SQL Server Notifications in a manufacturing environment

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Outline

- Introduction to Query Notifications
  - Example: software bug tracking
  - Polling, Triggers, and Notifications
  - Message Queues
- Case Study: Manufacturing Execution System (MES)
  - Assembly line stations, torque guns, barcode scanners, RFID readers, and testing equipment
  - Industrial PCs assist operators and enforce rules
  - Examples: Polling for vehicles, test results, and problematic incoming orders
- Conclusions

Introduction to Query Notifications

- Query Notifications are a caching mechanism intended to alleviate repetitious queries of data that do not change frequently
- Rather than polling a table and looking for changes:
  - Register a SQL query indicating what you want to know
  - Wait for SQL Server to send you a message indicating that the table has changed*
  - Perform your query or action
- *You may receive notifications whenever the server can’t guarantee that your cache is still valid

Example: software bug tracking

- Suppose that you use a bug tracking program which has a table like this:

	DefectID	Created	LastModified	Summary	Severity	Status	AssignedToUserID	CreatedByUserID	ProjectID
1	1	2013-05-...	2013-05-23...	MP3 files crash system	3	1	1	2	1
2	2	2013-05-...	2013-05-09...	Text is too big	0	4	NULL	3	1
3	3	2013-05-...	2013-05-19...	Sky is wrong shade of blue	1	2	4	5	2
4	4	2013-05-...	2013-05-23...	Can't play files more than 200 bytes long	2	3	1	1	1
5	5	2013-05-...	2013-05-15...	Installation is slow	0	2	2	2	1
6	6	2013-05-...	2013-05-29...	DivX is choppy on Pentium 100	2	1	1	6	1
7	7	2013-05-...	2013-05-10...	Client acts as virus	3	4	NULL	3	2
8	8	2013-05-...	2013-05-23...	Subtitles only work in Welsh	2	2	2	1	1
9	9	2013-05-...	2013-05-15...	Voice recognition is confused by background noise	1	4	NULL	5	2
10	10	2013-05-...	2013-05-09...	User interface should be more caramelly	0	0	1	2	2
11	11	2013-05-...	2013-05-29...	Burning a CD makes the printer catch fire	3	4	NULL	6	1

- Your manager, Greg, says that everyone should receive an email within 1 minute whenever there are at least 3 bugs, unclosed (Status=4) with a Severity of 3.
- How do you fulfill Greg's request?

SQL Query for severe, unclosed bugs

```
SELECT *  FROM [dbo].[Defect]
  where [Severity] = 3 and [Status] = 4
```

	DefectID	Created	LastModified	Summary	Severity	Status	AssignedToUserID	CreatedByUserID	ProjectID
1	7	2013-05-08 00:00:00.000	2013-05-10 00:00:00.000	Client acts as virus	3	4	NULL	3	2
2	11	2013-05-10 00:00:00.000	2013-05-29 00:00:00.000	Burning a CD makes the printer catch fire	3	4	NULL	6	1
3	17	2013-05-12 00:00:00.000	2013-05-13 00:00:00.000	Password displayed in plain text	3	4	NULL	1	2
4	26	2013-05-16 00:00:00.000	2013-05-18 00:00:00.000	Password reset changes passwords for all users	3	4	NULL	6	2

- At the moment, there are 4 bugs in the Defect table matching these criteria.
- Greg tells you to mark DefectIDs 7 and 11 as invalid (Status=2).
- But how will you know when another severe bug gets entered into this table?
- Possible solutions: polling, triggers, and notifications

Solution 1: Polling

- You edit one of your in house applications to repeat that SQL query **every minute** and send an email whenever the criteria are met
- Good: simple, deterministic, and fast (on your development system). Works with any db.
- Bad: Polling from multiple computers increases the database load, which slows down all SQL queries.
- Ugly: What if an update statement changes two rows at the same time in between polls?

Polling Code Example

```
private int lastCount = 0;
private void timer1_Tick(object sender, EventArgs e)
{
  using (SqlConnection connection = new SqlConnection())
  {
    using (SqlCommand command =
      new SqlCommand("SELECT count([DefectID]) C FROM [dbo].[Defect]
            where [Severity] = 3 and [Status] = 4;", connection))
    {
      connection.Open();
      using (SqlDataReader reader = command.ExecuteReader())
      {
        if (reader.Read())
        {
          int newCount = reader.GetInt32(0);
          if (newCount != lastCount && newCount >= 3)
          {
            lastCount = newCount;
            SendEmail();
          }}}}}}
```

- Timer1 is a Windows Forms Timer
- Still has problems: how frequently to poll? How reliable is it?

Multiple simultaneous updates

Before updates:

	DefectID	Created	LastModified	Summary	Severity	Status	AssignedToUserID
1	1	2013-05-...	2013-05-23...	MP3 files crash system	3	1	1
2	17	2013-05-...	2013-05-13...	Password displayed in plain text	3	4	NULL
3	26	2013-05-...	2013-05-18...	Password reset changes passwords for all users	3	4	NULL

```
UPDATE [dbo].[Defect]
        SET [Severity] = 3, [Status] = 4
        WHERE [DefectID] = 1

UPDATE [dbo].[Defect]
        SET [Severity] = 1, [Status] = 1
        WHERE [DefectID] = 26
```

After updates:

	DefectID	Created	LastModified	Summary	Severity	Status	AssignedToUserID
1	1	2013-05-01 ...	2013-05-23 ...	MP3 files crash system	3	4	1
2	17	2013-05-12 ...	2013-05-13 ...	Password displayed in plain text	3	4	NULL
3	26	2013-05-16 ...	2013-05-18 ...	Password reset changes pass...	1	1	NULL

- If these two updates happen between polls (or inside a transaction), no email is sent
- Otherwise, an email will be sent. Possibly unreliable.

Polling - Summary

- Simple but inefficient, polling is the traditional model for getting updates
- The polling interval is always a problem
- Timers can be unreliable in Windows

Solution 2: Triggers

- You write a database triggers for AFTER INSERT and AFTER UPDATE. The triggers redo the SQL query and send emails using dbmail.
- Good: The trigger only runs once, and it runs only on the database server, so only 1 email gets sent.
- Bad: The trigger always runs, even when unrelated rows are changed. The database is slower than it should be.
- Ugly: You accidentally introduce a bug in the trigger and it silently corrupts your data for two days before anyone notices!

Insert Trigger TSQL Code

```
CREATE TRIGGER dbo.tri_i_Defect  ON  dbo.Defect
AFTER INSERT AS BEGIN
SET NOCOUNT ON;

declare @newCount int, @addedCount int;

SELECT @newCount = count([DefectID])
FROM [dbo].[Defect]
where [Severity] = 3 and [Status] = 4;

SELECT @addedCount = count([DefectID])
from inserted
where [Severity] = 3 and [Status] = 4;

if(@addedCount > 0 and @newCount >= 3)
            exec msdb.dbo.sp_send_dbmail;
END
```

- Also need to write similar triggers for update and delete statements
- Be very careful about error handling!

Originating Statement

```
INSERT INTO [dbo].[Defect]
        ([Created],[LastModified],[Summary],[Severity],[Status]
        ,[AssignedToUserID],[CreatedByUserID],[ProjectID])
    VALUES (getdate(),null,'Changing fonts causes all text to reverse (right to left)',4,1
        ,null,2,1)
```

↳ **TRIGGER dbo.tri_i_Defect runs**

↳ Email might be sent

Transaction commits

- The triggers run in the context of the originating statement (i.e., the transaction)
- If trigger fails, then the originating statement fails! (Transaction aborts.)
- The trigger always runs, even when it's irrelevant to the business goals.

Triggers - Summary

- Use with caution. Debugging is not easy.
- Triggers are powerful and reliable because they always run! They must be fast because they are integral to the server.
- Triggers run in the context of the originating statement, which can cause seemingly unrelated applications to unexpectedly fail (table locks, cascading triggers).

Solution 3: Query Notifications

- You decide to try Query Notifications with C# or VB SqlDependency to receive a callback when the criteria are satisfied.
- Good: reliable, fast, and no redundant queries occur. Data can't be corrupted or lost.
- Bad: You have to learn a new way of doing database queries.
- Ugly: It's Microsoft specific (2005+), but Oracle has a similar mechanism

Query Notification Example

```
private string DbConnectionString = "Server=some-server.mycompany.com;
          Initial Catalog=defects; Integrated Security=True";
private SqlConnection BrokerConnection = null;
private SqlCommand BrokerCommand = null;
private DataSet BrokerDataSet = null;

public void CreateDep()
{
  SqlDependency.Start(DbConnectionString);

  BrokerConnection = new SqlConnection(DbConnectionString);
  BrokerCommand = new SqlCommand("SELECT [DefectID] FROM [dbo].[Defect]
          where [Severity] = 3 and [Status] = 4;", BrokerConnection);
  BrokerDataSet = new DataSet();

  StartListening();
}
```

- Part 1: Initialize the .NET runtime's background thread that manages all QNs in the application

QN Example – Part 2

```
private void StartListening()
{
  // Make sure the command object does not already have
  // a notification object associated with it, and there aren't any old results
  BrokerDataSet.Clear();
  BrokerCommand.Notification = null;

  // Create and bind the SqlDependency object to the command object.
  SqlDependency dependency = new SqlDependency(BrokerCommand);
  dependency.OnChange += new OnChangeEventHandler(OnDataChanged);

  // we don't have to care about these results,
  // but we must run the query at least once to receive notifications
  using (SqlDataAdapter adapter = new SqlDataAdapter(BrokerCommand))
    adapter.Fill(BrokerDataSet, "Defect");
}
```

- Part 2: Create the SqlDependency and tell SQL server to start listening for changes

QN Example – Part 3

```
void OnDataChanged(object sender,
        SqlNotificationEventArgs e)
{
  // Check COUNT(*) from table, then possibly send email
  // This event will occur on the worker thread pool.
  SendEmail();

  // must redo the query to resubscribe
  StartListening();
}
```

- Part 3: Receive a callback from the worker thread.
- Optional: subscribe again

QN Example – Part 4

```
private void Form1_FormClosed(object sender,
FormClosedEventArgs e)
{
  RemoveDep();
}

public void RemoveDep()
{
  // Release the dependency.
  SqlDependency.Stop(DbConnectionString);

  if (BrokerConnection != null)
    BrokerConnection.Close();
}
```

- Part 4: Clean up. Stop background thread, free server resources.

QN Benefits

```
private SqlCommand BrokerCommand = new SqlCommand(
        "SELECT [DefectID] FROM [dbo].[Defect] where  [Severity] = 3 and
                [Status] = 4;", BrokerConnection);
```

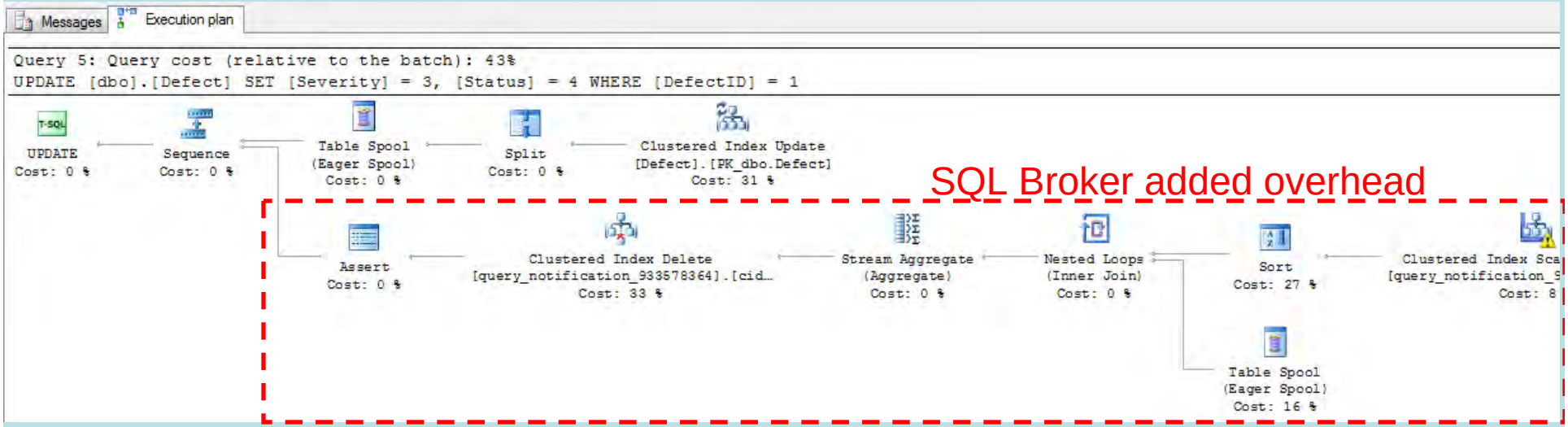
- The same notification works for Insert, Update, and Delete statements
- The notification is guaranteed to be delivered by the SQL Broker
- SQL Server won’t fire the notification unless the WHERE clause is satisfied
- Still need to check COUNT(*) when notification occurs

SQL Broker Operations

- The Broker dispatches a message to your application using a background thread
- Messages are based on meta information from your cached query and the changes to the table
- You could get unwanted notifications if:
  - the server restarts
  - the QN subscription expires
  - ALTER TABLE, DROP TABLE, etc.
  - there are too many simultaneous updates occuring to determine which of them might invalidate your cache

Consequences for other SQL

```
UPDATE [dbo].[Defect]
    SET [Severity] = 3, [Status] = 4
    WHERE [DefectID] = 1
```



- There is a slight cost to other SQL statements (ins/upd/del, not select)
- The cost is similar to updating a non-clustered index (until the QN is removed)

Query Notifications - Summary

- Estimated benefits of QN as compared to polling with 10 db updates per day:
  - Polling: 1 query/second * 86,400 sec/day * 100 clients = 8.6 M select queries.
  - QN: 100 clients * 3 queries = 300 select queries
    - (1: setup, 2: callback, 3: resubscribe)
- Query Notifications are easiest in C# or VB.NET with SqlDependency, but they are possible in any ODBC client
- Very reliable, but slightly slower than triggers

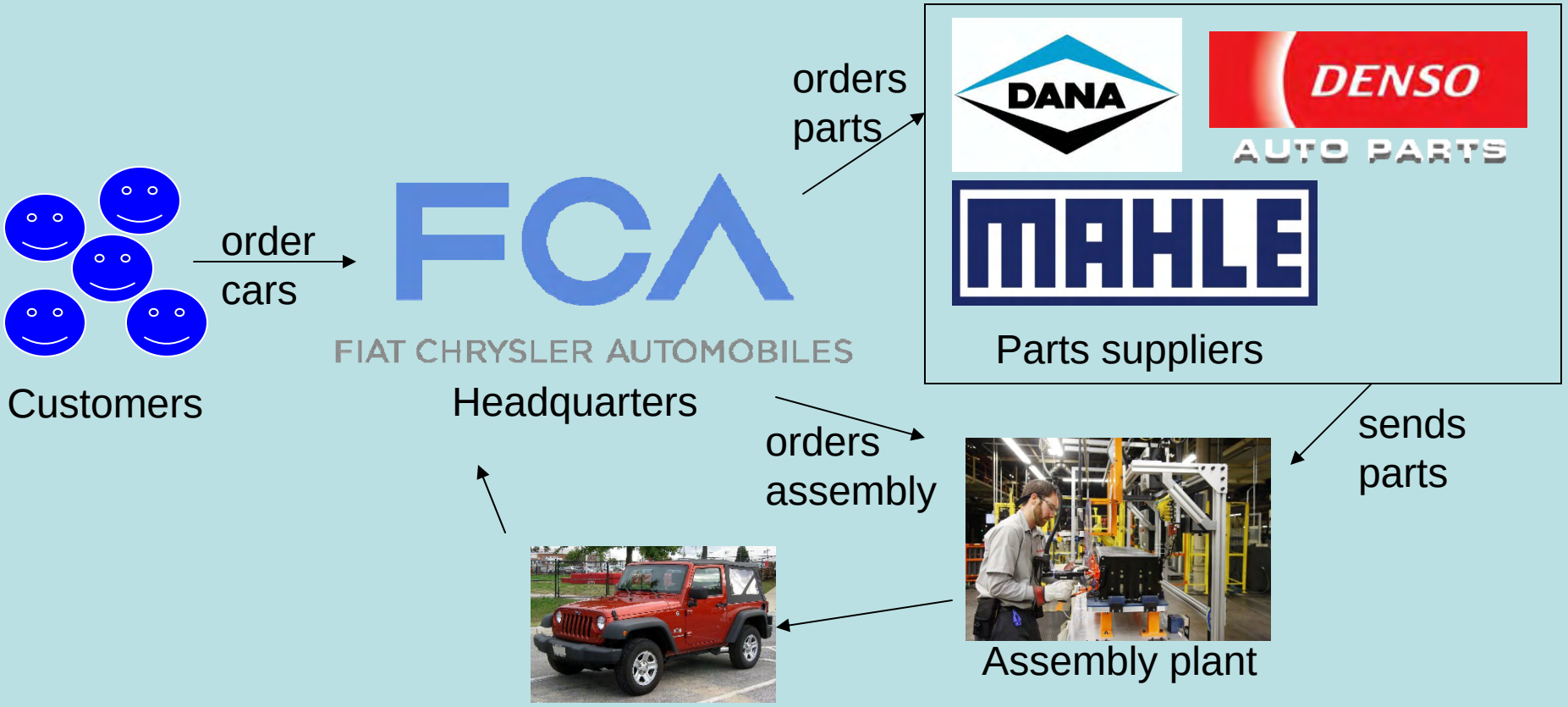
Message Queues

- SQL Server 2005+ has a message queuing service (Broker)
  - Used by Query Notifications, Database email, external clients
- Scales up to millions of messages per minute
- Message management is transactional, not protocol oriented

Transactional message mgmt.

- SQL Server makes message management easy because it uses transactions
  - If the client fails, the transaction aborts using the standard database mechanisms
- Unlike IBM Websphere MQ, the receiving client can be remote
- Unlike Apache ActiveMQ, queues can be bidirectional

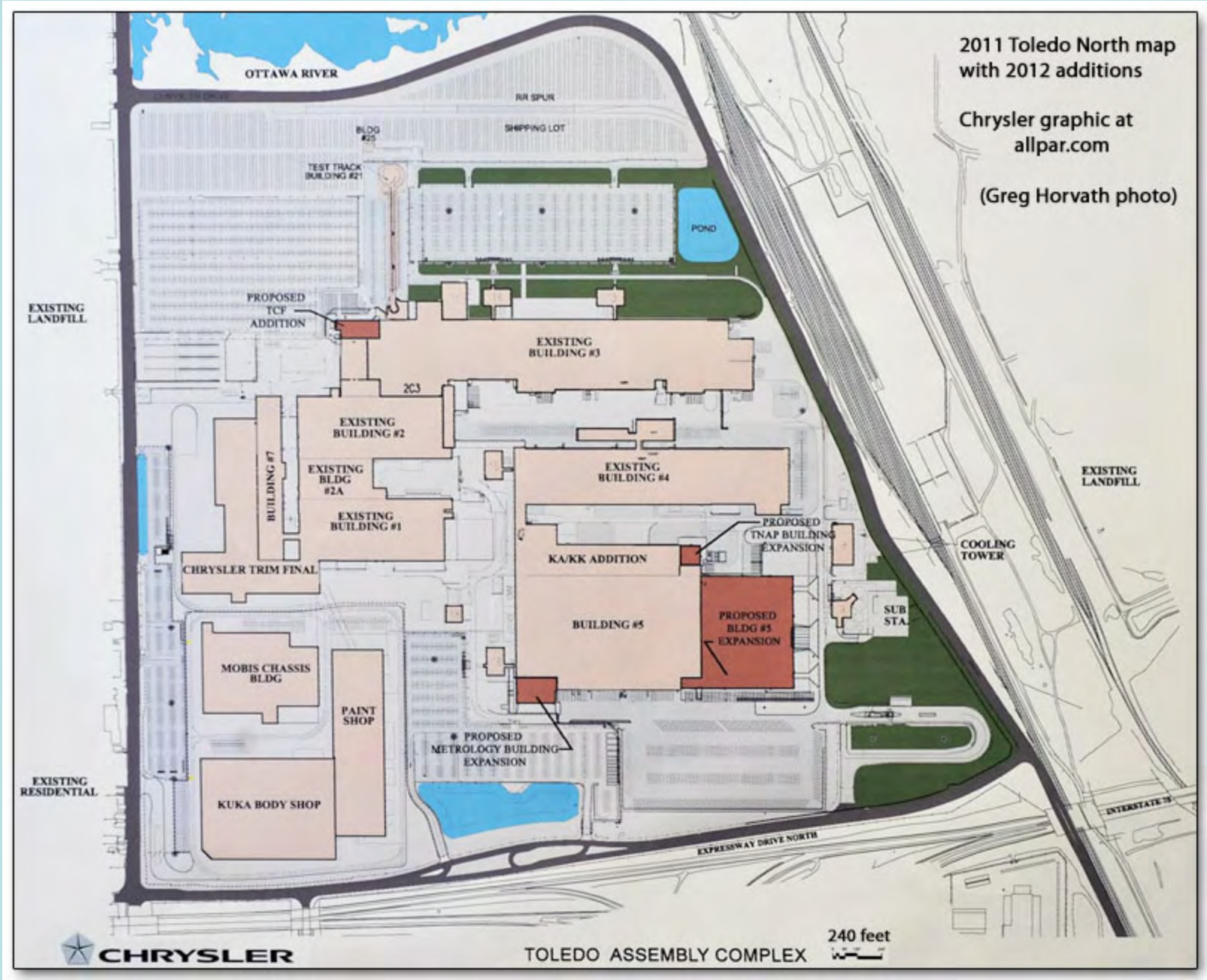
Uses of a Message Queue



- Each stage has at least one message queue
- Queue allows either sending or receiving computers to crash without loss of information
- Much like email, but for programs not people

Questions?

- Next: Case Study in an automotive assembly plant



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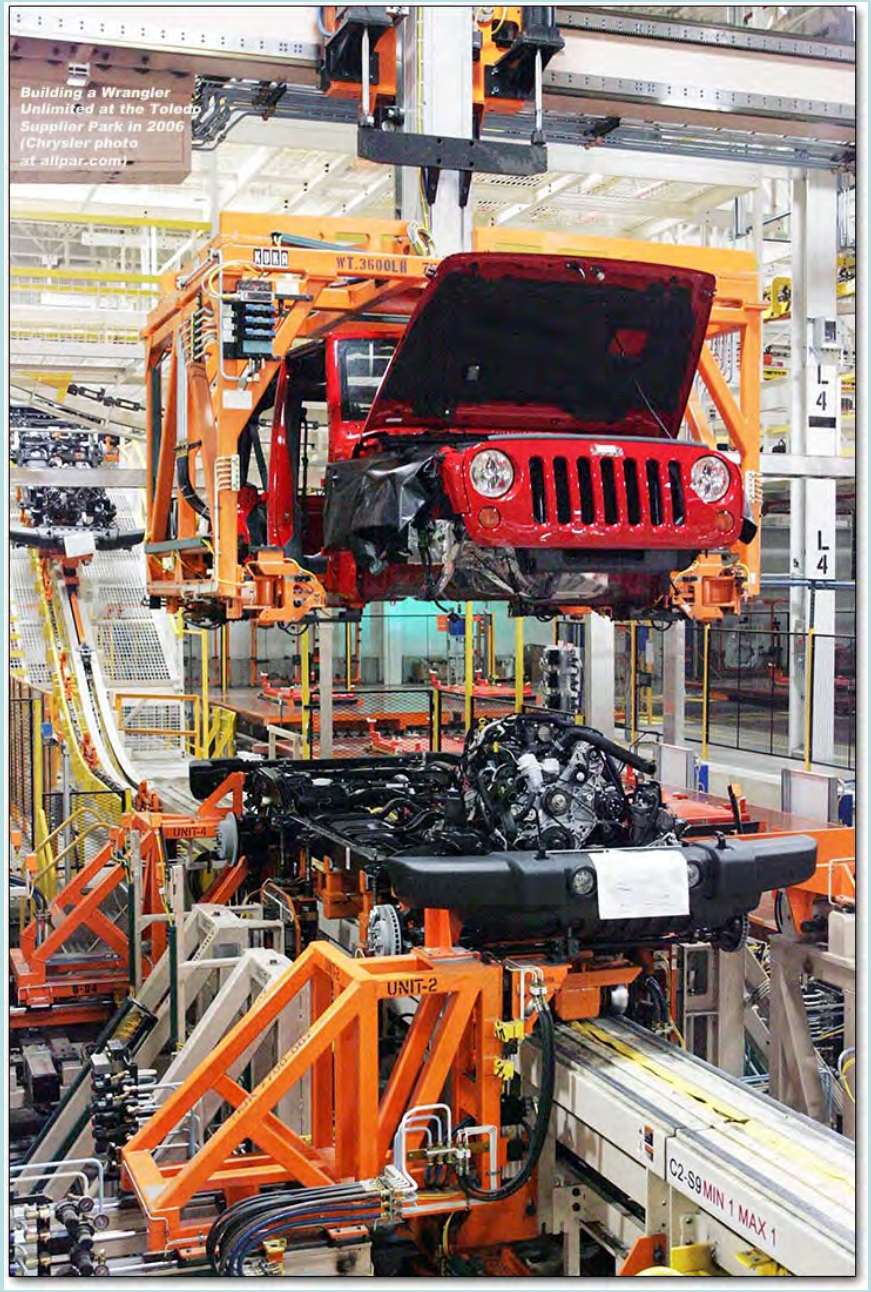

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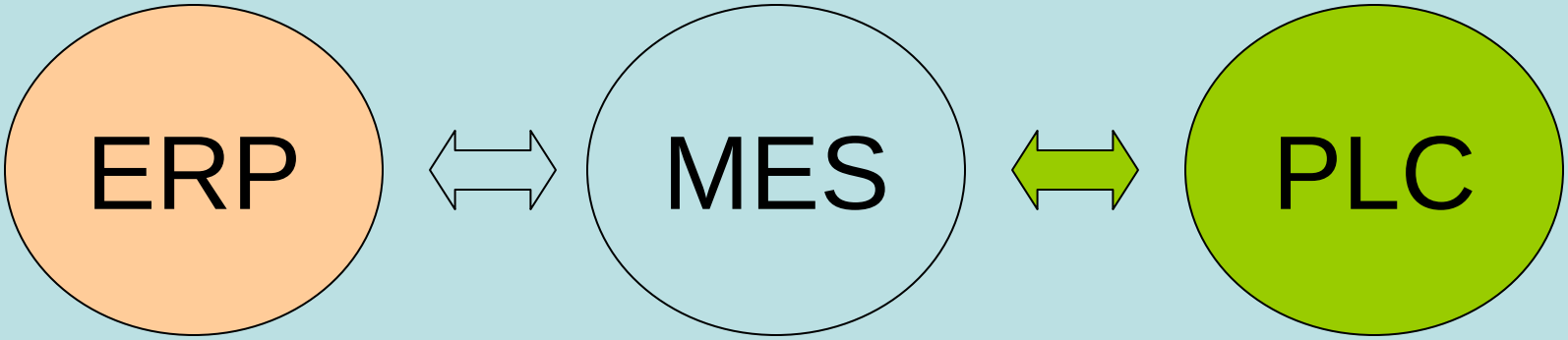
Assembly Plant Computer Systems



Enterprise Resource Planning

- Incoming orders
- Inventory management
- Billing
- Reports & Auditing

Manufacturing Execution System

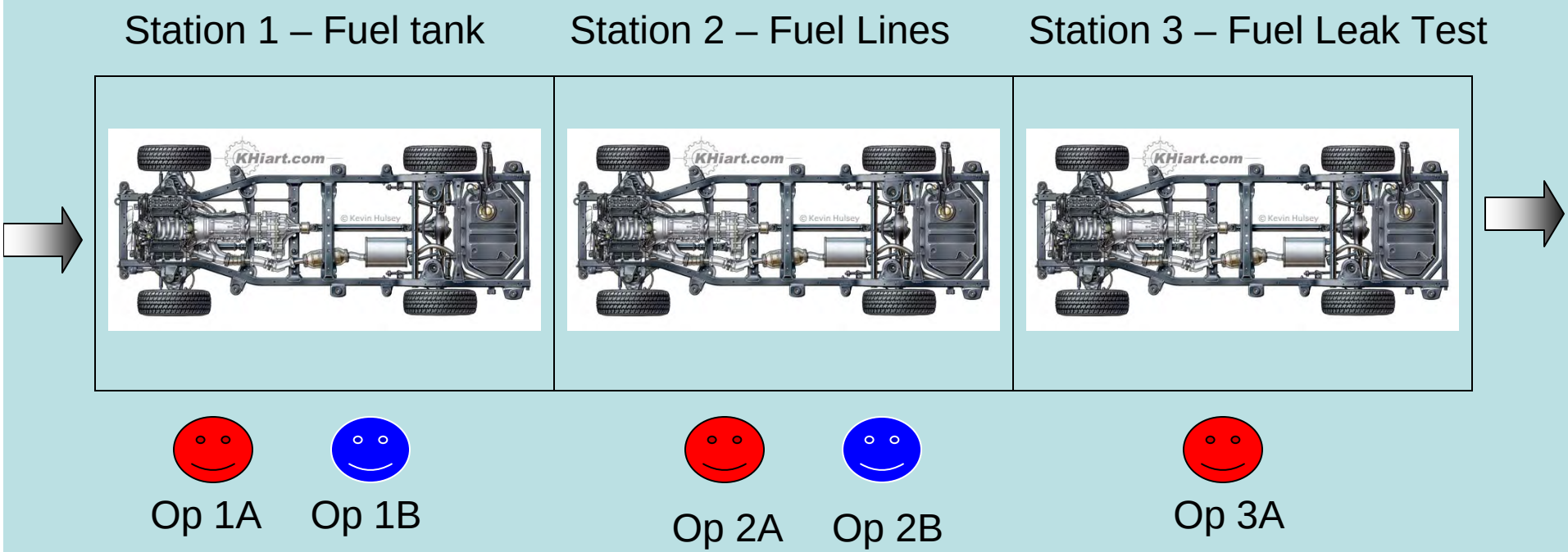
- Production database
- Individual computers (workstations, testing systems, inspections)
- Barcode scanners
- Torque guns

Programmable Logic Controllers

- Motors
- Sensors
- Robots
- Lights
- Buttons

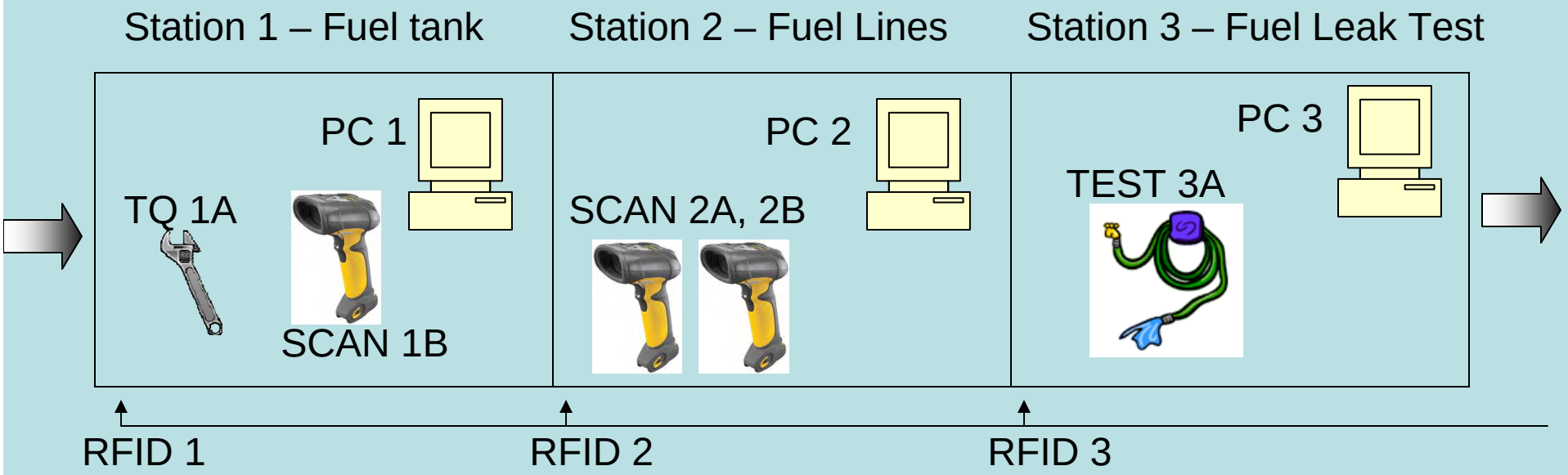
Each of these types of computer systems performs a different role in automotive assembly.

MES Intro – Fictional Assembly Line



- Operators at each station perform assembly tasks
  - E.g., Operator 1A attaches a fuel tank with two bolts. Op 1B scans a barcode on the fuel tank
  - Op 2A and 2B attach fuel line hoses and scan barcodes
  - Op 3A uses a leak testing system to verify that the fuel system is correctly installed

Intro – Assembly Line Computers



- RFID readers determine which vehicle is in which station
- Industrial PCs display instructions to the operators and control the other devices based on the current vehicle
- Torque wrenches are used to attach parts
- Barcode scanners are used to verify part numbers

Intro – Torque Guns

Manual torque wrench (“clicker”)

Electric nutrunner (“torque gun”)

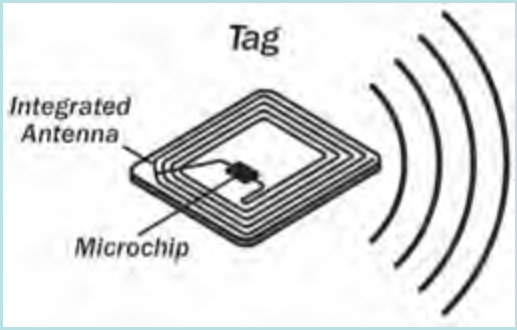
- Manual torque wrenches (“clickers”) are too slow and inaccurate
- Electronic torque guns are fast and precise. Operator fatigue and injury are also reduced.
  - Industrial PC tells the torque guns: how many torques on each part (e.g., 4 bolts), how much torque to apply (50 Nm), how many times to rotate (350°-450°)
  - Torque gun responds with data about what the operators actually did

Intro – Barcode Scanners

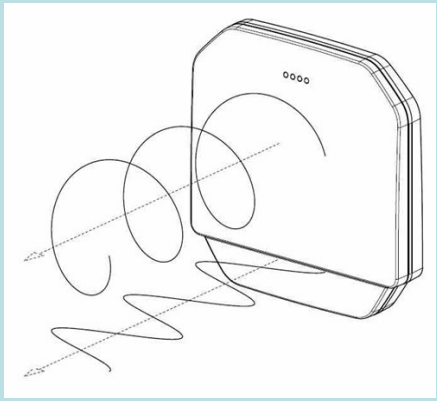
Rear axle barcodes

- The industrial PC enforces the following rules:
- After attaching a part, the part number must be scanned to make sure the right part was used
- The serial number must be scanned for billing
- Part numbers are often 8 digits followed by a 2 letter revision level (e.g., 12345678AB)
- Prefixes or checksums can be used to validate these inputs

Intro – RFID Tags and Readers

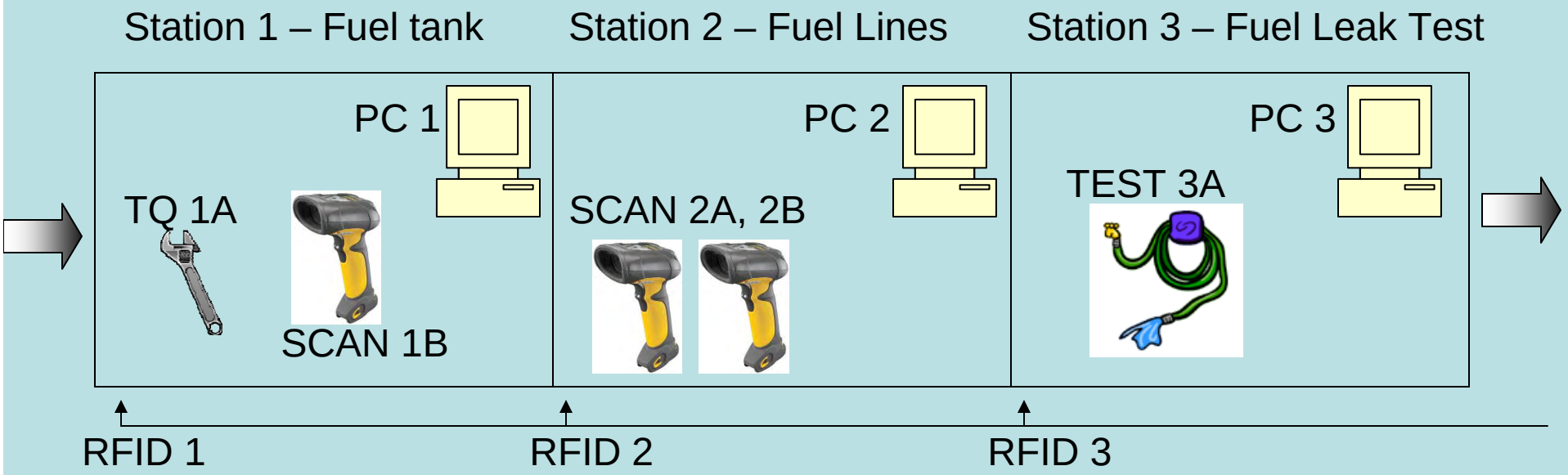


Passive RFID tag


RFID Reader

- The integrity of the RFID reader system is critical because the vehicles move through many different stations
- The Industrial PC reads database records to determine which vehicle is in which station
- Other database queries determine the operations and parts needed at the station for the current vehicle

Review of MES



- Industrial PCs display instructions to the operators and control the torque guns, barcode scanners, and other devices based on the current vehicle
- The operators rely on the Industrial PCs
  - To tell them which operations to perform
  - To enforce quality rules
  - To update the MES database server

Problem 1: Polling for vehicles

- How does each Industrial PC know that a new vehicle has arrived in station?
  - The RFID reader program updates a database table when it reads new tags
  - Traditional approach: poll the RFID table
  - Alternative approach: use query notifications
- Polling is the normal computer architecture for industrial line operations

PLCs are always in charge

Siemens Simatic PLC: a real time industrial control system for hundreds of devices, tolerant of extreme variations in power, temperature, vibration, electronic noise, and physical impact.

- Programmable Logic Controllers (PLCs) often use polling in normal operations:
- (ladder logic)

```
while(true)
        if(limit switch 1 is true and torque gun 5 has been used more than 4 times)
                turn on alarm 32;
        sleep(100);
```

- Polling is OK for PLCs because they use dedicated hardware on realtime systems
- But polling is a terrible idea MES computers

Polling for vehicles – RFIDTable

Tag	VIN	Station	Timestamp
50034	1C4	1	08:30:27
50057	1C5	2	08:31:53
30029	1C6	3	08:29:38

Suppose PC 2 wants to know when a new vehicle is in station 2:

```
OldVIN = ‘’
NewVIN = ‘’
While true:
        SELECT @NewVIN=VIN from RFIDTable where Station=2
        If NewVIN != OldVIN
                OldVIN = NewVIN
                Do stuff
        Sleep(1000)
```

Alternative: Query Notifications

- Each Industrial PC registers a QN for one row in the database table (by Station)
- When the RF-ID reader writes a new tag, the Industrial PC receives the notification and provides new instructions to the operators (part numbers, quality checks, etc.)
- The Industrial PC then resubscribes and waits for another notification

Problem 2: Polling for test results

- How do the operators know when the fuel leak test has failed?
  - Traditional approach: UHF radio calls (aka, walkie-talkie) are used to verbally call out problems
  - Alternative approach: Computer generated internal emails
- Radio calls are fast but unaccountable, unreliable, and unrecorded.

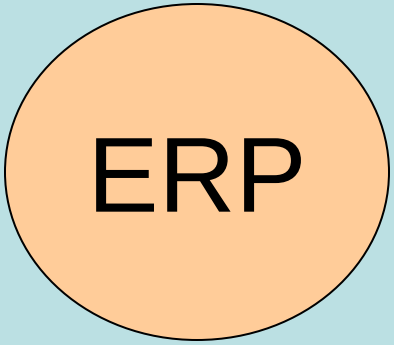
Alternative: Triggers

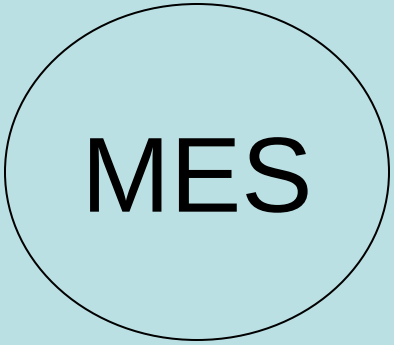
- There is no PC for the test results, so the database needs a different mechanism for notifying people
- Whenever a failure occurs, the database trigger sends an internal email
- iPods or other mobile devices are used to tell the plant supervisors to deal with the failures

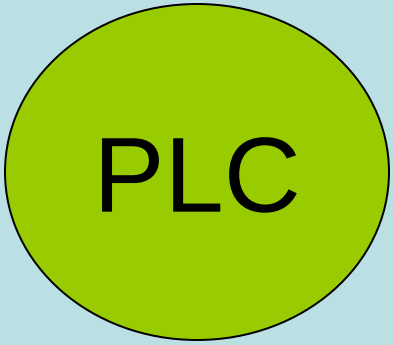
Problem 3: Polling for problematic incoming orders

- How do the operators know when there is a problem with an order that has just arrived?
  - Traditional approach: Manual inspection (or just wait until it causes a problem!)
  - Alternative approach: Use emails and message queuing to SAP/ERP system
- Message queue is already part of billing system

More Examples of Notifications







Enterprise Resource Planning

- New parts have arrived
- A part is changing revision levels (AB -> AC)
- A problem has occurred with supplier deliveries

Manufacturing Execution System

- A new build has an impossible combination of parts
- A repair was performed but not double-checked
- Computer hardware has failed (deadman switch)
- A vehicle failed a critical quality test

Programmable Logic Controllers

- A robot has failed to perform an operation (e.g. assembling tires or stamping a VIN on a vehicle)
- An operator has entered a forbidden area of the plant during production
- Motors are failing to run
- Sensors are reading impossible values

SQL Server Specific Advice

- Must schedule downtime to enable broker
- Stop SQL Server Agent (jobs)
- Switch to single_user
- ALTER DATABASE [Database_name]
  SET ENABLE_BROKER WITH NO_WAIT;
- Fix user permissions for Broker
- Go back to multi_user

Conclusions

- Query notifications are better than polling and readily available in SQL Server (or Oracle) databases
  - think differently about client design
  - use triggers with caution
- Manufacturing Execution Systems are large and complex
  - many points of failure
  - lots of legacy hardware and software
  - great opportunities for query notifications

Questions?

Protocol oriented message mgmt.

- Just try once:
  - Sender just sends each message once, doesn’t care if client receives it
  - Client doesn’t acknowledge messages, and it might not even put them in any particular order or remove duplicates or detect corruption
  - Optimized for speed and simplicity, not reliability
  - Analogous to UDP, streaming video, etc.

Message mgmt. 2

- Server with state (at least once delivery):
  - Server assigns numbers to messages and requires an acknowledgement of each message number.
  - Client still doesn't maintain state, but it does send acknowledgements. Delivery is guaranteed if server resends messages.
  - Application must ignore duplicate messages (idempotency).
  - E.g., Advanced Message Queuing Protocol

Message mgmt. 3

- Both server and client have state (exactly once delivery):
  - Both server and client have message numbers, and server must retransmit unacknowledged messages within the current window.
  - Client must perform reordering, remove duplicates, and detect corruption with checksums.
  - Latency can become a problem, but exactly once delivery is guaranteed
  - E.g., TCP

Why polling is bad for MES

- MES computers often run a general purpose OS (e.g., Microsoft Windows)
  - Windows is not a real-time OS, so timers aren't guaranteed to tick
  - Programs become unresponsive to OS and to users
  - Polling makes crashes difficult to recover because error handling inside the while loop becomes messy
- Tragedy of the commons
  - Database becomes overloaded with polling queries
  - Database locks get held for extended periods of time
  - Excessive network traffic causes packet loss and latency

Reliability

- Sources of unreliability
  - Polling: timers can be unreliable in Windows; choice of interval is difficult
  - Triggers: very reliable, but possibly harmful to unrelated queries
  - QNs: very reliable, but be careful about handling network socket errors
- Suggestions
  - Always do simulations and testing before deployment!
  - Always have a backup plan