Calgary Desk Company

The Linear Programming Strategy Report 2022

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Introduction

This report is to recommend a production schedule for Calgary Desk Company for the month of September. In this report we analyse and formulate the problem, and also find an optimal solution for the given constraints. We finally present the results and detail the amount of each resource needed, if our recommendation is implemented.

The aim of CALDESCO is to maximize profits for the month of September by first meeting all given quotas of production. This becomes our first priority since the amount of production will determine if CALDESCO will have financial gain or loss in the future. Additional constraints present include labour capacity and material availability.

In this task of maximizing profit, which is the product of the profit made by each type of desk and the number of desks of that type we produce, we have the following given constraints:

Conditions:

1. **Customer Orders for September:**
   The number of desks of each type we produce must be greater than or equal to the orders of that desk by clients.

2. **Aluminium Supplies:**
   The total aluminium we use to produce desks must be less than or equal to the total supply available to us i.e. 65000 sq. ft.

3. **Particle Board Supplies:**
   The total Particle Board we use to produce desks must be less than or equal to the total supply available to us i.e.60000 sq. ft.

4. **Pine Sheet Supplies:**
   The total Pine Sheet we use to produce desks must be less than or equal to the total supply available to us i.e.175000 sq. ft.

5. **Labour Availability:**
   We have a limited amount of man-hours to us, which we must utilize for operating production lines, performing desk assembly, finishing, and handcrafting.

6. **Production Line Availability:**
   At CALDESCO, there are 3 production lines available and each has its time limitations to which we must adhere.

7. **Production Quotas:**
   CALDESCO maintains its profit margins by adhering to strict production quotas for each type of desk, which we must take into account.

Assumptions

The following are the assumptions made during this study.

Assumptions:

1. CALDESCO is not concerned with restricting variables to be integers.

2. In sensitivity analysis, if a variable or a constraint varies, we keep all the other parameters unchanged.

3. CALDESCO manages to sell every single desk they produce thanks to its production quotas.

Parameters and Variables

For the above-given optimization problem with given constraints, we have formulated the following Linear Program which we have attached in the appendix section. The following describes the parameters and variables used in the AMPL code.

Parameters and variables:

1. **desk_profit {i in 1..9}:**

   This parameter describes the profit (in USD) for each type of desk, where i=
   =1: Economy Student Desk
   =2: Economy Standard Desk
   =3: Economy Executive Desk
   =4: Basic Student Desk
   =5: Basic Standard Desk
   =6: Basic Executive Desk
   =7: Handcrafted Student Desk
   =8: Handcrafted Standard Desk
   =9: Handcrafted Executive Desk

2. **september_orders {i in 1..9}:**

   Number of orders received for the above 9 different types of desks

3. **aluminum_supply:**

   Total aluminum supply available to us (in Sq. Ft.).

4. **aluminum_req {i in 1..9}:**

   Aluminium used by each of 9 above desks (in Sq. Ft.).

5. **particle_supply:**

   Total particle board supply available to us (in Sq. Ft.).

6. **particle_req {i in 1..9}:**

   Particle board used by each of 9 above desks (in Sq. Ft.).

7. **pine_supply**:

   Total pine sheets supply available to us (in Sq. Ft.).

8. **particle_req {i in 1..9}:**

   Pine sheets used by each of 9 above desks (in Sq. Ft.).

9. **total_labor:**

   Total man-minutes available to us (in man-minutes)

10. **labor_req {i in 1..9}:**

    The assembly and finishing man-minutes required for each type of desk (in man-minutes.).

11. **handy_req { i in 1..9}:**

    The handcrafting man-minutes required for each type of desk (in man-minutes.).

12. **line_req { i in 1..9, j in 1..3}:**

    A matrix storing the amount of time required for each desk on any particular production line. Rows represent the desk, columns represent the production line (in minutes.).

13. **no_of_orders {i in 1..9}:**

    Variable which will store the number of each desk we produce in an optimal solution.

14. **total_prod:**

    Represents the total number of desks produced in an optimal solution.

Justifying Objective Function

Assuming that CALDESCO manages to sell every single desk they produce, therefore we simply manufacture as many desks as feasible given the above constraints such that we **maximize the total profit** made from these desks.

Objective function:

```
maximize total_profit: sum{i in 1..9} desk_profit[i] * no_of_orders[i];
```

Here, we have the following:

1. **desk_profit[i]:**

   the individual profit made from selling a desk of type i.

2. **no_of_orders[i]:**

   the variable we optimize which gives the number of desks of type i that we manufacture.

Justifying Constraints

Our linear programming problem will have the following constraints:

1. **subject to** total_production: total_prod = sum{i in 1..9} no_of_orders[i];

   This constraint is to store the value of the total number of desks made in variable total_production.

2. **subject to** desk_demands {i in 1..9}: no_of_orders[i] >= september_orders[i];

   The constraint states that the number of desks we produce must meet the orders received by CALDESCO for september.

3. **subject to** alum_supply: sum{i in 1..9} no_of_orders[i] * aluminum_req[i] <= aluminum_supply;

   The constraint limits our production of desks as per the availability of aluminum.

4. **subject to** particle_board_supply: sum{i in 1..9} no_of_orders[i] * particle_req[i] <= particle_supply;

   The constraint limits our production of desks as per the availability of particle board sheets.

5. **subject to** pine_sheet_supply: sum{i in 1..9} no_of_orders[i] * pine_req[i] <= pine_supply;

   The constraint limits our production of desks as per the availability of pine sheets.

6. **subject to** labor_availability: sum{i in 1..9} (no_of_orders[i]*(2*line_req[i,1] + 2*line_req[i,2] + 2*line_req[i,3] + labor_req[i] + handy_req[i])) <= total_labor;

   This constraint is very important as it includes the number of man-minutes in labor that we have available and how many man-minutes it takes to make each type of desk including the production line manning, assembly work, and handcrafting labor.

7. **subject to** production_capacity {lin in 1..3}: line_limit[lin] >= sum{d in 1..9} no_of_orders[d] * line_req[d,lin] ;

This constrains the objective function by limiting the desks produced at each production line, each of which has a maximum limit.

8. **subject to** production_quotas1a: 0.2* total_prod <= sum{i in 1..3} no_of_orders[i];

9. **subject to** production_quotas1b: 0.5* total_prod >= sum{i in 1..3} no_of_orders[i];

10. **subject to** production_quotas2a: 0.4* total_prod <= sum{i in 4..6} no_of_orders[i];

11. **subject to** production_quotas2b: 0.6* total_prod >= sum{i in 4..6} no_of_orders[i];

12. **subject to** production_quotas3a: 0.1* total_prod <= sum{i in 7..9} no_of_orders[i];

13. **subject to** production_quotas3b: 0.2* total_prod >= sum{i in 7..9} no_of_orders[i];

14. **subject to** production_quotas4a: 0.2* total_prod <= no_of_orders[1] + no_of_orders[4] + no_of_orders[7];

15. **subject to** production_quotas4b: 0.35* total_prod >= no_of_orders[1] + no_of_orders[4] + no_of_orders[7];

16. **subject to** production_quotas5a: 0.4* total_prod <= no_of_orders[2] + no_of_orders[5] + no_of_orders[8];

17. **subject to** production_quotas5b: 0.7* total_prod >= no_of_orders[2] + no_of_orders[5] + no_of_orders[8];

18. **subject to** production_quotas6a: 0.05* total_prod <= no_of_orders[3] + no_of_orders[6] + no_of_orders[9];

19. **subject to** production_quotas6b: 0.15* total_prod >= no_of_orders[3] + no_of_orders[6] + no_of_orders[9];

The above 12 constraints help us to adhere to CALDESCO's production quotas for each type of desk, and each class of desk. Each type and class of desks which are produced must fit some percentage of the total desks produce so that the company stays profitable.

There are 2 constraints, one for less than, one for greater than for 3 types, and 3 classes of desks, making for a total of 12 constraints.

AMPL Codes

6.1 Model

case1.dat | case1.mod | result.txt | result_con.txt | result_var.txt

```
reset;

#params-----------------------------------------------------------------------

param desk_profit{i in 1..9};

param september_orders{i in 1..9};

param aluminum_supply;
param aluminum_req{i in 1..9};

param particle_supply;
param particle_req{i in 1..9};

param pine_supply;
param pine_req{i in 1..9};

param total_labor;
param labor_req{i in 1..9};
param handy_req{i in 1..9};


param line_req {i in 1..9,j in 1..3};
param line_limit{i in 1..3};


#variables--------------------------------------------------------------------

var no_of_orders{i in 1..9}>=0;
var total_prod>=0;

#objective function-----------------------------------------------------------

maximize total_profit: sum{i in 1..9} desk_profit[i] * no_of_orders[i];

```

case1.dat | case1.mod | result.txt | result_con.txt | result_var.txt

```
#constraints-------------------------------------------------------------------------------------:

subject to total_production: total_prod = sum{i in 1..9} no_of_orders[i];

subject to desk_demands {i in 1..9}: no_of_orders[i] >= september_orders[i];

subject to alum_supply: sum{i in 1..9} no_of_orders[i] * aluminum_req[i] <= aluminum_supply;

subject to particle_board_supply: sum{i in 1..9} no_of_orders[i] * particle_req[i] <= particle_supply;

subject to pine_sheet_supply: sum{i in 1..9} no_of_orders[i] * pine_req[i] <= pine_supply;

subject to labor_availability: sum{i in 1..9} (no_of_orders[i]*(2*line_req[i,1] + 2*line_req[i,2] + 2*line_req[i,3] + labor_req[i] + handy_req[i] )) <= total_labor;

subject to production_capacity {lin in 1..3}: line_limit[lin] >= sum{d in 1..9} no_of_orders[d] * line_req[d,lin] ;

subject to production_quotas1a: 0.2* total_prod <= sum{i in 1..3} no_of_orders[i];
subject to production_quotas1b: 0.5* total_prod >= sum{i in 1..3} no_of_orders[i];

subject to production_quotas2a: 0.4* total_prod <= sum{i in 4..6} no_of_orders[i];
subject to production_quotas2b: 0.6* total_prod >= sum{i in 4..6} no_of_orders[i];

subject to production_quotas3a: 0.1* total_prod <= sum{i in 7..9} no_of_orders[i];
subject to production_quotas3b: 0.2* total_prod >= sum{i in 7..9} no_of_orders[i];

subject to production_quotas4a: 0.2* total_prod <= no_of_orders[1] + no_of_orders[4] + no_of_orders[7];
subject to production_quotas4b: 0.35* total_prod >= no_of_orders[1] + no_of_orders[4] + no_of_orders[7];

subject to production_quotas5a: 0.4* total_prod <= no_of_orders[2] + no_of_orders[5] + no_of_orders[8];
subject to production_quotas5b: 0.7* total_prod >= no_of_orders[2] + no_of_orders[5] + no_of_orders[8];

subject to production_quotas6a: 0.05* total_prod <= no_of_orders[3] + no_of_orders[6] + no_of_orders[9];
subject to production_quotas6b: 0.15* total_prod >= no_of_orders[3] + no_of_orders[6] + no_of_orders[9];
```

6.2 Data

case1.dat | case1.mod | result.txt | result_con.txt | result_var.txt

```
#data:

param desk_profit :=
    1 20
    2 30
    3 40
    4 50
    5 80
    6 125
    7 100
    8 250
    9 325;

param september_orders :=
    1 750
    2 1500
    3 100
    4 400
    5 1500
    6 100
    7 25
    8 150
    9 50;

param aluminum_supply := 65000;
param aluminum_req :=
    1 14
    2 24
    3 30
    4 0
    5 0
    6 0
    7 0
    8 0
    9 0;

param particle_supply := 60000;
param particle_req :=
    1 8
    2 15
    3 24
    4 0
    5 0
```

case1.dat | case1.mod | result.txt | result

```
param particle_supply := 60000;
param particle_req :=
    1 8
    2 15
    3 24
    4 0
    5 0
    6 0
    7 0
    8 0
    9 0;

param pine_supply := 175000;
param pine_req :=
    1 0
    2 0
    3 0
    4 22
    5 40
    6 55
    7 25
    8 45
    9 60;

param total_labor := 230400;
param labor_req :=
    1 10
    2 11
    3 12
    4 15
    5 18
    6 20
    7 20
    8 25
    9 30;
param handy_req :=
    1 0
    2 0
    3 0
    4 0
    5 0
    6 0
    7 50
```

case1.dat | case1.mod | result.tx

```
param handy_req :=
    1 0
    2 0
    3 0
    4 0
    5 0
    6 0
    7 50
    8 60
    9 70;


param line_req:
            1 2 3 :=
    1       1.5 1.0 0.0
    2       2.0 1.0 0.0
    3       2.5 1.0 0.0
    4       0.0 1.0 3.0
    5       0.0 1.0 4.0
    6       0.0 1.0 5.0
    7       0.0 0.0 3.0
    8       0.0 0.0 4.0
    9       0.0 0.0 5.0;

param line_limit:=
1 9600
2 9600
3 19200;

```

6.3 Solutions or Results

:	_objname	_obj	_varname	_var	:=
1	total_profit	612113	'no_of_orders[1]'	750	
2	.	.	'no_of_orders[2]'	1500	
3	.	.	'no_of_orders[3]'	100	
4	.	.	'no_of_orders[4]'	525.537	
5	.	.	'no_of_orders[5]'	1657.5	
6	.	.	'no_of_orders[6]'	825.403	
7	.	.	'no_of_orders[7]'	25	
8	.	.	'no_of_orders[8]'	1069.24	
9	.	.	'no_of_orders[9]'	50	
10	.	.	total_prod	6502.69	

;

Sensitivity Analysis

Now that we have formulated the problem and obtained optimal results we can now focus on how we can change our constraints or variables and what kind of effect they will cause on our profits. A few natural questions to ask would be:

- How will my production plan change if I decide to produce 10 more economy student desks?
- If I increase the supply of Aluminium how will that affect my objective function?
- How much surplus do I have and how much can I reduce this to without having any impact on my profit levels?

The report below answers all possible such questions.

Solutions for each variable:

Our report suggests that we produce the following number of desks of each type in order to obtain the most optimal profits.

- **Economy student**: 750
- **Economy Standard:** 1500
- **Economy Executive:** 100
- **Basic Student:** 525.537
- **Basic Standard:** 1657.5
- **Basic Executive:** 825.403
- **Handcrafted Student:** 25
- **Handcrafted Standard:** 1069.24
- **Handcrafted Executive:** 50

If we produce these numbers we are promised a **profit of $612113.**

Variables	Economy Student	Economy Standard	Economy Executive	Basic Student	Basic Standard	Basic Executive	Hand Craft Student	Hand Craft Standard	Hand Craft Executive
Solutions	750	1500	100	525.537	1657.5	825.403	25	1069.24	50

Reduced Cost:

The reduced cost translates to how much the objective function (Total Profit) will reduce if a variable that is supposed to be zero is made non-zero. The reduced cost assumes value 0 if the variables have a definite value. Since our solution has a value for every single type of desk as shown above, every one of our reduced cost is 0 or a very low insignificant value.

Variable Upper Bounds:

Upper bound can be interpreted as how much we can increase our value of the coefficient of a variable in the objective function without having to re-solve our whole problem and in turn get new solutions.

Category	Economy Student	Economy Standard	Economy Executive	Basic Student	Basic Standard	Basic Executive	Hand Craft Student	Hand Craft Standard	Hand Craft Executive
Upper bound	24. 062	42.049	78.3773	61.6671	83.0628	171.259	188.363	270.172	328.766

- **Economy Student**: Currently the profit made out of each economy student desk is $20. We can make this as high as $24.0623 and we will still have the same solution for production levels. If it exceeds $24.0623 we have to solve the problem again in order to get new production levels.

- **Economy Standard**: Currently the profit made out of each economy standard desk is $30. We can make this as high as $42.0494 and we will still have the same solution for production levels. If it exceeds $42.0494 we have to solve the problem again in order to get new production levels.

- **Economy Executive**: Currently the profit made out of each economy student desk is $40. We can make this as high as $78.3373 and we will still have the same solution for production levels. If it exceeds $78.3373 we have to solve the problem again in order to get new production levels.

- **Basic Student**: Currently the profit made out of each economy student desk is $50. We can make this as high as $61.6671 and we will still have the same solution for production levels. If it exceeds $61.6671 we have to solve the problem again in order to get new production levels.

- **Basic Standard**: Currently the profit made out of each economy standard desk is $80. We can make this as high as $83.0628 and we will still have the same solution for production levels. If it exceeds $83.0628 we have to solve the problem again in order to get new production levels.

- **Basic Executive**: Currently the profit made out of each economy student desk is $150. We can make this as high as $171.259 and we will still have the same solution for production levels. If it exceeds $171.259 we have to solve the problem again in order to get new production levels.

- **Hand-Crafted Student**: Currently the profit made out of each economy student desk is $100. We can make this as high as $188.363 and we will still have the same solution for production levels. If it exceeds $188.363 we have to solve the problem again in order to get new production levels.

- **Hand-Crafted Standard**: Currently the profit made out of each economy standard desk is $250. We can make this as high as $270.172 and we will still have the same solution for production levels. If it exceeds $270.172 we have to solve the problem again in order to get new production levels.

- **Hand-Crafted Executive**: Currently the profit made out of each economy student desk is $325. We can make this as high as $328.766 and we will still have the same solution for production levels. If it exceeds $328.766 we have to solve the problem again in order to get new production levels.

Variable Lower Bounds:

Lower bound can be interpreted as how much we can decrease our value of the coefficient of a variable in the objective function without having to re-solve our whole problem and in turn get new solutions.

Category	Economy Student	Economy Standard	Economy Executive	Basic Student	Basic Standard	Basic Executive	Hand Craft Student	Hand Craft Standard	Hand Craft Executive
Lower Bound	-infinity	-infinity	-infinity	45.399	72.0293	121.219	infinity	246.892	infinity

- **Economy Student**: Currently the profit made out of each economy student desk is $20. We can make this as low as negative infinity and we will still have the same solution for production levels.This means this can be as low as possible and it would make no difference to the optimization problem and our production levels would be the same

- **Economy Standard**: Currently the profit made out of each economy standard desk is $30. We can make this as low as negative infinity and we will still have the same solution for production levels.This means this can be as low as possible and it would make no difference to the optimization problem and our production levels would be the same .

- **Economy Executive**: Currently the profit made out of each economy student desk is $40. We can make this as low as negative infinity and we will still have the same solution for production levels.This means this can be as low as possible and it would make no difference to the optimization problem and our production levels would be the same

- **Basic Student**: Currently the profit made out of each economy student desk is $50. We can make this as low as $45.3989 and we will still have the same solution for production levels. If we reduce it lower than $45.3989, we would have to solve the problem again in order to get the new production levels.

- **Basic Standard**: Currently the profit made out of each economy standard desk is $80. We can make this as low as $72.0293 and we will still have the same solution for production levels. If we reduce it lower than $72.0293, we would have to solve the problem again in order to get the new production levels.

- **Basic Executive**: Currently the profit made out of each economy student desk is $150. We can make this as low as $121.219 and we will still have the same solution for production levels. If we reduce it lower than $121.219, we would have to solve the problem again in order to get the new production levels.

- **Hand-Crafted Student**: Currently the profit made out of each economy student desk is $100. We can make this as low as negative infinity and we will still have the same solution for production levels. This means this can be as low as possible and it would make no difference to the optimization problem and our production levels would be the same

- **Hand-Crafted Standard**: Currently the profit made out of each economy standard desk is $250. We can make this as low as $246.892 and we will still have the same solution for production levels. If we reduce it lower than $246.892, we would have to solve the problem again in order to get the new production levels.

- **Hand-Crafted Executive**: Currently the profit made out of each economy student desk is $325. We can make this as low as negative infinity and we will still have the same solution for production levels.This means this can be as low as possible and it would make no difference to the optimization problem and our production levels would be the same.

Shadow Prices:

This can be interpreted as how much the objective value (Total Profit) changes for a unit change in each of the following constraints.

Category	Economy Student	Economy Standard	Economy Executive	Basic Student	Basic Standard	Basic Executive	Hand Craft Student	Hand Craft Standard	Hand Craft Executive
Shadow Price	-4.0623	-12.0494	-38.337	0	0	0	-88.36	0	-3.7655

- **Demand of Economy Student**: The current demand of desk type economy student is 750. The shadow price of this constraint is -$4.06234, which is the decrease in the amount of profit that we are maximizing, if the demand increases by 1 unit.

- **Demand of Economy Standard**: The current demand of desk type economy standard is 1500. The shadow price of this constraint is -$12.0494, which is the decrease in the amount of profit that we are maximizing, if the demand increases by 1 unit.

- **Demand of Economy Executive**: The current demand of desk type economy executive is 100. The shadow price of this constraint is -$38.3373, which is the decrease in the amount of profit that we are maximizing, if the demand increases by 1 unit.

- **Demand of Basic Student**: The current demand of desk type economy standard is 400. The shadow price of this constraint is 0, which means there will be no change in the optimization problem if we change the demand by 1 unit as we already have surplus of this constraint. Hence, adding one more wouldn't contribute to the profit.

- **Demand of Basic Standard**: The current demand of desk type economy standard is 1500. The shadow price of this constraint is 0, which means there will be no change in the optimization problem if we change the demand by 1 unit as we already have surplus of this constraint. Hence, adding one more wouldn't contribute to the profit.

- **Demand of Basic Executive**: The current demand of desk type economy standard is 125. The shadow price of this constraint is 0, which means there will be no change in the optimization problem if we change the demand by 1 unit as we already have surplus of this constraint. Hence, adding one more wouldn't contribute to the profit.

- **Demand of Hand-Crafted Student**: The current demand of desk type economy student is 100. The shadow price of this constraint is -$88.3629, which is the decrease in the amount of profit that we are maximizing, if the demand increases by 1 unit.

- **Demand of Hand-Crafted Standard**: The current demand of desk type hand-crafted standard is 250. The shadow price of this constraint is 0, which means there will be no change in the optimization problem if we change the demand by 1 unit as we already have surplus of this constraint. Hence, adding one more wouldn't contribute to the profit.

- **Demand of Hand-Crafted Executive**: The current demand of desk type economy student is 325. The shadow price of this constraint is -$3.7655, which is the decrease in the amount of profit that we are maximizing, if the demand increases by 1 unit.

Supply:

- Aluminum: We have a shadow price of 0. Demand is 65000. This means there is surplus and adding one more unit to resource availability won't make a difference as we are already not reaching limits.

- Particle Board: We have a shadow price of 0. Demand is 60000. This means there is surplus and adding one more unit to resource availability won't make a difference as we are already not reaching limits.

- Pine Sheet: We have a shadow price of $0.234495 which is the increase in our profit if pine sheet availability increases by 1 unit.

Labor:

We have a shadow price of $2.59735 which is the increase in our profit if labor availability increases by 1 unit.

Production Capacity of Lines:
Shadow Price of the production capacity of all the available 3 lines is 0. This means that there we aren't exploiting the maximum out of the productions lines and hence increasing the capacity of these lines would make no difference to the profits.

Production Quotas of different Lines:
The production has a constraint on what is the minimum and maximum composition of each line (economy, basic,hand-crafted). These constraints all have shadow price 0 which means we are not producing the limit of any of these lines and increasing the composition by 1 unit will have no effect on the profits

Production Quotas of different types/sizes of the desks:

- The production has a constraint on what is the minimum and maximum composition of each type/size (student, standard,executive). The shadow price of standard is 0 and hence increasing this composition by 1 unit will have no effect on profits.

- The shadow price of student is 0 for the maximum composition. But for the minimum constraint, the shadow price is $12.7924 which means that if you increase the minimum composition constraint by 1 unit our profits would increase by $12.7924.

- The shadow price for executive is 0 for the minimum composition but for maximum composition it is -$31.0932. This means that if we increase the maximum composition by 1 unit, it would decrease our profits by $31.0932.

Slack:

This can be interpreted as how much surplus availability we have in our constraints that we haven't used. If there exists a shadow price, then slack is 0 as it means we have used our resources to our maximum capacity .

Category	Economy Student	Economy Standard	Economy Executive	Basic Student	Basic Standard	Basic Executive	Hand Craft Student	Hand Craft Standard	Hand Craft Executive
Slack of Demand	0	0	0	125.537	157.501	725.403	0	919.244	0

- **Demand of Economy Student**: The slack is 0 and this means we are producing exactly how much is required and don't have any surplus.
- **Demand of Economy Standard**: The slack is 0 and this means we are producing exactly how much is required and don't have any surplus.
- **Demand of Economy Executive**: The slack is 0 and this means we are producing exactly how much is required and don't have any surplus.
- **Demand of Basic Student**: The slack is 125.537 which means our respective shadow price is 0. This means that we are producing 125.537 more than the demand and hence have a surplus.
- **Demand of Basic Standard**: The slack is 157.501 which means our respective shadow price is 0. This means that we are producing 157.501 more than the demand and hence have a surplus.
- **Demand of Basic Executive**: The slack is 725.403 which means our respective shadow price is 0. This means that we are producing 725.403 more than the demand and hence have a surplus.
- **Demand of Hand-Crafted Student**: The slack is 0 and this means we are producing exactly how much is required and don't have any surplus.
- **Demand of Hand-Crafted Standard**: The slack is 919.244 which means our respective shadow price is 0. This means that we are producing 919.244more than the demand and hence have a surplus.
- **Demand of Hand-Crafted Executive**: The slack is 0 and this means we are producing exactly how much is required and don't have any surplus.

Supply:

- **Aluminum:** We have a slack of 15500 for Aluminum. This means that out of the 65000 square feet of aluminum we have we are only using 49500 square feet to get the most optimal solution. The rest is surplus and hence the **shadow price for this constraint is 0.**

- **Particle Board:** We have a slack of 29100 for Particle Board. This means that out of the 60000 square feet of aluminum we have we are only using 30900 square feet to get the most optimal solution. The rest is surplus and hence the **shadow price for this constraint is 0.**

- **Pine Sheet:** The slack is 0 and this means we are using the pine sheet to its maximum extent and **don't have any surplus.**

Labour:

The slack is 0 and this means we are exploiting the labour to its maximum extent and don't have any more labour to deploy or use.

Production Capacity of Lines:

- Production capacity of line 1 has a maximum usage time of 9600 minutes and the slack is 5225. This means only 4375 minutes of this line is being used to get the most optimal solution. Hence the shadow price is 0.

- Production capacity of line 2 has a maximum usage time of 9600 minutes and the slack is 4241.56. This means only 5358.44 minutes of this line is being used to get the most optimal solution. Hence the shadow price is 0.

- Production capacity of line 3 has a maximum usage time of 19200 minutes and the slack is 2264.39. This means only 16935.61 minutes of this line is being used to get the most optimal solution. Hence the shadow price is 0.

Production Quotas of different Lines:

- The production quota of Economy Line has a slack of 1049.46 for the minimum composition. This means that we can reduce our production of the Economy line by 1049.46 and still ensure our constraint is satisfied but we get our optimal solution only when the current production levels are maintained.

- The production quota of Economy Line has a slack of 901.343 for the maximum composition. This means that we can increase our production of the Economy line by 901.343 and still ensure our constraint is satisfied but we get our optimal solution only when the current production levels are maintained.

- The production quota of Basic Line has a slack of 407.367 for the minimum composition. This means that we can reduce our production of the Basic line by 407.367 and still ensure our constraint is satisfied but we get our optimal solution only when the current production levels are maintained.

- The production quota of Basic Line has a slack of 893.17 for the maximum composition. This means that we can increase our production of the Basic line by 893.17 and still ensure our constraint is satisfied but we get our optimal solution only when the current production levels are maintained.

- The production quota of Hand-Crafted Line has a slack of 493.976 for the minimum composition. This means that we can reduce our production of the Hand-Crafted Line by 493.976 and still ensure our constraint is satisfied but we get our optimal solution only when the current production levels are maintained.

- The production quota of Hand-Crafted Line has a slack of 156.293 for the maximum composition. This means that we can increase our production of the Hand-Crafted Line by 156.293 and still ensure our constraint is satisfied but we get our optimal solution only when the current production levels are maintained.

Production Quotas of different types/sizes of the desks:

- The production quota of Student type has a slack of 0 for the minimum composition. This means that we cannot reduce our production of the Student type further as we are already at the lower limit of production and hence this has a non-zero shadow price.

- The production quota of Student type has a slack of 975.403 for the maximum composition. This means that we can increase our production of the Student type by 975.403 and still ensure our constraint is satisfied but we get our optimal solution only when the current production levels are maintained.

- The production quota of Standard type has a slack of 1625.67 for the minimum composition. This means that we can reduce our production of the Standard type by 1625.67 and still ensure our constraint is satisfied but we get our optimal solution only when the current production levels are maintained.

- The production quota of Standard type has a slack of 325.134 for the maximum composition. This means that we can increase our production of the Standard type by 325.134 and still ensure our constraint is satisfied but we get our optimal solution only when the current production levels are maintained.

- The production quota of Executive type has a slack of 650.269 for the minimum composition. This means that we can reduce our production of the Executive type by 650.269 and still ensure our constraint is satisfied but we get our optimal solution only when the current production levels are maintained.

- The production quota of Executive type has a slack of 0 for the maximum composition. This means that we cannot increase our production of the Executive type further as we are already at the upper limit of production and hence this has a non-zero shadow price.

Constraints Upper Bounds:

Constraints or Dual Upper Bound can be interpreted as the range in which we can change the given constraints without having to re-solve our whole problem and in turn get new solutions.

Category	Aluminium Supply	Particle board supply	Pine sheet supply	Labour Availability	Production line 1 capacity	Production line 2 capacity	Production line 3 capacity
Upper bounds	infinity	infinity	195940	239325	0	infinity	infinity

Supply:

- Aluminum: The availability of aluminum for the month of September is 65000 units. The upper bound is infinite, implying that even if we increase the aluminum availability to infinite units we will still use 49500 units which is the lower bound. The profit will not increase because the shadow price is 0. Therefore even if we increase the availability of aluminum we will still make the same profit

- Particle Board: Similarly, for particle board, we have an availability of 60000 units, shadow price of 0 and the upper bound as infinity. Therefore, like aluminum, even if we increase the availability of Particle boards it won't have any effect on the profit, since we will use only 30900 units.

- Pine Sheet: In the case of Pine sheet, the availability is 175000 units. The shadow price is 0.234495 and the upper bound is 195940. Which implies that the availability can be increased from 175000 till 195940 and the corresponding profit will increase by 0.234495(shadow price) for each unit increase in the availability.

Labor:

The labor availability for the month of september is 230400, the shadow price is 2.59735 and the upper bound is 239325 which implies that we can increase the availability from 230400 up until 239325 and the overall profit will increase by 2.59735 (shadow price) for each unit increase in the Labor availability.

Production Capacity of Lines:

- The maximum usage capacity for production line 2 is 9600 minutes, the shadow price is 0 and the upper bound is infinity units which implies that even if we increase the capacity it won't have any effect on the overall profit.

- The maximum usage capacity for production line 3 is 19200 minutes, the shadow price is 0 and the upper bound is infinity which implies that we can increase the capacity from 19200 to infinity without any effect on the overall profit.

Constraints Lower Bounds:

Category	Aluminium Supply	Particle board supply	Pine sheet supply	Labour Availability	Production line 1 capacity	Production line 2 capacity	Production line 3 capacity
Lower bounds	49500	30900	169646	200443	0	5358.44	16935.6

Lower bound can be interpreted as how much we can decrease our value of the coefficient of a constraints in the dual objective function without having to re-solve our whole problem and in turn get new solutions.

Supply:

- Aluminium: The availability of aluminium for the month of September is 65000 units and shadow price 0. The lower bound is 49500, implying that if we decrease the aluminium availability lower than 49500 units. We will have to re-solve the problem to calculate the new profit

- Particle Board: Similarly, for particle board, we have an availability of 60000 units, shadow price of 0 and the lower bound is 30900. Therefore, like aluminum, if we decrease the Particle board availability lower than 30900 units. We will have to re-solve the problem to calculate the new profit

- Pine Sheet: In the case of Pine sheet, the availability is 175000 units. The shadow price is 0.234495 and the lower bound is 169646. Which implies if we decrease the Pine sheet availability by one unit our profit will decrease by the factor of Shadow price(0.234495). And if we decrease the availability beyond the lower bound 169646 then we will have to re-solve the problem to calculate the new profit.

Labour:

The Labour availability is 230400 units. The shadow price is 2.59735 and the lower bound is 200443. Which implies if we decrease the labour availability by one unit our profit will decrease by the factor of Shadow price(2.59735). And if we decrease the availability beyond the lower bound 200443 then we will have to re-solve the problem to calculate the new profit.

Production Capacity of Lines:

- The maximum usage for production line 2 is 9600 minutes, the shadow price is 0 and the lower bound is 5358.44 units which implies that we can decrease the usage from 9600 up until 5358.44 without any change in the overall profit for each unit decrease in the

production capacity because shadow price is 0. And if we decrease the production usage beyond 5358.44 units then we will have to re-solve the problem to calculate the new profit.

- The maximum usage for production line 3 is 19200 minutes, the shadow price is 0 and the lower bound is 16935.6 units which implies that we can decrease the capacity from 19200 up until 16935.6 without any change in the overall profit for each unit decrease in the production usage because shadow price is 0. And if we decrease the production usage beyond 16935.6 units then we will have to re-solve the problem to calculate the new profit.

Lower and upper bound interpretation for Production quotas

- For the production quota of Economy desks we can produce 1049.46 less or 901.343 more desks than what we are producing now.

- For the production quota of Basic desks we can produce 407.367 less or 893.17 more desks than what we are producing now.

- For the production quota of Handcrafted desks we can produce 493.976 less or 156.293 more desks than what we are producing now.

- For the production quota of Student desks we can produce 281.915 less or 975.403 more desks than what we are producing now.

- For the production quota of Standard desks we can produce 1625.67 less or 325.134 more desks than what we are producing now.

- For the production quota of Executive desks we can produce 650.269 less or 331.807 more desks than what we are producing now.

THANK YOU

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