Wheelies on the Beltway

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Introduction

Allan, a maintenance technician at a local technology products distribution center, shook his head in body language that meant that cartons on the sorter had jammed together for the second time on his shift. The bar codes on the cartons would have to be read by a human bar code reader and the human would have to carry the cartons to their proper destinations. The human would probably be Allan.

The problem seemed to be more that the usual random carton too flat to be detected by the photo eyes on the conveyor belts or too light to maintain traction. When two or more cartons on the sorter are closer together than a minimum distance, the sorter cannot divert the cartons to their proper destinations. The cartons were tipping backward on their trailing edge. "Hey", Allan exclaimed, "The cartons are doing wheelies! We have got to get to work on this problem right away. The loss of the sorter could cost millions of dollars."

The Company

Allan works for a technology products company, one of the world's largest wholesale distributors of technology products and services. It has 140,000-plus resale customers in 130 countries and offers more than 225,000 products from more than 1,500 of the world's leading manufacturers. The technology products company had net sales of $22 billion in 1998 and $16.5 billion in 1997. The net income was $245 million in 1998 and $193.6 million in 1997.

The technology products company has 7 distribution centers in the U. S., including one in Tennessee and 29 outside the U. S. The U. S. business is approximately 50 % of the net sales and income. The technology products company also has two computer assembly centers, one in Tennessee and one in the Netherlands. Allan works at the distribution center in Tennessee.

Q1 What is the percent of net income to net sales for the years 1997 and 1998?

Q2 What is the percent profit for a company?

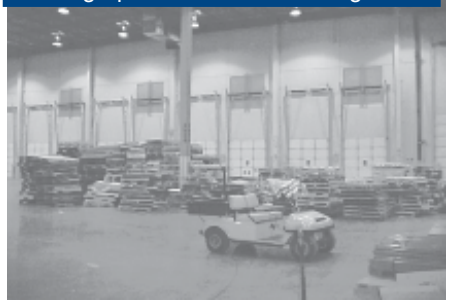
The Case Study Site

The distribution center warehouses and ships computers, computer components, and software to individuals and to retailers in the mid-south area. Computer component inventories at the center are shown in Photograph 1.

Photograph 1. Product storage bays.

Inventory is received at the docks shown in Photograph 2. The large number of pallets indicates how much inventory is received and stocked each day. The distribution center has over 6 miles of con-

Photograph 2. Product receiving docks.



veyor belts that transport a carton containing an order from the points where the items in the order are pulled from inventory to the shipping dock where the carton is loaded onto a truck for delivery. Some of the conveyors and cartons are shown in Photograph 9. The shipping docks are similar to the receiving docks. The most important conveyor in the system is a high-speed sortation conveyor that transports a carton containing a completed order to the correct shipping dock. The sortation conveyor is called a sorter for convenience. The sorter is shown in Photograph 3. The sorter mezzanine is on the second floor level. The sorter diverts cartons onto several roller conveyors that terminate on the ground floor level at the shipping docks. The roller conveyors are called declines (Photograph 4). Photograph 3 shows a carton on the sorter mezzanine diverting onto the declines. Note that the cartons on the declines (lower right in Photograph 3) are approaching one of the shipping docks (not shown). Just before a carton moves onto the sorter belt, a barcode on the carton identifies the correct decline and ship-

Q3 What are the costs associated with maintaining a large inventory?

Photograph 3. High speed sortation conveyor

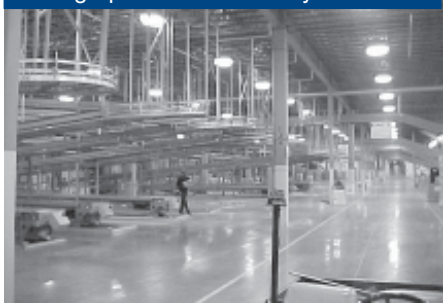
Q4 What force operates the declines?

Q5 What force operates the sorter?

Q6 What does a barcode look like and what is the pattern of a barcode scanner?

Q7 Why must cartons maintain their orientation?

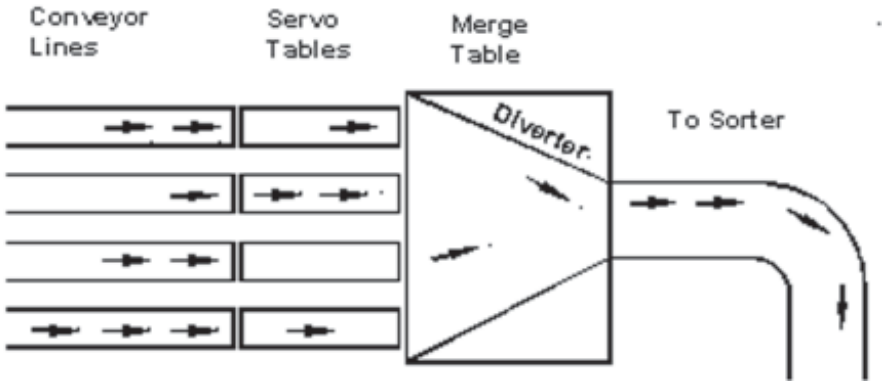
Photograph 4. Roller conveyor declines.



ping dock. Photograph 6 shows the barcode reader (left center) and cartons moving onto the sorter and maintaining a consistent orientation relative to the barcode reader. Photograph 8 shows cartons on the declines (right center below the lights).

Photograph 3 shows diverters or "shoes" on the sorter diverting a carton onto a decline. The diverter shoes sweep across the sorter belt from left to right. Since the sorter operates at high speed, there must be a minimum spacing between cartons for the diverter shoes to have enough time to divert one carton and avoid a collision with an oncoming carton.

Figure 1. The merge system.



Photograph 5. The merge system

Four conveyor lines that transport cartons from locations throughout the distribution center merge at the sorter. A sketch of the merge system is shown in Figure 1. The merge table is a wide conveyor belt with fixed diverter rails and it operates at the same speed as the sorter. The merge system transfers cartons smoothly from the 4 conveyor lines to the sorter.

Photograph 5 shows the incoming conveyor lines (background), the servo tables (Figure 1), the leading edge of the merge table, and a diverter rail on the merge table (foreground). At the merge station, cartons move onto the sorter at a high rate of speed in single file with a space or gap between cartons. Photograph 6 shows a typical spacing between cartons leaving the merge table moving onto the sorter. Cartons from the four conveyor lines entering the merge station at the same time would tend to jam together. The cartons would bunch together like vehicles in a traffic jam. A serious jam could shut down the sorter and the whole distribution center at a cost of $540,000 an hour on average.

A small jam of a few cartons would eliminate the spacing between cartons on the sorter and prevent the diverter shoes from diverting cartons correctly. To avoid this problem, the conveyor lines in Figure 1 are accumulating conveyors. Cartons collect at the terminal end of each conveyor line and only leave the line when they are called for. Cartons are called for on a first in first out basis. The cartons then move onto the servo tables shown in Figure 1 and Photograph 5. The four servo tables accelerate the cartons up to the sorter speed in coordinated movements in order to allow one carton onto the sorter at a time. When cartons appear on two or more of the servo tables at the same time, one of the servo tables feeds a carton onto the merge table while the other servo tables regulate their speed and position or brake to a complete stop. When the first carton is on the merge table, the next servo table in turn ramps up to speed very quickly and feeds its carton onto the merge table, and so on. The merge table operating at the same speed as the sorter smoothly diverts the carton onto the sorter. The result of the merge operation is an interleaved distribution of cartons on the sorter from each of the four conveyor lines. Merging is a continuous process that constantly avoids potential jams on the sorter.

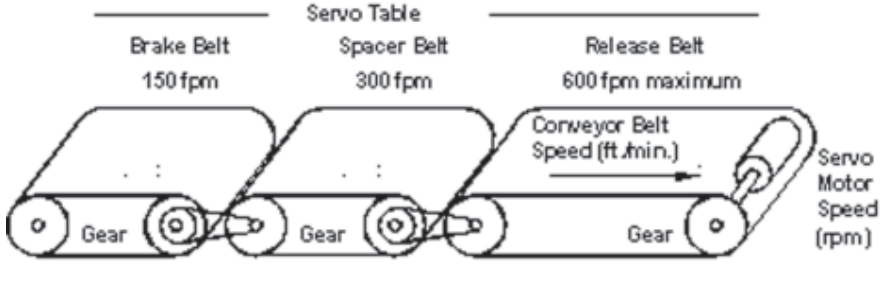
Photograph 6. Carton spacing on the sorter

A sketch of one of the servo tables is

Q8 Give an example of maintaining a given space between moving objects.

Q9 How are speed and spacing related?

Figure 2. Servo table details.



Q10 In terms of the release belt gear radius, what is the relationship between the speed of the servo table in feet per minute and the speed of the servomotor in revolutions per minute? Refer to Figure 2.

Q11 If the speed of the servo table is 600 fpm, what is the speed of the servomotor? (Based on your answers above.)

shown in Figure 2. The servo table is a segmented conveyor belt. A servomotor is directly geared to the release belt, the segment that feeds the carton onto the merge table. The spacer belt is geared to the release belt at one-half the release belt speed. The brake belt is geared to the spacer belt at one-half the spacer belt speed. The segments accelerate a carton 4 times its original speed.

The servomotor drives all three segments at the their respective speeds. The segments are said to be slaved to the servomotor. The servo tables regulate their speed and position and can even accelerate from a full stop to several hundred feet per minute very rapidly. For cartons to maintain their orientation and stability on the servo tables, they must weigh between 2 and 100 pounds and be able to accelerate and decelerate at 0.75 G without tipping and sliding (1 G = 32 feet per second).

A closed loop control system controls the servo table position and speed. Several photo eyes on each servo table detect the position of the cartons. Photograph 5 shows the photo eyes along the edges of the servo table belts. Tachometer and resolver feedback devices attached to the servomotor measure the speed and position of the servomotor. A dedicated motion controller reads the outputs from the photo eyes and feedback devices and sends speed and position commands to the servo tables. A programmable controller coordinates the operation of the complete merge and sort system.

Sorter Maximum and Current Operating Specifications

The sorter has a maximum speed of 600 feet per minute. The design spacing of cartons on the sorter is one carton per 3 feet, which represents an average carton length of 24" and a minimum spacing of 12". Compare the minimum spacing to the spacing in Photograph 6. The maximum throughput is 200 cartons per minute (600 fpm times 1 carton per 3 ft.). There are 3 sorts each day, 8 hours per sort. An estimate of the maximum capacity of the sorter is

(1 carton / 3 ft.)(600 ft./ min.)(60 min./hour)(8 hours / sort)(3 sorts / day) = 288,000 cartons / day

An estimate of the center's current sales is

(average charge / carton) (number of cartons / day) = sales / day

The average charge includes the cost of the product and the shipping charges. The current average charge per carton is $300. Due to inventory and direct labor costs, the center's current profit is approximately 2 % of sales.

The photographs of the sorter and the merge system show that cartons usually arrive at the sorter in clusters instead of a steady stream. The sorter load depends on the time of day, the season, and other factors. In order to evaluate the performance of the center on a daily or yearly basis, we can assume that at present, there is an average of 1 carton per 18 feet. Compare the present spacing to the spacing in Photograph 6. The programmable controller that coordinates the merge system and sort system could be programmed to test this assumption. The sorter is currently operating at a speed of 540 feet per minute and approximately 15 % of full capacity.

The distribution center is planning to increase its production within the next year. Upper level management wants to increase production at least 10 %. A new building and more floor space will increase warehousing capacity and the resulting orders will be routed into the existing sortation and merge system.

The Problem

While the plans for increasing production are developing, a problem occurs. A servo table is accelerating rapidly and cartons are moving in spurts and jerky movements on the servo table. There is some vibration and noise associated with the servo table movements. The cartons do "wheelies" on the servo table and lose their traction and orientation. Jams occur on the merge table and barcodes do not read correctly. Cartons will not sort correctly. They re-circulate at the end of the sorter and go back to the merge table and still do not sort correctly. Photograph 7 shows the end of the sorter where re-circulation occurs. Photograph 7 also shows a carton that does not appear to have been diverted to a decline. The efficiency of the merge and sort system is significantly reduced. The remaining servo tables appear to be operating correctly.

You and your group will represent the distribution center's plant manager. The plant engineer, the conveyor system design engineers, and the servo table manufacturer's representative have been notified and called together to give their report and to make recommendations to correct the problem. You will have to make the final decision. Listen to the following recommendations.

Recommendations

Karen, the servo table manufacturer's representative, recommends shutting down the ailing servo table for one day to replace certain critical mechanical components. The costs of material and labor for the work will be $ 10,000. There will

Q12 Calculate the current throughput rate in cartons per minute.

Q13 Calculate the current cartons per day production.

Q14 Calculate the current sales in dollars per day.

Q15 Calculate the current profit in dollars per day.

be a loss of sales and a corresponding loss of profit since one of the servo tables will be out of service for one day.

Karen warns that continuing to operate the servo table without the recommended maintenance might cause severe mechanical damage. The servo table would have to be replaced. It will take the manufacturer at least a week to fabricate another servo table even if the materials and parts are in stock. The costs of material and labor would be $25,000.

In addition to the servo table damage, there might be a significant possibility of personal injury in the event of a broken belt or other mechanical failure. In any event, the servo table is not ready for the planned increased in production.

George, the distribution center's engineer, disagreed vigorously with Karen. Up to the time that Allan discovered the problem, regular maintenance indicated that the electrical and mechanical components in the system were OK. Moreover, severe thunderstorms in the Tennessee area are common. Thunderstorms can disrupt computer programs and damage electronics components. George thinks that the problem is in the servo table's controller or program or the merge system's programmable controller. He recommends an examination of the servo table's controller parameters. He even thinks that he may be able to determine which parameters are incorrect. George estimates that the servo table would only have to be shut down for a couple of hours. "Don't fix it if it is not broken", George says.

The conveyor system's designers assure George that the merge system and sorter have the capability of operating at the current and at the higher production rates without any significant change in the existing design.

Q16 Based on your knowledge of programmable controllers, how could you determine the average number of cartons per day?

Q17 Increased production will increase the load or duty cycle on which components of the conveyor system?

Q18 Identify the problem and make a list of the possible solutions.

Q19 Run simulations of a closed loop sampled data control system with a step input. Set the sampling time to 0.1 s and the 2nd order process parameters to a natural frequency of 3.2 radians per second and a damping ratio of 0.6. Hold the sampling time and process parameters constant and vary the values of proportional, integral, and derivative gain. What effects do the gains have on the system response to the step input?

Q20 Which gains do you think may be related to the problem?

Q21 Which conveyors are involved in the problem and which ones could probably be eliminated?

Q22 As a technician, how would you troubleshoot the problem?

Q23 If you were the plant engineer, how would you get the problem corrected?

The Dilemma

Sam, the distribution center's manager, knows that he must make a decision immediately. The threat of lost production is not acceptable. And he cannot tell upper level management that the distribution center is not ready to increase production. In the past, Karen and George had always agreed on a recommendation. He stated,"Is Karen recommending that we spend $10,000 even if it is possible that there is no damage not to mention the down time? If I agree to George's recommendation, it would boost the distribution center's maintenance record by showing top management that major damage has been avoided and that the money we are spending on maintenance is effective. My main concern is that if George's recommendation does not work, we will risk having to spend $25,000 with an indefinite down time and even a risk of personal injury and a lawsuit. What should I do?"

Q24 Evaluate the alternative solutions through a costs/benefits analysis

Material handling web sites

http://www.accusort.com

http://ab.com

http://www.giddings.com

http://www.hksystems.com

http://www.hytrol.com

http://www.mhia.org

http://www.rapistan.com

http://www.software.rockwell.com

http://www.nsti.tec.tn.us/seatec/

Distribution Center Photographs

Photograph 7 shows the far end of the sorter where re-circulation occurs. Photograph 7 also shows a carton that does not appear to have been diverted onto a

Photograph 7. The far end of the sorter.

Q25 Look for information on the case study problem at the material handling web sites.

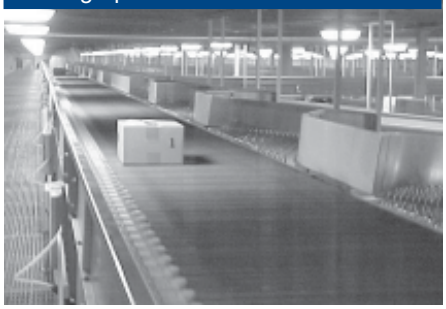
Q26 Look for other companies on Internet that use material handling equipment.

Q27 Give a progress report on the case study.

Q28 Give a presentation on the case study including the identification of the problem, the possible solutions, your costs/benefits analysis, and your decision.

Q29 Write a report on the case study including the identification of the problem, the possible solutions, your costs/benefits analysis, and your decision.

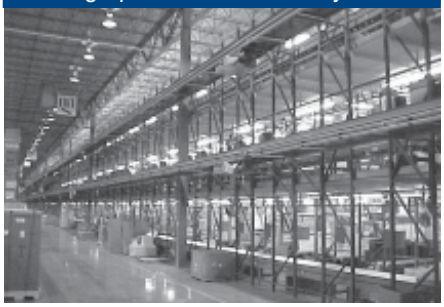
Photograph 8. Cartons on the declines.



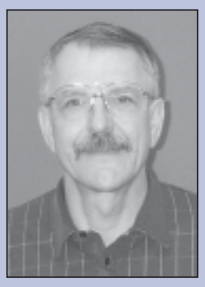
decline.

Photograph 8 shows the top of some cartons on their way down the declines (upper right corner below the lights). The numbers on the cartons identify the carton sizes. There are 4 sizes.

Photograph 9. Product conveyor lines.



Photograph 9 shows 3 levels of conveyor lines and cartons upstream from the merge system. These cartons eventually arrive at the merge table and sorter. The distribution center consists of 4 large buildings with a total of 600,000 square feet of floor space. In the building shown on Photograph 9, orders are filled and placed on the lower level conveyor and the upper level conveyors transport cartons from the other buildings through this building to the merge table and sorter.



James M. Northern

Mike Northern, P.E., is currently Program Coordinator of Electrical Engineering Technology at Southwest Tennessee Community College. Mr. Northern graduated from the University of Memphis with a B.S. in Electrical Engineering in 1970. While working as an engineer for Allen & Hoshall consulting engineers, he earned a B.S. in Psychology at the University of Memphis and later while teaching at Southwest Tennessee Community College he earned a M.S. in Technical Education at the University of Memphis. Mr. Northern worked as an engineer and senior engineer at Allen & Hoshall for 8 years in the area of rural power systems analysis and has been teaching at Southwest Tennessee Community College for 20 years in the areas of instrumentation and electrical engineering technology. He presented papers on programmable controllers and control systems at the Memphis Light Gas & Water's Engineer Day Seminars and at the Memphis Area Engineering Societies Conference at Christian Brothers University. As a team member of the South-East Advanced Technological Education Consortium (SEATEC), an NSF grant, Mr. Northern has worked closely with industry partners to introduce case study methods into technical education. As a mentor in the Bridge to Biomedical Science Careers, an NIH grant, he has worked closely with engineering faculty at the University of Memphis and mentored several students interested in biomedical careers. Mr. Northern is a member of the Society of Manufacturing Engineers (SME). He is married and has a son.

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INSTRUCTOR'S GUIDE

Synopsis

A technology products company sells over 225,000 products from more than 1500 of the world's leading manufacturers to 140,000-plus resale customers in the U.S. and abroad. The company had net sales of $22 billion and a net income of $245 million in 1998.

The case study takes place at the technology products distribution center and warehouse in Tennessee. Over 6 miles of conveyor belts transport cartons of computer products through the warehouse to shipping docks. The conveyor belts are divided into 4 major conveyor lines that merge into a single high-speed sorter conveyor operating at a speed of 540 fpm. Cartons on the sorter are diverted to the correct shipping dock.

For cartons to be diverted correctly, there must be a minimum spacing between cartons on the sorter. If cartons are too close together, they may be incorrectly diverted or worse, the diverter and packages may jam the sorter and cause a shut down of the whole distribution center at a cost of $540,000 an hour on average.

To maintain minimum spacing, there is a servo table on each of the 4 major conveyor lines merging at the sorter. The servo tables regulate speeds in order to only allow one carton onto the sorter at a time. One of the 4 servo tables is not operating correctly. The servo table is the problem in the case study.

The servo table manufacturer's representative recommends replacing critical parts on the servo table at a cost of $74,800. The distribution center's engineer suggests that the problem is not as bad as it looks. Checking and adjusting certain parameters in the servo table's controller can correct the problem. The distribution center's manager must make a decision immediately about how to proceed.

Competencies

The case study was designed for a control systems course or unit of instruction in the sophomore year of an Associates level electronics or electrical engineering technology program. Generally, students will have had courses, such as:

- Windows operating systems, word processing, and spread sheets in a microcomputer applications course
- AC-DC circuits and electronic circuits in circuits courses
- Digital circuits
- Algebra, trigonometry, and calculus
- Industrial electronics, motors, generators, and transformers
- A co-requisite programmable controllers course
- English composition and oral communications
- Social science and humanities electives

The following specific competencies are required for a student to be successful in the course and case study:

- Working knowledge of algebra
- Working knowledge of units of measure and unit fractions
- Conceptual understanding of calculus topics
  a) Simpson's rule or the trapezoidal rule for finding the area under a curve
  b) Integration – finding the area under a curve
  c) Differentiation – rate of change - finding the slope of a tangent to a point on a curve

Teaching the case study

The topics in the course or unit of instruction include open and closed loop control systems with 1st and 2nd order processes. The closed loop systems include ON/OFF, proportional, integral, and derivative control modes. The case study problem was fashioned to resemble the behavior of a closed loop control system by assuming that the proportional, integral, and derivative (PID) gains in the servo table controller are wrong.

There is no simple solution of the problem in the case study. Some students decide to take the manufacturer representative's advice. Spend $ 74,800

Student Objectives:

- Apply basic control system concepts
- Apply basic calculus concepts
- Apply control system simulation software to an industrial problem
- Use a programmable controller and programming software to simulate an industrial problem
- Research an industry on internet
- Apply written and oral communications skills
- Learn how to solve an industrial problem through problem-based cooperative learning
- Learn interdisciplinary skills
- Learn how to perform tasks and solve problems as a member of a group
- Practice decision making skills
- Troubleshooting

rather than risk $ 478,600. From the author's point of view, the best solution is the distribution center engineer's solution: the servo table controller parameters (i.e., the PID gains) are causing the erratic behavior of the servo table. This is essentially a software problem. Students may actually predict which controller gains will improve the control system.

The case study could be used in a manufacturing related technology or it could possibly be a stand-alone case study since it is rich in details about the company and the material handling industry.

The case study is flexible and may be modified for each instructor's needs. The class may be randomly divided into groups to facilitate cooperative learning. Answering the questions and problems in the case study in class is effective. From 5 % to 15 % of each student's grade should be based on the student's group performance.

At the engineering technology level, the students can simulate control systems using applications software rather than math software that requires students to derive equations and then program the equations. The case study might also be used at an engineering level. At the engineering level, math software would be more appropriate.

Answers to questions in the case study

1) What is the percent of net income to net sales for the years 1997 and 1998?

$$\frac{\text{net income}}{\text{net sales}} = \frac{\$193.6 \text{ million}}{\$16.5 \text{ billion}} = 1.17\% \text{ (1997)}$$

$$\frac{\text{net income}}{\text{net sales}} = \frac{\$245.0 \text{ million}}{\$22.0 \text{ billion}} = 1.11\% \text{ (1998)}$$

2) What is the percent profit for a company? Percent profit is the percent of net income to the total costs of doing business.

3) What are the costs associated with maintaining a large inventory? The cost of real estate, real estate taxes, labor costs, interest payments, and operating expenses.

4) What force operates the declines? Gravity.

5) What force operates the sorter? Motor torque.

6) What does a barcode look like and what is the pattern of the barcode scanner? The barcode is a series of parallel lines with varying widths. The widths produce a code. A laser scanner scans in a straight line across the bars determining the widths and the codes. The scanner will not work if the bars in the barcode are parallel to the scanner line.

7) Why must cartons maintain their orientation? To maintain an angle between the barcode and the scanner line. The scanner will not work if the bars in the barcode are parallel to the scanner line.

8) Give an example of maintaining a given space between moving objects. There is a minimum stopping distance between vehicles on a highway. The spacing between ducks or aircraft flying in a formation.

9) How are speed and spacing related? The greater the speed, the greater the spacing.

10) In terms of the release belt gear radius, what is the relationship between the speed of the servo table in feet per minute and the speed of the servomotor in revolutions per minute? Refer to Figure 2. Since the servomotor is directly geared to the release belt on the servo table, every rotation of the servomotor shaft and gear advances the release belt a distance equal to the circumference of the gear on the servomotor shaft. Therefore, the release belt speed in feet per minute is equal to the speed of the servomotor in rpm times the servomotor gear circumference in inches per revolution times an inches-to-feet conversion factor as follows.

$$B = R\,C\,(1\text{ft./12in.})$$
$$B = R\,(\pi D)(1\text{ft./12in.})$$
$$R = \frac{B}{C}\frac{12\text{ in.}}{1\text{ ft.}} = \frac{B}{\pi D}\frac{12\text{ in.}}{1\text{ ft.}}$$

B is the release belt speed in fpm
R is the servo motor speed in rpm
C is the gear circumference in inches per revolution
D is the gear diameter in inches per revolution

11) If the speed of the servo table is 600 fpm, what is the speed of the servomotor? (Based on your answers above.) Assume that the diameter of the gear is 5 inches.

$$R = \frac{B}{\pi D}\frac{12\text{ in.}}{1\text{ ft.}} = \frac{600\text{ fpm}}{\pi(5\text{ in./rev.})}\frac{12\text{ in.}}{1\text{ ft.}} = 485\text{ rpm}$$

A reasonable calculation would yield a servo speed of 0 to 6,000 rpm.

12) Calculate the current through put rate in cartons per minute.
The present spacing of cartons is 1 carton per 18 feet. The current speed of the sorter is 540 feet per minute.

Throughput=(1 carton/3 ft.)(540fpm) =30 cartons per minute

13) Calculate the current cartons per day production.

Cartons/day=(30 cartons/min.)(60 min./hour)(8 hours/sort)(3 sorts/ day)=43,200 cartons/day

14) Calculate the current sales in dollars per day. The current average costs per carton are $300.

Sales=($300/carton)(43,200 cartons/ day)=$12,960,000/day

15) Calculate the current profit. The current profit at the distribution center is assumed to be 2 % of sales.

Profit=(0.02)($12,960,000)=$259,200 per day

16) Based on your knowledge of programmable controllers, how could you determine the average throughput per day?

Count the number of cartons that get sorted in a day. Calculate the length of sorter belt that circulates in a day.

Assume that the count is 43,200 cartons. The sorter belt length is (540 fpm)(24 hours/day)(60 min./hour) = 777,600 ft. The average cartons per foot is

$$\frac{43{,}200 \text{ cartons}}{777{,}600 \text{ ft.}} = \frac{1 \text{ carton}}{18 \text{ ft.}}$$

or 0.0556 cartons per foot

Throughput=1 carton/18 ft.(540 fpm) = 30 cartons/minute

Note that students get a chance to make many reasonable assumptions.

17) Increased production will increase the load or duty cycle on which components of the conveyor system? At the time of writing, the distribution center was planning a new warehouse. The details are not available. The case study assumes the following. The new warehouse will have new major conveyor lines. The existing servo tables, merge table, and sorter have ample capacity. The cartons from the new lines will enter the existing system on the old main lines just upstream of the servo tables. Therefore, the load on the existing main lines will stay the same and the load on the existing servo tables, merge table, and sorter will increase.

18) Identify the problem and list the possible solutions. The problem is a malfunctioning servo table. The bad servo table causes the problems on the merge table and sorter. The problem could be an electronic problem in the servo table's controller or the controller's computer program. Since there are indications of vibration and noise, the problem could be broken or worn parts in the servo table itself. The solutions are to replace computer cards or modules in the controller or to down load a new program into the controller. It is possible that the gains in the bad servo table are wrong and can be tuned to optimize the servo response. It would be a good idea to compare the good servo and bad servo gains. Correcting the bad servo gains is another solution. To correct mechanical problems, replace broken or worn parts.

19) Run simulations of a closed loop sampled data control system with a step input. Set the sampling time to 0.1 s and the 2nd order process parameters to a natural frequency of 3.2 radians per second and a damping ratio of 0.6. Hold the sampling time and the 2nd order process parameters constant and vary the values of proportional, integral, and derivative gain. What effects do the gains have on the response to the step input? With a 2nd order process, the response will be over damped, critically damped, or under damped. The given damping ratio of 0.6 is an under damped process. With proportional only control mode, the response will have steady state error. Critical damping without steady state error is the desired solution to the problem in the case study. An under damped response will either have damped oscillations or go unstable. Any unstable response should be corrected by reducing gains. First, eliminate steady state error by adding integral control mode to proportional mode (i.e., steady state error times time is equal to area, hence integral mode which finds an area under a curve). Unfortunately, integral mode will increase damped oscillations in the response. Next, add derivative control mode to damp out the damped oscillations (i.e., rate of change varies with damped oscillations, hence derivative mode which opposes change proportional to the rate).

A possible "tuning" procedure is to

a) Select a proportional gain that pro duces a relatively stable response (typical values of k_p are 0- to 10).
b) Select an integral gain to eliminate steady state error (typical values of k_i are 0- to 10).
c) Select a derivative gain to damp out damped oscillations (typical values of k_d are 0- to 1).

20) Which gains do you think may be related to the problem? A combination of gains produces a critical response, the fastest and smoothest response. Since proportional-only steady state error is generally unacceptable, a combination of all three control modes is required. Proportional is the only stand-alone control mode. Integral and/or derivative must be added to proportional.

21) Which conveyors are involved in the problem and which ones could probably be eliminated? The problem is in the servo table. The 4-conveyor line, the merge table, and the sorter are probably OK.

22) As a technician, how would you troubleshoot the problem? When a problem occurs, isolate the problem by substituting good units for suspected units. In the case study, a servo table is clearly malfunctioning. Determine whether the problem is mechanical or electrical. If it is electrical, substitute spare parts to further isolate the problem. Other suggestions include:

- First let your own maintenance people determine the cause of the problem (be wary of outside advice).
- Transfer cartons to the three good servo tables (upstream of the merge station) – keep production going.
- Transfer cartons with a temporary conveyor.
- Transfer cartons by hand with temporary employees.
- Get the parts the manufacturer's representative wants to replace on order to save time but use the distribution center's maintenance people to do the work (saves money).
- There was some doubt about how accurately the maintenance records reflected the condition of the servo tables.
- Software can always be bad.
- Swap servo tables or servo table con trollers.

23) If you were the plant engineer, how would you get the problem corrected? Rely on your maintenance technicians and then seek outside help from vendors and engineers.

24)Evaluate the alternative solutions through a costs/benefits analysis.

Karen's Recommendation

Material and labor costs	$10,000
Lost sales are	
($12,960,000/day) (1servo/4) (1day) =$3,240,000	
Lost profit (at 2%)	$64,800
Total costs	$74,800

Benefits

- Medium costs
- Low risks
- Goes over the heads of the center's maintenance technicians
- Calls in vendors who may have their own agenda

Karen's Warning

Material and labor costs $25,000
Lost sales are

($12,960,000/day) (1 servo/4)
(1 week)(7 days/week) = $22,680,000

Lost profit (at 2%) $453,600
Total costs $478,600

Benefits

- There are no benefits. This is a disaster.
- Very high costs
- Indeterminate risks
- Possible personal injury and law suits

George's Recommendation

Material and labor costs $ 0
Lost sales are

($12,960,000/day)(1 day / 24 hours)
(2 hours)(1 servo /4) = $270,000

Lost profit (at 2%) $ 5,400
Total costs $ 5,400

Benefits

- Low costs
- High risks
- Boosts the center's maintenance record
- Uses the center's maintenance technicians

25) Look for information on the case study problem at the material handling web sites. Giddings and Louis makes servo table controllers. Allen Bradley makes programmable controllers. Hytrol makes conveyor systems (i.e., servo tables, merge tables, and sorters). Financial data for most companies can be found on their web sites.
26) Look for companies on Internet that use material handling equipment. Federal Express, Nike, etc.
27) Give a progress report on the case study.
28) Give a presentation on the case study including identification of the problem, the possible solutions to the problem, and your choice for the best solution.
29) Write a report on the case study including identification of the problem, the possible solutions to the problem, and your choice for the best solution.

Resources

The following resources can be used in many combinations:

- A text or class notes.
- Control systems simulation applications software or suitable math software.
- A programmable logic controller (PLC), programming PC, and software.
- Computer, Word, Excel, Power Point, Internet, etc.
- Projector and computer for Power Point presentations or overhead projector and transparencies.
- Material handling industry videos and web sites.

The case study should at least have some kind of software to simulate a control system. The simulations allow experiential learning and "What if" exercises. Simulating an application also has benefits. The course uses a Visual Basic program called Sampled Data Control Systems, written by the course instructor to simulate basic control systems (i.e., traditional 1st and 2nd order processes and PID controllers). The program is provided for the students' use. The program requires basic knowledge of the process and controller properties to simulate a control system and observe the response. The simulated response can be compared to the actual response of a programmable controller with a process simulator and PID instructions. Instant changes in the properties and responses facilitate trial-and-error learning. A math program, Matlab, requires derivation of system formulas and programming of the formulas to achieve the simulations but is general in capabilities. Matlab is commonly used in engineering controls classes. Course content should be covered before attempting to use simulators or performing laboratory exercises.

The case study could be used without a programmable controller, but it would be a plus since it adds realism to the case study. Allen Bradley is a common manufacturer of PLCs. Allen Bradley PLC 5/20Es are used in the controls class. The class uses the latest version of the Rockwell Automation PLC programming software, RSLogix 5. The program is provided for the students' use. For the programmable controller to operate in a closed loop, it would have analog I/O and a process simulator. The process simulator used in the class was designed by the course instructor and built by a lab technician. Rockwell Automation software is available to simulate a process.

Reports and preparations for a presentation should use Windows accessories such as Notepad and Paint to capture responses and insert into Word documents or an equivalent word processing program. The sales and throughput calculations in the case study questions could be accomplished with Excel or an equivalent spread sheet. Presentations should use Power Point or transparencies.

Epilogue

A problem in a servo table controller actually occurred at the distribution center. Most likely the problem was a failure of an electronics component or a connection. Controller boards were replaced. The record of the failure is based on an interview with one of the maintenance technicians at the distribution center. In the case study, the problem was fashioned to resemble the behavior of a closed loop control system by assuming that the gains in the servo table controller are wrong. The problem in the case study did not actually occur as described. Therefore, the solution is unknown. The solution offered by the manufacturer's representative and the center's engineer are both reasonable.