Auto Assembly Report

On Family Adventurers and Classic Transporters Production

Anne Lin
anqilin@ucsb.edu

Wei Wei
wei_wei@ucsb.edu

Haoran Li
hli@ucsb.edu

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Table of Contents

1 Description of the Problem

Our company assembles two models of midsized luxury cars. The first model, the Family Adventurer, is a four-door sedan with vinyl seats, plastic interior, standard features, and excellent gas mileage. It is marketed as a smart buy for middle-class families with tight budgets, and each Family Adventurer sold generates a modest profit of $3,700 for our company. The second model, the Classic Transporter, is a two-door luxury sedan with leather seats, a wooden interior, custom features, and navigational capabilities. It is marketed as a privilege of affluence for upper-middle-class families, and each Classic Transporter sold generates a profit of $5,300 for the company.

In this report, we will decide how many Family Adventurers and how many Classic Transporters to assemble in the plant to maximize our profit for next month. However, we are facing some constraints when deciding the maximized profit:

1. It takes 6 labor-hours to assemble one Family Adventurer and 10.5 labor-hours to assemble one Classic Transporter, and the plant only possesses a capacity of 48,500 labor-hours during the month.

2. Although Family Adventurers and Classic Transporters use the same door parts, the parts required to assemble the two models are not produced at the plant, so parts are instead shipped from other plants. For the next month, we will be able to obtain only 20,000 doors (10,000 left-hand doors and 10,000 right-hand doors) from the door supplier because a recent labor strike forced the shutdown of that particular supplier plant for several days.

3. A recent company forecast suggests that the demand for the Classic Transporter is limited to 3,500 cars, while there is no limit on the demand for the Family Adventurer within the capacity limits of the assembly plant.

After dealing with all the constraints, we will come up with an optimized number of Family Adventurers and Classic Transporters to assemble next month to maximize our profit, and we can get a maximized profit amount.

2 Selecting Model

2.1 Model Formulation

Since we must decide how many Family Adventures and how many Class Transporters to produce next month to calculate the profit, we will first introduce two variables, x_1 and x_2, denoting the number of Family Adventures and Class Transporters needed to be produced next month respectively.

We know that each Family Adventurer sold generates a profit of \$3,700 and each Classic Transporter sold generates a profit of \$5,300, so we can express our total profit next month as $3700x_1 + 5300x_2$, and we want to maximize this quantity.

To satisfy the constraints we mentioned in the description, we first need to make the total labor-hours less than 48,500, which means $6x_1 + 10.5x_2 \leq 48500$. Then, according to the availability of doors, since Family Adventurer is a four-door sedan and Classic Transporter is a two-door sedan, for simplicity concern, we only consider the limitation on right-hand doors, which gives $2x_1 + x_2 \leq 10000$. Finally, since the Classic Transporter demand is limited to 3,500 cars, there is no need for us to assemble more, making $x_2 \leq 3500$. Also, the number of car models assembled is not negative and can't be a fraction.

Combining all the results above, we formulate the mathematical model as:

$$\begin{aligned} \max \quad & 3700x_1 + 5300x_2, \\ \text{subject to} \quad & 6x_1 + 10.5x_2 \leq 48500 \\ & 2x_1 + x_2 \leq 10000 \\ & x_2 \leq 3500 \\ & x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}. \end{aligned} \tag{1}$$

2.2 Checking Linear Programming Criteria

Since we formulated a linear programming model, we need to justify that our model is appropriate. There are four assumptions to check if a model is appropriate for linear programming, Proportionality, Additivity, Certainty and Divisibility. If the four assumptions are all satisfied, then a linear programming model is good. If Divisibility is violated, then we will use integer programming.

Firstly, we know that any extra model of Family Adventure or Class Transporter added will exactly add \$3,700 or \$ 5,300 in our profit, 6 or 10.5 labor-hours, and 2 or 1 more right-hand doors. This means that our model satisfies the Proportionality criteria.

Secondly, the total profit is calculated by the sum of Family Adventurer's profit and Class Transporter's profit, and the total number of labor-hours and doors required is the sum of labor-hours and doors required for Family Adventure and Class Transporter separately. In this case, our model satisfies Additivity criteria.

Thirdly, since the profit, labor-hours, and the total number of doors required for Family Adventures and Class Transporters is certain and fixed, the Certainty criteria is met.

Finally, as we stated before, the number of car models assembled can't be a fraction, so the Divisibility criteria is violated. To solve this problem, we need to use integer programming. Since we indeed used integer programming by adding the integer constraints ($x_1, x_2 \in \mathbb{Z}$), **we can conclude that our model is appropriate.**

3 Solution of the Model

Objective Cell (Max)

Cell	Name	Original Value	Final Value
\$F\$10	Optimal Solution	0	27009300

Variable Cells

Cell	Name	Original Value	Final Value	Integer
\$B\$9	Solution Family Adventurer	0	3766	Integer
\$C\$9	Solution Classic Transporter	0	2467	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
\$D\$5	Labor-hour Required	48499.5	\$D\$5<=\$F\$5	Not Binding	0.5
\$D\$6	Door Required	9999	\$D\$6<=\$F\$6	Not Binding	1
\$D\$7	Demand Required	2467	\$D\$7<=\$F\$7	Not Binding	1033
\$B\$9:\$C\$9=Integer					

Figure 1: Excel Solution Output for this model

Using the Simplex Solver in Excel, we get the result in Figure 1. Note that not all of the information contained in this program output is essential for decision making, and we will only focus on the most important ones.

In the first "Objective Cell" section, the "Final Value" column shows the calculated maximized profit next month, which is \$27,009,300 here. In the second "Variable Cells" section, the "Final Value" column shows the number of Family Adventurers and Classic Transporters needed to be assembled next month to maximize profit. Here we can see 3,766 Family Adventurers and 2,467 Classic Transporters are required to be assembled next month.

Therefore, our final result is that, by satisfying all the constraints mentioned, if we assemble 3,766 Family Adventure models and 2,467 Class Transporter models next month, we will reach our maximized profit, which is \$27,009,300.

4 Interpretation of the Solution

Note that the "Cell Value" column in the third "Constraints" section shows the total number of labor-hours, pair of doors and Class Transporters demand consumed by assembling the corresponding numbers of Family Adventures and Class Transporters for the maximized profit.

From our result, the number of Class Transporters needed to be assembled next month is 2,467, far less than the maximum demand of 3,500. This shows that the limitation on the Classic Transporter market doesn't play a deciding role during our maximization process.

However, when assembling 3,766 Family Adventures and 2,467 Class Transporters, the labor-hour required next month is 4,8499.5 hours in total, which is less than the capacity of 48,500 labor-hours during the month by only 0.5 hours. The number of right-hand doors required next month is 9,999, which is less than the 10,000 available right-hand doors next month by 1 door. These two cases show that the constraints on labor-hours and availability of right-hand doors influence our maximum profit during our maximization process.

Therefore, if we can increase labor-hours or availability of right-hand doors, we may increase our maximum profit. Still, if other conditions hold the same, there is no need to increase the market demand for Class Transporters.

5 Recommendations

In this section we consider the above linear programming model modified in different ways, and for each situation we solve for optimal solutions and record the essential information from the solution reports in Figure 11 in Appendix B. We will base our recommendations on the relevant sub-tables of Figure 11 for each of the objectively fixed situations below, by recommending the strategy that gives the highest profit out of all possible strategies.

We consider 2 possible objective constraints that the company does not have control over:

- Reduced profit for Family Adventurers
- Quality problem of Family Adventurers

and 2 possible strategies can be used by the company:

- Advertising Campaign
- Overtime Labor

In the end of this section we also consider the board of directors's wishes and compare whether meeting full demand for Classic Transporters should be done for the original model above.

To read the sub-tables presented below, we note that the first two columns specifies all the strategy combinations. The 4th and 5th columns gives the optimal solution point of the LP problem corresponding to each of the specified setting, and the 6th column gives the maximized (raw) profit given such solution. The 7th column gives the maximized net profit in each setting, which is the raw profit with possible subtraction of 500000 if Advertising Campaign is used, and a subtraction of 1600000 if Overtime Labor is used.

If the reader wish to see the complete program outputs for the solutions in Figure 11, see Appendix C.

5.1 Using both $500,000 Advertising Campaign and Overtime Labor

Overtime Labor-hours	Advertising Campaign		Family Adventurer	Classic Transporter	Total Profit	Net Profit
No	No		3766	2467	27009300	27009300
No	Yes		3766	2467	27009300	26509300
Yes	No		3250	3500	30575000	28975000
Yes	Yes		2957	4084	32586100	30486100

Figure 2: The Contingency Table containing optimal solutions in all possible sittings when No Reduced profit and Quality Problem for Family Adventurers

The marketing department knows that it can pursue a targeted $500,000 advertising campaign that will raise the demand for the Classic Transporter next month by 20 percent.

If we only pursue this $500,000 Advertising Campaign, according to our previous interpretation, the increase in demand for Class Transporters won't increase our maximized profit, and we need to pay an extra $500,000. Our model result returns the same conclusion in the second row of Figure 2 that the "Net Profit" $26,509,300, which is $500,000 less than our original model. Therefore, we can't merely pursue a $500,000 Advertising Campaign.

Besides, we know that we can increase next month's plant capacity by using overtime labor, and we can increase the plant's labor-hour capacity by 25 percent. Then the labor-hour capacity increased by 12,125 hours to 60,625 hours. Since previously we interpreted that if we can increase labor-hours, we may increase our maximum profit, we updated the model and got the result as the third row of Figure 2. We can see that, by satisfying all the constraints, if we assemble 3,250 Family Adventure models and 3,500 Class Transporter models next month, we will reach the new maximized profit, which is $30,575,000, and it exceeds our previous maximized profit by $3,565,700.

There is a way of gaining more profit, which combines the use of $500,000 advertising campaign and the use of overtime labor. When only using overtime labor, the number of Class Transporters needed reaches the limitation on demand. If we raise the demand by pursuing the \$50,000 campaign, our maximum profit may increase. Updating the model by increasing the demand limitation and labor-hour constraint accordingly, the optimized result is in the fourth row of Figure 2. By satisfying all the new constraints, if we assemble 2,957 Family Adventure models and 4,084 Class Transporter models next month, we will reach the new maximized profit of \$32,586,100.

Knowing that the advertising campaign costs \$500,000, our total profit becomes $\$32,586,100 - \$500,000 = \$32,086,100$ not considering overtime labor cost. However, overtime labor does not come without an extra cost. In Figure 45, the number of total labor-hours required is 60,624, which exceeds the original labor-hour capacity by 12,124 labor-hours. Since our original model has the maximum profit of \$27,009,300, if the total cost of using overtime labor-hours for extra 12,124 labor-hours exceeds $\$32,086,100 - \$27,009,300 = \$5,076,800$, then there is no need to combine the \$500,000 advertising campaign with using overtime labor.

Therefore, if the total cost of using overtime labor-hours for an extra 12,124 labor-hours is less than \$5,076,800, we would suggest both pursuing the \$500,000 advertising campaign and using overtime labor to increase maximized profit. **Since we figured out the maximum usage of overtime labor-hours cost \$1,600,000, which is less than \$5,076,800, we can suggest both pursuing the \$500,000 advertising campaign and using overtime labor to increase maximized profit, and our maximized profit is** $\$32,586,100 - \$500,000 - \$1,600,000 = \$30,486,100$**, which is gained by assembling 2,957 Family Adventures and 4,084 Class Transporters next month.**

5.2 Reduced Profit on Family Adventurers

Overtime Labor-hours	Advertising Campaign		Family Adventurer	Classic Transporter	Total Profit	Net Profit
No	No		1960	3499	24032700	24032700
No	Yes		735	4199	24312700	23812700
Yes	No		3250	3500	27650000	26050000
Yes	Yes		2754	4200	29971200	27871200

Figure 3: The Contingency Table containing optimal solutions in all possible sittings when Reduced profit for Family Adventurers, but no Quality Problem

Suppose that dealerships are heavily discounting the Family Adventurers' price to move them off the lot. Because of a profit-sharing agreement with its dealers, the company is therefore not making a profit of \$3,700 on the Family Adventurer but is instead making a profit of \$2,800.

Without the targeted \$500,000 advertising campaign, the optimized profit for not using overtime labors against using overtime labors is seen in the first and third row of Figure 3. Notice that our "Net Profit" increased by a significant amount by using the advertising campaign strategy, so there is need a to increase labor hours.

Now including the use of the targeted $500,000 advertising campaign, we see from the fourth row of Figure 3 that we obtain the highest possible profit. We will need to assemble 2,754 Family Adventurers and 4,200 Classic Transporters in this case. The total labor-hour exceeds the original by 12,124 labor-hours. Taking the cost of the campaign into account, to make this situation profitable, the maximum cost of overtime labor-hours should be $\$29,971,200 - \$500,000 - \$27,650,000 = \$1,821,200$.

In conclusion, under the situation that the profit on Family Adventurers reduces to $2,800, if the maximum usage of overtime labor-hours for extra 12,124 labor-hours costs less than $1,821,200, we can reach our maximized profit by using both the targeted $500,000 advertising campaign and overtime labors. **Our maximum usage of overtime labor-hours cost $1,600,000, which is less than $1,821,200, so if the profit on Family Adventurers reduces to $2,800, we should use both the targeted $500,000 advertising campaign and overtime labors to maximize our profit, and our maximized profit is** $\$29,971,200 - \$500,000 - \$1,600,000 = \$27,871,200$**, which is gained by assembling 2,754 Family Adventures and 4,200 Class Transporters next month.**

5.3 Quality Problem on Family Adventurers

Overtime Labor-hours	Advertising Campaign		Family Adventurer	Classic Transporter	Total Profit	Net Profit
No	No		1568	3499	24346300	24346300
No	Yes		588	4199	24430300	23930300
Yes	No		3186	3498	30327600	28727600
Yes	Yes		2206	4198	30411600	28311600

Figure 4: The Contingency Table containing optimal solutions in all possible sittings when Quality Problem for Family Adventurers, but no Reduced profit

After the inspectors have discovered that in over 60 percent of the cases, two of the four doors on an Adventurer do not seal properly, the floor supervisor has decided to perform quality control tests on every Adventurer at the end of the line. With the test applied to every Family Adventurer Given the new assembly time for the Family Adventurer is 7.5 hours, we need to reconsider the amount of Family Adventurer and Classic Transporters to be assembled.

Firstly, assume there is no advertising campaign. With the hour of labor increased in Family Adventurer and every other constraint stay the same, the optimal solution is given as the first and third row in Figure 4. The first row is under the circumstance that no overtime labor is used, and third row is the circumstance that we are using overtime labor Note that "Net profit" is calculated by subtracting the $500,000 cost for holding the campaign and $1,600,000 overtime labor cost accordingly. After the subtraction of overtime labor cost, we can still see that there is an increase in our maximized profit, $28,727,600 now.

Now observe that if we in addition including the $500,000 advertising campaign, our profit is not optimized, as the fourth row in Figure 4 has a lower "Net profit" than that of the third row. Comparing the final values, we can see that using overtime labor but without the advertising campaign has the highest profit of $ 28,728,100. **Therefore, under the situation that the assembly time for the Family Adventurer is increased to 7.5 hours, in order to achieve the highest profit, we should only use overtime labor without trying the $500,000 advertising campaign. By assembling Family 3,186 Adventurers and 3,498 Classic Transporters, we gain the maximized profit of $ 28,727,600.**

5.4 Both Quality Problem and Reduced profit on Family Adventurers

Since the quality problem and the reduction of Family Adventurers are not mutually exclusive, we are going to consider the situation that both cases happen at the same time. Here we directly compare the "Net Profit" in each of the 4 possible cases and recognize that the maximum is reached in the fourth row of 5. **Therefore, given the new assembly time for the Family Adventurer is 7.5 hours when quality problem happens, and the new profit for each Family Adventurer is $2,800 instead of $3,700, our optimal net profit is $26,328,400 by assembling 2,203 Family Adventurers and 4,200 Classic Transporters.**

Overtime Labor-hours	Advertising Campaign		Family Adventurer	Classic Transporter	Total Profit	Net Profit
No	No		1568	3499	22935100	22935100
No	Yes		588	4199	23901100	23401100
Yes	No		3183	3500	27462400	25862400
Yes	Yes		2203	4200	28428400	26328400

Figure 5: The Contingency Table containing optimal solutions in all possible sittings when Both Reduced profit and Quality Problem for Family Adventurers

5.5 Meeting Full Demand on Classic Transporters

Full demand	Overtime Labor-hours	Advertising Campaign		Family Adventurer	Classic Transporter	Total Profit
No	No	No		3766	2467	27009300
Yes	No	No		1958	3500	25794600

Figure 6: Full Demand Problem Solution

Now we return to the most basic setting described in Section 2 when there are no Reduced profit and Quality Problem for Family Adventurers. We also do not use Advertising Campaign nor Overtime Labor.

Since the board of directors of our company wants to capture a larger share of the luxury sedan market, they would like to meet the full demand for Classic Transporters. We will recalculate the profit when meeting the full demand for Classic Transporters and compare it with the original solution to see if our calculated maximized profit can meet the criteria that decrease in profit is not more than $2,000,000.

In Section 3 (Solution of the Model), the final optimal profit is $27,009,300 by assembling 3,766 Family Adventurers and 2,467 Classic Transporters. This is also shown as the first row in Figure 6.

However, in this case, the number of Classic Transporter being assembled is fixed, which is the maximum demand of 3,500. Updating our model, we get the result as the second row in Figure 6. In this case, we will take 1,958 for the number of Family Adventurers to assemble.

We can see the profit with meeting the maximum demand of Classic Transporter is $25,794,600. Comparing the profit with the original optimal profit, the profit decrease in $\$27,009,330 - \$25,794,600 = \$1,214,730$, which is less than $2,000,000. **Therefore, we should meet the full demand for Classic Transporters since the decrease in profit of no more than $2,000,000**

Readers interested in whether it is worthwhile to meet the full demand for Classic Transporters in the alternative settings are encouraged to apply the same analysis done in the previous 4 subsections to the last 16 rows of Figure 11.

6 Final Conclusion

Initially, we build the linear program model for next month's assembling of the two types of cars. The maximized profit, number of Family Adventures and Class Transporters to assemble next month is:

Maximized Profit	Family Adventures	Class Transporters
$27,009,300	3,766	2,467

If the total cost of using overtime labor-hours for an extra 12,124 labor-hours is less than $5,076,800 (we decided to pay $1,600,000 for total overtime labor-hours here), by both pursuing the $500,000 advertising campaign and using overtime labor, the maximized profit and number of Family Adventures and Class Transporters to assemble next month is:

Maximized Profit	Family Adventures	Class Transporters
$30,486,100	2,957	4,084

If the situation that the profit on Family Adventurers reduces to $2,800 happened, by both pursuing the $500,000 advertising campaign and using overtime labor, the maximized profit and number of Family Adventures and Class Transporters to assemble next month is:

Maximized Profit	Family Adventures	Class Transporters
$27,871,200	2,754	4,200

If the situation that the assembly time for the Family Adventurer increases to 7.5 hours happened, by only using overtime labor without pursuing the $500,000 advertising campaign, the maximized profit and number of Family Adventures and Class Transporters to assemble next month is:

Maximized Profit	Family Adventures	Class Transporters
$28,727,600	3,186	3,498

If the situation that both the profit on Family Adventurers reduces to $2,800, and the assembly time for the Family Adventurer increases to 7.5 hours happened, by both pursuing the $500,000 advertising campaign and using overtime labor, the maximized profit and number of Family Adventures and Class Transporters to assemble next month is:

Maximized Profit	Family Adventures	Class Transporters
$26,328,400	2,203	4,200

In the original problem setting, if the board of directors of our company wants to meet the full demand for Classic Transporters with the decrease in profit of no more than $2,000,000, we are able to meet the full demand, and the maximized profit and number of Family Adventures and Class Transporters to assemble next month is:

Maximized Profit	Family Adventures	Class Transporters
$25,794,600	1,958	3,500

A Contingent Recommendations

This section provides a more direct way of obtaining the optimal strategy, by only selecting the highest "Net profit" among 4 choices.

A.1 No Reduced profit and Quality Problem for Family Adventurers

Overtime Labor-hours	Advertising Campaign		Family Adventurer	Classic Transporter	Total Profit	Net Profit
No	No		3766	2467	27009300	27009300
No	Yes		3766	2467	27009300	26509300
Yes	No		3250	3500	30575000	28975000
Yes	Yes		2957	4084	32586100	30486100

Figure 7: The Contingency Table containing optimal solutions in all possible sittings when No Reduced profit and Quality Problem for Family Adventurers

In this setting we can obtain the optimal strategy by comparing the "Net Profit"s of each possible strategies, which is defined as the total sales profit given by the optimal solution, subtract possibly 500000 if Advertising Campaign is used, and possibly 1600000 if Overtime Labor is used. We see from Figure 7 that the highest "Net Profit" is given by the strategy where we use both Advertising Campaign and Overtime Labor which gives 30486100 "Net Profit".

So the optimal strategy here is to use both Advertising Campaign and Overtime Labor, and

- Produce 2957 units of Family Adventurer next month
- Produce 4084 units of Classic Transporters next month

and obtain a "Net Profit" with amount 30486100.

A.2 Reduced profit for Family Adventurers, but no Quality Problem

Overtime Labor-hours	Advertising Campaign		Family Adventurer	Classic Transporter	Total Profit	Net Profit
No	No		1960	3499	24032700	24032700
No	Yes		735	4199	24312700	23812700
Yes	No		3250	3500	27650000	26050000
Yes	Yes		2754	4200	29971200	27871200

Figure 8: The Contingency Table containing optimal solutions in all possible sittings when Reduced profit for Family Adventurers, but no Quality Problem

In this setting we can obtain the optimal strategy by comparing the “Net Profit”s of each possible strategies, which is defined as the total sales profit given by the optimal solution, subtract possibly 500000 if Advertising Campaign is used, and possibly 1600000 if Overtime Labor is used. We see from Figure 8 that the highest “Net Profit” is given by the strategy where we use both Advertising Campaign and Overtime Labor which gives 27871200 “Net Profit”. Note this strategy does fulfill the full demand for Classic Transporters.

So the optimal strategy here is to use both Advertising Campaign and Overtime Labor, and

- Produce 2754 units of Family Adventurer next month
- Produce 4200 units of Classic Transporters next month

and obtain a “Net Profit” with amount 27871200.

A.3 Quality Problem for Family Adventurers, but no Reduced profit

Overtime Labor-hours	Advertising Campaign		Family Adventurer	Classic Transporter	Total Profit	Net Profit
No	No		1568	3499	24346300	24346300
No	Yes		588	4199	24430300	23930300
Yes	No		3186	3498	30327600	28727600
Yes	Yes		2206	4198	30411600	28311600

Figure 9: The Contingency Table containing optimal solutions in all possible sittings when Quality Problem for Family Adventurers, but no Reduced profit

In this setting we can obtain the optimal strategy by comparing the "Net Profit"s of each possible strategies, which is defined as the total sales profit given by the optimal solution, subtract possibly 500000 if Advertising Campaign is used, and possibly 1600000 if Overtime Labor is used. We see from Figure 9 that the highest "Net Profit" is given by the strategy where we only use Overtime Labor, and not Advertising Campaign, which gives 28727600 "Net Profit".

So the optimal strategy here is to use use Overtime Labor and not Advertising Campaign, and

- Produce 3186 units of Family Adventurer next month
- Produce 3498 units of Classic Transporters next month

and obtain a "Net Profit" with amount 28727600.

A.4 Both Reduced profit and Quality Problem for Family Adventurers

Overtime Labor-hours	Advertising Campaign		Family Adventurer	Classic Transporter	Total Profit	Net Profit
No	No		1568	3499	22935100	22935100
No	Yes		588	4199	23901100	23401100
Yes	No		3183	3500	27462400	25862400
Yes	Yes		2203	4200	28428400	26328400

Figure 10: The Contingency Table containing optimal solutions in all possible sittings when Both Reduced profit and Quality Problem for Family Adventurers

In this setting we can obtain the optimal strategy by comparing the “Net Profit”s of each possible strategies, which is defined as the total sales profit given by the optimal solution, subtract possibly 500000 if Advertising Campaign is used, and possibly 1600000 if Overtime Labor is used. We see from Figure 10 that the highest “Net Profit” is given by the strategy where we use both Advertising Campaign and Overtime Labor which gives 26328400 “Net Profit”. Note this strategy does fulfill the full demand for Classic Transporters.

So the optimal strategy here is to use both Advertising Campaign and Overtime Labor, and

- Produce 2203 units of Family Adventurer next month
- Produce 4200 units of Classic Transporters next month

and obtain a “Net Profit” with amount 26328400.

B Full Contingency Table

Full demand	Quality problem	Reduced profit	Overtime Labor-hours	Advertising Campaign		Family Adventurer	Classic Transporter	Total Profit	Net Profit	Add 2M	Preferable
No	No	No	No	No		3766	2467	27009300	27009300		
No	No	No	No	Yes		3766	2467	27009300	26509300		
No	No	No	Yes	No		3250	3500	30575000	28975000		
No	No	No	Yes	Yes		2957	4084	32586100	30486100		
No	No	Yes	No	No		1960	3499	24032700	24032700		
No	No	Yes	No	Yes		735	4199	24312700	23812700		
No	No	Yes	Yes	No		3250	3500	27650000	26050000		
No	No	Yes	Yes	Yes		2754	4200	29971200	27871200		
No	Yes	No	No	No		1568	3499	24346300	24346300		
No	Yes	No	No	Yes		588	4199	24430300	23930300		
No	Yes	No	Yes	No		3186	3498	30327600	28727600		
No	Yes	No	Yes	Yes		2206	4198	30411600	28311600		
No	Yes	Yes	No	No		1568	3499	22935100	22935100		
No	Yes	Yes	No	Yes		588	4199	23901100	23401100		
No	Yes	Yes	Yes	No		3183	3500	27462400	25862400		
No	Yes	Yes	Yes	Yes		2203	4200	28428400	26328400		
Yes	No	No	No	No		1958	3500	25794600	25794600	27794600	Yes
Yes	No	No	No	Yes		733	4200	24972100	24472100	26472100	No
Yes	No	No	Yes	No		3250	3500	30575000	28975000		Same
Yes	No	No	Yes	Yes		2754	4200	32449800	30349800	32349800	Yes
Yes	No	Yes	No	No		1958	3500	24032400	24032400	26032400	Yes
Yes	No	Yes	No	Yes		733	4200	24312400	23812400	25812400	Yes
Yes	No	Yes	Yes	No		3250	3500	27650000	26050000		Same
Yes	No	Yes	Yes	Yes		2754	4200	29971200	27871200		Same
Yes	Yes	No	No	No		1566	3500	24344200	24344200	26344200	Yes
Yes	Yes	No	No	Yes		586	4200	24428200	23928200	25928200	Yes
Yes	Yes	No	Yes	No		3183	3500	30327100	28727100	30727100	Yes
Yes	Yes	No	Yes	Yes		2203	4200	30411100	28311100	30311100	Yes
Yes	Yes	Yes	No	No		1566	3500	22934800	22934800	24934800	Yes
Yes	Yes	Yes	No	Yes		586	4200	23900800	23400800	25400800	Yes
Yes	Yes	Yes	Yes	No		3183	3500	27462400	25862400		Same
Yes	Yes	Yes	Yes	Yes		2203	4200	28428400	26328400		Same

Figure 11: The Complete Contingency Table containing all optimal solutions in all possible sittings

The above table summarizes of the solution of LP problems contingent on all possible situations of whether each of

- Advertising Campaign
- Overtime Labor
- Reduced profit for Family Adventurers
- Quality problem of Family Adventurers
- Full demand for Classic Transporters

happening. The first 5 columns specifies each situation.

The 6th and 7th columns gives the optimal solution point of the LP problem corresponding to each of the specified setting, and the 8th column gives the maximized (raw) profit given such solution. The 9th column gives the maximized net profit in each setting, which is the raw profit with possible subtraction of 500000 if Advertising Campaign is used, and a subtraction of 1600000 if Overtime Labor is used.

The last 16 columns corresponds to the setting where Full demand for Classic Transporters is required, and we compare the solutions in each of the settings here with that with out this additional constraint, by observing whether the reduction in net profit in this case exceeds 2000000, so we add 2000000 to each of the net profit here(if the solution is different) and compare with the net profit in the same setting but without this constraint. If the Add 2M column is larger than the net profit without the full demand restriction for a setting, we recognize that meeting full demand for Classic Transporters will be a more preferable choice, and we write Yes in the last column.

C Models and solution reports in alternative settings

C.1 Original Setting

C.1.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned}
\tag{2}
$$

C.1.2 Solution Report

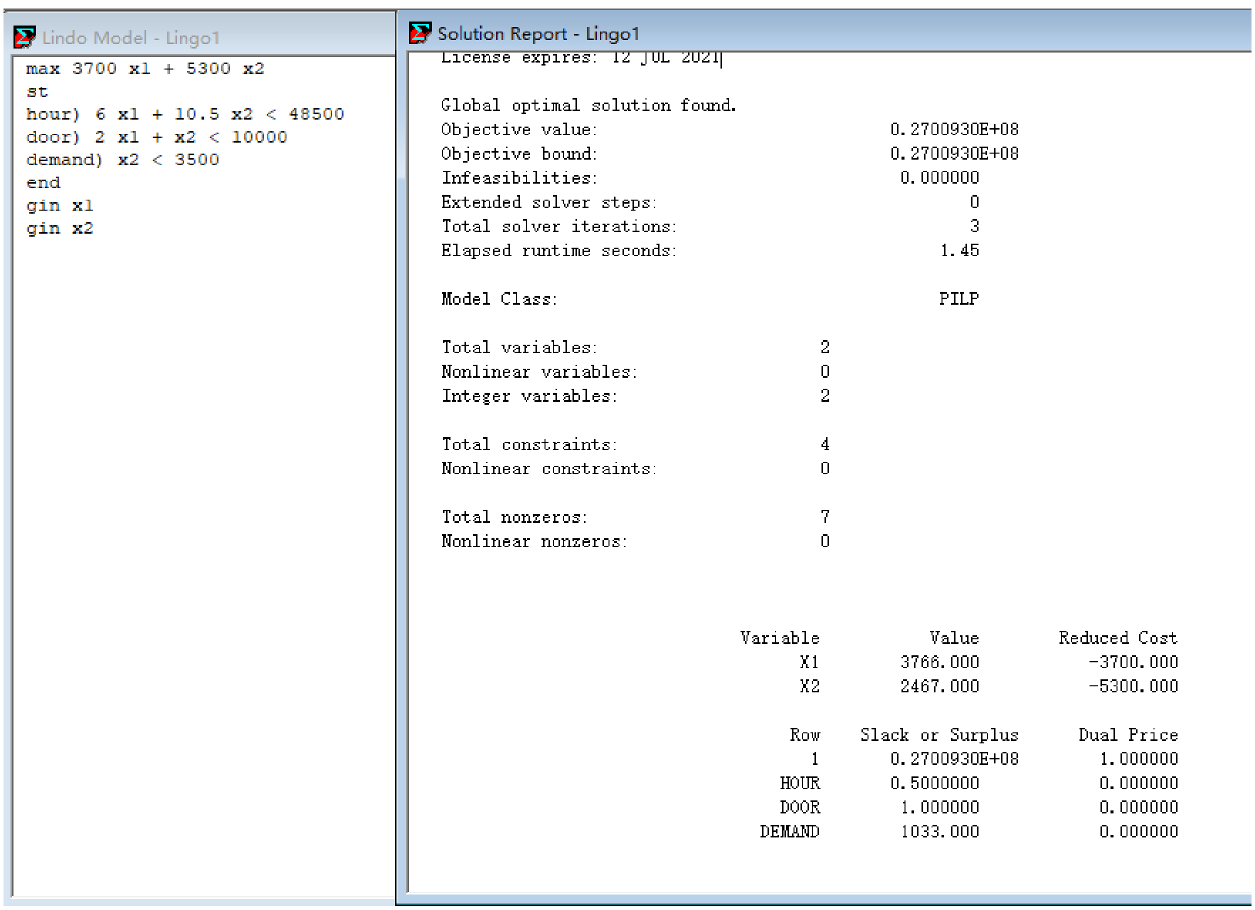


Figure 12: LINGO Solution Report

C.2 Campaign

C.2.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 4200 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned}
\tag{3}
$$

C.2.2 Solution Report

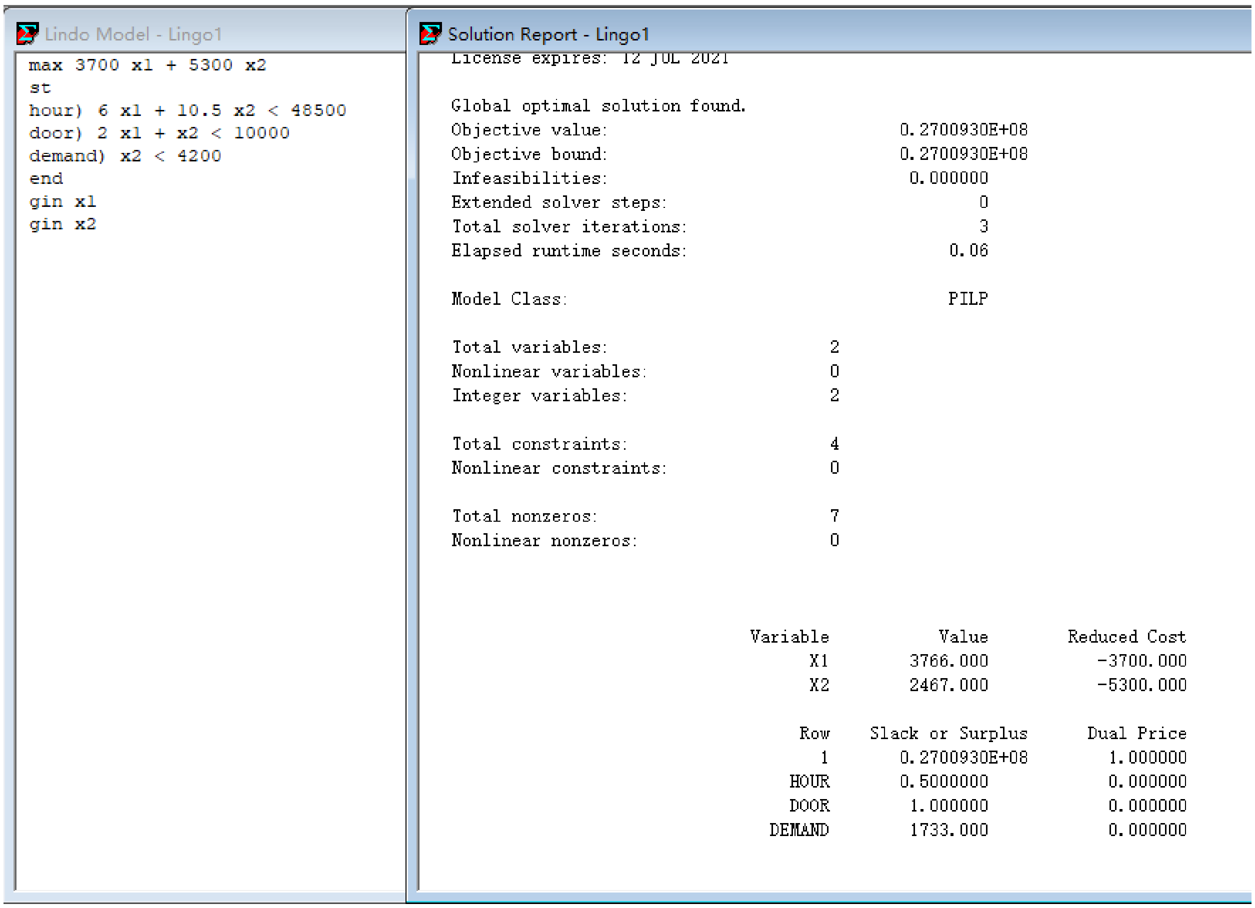


Figure 13: LINGO Solution Report

C.3 Overtime

C.3.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{4}
$$

C.3.2 Solution Report

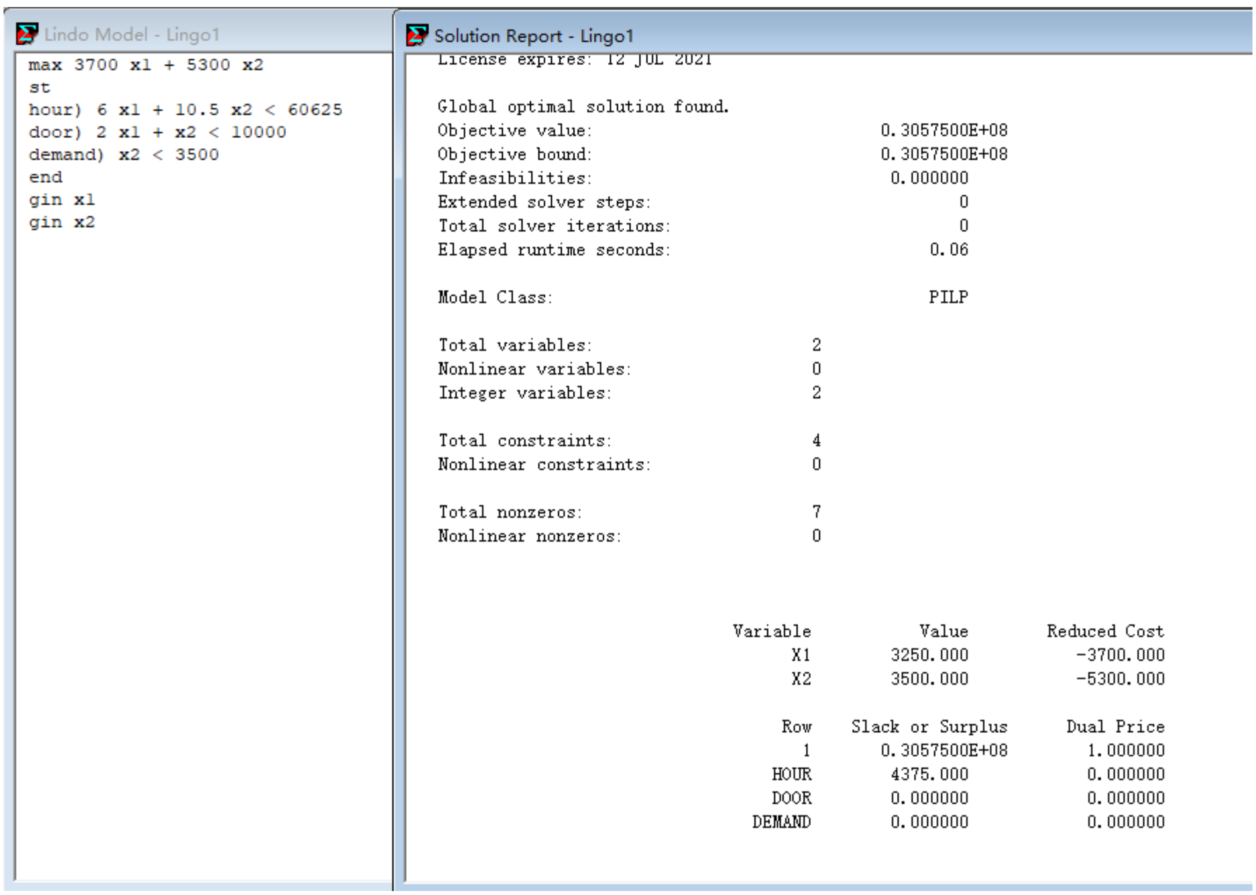


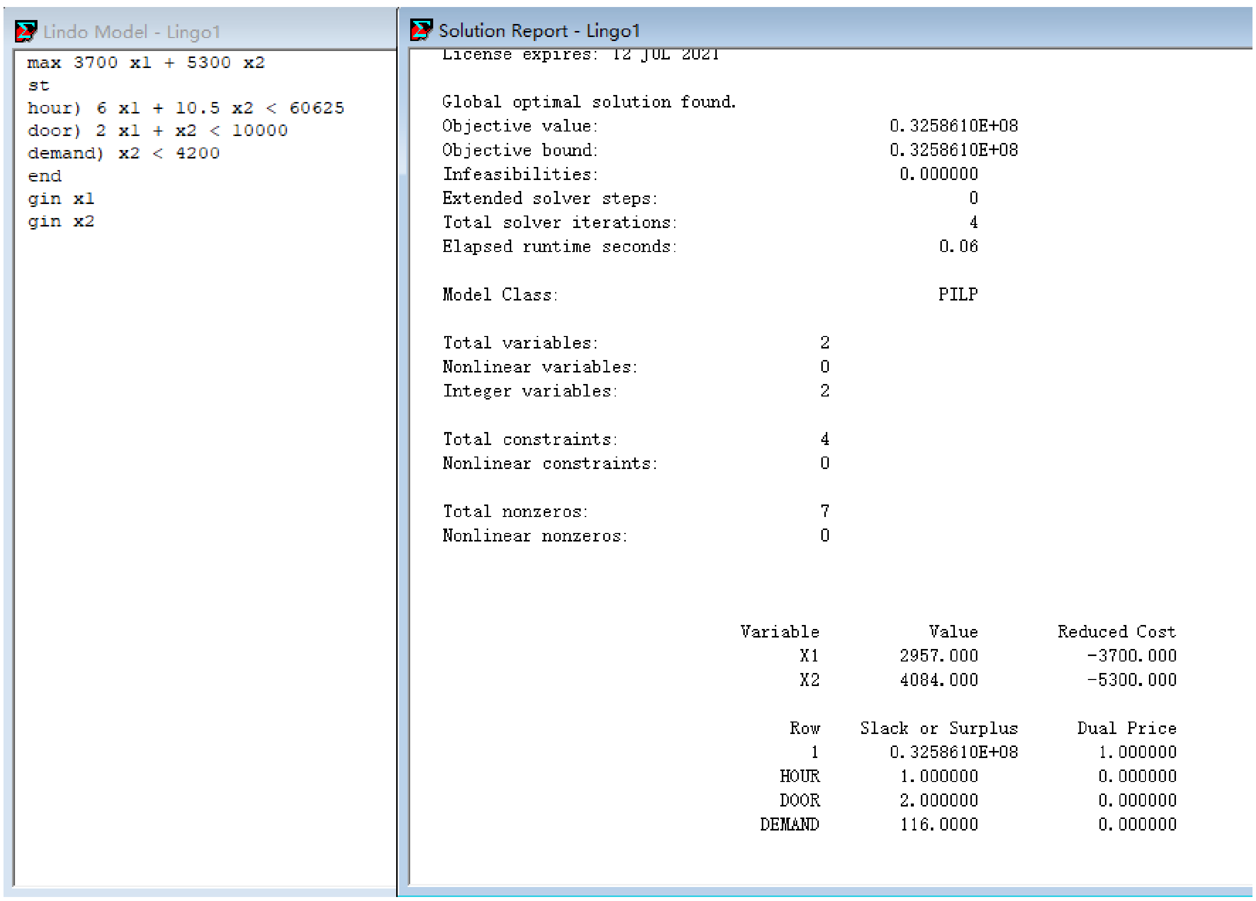
Figure 14: LINGO Solution Report

C.4 Overtime, Campaign

C.4.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 4200 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{5}
$$

C.4.2 Solution Report


Lindo Model - Lingo1

```
max 3700 x1 + 5300 x2
st
hour) 6 x1 + 10.5 x2 < 60625
door) 2 x1 + x2 < 10000
demand) x2 < 4200
end
gin x1
gin x2
```

Solution Report - Lingo1

```
License expires: 12 JUL 2021

Global optimal solution found.
Objective value:                      0.3258610E+08
Objective bound:                      0.3258610E+08
Infeasibilities:                       0.000000
Extended solver steps:                        0
Total solver iterations:                      4
Elapsed runtime seconds:                   0.06

Model Class:                               PILP

Total variables:                 2
Nonlinear variables:             0
Integer variables:               2

Total constraints:               4
Nonlinear constraints:           0

Total nonzeros:                  7
Nonlinear nonzeros:              0


                      Variable           Value        Reduced Cost
                            X1        2957.000           -3700.000
                            X2        4084.000           -5300.000

                           Row    Slack or Surplus      Dual Price
                             1       0.3258610E+08        1.000000
                          HOUR        1.000000            0.000000
                          DOOR        2.000000            0.000000
                        DEMAND        116.0000            0.000000
```

Figure 15: LINGO Solution Report

C.5 Reduced profit

C.5.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{6}
$$

C.5.2 Solution Report

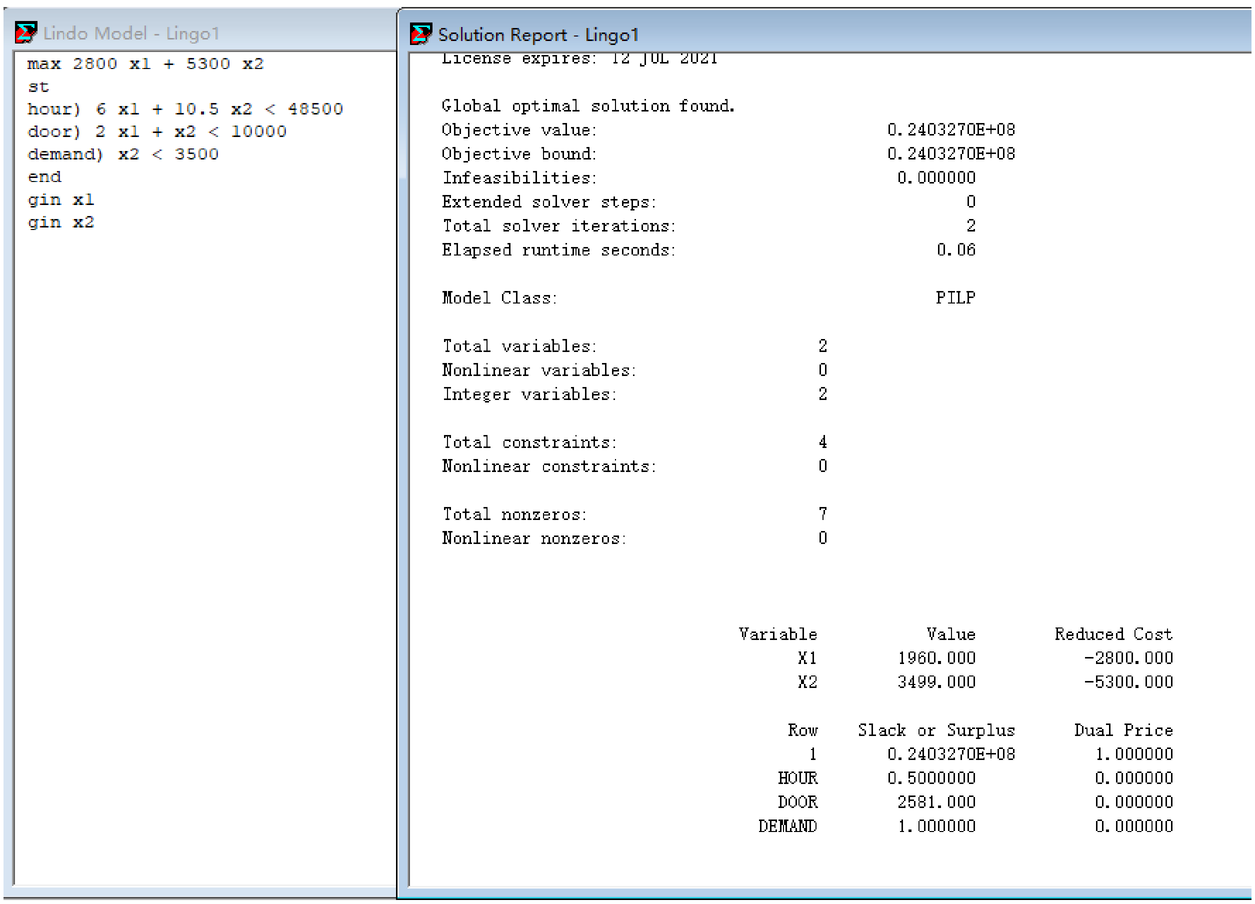


Figure 16: LINGO Solution Report

C.6 Reduced profit, Campaign

C.6.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \le 48500 \\
& 2x_1 + x_2 \le 10000 \\
& x_2 \le 4200 \\
& x_1, x_2 \ge 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{7}
$$

C.6.2 Solution Report

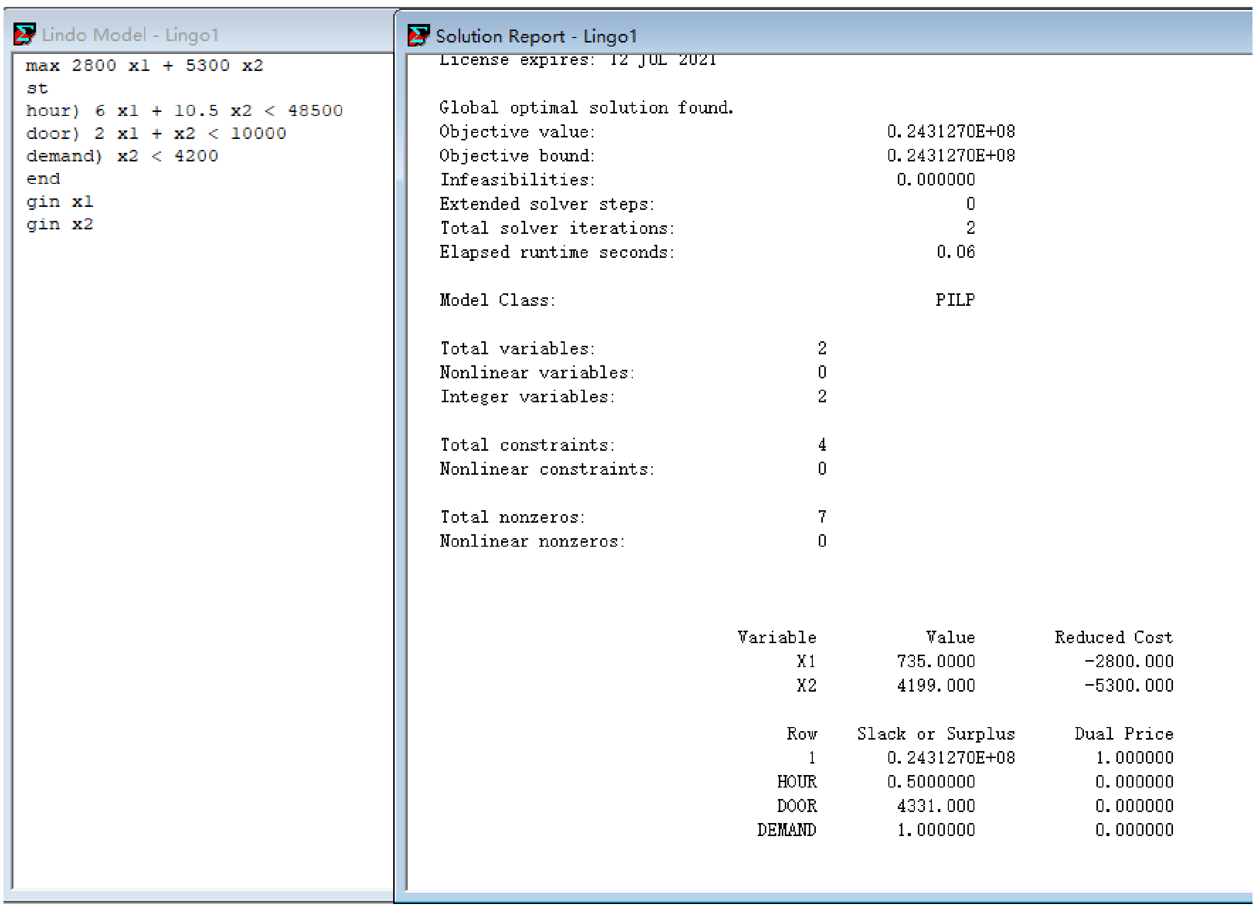


Figure 17: LINGO Solution Report

C.7 Reduced profit, Overtime

C.7.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{8}
$$

C.7.2 Solution Report

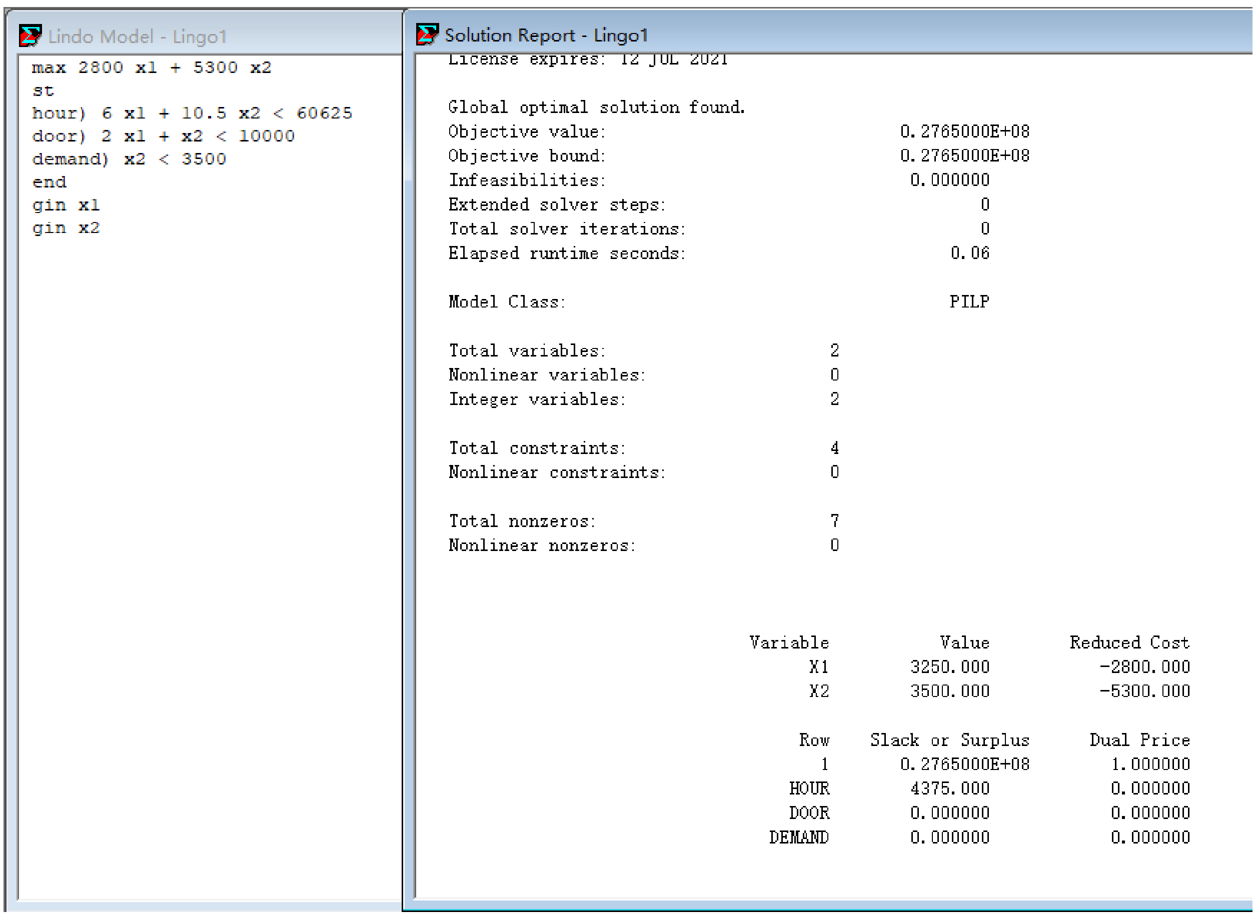


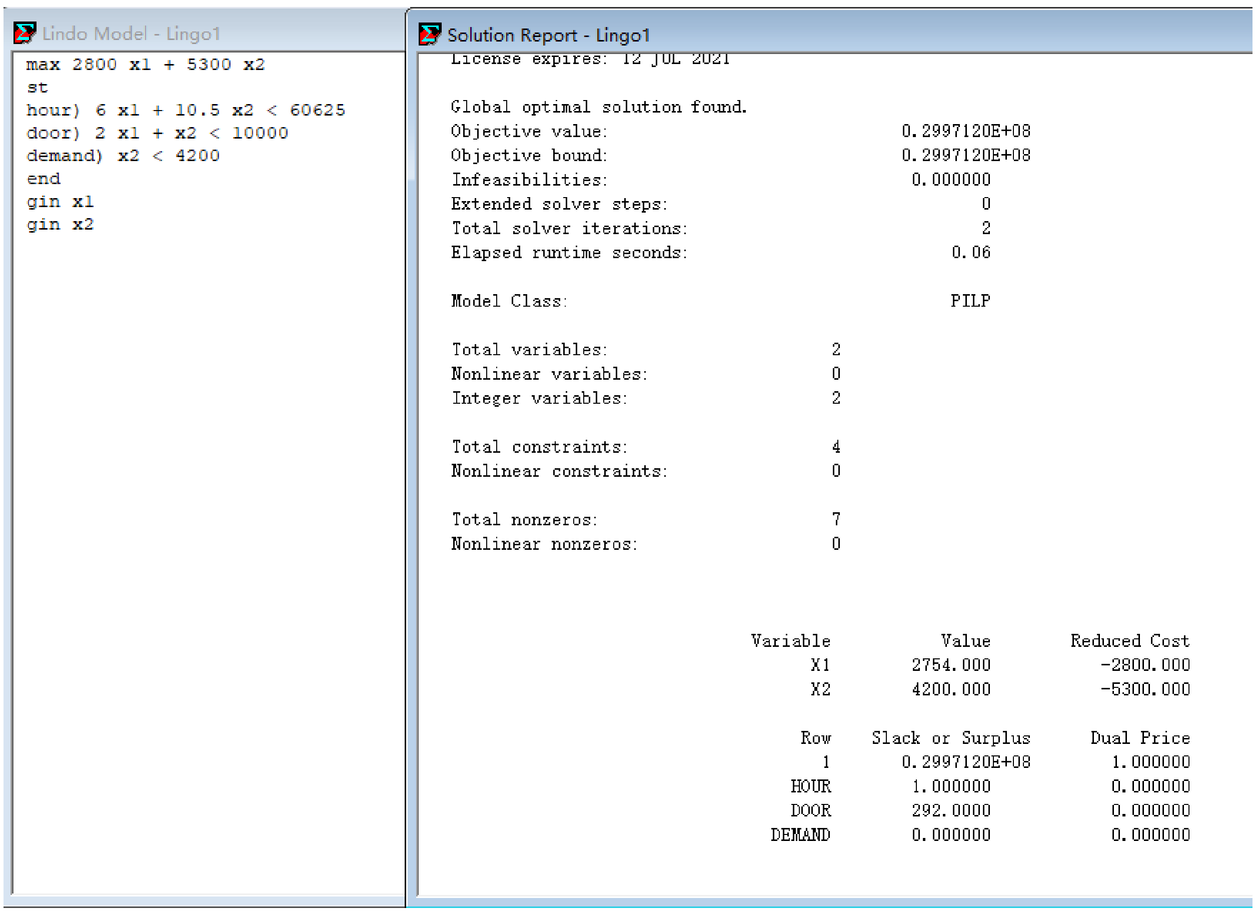
Figure 18: LINGO Solution Report

C.8 Reduced profit, Overtime, Campaign

C.8.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 4200 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned}
\tag{9}
$$

C.8.2 Solution Report



Lindo Model - Lingo1

```
max 2800 x1 + 5300 x2
st
hour) 6 x1 + 10.5 x2 < 60625
door) 2 x1 + x2 < 10000
demand) x2 < 4200
end
gin x1
gin x2
```

Solution Report - Lingo1

```
License expires: 12 JUL 2021

Global optimal solution found.
Objective value:                              0.2997120E+08
Objective bound:                              0.2997120E+08
Infeasibilities:                               0.000000
Extended solver steps:                                0
Total solver iterations:                              2
Elapsed runtime seconds:                           0.06

Model Class:                                       PILP

Total variables:                    2
Nonlinear variables:                0
Integer variables:                  2

Total constraints:                  4
Nonlinear constraints:              0

Total nonzeros:                     7
Nonlinear nonzeros:                 0


                              Variable           Value        Reduced Cost
                                    X1        2754.000           -2800.000
                                    X2        4200.000           -5300.000

                                   Row    Slack or Surplus      Dual Price
                                     1        0.2997120E+08        1.000000
                                  HOUR        1.000000            0.000000
                                  DOOR        292.0000            0.000000
                                DEMAND        0.000000            0.000000
```

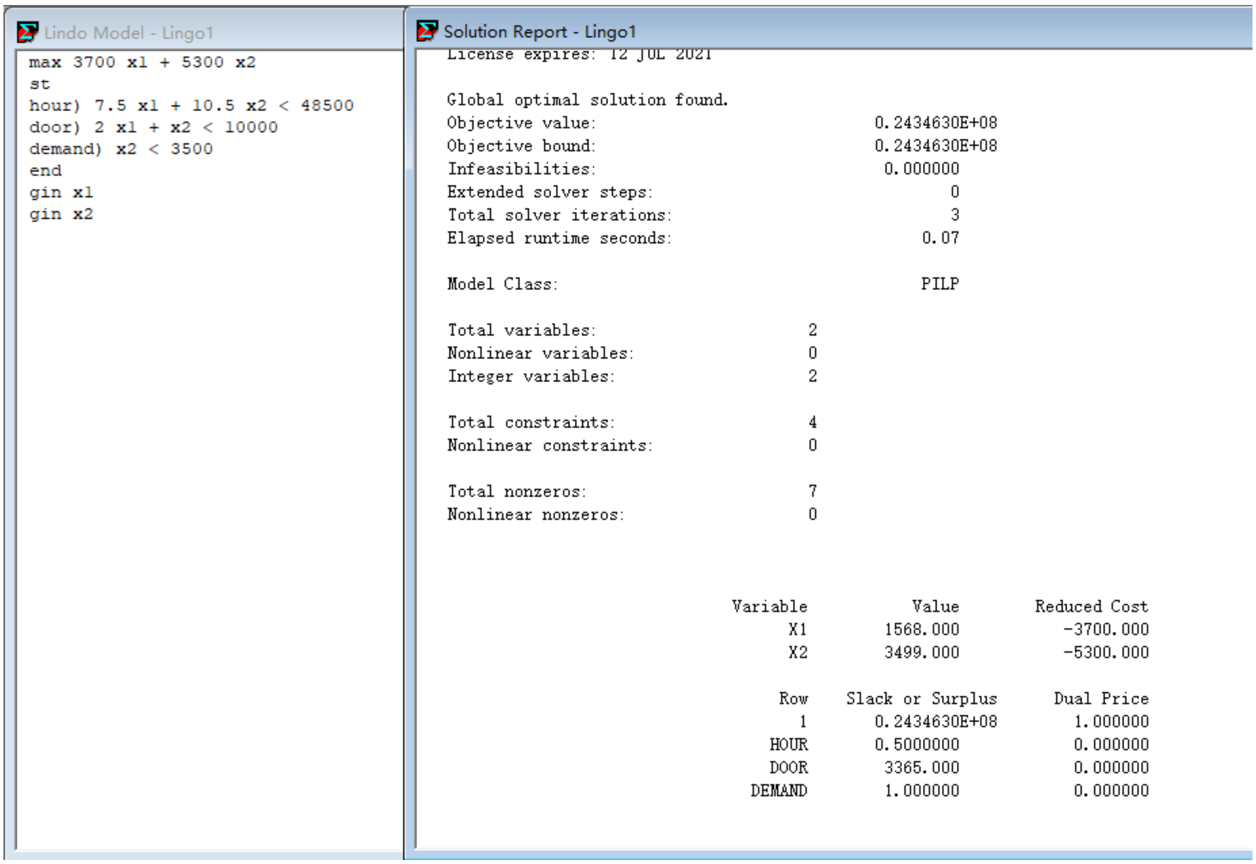
Figure 19: LINGO Solution Report

C.9 Quality problem

C.9.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{10}
$$

C.9.2 Solution Report



Lindo Model - Lingo1

```
max 3700 x1 + 5300 x2
st
hour) 7.5 x1 + 10.5 x2 < 48500
door) 2 x1 + x2 < 10000
demand) x2 < 3500
end
gin x1
gin x2
```

Solution Report - Lingo1

```
License expires: 12 JUL 2021

Global optimal solution found.
Objective value:                              0.2434630E+08
Objective bound:                              0.2434630E+08
Infeasibilities:                                   0.000000
Extended solver steps:                                    0
Total solver iterations:                                  3
Elapsed runtime seconds:                               0.07

Model Class:                                           PILP

Total variables:                      2
Nonlinear variables:                  0
Integer variables:                    2

Total constraints:                    4
Nonlinear constraints:                0

Total nonzeros:                       7
Nonlinear nonzeros:                   0


                                Variable           Value        Reduced Cost
                                      X1        1568.000           -3700.000
                                      X2        3499.000           -5300.000

                                     Row    Slack or Surplus      Dual Price
                                       1       0.2434630E+08        1.000000
                                    HOUR           0.5000000        0.000000
                                    DOOR            3365.000        0.000000
                                  DEMAND            1.000000        0.000000
```

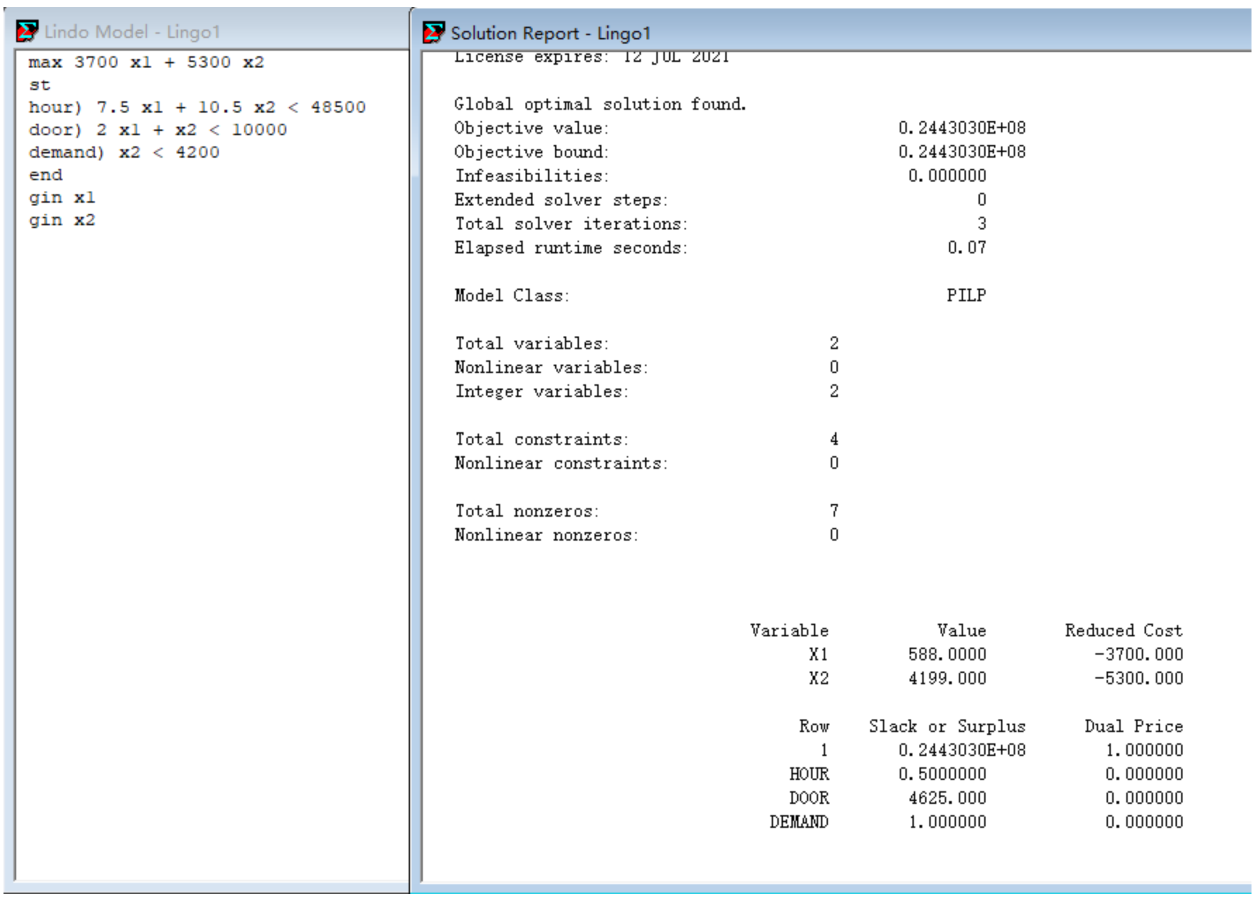
Figure 20: LINGO Solution Report

C.10 Quality problem, Campaign

C.10.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 4200 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{11}
$$

C.10.2 Solution Report



Lindo Model - Lingo1

```
max 3700 x1 + 5300 x2
st
hour) 7.5 x1 + 10.5 x2 < 48500
door) 2 x1 + x2 < 10000
demand) x2 < 4200
end
gin x1
gin x2
```

Solution Report - Lingo1

```
License expires: 12 JUL 2021

Global optimal solution found.
Objective value:                          0.2443030E+08
Objective bound:                          0.2443030E+08
Infeasibilities:                               0.000000
Extended solver steps:                                0
Total solver iterations:                              3
Elapsed runtime seconds:                           0.07

Model Class:                                       PILP

Total variables:                  2
Nonlinear variables:              0
Integer variables:                2

Total constraints:                4
Nonlinear constraints:            0

Total nonzeros:                   7
Nonlinear nonzeros:               0


                        Variable           Value        Reduced Cost
                              X1        588.0000           -3700.000
                              X2        4199.000           -5300.000

                             Row    Slack or Surplus      Dual Price
                               1       0.2443030E+08        1.000000
                            HOUR        0.5000000           0.000000
                            DOOR        4625.000            0.000000
                          DEMAND        1.000000            0.000000
```

Figure 21: LINGO Solution Report

C.11 Quality problem, Overtime

C.11.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{12}
$$

C.11.2 Solution Report

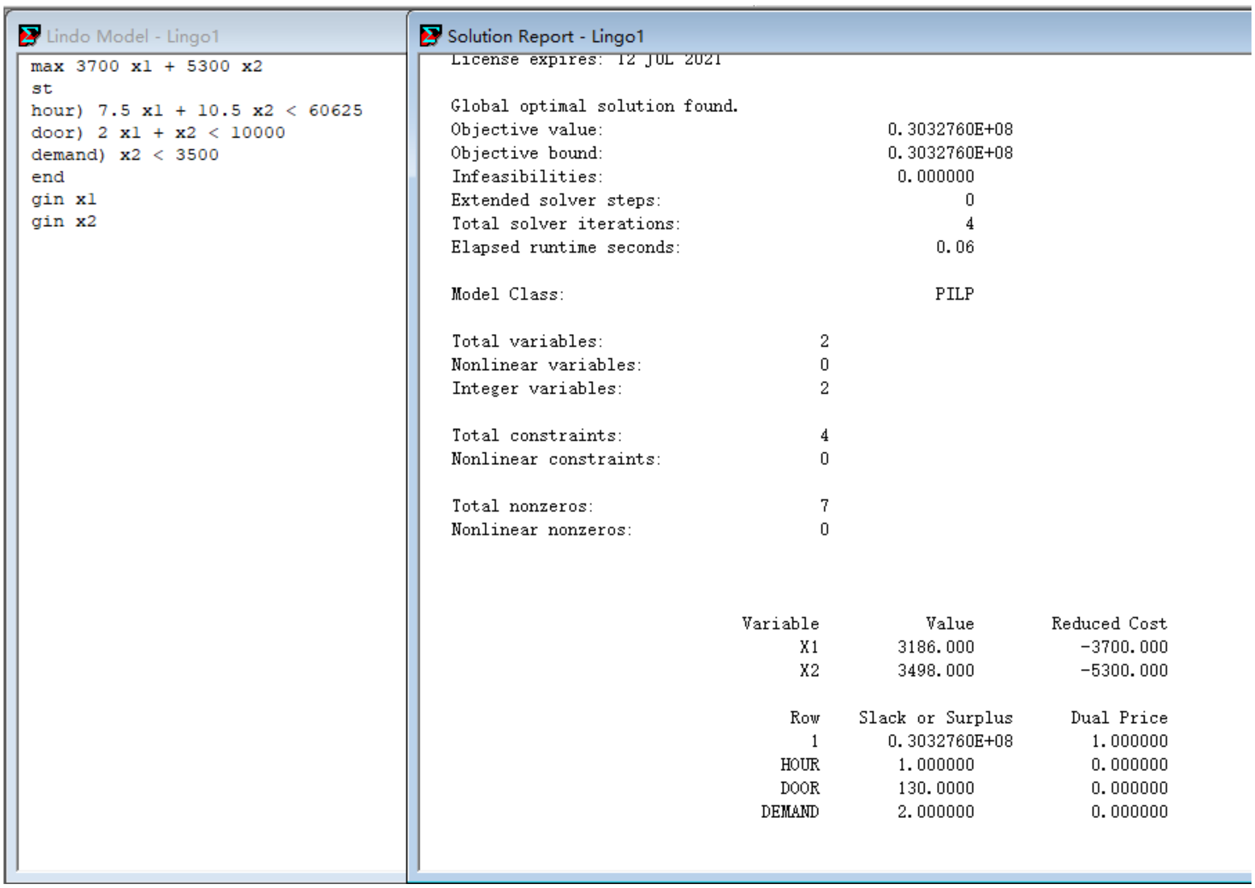


Figure 22: LINGO Solution Report

C.12 Quality problem, Overtime, Campaign

C.12.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 4200 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{13}
$$

C.12.2 Solution Report

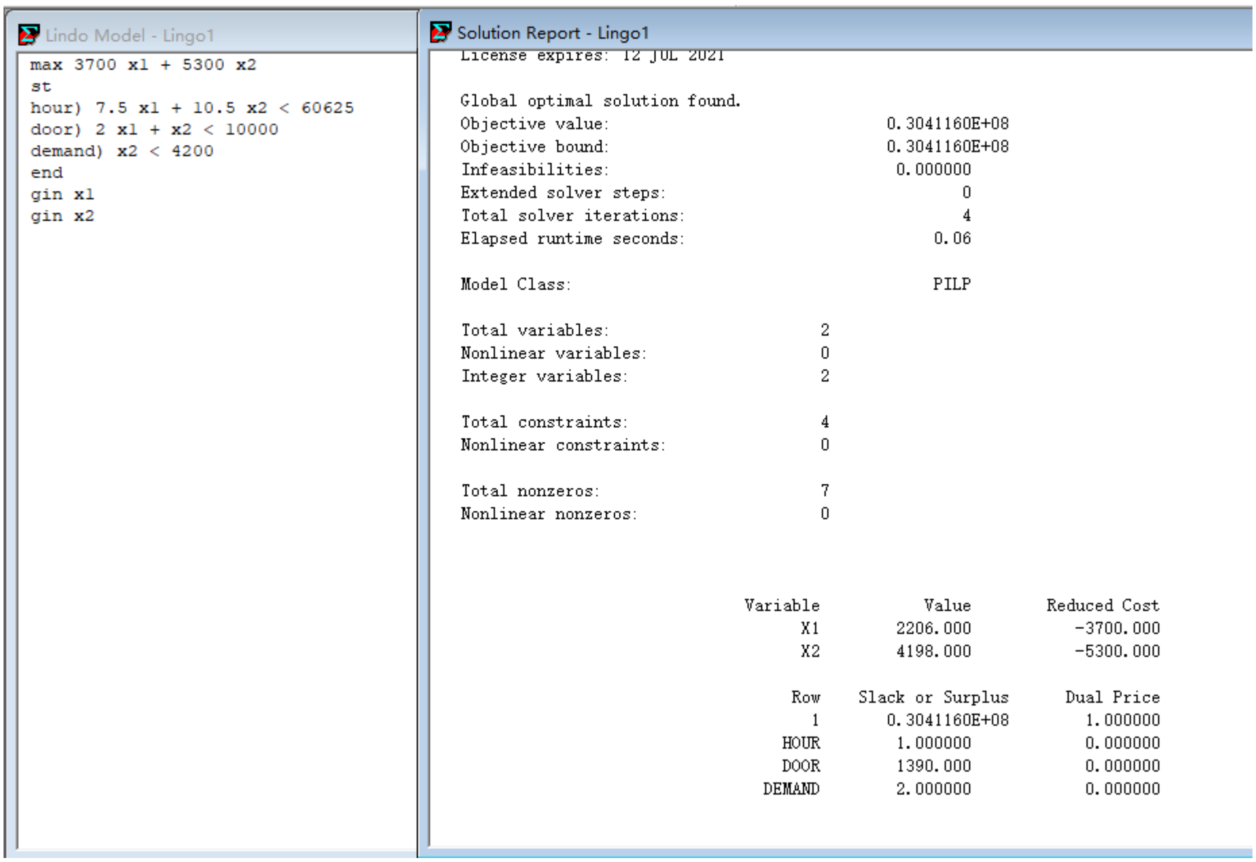


Figure 23: LINGO Solution Report

C.13 Quality problem, Reduced profit

C.13.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned}
\tag{14}
$$

C.13.2 Solution Report

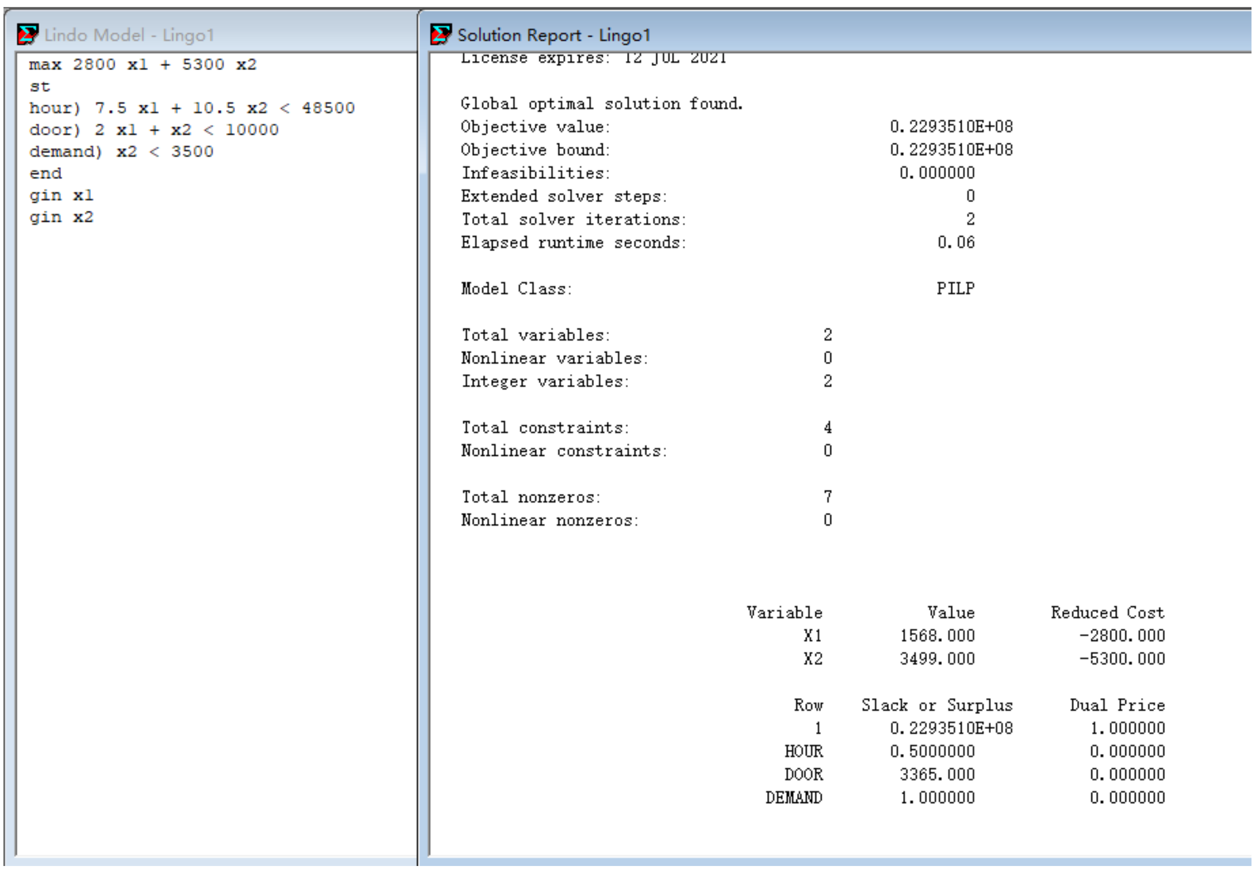


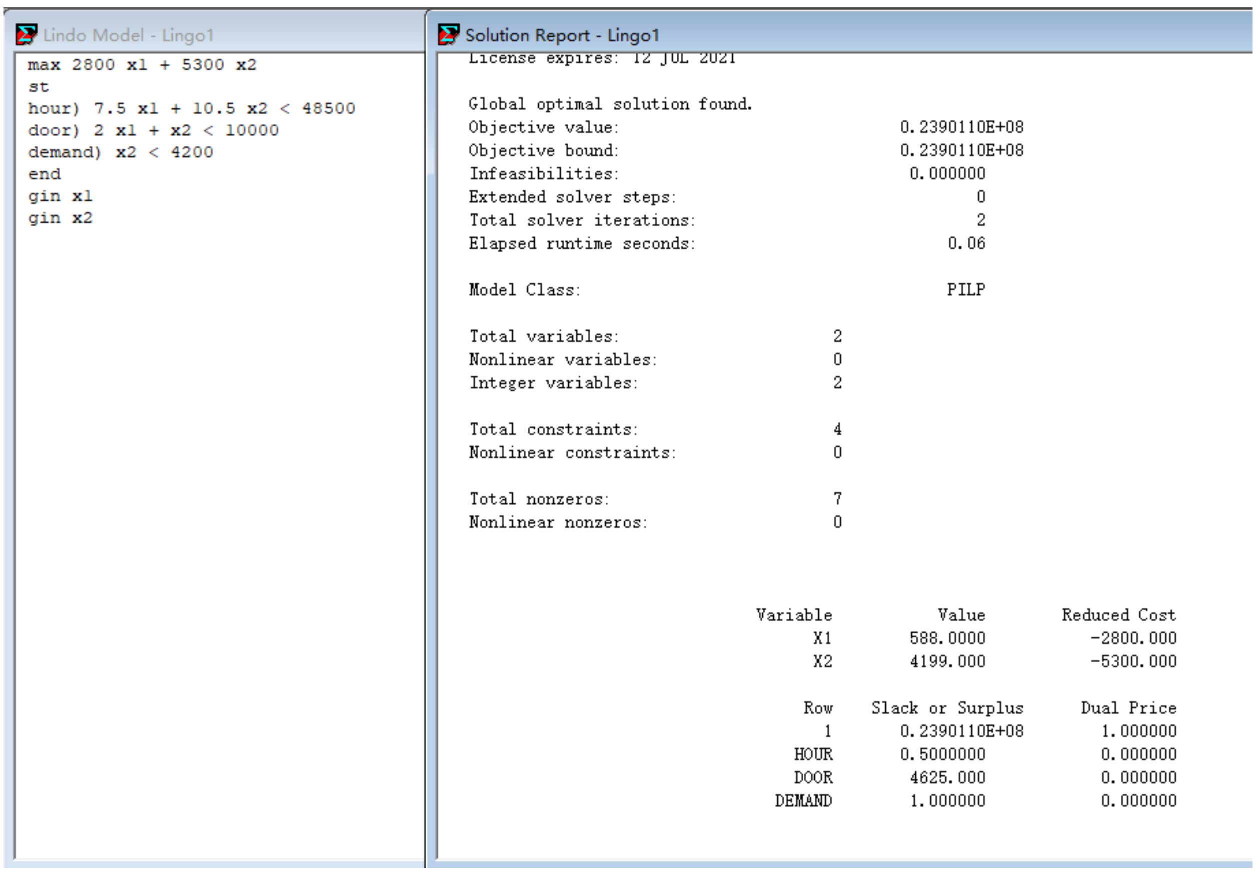
Figure 24: LINGO Solution Report

C.14 Quality problem, Reduced profit, Campaign

C.14.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 4200 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned}
\tag{15}
$$

C.14.2 Solution Report



Lindo Model - Lingo1

```
max 2800 x1 + 5300 x2
st
hour) 7.5 x1 + 10.5 x2 < 48500
door) 2 x1 + x2 < 10000
demand) x2 < 4200
end
gin x1
gin x2
```

Solution Report - Lingo1

```
License expires: 12 JUL 2021

Global optimal solution found.
Objective value:                              0.2390110E+08
Objective bound:                              0.2390110E+08
Infeasibilities:                                   0.000000
Extended solver steps:                                    0
Total solver iterations:                                  2
Elapsed runtime seconds:                               0.06

Model Class:                                           PILP

Total variables:                      2
Nonlinear variables:                  0
Integer variables:                    2

Total constraints:                    4
Nonlinear constraints:                0

Total nonzeros:                       7
Nonlinear nonzeros:                   0


                              Variable           Value        Reduced Cost
                                    X1        588.0000           -2800.000
                                    X2        4199.000           -5300.000

                                   Row    Slack or Surplus      Dual Price
                                     1       0.2390110E+08        1.000000
                                  HOUR       0.5000000            0.000000
                                  DOOR        4625.000            0.000000
                                DEMAND        1.000000            0.000000
```

Figure 25: LINGO Solution Report

C.15 Quality problem, Reduced profit, Overtime

C.15.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 \leq 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{16}
$$

C.15.2 Solution Report

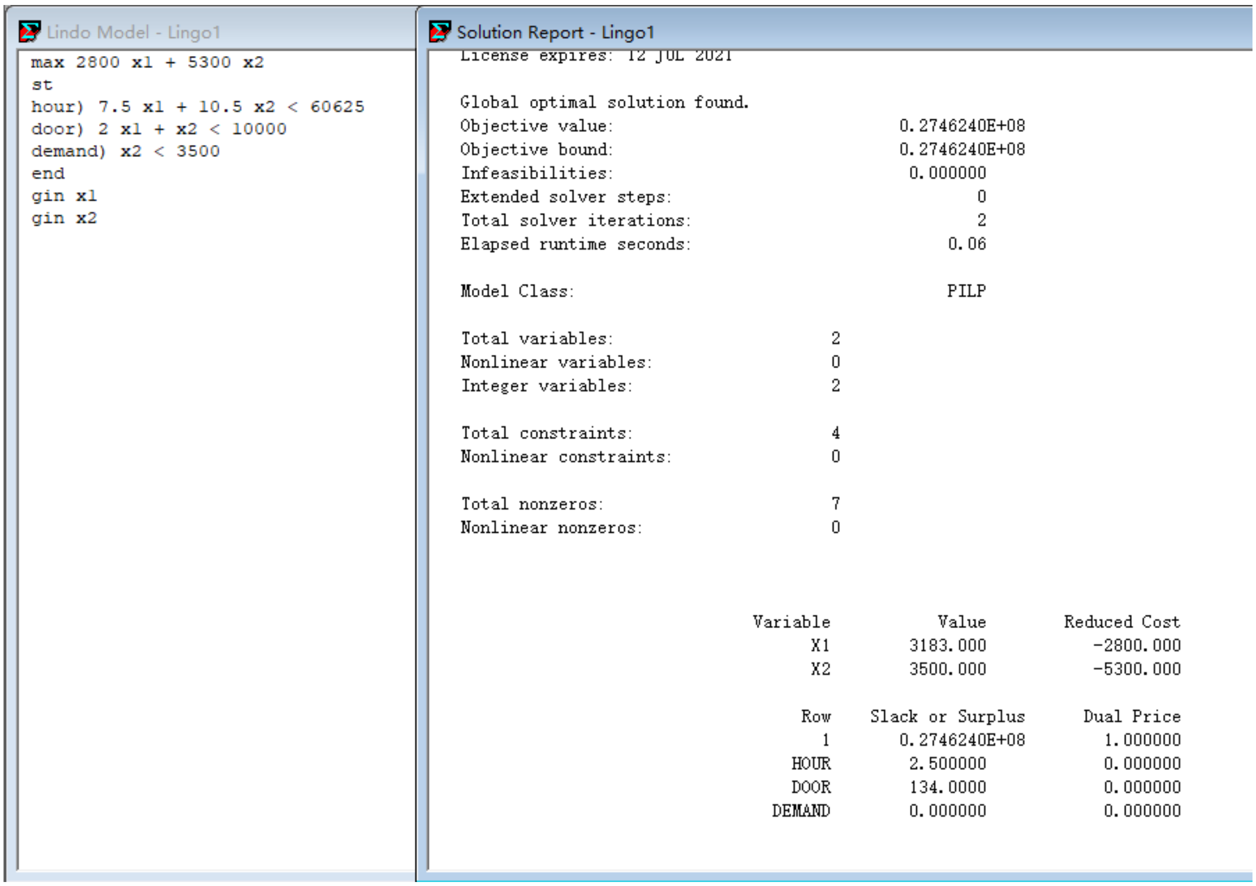


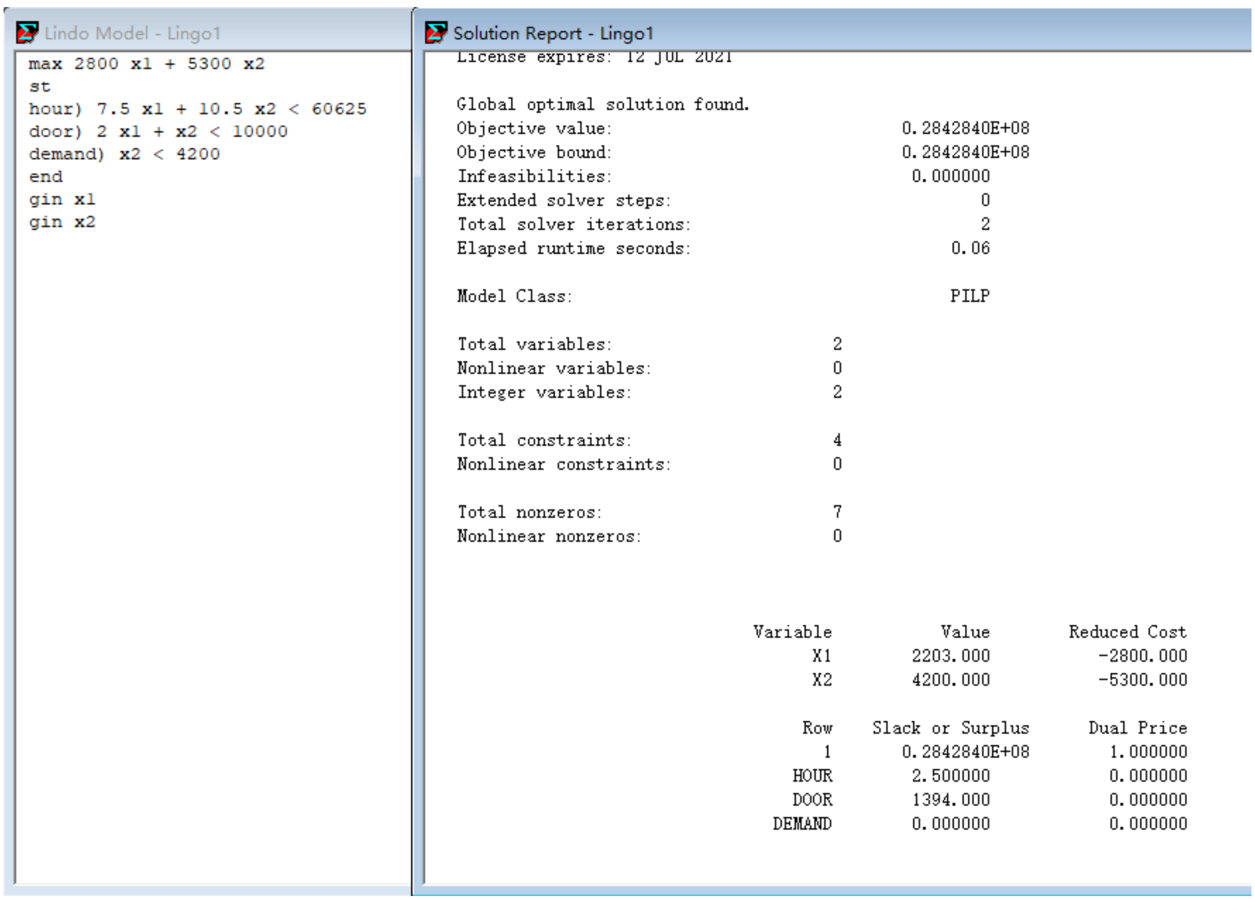
Figure 26: LINGO Solution Report

C.16 Quality problem, Reduced profit, Overtime, Campaign

C.16.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \le 60625 \\
& 2x_1 + x_2 \le 10000 \\
& x_2 \le 4200 \\
& x_1, x_2 \ge 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned}
\tag{17}
$$

C.16.2 Solution Report



Lindo Model - Lingo1

```
max 2800 x1 + 5300 x2
st
hour) 7.5 x1 + 10.5 x2 < 60625
door) 2 x1 + x2 < 10000
demand) x2 < 4200
end
gin x1
gin x2
```

Solution Report - Lingo1

```
License expires: 12 JUL 2021

Global optimal solution found.
Objective value:                           0.2842840E+08
Objective bound:                           0.2842840E+08
Infeasibilities:                            0.000000
Extended solver steps:                             0
Total solver iterations:                           2
Elapsed runtime seconds:                        0.06

Model Class:                                    PILP

Total variables:                    2
Nonlinear variables:                0
Integer variables:                  2

Total constraints:                  4
Nonlinear constraints:              0

Total nonzeros:                     7
Nonlinear nonzeros:                 0


                      Variable           Value        Reduced Cost
                            X1        2203.000           -2800.000
                            X2        4200.000           -5300.000

                           Row    Slack or Surplus      Dual Price
                             1       0.2842840E+08        1.000000
                          HOUR        2.500000            0.000000
                          DOOR        1394.000            0.000000
                        DEMAND        0.000000            0.000000
```

Figure 27: LINGO Solution Report

C.17 Full demand

C.17.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned}
\tag{18}
$$

C.17.2 Solution Report

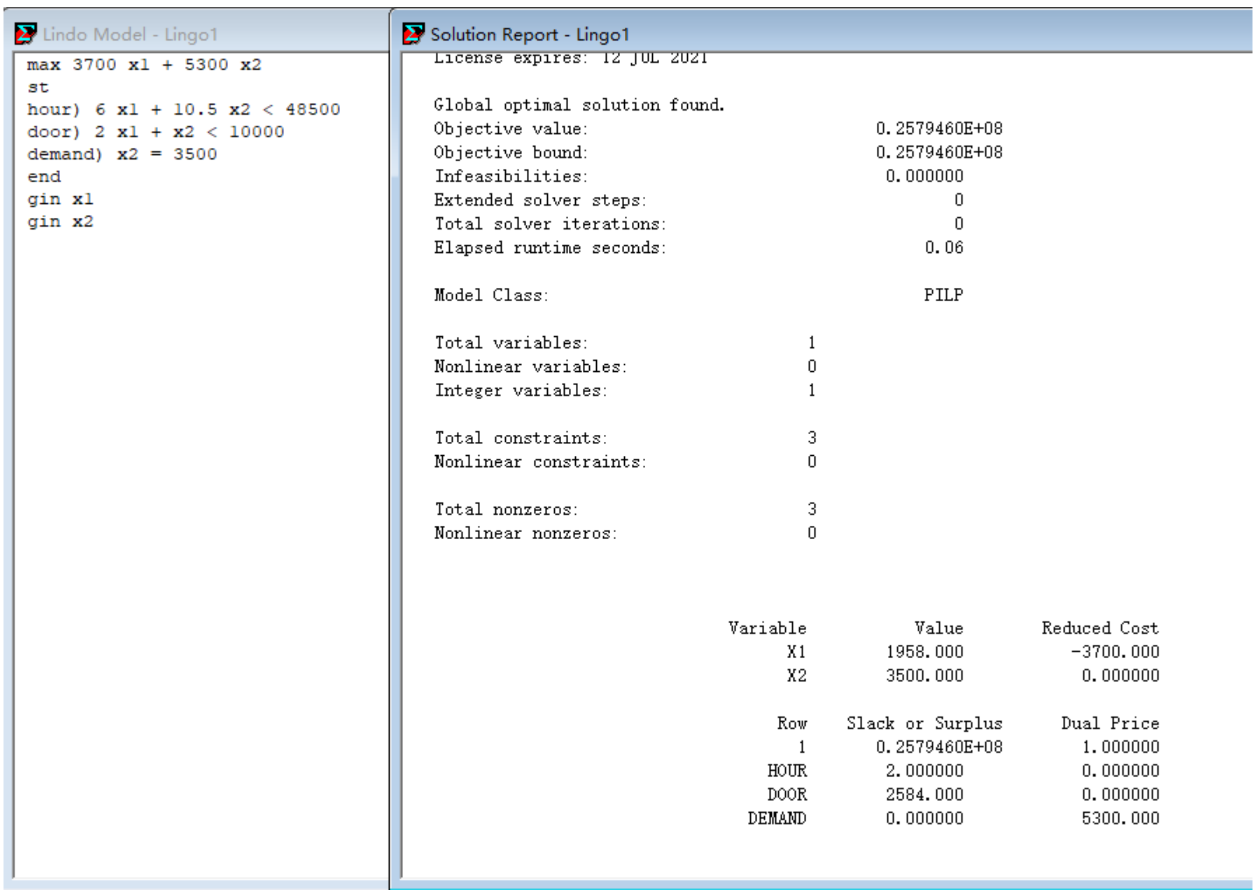


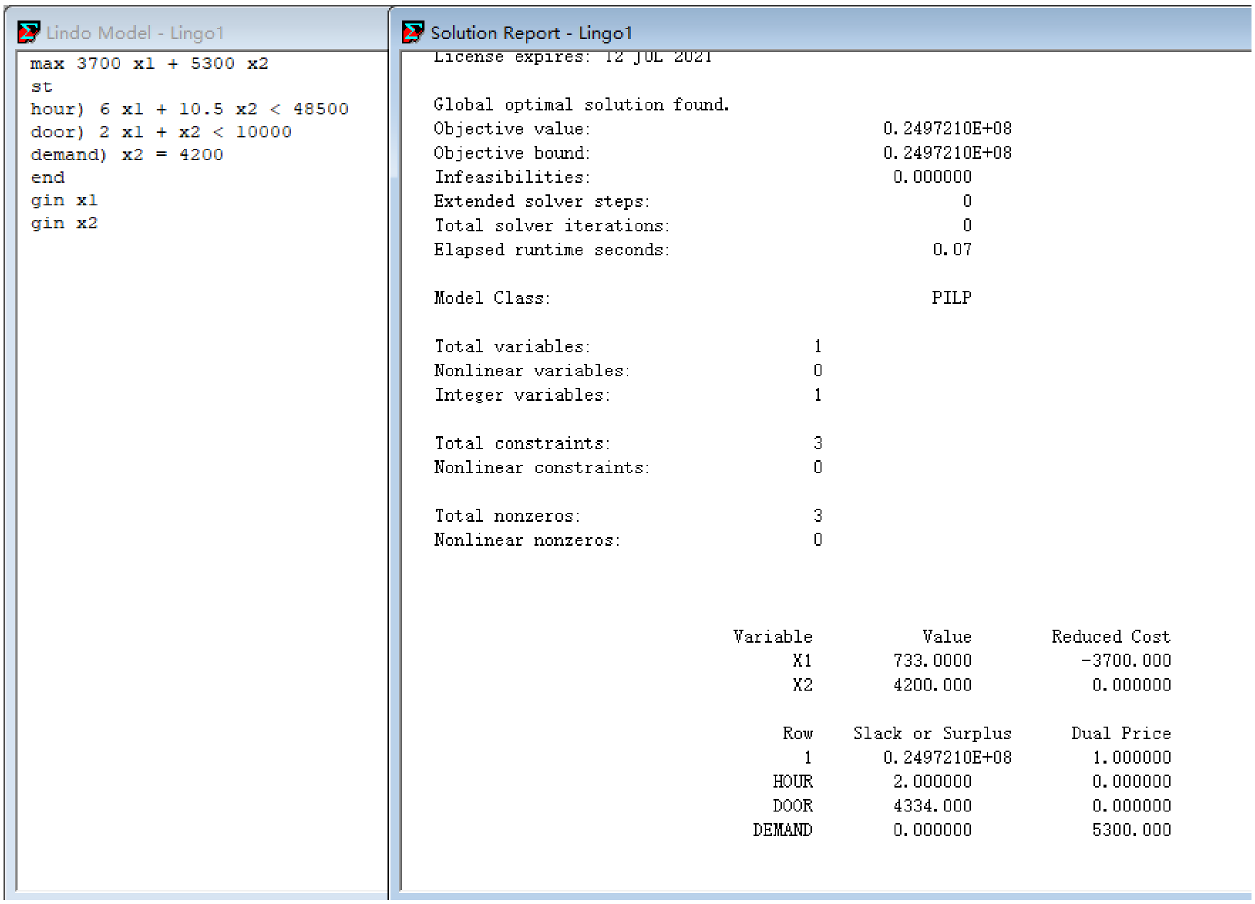
Figure 28: LINGO Solution Report

C.18 Full demand, Campaign

C.18.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 4200 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{19}
$$

C.18.2 Solution Report



Lindo Model - Lingo1

```
max 3700 x1 + 5300 x2
st
hour) 6 x1 + 10.5 x2 < 48500
door) 2 x1 + x2 < 10000
demand) x2 = 4200
end
gin x1
gin x2
```

Solution Report - Lingo1

```
License expires: 12 JUL 2021

Global optimal solution found.
Objective value:                              0.2497210E+08
Objective bound:                              0.2497210E+08
Infeasibilities:                               0.000000
Extended solver steps:                                0
Total solver iterations:                              0
Elapsed runtime seconds:                           0.07

Model Class:                                       PILP

Total variables:                   1
Nonlinear variables:               0
Integer variables:                 1

Total constraints:                 3
Nonlinear constraints:             0

Total nonzeros:                    3
Nonlinear nonzeros:                0


                          Variable           Value        Reduced Cost
                                X1        733.0000           -3700.000
                                X2        4200.000            0.000000

                               Row    Slack or Surplus      Dual Price
                                 1       0.2497210E+08        1.000000
                              HOUR        2.000000            0.000000
                              DOOR        4334.000            0.000000
                            DEMAND        0.000000            5300.000
```

Figure 29: LINGO Solution Report

C.19 Full demand, Overtime

C.19.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{20}
$$

C.19.2 Solution Report

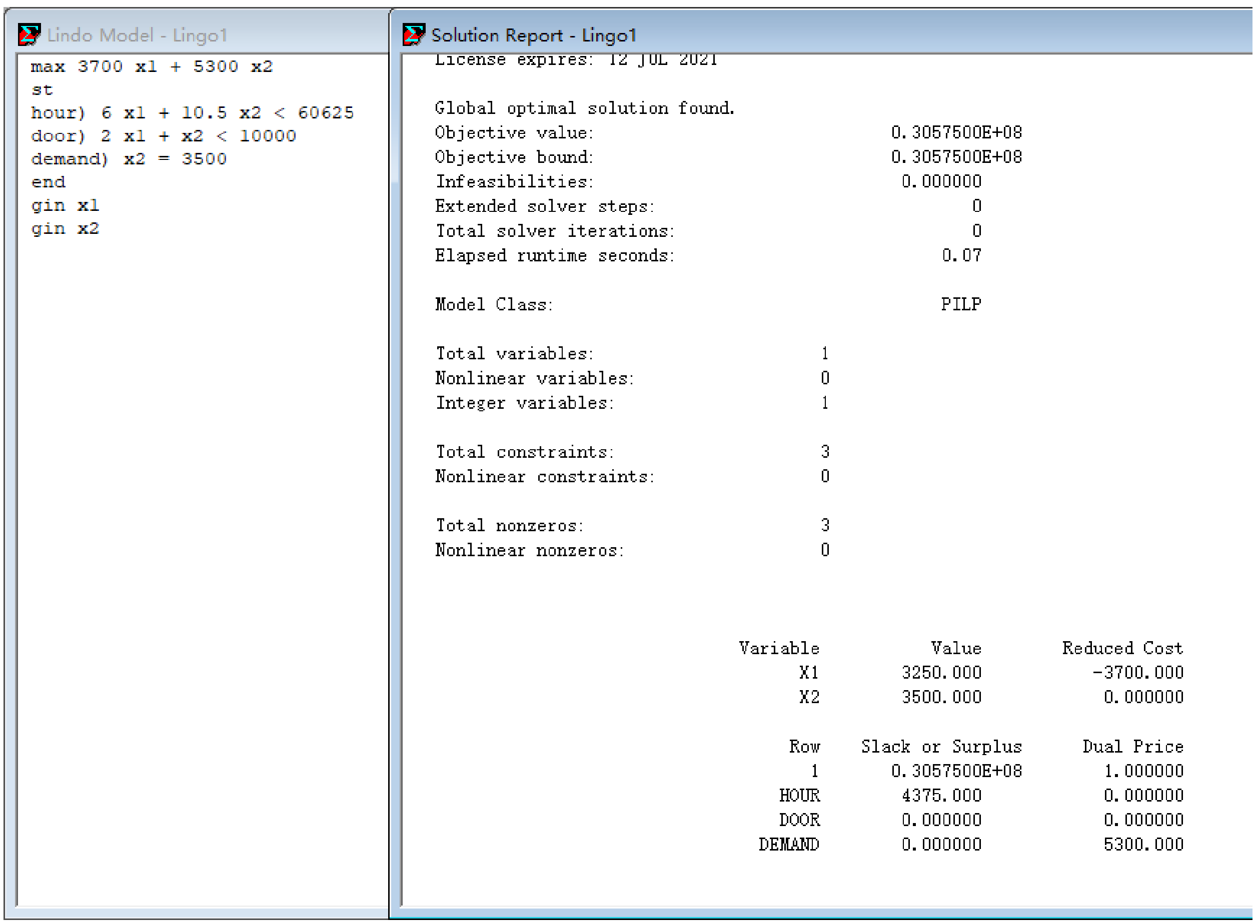


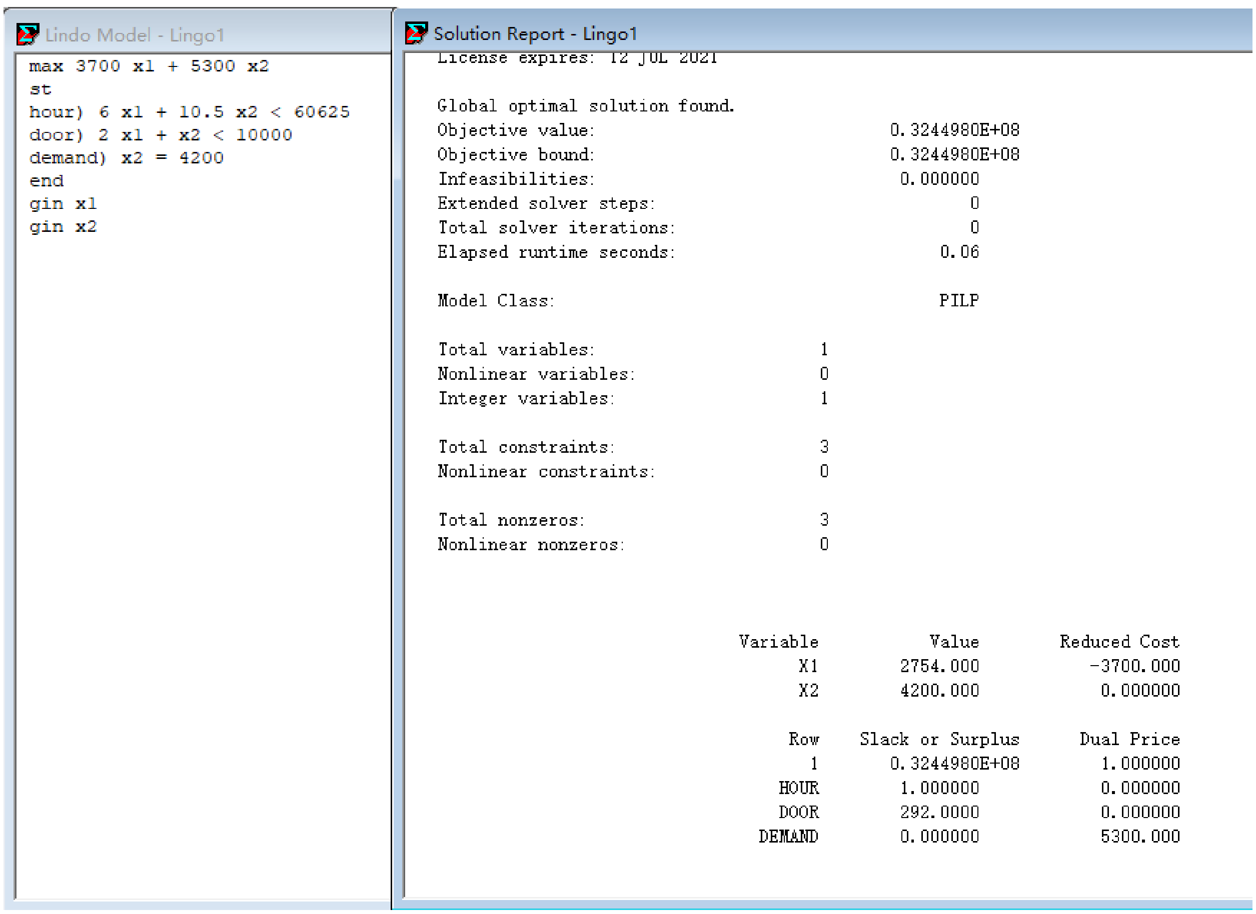
Figure 30: LINGO Solution Report

C.20 Full demand, Overtime, Campaign

C.20.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \le 60625 \\
& 2x_1 + x_2 \le 10000 \\
& x_2 = 4200 \\
& x_1, x_2 \ge 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{21}
$$

C.20.2 Solution Report



Lindo Model - Lingo1

```
max 3700 x1 + 5300 x2
st
hour) 6 x1 + 10.5 x2 < 60625
door) 2 x1 + x2 < 10000
demand) x2 = 4200
end
gin x1
gin x2
```

Solution Report - Lingo1

```
License expires: 12 JUL 2021

Global optimal solution found.
Objective value:                              0.3244980E+08
Objective bound:                              0.3244980E+08
Infeasibilities:                               0.000000
Extended solver steps:                                0
Total solver iterations:                              0
Elapsed runtime seconds:                           0.06

Model Class:                                       PILP

Total variables:                      1
Nonlinear variables:                  0
Integer variables:                    1

Total constraints:                    3
Nonlinear constraints:                0

Total nonzeros:                       3
Nonlinear nonzeros:                   0


                            Variable           Value        Reduced Cost
                                  X1        2754.000           -3700.000
                                  X2        4200.000            0.000000

                                 Row    Slack or Surplus      Dual Price
                                   1       0.3244980E+08        1.000000
                                HOUR        1.000000            0.000000
                                DOOR        292.0000            0.000000
                              DEMAND        0.000000            5300.000
```

Figure 31: LINGO Solution Report

C.21 Full demand, Reduced profit

C.21.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{22}
$$

C.21.2 Solution Report

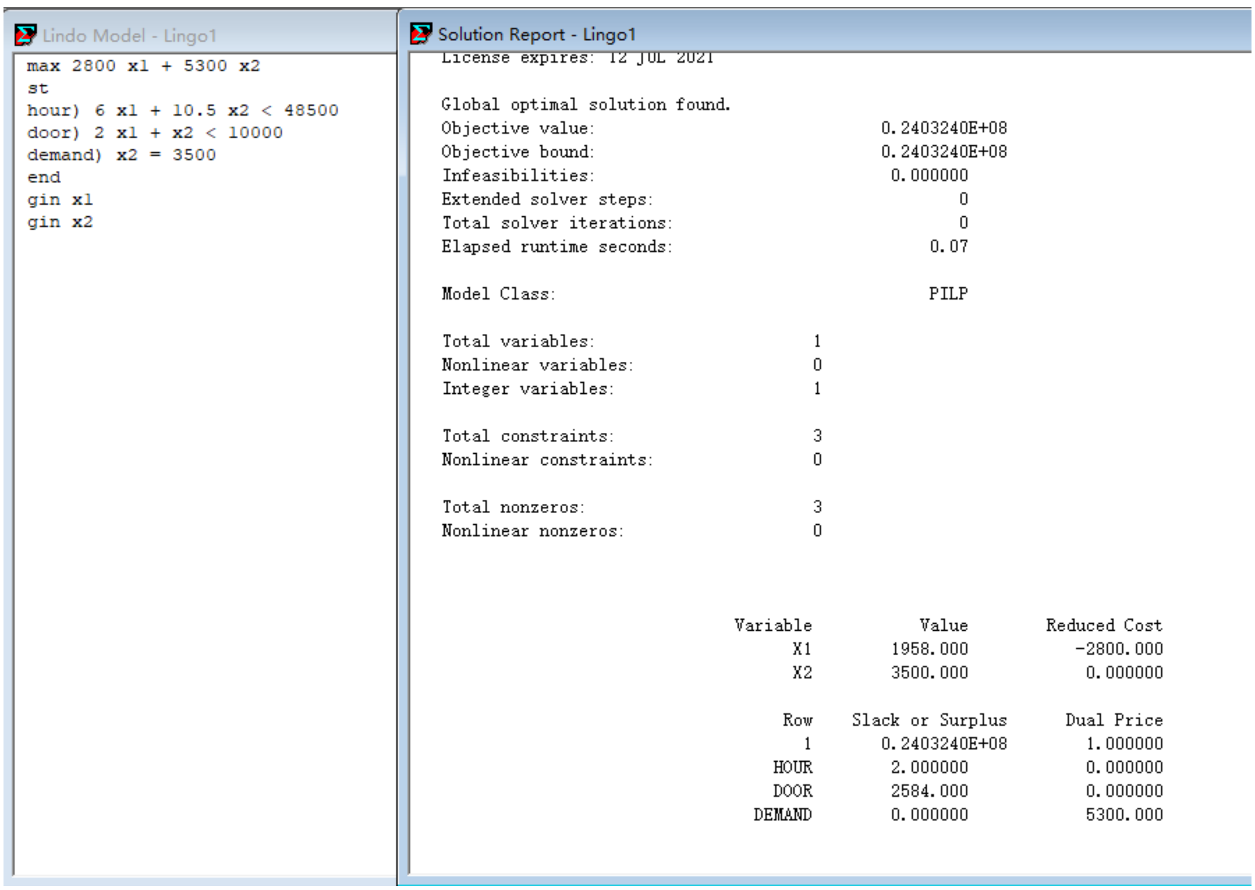


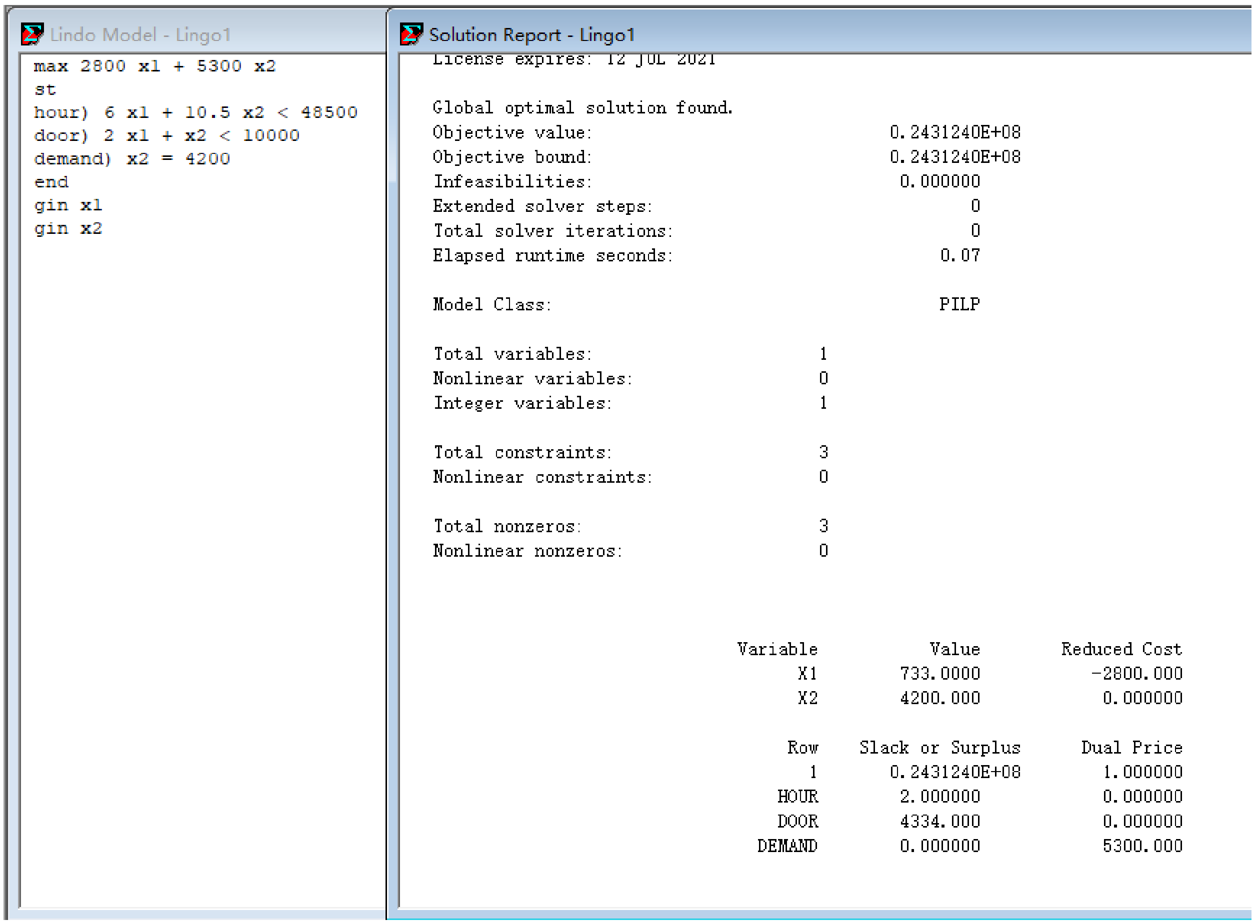
Figure 32: LINGO Solution Report

C.22 Full demand, Reduced profit, Campaign

C.22.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 4200 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned}
\tag{23}
$$

C.22.2 Solution Report



```
Lindo Model - Lingo1
max 2800 x1 + 5300 x2
st
hour) 6 x1 + 10.5 x2 < 48500
door) 2 x1 + x2 < 10000
demand) x2 = 4200
end
gin x1
gin x2
```

```
Solution Report - Lingo1
License expires: 12 JUL 2021

Global optimal solution found.
Objective value:                          0.2431240E+08
Objective bound:                          0.2431240E+08
Infeasibilities:                          0.000000
Extended solver steps:                           0
Total solver iterations:                         0
Elapsed runtime seconds:                      0.07

Model Class:                                  PILP

Total variables:                    1
Nonlinear variables:                0
Integer variables:                  1

Total constraints:                  3
Nonlinear constraints:              0

Total nonzeros:                     3
Nonlinear nonzeros:                 0


                        Variable           Value        Reduced Cost
                              X1        733.0000           -2800.000
                              X2        4200.000            0.000000

                             Row    Slack or Surplus      Dual Price
                               1      0.2431240E+08        1.000000
                            HOUR        2.000000            0.000000
                            DOOR        4334.000            0.000000
                          DEMAND        0.000000            5300.000
```

Figure 33: LINGO Solution Report

C.23 Full demand, Reduced profit, Overtime

C.23.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned}
\tag{24}
$$

C.23.2 Solution Report

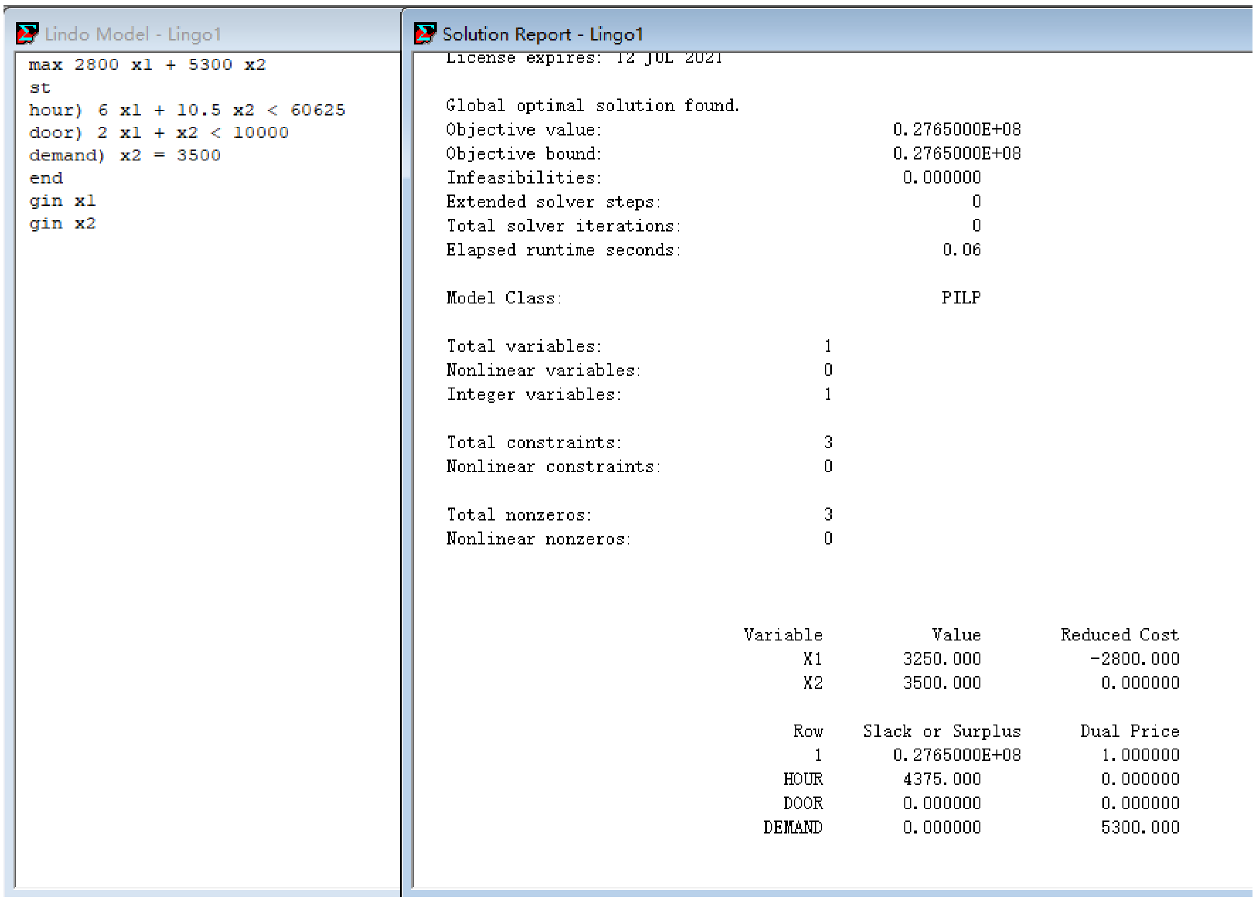


Figure 34: LINGO Solution Report

C.24 Full demand, Reduced profit, Overtime, Campaign

C.24.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 6x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 4200 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned}
\tag{25}
$$

C.24.2 Solution Report

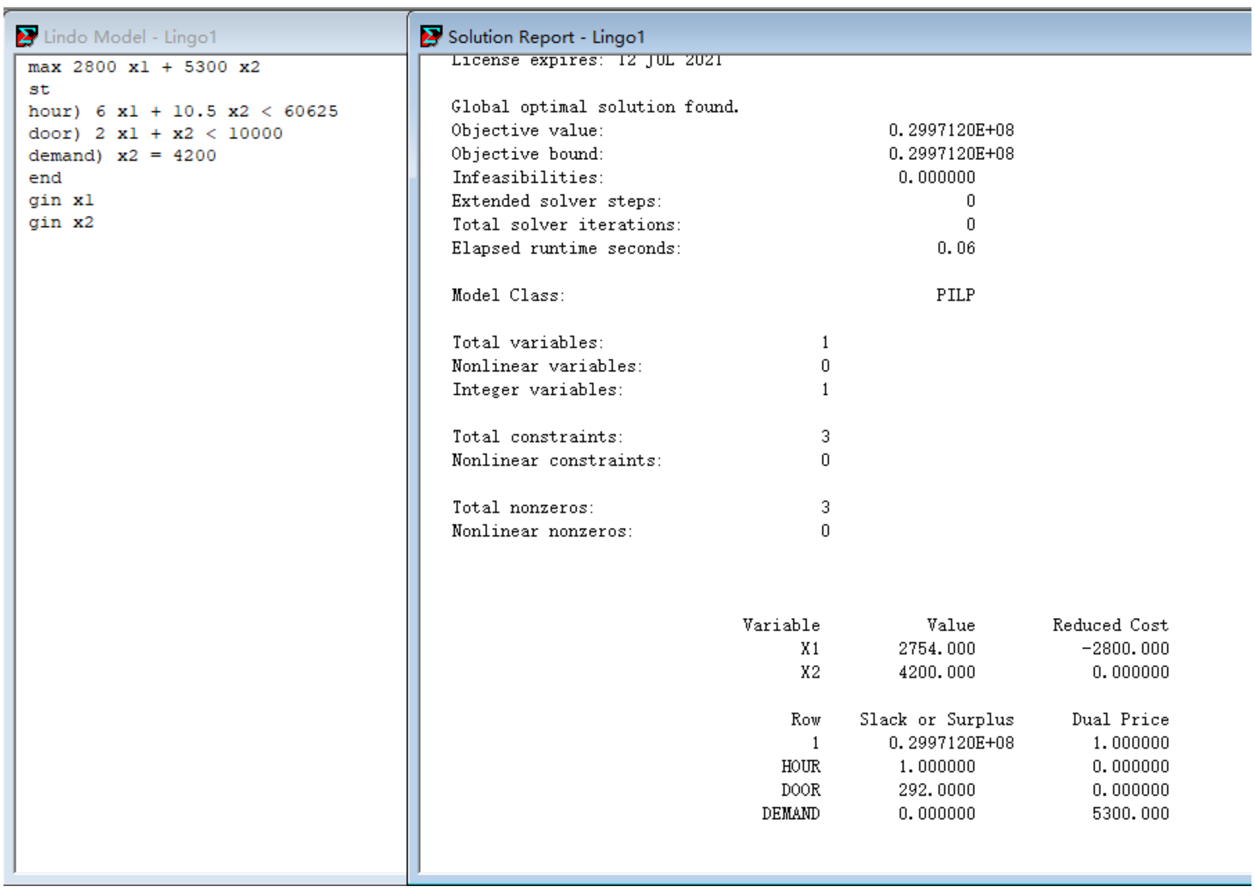


Figure 35: LINGO Solution Report

C.25 Full demand, Quality problem

C.25.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \le 48500 \\
& 2x_1 + x_2 \le 10000 \\
& x_2 = 3500 \\
& x_1, x_2 \ge 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{26}
$$

C.25.2 Solution Report

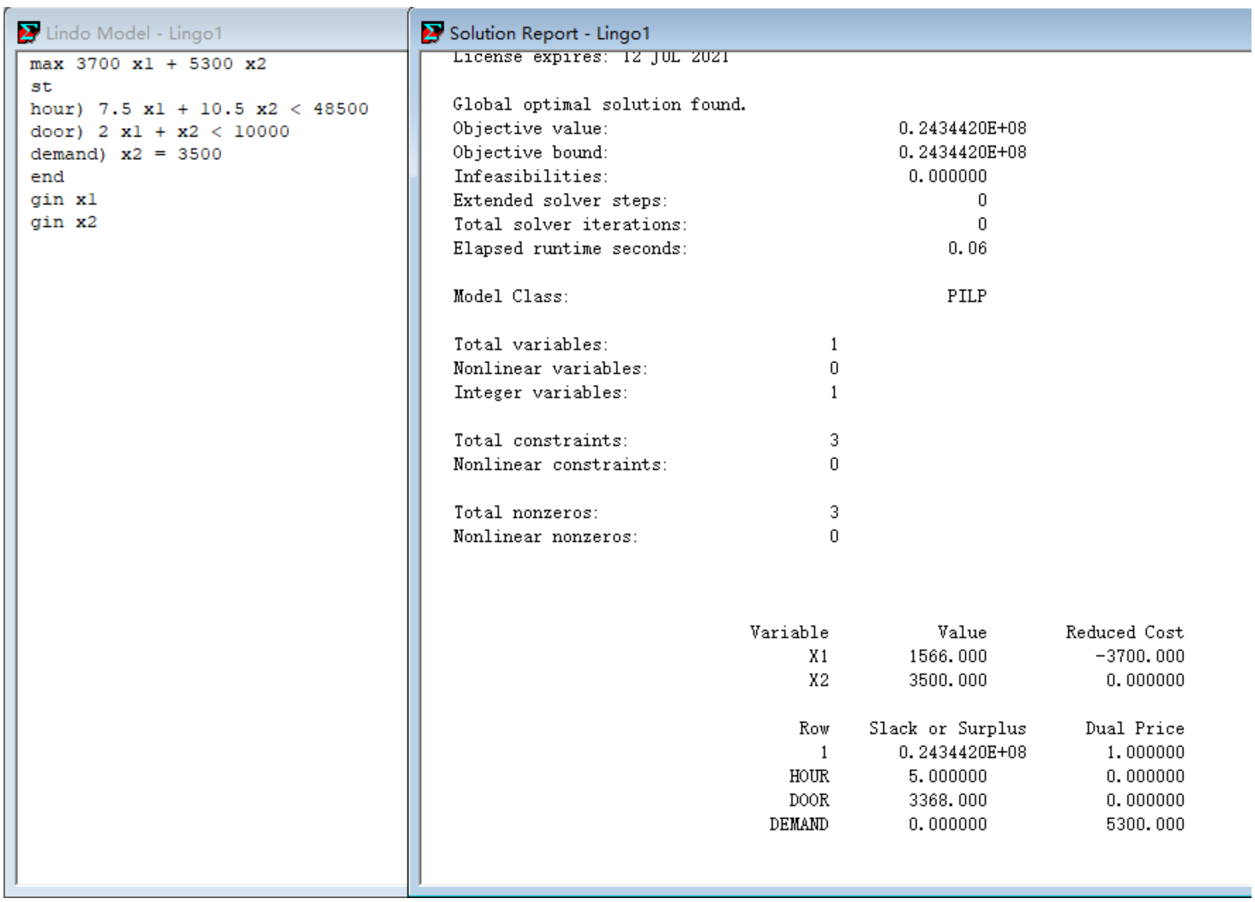


Figure 36: LINGO Solution Report

C.26 Full demand, Quality problem, Campaign

C.26.1 Model

$$\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 4200 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{27}$$

C.26.2 Solution Report

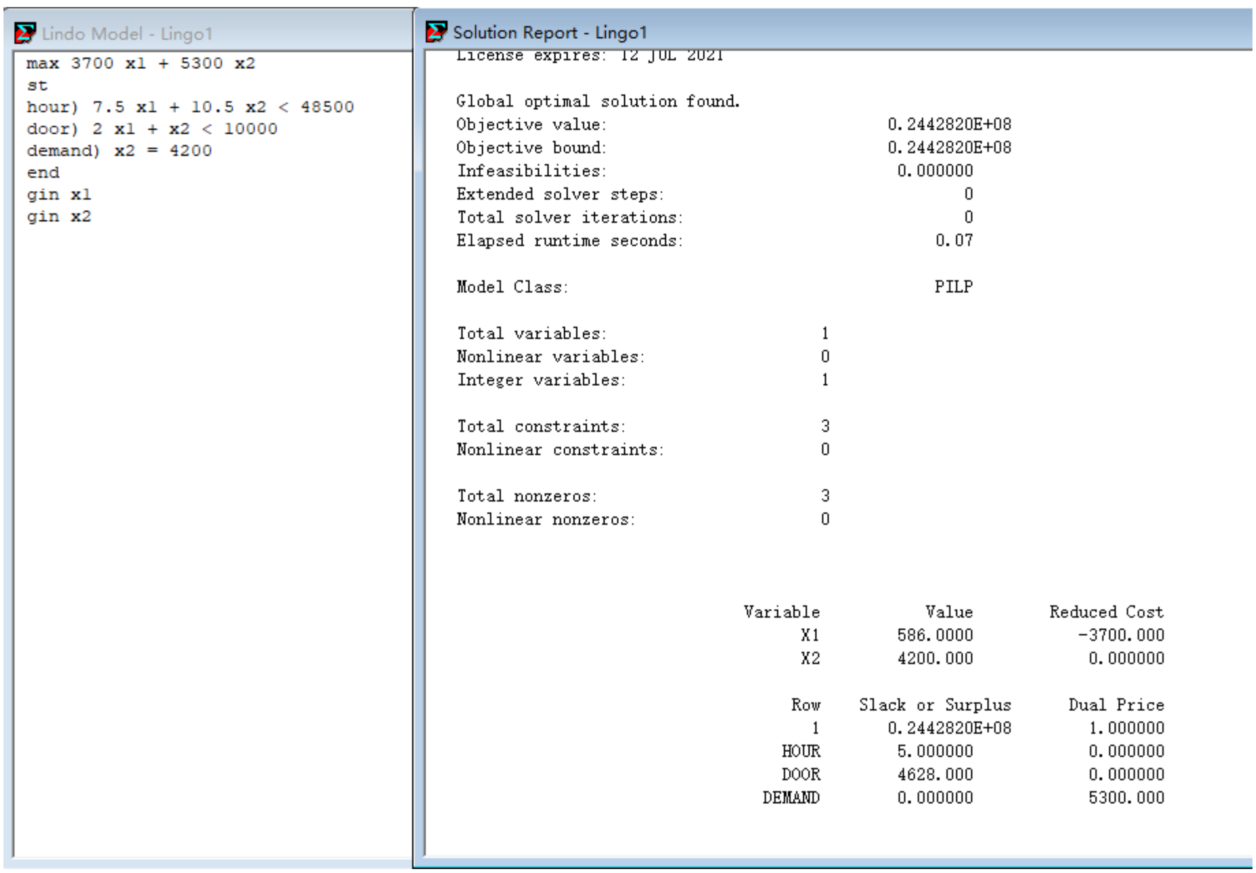


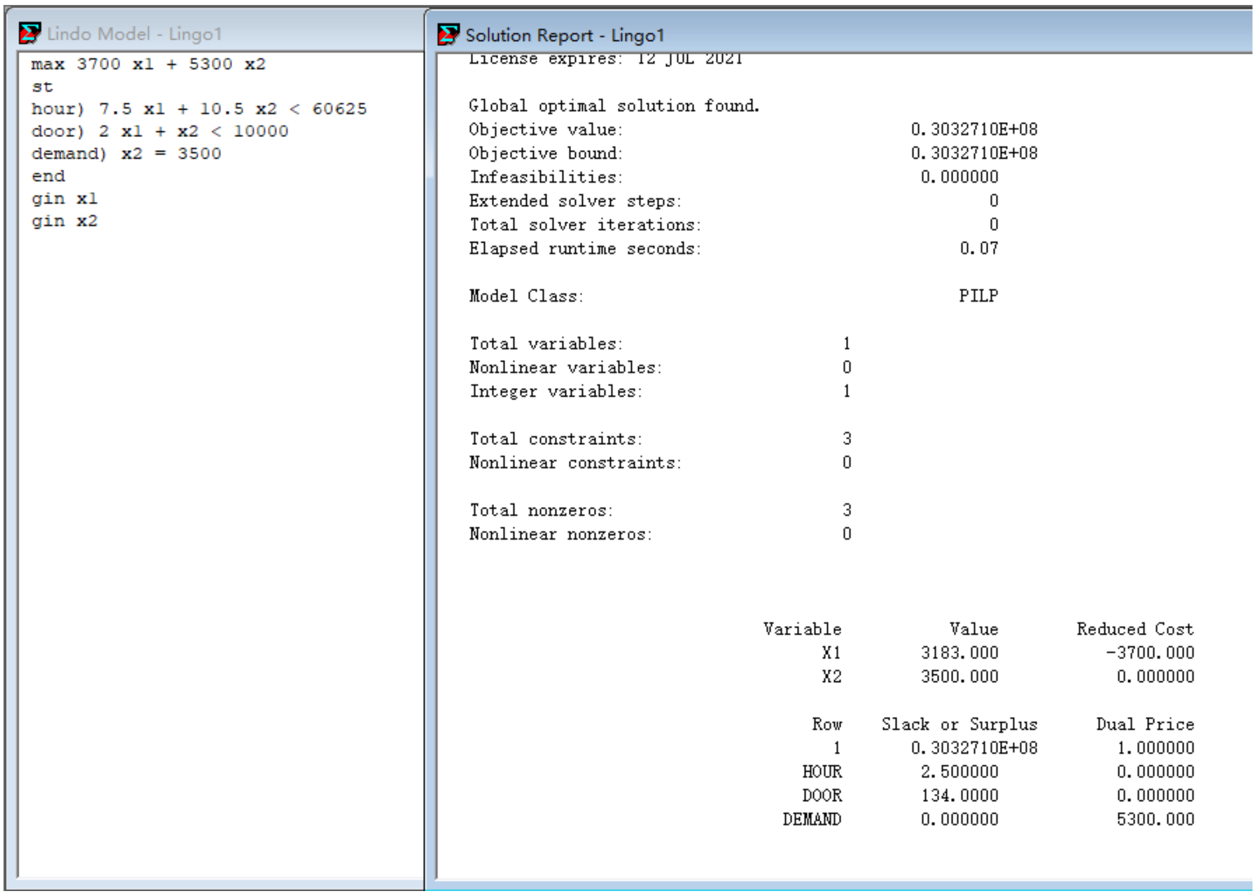
Figure 37: LINGO Solution Report

C.27 Full demand, Quality problem, Overtime

C.27.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{28}
$$

C.27.2 Solution Report



Lindo Model - Lingo1

```
max 3700 x1 + 5300 x2
st
hour) 7.5 x1 + 10.5 x2 < 60625
door) 2 x1 + x2 < 10000
demand) x2 = 3500
end
gin x1
gin x2
```

Solution Report - Lingo1

```
License expires: 12 JUL 2021

Global optimal solution found.
Objective value:                              0.3032710E+08
Objective bound:                              0.3032710E+08
Infeasibilities:                               0.000000
Extended solver steps:                                0
Total solver iterations:                              0
Elapsed runtime seconds:                           0.07

Model Class:                                       PILP

Total variables:                    1
Nonlinear variables:                0
Integer variables:                  1

Total constraints:                  3
Nonlinear constraints:              0

Total nonzeros:                     3
Nonlinear nonzeros:                 0


                            Variable           Value        Reduced Cost
                                  X1        3183.000           -3700.000
                                  X2        3500.000            0.000000

                                 Row    Slack or Surplus      Dual Price
                                   1       0.3032710E+08        1.000000
                                HOUR            2.500000        0.000000
                                DOOR            134.0000        0.000000
                              DEMAND            0.000000        5300.000
```

Figure 38: LINGO Solution Report

C.28 Full demand, Quality problem, Overtime, Campaign

C.28.1 Model

$$
\begin{aligned}
\max \quad & 3700x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 4200 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{29}
$$

C.28.2 Solution Report

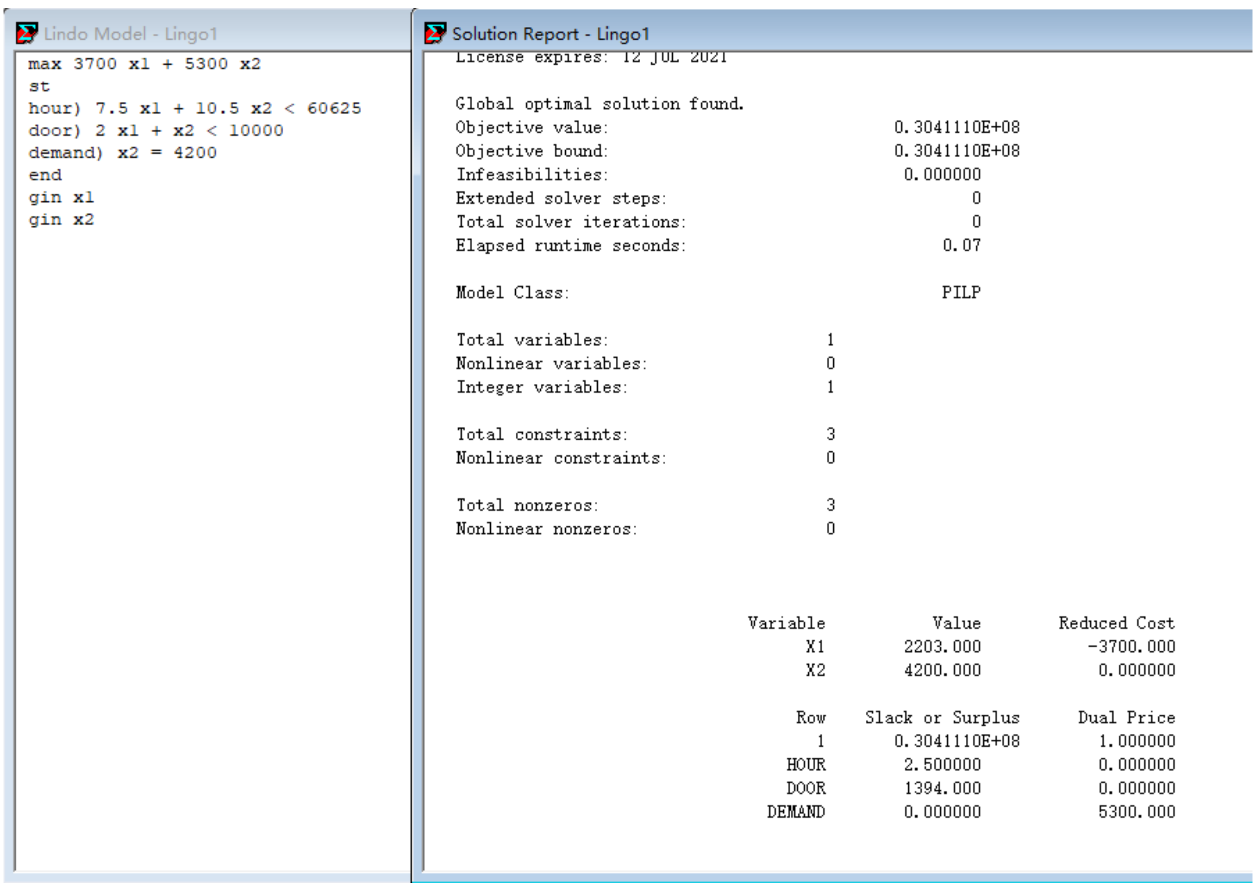


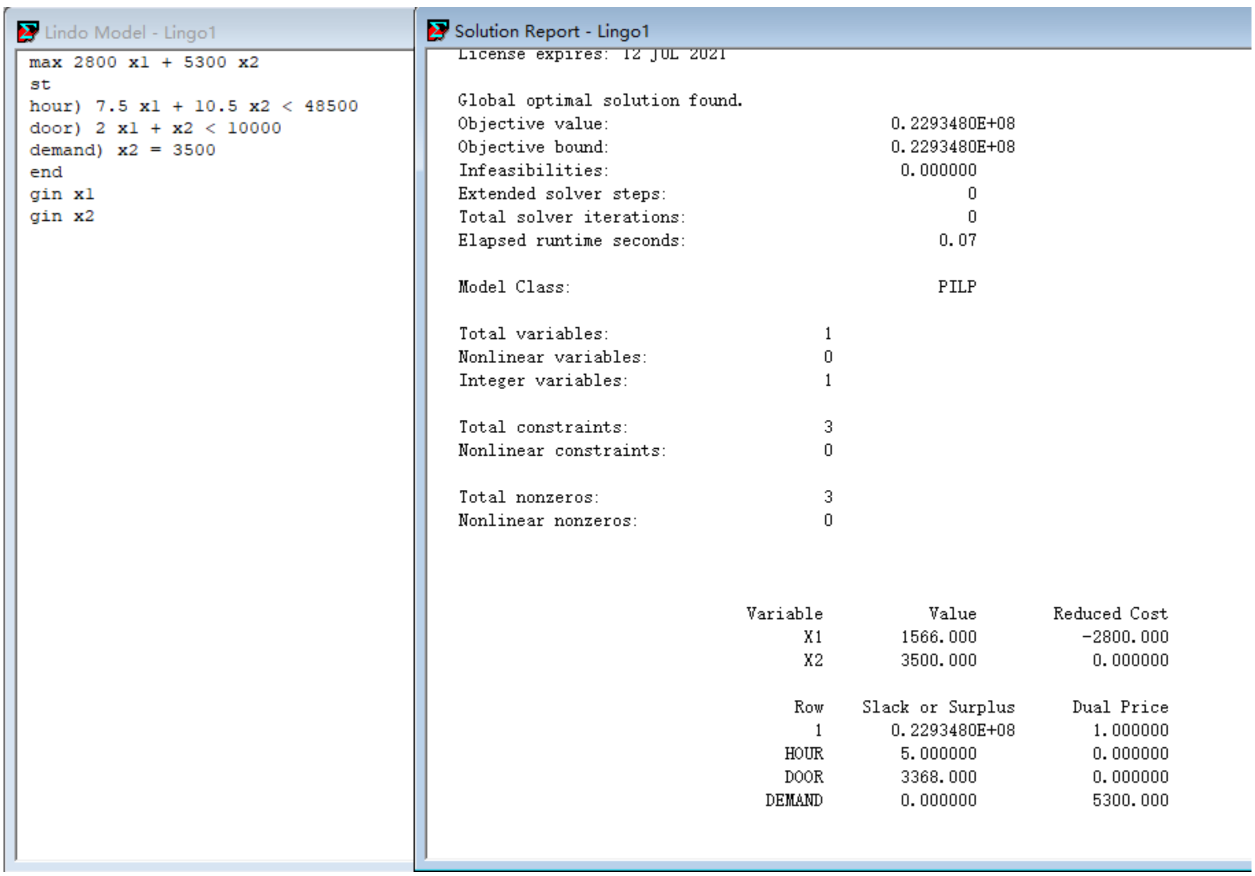
Figure 39: LINGO Solution Report

C.29 Full demand, Quality problem, Reduced profit

C.29.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{30}
$$

C.29.2 Solution Report



Lindo Model - Lingo1

```
max 2800 x1 + 5300 x2
st
hour) 7.5 x1 + 10.5 x2 < 48500
door) 2 x1 + x2 < 10000
demand) x2 = 3500
end
gin x1
gin x2
```

Solution Report - Lingo1

```
License expires: 12 JUL 2021

Global optimal solution found.
Objective value:                              0.2293480E+08
Objective bound:                              0.2293480E+08
Infeasibilities:                               0.000000
Extended solver steps:                                0
Total solver iterations:                              0
Elapsed runtime seconds:                           0.07

Model Class:                                       PILP

Total variables:                      1
Nonlinear variables:                  0
Integer variables:                    1

Total constraints:                    3
Nonlinear constraints:                0

Total nonzeros:                       3
Nonlinear nonzeros:                   0


                                Variable           Value        Reduced Cost
                                      X1        1566.000           -2800.000
                                      X2        3500.000            0.000000

                                     Row    Slack or Surplus      Dual Price
                                       1     0.2293480E+08        1.000000
                                    HOUR        5.000000            0.000000
                                    DOOR        3368.000            0.000000
                                  DEMAND        0.000000            5300.000
```

Figure 40: LINGO Solution Report

C.30 Full demand, Quality problem, Reduced profit, Campaign

C.30.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 48500 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 4200 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned}
\tag{31}
$$

C.30.2 Solution Report

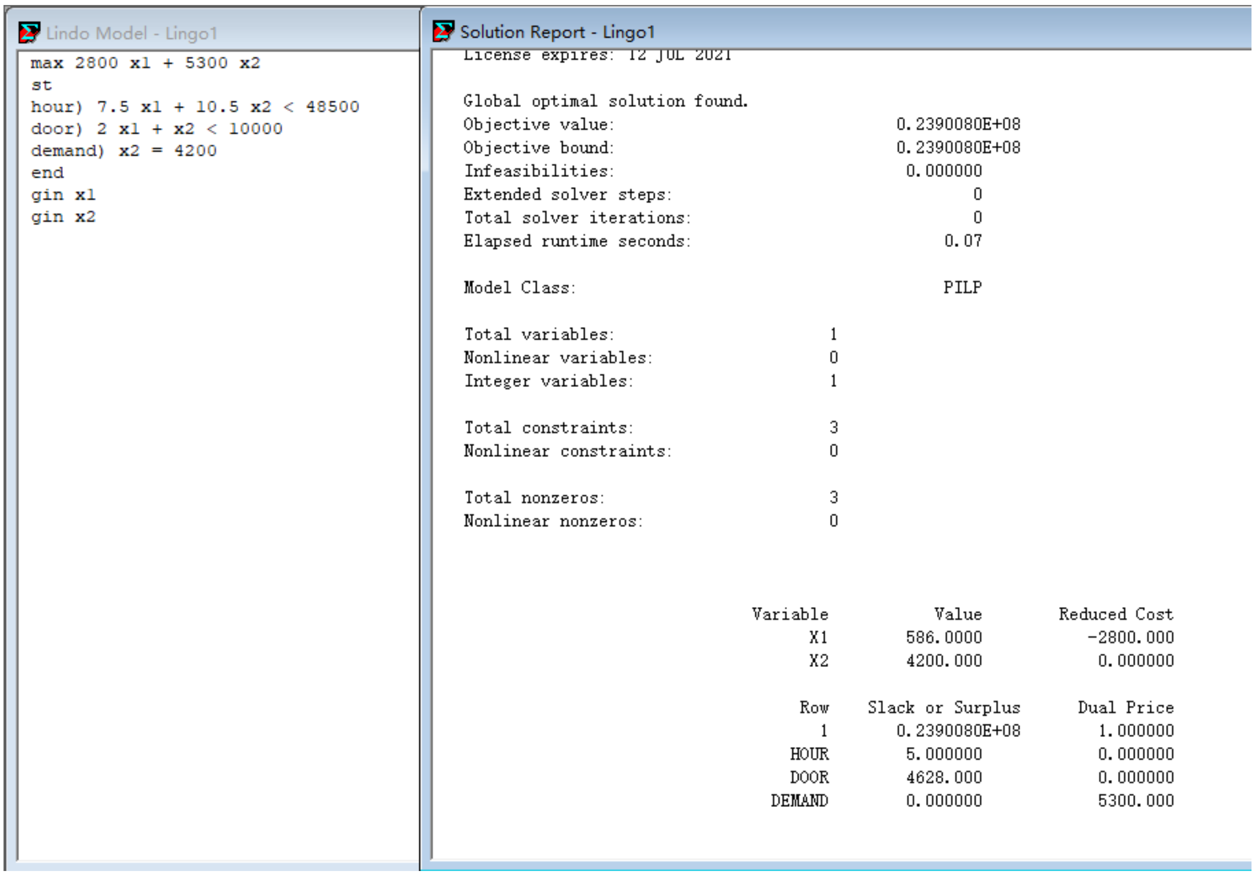


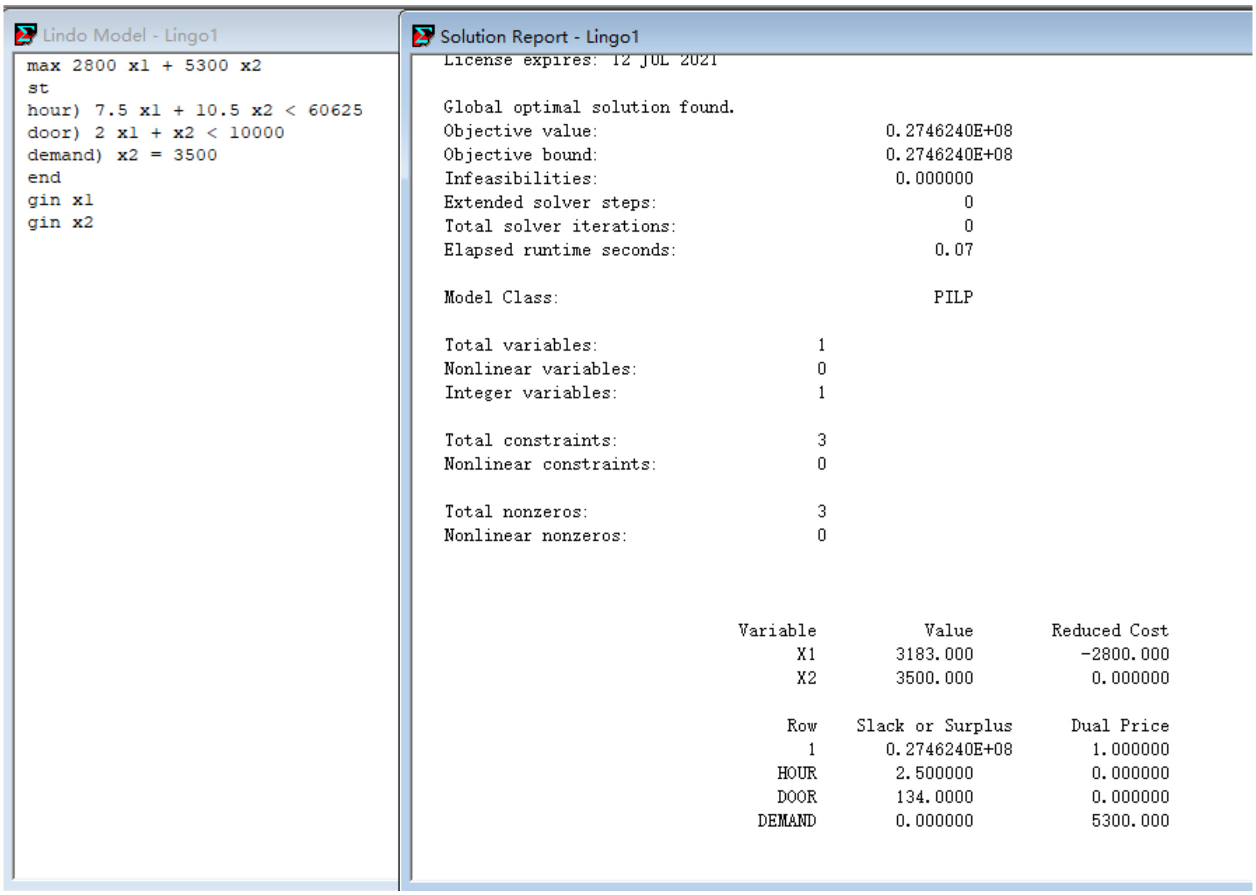
Figure 41: LINGO Solution Report

C.31 Full demand, Quality problem, Reduced profit, Overtime

C.31.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 3500 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned}
\tag{32}
$$

C.31.2 Solution Report



Lindo Model - Lingo1

```
max 2800 x1 + 5300 x2
st
hour) 7.5 x1 + 10.5 x2 < 60625
door) 2 x1 + x2 < 10000
demand) x2 = 3500
end
gin x1
gin x2
```

Solution Report - Lingo1

```
License expires: 12 JUL 2021

Global optimal solution found.
Objective value:                              0.2746240E+08
Objective bound:                              0.2746240E+08
Infeasibilities:                               0.000000
Extended solver steps:                                0
Total solver iterations:                              0
Elapsed runtime seconds:                           0.07

Model Class:                                       PILP

Total variables:                      1
Nonlinear variables:                  0
Integer variables:                    1

Total constraints:                    3
Nonlinear constraints:                0

Total nonzeros:                       3
Nonlinear nonzeros:                   0



                                Variable           Value        Reduced Cost
                                      X1        3183.000           -2800.000
                                      X2        3500.000            0.000000

                                     Row    Slack or Surplus      Dual Price
                                       1       0.2746240E+08        1.000000
                                    HOUR        2.500000            0.000000
                                    DOOR        134.0000            0.000000
                                  DEMAND        0.000000            5300.000
```

Figure 42: LINGO Solution Report

C.32 Full demand, Quality problem, Reduced profit, Overtime, Campaign

C.32.1 Model

$$
\begin{aligned}
\max \quad & 2800x_1 + 5300x_2, \\
\text{subject to} \quad & 7.5x_1 + 10.5x_2 \leq 60625 \\
& 2x_1 + x_2 \leq 10000 \\
& x_2 = 4200 \\
& x_1, x_2 \geq 0, x_1, x_2 \in \mathbb{Z}.
\end{aligned} \tag{33}
$$

C.32.2 Solution Report

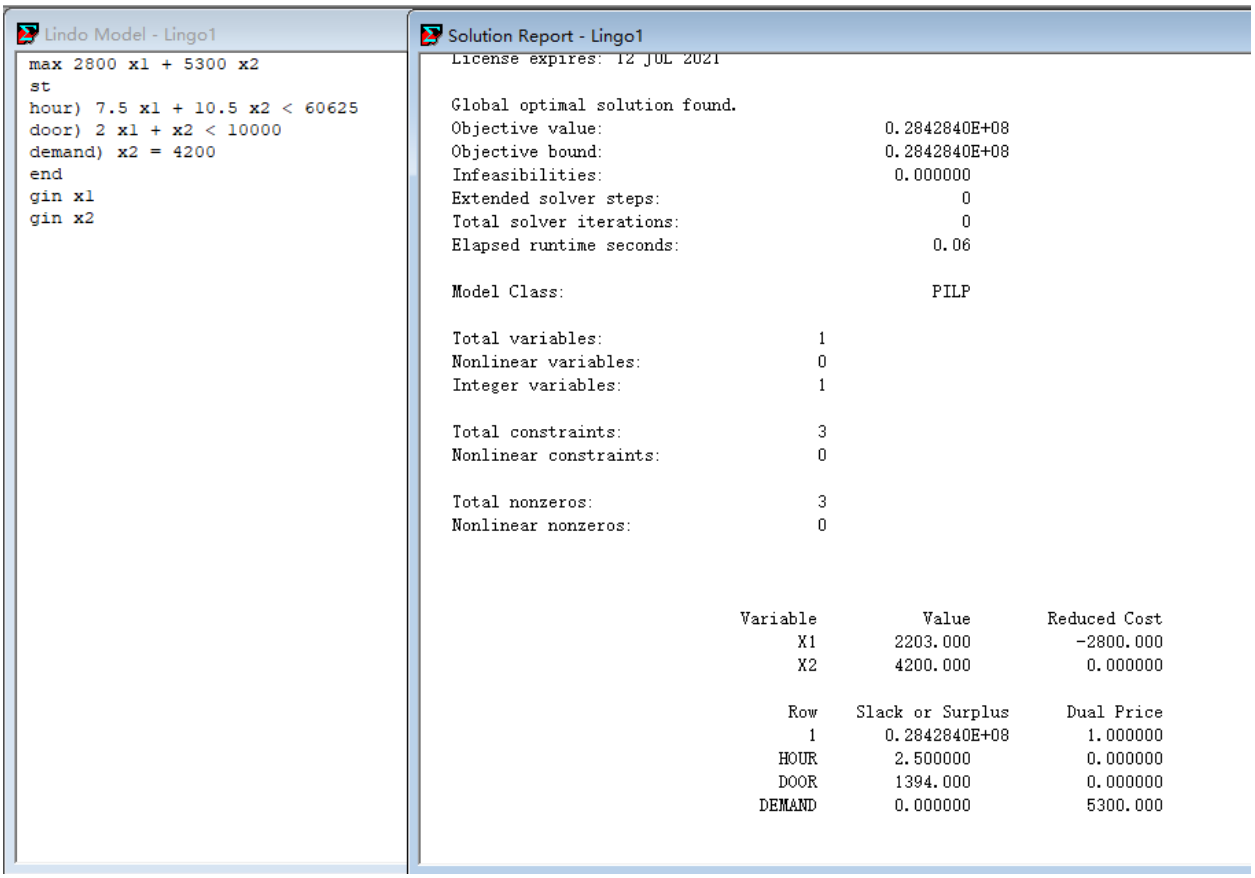


Figure 43: LINGO Solution Report

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$F$22	Optimal Solution	-500000	26509300

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$21	Solution Family Adventurer	0	3766	Integer
$C$21	Solution Classic Transporter	0	2467	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$17	Labor-hour Required	48499.5	$D$17<=$F$17	Not Binding	0.5
$D$18	Door Required	9999	$D$18<=$F$18	Not Binding	1
$D$19	Demand Required	2467	$D$19<=$F$19	Not Binding	1733
$B$21:$C$21=Integer					

(a) Solution: Only Adopt Advertising Campaign

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$F$33	Optimal Solution	0	30575000

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$32	Solution Family Adventurer	0	3250	Integer
$C$32	Solution Classic Transporter	0	3500	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$28	Labor-hour Required	56250	$D$28<=$F$28	Not Binding	4375
$D$29	Door Required	10000	$D$29<=$F$29	Binding	0
$D$30	Demand Required	3500	$D$30<=$F$30	Binding	0
$B$32:$C$32=Integer					

(b) Solution: Only Use Overtime Labor

Figure 44: Only Campaign vs. Only Overtime Labor

D Excel Solution Reports

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$F$45	Optimal Solution	0	32586100

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$44	Solution Family Adventurer	0	2957	Integer
$C$44	Solution Classic Transporter	0	4084	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$40	Labor-hour Required	60624	$D$40<=$F$40	Not Binding	1
$D$41	Door Required	9998	$D$41<=$F$41	Not Binding	2
$D$42	Demand Required	4084	$D$42<=$F$42	Not Binding	116
$B$44:$C$44=Integer					

Figure 45: Solution for Combination of Advertising Campaign and Overtime Labor

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$F$57	Optimal Solution	0	27650000

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$56	Solution Family Adventurer	0	3250	Integer
$C$56	Solution Classic Transporter	0	3500	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$41	Door Required	9998	$D$41<=$F$41	Not Binding	2
$D$53	Door Required	10000	$D$53<=$F$53	Binding	0
$D$54	Demand Required	3500	$D$54<=$F$54	Binding	0
$B$56:$C$56=Integer					

(a) Solution: No Overtime Labors Campaign

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$F$68	Optimal Solution	0	27650000

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$67	Solution Family Adventurer	0	3250	Integer
$C$67	Solution Classic Transporter	0	3500	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$63	Labor-hour Required	56250	$D$63<=$F$63	Not Binding	4375
$D$64	Door Required	10000	$D$64<=$F$64	Binding	0
$D$65	Demand Required	3500	$D$65<=$F$65	Binding	0
$B$67:$C$67=Integer					

(b) Solution: Use Overtime Labors

Figure 46: Without $500,000 Advertising Campaign Under Reduced Profit Situation

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$F$68	Optimal Solution	0	24312700

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$67	Solution Family Adventurer	0	735	Integer
$C$67	Solution Classic Transporter	0	4199	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$63	Labor-hour Required	48499.5	$D$63<=$F$63	Not Binding	0.5
$D$64	Door Required	5669	$D$64<=$F$64	Not Binding	4331
$D$65	Demand Required	4199	$D$65<=$F$65	Not Binding	1
$B$67:$C$67=Integer					

(a) Solution: No Overtime Labors Campaign

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$F$68	Optimal Solution	0	29971200

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$67	Solution Family Adventurer	0	2754	Integer
$C$67	Solution Classic Transporter	0	4200	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$63	Labor-hour Required	60624	$D$63<=$F$63	Not Binding	1
$D$64	Door Required	9708	$D$64<=$F$64	Not Binding	292
$D$65	Demand Required	4200	$D$65<=$F$65	Binding	0
$B$67:$C$67=Integer					

(b) Solution: Use Overtime Labors

Figure 47: With $500,000 Advertising Campaign Under Reduced Profit Situation

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$F$10	optimal value=	27009300	24346300

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$10	Number of produce Family	3766	1568	Integer
$C$10	Number of produce Classic	2467	3499	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$6	Hours of labor	48499.5	$D$6<=$F$6	Not Binding	0.5
$D$7	Pairs of door	6635	$D$7<=$F$7	Not Binding	3365
$D$8	Limitation of demand	3499	$D$8<=$F$8	Not Binding	1
$B$10:$C$10=Integer					

(a) Solution: No Overtime Labors

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$F$10	optimal value=	28812100	28728100

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$10	Number of produce Family	2209	3189	Integer
$C$10	Number of produce Classic	4196	3496	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$6	Hours of labor	60625.5	$D$6<=$F$6	Binding	0
$D$7	Pairs of door	9874	$D$7<=$F$7	Not Binding	126
$D$8	Limitation of demand	3496	$D$8<=$F$8	Not Binding	4
$B$10:$C$10=Integer					

(b) Solution: Using Overtime Labors

Figure 48: Without $500,000 Advertising Campaign Under Quality Problem

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$F$10	optimal value=	23846300	23930300

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$10	Number of produce Family	1568	588	Integer
$C$10	Number of produce Classic	3499	4199	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$6	Hours of labor	48499.5	$D$6<=$F$6	Not Binding	0.5
$D$7	Pairs of door	5375	$D$7<=$F$7	Not Binding	4625
$D$8	Limitation of demand	4199	$D$8<=$F$8	Not Binding	1
$B$10:$C$10=Integer					

(a) Solution: No Overtime Labors Campaign

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$F$10	optimal value=	22330300	28312100

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$10	Number of produce Family	588	2209	Integer
$C$10	Number of produce Classic	4199	4196	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$6	Hours of labor	60625.5	$D$6<=$F$6	Binding	0
$D$7	Pairs of door	8614	$D$7<=$F$7	Not Binding	1386
$D$8	Limitation of demand	4196	$D$8<=$F$8	Not Binding	4
$B$10:$C$10=Integer					

(b) Solution: Using Overtime Labors

Figure 49: With $500,000 Advertising Campaign Under Quality Problem

Objective Cell (Max)

Cell	Name	Original Value	Final Value
$F$68	Optimal Solution	0	25794600

Variable Cells

Cell	Name	Original Value	Final Value	Integer
$B$67	Solution Family Adventurer	0	1958	Integer
$C$67	Solution Classic Transporter	0	3500	Integer

Constraints

Cell	Name	Cell Value	Formula	Status	Slack
$D$63	Labor-hour Required	48498	$D$63<=$F$63	Not Binding	2
$D$64	Door Required	7416	$D$64<=$F$64	Not Binding	2584
$D$65	Demand Required	3500	$D$65=$F$65	Binding	0
$B$67:$C$67=Integer					

Figure 50: Full Demand Problem Solution