Log allocation and soft optimization: a de novo programming approach

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Abstract

Describes how to efficiently allocate logs to a set of interdependent utilization facilities while simultaneously designing the optimal characteristics of the production system. Using the external reconstruction algorithm (a de novo algorithm), selected resource constraints are considered "soft" and are determined through analysis. This procedure facilitates the design of an optimal production system and is not limited to the solution of a prespecified problem wherein all constraints are taken as fixed. The procedure is demonstrated by applying it to a representative log allocation problem facing owners of a vertically integrated utilization complex. Results illustrate the range of increased profits that can be expected when the optimal set of resource inputs is available.

Managers of forest products manufacturing facilities are faced with the problem of efficiently utilizing the raw materials under their control. Usually, efficiency is measured in terms of increased physical (economic) outputs per unit input. For over 25 years, linear programming (LP) has been the preferred optimization technique used to model the allocation of logs to a set of vertically integrated conversion facilities consisting of sawmills, veneer plants, pulpmills, and log sales activities (1,13). Most of these models take the supply of logs as a fixed input and efficiently allocate them to the conversion facilities under conditions where it is assumed that the firm faces a perfectly elastic product demand curve. Further, it is assumed that the supply of logs has been efficiently manufactured either in the woods or at the log conversion center prior to the allocation decision.

The crosscutting of trees into logs to produce the most efficient utilization of the tree has also been studied extensively over the past 25 years. Although LP was initially suggested as a possible modeling strategy, this process is now usually modeled using dynamic programming (DP) (4). Reasons for this relate to limitations of LP models to only handling a fixed number of crosscutting strategies for a tree of given characteristics. However, the use of DP allows an almost infinite array of crosscutting possibilities. As with the log allocation decision, most crosscutting models assume that the firm faces a perfectly elastic product demand curve.

Two problems inherent in the crosscutting and log allocation processes are that they are usually modeled as separate unrelated processes whereby managers at different points in the production process make decisions in a sequential fashion. And, both decisions presume that unlimited logs or other products can be marketed at a fixed price. However, harvesting (i.e., crosscutting to long logs) often occurs in the woods several months before the logs are processed by the mills. As a result, there has been a tendency to treat crosscutting in the woods and later allocation of the logs as separate activities. Doing so, however, precludes coordinated planning that could lead to the design of better overall performance.

McPhalen (12) and Mendoza (9) recognized this limitation and independently developed models that attempt to jointly optimize the crosscutting and log allocation decisions. In these two studies, DP for the crosscutting problem and LP for the log allocation problem were combined using Gilmore and Gomory's (5,6) column generation technique to maximize revenues from the sale of products subject to fixed market constraints (10). The two studies dif-

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fered in a number of technical details, but both addressed the same basic problem.

Recently, Sessions et al. (14), Eng et al. (3), and Maness (8) also addressed aspects of this problem. Sessions et al. developed a heuristic, binary search procedure that maximizes net returns from crosscutting a tree subject to the constraint that a given percentage of the volume must be in some prespecified log length. Their algorithm iteratively searches for a crosscutting pattern that meets the length-volume constraint by systematically adjusting log prices by some percentage increase (decrease) until the constraint is satisfied. The final set of adjusted log prices is then used to produce crosscutting guides for field use.

Eng et al. (3) and Maness (8) used the column generation technique to generate additional crosscutting strategies at each iteration of the model. Maness also utilized a product price schedule that declines in a stepwise fashion with increasing volume produced instead of a set of market constraints to help guide the production process. Further, he generated additional sawing strategies at each iteration of his model using a heuristic algorithm.

Apart from these studies, which jointly optimize crosscutting and log allocation decisions, the major limitation of almost all other analyses is that they attempt to determine optimal solutions to prespecified problems. That is, the models attempt to optimize systems with given sets of fixed resources such as raw materials, markets, production facilities, and material balance (technological) constraints. As we will demonstrate, this often results in the suboptimal allocation of scarce resources.

Crosscutting of trees, the subsequent allocation of logs to conversion facilities, and the manufacture of primary (lumber, veneer, pulp) and secondary (plywood, furniture, paper) products should be viewed as a set of interdependent activities. The production planning problem should be expanded to include the design of an optimal system whereby the production inputs are not taken as fixed but are to be determined simultaneously with production output levels. Thus, a truly optimal allocation of resources can be achieved. This approach (called de novo programming) assumes that many of the constraints that might be taken as fixed in the short term are variable when viewed in the long term, and decisions governing their determination are to be made. In this paper, the availability and distribution of various types of logs are not taken as fixed, but are viewed as variable and are to be determined. Further, the analysis assumes that the firm faces a perfectly elastic product demand curve for its products.

Soft optimization

Soft optimization takes its name from the fact that the righthand side (RHS) of selected resource constraints are considered to be unknown and are to be determined through analysis. Thus, unlike the usual case where the RHS is considered to be fixed (hard), in soft optimization the RHS is viewed as soft (7). The problem then becomes one of determining the optimal production schedule along with the RHS of the soft constraints, i.e., the system is to be designed and not just optimized.

Zeleny's (16) external reconstruction algorithm (ERA) is an example of a de novo algorithm that can be used to solve problems of this nature. It is an iterative algorithm that works through the use of an aggregate constraint that (initially) consists of a) all fixed inequality constraints to be reconstructed during later iterations; b) all soft inequality constraints to be designed; or c) a combination of these. All equality constraints are taken as fixed and are excluded from the aggregate constraint. The ERA takes advantage of the fact that only binding constraints characterize optimal solutions to LP problems, making it unnecessary to initially work with all constraints. Instead, the ERA is used to reconstruct (sequentially add) all fixed (and potentially binding) constraints while determining the optimal levels of the soft constraints.

At each iteration of the ERA, the most violated fixed inequality is decoupled from the aggregate constraint and a new LP is solved. The new problem consists of one additional fixed constraint and the revised aggregate constraint. This process continues until all fixed inequalities are satisfied.

For example, consider the mathematical model shown below:

$$\text{Max } Z = \Sigma_j c_j x_j \qquad [1]$$

s.t.

$$\Sigma_j a_{ij} x_j \leq b_i \qquad i = 1,2,\ldots,m \qquad [2]$$

$$x_j \geq 0 \qquad j = 1,2,\ldots,n \qquad [3]$$

Suppose that s of the m constraints are soft, while the remaining h ($h = m - s$) constraints (including any equalities) are hard. Given this situation, the mathematical model for de novo programming is:

$$\text{Max } Z = \Sigma_j c_j x_j$$

s.t.

$$\Sigma_j a_{ij} x_j \leq b_i \qquad \text{for all } i \in h \qquad [4]$$

$$\Sigma_j (\Sigma_i a_{ij} p_i) x_j = \Sigma_i p_i b_i \leq B \qquad \text{aggregate constraint} \qquad [5]$$

$$x_j \geq 0$$

where:

$p_i > 0$ = per unit cost of a given resource b_i, which is to be designed

B = amount of money available for the purchase of scarce resources

Equation [5] is used to determine the amount of each resource to purchase in order to design the most efficient system. As constraints are decoupled from the aggregate constraint (Eq. [5]), they are treated as fixed (moved to Eq. [4]), B is reduced, and another iteration is performed. A full description of the ERA is available in Zeleny (15-17), and applications of this approach to forest land management planning and log allocation are described by Bare and Mendoza (2) and Mendoza and Bare (11), respectively.

Log allocation model

To demonstrate the potential gains from using soft optimization to design an optimal wood utilization conversion system, we will describe and solve a sample problem characteristic of the industry, under a variety of scenarios. This problem assumes that the firm faces a perfectly elastic market for its products and uses market constraints (see cases 2 and 4) on product outputs to restrict production. The problem assumes that the firm is operating one timber sale (more can be easily assumed) or a large sort yard wherein the trees have been initially crosscut into combinations of long[1] log lengths resulting in a log frequency distribution. Thus, the crosscutting of trees has already taken place, and is not part of the system being optimized. However, as shown in cases 3 and 4, soft optimization can be used to design the RHSs of these log distribution constraints. Only one species (Douglas-fir) is assumed and all logs are allocated to either a sawmill, veneer mill, pulpmill, or sold on the export market.

The sawmill desires even length logs from 24 to 40 feet long, which it converts into five grades of lumber and uses to produce chips and sawdust as by-products. A two-sided mill is assumed, with small and large log sides. The small log side uses logs from 6 to 12 inches in diameter and can process 6 logs per minute and the large log side takes logs from 14 to 20 inches in diameter and can process 3 logs per minute.

The veneer mill desires 17-, 26-, or 34-foot logs, which are converted into three grades of 3/8-inch green veneer and chips as a by-product. Only logs 14 inches and greater are peeled for veneer. The pulpmill can convert any size log plus sawmill and veneer mill by-products (chips or sawdust) into bleached kraft pulp. Finally, logs are also available for allocation to the log export market. This market requires logs to be 26, 30, 33, 36, 39, or 40 feet long, with a stipulation that the average length be at least 33 feet.

One unique feature inherent in the log allocation model is that the four market options may compete directly for certain log sizes. For example, a 26-foot log can be allocated to any of the four markets. Second, since we begin by assuming a situation where the timber has already been crosscut into log lengths, it may be desirable to allow one of the markets to take logs normally crosscut for another. For example, it might be more profitable to take some 38-foot logs originally manufactured for the sawmill, trim them back to 36 feet, and sell them in the export market. This is allowed in the model formulation. When this occurs, the log's cost is calculated based on its original size, but product recoveries are based on the reduced size. The trimmed portion of the log is assumed to be chipped.

A variety of constraints are imposed on the log allocation process. First, the number of logs allocated to the two-sided sawmill must be kept in balance. Within ±10 percent, the number of logs allocated to the small side must be twice that allocated to the large side. Second, as just mentioned, the average length of export logs must be at least 33 feet long. Third, a material balance equation governs the recovery of pulp from logs of different sizes, chips, and sawdust. Fourth, similar recovery equations control the recovery of lumber, veneer, chips, and sawdust for the sawmill and veneer mill. The objective function seeks to maximize profit under conditions of a perfectly elastic product demand curve. Initially, a log distribution is assumed and constraints are added to prevent the over allocation of logs. In all, there are 112 constraints and 332 activities.

[1] Long (woods) length logs are combinations of two or more log lengths that are actually processed by a mill.

TABLE 1. — *Log allocation for case 1.*[a]

	Number of logs allocated											
	Log length											
	17	24	26	28	30	32	33	34	36	38	39	40
6-inch diameter												
Sawmill		9	12	12	10	8						
Pulpmill	10											
Veneer mill												
Export							2					
8-inch diameter												
Sawmill	16	10	20	23	19	12						
Pulpmill												
Veneer mill												
Export							9	3	2	1		
10-inch diameter												
Sawmill	24	26	31	24	38	24						
Pulpmill												
Veneer mill												
Export							16	10	5	1		
12-inch diameter												
Sawmill	32	26	34	44	26.1	50						
Pulpmill												
Veneer mill												
Export					21.9		40	28	16	6	4	1
14-inch diameter												
Sawmill	30	31		24	28	44						
Pulpmill												
Veneer mill			19									
Export							16	20	12	4	6	
16-inch diameter												
Sawmill		28	28									
Pulpmill												
Veneer mill	24			19								
Export			13		30	22	9	10	12	9		3
18-inch diameter												
Sawmill		28										
Pulpmill												
Veneer mill	16		30	12								
Export					19	16	21	8	10	14	2	4
20-inch diameter												
Sawmill												
Pulpmill												
Veneer mill	10	12	16	9								
Export					20	10	18	10	4	10	8	2

[a] All logs in initial log distribution are allocated. Underlined values show logs originally crosscut for one market being allocated to a different market.

Case 1

Given the initial availability of logs, recovery relationships, costs, and market prices, an LP run is made to establish baseline results. No market constraints on product outputs are included in this run. To simplify the presentation of results, only the RHS of the log availability constraints (initially given and subsequently designed), product outputs, and objective function values associated with the different runs, are presented. However, this information is adequate for describing the advantages of soft optimization.

The objective function value for this run is $101,991 and all logs available are allocated as shown in Table 1. The products produced from this allocation are summarized in Table 2. Table 1 shows a number of cases where logs are allocated to markets that differ from the primary use for the length actually crosscut. Some of these are 17-foot lengths for the veneer mill, which were mistakenly crosscut from stems that were too small in diameter. These logs are used by the sawmill. Other lengths such as 34- and 38-foot logs originally crosscut for the sawmill are trimmed back to 33 and 36 feet, respectively, for export sales. In total, more than 20 percent of the precut logs are allocated to markets other than the one originally intended. Clearly, better design and coordination could improve profits.

Case 2

If market constraints are imposed on selected product outputs, we would expect the maximum profit to decrease. However, the presence of such constraints is a fact of business life that can be easily represented. Further, this tends to temper the assumption of a perfectly elastic demand curve for products by placing bounds on the range over which such prices prevail. Thus, a second run is made whereby the following product output levels are specified:

Lumber (MBF = 1,000 board feet):
- Select: ≥ 1.0 MBF
- Select Structural and No. 1: ≤ 50.0 MBF
- Standard and Better: ≤ 80.0 MBF
- Utility: ≤ 15.0 MBF
- Economy: ≤ 5.0 MBF

Sawmill residues (BDU = bone dry unit (2,400 lb.)):
- Chips: ≤ 50.0 BDU
- Sawdust: ≤ 10.0 BDU

Veneer (MSF, 3/8 in. = 1,000 ft.^{2}, 3/8-in. thickness):
- AB Grade: ≥ 25.0 MSF, 3/8 in.
- CD Grade: ≤ 120.0 MSF, 3/8 in.
- Utility: ≤ 4.0 MSF, 3/8 in.

Veneer residues:
- Chips: ≤ 20.0 BDU

Pulp (metric tons = 2,204 lb.):
- Pulp: ≥ 70.0 metric tons

In the presence of these market constraints on product output, the maximum profit decreases to $89,413 and all logs are allocated as shown in Table 3 with the product outputs summarized in Table 2 for case 2.

In order to meet the assumed market constraints on product output, the allocation of logs has shifted dramatically and the maximum profit has decreased by $12,578. However, a feasible solution is obtained. As with case 1, there are instances where logs are allocated to markets other than their primary intended use. Compared to case 1, the percentage of these logs rises slightly. This is expected due to the addition of the market constraints.

Case 3

Next, we wish to design a more efficient system by investigating whether a different log mix, purchased at the same implicit cost as in cases 1 and 2, might lead to a more profitable log allocation. The recovery technology and all costs and prices are held constant but the optimal amount of each log type to purchase is designed to better match the production processes. The design criterion used is dollars of budget available for log purchase. Given the costs of purchasing a log of a specified diameter and length, we seek to determine how many logs of each type to purchase to maximize profit. Thus, the RHS of each log availability constraint is now taken as soft and is designed to achieve larger profits.

Given the purchase cost of each log type and the original log pool available, it is easy to calculate that $42,152 was implicitly budgeted to purchase the 1,456 logs available for the first two cases. Thus, we now wish to use the de novo approach and define an aggregate budget con-

TABLE 2. — *Summary of product outputs for various cases.*

	Case no.			
	1	2	3	4
Lumber (MBF)				
Select	0.54	1.00	0.00	1.00
Structural and No. 1	59.57	44.58	0.00	43.41
Standard and Better	94.43	54.22	0.00	54.29
Utility	18.73	11.66	0.00	11.46
Economy	7.29	4.23	0.00	4.09
Sawmill residues				
Chips (BDU)	73.93	40.14	0.00	41.14
Sawdust (BDU)	16.29	10.00	0.00	10.00
Veneer (MSF) (3/8")				
AB grade	34.36	25.00	0.00	25.00
CD grade	137.56	104.62	0.00	92.31
Utility	4.51	3.34	0.00	3.05
Veneer residues				
Chips (BDU)	29.07	20.00	0.00	20.00
Pulp (metric tons)				
Pulp	59.95	103.18	0.00	70.00
Profit ($)	101,991	89,413	121,847	104,959

TABLE 3. — *Log allocation for case 2.*[a]

	Number of logs allocated											
	Log length											
	17	24	26	28	30	32	33	34	36	38	39	40
6-inch diameter												
Sawmill	10	9	12	12	10	8						
Pulpmill												
Veneer mill												
Export							2					
8-inch diameter												
Sawmill	16	10	20	23	19	12						
Pulpmill												
Veneer mill												
Export							9	3	2	1		
10-inch diameter												
Sawmill	24	26	22									
Pulpmill			9	24	38	24						
Veneer mill												
Export							16	10	5	1		
12-inch diameter												
Sawmill	32											
Pulpmill		26	34	44	37.7	50						
Veneer mill												
Export					10.3		40	28	16	6	4	1
14-inch diameter												
Sawmill												
Pulpmill		31	11.8	24								
Veneer mill	30		7.2									
Export					28	44	16	20	12	4	6	
16-inch diameter												
Sawmill		28	10.3									
Pulpmill			30.7									
Veneer mill	24			19								
Export					30	22	9	10	12	9		3
18-inch diameter												
Sawmill		28		12								
Pulpmill												
Veneer mill	16		30									
Export					19	16	21	8	10	14	2	4
20-inch diameter												
Sawmill		12	3.8	9	20	10	14.2					
Pulpmill												
Veneer mill	10		12.2									
Export							3.8	10	4	10	8	2

[a] All logs in initial log distribution are allocated. Underlined values show logs originally crosscut for one market being allocated to a different market.

straint that restricts our budget to this same level, while simultaneously maximizing profit from the allocation of logs as before. Using the log costs, an aggregate budget constraint replaces the 96 log availability constraints representing the 12 log lengths and 8 diameter sizes used in cases 1 and 2. In case 3, the market constraints on product outputs are removed, but in case 4 they are reimposed per case 2. All other constraints are retained as fixed per the first two cases.

With the freedom to purchase the optimal set of logs, the model now produces a maximum profit of $121,847. All logs available are designed for the export market, implying no lumber, veneer, or pulp production. This solution is directly comparable with the case 1 solution, as no market restrictions exist on product outputs. However, due to the flexibility introduced by designing an optimal log mix, greater profits are achieved.

The optimally designed log mix for case 3 calls for a total of only 562 logs, each 40 feet long and 18 inches in diameter, and all of them are to be exported. The purchase price of these logs exhausts the budget of $42,152.

Comparing the case 1 and case 3 solutions clearly shows the advantages to be gained when the RHS of selected log availability constraints are designed and not taken as given. Almost $20,000 in additional profit is realized for the same budget. Of course, to realize these larger profits, a ready supply of the desired log types must be available at the given prices and an unlimited mix of outputs must be allowed, i.e., a perfectly elastic product demand curve must be assumed and no product order constraints must be met. Either these logs must be available for purchase on the log market or the stand being harvested must be capable of yielding such a log distribution. If neither condition applies, constraints similar to those assumed in cases 1 and 2 must be reintroduced. The effects of this on the optimal solution are shown in case 4.

Case 4

Case 4 is similar to case 3 except that the restrictions on product outputs are reimposed per case 2. The maximum profit for case 4 is $104,959, which is less than for case 3 but still in excess of case 2. Thus, the advantages of designing the optimal log mix are obvious. The product outputs for case 4 are summarized in Table 2.

The case 4 optimal log mix specifies that 2,180.8 logs be purchased at a total cost of $42,152. The desired log mix is: a) 349.7 logs 40 feet in length and 18 inches in diameter for export; b) 1147.6 logs 17 feet in length and 6 inches in diameter for the pulpmill; c) 387.5 logs 17 feet in length and 6 inches in diameter for the small log sawmill; d) 120.4 logs 30 feet in length and 14 inches in diameter and 94.9 logs 24 feet in length and 20 inches in diameter for the large log sawmill; and e) 16.3 logs 34 feet in length and 14 inches in diameter and 64.4 logs 28 feet in length and 20 inches in diameter for the veneer mill. As with case 3, it is assumed that these log types can be readily purchased at the prevailing log prices assumed. Further, this is not a limitation of the model, but reflects the reality of the input assumptions. If one is operating one or more timber stands rather than buying from a log market, the stand(s) may be incapable of yielding the optimally designed log mix. However, the logging manager may have a good idea of the potential yield of various log types available based on the timber characteristics.

To demonstrate, case 4 is altered by assuming that the potential number of logs 6 inches in diameter and 17 feet long is limited to 500 and that the number of logs 18 inches in diameter and 40 feet long is limited to 200. Adding these two constraints to case 4 and designing the optimal system yields a maximum profit of $104,224. The optimal allocation of logs now shows that: a) 149.1 logs 39 feet in length and 18 inches in diameter and 200 logs 40 feet in length and 18 inches in diameter are exported; b) 500 logs 17 feet in length and 6 inches in diameter and 300.6 logs 30 feet in length and 6 inches in diameter go to the pulpmill; c) 350.4 logs 17 feet in length and 8 inches in diameter go to the small sawmill; d) 92.9 logs 30 feet in length and 14 inches in diameter and 101.8 logs 24 feet in length and 20 inches in diameter go to the large sawmill; and e) 16.3 logs 34 feet in length and 14 inches in diameter and 64.4 logs 28 feet in length and 20 inches in diameter go to the veneer mill. As with case 4, the entire budget of $42,152 is spent.

Summary

This paper has briefly introduced the subject of soft optimization using a de novo formulation of the log allocation problem. The model assumes that the firm faces a perfectly elastic product demand curve and wishes to determine the optimal sizes of logs to purchase in order to maximize profit. While this paper does not deal directly with the crosscutting problem, it does identify the types of logs to procure or merchandise. Thus, it does clearly show the importance of correctly defining the available log supply prior to making the log allocation decision.

The case studies also illustrate the potential gains in profit that can be realized when the RHS of selected constraints are taken as soft and not hard as in traditional LP formulations. Thus, a long-term log procurement strategy is identified and can be worked toward as a goal. This is all made possible by designing optimal production levels and not simply optimizing within the boundaries of a prespecified system.

The methodology of soft optimization can be similarly applied in many other areas of forest products manufacture. Consider, for example, a plywood plant manager who wishes to plan on how to meet a set of customer orders. Rather than the usual approach of maximizing profits in meeting the orders, subject to fixed (and possibly suboptimal) limitations on the log and/or veneer resources available, soft optimization allows the manager to design the best combination of log and veneer inputs to acquire in order to meet the orders while simultaneously maximizing profits.

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Resolution on tropical woods supported

Thirty-five leaders from industry, government, academia, and the environmental community have endorsed a resolution to promote tropical forest conservation and sustainable timber harvesting. Among the points contained in the resolution is the rejection of an across-the-board, nonselective boycott of tropical wood products.

The resolution embodies the main points of agreement from a workshop on the U.S. tropical timber trade convened by the Rainforest Alliance in New York on April 14 to 15. Individuals from the United States, Brazil, Indonesia, Malaysia, Venezuela, Ghana, Canada, and the United Kingdom attanded the workshop.

The issue of whether Americans concerned about tropical deforestation (occurring at a rate of close to 100 acres per minute) should boycott tropical timber products, such as paneling and furniture, was at the center of the debate. "If consumers refuse to buy items made of tropical wood, the financial value of tropical forests will go down," argued Peter Ashton, of Harvard University's Arnold Arboretum. The forests would then be more likely to be converted "into something that does have value, namely plots for agriculture," Ashton said.

Fabio Feldmann, a member of Brazil's National Congress and a leading advocate of the environment, warned that a boycott of tropical wood products could cause an anticonservation backlash in Brazil. "Many times, environmentalists in the United States think they are helping Brazilian environmentalists, but in reality they sometimes hurt us," he claimed.

The resolution calls for an international system for rating timber production according to sustainability, a step which could serve as the basis for a labeling program for retailers and consumers. The resolution also establishes priority areas for policy reform, research, and funding. These range from pricing mechanisms and the rights of native forest dwellers to substantially increased funding for the struggling International Tropical Timber Organization. A steering committee has been formed to help promote these aims.

Daniel Katz, president of the Rainforest Alliance, said the gathering and subsequent resolution was a significant step forward for the rainforest conservation movement. "This is the first time that experts from such diverse backgrounds have sat down to grapple with the difficult question of precisely what Americans can do to save tropical forests," he explained. "It is imperative that the environmental community not tackle this problem alone. We must involve the wood products industry and the tropical forest nations if we really want to save the forests."

13th AAES *Directory* now available

The 13th edition of the *Directory of Engineering Societies and Related Organizations* has recently become available. The guide is published by the American Assoc. of Engineering Societies (AAES). The 1989 edition will contain nearly 300 international and foreign organizations not listed in earlier editions.

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