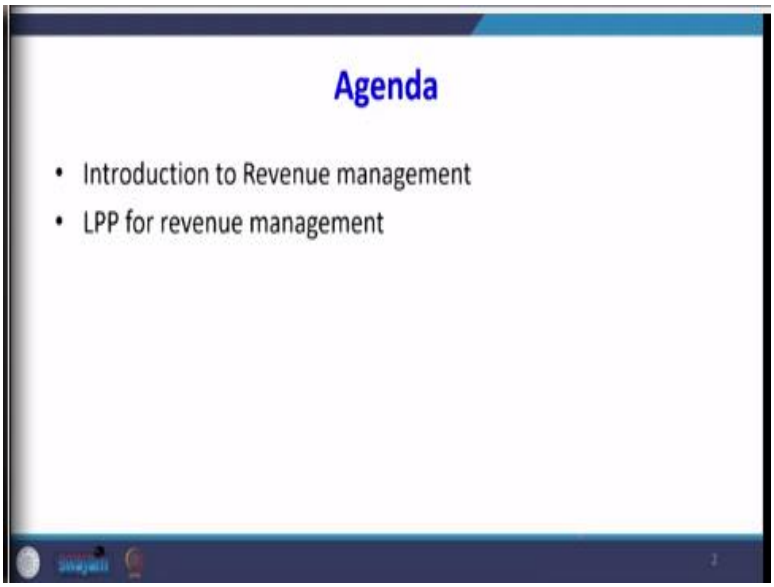
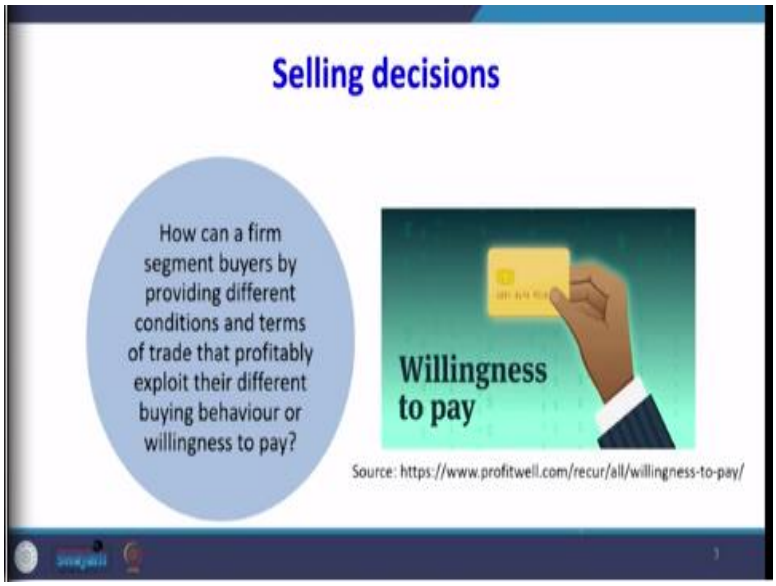
Decision Making With Spreadsheet
Prof. Ramesh Anbanandam
Department of Management Studies
Indian Institute of Technology-Roorkee

Lecture-18
Revenue Management

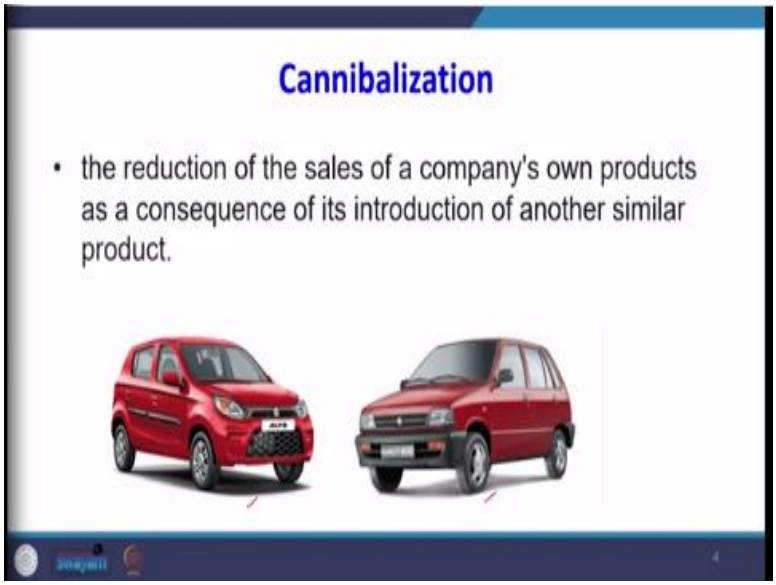
Dear students, in the previous class, I discussed portfolio management. In this lecture, I am going to discuss revenue management. So, the agenda for this lecture is an introduction to revenue management; I will explain basic concepts about revenue management.



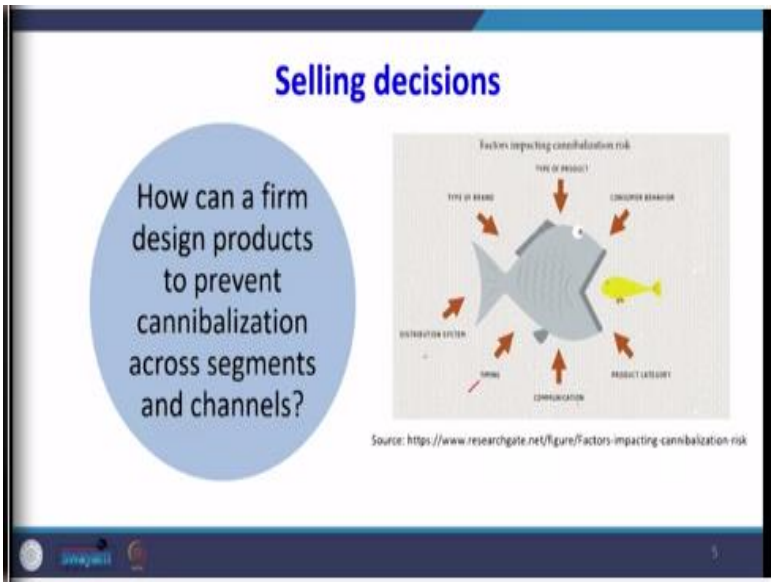
Where it is used, what are the prerequisites for applying revenue management? Then I will take 1 problem, then I will formulate a linear programming problem for revenue management, then I will solve it.



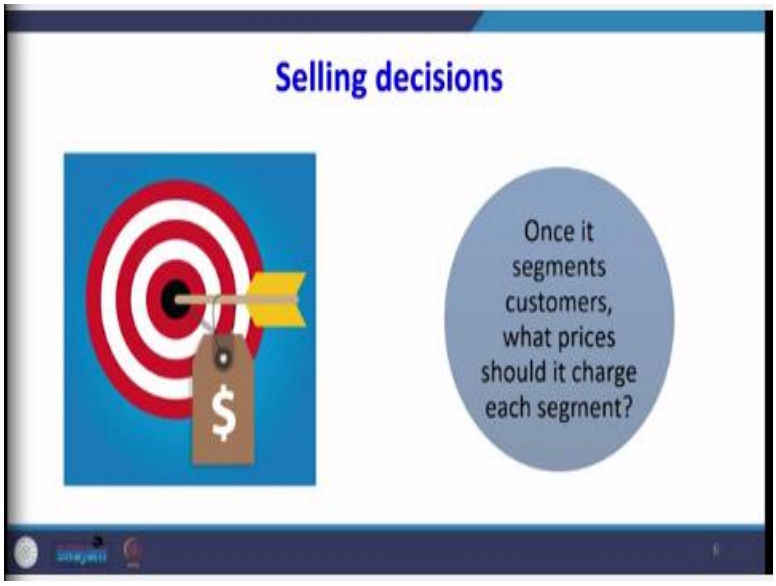
Selling decisions: How can a firm segment buyer by providing different conditions and terms of trade that profitably exploit their different buying behavior or willingness to pay? The company may make revenue by exploiting their buying behavior and willingness to pay.



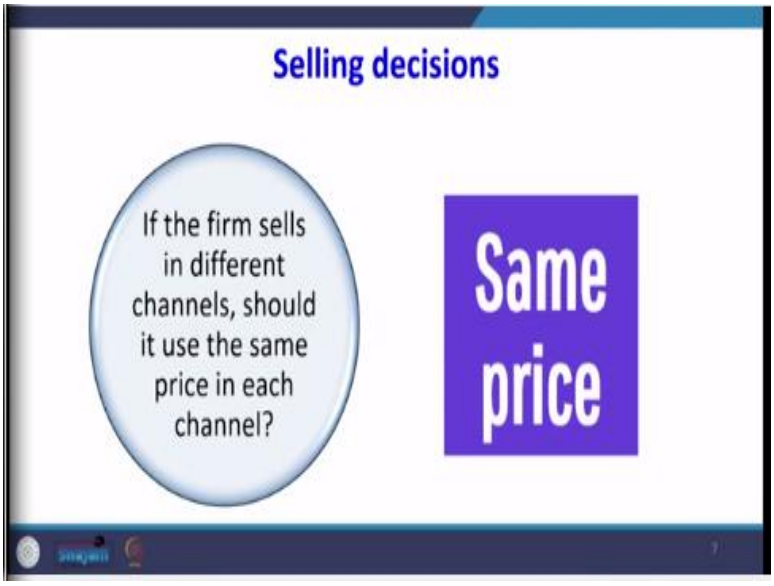
I am going to introduce the term cannibalization because there is a connection between the cannibalization revenue management and the problem that has arisen. So, the meaning of cannibalization is the reduction of sales of a company's own products as a consequence of the introduction of another similar product. For example, on the left-hand side, you can see the Maruti Alto. Before that, there was a Maruti 800; when the Maruti Alto was introduced, the production of the Maruti 800 was stopped; this is an example of cannibalization.



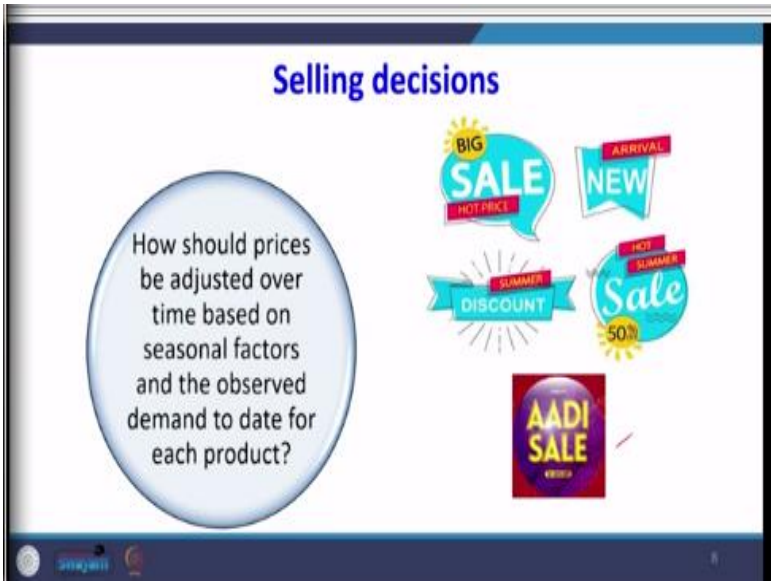
So, if you want to make selling decisions, the important question that should be answered is how a firm can design products to prevent cannibalization across segments and channels. The right side of the picture says there are different ways we can prevent cannibalization or we can modify the demand. For example, timing, giving the product some even nowadays say that e-commerce portals people are willing to pay for a longer time, there is a lesser charge if you want an immediate delivery, there is a more charge. And the distribution system type of brand, type of products, consumer behavior, and product category and communications, are factors impacting cannibalization risk.



Once it segments the customers, what price should it charge for each segment? One way to make more sales is by modifying the demand; how can we modify the demand? Different customers have different buying behaviors, so we can segment the customers. Once the segment is done, then what prices have to be fixed for them? That is a vital selling decision.



One possibility is that if the firm sells in different channels, should it use the same price in each channel? The company may sell the product in different channels online or offline. Is it good to have the same price for different channels, or do we want to price different prices for different channels?



How should prices be adjusted over time based on seasonal factors and the observed demand to date for each product? For example, some seasonal products, the seasonal products, for example,

say AADI sales seasonal products are sold at discounts, maybe big hotels, and there may be a season and off seasons. In off seasons, the hotel rooms are sold out at lower prices when compared to seasons because what they are doing, they are modifying the price.

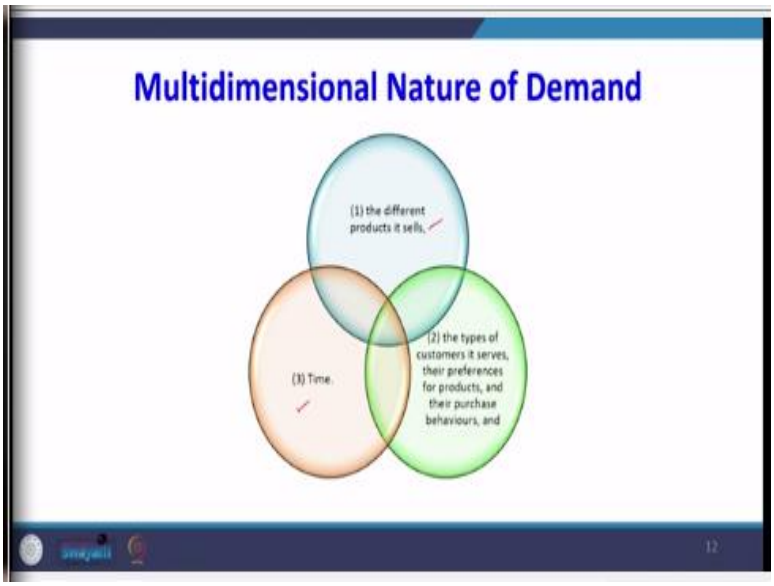
If your product is in short supply, to which segment and channels should it allocate the products? In this example, when there was COVID the peak, there was a short supply of gloves and masks. So, what will happen if people start to sell at higher prices?

So, what is new about this revenue management? So, the revenue management is not the demand management decisions themselves but rather how these decisions are made. The true innovation of revenue management lies in the method of decision-making; the concept of this revenue

management is not something new. But now it has got very much importance because the quality of the decision making process has improved.

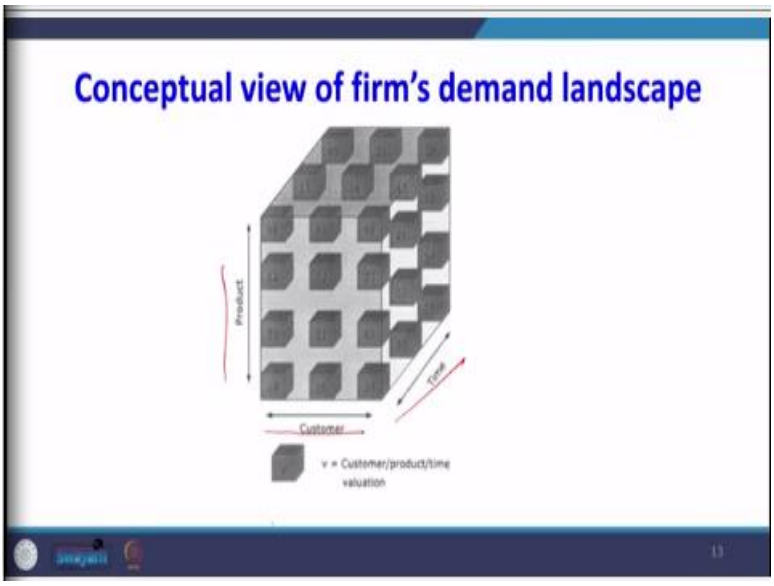
Because of the technologically sophisticated, detailed, and intentionally operational approach to making demand management decisions. Now, with the help of technology, we are able to collect, where we are able to capture the exact demand of the customers. So, because of this sophisticated technology we are able to manage, we are able to do revenue management a little easier than in the olden times.

Now, the concept of artificial intelligence and machine learning, these kinds of techniques are used in revenue management. So, these are helping it possible to manage demand on a scale and complexity. Even on a large scale, problems can easily be solved with the help of AI and machine learning. It is possible to improve the quality of demand management decisions because of these new tools, because of the availability of computing technologies, so the demand management decisions can be improved.



When we say the demand there are different dimensions for the demand, 3 dimensions normally. We can say the different the product itself will have it is own demand, but the same product at different times will have different demand. For example, during, say, hotels, the demand is the same, but during the season times, the demand is more, and during the season, the demand is less. So, the second dimension of this demand is time, and the third dimension, we can say, is the type of customers themselves, their preferences for products, their purchase behaviors, and so on.

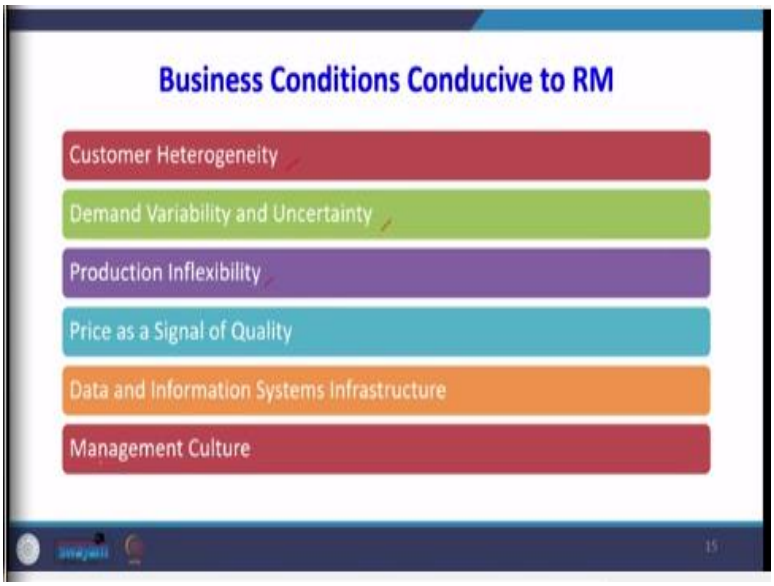
Maybe on the Indian railway, we can see there are tatkal tickets; there is a regular ticket there. Some people are willing to book Tatkal tickets who were planning for a short period of time, and people are willing to pay at higher prices, so the customer behavior. So, there are 3 dimensions of demand: one is the product itself, the second one is the time, and the third one is the type of customer. So, we can manage the demand by using these 3.



This is the conceptual view of a firm's demand landscape. You see the different customers, the time, and the product. So, maybe one-time purchasers, regular purchasers, those who are willing to wait, and those who are not willing to wait. So, we can manage the demand by using these 3 dimensions.

However, this demand management decision has a strong linkage with operations and other business domains. Multiple products may share production capacity or have joint production costs; customers may choose among substitute products at any given point in time, or customers may strategize over their timing in purchasing a given product. So, demand decisions for different products, customers, and time periods may also be linked to information the firm gains.

The most important point is what kind of information? Nowadays, because of social media and other network sites, collecting customer information has become easy, and managing the demand has also become easy. Once we manage the demand, it will have strong linkages with other domains of the business.

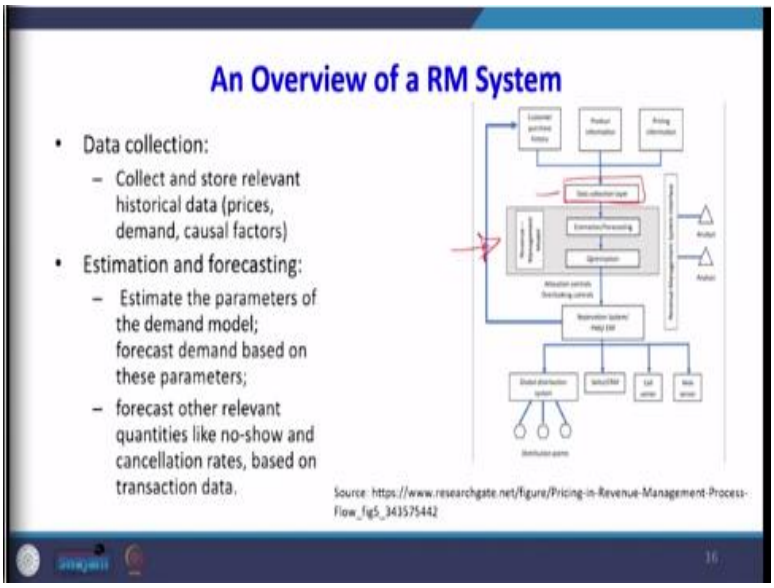


What are the business conditions conducive to revenue management? The first point is customer heterogeneity; the same product is valued differently by different people, and the tatkal tickets people are willing to pay at higher prices is one important requirement. The second requirement is demand variability and uncertainty. Obviously, the variability of demand is high, and it is uncertain; very difficult to predict that time. You can use the concept of revenue management; see airline tickets; demand variability is very high.

Production inflexibility Obviously, every production capacity is fixed, so the production whenever there is a production that is not flexible, it is inflexible. The only way to manage the demand is by changing the price or the way we deliver the product, that is, by changing the time, that is another requirement. The next requirement is price as a signal of quality, so people are paying more price, they expect higher services. So, there should be a direct connection between price and sign of quality; it is not necessary to say that higher price means higher quality.

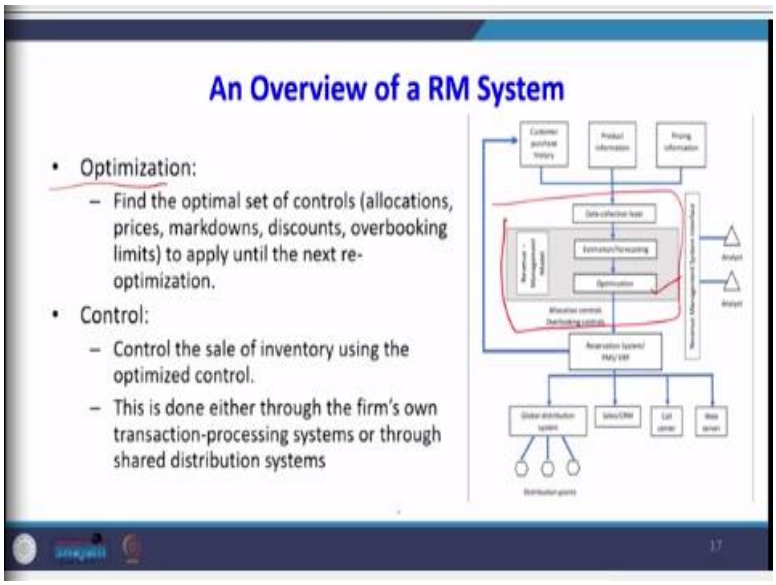
But here, the customers have the perception that higher prices in the sense they will be getting high-quality service, which is another requirement for revenue management. Another thing is

data and information system infrastructure, which will be a very strong data and information system infrastructure because that is the core of the revenue management data. Then, the management culture, some management may be against charging different prices for the same service. So, management support and culture are also important for revenue management.

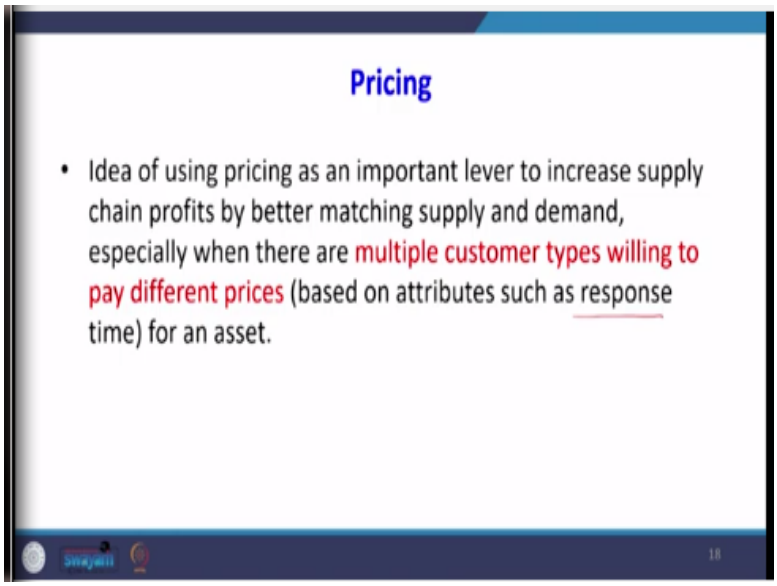


Now we will see the overview of the revenue management system. On the right-hand side, I have brought the picture. The first one is data collection; where can we collect it? See that there is data collection. Where can we collect the data? Customer purchase history: assume an example of airline ticket pricing, airline ticket, customer purchase history, product information, and pricing information; these are the 3 sources where we can collect the data.

So, collect and store relevant historical data. The second stage is estimation and forecasting. Here, estimate the parameters of the demand model and forecast demand based on these parameters. Then, forecast other relevant quantities like no-show and cancellation rates based on transaction date. So, this is the second component after collecting the data, which is forecasting a revenue management system.



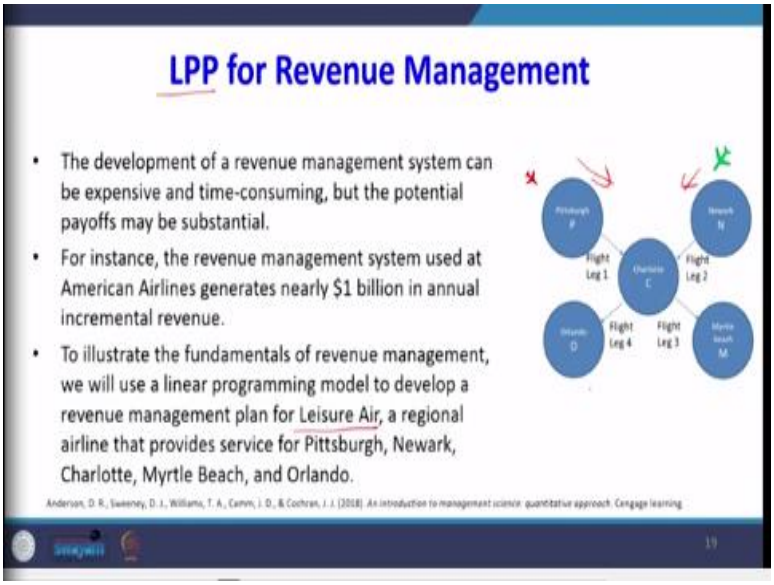
The next one is optimization; what we are discussing is in the optimization part. Finding the optimal set of controls like allocations, allocation of seats, fixing the prices, markdown, reducing the prices, giving the discounts, and overbooking limits. So, to apply until the next re-optimization, the core we can say the core of the revenue management system is optimization, these portions, this portions, see this is optimization. The last one is control; control the sale of inventory using optimized control. This is done either through the firm's own transaction processing system or through shared distribution systems.



The easiest way to manage the demand is just by changing the pricing. So, the idea of using pricing as an important lever to increase supply chain profits by better matching supply and demand, especially when there are multiple customer types willing to pay different prices. There

are different types of people who are willing to pay different prices based on attributes such as the response time of an asset.

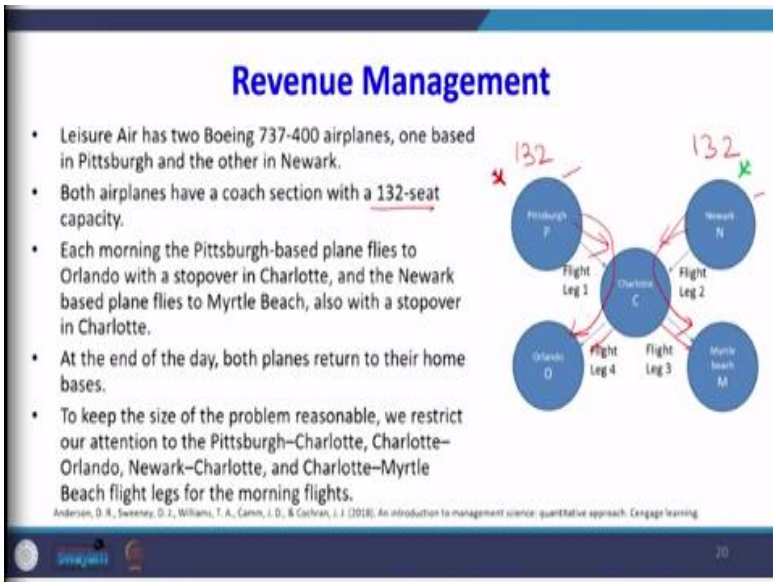
For example, we are spending time on speed posts and ordinary posts because of speed posts in the sense that people do not want to wait. The document had to be sent in a very, very short period, and at that time, people preferred speed post by paying more price. So, we can send it by ordinary post. Also, people are willing to wait, so that way, the easiest way to manage the demand is pricing; that is what we are going to do.



Now I have taken one sample problem for revenue management that I am going to formulate with the help of using linear programming problem, and then I am going to solve and interpret it, this problem is taken from Anderson et al., So, the development of revenue management system can be expensive and time-consuming but the potential payoff may be substantial. The revenue management system that I discussed in the previous slides is very complicated system and very expensive and very time-consuming for making decisions, but we are going to use the LP model to make some informed decisions.

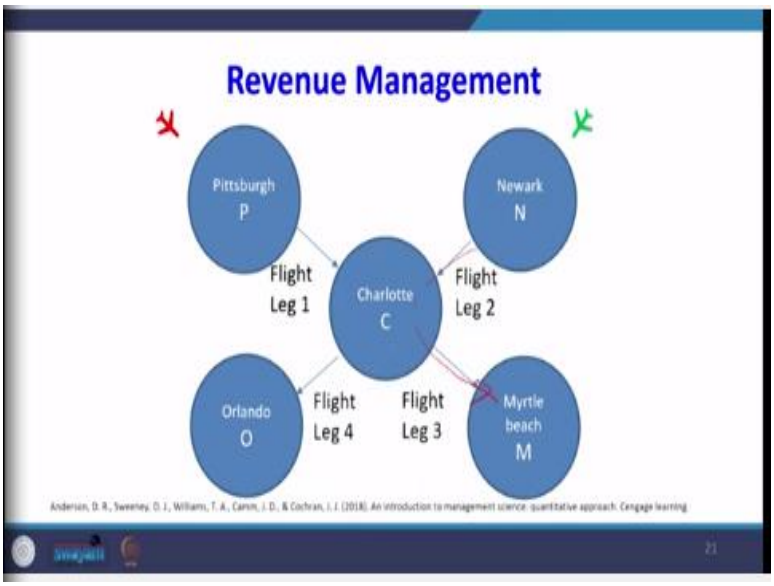
For instance, the revenue management system used at American Airlines generates nearly 1 billion dollars in annual incremental revenue. To illustrate the fundamentals of revenue management, we will use a linear programming model to develop a revenue management plan for Leisure Air, that is the airline which was an example which is given in the book by Anderson

et al., A regional airline that provides service for Pittsburgh, Newark, Charlotte, Myrtle Beach, and Orlando. So, there is a Pittsburgh, this one Newark; this is the origination and the origin, the destination is Orlando, Myrtle Beach via Charlotte.

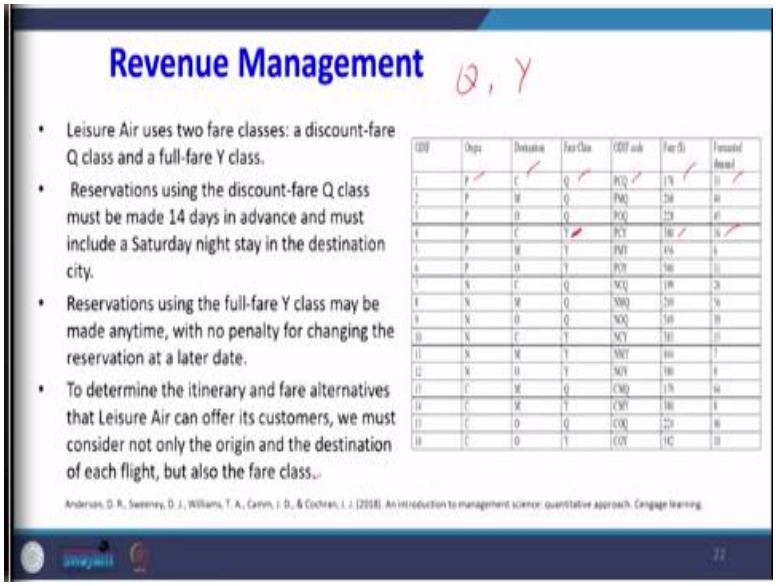


Now, I will discuss the problem context. So, Leisure Air has 2 Boeing 737-400 airplanes, one based in Pittsburgh here, another one in Newark. Both airplanes have a coach section with 132 seat capacity, this capacity is 132 seats. Each morning, the Pittsburgh-based plane flies to Orlando with a stopover in Charlotte, so this is coming this way. And the Newark-based planes fly to Myrtle Beach also with a stopover at Charlotte, so this flight is coming by this way, there is a stopover.

At the end of the day, both planes return to their home bases; it is going back. To keep the size of the problem reasonable, we restrict our attention to Pittsburgh-Charlotte this leg and Charlotte-Orlando this leg, then Charlotte-Myrtle Beach this leg and Newark-Charlotte this leg. So, we are considering only 4 legs, so we are not considering the return of these 2 flights; we are considering only one way.

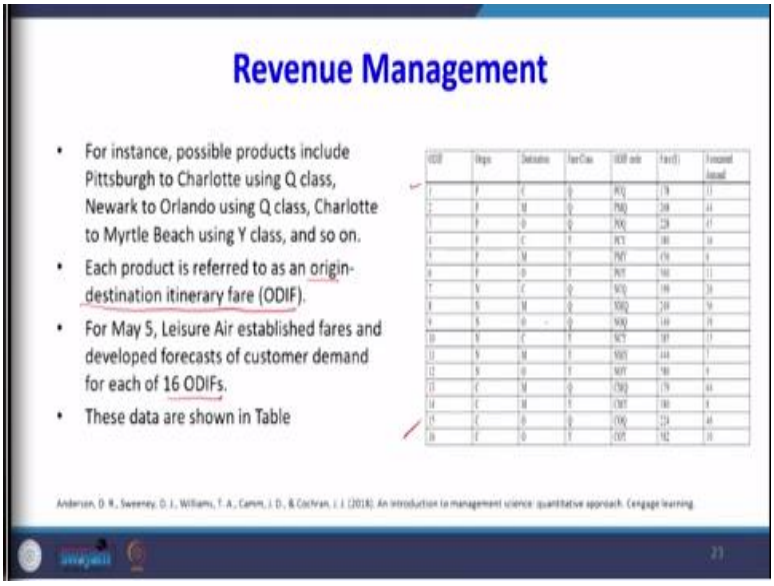


The flight starts here, it goes to Orlando via Charlotte, this flight starts here it goes to Myrtle Beach via Charlotte, and there is a stopping also here.

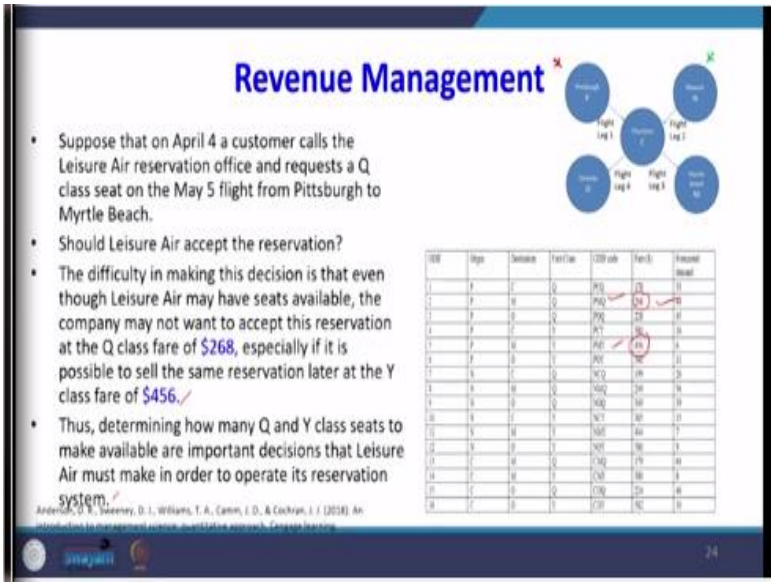


Leisure Air uses 2 fare classes; they have 2 kinds of tickets: one is Q-type tickets, and the other is A y-type ticket, Q-class, and Y-class. Reservations using discount fare Q class must be made 14 days in advance and must include a Saturday night stay in the destination city. The reservation using full fare class Y may be made anytime with no penalty for changing the reservation at a later date. To determine the itinerary and the fair alternative that Leisure Air can offer is customers, we must consider not only the origin and the destination of each flight but also the fare class.

Because there are 2 fare classes there, one is Q class and Y class. So, here you can see origin P, destination C, Q class, so the variable which I am going to consider is P, C, Q, the fare is 178 dollars, and the forecast demand is 33. You see that you see P, C, Y, this is a Y class ticket, but here the fare is 380 dollars, and forecast demand is 16. So, for each leg, there are 2 possibilities: one is a Q-class ticket, and the other one is a Y-class ticket.

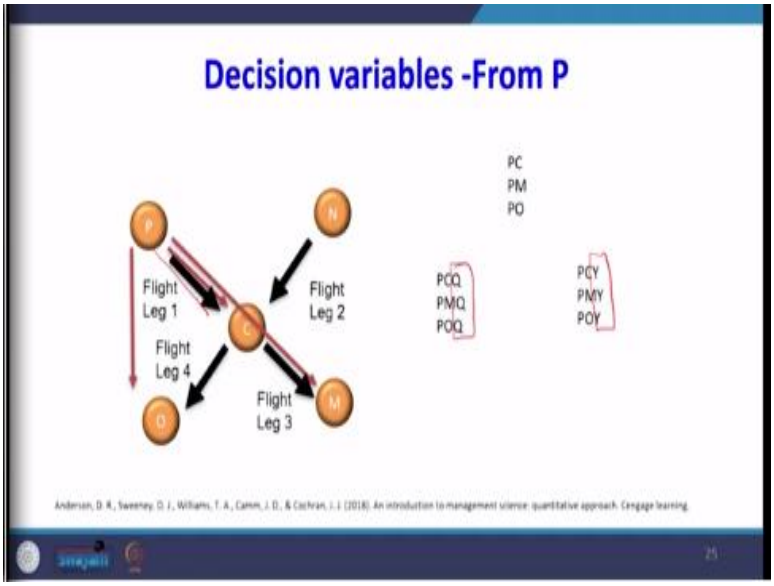


For instance, the possible products include Pittsburgh to Charlotte using the Q class, Newark to Orlando using the Q class, Charlotte to Myrtle Beach using the Y class, and so on. Because in every leg, there are 2 possible products: one is a Q class, and another 1 is a Y class. So, each product is referred to as an origin-destination itinerary fair ODIF; this is important terminology. For May 5, Leisure Air established fares and developed a forecast for customer demand for every 16 ODIFs. So, we have 1 to 16, this data is given in this table.

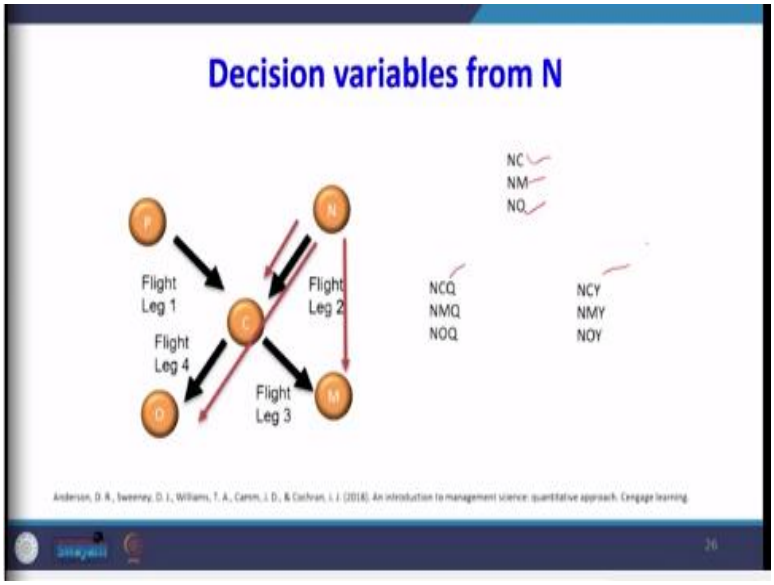


Suppose that on April 4, a customer calls the Leisure Air reservation office and requests a Q class seat on May 5, a flight from Pittsburgh to Myrtle Beach. So, the variable that we used is PM, so here is PM. Now PM, there are 2 kinds of tickets available PMQ is there; similarly, PMY is there, the fare is for PMQ 268, and PMY is 456. The difficulty in making this decision is whether Leisure Air should accept the reservation.

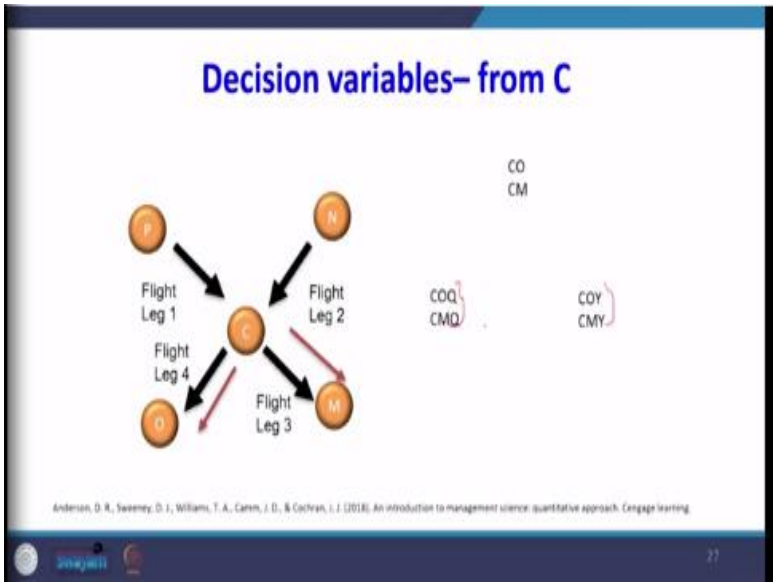
The difficulty in making this decision is that even though Leisure Air may have seats available, the company may not want to accept this reservation at the Q class fare 268, I am saying this 268. Especially if it is possible to sell the same reservation later at Y class fare for 456. So, if there is a possibility to sell at Y class, they do not want to go for any additional tickets. Thus, determining how many Q and Y class seats to make available are important decisions that the Leisure Air must make to operate it is reservation system. So, that is what we are going to suggest: how many Q and Y class seats have to be made available?



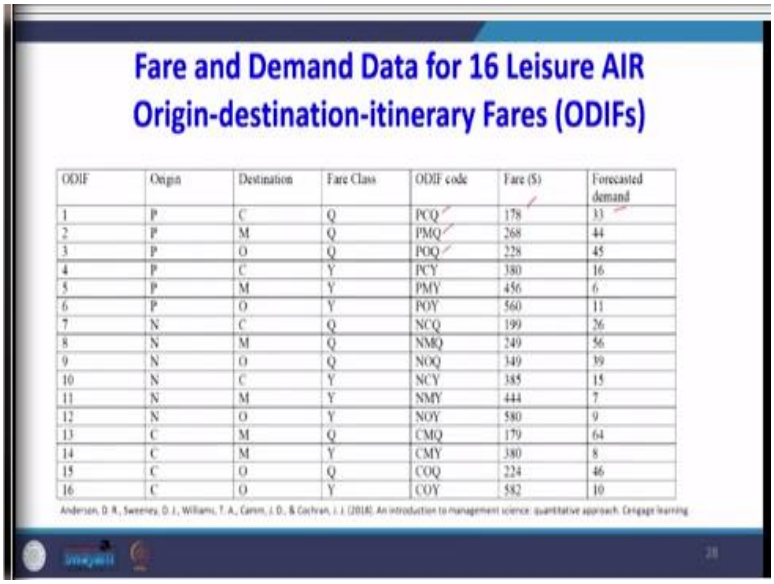
The next stage is formulating the decision variables. So, PC, this is 1 leg PC, then PM, suppose a flight starts from here somebody can book PC and PM and PO. There are 3 types in each case there are Q type tickets, Y type tickets. So, there are 6 decision variables here.



Similarly when the flight starts from the origin of N Newark, there is a NC, NO, NM. There are 2 categories, Q class, and Y class, so there will be another 6 variables.

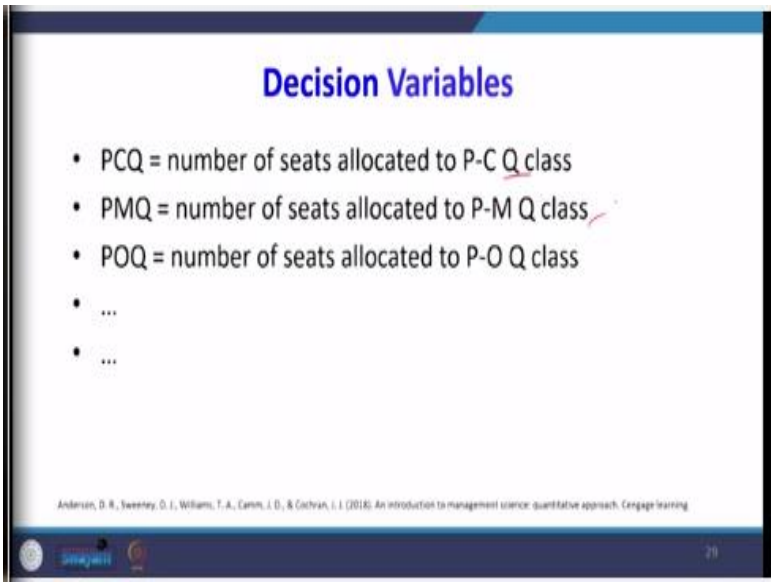


Not only that, somebody can book the ticket from CO and CM, so there are 2 categories, Q and Y, and another 4 decision variables.

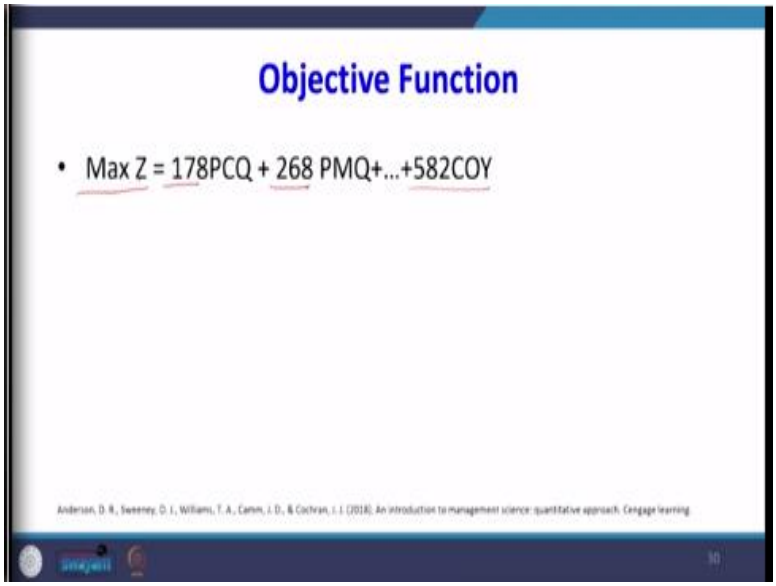


ODIF	Origin	Destination	Fare Class	ODIF code	Fare ($)	Forecasted demand
1	P	C	Q	PCQ	178	33
2	P	M	Q	PMQ	268	44
3	P	O	Q	POQ	228	45
4	P	C	Y	PCY	380	16
5	P	M	Y	PMY	456	6
6	P	O	Y	POY	560	11
7	N	C	Q	NCQ	199	26
8	N	M	Q	NMQ	249	56
9	N	O	Q	NOQ	349	39
10	N	C	Y	NCY	385	15
11	N	M	Y	NMY	444	7
12	N	O	Y	NOY	580	9
13	C	M	Q	CMQ	179	64
14	C	M	Y	CMY	380	8
15	C	O	Q	COQ	224	46
16	C	O	Y	COY	582	10

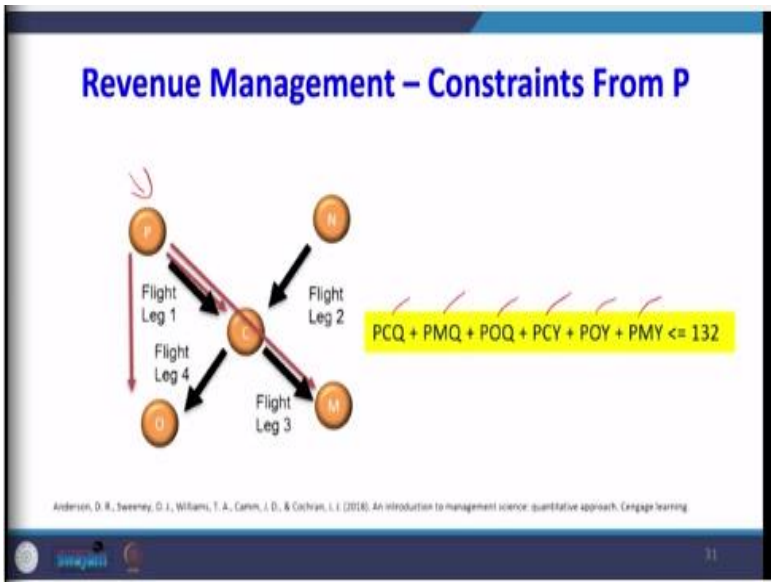
Now this represents PCQ, PMQ, and POQ. Like this, there will be a 16-decision variable. The fare is given, and the forecast demand is also given. So, what we have to suggest is how many seats have to be allocated on each leg. So, our profit is maximized.



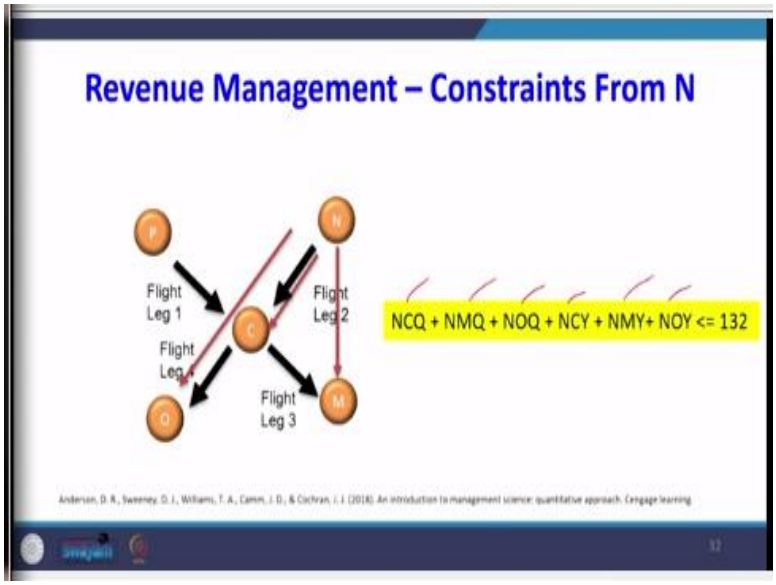
So, when I say PCQ number of seats allocated to P to C in the Q class, PMQ number of seats allocated to PM to Q class, if you put Y, it is Y class.



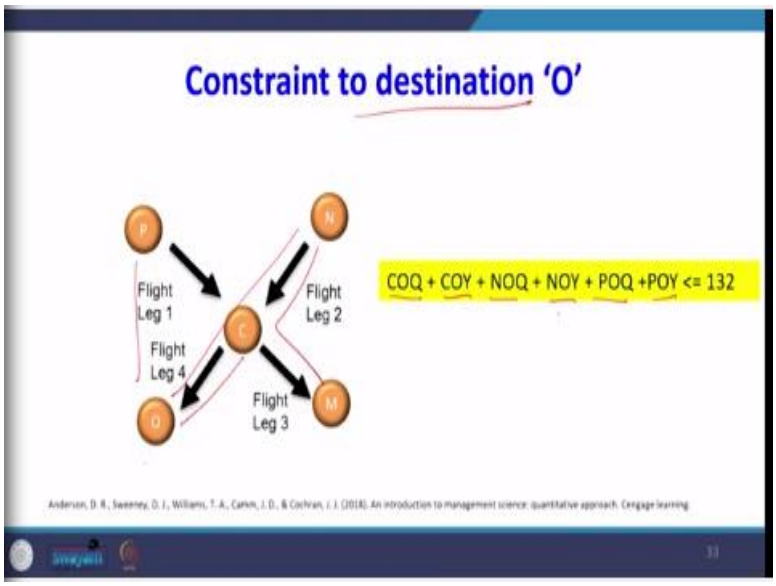
Like this, we must write all the decision variables. So, the objective function is this is the ticket fare: the PCQ ticket fare is 178, and the PMQ ticket fare is 268. This for all, 16 decision variables there will be all 16 decision variables will form the objective function. So, the objective function is that must be maximized.



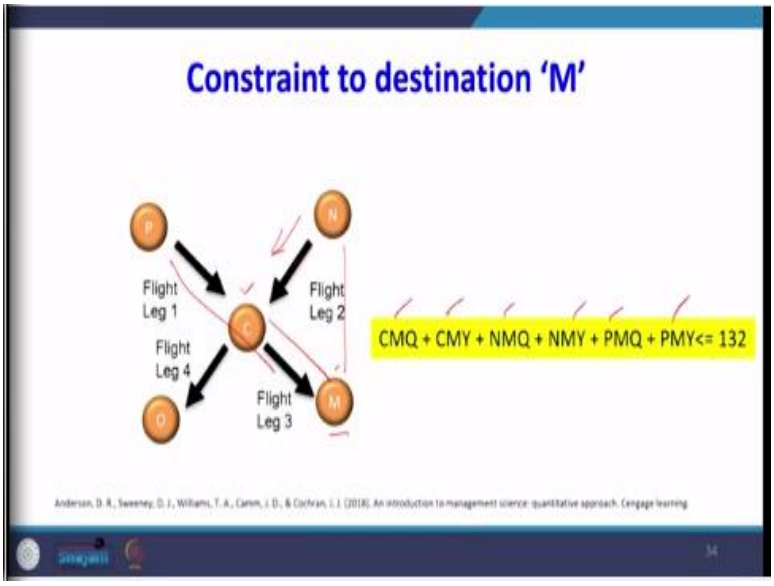
Now we will go for writing constraints. So, suppose a flight starts; this is called the origin constraint. what are the different ways? So, wherever the different way to start from P, somebody may book the ticket PC, so there is a 2-way PCQ, PCY. Somebody may book ticket PM, so PMQ PMY, and somebody may book ticket PO, so POQ POY. But that cannot exceed 132 because the seating capacity is 132.



Similarly the other flight starts from Newark, so different possibilities, for example, NC. So, NC, NCY, NCQ, then NO, in NO, there will be NOQ, NOY, then NM, NMQ, NMY. So, if this seats when we add these seats that also should not exceed 132.

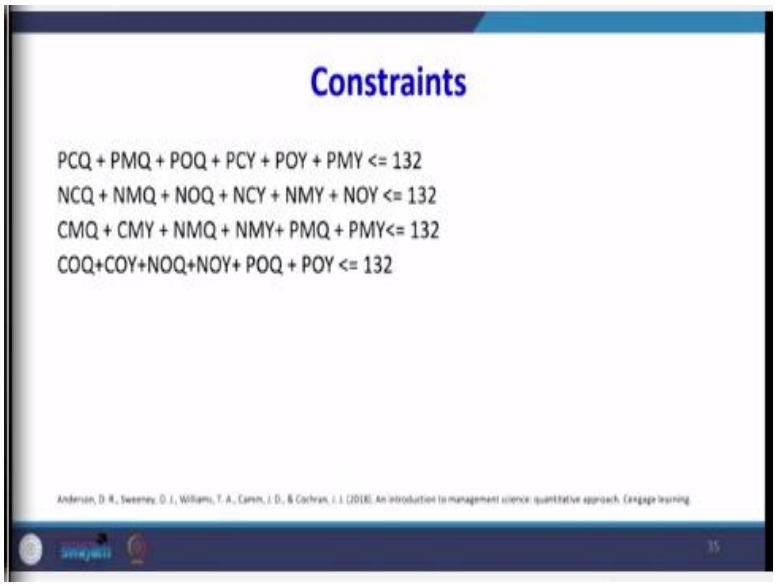


Now, I am going to write another 2 types of constraint that is called destination constraint. So, what are the different ways to reach this destination, O? So, I can come from CO, I can come from ON, I can come from PO. So, when I go to CO, there are 2 tickets, COQ, COY, so PO there are 2 tickets, POQ, POY, then somebody may book tickets N to O, so NOQ, NOY. Here, you should remember even though this flight goes NC this route NCM, he can get down at point C, and he can get another flight, which means somebody booking directly from N to O. Because this flight will not go to O but he can get down here then he can get this flight which is coming from P to reach the O that is why the NOY is possible.

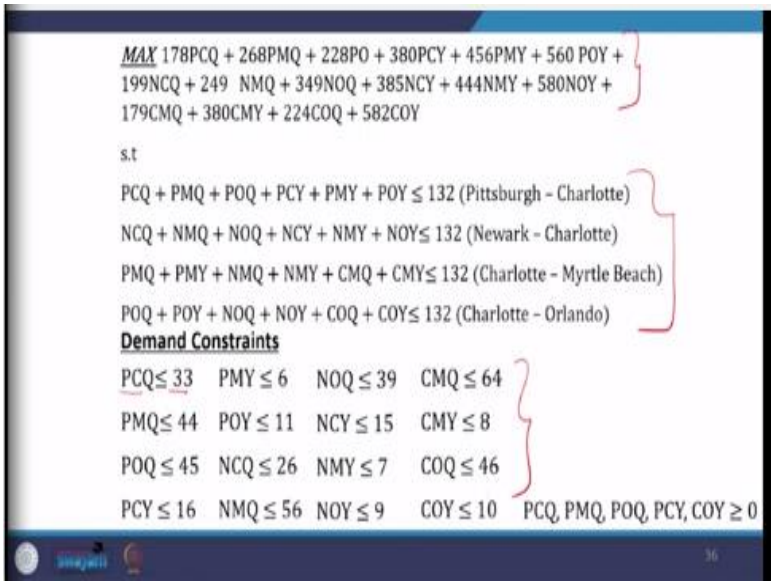


Similarly, for this destination M, so CM, there are 2 types of tickets: CMY, CMQ, then PM is possible, so PMQ, PMY, then NM is also possible NMQ NMY. You see that somebody starting

from P, if you want to reach M, he cannot go the same flight, he has to get down here at C, then he has to get into another flight coming from N. So, this is the destination constraint that should not exceed 132.



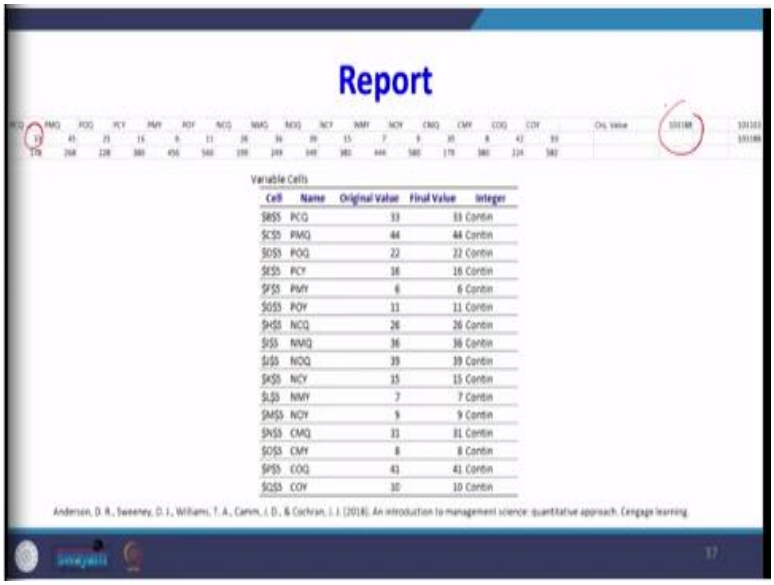
Now I have written all the constraints, all 4 constraints.



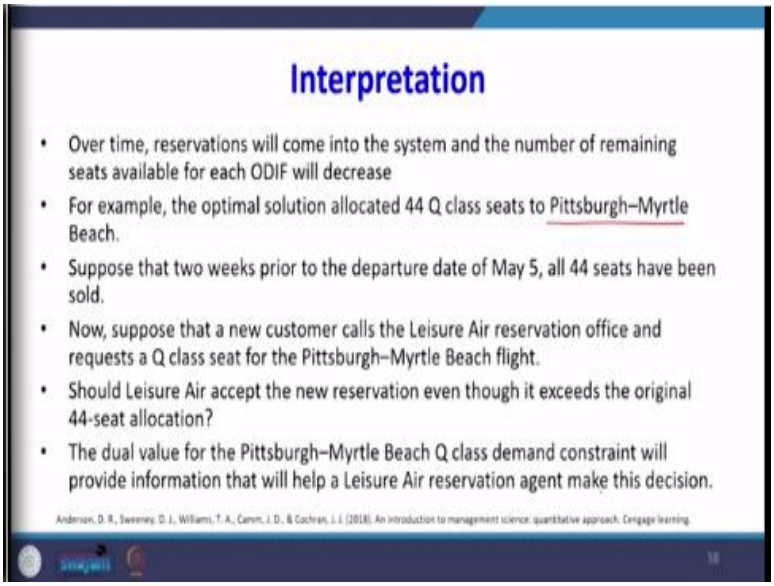
Apart from this, there are other constraints; there is the demand constraint because the minimum, so the PCQ ticket demand is 33, which must be fulfilled. So, here I have written my objective function, here I have written my constraint, and here I have written my demand constraint. So, I am going to solve this problem using a solver. Now, I have formulated a linear programming problem for revenue management that I will solve with the help of Excel.

So, I entered the value of decision variables and the coefficient of the objective function, then I wrote the constraints, and I wrote the right-hand sides. Now I will solve this one, so go to data, then solver. Now you see the objective function value is the T4. This has to be maximized, and the changing variable cell is B5 to Q5. So, here, if all the constraints are less than or equal to type, then I am going to solve it.

Now I have got to the value of the objective function in T4, that is 103188, and I have got the value for each decision variable. For example, for PCQ, in that leg ticket, so Q class ticket, I have to allocate 33 seats; for PMQ, I have to allocate 45 seats. So, this is the output of the revenue management problem. Now, I am going to interpret the shadow price of this problem; I have brought the output into the presentations, and I will explain with the help of the screenshot that I have taken from this Excel output.

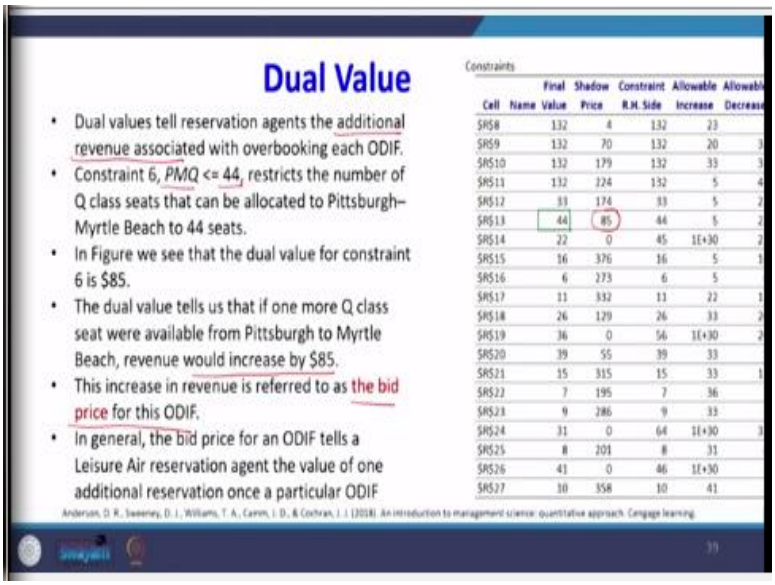


Here, I have the value of my decision variables, and here, I have the value of my objective function.



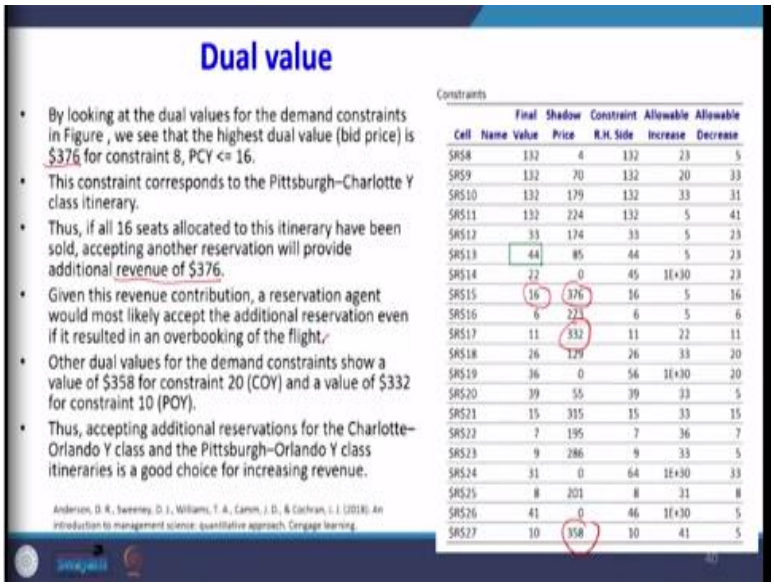
Now, we will interpret, so over time, the reservation will come into the system, and the number of remaining seats available for each ODIF will decrease. For example, the optimal solution allocated is 44 Q-class seats between Pittsburgh and Myrtle Beach. Suppose that 2 weeks prior to the departure date on May 5, all 44 seats have been sold. Now, suppose that a new customer calls the Leisure Air reservation office and requests a Q-class seat for the Pittsburgh-Myrtle Beach flight.

Should Leisure Air accept the new reservation even though it exceeds the original 44-seat allocations? So, in that leg the demand was 44 all the seats were allocated; now there are new customers asking for one more ticket on that is more than the demand. So, whether we have to accept this new reservation or not? So, we are going to interpret this answer with the help of interpreting the dual value. So, the dual value for the Pittsburgh-Myrtle Beach Q class demand constraint will provide information that will help the Leisure Air reservation agent make this decision.



Now you see, the dual value tells reservation agents the additional revenue associated with overbooking each ODIF. So, the constraint 6, we know the PMQ type is 44. So, the constrained PMQ less than or equal to 44 restricts the number of Q-class seats that can be allocated to Pittsburgh-Myrtle Beach to 44 seats. The figure shows that the dual value for this constraint is 85 here; 44 seats are allocated, and the shadow price is 85.

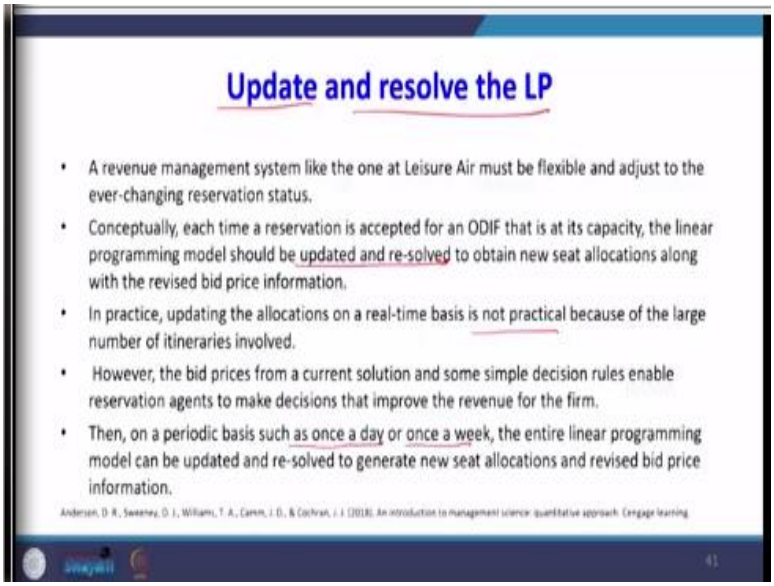
So, the dual value tells us that if one more Q-class seat were available from Pittsburgh to Myrtle Beach, the revenue would increase by 85 dollars. So, this increase in revenue is referred to as the bid price for this ODIF. So, in general, the bid price for an ODIF tells the Leisure Air reservation agent the value of one additional reservation once a particular ODIF is filled. So, this 85 says that if you are selling in that category one more ticket, your revenue will increase by 85 dollars.



Now we look at the other shadow price then we will interpret. By looking at the dual value for the demand constraint figure, we see that the highest dual value is 376; where is that 376? Here, the number of seats allocated is 16. So, this constraint corresponds to Pittsburgh-Charlotte Y class itinerary. Thus, if all 16 seats are allocated to this itinerary, so accepting another reservation will provide an additional revenue of 376 dollars.

So, given this revenue contribution, the reservation agent would most likely accept the additional reservation even if it resulted in overbooking of the flight even though there is overbooking, so that will give you the revenue of additional revenue of 376 dollars. So, other dual values for the demand constraint show the value of 358, for example here, 358, for constraint 20, and the value of 332 for constraint N.

So, accepting additional reservations for the Charlotte-Orlando Y class and the Pittsburgh-Orlando Y class itinerary is a good choice for increasing the revenue. So, what we are interpreting from the shadow price? In that category of the tickets, even though the demand is fulfilled when you go for overbooking, you will get that much additional revenue, which is equivalent to your shadow price.



But here is what you have to do. Every time, we must update and resolve this LP model that we have proposed. A revenue management system like the one at Leisure Air must be flexible and adjust to ever-changing reservation status. Conceptually, each time a reservation is accepted for an ODIF that is at it is capacity; the LP model should be updated and resolved to obtain a new allocation along with revised bid price information.

So, in practice, updating the allocations on a real-time basis is not practical because of the large number of itineraries involved. However, the bid prices for the current solution and some simple decision rules enable reservation agents to make decisions that improve the firm's revenue. Then, on a periodic basis, such as once a day or once a week, the entire LP model can be updated and resolved to generate new seat allocations and revised bid price information.

So, in this lecture, what have we studied? I introduced the concept of revenue management and different requirements, and then I explained the need for revenue management. After that, I took one revenue management problem, which I formulated in the form of a linear programming problem, and then I solved it using a solver. Then I interpreted the dual value, so the dual value gives important information, that is, if an additional ticket is sold, how much more revenue can we get from it? So, this LP model is very useful for solving revenue management problems; thank you.