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# Supplier selection by using the goal programming approach

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**Abstract.** Supplier selection problems have been considered widely in literature; however, considering the availability and reliability of the products provided by suppliers has been investigated less. In this regard, the presented work addresses a supplier selection problem in which the reliability of the parts is one of their main factors for supplier selection. This paper develops a multiobjective mathematical goal programming model to allocate the system's components orders to the suppliers. The model minimizes the system construction costs and maximizes the probability of working the system in nominal and half capacity. The similarity of the ordered components affects their delivery lead times and prices. The model determines the optimal solution for an industrial system composed of 4 parts. The proposed approach includes using the reliability block diagram to develop the Markov chain model. A multiobjective binary nonlinear mathematical program uses the Markov model to select the optimal components suppliers. Solving the model by goal programming approach provides the possibility of reflecting the decision-maker opinion relative to the construction cost's importance compared to system availability.

**Keywords:** Reliability block diagram(RBD), goal programming, concurrent engineering, Markov chain

## 1 Introduction

This paper presents a multiobjective approach to determine the components suppliers for making the feedwater system (FWS) of heat-recovery steam-generator boilers used in combined cycle power plants. A nonlinear binary goal programming model uses the Markov chain results to optimize total costs, including components price, system construction delays penalty, and the system's availability.

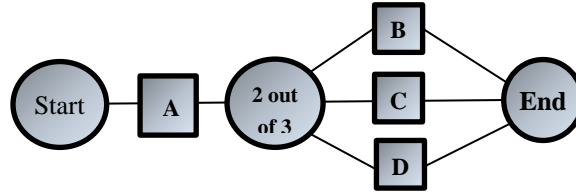
Many kinds of research applied optimization approaches such as integer programming, mixed integer programming, nonlinear programming, and heuristics to deal with serial-parallel and multistate systems' availability and supplier selection in supply chains. Levitin et al. determined the optimal versions of components and redundancy of different subsystems in multistate series-parallel systems [1]. Rui and et al. improved design configuration by developing a reliability optimization algorithm [2]. Yi and et

al. view a reliability optimization problem by selecting components reliability among different alternative levels when the system's overall performance is a function of each part's failure rate [3]. Montoro-Cazorla et al. studied a system subjected to shocks governed by a Poisson process, and the internal failures and the inspection times exponentially distributed [4]. Ge et al. developed an optimization model to determine critical components' reliability in a serial system [5]. Carpitella et al. developed a mathematical model for calculating a k-out-of-n system's stationary availability using the Markov chain model [6]. Chambari et al. proposed a bi-objective simulation-based and a customized NSGA-II optimization algorithm for a redundancy allocation problem [7]. Es-Sadqi et al. attempted to find the optimal system configuration that maximizes the availability and minimizes the investment cost. They evaluated the genetic algorithm and the constraint programming performance and proposed a new optimization method based on forwarding checking as a solver [8]. Sawik investigated a multi-period supplier selection problem in a supply chain with disruption and delay risks and then proposed a dynamic portfolio approach. This approach helps decision-makers decide on the suppliers of finished products, but it does not discuss the availability of the ordered parts [9]. Chen et al. developed a model to consider supplier selection and project scheduling simultaneously. They studied multiple concurrent projects that were independent operationally but with similar suppliers, when these projects' activities began as their needed resources became available. Then, this model was solved using a mathematical programming-based heuristic [10]. Bodaghi et al. introduced a weighted fuzzy multiobjective model to address supplier selection, customer order scheduling, and order quantity allocation in supply chains. They considered the reliability of on-time delivery of customer orders and evaluated the flexibility of suppliers [11]. Yoon et al. incorporated supplier selection with risk mitigation policies and utilized multiobjective optimization-based simulation for their model [12]. They showed that the use of upstream and downstream strategies simultaneously leads to better results. Cui et al. investigated sustainable supplier selection in deferent multitier supply chain structures and combined fuzzy set theory, stepwise weight assessment ratio analysis, plus a Bayesian network to propose their model [13].

The previous researches did not consider the life cycle cost, reliability, and availability of the system simultaneously. This paper attempts to consider more real world parameters by developing a multiobjective mathematical goal programming model for assigning system component orders to the suppliers. This model minimizes system construction costs and maximizes the likelihood of the system operating at nominal and half-load capacity, while the similarity of the ordered components leads to change their delivery time and price. Using the proposed approach to select the components supplier of a typical industrial system illustrates the model application for an industrial system. The following sections explain this model and solve it for a numerical example and discuss the results.

## 2 The proposed model

The discussed problem concerns selecting the suppliers for critical components of FWS (Figure 1).



**Fig 1.** Studied series-parallel system

Component B, C, and D are feedwater pumps. Each of them provides 50% of the nominal system capacity, and component A is the instrumentation device that controls the overall system parameters. Several suppliers offer different qualities (i.e., failure and repair rates), prices, and delivery lead times. The availability of the system depends on the reliability and reparability of its components. Also, suppliers offer incremental quantity discounts; however, large orders result in higher delivery lead time. During the system exploitation phase, the system may be in one of three states, according to the failure of its components: working at nominal capacity (NC), half capacity (HC), and shutdown (SD). NC occurs when A and at least two out of B, C, and D are working. HC occurs when A and only one out of B, C, and D are working. SD results from failure of A or all B, C, and D. Figure (2) illustrates the Markov model of all possible states for this system. In this figure, oval, trapezoid, and rectangular forms represent NC, HC, and SD. Operation of components B, C, and D are identical, and ordering one of them to supplier j, delivery lead time, and the price will be  $L_{Bj}$  and  $C_{Bj}$ , respectively. By ordering two components among these components to supplier j, the unit price and delivery lead time of each of them will be  $C'_{Bj}$  and  $L'_{Bj}$ , respectively. Finally, by ordering all these three components to supplier j, price and delivery time values will be  $C''_{Bj}$  and  $L''_{Bj}$ , respectively. Assembling B, C, D should begin after A, and simultaneous assembly of B, C, D does not change their assembly times. Times and costs of assembling processes are deterministic and known and independent from the quality of the components. Deterministic weighting factors express the goals' importance.

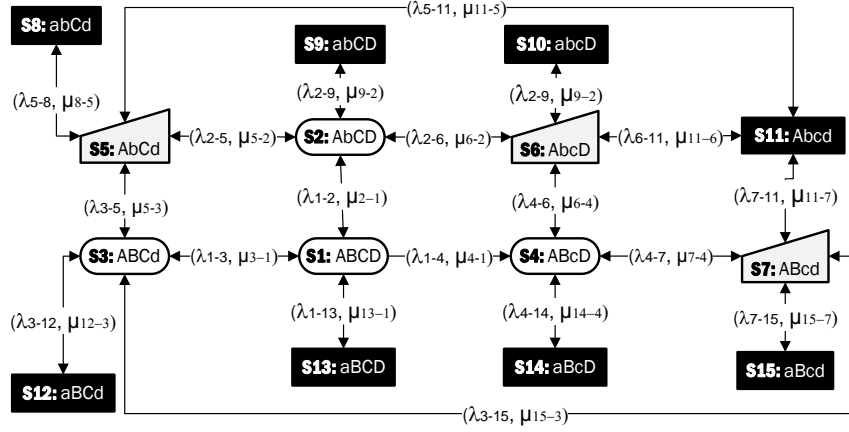


Fig 2. The system's Markov model Diagram

### 3 The mathematical model

The model indices, parameters, and decision variables are as follows:

$i = A, B, C, D$  : The components

$j = 1, 2, \dots, J$  : The components' suppliers

$k = 1, 2, \dots, K$  : The assembly process

$l = 1, 2, \dots, L$  : The system states

$m = 1, 2, 3$ : The goals

$C_{Aj}$  = Purchasing price of A from supplier j

$C_{Bj}$  = Unit price of B, C, or D from supplier j when purchasing separately

$C'_{Bj}$  = Unit price of purchasing two of B, C, and D from supplier j

$C''_{Bj}$  = Unit price of purchasing similar B, C, and D from supplier j

$R_{ij}$  = reliability of component i offered by supplier j

R = Minimum requested system's reliability

T = System construction completion deadline

B = The maximum available budget for purchasing components

n = Number of components (n=4)

$C^D$  = Daily delay penalty for system construction

$L_{Aj}$  = Delivery lead time of component A from the supplier j

$L_{Bj}$  = Delivery lead time of ordering one of B, C, or D from the supplier j

$L'_{Bj}$  = Delivery lead time of ordering two similar components among B, C, or D to supplier j

$L''_{Bj}$  = Delivery lead time of ordering all components B, C, and D to supplier j

$F_{Ak}$  = Time of process k for assembling component A  
 $F_{Bk}$  = The time of process k for assembling each of components B, C or d  
 $K_A$  = Set of required processes for assembling component A  
 $K_B$  = Required assembly processes on components B, C, and D  
 $\mu_{ij}$  = The rate of repair of component i, offered by supplier j  
 $\lambda_{ij}$  = The rate of failure of component i, offered by supplier j  
 $b_m$  = The value of goal m  
 $w_m$  = The weighting factor of the undesirable deviation from goal m  
 $A_1$  = The components purchase cost  
 $A_2$  = The total construction delay penalty  
 $y_{ij}$  = Binary variable with values 1, if component i is ordered from supplier j, and zero otherwise.

$R_i$  = reliability of component i

$R_e$  = reliability of the entire system

$P_0$  = Expected percentage of time of SD during the system exploitation phase

$P_{50}$  = Expected percentage of time of HC during the system exploitation phase

$S_l$  = Expected percentage of time that the system spends in state l

$\mu_i$  = The rate of repair of component i

$\lambda_i$  = The rate of failure of component i

$T^c$  = Completion time of the system construction

$T_c^i$  = Completion time of assembling component i

$T^B$  = The time of delivery of all components B, C, and D

$d_m^+, d_m^-$  = Positive and negative deviations from goal m

Equations (1) to (35) show the objective function and constraints of the model.

$$\text{Min } Z = w_1 d_1^+ + w_2 d_2^+ + w_3 d_3^+ \quad (1)$$

Subjected to:

$$A_1 = \sum_{j=1}^3 y_{Bj} y_{Cj} y_{Dj} (3C_{Bj}''') \quad (2)$$

$$\begin{aligned}
 &+ \sum_{j=1}^3 (y_{Bj} y_{Cj} (1 - y_{Dj}) + y_{Bj} y_{Dj} (1 - y_{Cj}) \\
 &+ y_{Cj} y_{Dj} (1 - y_{Bj})) \times (2C_{Bj}') \\
 &+ \sum_{j=1}^3 (y_{Bj} (1 - y_{Cj}) (1 - y_{Dj}) \\
 &+ y_{Cj} (1 - y_{Bj}) (1 - y_{Dj}) + y_{Dj} (1 - y_{Bj}) (1 - y_{Cj})) \\
 &\times C_{Bj} + \sum_{j=1}^3 y_{Aj} C_{Aj}
 \end{aligned}$$

$$P_0 = S_8 + S_9 + S_{10} + S_{11} + S_{12} + S_{13} + S_{14} + S_{15} \quad (3)$$

$$P_{50} = S_5 + S_6 + S_7 \quad (4)$$

$$P_0 - d_2^+ = b_2 \quad (5)$$

$$P_{50} - d_3^+ = b_3 \quad (6)$$

$$T^A = \sum_{j=1}^3 y_{Aj} L_{Aj} + \sum_{k \in k_A} F_{Ak} \quad (7)$$

$$T^B = \sum_{j=1}^3 y_{Bj} y_{Cj} y_{Dj} L_{Bj}'' \quad (8)$$

$$\begin{aligned} &+ \left( \sum_{j=1}^3 (y_{Bj} y_{Cj} (1 - y_{Dj}) + y_{Bj} y_{Dj} (1 - y_{Cj}) \right. \\ &+ \left. y_{Cj} y_{Dj} (1 - y_{Bj})) \times \text{Max}(L_{Bj}, L_{Bj}') \right) \\ &+ \left( \sum_{j=1}^3 (y_{Bj} (1 - y_{Cj}) (1 - y_{Dj}) \right. \\ &+ \left. y_{Cj} (1 - y_{Bj}) (1 - y_{Dj}) + y_{Dj} (1 - y_{Bj}) (1 - y_{Cj})) \right) \\ &\times \text{Max}(L_{Bj}, L_{Bj}') \end{aligned}$$

$$T^C = \max(T^B, T^A) + \sum_{k \in k_B} F_{Bk} \quad (9)$$

$$A_2 = \max(0, T^c - T) C^D \quad (10)$$

$$A_1 + A_2 - d_1^+ = b_1 \quad (11)$$

$$A_1 \leq B \quad (12)$$

$$\mu_i = \sum_{j=1}^3 Y_{ij} \mu_{ij} \quad \forall i \quad (13)$$

$$\lambda_i = \sum_{j=1}^3 Y_{ij} \lambda_{ij} \quad \forall i \quad (14)$$

$$\sum_{j=1}^3 y_{ij} = 1 \quad \forall i \quad (15)$$

$$y_{ij} \in \{0,1\} \quad \forall i,j \quad (16)$$

$$(\lambda_1 + \lambda_2 + \lambda_3 + \lambda_4) S_1 = \mu_2 S_2 + \mu_4 S_3 + \mu_3 S_4 + \mu_1 S_{13} \quad (17)$$

$$(\lambda_1 + \mu_2 + \lambda_3 + \lambda_4) S_2 = \lambda_2 S_1 + \mu_4 S_5 + \mu_3 S_6 + \mu_1 S_9 \quad (18)$$

$$(\lambda_1 + \mu_4 + \lambda_3 + \lambda_2) S_3 = \lambda_4 S_1 + \mu_2 S_5 + \mu_1 S_{12} + \mu_3 S_7 \quad (19)$$

$$(\lambda_1 + \mu_3 + \lambda_2 + \lambda_4) S_4 = \lambda_3 S_1 + \mu_4 S_7 + \mu_2 S_6 + \mu_1 S_{14} \quad (20)$$

$$(\lambda_1 + \mu_2 + \lambda_3 + \mu_4) S_5 = \lambda_4 S_2 + \lambda_2 S_3 + \mu_3 S_{11} + \mu_1 S_8 \quad (21)$$

$$(\lambda_1 + \mu_2 + \lambda_4 + \mu_3) S_6 = \lambda_3 S_2 + \lambda_2 S_4 + \mu_4 S_{11} + \mu_1 S_{10} \quad (22)$$

$$(\lambda_1 + \mu_3 + \lambda_2 + \mu_4) S_7 = \lambda_4 S_4 + \lambda_3 S_3 + \mu_2 S_{11} + \mu_1 S_{15} \quad (23)$$

$$\mu_1 S_8 = \lambda_1 S_5 \quad (24)$$

$$\mu_1 S_9 = \lambda_1 S_2 \quad (25)$$

$$\mu_1 S_{10} = \lambda_1 S_6 \quad (26)$$

$$(\mu_2 + \mu_3 + \mu_4) S_{11} = \lambda_4 S_6 + \lambda_2 S_7 + \lambda_3 S_5 \quad (27)$$

$$\mu_1 S_{12} = \lambda_1 S_3 \quad (28)$$

$$\mu_1 S_{13} = \lambda_1 S_1 \quad (29)$$

$$\mu_1 S_{14} = \lambda_1 S_4 \quad (30)$$

$$\mu_1 S_{15} = \lambda_1 S_7 \quad (31)$$

$$\sum_{l=1}^{15} S_l = 1 \quad (32)$$

$$R_e = 1 - P_0 \quad (33)$$

$$R_e \geq R \quad (34)$$

$$P_{100} = S_1 + S_2 + S_3 + S_4 \quad (35)$$

The objective function (1) minimizes a weighted summation of deviations from the goals. Equation (2) calculates total purchasing costs according to their suppliers' components' similarity and the offered price. Equations (3) and (4) calculate the SD and HC proportion time, respectively. Equations (5) and (6) calculate deviations from the second and third goals. Equation (7) is the assembly time of component A by adding its delivery lead time and times of its assembly processes. According to their suppliers and order sizes, equation (8) calculates the delivery lead time of all B, C, and D. Supposing that larger orders increase delivery lead time, this equation can be written, simplifies this equation by removing the max operators. Constraint (9) calculates the completion time of the system construction project by adding the possible earliest time of starting assembly processes of components B, C, and D, with the time of these processes. The max operator indicates these processes can begin after delivering B, C, and D and completing A's assembly. Equation (10) calculates the construction delay penalty by multiplication the daily delay penalty by the difference between the project's end time and its deadline. Equation (11) calculates the total construction cost by adding the component purchasing price and construction delay penalty. The model ignores the assemblies' processes' costs because they are constant and independent from decision variables. Constraint (12) limits the maximum components' purchasing cost to a predefined level. Equations (13) and (14) determine the components' failure and repair rates, respectively, considering their suppliers. Equation (15) indicates that the supplier for each element is unique. Constraint (16) determines the domain of binary variables. Constraints (17) to (32) are Markova processes equilibrium equations, written according to figure (2), and ensure that the sum of the input streams to each state, in the long term, is equal to the sum of the output streams and the sum of all times ratio is 1. Constraint (33) calculates the entire system's reliability as the proportion of times it is not shutting down, and equation (34) ensures the requested minimum level of system reliability. Constraint (35) calculates the ratio of times that the system will work at nominal capacity states. It facilitates the analyses of the results.

## 4 Numerical results

Table (1) presents the problem parameter values, and table (2) shows the optimal solution. The optimal reliability is 0.99, 0.9, 0.9, and 0.95 for A, B, C, and D, respectively. Component A does not have any redundant components, making component A more critical. The entire system's reliability is about 0.85 (i.e., the system works at NC and HC modes, 55% and 29.7% of the time, respectively) and 0.15% of



the times the system is at SD state. Deviation from the second and third goals is very high, resulting from the relative importance (i.e., higher weighted factor) of the first goal. Components' purchase price and the project delay penalty are so high that ordering higher reliability components is not justifiable despite a sufficient purchase budget.

**Table 1.** The model parameters values

Para.	Value	Para.	Value	Para.	Value	Supplier (j)			
						1	2	3	
B	1200	n	4	R	0.8				
$R_{i1}$	0.9	$R_{i2}$	0.95	$R_{i3}$	0.99	<b>Relia-</b>	<b>0.9</b>	<b>0.95</b>	<b>0.99</b>
$\mu_{i1}$	0.05	$\mu_{i2}$	0.07	$\mu_{i3}$	0.1	<b>bility</b>			
$\lambda_{i1}$	0.05	$\lambda_{i2}$	0.03	$\lambda_{i3}$	0.01	$C_{Aj}$	200	220	240
$b_1$	6100	$b_2$	0.05	$b_3$	0.05	$C_{Bj}$	300	340	380
$w_1$	0.01	$w_2$	200	$w_3$	40	$C'_{Bj}$	250	280	320
T	75	$C^D$	300			$C''_{Bj}$	200	240	280
						$L_{Aj}$	5	7	17
						$L_{Bj}$	6	19	31
						$L'_{Bj}$	8	24	37
						$L''_{Bj}$	12	30	42

Assembly process (k)	1	2	3	4	5
$F_{Ak}$	3	5	7	4	2
$F_{Bk}$	6	13	16	5	-

**Table 2.** The model's optimal solution

Decision variable	Value	Decision variable	Value
$A_1$	1080	$R_1$	0.99
$A_2$	5100	$R_2$	0.9
$R_e$	0.847	$R_3$	0.9
$P_{50}$	0.297	$R_4$	0.95
$P_0$	0.153	Z	31.363
$d_1^+$	80	$T^c$	92
$d_3^+$	0.247	$d_2^+$	0.103

## 5 Discussion

This paper uses goal programming as a multiobjective decision-making approach to optimize the systems' design configuration by considering the system life cycle's parameters. The model objective is achieving a sufficiently low construction cost and increasing the system's availability during its exploitation. These objectives are defined based on the supply chain's criteria and alternatives.

Considering the components' constant failure and repair rates justifies using the exponential distribution function as a memoryless probability distribution. This assumption is required to use the Markov model. Otherwise, system simulation models may

create the same results. However, integrating the simulation model in the goal program model will remain a modeling challenge. Using the more appropriate probability distributions (e.g., the Normal distribution function) improves the model's result. The goals' weighting factors express the decision-maker opinion relative to the construction cost's importance compared to system availability. Reducing construction costs is a short-term objective, leads to decreasing the system availability and customer satisfaction.

Varying the goals' weighting factors changes the priorities between the system construction cost and system availability. The model applicability can be improved, by considering uncertainty in the model parameters, such as component repair and failure rates and system costs. Besides, the goal weighting factors may express as fuzzy numbers or linguistic variables. Future research may also model the effect of using similar components on their repair rates and system availability.

## 6 Conclusions

This paper developed a nonlinear binary goal programming model to select suppliers of an industrial system's components. The model minimizes the system's life cycle cost, including the cost of purchasing price and the construction delay penalty, and maximizes the system's availability concurrently. The numerical results illustrate the effect of the order sizes on the components' prices and delivery lead times. They also show how varying the goals' weighting factors provides a trade-off between short-term (minimizing the system construction cost) and long-term objectives (maximizing the system availability).

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