

Decision Support System for Managers
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Week – 12
Module – 06
Lecture – 60
DSS for Multi-item Production-Distribution Planning

Hi, welcome to this last module on ‘Decision Support Systems for Operations Management’!
And in this module, we are basically going to talk about ‘Decision Support Systems for Multi-
- item Production-Distribution Planning’; ok.

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So, we will be basically discussing about the formulation of this kind of problems where, multiple items are involved and there are multiple plants; ok. So, multi-item production-distribution planning for a multi-plant operating company is the topic of today’s discussion.

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Multi-Item Production-Distribution Planning

❖ Background of the Problem

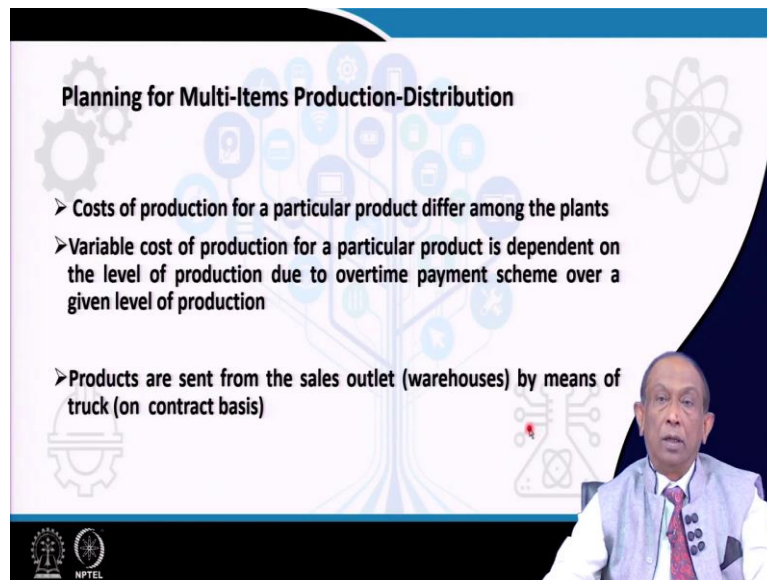
- Company engaged in the manufacturing of consumer goods
- Four manufacturing plants situated at different places in the country
- Eight warehouses at different locations
- Product 1 can be manufactured in all the four plants
- Product 2 can be manufactured in plant 1, plant 2, and plant 3 only.

The slide features a background with various icons related to manufacturing and logistics, including gears, a network diagram, and a chemical structure. A video inset in the bottom right corner shows a man in a white shirt and tie speaking. The NPTEL logo is visible in the bottom left corner of the slide.

Let us talk about the background of the problem, it is a real life problem; wherein a company is engaged in the manufacturing of consumer goods basically the company is producing batteries. Now, they have four manufacturing plants situated at different places in the country and they have eight warehouses at different locations within the country and to make the whole thing much more simplified we are basically restricting ourselves to two products; ok.

So, product 1 can be manufactured in all the four plants, we have already said that the company is having four manufacturing plants and product 1 is manufactured in all the four plants. Product 2 can be manufactured in plant 1, plant 2 and plant 3 only, it cannot be manufactured in plant 4.

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Planning for Multi-Items Production-Distribution

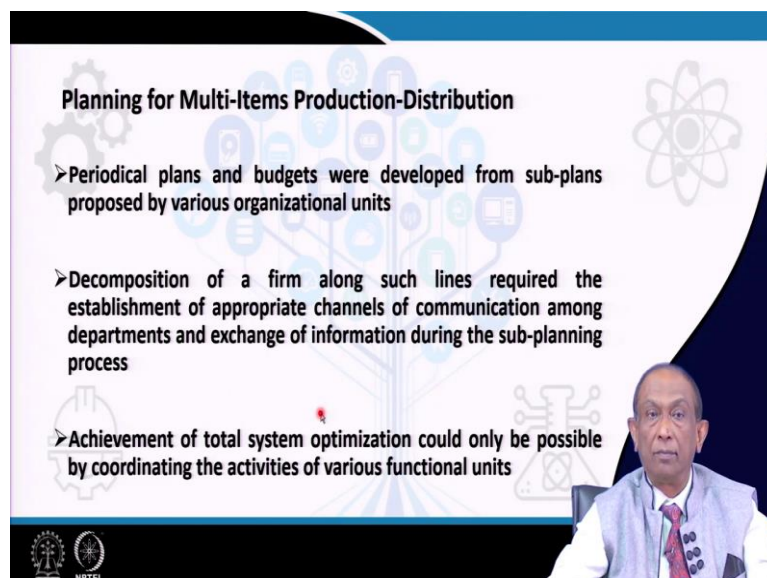
- Costs of production for a particular product differ among the plants
- Variable cost of production for a particular product is dependent on the level of production due to overtime payment scheme over a given level of production
- Products are sent from the sales outlet (warehouses) by means of truck (on contract basis)

The slide features a background with a stylized tree of icons representing various business and technology concepts. A speaker, a man in a white shirt and tie, is visible in the bottom right corner. The NPTEL logo is in the bottom left corner.

Now, the costs of production for a particular product differ among the plants this is the first observation that was noted by the operations management group of that company. Variable cost of production for a particular product is dependent on the level of production due to some overtime payment scheme existing in the company.

And this overtime payment is dependent on the amount of production that takes place over a given level of production. Products are sent from the sales outlet that is the warehouses by means of trucks and this is on contract basis.

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Planning for Multi-Items Production-Distribution

- Periodical plans and budgets were developed from sub-plans proposed by various organizational units
- Decomposition of a firm along such lines required the establishment of appropriate channels of communication among departments and exchange of information during the sub-planning process
- Achievement of total system optimization could only be possible by coordinating the activities of various functional units

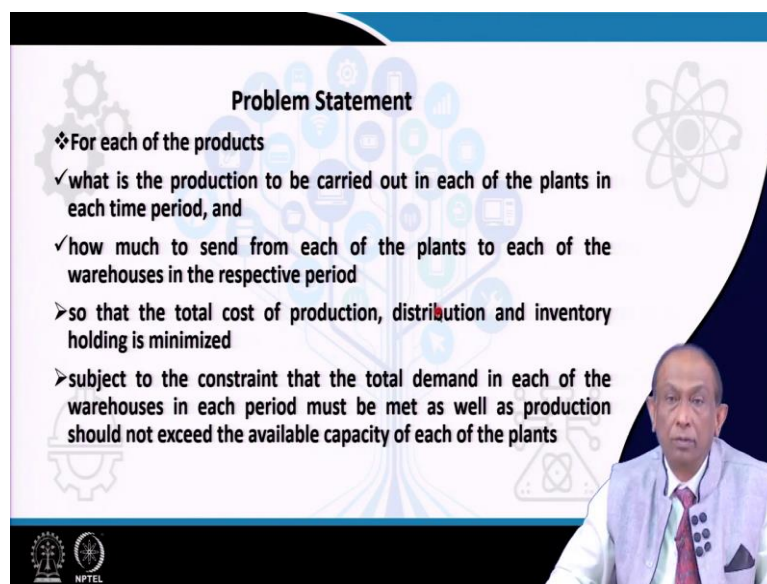
The slide features a background with a stylized tree of icons representing various business and technology concepts. A speaker, a man in a white shirt and tie, is visible in the bottom right corner. The NPTEL logo is in the bottom left corner.

Now, in this company before such kind of decision support systems were implemented they used to have periodical plans and budgets that were developed from sub plans proposed by various organizational units.

Now decomposition of a firm along such lines require the establishment of appropriate channels of communication among departments and they have to carry out exchange of information during this sub-planning process.

So, until and unless the entire coordination activities takes place in a most efficient manner it becomes very difficult to operate. So, that is why achievement of total system optimization in such a circumstance can only be made possible by coordinating the activities of various functional units of the plant in the most efficient manner.

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Problem Statement

- ❖ For each of the products
 - ✓ what is the production to be carried out in each of the plants in each time period, and
 - ✓ how much to send from each of the plants to each of the warehouses in the respective period
 - so that the total cost of production, distribution and inventory holding is minimized
 - subject to the constraint that the total demand in each of the warehouses in each period must be met as well as production should not exceed the available capacity of each of the plants

The slide features a background with gear and atom icons. In the bottom right corner, there is a video inset of a man in a white shirt and red tie speaking. The NPTEL logo is visible in the bottom left corner.

Now, when this decision support system was proposed the company management deliberated upon the different problems that they were facing and they also expressed what they expect out of the system.

So, a detailed requirement analysis was carried out and based on that the problem was formulated. So, what is the problem? The problem is that for each of the products that the plant is manufacturing, they would like to know from the system: what is the production volume that must be carried out in each of the plants in each time period; this is the first.

So, how much production should take place in each of the plant in each time period and since this is a production distribution problem from the distribution aspect how much to send from each of the plants to each of the warehouses in the respective period.

First portion is the production related the level of production to be carried out in each of the plants in each time period and in that same time period how much to send from each of the plants to each of the warehouses that is the sales outlets.

In such a way, that the total cost of production, distribution and inventory holding is minimized. So, the objective function is minimized total cost of production, distribution and inventory holding. Subject to the constraint that the total demand in each of the warehouses that is in each of the sales outlets in each period must be met as well as the production should not exceed the available capacity of each of the plants.

So, once again the problem statement is minimize total cost of production, distribution and inventory holding subject to the constraint that the total requirement in each of these sales outlets in each period must be met this is the first constraint.

The second constraint is that the production should not exceed the available capacity of each of the plants. The decision variables are the level of production that need to be carried out in each of the plants in each time period and the second one is how much to send from each of the plants to each of the sales outlets in that period in that respective period. So, let us see how the problem has been formulated.

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The slide features a central graphic of a tree with various icons (gears, a smartphone, a laptop, a document, a person) as leaves. The title 'Problem Statement' is at the top center. The bullet points are as follows:

- The planning horizon is taken as one year and
- Each time period is considered to be of six (6) months duration
- to help the management in making production-related decisions in their semi-annual budget meeting

The slide also includes a hard hat icon on the left, a circuit board icon on the right, and the NPTEL logo at the bottom left. A speaker is visible in the bottom right corner of the slide frame.

And before we get into that mathematical statement of problem formulation, we need to also state that the planning horizon is taken as one year and every year before the strategic planning of the company takes place the results of the decision support system must be made available to the planning managers.

And each time period is considered to be of 6 months duration because that will help the management in making production related decision in their semi-annual budget meeting. So, once again the planning horizon is 1 year and within 1 year each time period is of 6 months duration. So, there are two time periods within 1 year.

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Problem Statement

- ✓ At which manufacturing location increase of capacity in each time period will be profitable for the company ?
- ✓ The sensitivity of the transport-related costs, the demand pattern remaining the same

The slide features a background with a stylized tree of icons and various symbols like gears, a hard hat, and a circuit board. The NPTEL logo is visible in the bottom left corner. A speaker is overlaid on the right side of the slide.

The management is also interested to know that, at which manufacturing location increase of capacity in each time period will be profitable for the company. And they also would like to know the sensitivity of the transport related costs, the demand pattern remaining the same.

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Data Collection

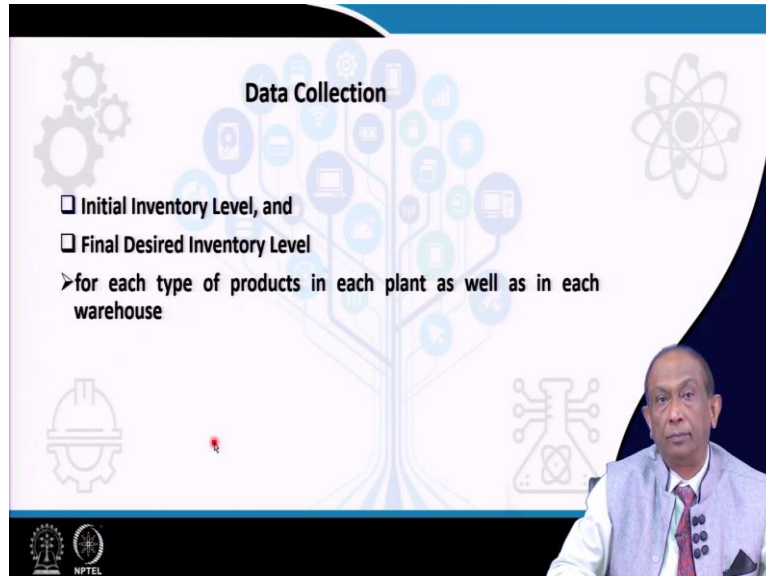
- Forecasted Demand for the products in each period at each of the Warehouses
- Transportation Costs for each type of products to be shipped from each plant to each warehouse

The slide features a background with a stylized tree of icons and various symbols like gears, a hard hat, and a circuit board. The NPTEL logo is visible in the bottom left corner. A speaker is overlaid on the right side of the slide.

Related to collection of data the decision support systems personnel they collected forecasted demand for the products in each period at each of the warehouses that is the sales outlets. So, you require the forecast demand of different products in each period at each of the sales

outlets and that was collected. Transportation costs for each type of products to be shipped from each plant to each warehouse were also collected.

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Data Collection

- Initial Inventory Level, and
- Final Desired Inventory Level

➤ for each type of products in each plant as well as in each warehouse

The slide features a background with a stylized tree of icons representing various data points and a speaker in the bottom right corner. The NPTEL logo is visible in the bottom left corner.

The other relevant data needed for solving this problem where the initial inventory level at each of the plants and sales outlets. The final desired inventory level for each type of products in each plant as well as in each warehouse so, initial and final inventory level for each type of products in each plant as well as in each warehouse were collected.

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Data Collection

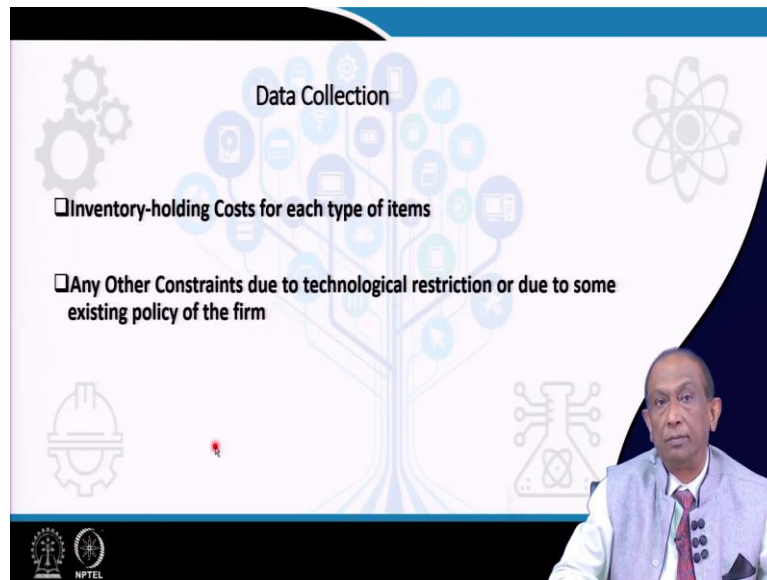
- Available production capacity of the respective plants
- Regular-time production cost, as well as
- Overtime production cost

➤ for each type of products in each of the plants

The slide features a background with a stylized tree of icons representing various data points and a speaker in the bottom right corner. The NPTEL logo is visible in the bottom left corner.

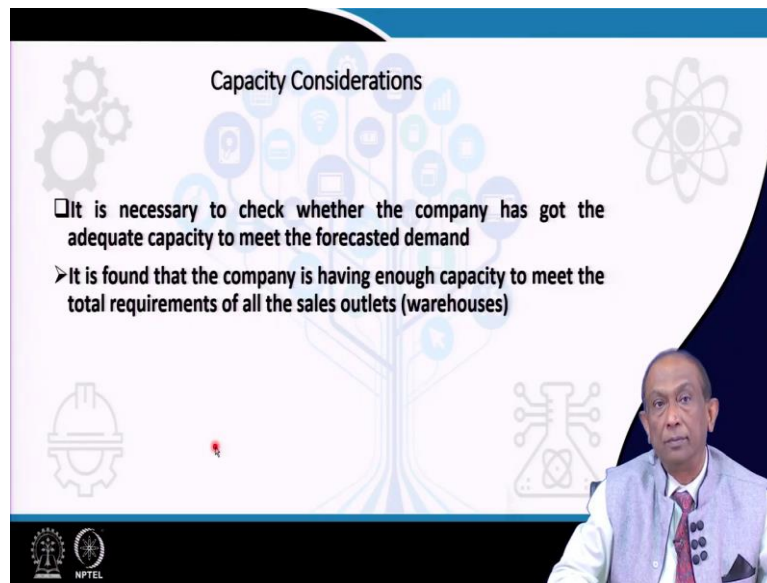
The other additional data that were required or the available production capacity of the respective plants a regular time production cost of the different products as well as overtime production cost for each type of products in each of these plants.

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Inventory holding costs for each product that is for each type of items were also collected from the finance department. And also the DSS team they interviewed the operating managers to find out whether there are any other constraints due to technological restrictions or due to some existing policy of the firm and they have one such kind of constraints which was also noted and the relevant data collected.

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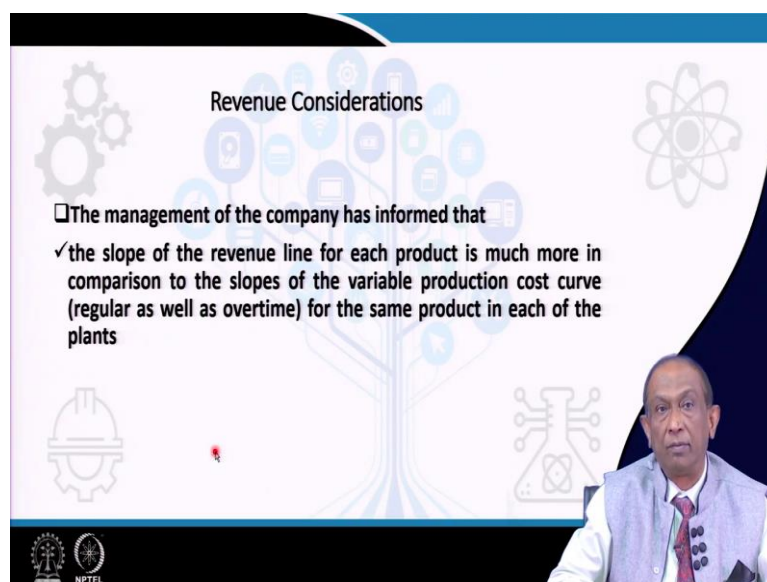
The slide is titled "Capacity Considerations" and features a background with a stylized tree of icons representing various business and technology concepts. The text on the slide is as follows:

- It is necessary to check whether the company has got the adequate capacity to meet the forecasted demand
- It is found that the company is having enough capacity to meet the total requirements of all the sales outlets (warehouses)

The slide also includes a small red cursor icon and the NPTEL logo at the bottom left. A speaker overlay is visible in the bottom right corner.

So, before the problem was solved it was necessary to check whether the company has got the adequate capacity to meet the forecasted demand that feasibility first need to be established. So, that capacity planning exercise was done separately and it was found that the company was having enough capacity to meet the total requirements of all the sales outlets that is the warehouses.

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The slide is titled "Revenue Considerations" and features the same background as the previous slide. The text on the slide is as follows:

- The management of the company has informed that
- ✓ the slope of the revenue line for each product is much more in comparison to the slopes of the variable production cost curve (regular as well as overtime) for the same product in each of the plants

The slide also includes a small red cursor icon and the NPTEL logo at the bottom left. A speaker overlay is visible in the bottom right corner.

The management of the company has informed that the slope of the revenue line for each product rather the contribution of each product is much more in comparison to the slope of

the variable production cost curve for the same product in each of the plants. So, definitely the products are profitable.

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The slide is titled "Revenue Considerations" and features a background with various icons including gears, a tree, a lightbulb, and a chemical flask. The text on the slide is as follows:

- It implies that it is profitable for the company to produce even in the overtime zones
- ✓ in spite of the overtime production costs being higher than regular-time production costs, the production rate remaining the same

The slide also includes the NPTEL logo in the bottom left corner and a small red cursor icon.

It implies that it is profitable for the company to produce even in the overtime zones. In spite of the overtime production costs being higher than the regular time production costs, while the production rate remains the same.

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The slide is titled "Selection of the Mathematical Model" and features the same background icons as the previous slide. The text on the slide is as follows:

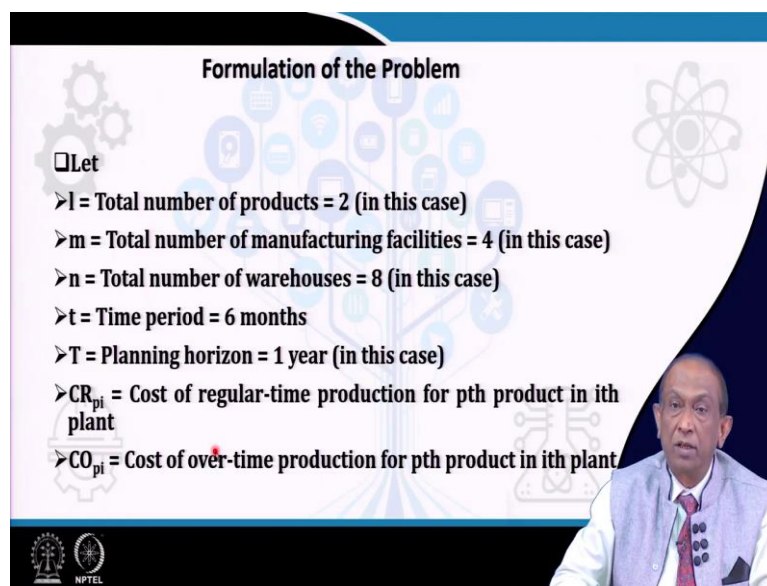
- ❖ From the analysis of actual past data, it is found that a linear transportation cost and a piece-wise linear production cost adequately describes the transportation and production cost behavior of the firm
- ❖ The constraint set is also linear
- ✓ Hence a linear programming approach to this problem is the obvious choice

The slide also includes the NPTEL logo in the bottom left corner and a small red cursor icon.

From the analysis of actual past data, it was found that a linear transportation cost and a piece wise linear production cost adequately describes the transportation and production cost behaviour of the firm.

The constraint set is also linear. Hence, a linear programming approach to this problem is the obvious choice accordingly a piecewise linear programming problem model was embedded in the decision support system. And in this lecture we are going to discuss about the formulation of that particular model.

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Formulation of the Problem

□ Let

- l = Total number of products = 2 (in this case)
- m = Total number of manufacturing facilities = 4 (in this case)
- n = Total number of warehouses = 8 (in this case)
- t = Time period = 6 months
- T = Planning horizon = 1 year (in this case)
- CR_{pi} = Cost of regular-time production for p th product in i th plant
- CO_{pi} = Cost of over-time production for p th product in i th plant

The slide features a background with various icons related to manufacturing and logistics, such as gears, a network diagram, and a molecular structure. In the bottom right corner, there is a video inset showing a man in a white shirt and tie speaking.

Now, there are some notations let l be the total number of products which is equal to 2 in this case, m denotes the total number of manufacturing facilities which is equal to 4 for this problem, n denotes the total number of warehouses which is 8 in this case, t is the time period equal to 6 months.

So, number of periods equal to 2 since the planning horizon which is denoted by capital T is 1 year. Let CR subscript pi CR_{pi} equal to cost of regular-time production for the p th product in the i th plant and CO_{pi} is the cost of over-time production for the p th product in the i th plant.

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Formulation of the Problem

□ Let

- β_{pij} = Cost of transportation for pth product from ith plant to jth warehouse
- h_{pit} = Cost of inventory holding for pth product in ith plant for time period t
- \bar{h}_{pjt} = Cost of inventory holding for pth product in jth warehouse for time period t
- R_{pit} = Regular-time production of pth product in ith plant in time period t
- O_{pit} = Overtime production of pth product in ith plant in time period t

Beta pij is the cost of transportation for the product p from the i th plant to the j th warehouse, small h pit is the cost of inventory holding for the p th product in the i th plant for the time period t, h bar pjt is the cost of inventory holding for the p th product in the j th warehouse for time period t. R pit denotes the regular time production of the p th product in the i th plant in time period t and O pit is the overtime production of the p th product in the i th plant in time period t.

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Formulation of the Problem

□ Let

- X_{pijt} = Amount of shipment of pth product to be sent from ith plant to jth warehouse in time period t
- IN_{pit} = Amount of inventory of pth product in ith plant for time period t
- Z_{pjt} = Amount of Inventory of pth product in jth warehouse for time period t
- D_{pjt} = Demand for pth product in jth warehouse in time period t
- IN_{pit-1} = Amount of inventory of pth product in ith plant at the beginning of time period t i.e. at the end of time period (t-1)

So, the decision variables are X_{pijt} is the amount of shipment of the p th product to be sent from the i th plant to the j th warehouse in time period t . IN_{pit} is the amount of inventory of the p th product in the i th plant in time period t . Z_{pjt} is the amount of inventory of the p th product in the j th warehouse in time period t .

D_{pjt} is the demand for the p th product in the j th warehouse in time period t and IN_{pit-1} is the amount of inventory of the p th product in the i th plant at the beginning of time period t that is at the end of time period $t-1$ initial inventory.

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Formulation of the Problem – Multi-Item Production-Distribution Planning

Problem Formulation:

$$\text{Minimize } \sum_{p=1}^l \sum_{i=1}^m CR_{pi} \sum_{t=1}^T R_{pit} + \sum_{p=1}^l \sum_{i=1}^m CO_{pi} \sum_{t=1}^T O_{pit} +$$

$$\sum_{p=1}^l \sum_{i=1}^m \sum_{j=1}^n \beta_{pij} \sum_{t=1}^T X_{pijt} + \sum_{p=1}^l \sum_{i=1}^m \sum_{t=1}^T h_{pit} \cdot IN_{pit} + \sum_{p=1}^l \sum_{t=1}^T \sum_{j=1}^n \bar{h}_{pj} \cdot Z_{pj}$$

$\square p = 1, 2, 3, \dots, l$
 $\square i = 1, 2, 3, \dots, m$
 $\square j = 1, 2, 3, \dots, n$
 $\square t = 1, 2, 3, \dots, T$

So, the problem formulation is minimize sum over p equal to 1 to l since we have two products. So, the value of l is 2 i varying from 1 to m , CR_{pi} into R_{pit} ; that means this portion denotes the regular time production cost plus CO_{pi} into O_{pit} . So, this portion denotes the overtime production cost.

So, we are going to minimize regular time production cost plus overtime production cost plus β_{pij} multiplied by X_{pijt} ; that means, this is the transportation cost from the i th plant to the j th warehouse for the p th product and then we have summed it over. So, we are considering all the products and from all plants to all warehouses. This portion denotes the inventory holding cost at the plant level and this portion denotes the inventory holding cost at the warehouse level.

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Formulation of the Problem – Multi-Item Production-Distribution Planning

Problem Formulation:

□ In this case, since $l = 2$, $m = 4$, $n = 8$, and $t = 1, 2$, this problem can be rewritten as;

Minimize $\sum_{p=1}^2 \sum_{i=1}^4 CR_{pi} \sum_{t=1}^2 R_{pit} + \sum_{p=1}^2 \sum_{i=1}^4 CO_{pi} \sum_{t=1}^2 O_{pit} + \sum_{p=1}^2 \sum_{i=1}^4 \sum_{j=1}^8 \beta_{pij} \sum_{t=1}^2 X_{pijt} + \sum_{p=1}^2 \sum_{i=1}^4 \sum_{t=1}^2 h_{pit} \cdot IN_{pit} + \sum_{p=1}^2 \sum_{t=1}^2 \sum_{j=1}^8 \bar{h}_{pj} \cdot Z_{pj}$

So, when we are putting the corresponding values we get the objective function like this. Constraints; first constraints is we have total 14 Constraints for material balance at plants.

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Formulation of the Problem – Constraints and Bounds

Constraints due to Material Balance at Plants:

➤ Total No. of Constraints = 14

$$IN_{pit-1} + (R_{pit} + O_{pit}) - IN_{pit} - \sum_{j=1}^8 X_{pijt} = 0$$

➤ $p = 1, 2$
 ➤ $i = 1, 2, 3, 4$
 ➤ $j = 1, 2, 3, \dots, 8$
 ➤ $t = 1, 2$

So, this equation is initial inventory plus the sum of regular plus overtime production minus the dispatches from the plant to the warehouses will give raise to the final inventory of the product be at the plant i for the time period t.

That means the material balance equation is initial inventory plus the sum of regular and overtime production minus the dispatches will give the final inventory we have made side

transfer. So, we get this equation and when we consider all the products all the plants and the all the warehouses total number of constraints will come out to be 14.

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Formulation of the Problem – Constraints and Bounds

Constraints due to Material Balance at Warehouses:

- Total no. of constraints = 32

$$Z_{pj,t-1} + \sum_{i=1}^4 X_{pij,t} - Z_{pj,t} - D_{pj,t} = 0,$$

❖ for $p = 1, 2; i = 1, 2, 3, 4; j = 1, 2, 3, \dots, 8; t = 1, 2$

Constraints due to material balance at warehouses. Here again the initial inventory for a product at a particular warehouse plus the total amount of receipt for the same product from all the plants to that particular sales outlet in that period; minus the demand for the same product from that sales outlet in that period will give rise to the final inventory of the product p in that sales outlet over the time period t. So, we have 32 constraints.

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Formulation of the Problem – Constraints and Bounds

Constraints due to Certain Policy of the Company:

- Total No. of Constraints = 16

$$R_{12t} + O_{12t} \leq \frac{2}{3} (R_{22t} + O_{22t} + R_{12t} + O_{12t}); t = 1, 2, \dots \text{ PDS 121 \& PDS 122}$$

$$R_{12t} + O_{12t} \geq \frac{1}{3} (R_{22t} + O_{22t} + R_{12t} + O_{12t}); t = 1, 2, \dots \text{ PD 121 \& PD 122}$$

$$R_{22t} + O_{22t} \leq \frac{2}{3} (R_{22t} + O_{22t} + R_{12t} + O_{12t}); t = 1, 2, \dots \text{ PDS 221 \& PDS 222}$$

$$R_{22t} + O_{22t} \geq \frac{2}{3} (R_{22t} + O_{22t} + R_{12t} + O_{12t}); t = 1, 2, \dots \text{ PD 221 \& PD 222}$$

There were constraints due to certain policies of the company what they said that for the product 1; in the second plant over a time period t a regular time production plus overtime production for the first product in the second plant must be less than equal to two- third of the total production considering the second product.

So, the total production for the first product in the second plant must lie between one-third of the total production considering all the products but less than two-third. So, this is basically a policy level constraint, and this constraint is also for the second product like this, there are certain policy constraints which have been incorporated.

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Formulation of the Problem – Constraints and Bounds

Constraints due to Available Capacity:

➤ Total No. of Constraints = 6

$$R_{11t} + O_{11t} + R_{21t} + O_{21t} \leq 11760; t = 1, 2, \dots \text{ CAP 11 \& CAP 12}$$
$$R_{12t} + O_{12t} + R_{22t} + O_{22t} \leq 16800; t = 1, 2, \dots \text{ CAP 21 \& CAP 22}$$
$$R_{13t} + O_{13t} + R_{23t} + O_{23t} \leq 20160; t = 1, 2, \dots \text{ CAP 31 \& CAP 32}$$

Note: The right hand side values in each of the above three equations denote the available capacity of plants 1, 2 and 3 in each period of time being considered.

Constraints due to available capacity total number of constraints are 6 the first equation is regular time production. For the first product in the first plant over time period t plus overtime production plus the regular time production for the second product in the first plant plus the overtime production of the second product in the first plant in the same period.

So, this is the total production in the first plant, considering both regular and overtime and both the products combined that must be less than equal to sum value which we have specified by the company management for the first plant depending on the capacity planning exercise that they had done.

Similarly, in the second plant the total capacity restriction in terms of numbers were this much and for the third plant, for the fourth plant they did not specify anything. So, the right

hand side values in each of the above 3 equations denote the available capacity of the plants 1, 2 and 3 in each period of time being considered.

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Formulation of the Problem – Constraints and Bounds

Constraints due to Regular Time Production Capacity:

- Total No. of Constraints = 2
- ☐ Regular time production capacity in plant 1 in each period of time is 8400 units

✓ For this given condition,

$$R_{111} + R_{211} \leq 8400; \text{KAP 11}$$
$$R_{112} + R_{212} \leq 8400; \text{KAP 12}$$

The slide features a background with a stylized tree of icons representing various engineering and technology fields. A speaker is visible in the bottom right corner, and the NPTEL logo is in the bottom left.

Constraints due to regular time production capacity, the regular time production capacity in plant 1 in each period of time is again given in terms of some number of units. So, for this given condition we have these 2 sets of constraints.

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Formulation of the Problem – Constraints and Bounds

Constraints due to Regular Time Production Capacity:

- Total No. of Constraints = 2
- ☐ Regular time production capacity in plant 3 in each period of time is 15120 units

✓ For this given condition,

$$R_{131} + R_{231} \leq 15120; \text{KAP 31}$$
$$R_{132} + R_{232} \leq 15120; \text{KAP 32}$$

The slide features a background with a stylized tree of icons representing various engineering and technology fields. A speaker is visible in the bottom right corner, and the NPTEL logo is in the bottom left.

Similarly, for plant 2 and plant 3 these are the restrictions for regular time production capacity.

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Formulation of the Problem – Constraints and Bounds

Bounds:

- Total No. of Bounds = 4
- ❑ Regular time production capacity in plant 4 for product 1 in each period of time is 7392 units
- ❑ It is given that only product 1 can be manufactured in plant 4

✓ For this given condition,

$$R_{141} \leq 7392$$
$$R_{142} \leq 7392$$

And there were certain bounds there were 4 regular time production capacity in plant 4 for product 1 in each period of time is given and it was mentioned right in the beginning that only product 1 can be manufactured in plant 4. So, for this condition we have these two inequalities.

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Formulation of the Problem – Constraints and Bounds

Bounds:

- ❑ Overtime production capacity in plant 4 for product 1 in each period of time is 2520 units
- ❑ It is given that only product 1 can be manufactured in plant 4

✓ For this given condition,

$$R_{141} \leq 2520$$
$$R_{142} \leq 2520$$

Similar inequalities were obtained considering overtime production capacity in plant 4 for product 1 and that limit was 2520 units. So, for these given condition these two inequalities hold good.

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The slide features a dark blue header with the word 'REFERENCES' in white. Below the header, two bullet points are listed in black text. In the bottom right corner, there is a small video inset showing a man in a light blue vest and white shirt speaking.

And these are the references that were used for formulating this problem; this problem was solved by embedding some python code inside a decision support system because they wanted to be a regular exercise for their semi-annual budget and strategic planning process.

Only thing the capacity restrictions instead of the numbers that were supplied, the code was designed in such a manner that these right hand side constraints were equated to some variables, where the managers can periodically change the right hand side constraint values and the linear programming problem was solved. Such kind of problems also if one wants to carry out a one-time exercise, they can use excel solver.

But in that case you have to use the premium solver version because the problem size can be very large. And then like what we discussed in the product mix problem, you can carry out sensitivity analysis to give answers to those questions which the management was interested in right at the beginning of the problem we studied that. So, thank you all for your cooperation and support!

Thanks a lot!