDP, per capita GDP, and land value increases. Indicators assess the impact on social population: changes in income of communities around the port, population migration, and Human Development Index (HDI). While the impact on regional aspects is assessed by indicators such as land suitability or spatial patterns and changes in land use utilization around the port of Sapudi. Changes in land use and the availability of port facilities were used as indicators to assess the environmental aspects of Sapudi Port. Figure 2 describes the criteria tree used in this research.

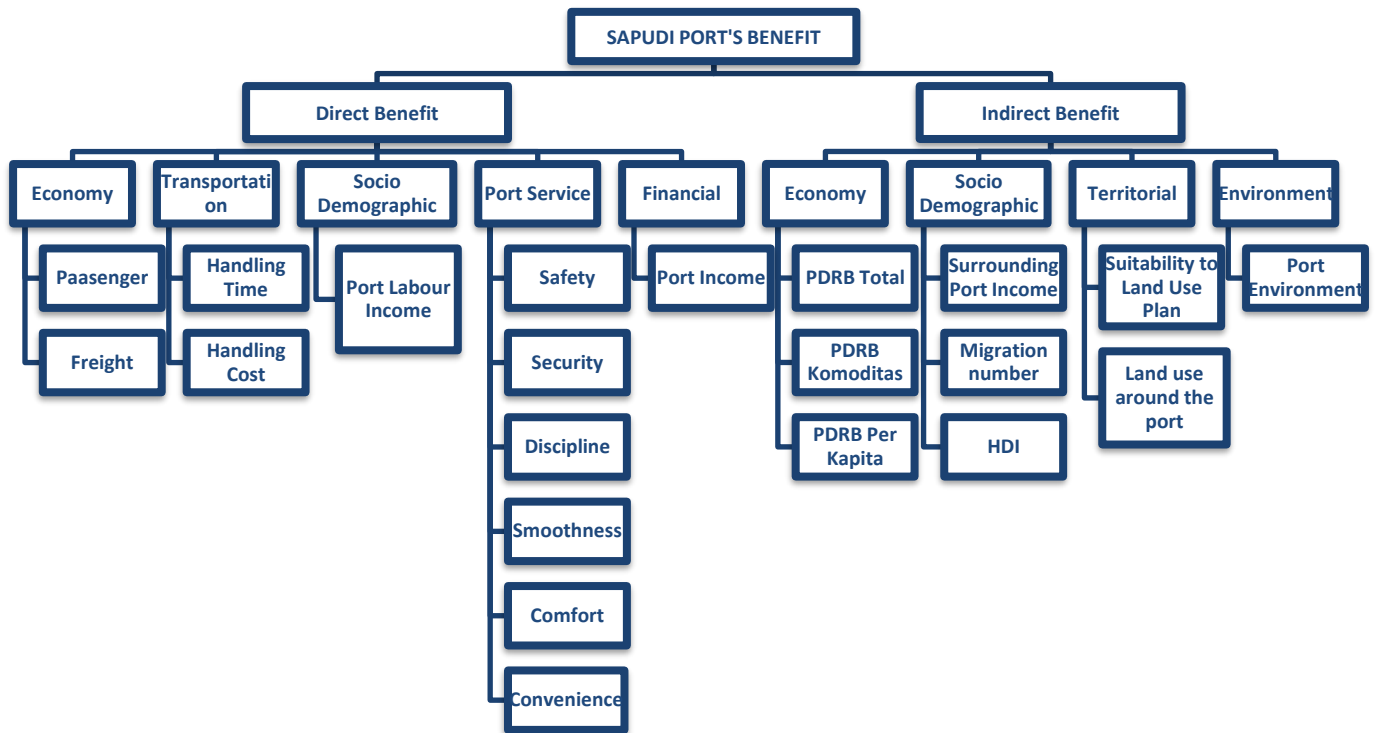


Figure 2. Criteria Tree

The weight of the criteria and the benefit value were calculated using AHP methods based on expert judgement and primary and secondary data. Table 7 shows the value of benefit calculations using AHP.

The results of AHP show that the Sapudi Port has a high benefit value, indicated by a high score of more than 50 points. Among all the benefits, suitability to the land use plan and the contribution to the human development index have the highest value. It means that the Sapudi Port has followed the land use masterplan correctly and has contributed to the development of the residence in the surrounding area. Meanwhile, some aspects need to improve, such as the impact on the income of the surrounding area, the condition of the port environment, and the comfort of the service. Given the benefit value of Sapudi Port, it is essential to improve the operation and develop the Sapudi Port to optimize the benefit.



Table 7. Weight criteria and benefit value of Sapudi Port

Level 2 Criteria	Value	Weight	Level 3 Criteria	Value	Weight	Level 4 Criteria	Value	Weight	Description
Direct Benefit	54,12	0,75	Economy	59,46	0,42	Passenger	78,37	0,33	Passenger Growth Rate
						Freight	50	0,67	Freight Growth Rate
			Transportation	58,5	0,29	Handling time	67	0,5	Change in handling time
						Handling Cost	50	0,5	Handling Cost Efficiency
			Socio Demographic	46,15	0,14	Port Labour Income	46,15	1	Changes in port labour income
			Financial	31	0,1	Port Income	51,68	0,5	Port Income Growth
						Investment and Income Ratio	10,32	0,5	Changes in ratio values
			Port Service	53,33	0,06	Safety	50	0,41	Ratio between safety related cases and port activities
						Security	59,6	0,14	Number of Security Related Case
						Discipline	47,11	0,06	Qualitative Judgement
						Smoothness	62,91	0,18	Qualitative Judgement

Level 2 Criteria	Value	Weight	Level 3 Criteria	Value	Weight	Level 4 Criteria	Value	Weight	Description
						Comfort	36,68	0,05	Qualitative Judgement
						Convenience	53,16	0,16	Qualitative Judgement
Indirect Benefit	53,59		Economy	54,74	0,56	Economy GDP	65,66	0,11	Economy GDP Growth
						Commodity GDP	72,71	0,23	Commodity GDP Growth
						GDP per Capita	42,68	0,3	GDP per Capita Growth
						Land Value	50	0,36	Changes in Land Value
			Socio Demographic	46,29	0,28	Surrounding Port Income	25	0,62	Changes in the income of the residences
						Migration number	50	0,1	Cumulative migration number
						Human Development Index (HDI)	91,41	0,28	Human Development Index
			Territorial	90	0,1	Suitability to Land Use Plan	100	0,8	Suitability to Land Use Plan
						Land use around the port	50	0,2	Changes in Land Use
			Environment	20	0,07	Port Environment	20	1	Availability of Port Facilities

**CONCLUSION AND FURTHER RESEARCH**

This study analyzes the benefits of the Sapudi feeder port as the basis for future government policy evaluation and determination. The Analytic Hierarchy Process method is proposed as a tool to determine the value of benefits by selecting qualitative and quantitative criteria. This research

shows that the port is quite useful based on the value of the benefits generated. In the implementation of this research process, the authors found that the value of direct benefits is relatively the same as the indirect benefits obtained, with the main criteria that are very influential in this research: economic, transportation, service, and territorial criteria. Meanwhile, some aspects still need to be improved, including the amount of loading and unloading, convenience, port environment, and the benefits of the port's existence to the surrounding community. For future work, the author needs to explore further the enhancement of Port benefits from these aspects.

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