A Supplier-Manufacturer Relationship Model for Teak Forest Carbon Sequestration and Teak Log Demand Fulfillment with Sustainability Consideration

Ririn Dewi Cahyani, Muh. Hisjam, Wahyudi Sutopo, and Kuncoro Harto Widodo

Abstract**—**Availability of raw materials is important for Indonesia as a furniture exporting country. Teak log as raw materials is supplied to the furniture industry by Perum Perhutani (PP). PP needs to involve carbon trading for nature conservation. PP also has an obligation in the Corporate Social Responsibility program. PP and furniture industry also must prosecute the regulations related to ecological issues and labor rights. This study has the objective to create the relationship model between supplier and manufacturer to fulfill teak log demand that involving teak forest carbon sequestration. A model is formulated as Goal Programming to get the favorable solution for teak log procurement and support carbon sequestration that considering economical, ecological, and social aspects of both supplier and manufacturer. The results show that the proposed model can be used to determine the teak log quantity involving carbon trading to achieve the seven goals to be satisfied the sustainability considerations.

Keywords**—**Availability of teak log, support carbon sequestration, goal programming, sustainability consideration.

I. INTRODUCTION

INDONESIA is known as one of the largest furniture exporter in the world. In 2006 the position of Indonesia's furniture exports in the world is ranked eighth in the order of the highest ranked China, Canada, Mexico, Italy, Vietnam, Malaysia, and the Taiwan [1]. Growing world demand causes rise in export value of furniture. This is evident from the increase in export performance of Indonesian furniture and handicraft during 2010 reached 2.70 billion US dollar and in 2009 amounted to 2.25 billion US dollar, up 20.17%. [2].

Perum Perhutani (PP) is a State Owned Enterprise (SOE) in Indonesia who has the duty and authority to conduct planning, administration, utilization and protection of forests in the working area. Perum Perhutani (PP) is a vision of sustainable forest management for the overall prosperity of the people. PP supplies teak logs to furniture industry to meet customer demand for furniture. However, PP also must maintain to preserve the natural forests in minimizing the amount of carbon in the atmosphere, mostly due to the use of fossil fuels the world [3]. Therefore, PP needs to involve the carbon trading in supporting the stability of teak forest carbon sequestration. Carbon trading conducted between PP (sellers of carbon credits) as a provider of land that is maintained for the area of carbon trading, while the buyer is the party responsible for reducing emissions from deforestation and forest degradation [4], [5]. As a corporate government, PP must run Corporate Social Responsibility (CSR) [6]. PP needs to issue a CSR to prevent illegal logging would harm the country and disrupt the balance of the forest. Health and safety PP's employee need to be considered by the procurement of Personal Protective Equipment (PPE) [7].

An object study was held in Kesatuan Bisnis Mandiri Industri Kayu Brumbung (KBM IKB) – one of the independent business entity owned by PP. KBM IKB is one of export – oriented furniture industry in Central Java, Indonesia. The teak log for raw material in KBM IKB is bought from PP. In order to maximize profit, KBM IKB should maximize the use of teak log that has been allocated PP and minimizing waste. Waste can be recycled into Finger Joint Laminating (FJL) by providing value added. KBM IKB also prosecutes government regulation for the social aspect, namely employee safety and healthy. KBM IKB must provide PPE for KBM IKB's employee.

The model is required to determine the new paradigm of business contract in three aspects i.e. economical, ecological, and social aspects for securing availability of teak log in export oriented furniture industry and supporting stability of teak forest carbon sequestration with sustainability considerations [8] – [10]. It is possible that all aspects are conflicted; consequently we propose a relationship model between supplier and manufacturer by considering Goal Programming (GP) technique [11].

This paper is organized as follows. In Section I, we propose the background of our research. In Section II, we describe the problems in real system. In Section III, we provide mathematical modeling for solving the problem. In Section IV, we design the solution method, numerical example, and results. In Section V, we deliver the summary and conclusion.

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II. Problem Description

The problems that will be investigated are 3 aspects i.e. economical, ecological, and social aspects. Analyzing entity design between PP and KBM IKB will help exploring the problem. Entity design between PP and KBM IKB is shown by Fig. 1.

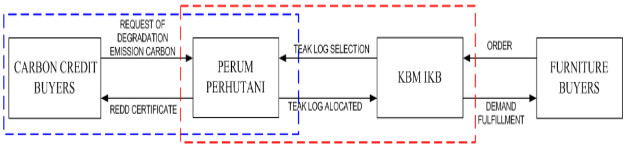

Fig. 1 Entity framework on the scope of study

From the Fig. 1, there are four entities involved either directly or indirectly. PP and KBM IKB are an entity directly involved, while the entity indirectly involved are carbon credit buyers and furniture buyers. Can be seen that the four entities are related. KBM IKB receives an order from the customer. Then KBM make a reservation in accordance with the requirement of teak logs. PP gives teak log allocation to the furniture industry for further processing into furniture in meeting customer demand. In addition to meet the needs of the furniture industry, PP also needs to meet demand in the trading of carbon emission reduction. PP has the demand reduction in emissions of carbon credit buyers i.e. governments, business entities, international organizations [4]. Reduction in carbon emissions made by the Reduction Emission from Deforestation and Degradation (REDD) mechanism that has the potential reduction in carbon emissions that most [12]. PP gives a certificate as proof of REDD carbon reduction.

In this model, PP is as a supplier and KBM IKB is as a manufacturer. Therefore we consider economic variable, ecological variable, and social variable. So we develop seven goals that can be categorized in three main objectives.

From the supplier side, we developed four goals. The first goal comes from economic variable, which does maximize PP's profit. The second goal is about ecological variable that does maximize conserved forest. The third goal is about social variable that does maximize PP's CSR which must be taken out by PP. The fourth goal is about social variable too that does maximize for the PP's employees.

In the other hand, we also developed three goals from the manufacturer side. The fifth goal comes from economic variable that does maximize profit. The sixth goal is about ecological variable, which does maximize waste selling to minimize dispose waste. The last goal is about social variable, which does maximize PPE for the KBM IKB's employees. The seven goals are shown by Fig. 2.

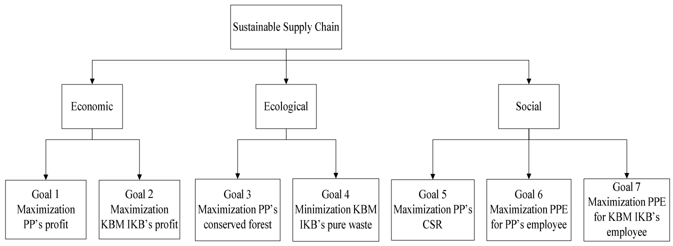

Fig. 2 The seven goals of sustainable supply chain

Thus, in this paper developed a relationship model between supplier (PP) and manufacturer (KBM IKB) on teak log procurement which involves the procurement of carbon trading in support of increasing stability of teak forests carbon sequestration with sustainability considerations. This is expected give the model a win-win solution for PP as a supplier and KBM IKB as a manufacturer.

III. Mathematical Modelling

This paper consider three aspects and its mean the model will be developed is multi objectives. The model is based on our previous work [10], [13]. GP is a suitable tool for decision maker to analyze the achievement of the desired goals considering different and sometimes conflicting multiple objectives.

A. Index and Notation

The notations in the formulation will be described and all of the cost parameters are measured in Indonesian Domestic Rupiah (IDR).

1. Parameters

PP_t : PP profit in period t (IDR)
P_j^L : Selling price of teak log type j (IDR/ m^3)
ρ_o : Carbon density for Class Age o (tC/ ha)
P_t^c : Selling price of carbon in period t (IDR/ tC)
P^s : Feed price of teak log (IDR/ ha)
P^m : Fertilizer price (IDR/ ha)
C^c : Maintenance cost (IDR/ ha)
C^h : Harvesting cost (IDR/ ha)
C^t : Transportation cost of teak log (IDR/ m^3)
CSR_t : CSR cost paid by PP in period t (IDR)
PB_t : KBM IKB profit in periode t (IDR)
Q_{kt}^f : Volume of product type k in period t (m^3)
P_k^f : Selling price of product type k (IDR/ m^3)
W_t : Total waste in period t (m^3)
P_t^w : Waste price in period t (IDR/ m^3)
FJL_t : Total Finger Joint Laminating in period t (m^3)
P_t^{FJL} : Selling price of FJL in period t (IDR/ m^3)
C^o : Overhead cost (IDR/ m^3)
C^L : Labor cost (IDR/ m^3)
C_j^L : Holding cost percentage of teak log type j
PPE_t^{PP} : Total PPE cost of PP in period t (IDR)
PPE_t^{BB} : Total PPE cost of KBM IKB in period t (IDR)
TF_t : Total forest area in period t (ha)
α_j : Conversion value from teak log to waste for type j

β : Percentage of CSR cost
C_t^{PP} : PPE procurement cost of PP in period t (IDR/ employee)
C_t^{BB} : PPE procurement cost of KBM IKB in period t (IDR/ employee)
E_t^{PP} : Total PP employees in period t (employees)
E_t^{BB} : Total KBM IKB employees in period t (employee)
n_i : Negative deviation of function i
p_i : Positive deviation of function i
ω_i : desired value of function i

2. Decision Variables

AC_t : Carbon trade area in period t (ha)
F_t^p : Planted forest area in period t (ha)
F_t^h : Harvested forest area in period t (ha)
F_t^c : Conserved forest area in period t (ha)
Q_{jt}^L : Teak log bought by KBM IKB type j in period t (m^3)

B. Objective Function

There are three aspects considered in this paper and two entities, PP as a supplier and KBM IKB as manufacturer. The seven objective functions will cover all aspects from two entities.

$$\sum_{t=1}^{5} PP_t = \sum_{j=1}^{2}\sum_{t=1}^{5} Q_{jt}^L P_j^L + \sum_{o=1}^{8}\sum_{t=1}^{5} AC_{ot}\,\rho_o\, P_t^c - \sum_{t=1}^{5} F_t^p (C^L + P^s + P^m) - \sum_{t=1}^{5} F_t^h C^h - \sum_{t=1}^{5} F_t^c C^c - \sum_{t=1}^{5} PPE_t^{PP} - \sum_{t=1}^{5} CSR_t \quad (1)$$

$$\sum_{t=1}^{5} PB_t = \sum_{k=1}^{2}\sum_{t=1}^{5} Q_{kt}^f P_k^f + \sum_{t=1}^{5} W_t P_t^w + \sum_{t=1}^{5} FJL_t P_t^{FJL} - \sum_{j=1}^{2}\sum_{t=1}^{5} Q_{jt}^L P_j^L - \sum_{k=1}^{2}\sum_{t=1}^{5} Q_{kt}^f (C^o + C^L) - \sum_{j=1}^{2}\sum_{t=1}^{5} Q_{jt}^L P_j^L C_j^L - \sum_{j=1}^{2}\sum_{t=1}^{5} Q_{jt}^L C^t - \sum_{t=1}^{5} PPE_t^{BB} \quad (2)$$

$$F_t^c = TF_t + F_t^p - F_t^h \quad (3)$$

$$\sum_{t=1}^{5} W_t = \sum_{j=1}^{2}\sum_{t=1}^{5} \alpha_j\, Q_{jt}^L \quad (4)$$

$$\sum_{t=1}^{5} CSR_t = \sum_{t=1}^{5} \beta\ PP_t \quad (5)$$

$$\sum_{t=1}^{5} PPE_t^{PP} = \sum_{t=1}^{5} C_t^{PP} E_t^{PP} \quad (6)$$

$$\sum_{t=1}^{5} PPP_t^{BB} = \sum_{t=1}^{5} C_t^{BB}\ E_t^{BB} \quad (7)$$

Equation (1) and (2) state economic goal. The first goal (1) is maximization of PP's profit. The second goal (2) is maximization of KBM IKB's profit. Equation (3) and (4) state ecological goal. The third goal (3) is maximization conserved forest. The fourth goal (4) is minimization waste from furniture production. Equation (5), (6), and (7) state social goal. Equation (5) states the fifth goal, maximization CSR from PP. The sixth goal (6) is maximization of PPE for PP's employee safety. The last goal (7), maximization of PPE for KBM IKB's employee safety.

C. Mathematical Formulation

The objective function is changed to soft constraint in GP. Constraint function is changed to hard constraint in GP. The objective function is added with positive deviation, negative deviation, and desired value. The model then can be formulated as GP below:

1. Objective Function

$$\text{Min}\ \left(\sum_{i \epsilon I} (n_i + p_i) \right) \quad (8)$$

Soft constraint:

$$\sum_{j=1}^{2}\sum_{t=1}^{5} Q_{jt}^L P_j^L + \sum_{o=1}^{8}\sum_{t=1}^{5} AC_{ot}\,\rho_o\, P_t^c - \sum_{t=1}^{5} F_t^p (C^L + P^s + P^m) - \sum_{t=1}^{5} F_t^h C^h - \sum_{t=1}^{5} F_t^c C^c - \sum_{t=1}^{5} PPE_t^{PP} - \sum_{t=1}^{5} CSR_t + n_1 - p_1 = \omega_1 \quad (9)$$

$$\sum_{k=1}^{2}\sum_{t=1}^{5} Q_{kt}^f P_k^f + \sum_{t=1}^{5} PW_t P_t^{pw} + \sum_{t=1}^{5} FJL_t P_t^{FJL} - \sum_{j=1}^{2}\sum_{t=1}^{5} Q_{jt}^L P_j^L - \sum_{k=1}^{2}\sum_{t=1}^{5} Q_{kt}^f (C^o + C^L) - \sum_{j=1}^{2} P_j^L C_j^L - \sum_{j=1}^{2}\sum_{t=1}^{5} Q_{jt}^L C^t - \sum_{t=1}^{5} PPE_t^{BB} + n_2 - p_2 = \omega_2 \quad (10)$$

$$TF_t + F_t^p - F_t^h + n_3 - p_3 = \omega_3 \quad (11)$$

$$\sum_{j=1}^{2}\sum_{t=1}^{5} \alpha_j\, Q_{jt}^L + n_4 - p_4 = \omega_4 \quad (12)$$

$$\sum_{t=1}^{5} \beta\ PP_t + n_5 - p_5 = \omega_5 \quad (13)$$

$$\sum_{t=1}^{5} C_t^{PP} E_t^{PP} + n_6 - p_6 = \omega_6 \quad (14)$$

$$\sum_{t=1}^{5} C_t^{BB} E_t^{BB} + n_7 - p_7 = \omega_7 \quad (15)$$

2. Hard Constraint

$$AC_t = F_t^c - F_t^p \quad (16)$$

$$F_{t-1}^h = F_t^p \quad (17)$$

$$Q_{kt}^f / 1239 = F_t^h \quad (18)$$

$$Q_{jt}^L = Q_{kt}^f \quad (19)$$

$$Q_{kt}^f \le d \quad (20)$$

$$Q_{kt}^f \le 12960 \quad (21)$$

where n_i and p_i are defined as preferential weight, negative deviational variable, and positive deviational of the goal, ω_i denote the target level for each goal respectively. In this paper the number of goals is seven. Some literatures defined (8) as the achievement function, which must be minimized to ensure that the solution is closely as possible to the desired goals [11].

IV. Solution Method, Numerical Example, And Results

In this computational study, we analyze the impact of the changes in parameters in the supplier-manufacturer relationship model between PP and KBM IKB considering several goals that must be achieved.

A. Solution Method

The algorithm used to solve the GP formulation was simplex method. The algorithm to solve this model is given by Fig. 3.

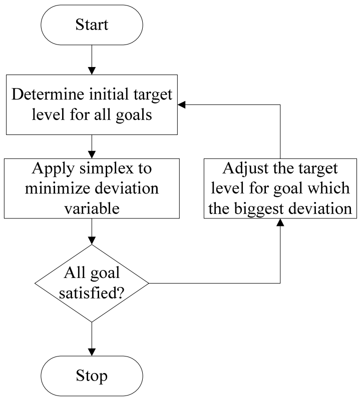

Fig. 3 Solution procedure for solving a mathematical model

The first step to solve the GP formulation is determining initial target level for all goals. Initial target level is determined by decision maker. It will be compared with the result of GP formulation. The second step is applying simplex to minimize deviation variable, there are positive variable and negative variable. Then compare the result with initial target level and check them satisfied or not. If there are goals not satisfied yet, adjust the target level goal which the biggest deviation until all goals satisfied.

B. Numerical Example

In order to illustrate the capabilities of the proposed-model, a numerical example has been done. Each forest age class teak is presented in Table I. Carbon density of each age class teak is presented in Table II. All parameter cost for the computational study is presented in Table III. The furniture demand is shown in Table IV. The furniture price and teak log price can be seen in Table V and Table VI. The conversion value from furniture to log and conversion value from log to waste can be seen in Table VII and Table VIII. The PP's PPE price and KBM IKB's PPE price are shown in Table IX and Table X.

TABLE I
FOREST AREA

Age Class (KU)	Area (ha)
KU I	7,551.79
KU II-VII	6,036.90
KU VIII-XII	43.40
Total	13,632.09

Teak forest area is used Perum Perhutan KPH Kendal Unit I Central Java [14]. As for the density of carbon per hectare, calculated on the rate of growth over the past 60 years [15]. Current prices in the international carbon market reached 5-6 US dollar per ton [16].

TABLE II
CARBON DENSITY

Age Class (KU)	Carbon Density (tC/ha)
KU I	12.616
KU II	48.413
KU III	125.121
KU IV	215.361
KU V	292.054
KU VI	324.76

TABLE III
PARAMETER COST

Parameter	Quantity	Units
Planting cost	7,437,600	IDR/ ha
Maintenance cost	160,500	IDR/ ha
Harvesting cost	16,785,300	IDR/ ha
Distribution cost	2,520	IDR/ m^3 km
Labor cost	92,005	IDR/ m^3
Overhead unit cost	1,064,815	IDR/ m^3

TABLE IV
FURNITURE DEMAND

Period	A	B	Units
1	513.77	595.64	m^3
2	601.09	1017.08	m^3
3	593.34	976.73	m^3
4	586.81	1417.59	m^3
5	604.97	1411.64	m^3

TABLE V
FURNITURE PRICE

Type	Price	Units
A	35.000.000	IDR/m^3
B	15.000.000	IDR/m^3
C	9.700.000	IDR/m^3

Furniture products sold in the KBM IKB grouped into three types, namely the product A, product B and product C. Product A consist of Garden Furniture and Housing Component. Product B consists of Flooring and Parquet. Product C is the result of recycle of waste generated. FJL manufactured from 70% of raw materials both AII and AIII.

TABLEVI
TEAK LOG PRICE

Type	Price	Holding Cost / yr	Units
AII	2,750,000	82,500	IDR/m^3
AIII	4,500,000	135,000	IDR/m^3

TABLE VII
CONVERSION VALUE FROM FURNITURE TO LOG

Furniture Type	Log Type	Conversion
A	AII	20.0
A	AIII	5.9
B	AII	5.6
B	AIII	12.5

TABLE VIII
CONVERSION VALUE FROM LOG TO WASTE

Furniture Type	Log Type	Conversion
A	AII	95%
A	AIII	83%
B	AII	82%
B	AIII	92%

Waste generated in the form of 70% dust and 30% teak log scrap. Price of dust and scrap each is IDR 10.000, - /m^3 and IDR 33.000, - /m^3.

TABLE IX
PP'S PPE PRICE

PPE	Price	Units
Helmet	15,000	IDR
Mask	9,000	IDR
Gloves	5,000	IDR
Safety shoes	300,000	IDR

TABLE X
KBM IKB'S PPE PRICE

PPE	Price	Units
Helmet	15,000	IDR
Mask	9,000	IDR
Gloves	5,000	IDR
Safety shoes	300,000	IDR
Earplugs	32,000	IDR
Overall	150,000	IDR

C.Results

There are 3 scenarios that can be run to get the best result. The scenarios are shown in Table XI. We set scenario K to optimistic target level, scenario L to pessimistic target level, whereas scenario M to normal target level. The best scenario must satisfy all of goals. The results of scenario K, L, and M can be seen on Table XII.

TABLE XI
SCENARIO

Scenario	Goal	Target Level
K	ω_1	At most 20% from PP's profit
	ω_2	At most 10% from KBM IKB's profit
	ω_3	At most 30% from total forest
	ω_4	At least 5% from total pure waste
	ω_5	At most 2% PP's profit
	ω_6	Equal all of PPE cost
	ω_7	Equal all of PPE cost
L	ω_1	At most 3% from PP's profit
	ω_2	At most 2% from KBM IKB's profit
	ω_3	At most 30% from total forest
	ω_4	At least 3% from total pure waste
	ω_5	At most 2% PP's profit
	ω_6	PPE cost without gloves & mask
	ω_7	PPE cost without overall
M	ω_1	At most 5% from PP's profit
	ω_2	At most 2% from KBM IKB's profit
	ω_3	At most 30% from total forest
	ω_4	At least 3% from total pure waste
	ω_5	At most 2% PP's profit
	ω_6	Equal all of PPE cost
	ω_7	Equal all of PPE cost

TABLE XII
RESULTS FROM ALL SCENARIOS

Scenario	Goal	Target Level	Achieved Value	Satisfied
K	ω_1	894,239,704,000	859,755,900,000	No
	ω_2	33,165,941,000	30,730,950,000	No
	ω_3	4,090	13,627	Yes
	ω_4	34,913	35,581	No
	ω_5	17,884,794,000	17,195,120,000	No
	ω_6	939,295,000	939,295,000	Yes
	ω_7	255,500,000	255,500,000	Yes
L	ω_1	767,555,746,000	859,795,100,000	Yes
	ω_2	30,723,721,000	30,805,950,000	Yes
	ω_3	4,090	13,627	Yes
	ω_4	36,648	35,581	Yes
	ω_5	15,351,115,000	17,195,900,000	Yes
	ω_6	889,325,000	889,325,000	Yes
	ω_7	180,500,000	180,500,000	Yes
M	ω_1	782,459,741,000	859,755,900,000	Yes
	ω_2	30,723,721,000	30,730,950,000	Yes
	ω_3	4,090	13,627	Yes
	ω_4	35,648	35,581	Yes
	ω_5	15,649,195,000	17,195,118,000	Yes
	ω_6	939,295,000	939,295,000	Yes
	ω_7	255,500,000	255,500,000	Yes

To illustrate the capabilities of the model, we take real data from PP and furniture industry in Central Java. Target level of PP's profit (ω_1), made as closely as possible due to the involvement of carbon trading that would provide a high intake in PP. Based on the government regulation, the minimum area of forest must cover at least 30% of area within. Felling of teak can be done at least at the age of 40 years. CSR cost that must be taken out by PP is 2% from profit [6], [17].

In optimistic scenario K, all goals set by decision makers are satisfied except ω_1, ω_2, ω_4, and ω_5. ω_1 refers to PP's profit, it's mean that the target level for PP's profit is too large as well as the ω_2. ω_2 refers to KBM IKB's profit. ω_4 refers to waste that produced by KBM IKB. ω_5 refers to CSR that issued by PP. In order to satisfy all goals, decision makers can adjust the target level set in scenario K.

Scenario L is one alternate solution which its target level is lower than the scenario K. It can be seen in Table XI that all target levels are lowered, except ω_3 and ω_5. ω_3 refers to forest that maintained in accordance with government regulation. ω_5 refers to goal set by decision makers to comply with goverment regulation about CSR. The result from scenario L is all goals are satisfied. In the L scenario all the goals can be achieved, but ω_6 and ω_7 goals of the procurement of PPE in PP and KBM IKB yet has a complete PPE. Therefore, it is necessary to adjust the target level. Decision makers can improve the target level until the achieved value is approaching the target value and the goal is still satisfied.

Favorable solution for GP formulation can be seen in scenario M. It can be seen that all goals are satisfied. It is the best scenario because if the target levels are increased, the goals will not be satisfied. From the result, the PP's profit is IDR 859, 755, 900, 000,- and the KBM IKB's profit is IDR 30,730,950,000,-. The conserved forest is more than 30% of total forest so it is not violate the goverment regulation. The pure waste can be minimized. CSR cost that must be taken out by PP is IDR 17, 195, 118, 000,-. All of PPE can be bought by PP and KBM IKB for improving employee safety.

V. Conclusion

In this paper, we developed a relationship model between supplier and manufacturer with sustainability considerations that involving carbon trading. The model can determine the value of decision variables consist of carbon trade area, planted forest area, conserved forest area, harvested forest area, teak log sold by supplier, teak log bought by manufacturer, and furniture sold by manufacturer. The proposed models can be used to achieve the seven goals for securing availability of teak log in export-oriented furniture industry and support the teak forest carbon sequestration with sustainability considerations.

Further research can be conducted in adding more teak manufacturer supplied by the PP with considering aspects of sustainability.

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