EXERCISE QUESTIONS Process Flow Measures (Little's Law)

Question 1
A bank finds that the average number of people waiting in line during lunch hour is 10. On average, during this period, 2 people per minute leave the bank after receiving service. On average, how long do bank customers wait in line?

SOLUTION

$$\text{Flowtime} = \frac{\text{Inventory}}{\text{Flowrate}} = \frac{10 \text{ people}}{2 \text{ people/min}} = 5 \text{ min}$$

Question 2
At the drive-through counter of a fast-food outlet, an average of 10 cars waits in line. The manager wants to determine if the length of the line is having any impact on potential sales. A study reveals that, on average, 2 cars per minute try to enter the drive through area, but 25 percent of the drivers of these cars are dismayed by the long line and simply move on without placing orders. Assume that no car that enters the line leaves without service. On average, how long does a car spend in the drive-through line?

SOLUTION

$$\text{Flowtime} = \frac{\text{Inventory}}{\text{Flowrate}} = \frac{10 \text{ cars}}{.75(2)\text{cars/min}} = 6.\bar{6} \text{ min}$$

Question 3
Checking accounts at a local bank carry an average balance of $3,000. The bank turns over its balance 6 times a year. On average, how many dollars flow through the bank each month?

SOLUTION

$$\text{Flowrate} = \frac{\text{Inventory}}{\text{Flowtime}} = \frac{\$3{,}000}{12/6 \text{ months}} = \$1{,}500/\text{month}$$

Question 4

Orange Juice Inc. Produces and markets fruit juice. During the orange harvest season, trucks bring oranges from the fields to the processing plant during a workday that runs from 7 am to 6pm. On peak days, approximately 10,000 kilograms of oranges are trucked in per hour. Trucks dump their contents in a holding bin with a storage capacity of 6,000 kilograms. When the bin is full, incoming trucks must wait until it has sufficient available space. A conveyor moves oranges from the bins to the processing plant. The plant is configured to deal with an average harvesting day, and maximum throughput (flow rate) is 8,000 kilograms per hour.

a) Assuming that oranges arrive continuously over time, construct an inventory buildup diagram for Orange Juice Inc. In order to process all the oranges delivered during the day, how long must the plant operate on peak days? (Assume, too, that because Orange Juice Inc. Makes fresh juice, it cannot store oranges.)

b) Assuming, finally, that each truck holds about 1,000 kilograms of oranges, at what point during the day must a truck first wait before unloading into the storage bin?

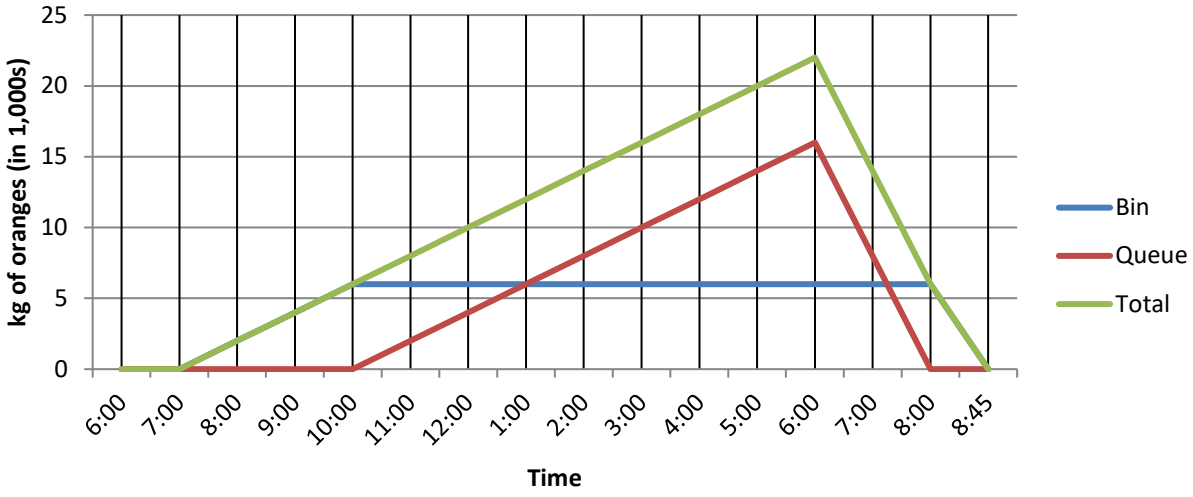
c) How long will truck wait, on average?

SOLUTION

Oranges arrive at a rate of 10,000 kg/hr and are processed at a rate of 8,000 kg/hr, implying that oranges accumulate in the holding bin at a rate of 2,000 kg/hr until the bin reaches its capacity of 6,000 kg. Obviously, this would take 3 hours (from 7 am through to 10 am).

After 10am, the surplus oranges will wait in trucks queued up to dump their load into the storage bin. This surplus of arrivals over processing (2,000 kg/hr) continues through from 10am through 6pm (a total of 8 hours) for a total of 16,000 kg of oranges awaiting in the queue. At a processing rate of 8,000 kg/hr, it takes the process an additional 2 hours to process the 16,000 kg of surplus arrivals, until 8pm.

Finally, at 8pm, all that remains is the bin of 6,000 kg of oranges. At a processing rate of 8,000 kg/hr, this would take 0.75 hours, or 45 minutes. At 8:45 pm, the process has completely processed all orange deliveries.



b) As demonstrated in the previous figure, the bin is full at 10am and therefore the subsequent truck will be forced to wait. If the truck arriving at 10am fills the bin to capacity, the next truck arrives 6 minutes later at 10:06. The 6 minutes is derived from the flowrate: 10,000 kg/hr ÷ 1,000 kg/truck = 10 trucks/hr (or one truck every 6 minutes).

c) At 10:00AM, there are no trucks (0) in the queue. At 6:00PM, there are 16,000kg of oranges (or 16 trucks) in the queue. Given the linear relationship depicted in the above figure, the average number of trucks in the queue is simply 8. Average "truck inventory" is 8 trucks. It's also a linear decline from 6:00PM (at a peak value of 16 trucks in the queue) to no trucks in the queue at 8:00PM and so the average remains 8 trucks for the full duration between 10:00AM and 8:00PM.

The "truck flowrate" is 8 trucks per hour. Recall that each truck carries 1,000 kg of oranges and that the plant processes oranges at a rate of 8,000 kg per hour - equivalent to 8 truckloads per hour.

$$\text{Flowtime} = \frac{\text{Inventory}}{\text{Flowrate}} = \frac{8 \text{ trucks}}{8 \text{ trucks/hr}} = 1 \text{ hr}$$

Question 5

Jasper Valley Motors (JVM) is a family-run auto dealership selling both new and used vehicles. In an average month, JVM sells a total of 160 vehicles. New vehicles represent 60% of sales, and used vehicles represent 40% of sales. Max has recently taken over the business from his father. His father always emphasized the importance of carefully managing the dealership's inventory. Inventory financing was a significant expense for JVM. Max's father consequently taught him to keep inventory turns as high as possible.

A) Examining the dealership's performance over recent years, Max discovered that JVM had been turning its inventory (including both new and used vehicles) at a rate of 8 times per year. What is JVM's average inventory (including both new and used vehicles)?

B) Drilling down into the numbers, Max has determined that the dealership's new and used businesses appear to behave differently. He has determined that turns of new vehicles are 7.2 per year, while turns of used vehicles are 9.6 per year. Holding a new vehicle in inventory for a month costs JVM roughly $175. Holding the average used vehicle in inventory for a month costs roughly $145. What are JVM's average monthly financing costs per vehicle?

C) A consulting firm has suggested that JVM subscribe to its monthly market analysis service. They claim that their program will allow JVM to maintain its current sales rate of new cars while reducing the amount of time a new car sits in inventory before being sold by 20%. Assuming the consulting firm's claim is true, how much should Max be willing to pay for the service?

SOLUTION

a)

$$\text{Inventory} = \text{Flowrate} \times \text{Flowtime} = 160 \text{ veh/month} \times \frac{12 \text{ months}}{8} = 240 \text{ vehicles}$$

b)

$$\text{Inventory} = \text{Flowrate} \times \text{Flowtime}$$

New: $(0.6)160 \text{ veh/month} \times \frac{12 \text{ months}}{7.2} = 160 \text{ vehicles}$

Used: $(0.4)160 \text{ veh/month} \times \frac{12 \text{ months}}{9.6} = 80 \text{ vehicles}$

$$\text{Costs} = 160 \text{ vehicles } (\$175/\text{month/vehicle}) + 80 \text{ vehicles}(\$145/\text{month/vehicle}) = \$39{,}600$$

c)

$$\text{Inventory} = \text{Flowrate} \times \text{Flowtime} = (0.6)160 \text{ veh/month} \times \frac{12 \text{ months}}{7.2}(0.8) = 128 \text{ vehicles}$$

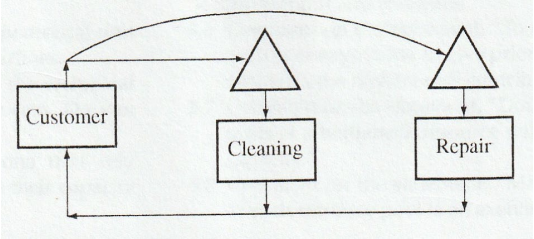
This is a reduction of 160 - 128 = 32 vehicles, or $32 \text{ vehicles} \times (\$175/\text{month/vehicle}) = \$5{,}600/\text{month}$

Question 6

Cheapest Car Rental rents cars at the Chicago airport. The car rental market consists of two segments: the short-term segment, which rents for an average of 0.5 week, and the medium-term segment, which rents for an average of 2 weeks. Cheapest currently rents an average of 200 cars a week to the short-term segment and 100 cars a week to the medium-term segment.

Approximately 20% of the cars returned (evenly distributed across both segments) are found to be defective and in need of repairs before they can be made available for rent again. The remaining cars not needing repairs are cleaned, filled with gas, and made available for rent. On average, there are 100 cars waiting to be cleaned. The average cost of this operation is 5$ per car. Cars needing repairs spend an average of 2 weeks in the repair shop and incur and average cost of $150 per car. Assume that cars are rented as soon as they are available for rent, that is, as soon as they have been cleaned or repaired.

Short-term renters pay $200 per week, while medium-term renters pay $120 per week. The flow of cars is shown in the figure below.



A) Identify throughput, inventory, and flow time at each stage.

B) What profit does Cheapest earn per week with the current system? Assume that each car loses $40 in value per week because of depreciation.

C) Cheapest is comparing two possible improvements:

1. Decrease time in repairs from 2 weeks to 1 week.
2. Decrease cost per repair from $150 per car to $120 per car while keeping flow time in repairs at 2 weeks.
   Assume that the effort that is required in which case is the same. Which change do you think will be more effective? Why?

SOLUTION

a)

Cleaning:
Flowrate = 80% of 300 cars/week = 240 cars/week
Inventory = 100 cars
Flowtime = Inventory / Flowrate = 100 cars / 240 cars/wk = 0.42 weeks

Repair:
Flowrate = 20% of 300 = 60 cars/week
Flowtime = 2 weeks
Inventory = Flowrate × Flowtime = 60 cars/week × 2 weeks = 120 cars

Customer:
Flowrate: 200 cars/week + 100 cars/week = 300 cars/week
Inventory: 200 cars/week × 0.5 weeks + 100 cars/week × 2 weeks = 300 cars
Flowtime = Inventory / Flowrate = 300 cars / 300 cars/week = 1 week

b)

Revenue from Short-term Rentals: (200 rentals/wk) × ($200/wk) × (0.5 wk/rental)= $20,000/wk
Revenue from Medium-term: (100 rentals/wk) × ($120/wk) × (2 wk/rental)= = $24,000/week
Total Revenue = $44,000/week

Expenses from cleaning: $5/cleaning × 240 cleanings / week = $1,200 / week
Expenses from repair: $150/repair × 60 repairs / week = $9,000 / week
Expenses from depreciation: $40/car/week × (100 + 120 + 300) cars = $20,800 / week
Total Expenses = $31,000

Profit = Revenue - Expenses = $44K/week - $31K/week = $13K/week

c)

Option 1: Decrease repair time from 2 weeks to 1 week
Inventory = Flowrate × Flowtime = 60 cars/week × 1 weeks = 60 cars
This is a reduction of (120 - 60) cars = 60 cars
This in turn reduces losses through depreciation of $40/car/week × 60 cars = $2,400/week

Option 2: Decrease repair costs from $150/repair to $120/repair
Expenses from repair: $120/repair × 60 repairs / week = $7,200 / week
Expenses due to repairs have decreased from $9,000/week to $7,200/week (or a savings of $1,800/week)

Option 1 generates the most savings.

Question 7

The Evanstonian is an upscale independent hotel that caters to both business and leisure travelers. On average, one-third of the guests checking in each day are leisure travelers. Leisure travelers generally stay for 3.6 nights – twice as long as the average business customer.

A) on an average day, 135 guests check into The Evanstonian. On average, how many guests of each type are in the hotel on any given day?

B) How many times per month does the hotel turn over its inventory of guests (assume 30 days per month)?

C) The average business traveler pays a rate of $250 per night, while leisure travelers pay an average rate of $210 per night. What is the average revenue The Evanstonian receives per night per occupied room?

SOLUTION

a)

Leisure:

$\text{Flowrate} = \frac{1}{3}(135 \text{ guests/day}) = 45 \text{ guests/day}$

$\text{Flowtime} = 3.6 \text{ days}$

$\text{Inventory} = \text{Flowrate} \times \text{Flowtime} = 45 \text{ guests/day} \times 3.6 \text{ days} = 162 \text{ guests}$

Business:

$\text{Flowrate} = \frac{2}{3}(135 \text{ guests/day}) = 90 \text{ guests/day}$

$\text{Flowtime} = 1.8 \text{ days}$

$\text{Inventory} = \text{Flowrate} \times \text{Flowtime} = 90 \text{ guests/day} \times 1.8 \text{ days} = 162 \text{ guests}$

In any given day there are 162 leisure guests and 162 business guests for a total of 324 guests.

b)

$$\frac{1}{Flowtime} = \frac{1}{3.6 \text{ days}}(30 \text{ days/month}) = 8.\overline{3} \text{ turns per month (Leisure)}$$

$$\frac{1}{Flowtime} = \frac{1}{1.8 \text{ days}}(30 \text{ days/month}) = 16.\overline{6} \text{ turns per month (Business)}$$

Or, using an average stay of $0.\overline{3}(3.6 \text{ days}) + 0.\overline{6}(1.8 \text{ days}) = 2.4 \text{ days}$

$$\frac{1}{Flowtime} = \frac{1}{2.4 \text{ days}}(30 \text{ days/month}) = 12.5 \text{ turns per month (aggregate)}$$

c) Exactly half of the guests are leisure guests (162) and the other half are business guests (162). The average nightly revenue per occupied room is therefore ($250+$210)/2 = $230/night.

Question 8 (Hospital ER)

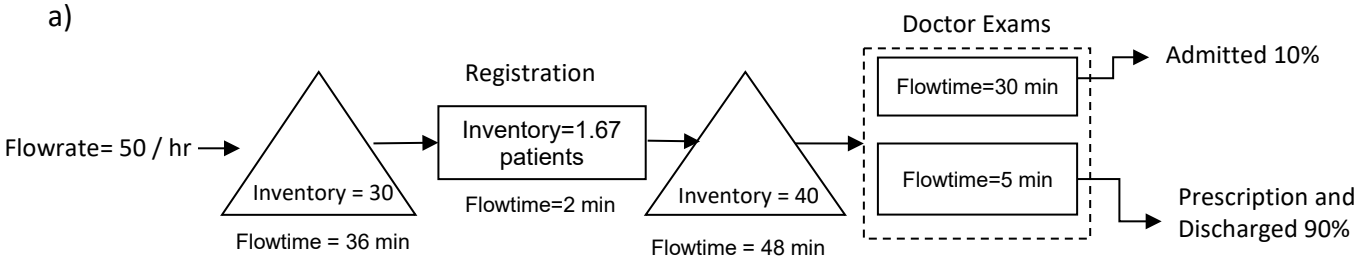
A hospital emergency room (ER) is currently organized so that all patients register through an initial check in process. At his or her turn, each patient is seen by a doctor and then exits the process, either with a prescription or with admission to the hospital. Currently, 50 people per hour arrive at the ER, 10% of who are admitted to the hospital.

On average 30 people are waiting to be registered and 40 are registered and waiting to see a doctor. The registration process takes, on the average, 2 min/patient. Among patients who receive prescriptions, average time spent with a doctor is 5 minutes. Among those admitted to the hospital, average time is 30 min.

a) On average, how long does a patient stay in the ER?
b) On average, how many patients are being examined by doctors?
c) On average, how many patients are in the ER?

SOLUTION

a)



The flowtime through the buffer awaiting check-in is:

$$\text{Flowtime} = \frac{\text{Inventory}}{\text{Flowrate}} = \frac{30 \text{ patients}}{50 \text{ patients/hr}} = 0.6 \text{ hours} = 36 \text{ minutes}$$

The inventory at registration is:

$$\text{Inventory} = \text{Flowrate} \times \text{Flowtime} = \frac{50 \text{ patients/hr}}{60 \text{ min/hr}} \times 2 \text{ min} = 1.67 \text{ patients}$$

The flowtime through the *second* buffer awaiting is:

$$\text{Flowtime} = \frac{\text{Inventory}}{\text{Flowrate}} = \frac{40 \text{ patients}}{50 \text{ patients/hr}} = 0.8 \text{ hours} = 48 \text{ minutes}$$

Total flowtime: 36 min + 2 min + 48 min + 0.1(30 min) + 0.9(5 min) = 93.5 minutes

b) Admissions: Inventory = (0.5 hr) × (0.1)(50 patients/hr) = 2.5 patients
Prescriptions: Inventory = (5/60 hr) × (0.9)(50 patients/hr) = 3.75 patients
Total Inventory = 6.25 patients

c) Throughout the entire process, we expect 30 + 1.67 + 40 + 6.25 = 77.92 patients.

Question 9 (Mr. Penguin)

Mr. Penguin is a tuxedo rental agency, which provides the formal attire for special occasions at a price of $350 per week. On average Mr. Penguin serves 180 customers a week. Approximately one-third of the tuxedos returned are damaged during the rental period and require repairs before they can be made available for rent again. Damaged tuxedos are sent for repairs to a tailor (who fixes and cleans the tuxedos) and are ready for rent in 2 weeks. The remaining tuxedos, which do not require repairs, are cleaned in-house. On average there are 60 tuxedos waiting to be cleaned or being cleaned. The average cost of cleaning is $10/tux. Tuxedos needing repairs incur an average cost of $175/tux. Assume that tuxes are rented as soon as they are available for rent, that is, as soon as they have been cleaned or repaired.

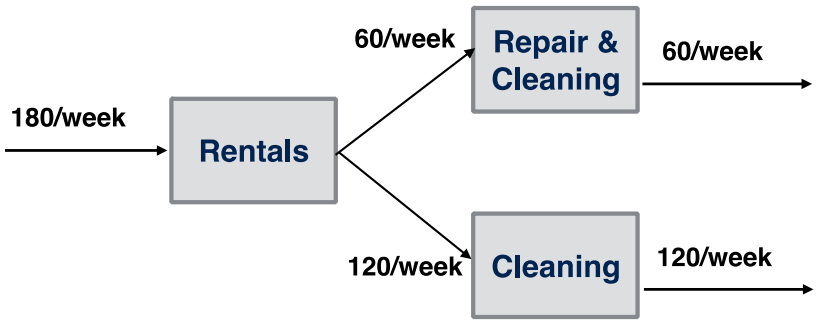
a. Draw the process flow chart for Mr. Penguin.
b. If customers on average rent tuxedos for the entire week, then how many tuxedos does Mr. Penguin require to run their business? What is Mr Penguin's per week profit?
c. If customers on average rent tuxedos for a period of 0.5 weeks, then how does throughput, inventory, flow time, and profit change?

Mr. Penguin re-builds his system such that repairs are also in-house. The in-house repairs are substantially cheaper at a cost of $100/tux, but it takes 2.5 weeks to repair before being sent to the in-house cleaners. The additional work of repairing also has an impact on the cleaning service, slowing cleaning down to an average of 1 week per tux. For the new system, if necessary, he will purchase new tuxedos at $3000 per tuxedo. Assume that Mr. Penguin will only own the minimum number of tuxedos necessary to carry out the operation.

a. Draw the process flow chart for the new system.
b. How many weeks does Mr. Penguin need to recover his investment if rental periods are typically 0.5 weeks?
c. What about if customers rent for a period of 1 weeks?

SOLUTION

a)



b)

Rentals
Flowrate = 180 tuxedos/wk
Flowtime = 1 wk
Inventory = Flowrate × Flowtime = 180 tux/wk × 1 wk = 180 tuxedos

Repairs
Flowtime = 2 wk
Flowrate = 180 tuxedos/wk ÷ 3 = 60 tuxedos/wk
Inventory = Flowrate × Flowtime = 60 tux/wk × 2 wk = 120 tuxedos

Cleaning
Flowrate = 180 tuxedos/wk ÷ 3/2 = 120 tuxedos/wk
Inventory = 60 tuxedos
Flowtime = Inventory ÷ Flowrate = 60 tuxedos ÷ 120 tuxedos/wk = 0.5 weeks

Total Inventory = 180 + 120 + 60 = 360 tuxedos

Profit = $350/rental (180 rental/wk) - $175/tuxedo (60 tuxedos/wk) - $10/tuxedo (120 tuxedos/wk)
= $63,000/wk - $10,500/wk - $1,200/wk
= $51,300/wk

c) Assuming the flowrate remains consistent, nothing changes for Cleaning or Repairs.

Rentals
Flowrate = 180 tuxedos/wk
Flowtime = 0.5 wk
Inventory = Flowrate × Flowtime = 180 tux/wk × 0.5 wk = 90 tuxedos

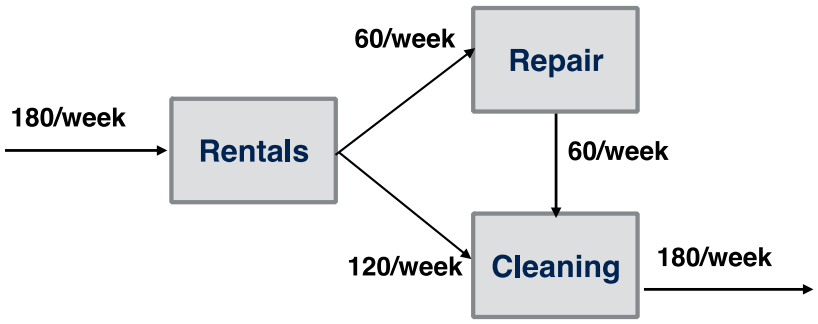
New Total Inventory = 90 + 120 + 60 = 270 tuxedos

Each rental will now be only for a half week and instead of $350 per rental (for a full week), it is now $175 per rental (for a half week).

Profit = $175/rental (180 rental/wk) - $175/tuxedo (60 tuxedos/wk) - $10/tuxedo (120 tuxedos/wk)
= $31,500/wk - $10,500/wk - $1,200/wk
= $19,800/wk

New process for in-house repairs…

a)



b)

Rentals
Flowrate = 180 tuxedos/wk
Flowtime = 0.5 wk
Inventory = Flowrate × Flowtime = 180 tux/wk × 0.5 wk = 90 tuxedos

Repairs
Flowtime = 2.5 wk
Flowrate = 180 tuxedos/wk ÷ 3 = 60 tuxedos/wk
Inventory = Flowrate × Flowtime = 60 tux/wk × 2.5 wk = 150 tuxedos

Cleaning
Flowrate = 180 tuxedos/wk ÷ 3/2 + 60 tuxedos/wk = 180 tuxedos/wk
Flowtime = 1 weeks
Inventory = Flowrate × Flowtime = 180 tux/wk × 1 wk = 180 tuxedos

Total Inventory = 180 + 150 + 90 = 420 tuxedos
This is an increase of 150 tuxedos, at a cost of $3,000/tuxedo = capital investment of $450,000

Profit = $175/rental (180 rental/wk) - $100/tuxedo (60 tuxedos/wk) - $10/tuxedo (180 tuxedos/wk)
= $31,500/wk - $6,000/wk - $1,800/wk
= $23,700/wk

The weekly profit will pay off the capital investment in $450,000 ÷ $23,700/wk ≅ 19 weeks

c) In this case, the revenue increases back to $350 for each rental…

Profit = $350/rental (180 rental/wk) - $100/tuxedo (60 tuxedos/wk) - $10/tuxedo (180 tuxedos/wk)
= $63,000/wk - $6,000/wk - $1,800/wk
= $55,200/wk

Total Inventory = 180 + 150 + 180 = 510 tuxedos
This is an increase of 150 tuxedos, at a cost of $3,000/tuxedo = capital investment of $450,000

The weekly profit will pay off the capital investment in $450,000 ÷ $55,200/wk ≅ 8.2weeks, or by the end of the 9th week.

Question 10 (Kingston Car Rentals)
Kingston Car Rentals (KCR) rents cars at Kingston airport. Their market consists of two segments: the short-term segment, which rents for an average of 0.5 weeks, and the medium-term segment, which rents for average of 2 weeks. KCR currently rents an average of 200 cars a week to the short-term segment and 10 cars a week to the medium-term segment.

Approximately 20% of the cars returned (evenly distributed across both segments) are found to be defective and in need of repair before they can be made available for rent again. The remaining cars not needing repair are cleaned and made available for rent. On average, there are 100 cars waiting to be cleaned. The average cost of cleaning is $5 per car. Cars needing repairs spend an average of 2 weeks in the repair shop and incur an average cost of $150 per car. Cars returning from repair are also cleaned before made available for rent. Assume that cars are rented as soon as they are available for rent, that is, as soon as they have been cleaned and repaired.

Short-term renters pay $200 per week, while medium-term renters pay $120 per week.

a. What profit does KCR earn per week with the current system? Assume that each car loses $40 in value per week because of depreciation.
b. KCR is comparing two possible improvements. Option 1: Decrease time in repairs from 2 weeks to 1 week. Option 2: Decrease cost per repair from $150 per car to $120 per car while keeping flow time in repairs at 2 weeks. Assuming that the effort required in each case is the same, which option will be more effective? Why?

SOLUTION

Rented
Short-Term
Flowtime = 0.5 wk
Flowrate = 200 cars/wk
Revenue = $200/wk/car

Medium-Term
Flowtime = 2 wk
Flowrate = 10 cars/wk
Revenue = $120/wk/car

Repair
Flowrate = 0.2(210 cars/wk) = 42 cars/wk
Flowtime = 2 wk
Cost = $150/car

Cleaning
Flowrate = 210 cars/wk
Inventory = 100 cars
Cost = $5/car

a) Because the problem includes depreciation, we need to sort out the total inventory level throughout the system.

Short-Term Rental
Inventory = (0.5 wk) × (200 cars/wk) = 100 cars

Medium-Term Rental
Inventory = (2 wk) × (10 cars/wk) = 20 cars

Repair
Inventory = (42 cars/wk) × (2 wk) = 84 cars

Cleaning
Inventory = 100 cars

Total Inventory = 304 cars

Total Profit = (Short-Term Profit) + (Long-Term Profit) – (Repair Cost) – (Cleaning Cost) – (Depreciation)
= (200 cars/wk)(0.5 wk)($200/wk/car) + (10 cars/wk)(2 wk)($120 cars/wk/car) –
(42 cars/wk)($150/car) – (210 cars/wk)($5/car) – (304 cars)($40/wk/car)
= $2,890/wk

b)

Option 1: Decrease Time in Repairs

Repair
Inventory = (42 cars/wk) × (1 wk) = 42 cars
That reduces total inventory by 42 cars (initially, there were 84 cars in repair).
This, in turn, reduces the deprecation for a cost savings of (42 cars)($40/car/wk) = $1,680/wk (savings)

Option 2: Decrease repair costs
This is a reduction of $30 (from $150/car to $120/car)
Resulting in a weekly savings of (42/cars/wk)($30/car) = $1,260/wk) savings)

We save more money by reducing the flowtime through repair as it results in lower inventory levels. The savings in reduced vehicle depreciation are greater than the savings achieved by the reduced cost of individual repairs in Option 2.