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**THE PLANT LOCATION PROBLEM BY AN EXPANDED
LINEAR PROGRAMMING MODEL**

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Abstract

Plant location models are considered only with the aim of locating the plant without taking supplier and warehouse location problems. The models were developed on the idea that the minimization of the cost methodology. However the general system should be considered as a network in accordance with the supply chain concept and the optimization of the upper system should be aimed. The system should be modeled considering suppliers, plants, warehouses and markets.

The study stands on the systems approach and models the problem as a network considering different parties in the supply chain. Facility location factors are stated and classified as quantitative and qualitative. For the quantitative factors cost becomes significant to assign weights to each quantitative factor inversely proportional to the cost and then coefficients are assigned to qualitative factors through Analytical Hierarchy Process. A linear integer programming model is proposed for the location selection.

Keywords: *Facility location, combination of qualitative and quantitative factors, Analytical Hierarchy Process*

1. INTRODUCTION

Almost every private and public sector faces with the task of locating facilities. For the consideration of Verter and Dincer (1995); this type of work is gaining importance because of the emerging world is going global. Therefore, plants are placed in different

countries and different regions. Models developed to analyze facility location decisions for the optimized one or more objectives, subject to physical, structural, and policy constraints, governmental implementations, incentives in variety in a static or deterministic setting. As Current, J., Rarick, S., Revelle C. (1998) comments because of the large capital outlays that are involved, facility location decisions are executed in the long-term. Consequently, there may be considerable uncertainty of the parameters of the location decision.

Facility location has an important role because the site selection directly relates with the warehouse systems, inventory control and handling, customers and suppliers. A good location gives a strategic advantage against competitors. To give service to potential customers better by short distances stated by Jayaraman and Vaidyanathan (1998) as locating more outlets a company enhances its accessibility and hence improves its overall customer service. Kumral M. (2004) said that the determination of a facility location is a well-known phenomenon in operational research area. The facility location means the placement of a planned facility with regard to other facilities according to some constraints. There are both quantitative and qualitative methods applied for the facility location problems explained by Chen and Sha (2001).

2. FACILITY LOCATION FACTORS

In real life there exist many factors directly or indirectly affect on the facility location selection. As global location factors it can be defined as; government stability, governed regulations, political and economic systems, exchange rates, culture, climate, export & import regulations, tariffs and duties, raw material availability, availability of suppliers, transportation & distribution systems, labor force, available technology, technical expertise, cross-border trade regulations and group trade agreements. On the other hand, for the selection of the region, city or country the factors considered are; labor, proximity to customers, number of customers, construction costs, land cost, availability of modes and quality of transportation, transportation costs, local business regulations, business climate, tax regulations financial services, incentive packages applied to that region and labor force education are both critical and important in facility location selection. Therefore it is clear that there is a need in location problem approaches concentrating on the combination of qualitative and quantitative factors.

3. WAREHOUSE LOCATION

Warehouse planning and control structure refers to high importance because of storage and pick-up processes. According to Toloken (2000), the growth of warehouse functions to include call centers, light assembly or back-office functions, along with the development of the Internet and better-computerized inventory, are leading companies to have fewer but rises a requirement to larger warehouse and distribution facilities.

Locating facilities and allocating demand to these facilities is a huge problem. There is a trade-off between the cost of construction and operating of the facility and the cost of transportation. Low facility costs and high transportation costs implies the decentralization concept. Lead times, customer service and response depend on the

warehouses. Therefore, the location of the warehouse is also important as facility location. One part of the Warehouse Management Systems contains also warehouse location. One aim is to minimize the travel or shipment distance as location selection.

In this study the factors of inventory holding cost, fixed cost of locating warehouse, shipping cost from warehouse to the customer is considered. All the calculations are respected according to the qualitative and quantitative constraints of both warehouse and plant.

4. APPROACHES ON FACILITY LOCATION

Classical plant location problems have been discussing over the years, as initiating with the work of Weber (1909), however, the workable models are constituted only in the 1960s with the arrival of automatic computation capabilities implied by Laporte and Reville (1996). Many methods can be applied in facility location problems. One is the metric k-median method used by Arya, N. et al. (2004). It is stated the locality gap of a local search procedure for a minimization problem as the maximum ratio of a locally optimum solution (obtained using this procedure) to the global optimum.

Junghirapanich and Benjamin (1995) ensures a chronological summary of research studies between the years 1875 to 1990 on general industrial location, implying that, frequently in the past, a limited number of quantitative factors such as transportation and labor costs were considered when firms made a location decision, but that more recently an increasingly wide range of both qualitative and quantitative factors have been evident. Costs are a major concept in many international location decisions and there may be trade-offs between different types of costs. Atthirawong and MacCarthy (2003) states location factors mainly influencing international location decisions.

The location facility problems cover formulations, which is in the range of complexity from simple single commodity linear deterministic model types to the multi commodity nonlinear stochastic versions as suggested by Jayaraman and Vaidyanathan (1998). Hoffman and J Schniederjans (1994) concerns that for the global expansion strategies of the companies facility location has an important role. Unfortunately little has been written to aid companies on these strategies.

According to Jayaraman, Vaidyanathan (1998) mathematical models have many benefits for the supply chain network design methodology. They address the questions of how many facilities should be sited, where the location for the facility is and how the location factors affect on this selection.

Considered by P. T. Chuang (2002), QFD approach is used for the facility location factors. Location criteria and weighted factors are all assessed and the model contains location requirements (quality requirements as they respected), location criteria (quality characteristics as they respected), importance weighting of requirement, importance degree of location criteria and normalized degree of location criteria. All of these are schemed in a matrix. The aim is to satisfy whether location requirements and location criteria.

The aim of this paper is to formulate the optimization within the phases of the supply chain members to create an effective and efficient system through the combination

of quantitative and qualitative factors. Besides, to explore proposing an integrated model for decision support systems is also significant.

5. SUPPLY CHAIN NETWORK DEFINITION AND MODELING

Supply chain network concept is gaining importance on logistics operations and strategic management. supply chain is behaved as a network of nodes including suppliers, plants, warehouses and markets. All the members of these four parts are respected as nodes. In supply network, the aim is to focus on the network that is formed by the flow of material, services, and associated information. One could extend the approach towards “technology chains” and “knowledge networks”. This approach is mentioned by Mills, Schmitz and Frizelle (2004). Today the manufacturers must find a way to improve their supply chain partners in a way that all of the chain members must ensure flexibility, speed and less costly ways.

Korpela and Lehmusvaara (1999), mentions that cost or profit based optimization with capacity restrictions is the most widely used method for supply chain network design. Today’s business environment require more customer driven approaches by using associated techniques like AHP, DEA etc. In this respect, Korpela and Lehmusvaara (1999) stated that, MILP, mixed integer linear programming can also be adaptive for increasing the advantages of the selecting the site of the location of plant and warehouse. Thus, the plant and warehouse, two important facilities of the supply chain network, can be located based on multiple quantitative and qualitative criteria instead of just only costs or profits.

6. METHODOLOGY

1. The facility location factors are listed.
2. The factors are grouped as quantitative and qualitative.
3. The quantitative factors are based on cost categories and each alternative has a cost value from each cost category.
4. Each cost value at each cost category is normalized and weighted inversely proportional to the cost. These normalized numbers will become coefficients in step 6 at the linear integer programming model.
5. The general criteria are stated and then AHP is applied and as a result weight for each qualitative factor is noted in order to be used as a coefficient in the step 6.
6. General linear integer programming model is designed with a Maximizing objective function; weights coming from cost figures become the coefficients of the quantitative factors and weights coming from the AHP become the coefficients of qualitative factors.

STEP 1: The plant or facility location problem enlarged to a form of location problem for all network including warehouses and suppliers as well. The global competition enforces firms to operate global business operations in which location problem becomes a global problem. As a result of this global perspective the factors associated to location factors contains global factors as well as local factors.

- ❖ Government Stability
- ❖ Exchange Rates
- ❖ Export & Import Regulations
- ❖ Labor force & Education

- ❖ Labor cost
- ❖ Proximity to customers
- ❖ No. of customers
- ❖ Construction & leasing costs
- ❖ Land cost
- ❖ Modes and quality of transport
- ❖ Transportation costs
- ❖ Community attitude
- ❖ Incentive packages
- ❖ Environmental regulations
- ❖ Raw material availability
- ❖ Infrastructure
- ❖ Quality of life
- ❖ Tax
- ❖ Proximity of suppliers
- ❖ Holding costs

STEP 2: The location factors are classified as quantitative (cost oriented) and qualitative factors.

QUANTITATIVE

- ❖ Labor cost
- ❖ Land cost
- ❖ Holding costs
- ❖ Exchange Rates
- ❖ Export & Import Regulations
- ❖ Incentive packages
- ❖ Tax
- ❖ Construction & leasing costs
- ❖ Transportation costs

QUALITATIVE

- ❖ Modes and quality of transport
- ❖ Proximity to customers
- ❖ Community attitude
- ❖ Government Stability
- ❖ Environmental regulations
- ❖ Raw material availability
- ❖ Infrastructure
- ❖ No. of customers
- ❖ Quality of life
- ❖ Labor force & Education
- ❖ Proximity to competitors
- ❖ Proximity of suppliers

STEP 3: For each plant location alternative and for each warehouse location alternative the total cost amounts are calculated and at each cost category.

STEP 4: Then each alternative are normalized inversely proportional to the amount of cost. So each alternative has a coefficient at each cost category and these coefficients sum up to 1.

LAND COST

$$LC_{pi} = SI_{pi} LA_{pi} \quad (6.1)$$

SI_{pi} = size of plant in site i

LA_{pi} = unit land cost of plant at site i

LC_{pi} = total land cost of plant at site i

α LC_{pi} = inversely normalized, will be denoted with a_{fi} in linear int. prog. model

$$LC_{wi} = SI_{wi} LC_{wi}$$

(6.2)

SI_{wi} = size of warehouse in site i

LA_{wi} = unit land cost of warehouse at site i

LC_{wi} = total land cost of warehouse at site i

α LC_{wi} = inversely normalized, will be denoted with s_{fm} in linear int. prog. model

LABOR COST

$$LBC_{pi} = LR_{pi} LB_{pi} \quad (6.3)$$

LR_{pi} = labor requirement for plant at site i

LB_{pi} = unit labor cost of plant at site i

LBC_{pi} = total labor cost of plant at site i

α LBC_{pi} = inversely normalized, will be denoted with a_{fi} in linear int. prog. model

$$LBC_{wi} = LR_{wi} LB_{wi} \quad (6.4)$$

LR_{wi} = labor requirement for warehouse at site i

LB_{wi} = unit labor cost of warehouse at site i

LBC_{wi} = total labor cost of warehouse at site i

α LBC_{wi} = inversely normalized, will be denoted with s_{fm} in linear int. prog. model

CONSTRUCTION COST

$$CNC_{pi} = BR_{pi} CN_{pi} \quad (6.5)$$

BR_{pi} = building requirements for plant at site i

CN_{pi} = unit construction cost of plant at site i

CNC_{pi} = total construction cost of plant at site i

α CNC_{pi} = inversely normalized, will be denoted with a_{fi} in linear int. prog. model

$$CNC_{wi} = BR_{wi} CN_{wi} \quad (6.6)$$

BR_{wi} = building requirements for warehouse at site i

CN_{wi} = unit construction cost of warehouse at site i

CNC_{wi} = total construction cost of warehouse at site i

α CNC_{wi} = inversely normalized, will be denoted with s_{fm} in linear int. prog. model

TRANSPORTATION COST

$$\sum_{t=1}^n q_t ts_t p_i + \sum_{j=1}^m q'_j t' p_i w_j = TS_t W_j P_i \quad (6.7)$$

q_t = quantity send from supplier t to plant at site i

$ts_t p_i$ = unit transportation cost from supplier t to plant at site i

q'_j = quantity send from plant at site i to warehouse at site i

$t' p_i w_j$ = unit transportation cost from plant at site i to warehouse at site i

$TS_t W_j P_i$ = total transportation cost from supplier to plant at site i and from plant at site i to warehouse at site i.

α $TS_t W_j P_i$ = inversely normalized, will be denoted with a_{fi} in linear int. prog. model

$$\sum_{j=1}^m k_j tw_i b_j = TW_i B_j \quad (6.8)$$

k_j = quantity send from warehouse at site i to market j

$tw_i b_j$ = unit transportation cost from warehouse at site i to market j

$TW_i B_j$ = total transportation cost from warehouse at site i to market j

α $TW_i B_j$ = inversely normalized, will be denoted with s_{fm} in linear int. prog. model

EXPORT&IMPORT REGULATIONS

$$\sum_{t=1}^n x_t rs_t p_i + \sum_{j=1}^m d_j zp_i w_j = TIS_t P_i W_j \quad (6.9)$$

x_t = quantity send from supplier t to plant at site i.

rs_{tp_i} = import&export cost per unit send from supplier t to plant at site i.
 d_j = quantity send from plant at site i to warehouse at site j
 zp_iw_j = import&export cost per unit send from plant at site i to warehouse at site j
 $TIS_{tP_iW_j}$ = total import&export cost of materials send from supplier t to plant at site i and from plant at site i to warehouse at site j.
 $\alpha TIS_{tP_iW_j}$ = inversely normalized, will be denoted with a_{fi} in linear int. prog. model

$$\sum_{j=1}^m g_j r w_{i,c_j} = TIW_{iC_j} \quad (6.10)$$

g_i = quantity send from warehouse at site i to customer j.
 rw_{i,c_j} = import&export cost per unit send from warehouse at site i to customer j.
 TIW_{iC_j} = total import&export cost of materials send from warehouse at site i to customer j.
 αTIW_{iC_j} = inversely normalized, will be denoted with s_{fm} in linear int. prog. model

INVENTORY HOLDING COST

$(HC)_i V_i P_i$ = annual inventory cost for plant at site i (6.11)
 $(HC)_i$ = annual inventory holding cost for plant at site i.
 $V_i P_i$ = annual amount of inventory hold at plant at site i
 $\alpha (HC)_i V_i P_i$ = inversely normalized, will be denoted with a_{fi} in linear int. prog. model

$(HC)_j V_j W_j$ = annual inventory cost for warehouse at site j (6.12)
 $(HC)_j$ = annual inventory holding cost for warehouse at site j.
 $V_j W_j$ = annual amount of inventory hold at warehouse at site j
 $\alpha (HC)_j V_j W_j$ = inversely normalized, will be denoted with a_{fi} in linear int. prog. model

TAX

$TX_j P_i$ = tax with kind j applied to plant at site i (6.13)
 X_j = tax with kind j
 $\alpha TX_j P_i$ = inversely normalized, will be denoted with a_{fi} in linear int. prog. model

$TX_j W_i$ = tax with kind j applied to warehouse at site i
 (1.14)

X_j = tax with kind j
 $\alpha TX_j W_i$ = inversely normalized, will be denoted with s_{fm} in linear int. prog. model

INSURANCE COST

$(TIN)_j P_i$ = insurance with kind j applied to plant at site i (6.15)
 $(TIN)_j$ = insurance with kind j
 $\alpha (TIN)_j P_i$ = inversely normalized, will be denoted with a_{fi} in linear int. prog. model

$(TIN)_j W_i$ = insurance with kind j applied to warehouse at site i (6.16)
 $(TIN)_j$ = insurance with kind j

$\alpha (TIN)_j W_i =$ inversely normalized, will be denoted with S_{fm} in linear int. prog. model

INCENTIVE PACKAGES

$(TIP)_j P_i =$ insurance with kind j applied to plant at site i (6.17)

$(TIP)_j =$ incentive package with kind j

$(TIP)_j P_i =$ *normalized*, will be denoted with a_{fi} in linear int. prog. model

$(TIP)_j W_i =$ insurance with kind j applied to warehouse at site i (6.18)

$(TIP)_j =$ incentive package with kind j

$(TIP)_j W_i =$ *normalized*, will be denoted with S_{fm} in linear int. prog. model

STEP 5: AHP, Analytical Hierarchy Process, which is used for analyzing the customer-specific needs for logistics service and for evaluating the alternative factory and warehouse locations. The form seen in figure 1 can be filled in order to be used in AHP. The qualitative factors will be pair wised compared based on the criteria as quality, availability and performance. Then the weights for each objective are calculated.

OBJ MATRIX	QUA	AVA	PER	
QUALITY				
AVAILABILITY				
PERFORMANCE				
ANORM (OBJ)	QUA	AVA	PER	WEIGHT
QUALITY				
AVAILABILITY				
PERFORMANCE				

Chart 6.1 Each site alternative for each facility at each objective; the location factors are once more pair wised compared based on the form seen on figure2

FOR PLANT AT SITE 1														
QUALITY MATRIX	Prox. of Supp.	No. of Suppl/line	No. of Cust.	Prox. to Cust.	Exchange Rates	Politi. Stability	Labor quality	Quality of life	Raw Mat. avail	Infrastructure	Comm. attitude	Env. Regulations	Modes of transport	Prox to compet
Prox. Of Supp.	1													
Number of Supp		1												
Number of Cust.			1											
Prox to Cust				1										
Exchange rates					1									
Politi. Stability						1								
Labor Quality							1							
Quality of Life								1						
Raw Material ava									1					
Infrastructure										1				
Comm. Attitude											1			
Env. Reg.												1		
Modes of transport													1	
Prox to Compet														1

Chart 6.2 An example of the AHP procedure for limited number of factors, five in this case, is solved and coefficients for each location factor is calculated for the alternative named as plant at site 1 as seen in figure 3. The total score values will be used in the final linear integer prog. model as the coefficients of the qualitative location factors.

OBJ MATRIX					FOR PLANT AT SITE 1				
QUALITY	1	3	2						
AVAILABILITY	0.2	1	0.5						
PERFORMANCE	0.5	2	1						
ANORM (OBJ)	QUA	AVA	PER	WEIGHT					
QUALITY	0.59	0.63	0.57	0.59					
AVAILABILITY	0.12	0.13	0.14	0.13					
PERFORMANCE	0.29	0.25	0.29	0.28					

QUALITY MATRIX						ANORM (QUALITY)						
	Polit.stability	Prox.of Supp	Comm.attitude	Prox.toCust.	Quality of life		Polit.stability	Prox.of Supp	Comm.attitude	Prox.toCust.	Quality of life	WEIGHT'S
Polit.stability	1.00	0.33	2.00	0.75	0.67	0.14	0.10	0.32	0.18	0.09	0.17	
Prox.of Supp	3.00	1.00	1.33	1.20	2.00	0.41	0.30	0.22	0.28	0.28	0.30	
Comm.attitude	0.50	0.75	1.00	0.80	1.50	0.07	0.22	0.16	0.19	0.21	0.17	
Prox.to Cust	1.25	0.80	1.20	1.00	2.00	0.17	0.24	0.19	0.24	0.28	0.22	
Quality of life	1.50	0.50	0.67	0.50	1.00	0.21	0.15	0.11	0.12	0.14	0.14	
	7.25	3.38	6.20	4.25	7.17							

AVAILAB MATRIX						ANORM (AVAILAB)						
	Polit.stability	Prox.of Supp	Comm.attitude	Prox.toCust.	Quality of life		Polit.stability	Prox.of Supp	Comm.attitude	Prox.toCust.	Quality of life	WEIGHT'S
Polit.stability	1.00	0.50	1.25	0.67	0.67	0.15	0.07	0.21	0.20	0.13	0.15	
Prox.of Supp	2.00	1.00	0.80	0.33	1.33	0.30	0.15	0.13	0.10	0.26	0.19	
Comm.attitude	0.75	1.20	1.00	0.57	0.80	0.11	0.18	0.17	0.17	0.16	0.16	
Prox.to Cust	1.50	3.00	1.75	1.00	1.25	0.22	0.44	0.29	0.30	0.25	0.30	
Quality of life	1.50	0.75	1.25	0.80	1.00	0.22	0.11	0.21	0.24	0.20	0.20	
	6.75	6.45	6.05	3.37	5.05							

PERF MATRIX						ANORM (PERF)						
	Polit.stability	Prox.of Supp	Comm.attitude	Prox.toCust.	Quality of life		Polit.stability	Prox.of Supp	Comm.attitude	Prox.toCust.	Quality of life	WEIGHT'S
Polit.stability	1.00	0.80	0.80	0.67	2.00	0.182	0.24	0.13	0.15	0.23	0.19	
Prox.of Supp	1.25	1.00	2.00	1.50	3.00	0.227	0.3	0.31	0.34	0.34	0.31	
Comm.attitude	1.25	0.50	1.00	0.57	1.20	0.227	0.15	0.16	0.13	0.14	0.16	
Prox.to Cust	1.50	0.67	1.75	1.00	1.50	0.273	0.2	0.27	0.23	0.17	0.23	
Quality of life	0.50	0.33	0.82	0.67	1.00	0.091	0.1	0.13	0.15	0.11	0.12	
	5.50	3.30	6.38	4.40	8.70							

TOTAL SCORE		NOTATIONS FOR QUALITATIVE FACTORS OF THE PLANT AT SITE 1 IN THE INTEGER PROG. MODEL (FOR WAREHOUSE THE QUALITATIVE FACTORS WILL BE DENOTED WITH Γ11...Γ31)	
Polit.stability	0.170	b ₁₁	}
Prox.of Supp	0.286	b ₂₁	
Comm.attitude	0.166	b ₃₁	
Prox.to Cust	0.235	b ₄₁	
Quality of life	0.143	b ₅₁	

Chart 6.3

STEP 6: As an application the problem requires to select one site for the plant and one site for the warehouse. The integer linear prog. model will enable us to combine qualitative and quantitative factors in the same methodology which is based on operations research. To be more in line with the managers there can be a coefficient assigned as a weight to quantitative factors denoted by β and $1-\beta$ to qualitative factors.

LINEAR INTEGER PROGRAMMING MODEL

$$\begin{aligned}
 & \text{QUANTITATIVE FACTORS} \qquad \text{QUALITATIVE FACTORS} \qquad \text{QUANTITATIVE FACTORS} \qquad \text{QUALITATIVE FACTORS} \\
 & \underbrace{\hspace{10em}} \qquad \underbrace{\hspace{10em}} \qquad \underbrace{\hspace{10em}} \qquad \underbrace{\hspace{10em}} \\
 \text{MAXZ} = & \beta \sum_{i=1}^n \sum_{f=1}^c a_{fi} y_i + (1-\beta) \sum_{i=1}^n \sum_{h=1}^p b_{hi} y_i + \beta \sum_{e=1}^m \sum_{f=1}^c s_{fm} y_e + (1-\beta) \sum_{e=1}^m \sum_{h=1}^p r_{he} y_e \quad (6.19) \\
 & \underbrace{\hspace{15em}} \qquad \underbrace{\hspace{15em}} \\
 & \text{FOR PLANT LOCATION} \qquad \text{FOR WAREHOUSE LOCATION}
 \end{aligned}$$

s.t.

$$\sum_{i=1}^n y_i = 1 \quad (6.20)$$

$$\sum_{e=1}^m y_e = 1 \quad (6.21)$$

$$y_i, y_e = 0 \text{ or } 1 \quad (6.22)$$

$$a_{fi}, b_{hi}, s_{fm}, r_{he} \geq 0 \quad (6.23)$$

7. CONCLUSION&FURTHER RESEARCH

The study stands on one of the most strategic actions taken by the management, facility location decision. It is implied that the facility selection problem should be based on the systems approach and for the problem both plant and warehouse locations can be discussed as a whole. In global competition as strategic management implies long-term aims should be stated. So for success limiting the management with just a certain number of criteria can be misleading for the global competition. The study mentions the importance of qualitative factors, which is an important point in the management as well as quantitative factors because it would be a failure to be based solely on qualitative factors. The vice versa is also true that depending solely on quantitative factors would also be a reason for a failure. Especially in strategic decisions like facility location the importance of the accuracy increases. As a result the need for a new way of thinking and a new methodology is required for the management in order to combine quantitative and qualitative factors.

The methodology in the study is a combination of both qualitative and quantitative factors. Initially the factors are stated and then they are grouped into quantitative and qualitative factor. Then the quantitative factors are modeled based on the cost figures and then inversely normalized in order to assign an coefficient to each factor to be used in the linear integer prog. model. Then the qualitative factors are subject to AHP. The result of the AHP became the coefficients of the qualitative factors to be used in the linear integer prog. model.

The linear integer-programming model is based on MAX objective, which implies the difference between the MIN objectives of the previous techniques which were solely based on minimization of the costs. Therefore the combination of qualitative and quantitative factors are succeeded through the technics of operational research. Future research should be conducted and field studies can be applied using this methodology enabling the researchers the applicability of the methodology. The methodology and the models can also be enlarged to cover more points of the supply chain and more factors can also be added.

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