Research Paper

End-to-End Delay QoS Attribute-Based Bundling Strategy of Wireless Improved Reverse Charging Network Pricing Model

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Abstract

In this article, a multi-link internet reverse charging (IRC) scheme model in a multi-service network with the addition of a *bundling* strategy is proposed. Reverse charging schemes in multi-link and multi-service networks are rarely discussed in previous studies. This pricing scheme is designed with the aim of maximizing service provider profits by minimizing internet usage costs. The basic cost and satisfaction level of the service provided by the ISP (Internet Service Provider) is focused on this effort. The model formed in this study is a *Mixed Integer Non-Linear Programming* (MINLP) model that is completed using software LINGO 13.0. This problem comprises two cases, when α (base price) case as a parameter and β (quality premium) as a parameter or variable with sub–cases PQ_{ij} (the changes on cost with changes on QoS) increases in *usage based* pricing schemes. Thus, the results obtained can be a consideration for ISPs in determining the price of services that can support an ISP. The updated IRC model provides a more optimal solution than the original IRC model.

Keywords
pricing scheme, LINGO 13.0, ISP, bundling, end-to-end delay

1. INTRODUCTION

Internet Service Provider (ISP) (Petrova (2003) ; Wu et al. (2010)) competes in providing the best internet service to achieve customer satisfaction. According to Stremersch and Tellis (2002) and Yang (2004) high-speed data transmission requires an application to connect consumers to the internet which will allow different quality QoS (Shalunov and Teitelbaum (2003) ; Kolhar et al. (2016)) networks. By providing the best quality service (Bandung and Sumardi (2016) ; Fang et al. (2018) ; Puspita FM and Taib BM (2013)), ISP can get the maximum benefit by providing the best quality information to serve users.

Internet Reverse Charging (IRC) (Puspita et al., 2019) model is a model that introduces service quality and speed of user access by focusing on *charging* is only done by one ISP to ISP customers so do not allow others to do the reverse charging. The IRC model focuses on switching 3G and 4G (Fagbohun (2014) ; Pagani and Fine (2008)) networks when hosting. Charging schemes can allow ISPs to benefit from their own customers and not from other customers (Blake et al., 1998).

Research by (Puspita et al., 2020) discussed the Improved IRC model of the wireless network pricing scheme on the QoS end-to-end delay attribute with restrictions on multi-link networks

and service classes by making it easy for ISPs to set basic price (α) and quality premium (β), and it can be proven strongly that the ISP will get the highest profit. According to Sain and Herpers (2003), a multi-link network (Puspita et al. (2015) ; Odarchenko et al. (2018)) is shown to carry a wide variety of services and applications with different characteristics and a variety of times. The end-to-end delay attribute refers to the time it takes for a packet to be sent across the network from source to destination.

ISPs are usually faced with the problem of determining the right model in offering information service products quickly and profitably. To adjust the price, the ISP should understand the quality of service that can affect the user's need to use ISP products. The strategy carried out by ISPs in offering a product usually uses a bundle pricing strategy (Wu et al. (2008) ; Venkatesh (2017) ; Puspita et al. (2015)) to attract consumer interest and this strategy is considered to be able to get the maximum benefit from some of the products offered (Venkatesh, 2017). Error in set of information services product strategy may have an impact on his interest is not the customer to choose a product *bundling* offered.

This research is based on the previous IRC model (Puspita et al., 2019) which was updated with the addition of a *bundling* problem optimization model (Wu et al. (2008);Puspita et al. (2016)

) to maximize income for service providers with a usage-based pricing scheme. The updated model involves a utility function (Kuo and Liao (2005);Merayo Álvarez et al. (2017)) in consideration of customer satisfaction in each service and product sales using a *usage-based* pricing scheme (Wu and Banker, 2010) with the hope that service providers are able to compete in the market and consider customer satisfaction. The utility function (Kuo and Liao (2005); Merayo Álvarez et al. (2017); Odlyzko (1998)) used in this model is proposed by Yang et al. (2004) because it can meet customer satisfaction and is easy to analyze for homogeneity and heterogeneity which has an impact on price choices (Indrawati et al., 2014).

2. RESEARCH METHOD

2.1 Data

The data used in this study basically is used for validating the model designed. It is secondary data obtained from a local server in Palembang. The research includes traffic-files data obtained from January 1, 2020 to January 28, 2020. The data contains inbound and outbound bandwidths in bit per second per day for 28 days. Data is divided into two classifications which are bandwidth usage in peak hours and in off peak hours to show the highest consumption consumer level (Indrawati et al., 2014) in using the network both in peak hour and off peak hour.

2.2 Methods

The following are the research steps:

1. Data is carried out in one of the local server in Palembang at the beginning of the semester with secondary data for 28 days (1 January 2020-28 January 2020). The data used in this research include data traffic files that is used for validating the model designed.

2. Describe the data that has been grouped based on capacity usage.

3. Describe the parameters and decision variables used in the updated IRC model for bandwidth consumption in the network

4. Determine an updated IRC model for *end-to-end* delay consumption in the network based on 2 cases and 2 sub- cases in a *usage based* pricing scheme .

5. Seek a solution to the updated IR C model in Step 5 using the LINGO 13.0 application software.

6. Analysis of the results obtained.

3. RESULTS AND DISCUSSION

3.1 Original Model

The IRC model used in this study is based on the model proposed by Puspita et al. (2020) Its objective functions are as follows:

Max

$$R = \sum_{j=1}^{2}\sum_{i=1}^{2}((PR_{ij}+PQ_{ij})+(\alpha+\beta I_i)p_{ij}x_{ij}+\sum_{i=1}^{3}\sum_{j=1}^{3}(P_j-B_j)T_{ij}-\sum_{j=1}^{3}MY_j)$$

(1)

Subject to:

$$I_i d_{ij} x_{ij} \le a_i C$$

$$\sum_{i=1}^{2}\sum_{j=1}^{2} I_i d_{ij} x_{ij} \le a_i C$$

$$\sum_{i=1}^{2} a_i \le 1 \le 1, a_i \epsilon\{0, 1\}$$

$$m_i \le I_i \le 1, m_i \ge 0$$

$$0 \le x_{ij} \le n_i, x_{ij} \ge 0$$

$$PQ_{ij} = \left(1 \pm \frac{x}{350}\right) PB_{ij}Lx$$

$$PB_{ij} = a_{ij}(e - e^{-xB})T_I/100$$

$$Lx = a(e - e^{-xB})$$

$$f \le a_{ij} \le g$$

$$h \le T_I \le k$$

$$0 \le x \le 1$$

$$0.8 \le B \le 1.07$$

$$a = 1$$

Then, the model is given the addition of *bundling* problem optimization Wu et al. (2008) and Puspita et al. (2016) where the parameters and variables are given in Table 1 and Table 2, respectively. Its objective functions are as follows:

Maxs

$$R = \sum_{i=1}^{3}\sum_{j=1}^{3}(P_j - B_j)X_{ij} - \sum_{j=1}^{3}MY_j$$

(2)

$$S_i \ge (R_{ij} - P_j)Y_j, i = 1, ..., I; j = 1, ..., J$$

$$S_i = \sum_{j=1}^{J}(R_{ij} - P_j)Y_j, i = 1, ..., I; j = 1, ..., J$$

$$(R_{ij} - P_j)X_{ij} \ge 0, i = 1, ..., I; j = 1, ..., J$$

$$\sum_{j=1}^{J} X_{ij} \le 1, i = 1, ..., I$$

$$X_{ij} \le Y_j, i = 1, ..., I; j = 1, ..., J$$

$$S_i \ge 0, i = 1, ..., I$$

$$P_j \ge 0, j = 1, ..., J$$

$$Y_j = \begin{cases} 1 & \text{for} & \text{ISP provide bundle in j service} \\ 0 & \text{for} & otherwise \end{cases}$$

$$X_{ij} = \begin{cases} 1 & \text{for} & \text{choose bundle in j service} \\ 0 & \text{for} & otherwise \end{cases}$$

$$X_i \le \bar{X}_i Z_i$$

$$Y_i \le \bar{Y}_i Z_i$$

$$U_{i(Xi,Yi)} - P_X X_i - P_Y Y_i - PZ_i \ge 0$$

$$Z_i = 0 or 1$$

Table 1. Parameters for each Case in IRC model

Case 1 : α and β as Parameters	
α	: Basic price set by ISP
β	: for each service there exist the quality premium
C_1	: Total number of capacity that can be achieved in peak hours
C_2	: Total number of capacity that can be achieved in off-peak hours
PR_{ij}	: Connection cost to the available QoS
p_{ij}	: User I' price of service on link j
m_i	: Minimum number QoS available for services i
n_i	: Users I' number of service
d_{ij}	: Capacity requirement available for service i on link j
f_i	: Value ranges that ISP predeterminedt for a_{ij}
h	: The limit of traffic load allowed for T_l
k	: The limit of traffic load allowed for T_l
g_i	: The range of values the service provider has set for a_{ij}
B_j	: Cost in bundling each service j
I	: Potential consumer numbers as a marketing determination
J	: Service number available in ISP
M	: Marginal cost if adding greater than one bundle service to menu
V_{ik}	: The price of the i customer order for each k-th favorite service
R_{ij}	: The total order price for ith consumer on each k-th preferable service
P	: Costs that will be incurred by consumers for following the service
P_X	: Price set unit fixed by ISP in peak hours
P_Y	: Price set unit fixed by ISP in off-peak hours
$U_{i(X_i, Y_i)}$	: Consumer utility function i for peak and off-peak consumption levels
X_i	: The highest consumption consumer level i in using the program in peak hour
Y_i	: The highest consumption consumer level i in using the program in off-peak hours

Table 2. Decision Variables for Each Case in IRC Model

Case 1 : α dan β as Parameter	
PQ_{ij}	: The changes on cost with changes on QoS
x_{ij}	: Users applying service i at link j
PB_{ij}	: Main fee for having a connection for service i and j link
a_{ij}	: Factor of linearity cost in the service i and link j
I_i	: minimum required for basic price of service i
T_l	: Load of traffic
Lx	: Factor of linearity
x	: Increase or decrease parts in QoS value
B	: Set of linear parameter
P_j	: The price assign for j good bundles
S_i	: Consumer surplus for customer i
R	: Function for income
T_{ij}	: The decision variable stating consumer i whether to choose to join the bundle of j goods or not
Y_j	: The decision variable stating consumer i whether to choose to join the bundle of j goods on the menu or not.
Xa_i	: Service level of consumer consumption in peak hours
Yb_i	: Service level of consumer consumption in peak hours
Z_i	: Decision variables to be1 joining the bundle or otherwise

3.2 Updated Improved Model

The updated model is then designed by adding an Objective Function (1) with an Objective Function (2). Since the model is considered to determine the base cost (α) as a parameter and varying the premium quality (β) as a parameter and a variable in proving the contribution of ISPs in the network, the models are divided into 2 cases, namely Case 1 (α and β as parameter) and Case 2 (α as a parameter and β as a variable). Each case is further divided into 2 sub-cases, namely sub-case I PQ_{ij} and x increase *and* sub-case II where x decreases. The pricing scheme used is *usage based*, namely the internet pricing scheme with a system of how much internet access is used so that much must be paid.

The description of the updated IRC *wireless* network pricing scheme with the QoS *attribute* end-to-end delay and the Cobb-Douglas utility function is described in Table 1-3. Table 1 represents the parameters used for each case in the updated IRC model and describes the symbols or indexes required in each case. Table 2 presents the decision variables used for each case, while Table 3 has applied the parameter values in the model.

In Case 2, when α as constants and β as a variable based on the case 1 with the exception of m_i, n_i, β, price for service i and b_i, a maximum base price required for service i. After determining the parameters and decision variables in each case, the next step is to determine the value of the parameters used in the model based on the internet usage-based pricing scheme as shown in Table 3 as follows:

where

a: Peak hour service constant

b: Non peak hour service constant

When all the parameters, variable, and the value of the parameter is set, then the model is designed in Eq. (3) - (33). The internet pricing scheme in case 1 and case 2 show that the basic service price (α) is chosen as the parameter and the premium quality (β) is also the parameter. Assuming all consumers have the same level of satisfaction and the same maximum level of users, and assuming that costs during QoS changes are considered to be increasing.

Case 1 : α and β as constants The objective functions are as follows:

Max

$$R = \sum_{j=1}^{2} \sum_{i=1}^{2} (PR_{ij} - PQ_{ij}) + (\alpha + \beta I_i) p_{ij} x_{ij} + \sum_{i=1}^{3} \sum_{j=1}^{3} (P_j - B_j) T_{ij} - \sum_{j=1}^{3} M Y_j \tag{3}$$

Based on Eq. (1.1a) then

$$
\begin{aligned}
I_1(236.1545667)x_{11} &\leq a_1(350000) \\
I_2(236.1545667)x_{11} &\leq a_1(350000) \\
I_1(236.1545667)x_{11} &\leq a_1(370000) \\
I_2(236.1545667)x_{11} &\leq a_1(370000)
\end{aligned} \tag{4}
$$

Table 3. Parameter Value for Each Case on the updated IRC model

Parameter	Value
PR_{11}	0.5
PR_{21}	0.6
PR_{12}	0.7
PR_{22}	0.8
$p_{11}, p_{21}, p_{12}, p_{22}$	15
l	0.1
β	0.5
C_1	350,000
C_2	370,000
m_1	0.01
C_2	0.01
$d_{11}, d_{21}, d_{12}, d22$	207530.187
n_1	10
n_2	10
V_{11}	500
V_{12}	800
V_{21}	600
V_{22}	900
M	200
B_1	300
B_2	500
a	4
b	3
Xa	82641.1987
Yb	48685.8447

Based on Eq. (1.1b) we have

$$
\begin{aligned}
(I_1 d_{11} x_{11}) + (I_2 d_{21} x_{21}) &\leq (a_1 + a_2) C_1 \\
(I_1 d_{11} x_{11}) + (I_2 d_{21} x_{21}) &\leq (a_1 + a_2) C_2
\end{aligned} \tag{5}
$$

Based on Eq. (1.1c) we have

$$a_1 + a_2 = 1 \tag{6}$$

Based on Eq. (1.1d) we have

$$
\begin{aligned}
0.01 &\leq I_1 \leq 1 \\
0.01 &\leq I_2 \leq 1
\end{aligned} \tag{7}
$$

Based on Eq. (1.1e) we have

$$
\begin{aligned}
0 &\leq x_{11} \leq 30 \\
0 &\leq x_{21} \leq 30 \\
0 &\leq x_{12} \leq 30 \\
0 &\leq x_{22} \leq 30
\end{aligned} \tag{8}
$$

Table 4. Optimal solutions of the Updated IRC Model in α and β as constants Cases

Variable Model Class	PQ_{ik} and x increase MINLP	PQ_{ik} increase x decrease MINLP
Objective	1861.02	1860.85
PQ_{11}	8.467065	8.438705
PQ_{21}	7.92126	7.876
PQ_{12}	7.355456	7.313
PQ_{22}	6.789652	6.75
x_{11}	0	0
x_{21}	0	0
x_{12}	0	0
x_{22}	10	10
PB_{11}	3.56291	3.56291
PB_{21}	3.325383	3.325383
PB_{12}	3.087855	3.087855
PB_{22}	2.850328	2.850328
a_{11}	0.15	0.15
a_{21}	0.14	0.14
a_{12}	0,13	0,13
a_{22}	0.12	0.12
I_1	0.505	0.505
I_2	0.1782873	0.1782873
B	1.07	1.07
T_I	1000	1000
Lx	2.375273	2.375273
x	1	1
Xa	0.8635928	0.8635928
Yb	0.6476947	0.6476947
P_1	1299.9	1299.9
P_2	1.1	1.1
S_1	0.1	0.1
S_2	200.1	200.1
Z	1	1
T_{11}	1	1
T_{21}	0	0
T_{12}	1	1
T_{22}	0	0
Y_1	1	1
Y_2	0	0

Based on Eq. (1.1f) then

$$PQ_{11} = \left(1 \pm \frac{x}{350}\right) PB_{11} Lx$$
$$PQ_{21} = \left(1 \pm \frac{x}{350}\right) PB_{21} Lx$$
$$PQ_{12} = \left(1 \pm \frac{x}{350}\right) PB_{12} Lx \tag{9}$$
$$PQ_{22} = \left(1 \pm \frac{x}{350}\right) PB_{22} Lx$$

Based on Eq. (1.1g) then

$$PB_{11} = a_{11}(e - e^{-xb})\frac{T_I}{100}$$
$$PB_{12} = a_{12}(e - e^{-xb})\frac{T_I}{100}$$
$$PB_{21} = a_{21}(e - e^{-xb})\frac{T_I}{100} \tag{10}$$
$$PB_{22} = a_{22}(e - e^{-xb})\frac{T_I}{100}$$

Based on Eq. (1.1h) then

$$Lx = a(e - e^{-xB}) \tag{11}$$

Based on Eq. (1.1i) then

$$0.05 \leq a_{11} \leq 0.11$$
$$0.06 \leq a_{21} \leq 0.12$$
$$0.07 \leq a_{12} \leq 0.13 \tag{12}$$
$$0.08 \leq a_{22} \leq 0.14$$

Based on Eq. (1.1j) then

$$50 \leq T_I \leq 1000 \tag{13}$$

Based on Eq. (1.1k) then

$$0 \leq x \leq 1 \tag{14}$$

Based on Eq. (1.1l) then

$$0.8 \leq B \leq 1.07 \tag{15}$$

Based on Eq. (1.1m) then

$$a = 1 \tag{16}$$

Based on Eq. (2.2a) then

$$S_1 \geq (R_{11} - P_1)Y_1$$
$$S_1 \geq (R_{12} - P_2)Y_2$$
$$S_2 \geq (R_{21} - P_1)Y_1 \tag{17}$$
$$S_2 \geq (R_{22} - P_2)Y_2$$

Based on Eq. (2.2b) then

$$S_1 = (R_{11} - P_1)T_{11} + (R_{12} - P_2)T_{12}$$
$$S_2 = (R_{21} - P_1)T_{21} + (R_{22} - P_2)T_{22} \tag{18}$$

Based on Eq. (2.2c) then

$$(R_{11} - P_1)T_{11} \geq 0$$
$$(R_{12} - P_2)T_{12} \geq 0$$
$$(R_{21} - P_1)T_{21} \geq 0 \tag{19}$$
$$(R_{22} - P_2)T_{22} \geq 0$$

Based on Eq. (2.2d) then

$$T_{11} + T_{12} \leq 1$$
$$T_{21} + T_{22} \leq 1 \tag{20}$$

Based on Eq. (2.2e) then

$$T_{11} \geq Y_1$$
$$T_{21} \geq Y_1$$
$$T_{12} \geq Y_2 \tag{21}$$
$$T_{22} \geq Y_2$$

Based on Eq. (2.2f) we have

$$S_1 \geq 0.1$$
$$S_2 \geq 0.1 \tag{22}$$

Based on Eq. (2.2g) then

$$P_1 \geq 0$$
$$P_2 \geq 0 \tag{23}$$

Based on Eq. (2.2h) then

$$T_{11}, T_{21}, T_{12}, T_{22} \epsilon \{0, 1\} \tag{24}$$

Based on Eq. (2.2i) then

$$Y_1; Y_2 \epsilon \{0, 1\} \tag{25}$$

Based on Eq. (2.2j) then

$$Xa \leq (82641.19873)Z \tag{26}$$

Based on Eq. (2.2k) then

$$Yb \leq (48685.84473)Z \tag{27}$$

Based on Eq. (2.2l) then

$$Xa^4 Yb^3 - P_x Xa - P_y Yb - PZ \geq 0 \tag{28}$$

Based on Eq. (2.2m) then

$$Z = 1 \tag{29}$$

Constraint (29) is decision to join the program, so that the consumer had to decide which level of consumption was optimal X and Y which could not exceed the limit of the consumer's maximum level of consumption $\bar{X}$ and $\bar{Y}$ for Eq. (26) and (2). To maximize the level of customer satisfaction based on the price set by the information service provider, the level of satisfaction must have a non-negative value such as Eq. (28).

Case 2 : α as Constant and β as Variable

For case 2, the model will be designed with considering α as constant and β as variable as follows.

Max

$$R = \sum_{j=1}^{2}\sum_{i=1}^{2}(PR_{ij}-PQ_{ij})+(\alpha+\beta I_i)p_{ij}x_{ij}+\sum_{i=1}^{3}\sum_{j=1}^{3}(P_j-B_j)T_{ij}-\sum_{j=1}^{3}MY_j \tag{30}$$

Followed by Constraints (2) to Constraints (29) and the following constraints added, i.e.

$$\beta_2 I_2 \geq \beta_1 I_1$$
$$0.01 \leq \beta_1 \leq 0.5 \tag{31}$$
$$0.01 \leq \beta_2 \leq 0.5$$

To make use of n -pricing scheme usage based, then the added constraints are as follows.

$$P_x > 0; P_y; P = 0 \tag{32}$$

Table 4 is a comparison of the values of the decision variables as Table 2 showed, that are obtained from the wireless internet pricing scheme model for each case in achieving the optimal solution. Based on Table 4, It can be seen that the variable values stated in Table 2, in the *usage based* pricing scheme for sub-case 1 and sub-case 2 are not much different. The value of the variable PQ_{ij} which states that the change in costs during the change in QoS in case 1 and case 2 is different, the values x, Tl, a_{ij}, I_i, x, for sub-case 1 and sub-case 2 have the same variable values.

Table 5 is a comparison of the values of the decision variables, again as Table 2 displayed, that are obtained from the wireless internet pricing scheme model for each sub-case in achieving the optimal solution. Based on Table 5 it can be seen that the variable values explained in Table 2, in the usage based pricing scheme for Case 1 and Case 2 are not much different. The value of the variable PQ_{ij} which states that the changes in costs during the change in QoS in sub-case 1 and sub-case 2 are different, the values Lx, T_l, a_{ij}, I_i, x, and others, for sub-case 1 and sub-case 2 have the same variable values.

After deciding the optimal solution for each case, analysis the results obtained to compare them with the optimal results

in the original IRC model (Puspita et al., 2019) using the same parameter values and data is conducted.

Case 1: Case α and β as Parameters Table 6 presents the optimal solution of the two models for Case 1 (α and β as parameters) with a *usage-based* pricing scheme.

The optimal solution obtained in Table 6 for the IRC model (Puspita et al., 2020) is obtained from the PQ_{ij} increasing and x increasing sub - case, which means that there is an increase in cost changes along the changes in QoS and QoS values. Likewise for the model IRC renewed obtained from subcase PQ_{ij} increasing and x increasing the use of pricing schemes *usage based*. In this case, with different constraints still at the same values that generate maximum profit ISP that delivers the quality of service and speed of user access.

Based on Table 6 which presents the comparison of the optimal solution of the updated IRC model with an objective value of 1861.02 is greater than the optimal solution of *Improved* IRC with an objective value of 61.25. In this case proved that the model IRC renewed the better to achieve maximum profit ISP that delivers the quality of service and speed of user access with a difference of optimal solutions for 1799.5 kpbs. However, to achieve a better optimal solution, the number of iterations and memory used is quite large.

Case 2 : α as Parameter and β as Variable Table 7 presents the optimal solution of the two models for Case 1 (α as a parameter and β as a variable) with a *usage-based* pricing scheme .

The optimal solution obtained in Table 7 for the IRC model (Puspita et al., 2019) is obtained from the PQ_{ij} increasing and x increasing sub - case, which means that there is an increase in cost changes along the changes in QoS and QoS values. Likewise for the model IRC renewed obtained from subcase PQ_{ij} increasing and x increasing the use of pricing schemes usage based. In this case, with different constraints still at the same values that generate maximum profit ISP that delivers the quality of service and speed of user access.

Based on Table 7, which presents a comparison of the optimal solution of the updated IRC model with an objective value of 1848.23 is greater than the optimal solution of IRC (Puspita et al., 2020) with an objective value of 48.9034. In this case it is evident that the updated IRC model is better at achieving the maximum ISP benefits that deliver service quality and user access speed with an optimal solution difference of 1799.5966/kpbs. However, to achieve a better optimal solution, the number of iterations and memory used is quite large.

4. CONCLUSIONS

By adding a *bundling* strategy to the IRC *wireless* network pricing scheme , information service providers get more revenue than using the IRC model alone (Puspita et al., 2020) . However, obtaining the maximum income has to be paid with the number of iterations which have an effect on the greatly increased internet resources. In case 2, the objective value obtained is smaller than the objective value in case 1. The number of iterations in case 1 is greater.

For further investigation, it needs to also seek for possibility to add more links to have more real network. It deals with also with the software application abilities to run in many variables and parameters involved.

5. ACKNOWLEDGEMENT

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Table 5. Optimal Solution of the Updated IRC Model in α as Constant and β as Variable Cases

Variable Model Class	PQ_{ik} and x increase MINLP	PQ_{ik} increase x decrease MINLP
Objective	187.724	18.696
PQ_{11}	8.467065	8.438705
PQ_{21}	7.92126	7.876125
PQ_{12}	7.355456	7.313545
PQ_{22}	6.789652	6.750964
x_{11}	0.5	0.5
x_{21}	0.5	0.5
x_{12}	0	0
x_{22}	0	0
PB_{11}	0	0
PB_{21}	10	10
PB_{12}	3.56291	3.56291
PB_{22}	3.325383	3.325383
a_{11}	3.087855	3.087855
a_{21}	2.850328	2.850328
a_{12}	0.15	0.15
a_{22}	0.14	0.14
I_1	0.13	0.13
I_1	0.12	0.12
B	1.07	1.07
T_1	1000	1000
Lx	2.375273	2.375273
x	1	1
Xa	0.8635929	0.8635929
Yb	0.6476946	0.6476946
P_1	1299.9	1299.9
P_2	0.1	0.1
S_1	0.1	0.1
S_2	200.1	200.1
Z	1	1
T_{11}	1	1
T_{21}	0	0
T_{12}	1	1
T_{22}	0	0
Y_1	1	1
Y_2	0	0

Table 6. Comparison of Optimal Solutions between the IRC Model and the Updated IRC Model in the Case of α and β as Parameters

Solver Status	Value Case α dan β as Parameter	
	Model IRC (Puspita, et al., 2019)	*Model IRC* *updated*
Model Class	*MINLP*	*MINLP*
State	*Local Optimal*	*Local Optimal*
Objective	61.525	1861.02
Infeasibility	0	9.0955×10^{-14}
Iterations	84	570
Extended Solver Status		
Solver Type	*Branch and Bound*	*Branch and Bound*
Best Objective	61.525	1861.02
Steps	3	11
Update Interval	2	2
GMU (K)	35	48
ER (Sec)	1	0

Table 7. Comparison of Optimal Solutions between the IRC Model and the Updated IRC Model in α as a parameter and β as a variable Case

Solver Status	Value Case A dan B as Parameter	
	Model IRC (Puspita, et al., 2019)	*Model IRC* *updated*
Model Class	*MINLP*	*MINLP*
State	*Local Optimal*	*Local Optimal*
Objective	48.9034	1848.23
Infeasibility	0	9.0955×10^{-14}
Iterations	44	228
Extended Solver Status		
Solver Type	*Branch and Bound*	*Branch and Bound*
Best Objective	48.9034	1848.23
Steps	2	2
Update Interval	2	2
GMU (K)	37	49
ER (Sec)	0	0