Bolt Technology in a Digital Age

By John Doyle, founder of ExcelWraps

A SmartFleet by ExcelWraps paper, presented to the Engineering Integrity Society, February 2024

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1 Abstract

MoreVision specialises in engineering analysis, testing, and software development. MoreVision founder John Doyle discusses the value of digital records for preventing bolt failures. He advises storing all records related to bolts in a digital format for easy tracking. John uses his broad engineering experience and gives examples and insights of bolt failures. He introduces digital tools like ExcelCalcs, which shares bolting analysis knowledge, and ExcelWraps, which creates production workflow records. Last year ExcelWraps was set up a data exchange with a digital torque wrench website using an API connection. This both programs wrenches and extract bolt tightening records into the production workflow records. All you need to use this technology is simply your existing Excel skills.

He reflects on the application of this technology in the light of the most recent bolt failure, the Alaskan Airlines door plug explosion in January 2024.

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2 Introduction

On January 9, 2024, a door plug exploded on an Alaskan Airlines flight, due to a bolting failure. Boeing had to investigate the design, testing, manufacturing, installation, and maintenance of the bolts to understand and remedy the root cause of the problem. Before jumping into the body of this report consider how your own organisation would react to a bolting failure resulting in the potential for loss of life.

3 Bolting Case Studies

Based on his nearly 40 years of experience in handling bolt issues the following figures show some 10 case studies:

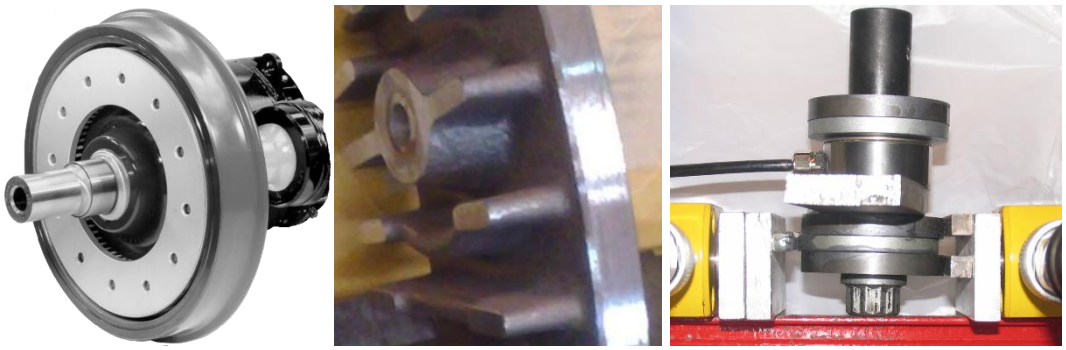


Figure 1 – Bolted brake disk missing bolts. Pretension/slip tests and effect of movement under thermal expansion and contraction.

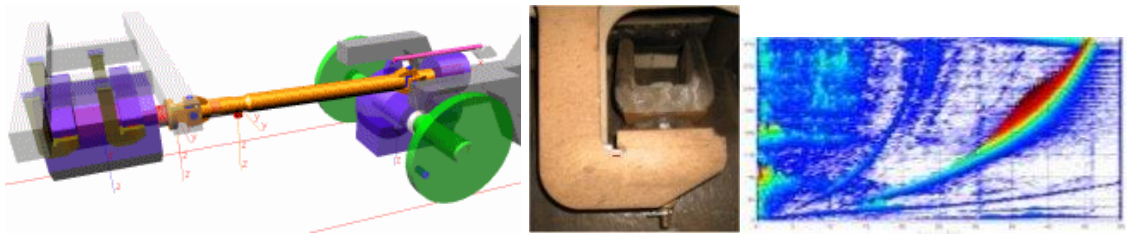


Figure 2 – Traction motor mounting bracket fatigue failure featuring resilient mount thermal hardening. Digital signal processing software shows that the stiffened mount moves the maximum response frequency to coincide with the railway vehicle running speed.

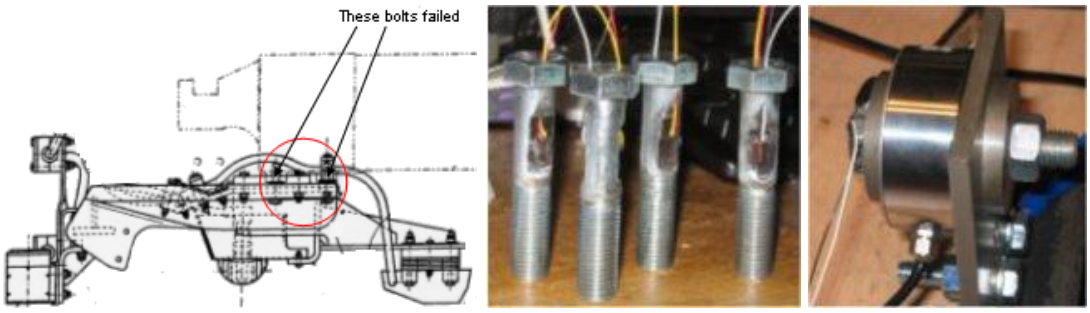


Figure 3 – Bogie mounted antennae resonance induced loading not considered in design.

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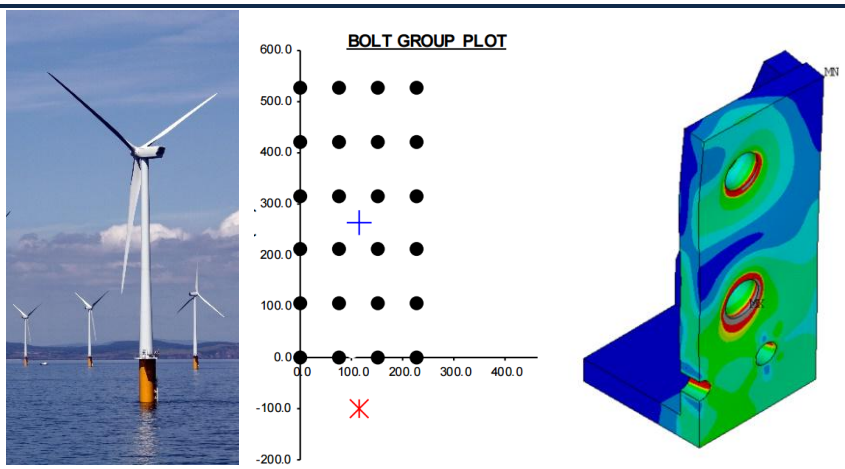


Figure 4 – Wind turbine tower connection to pile change design from bolts to dowels to maximise shear capacity.



Figure 5 – Change of bolt supplier projects, generally allowed provided preload is not degraded and backed up with preload testing.

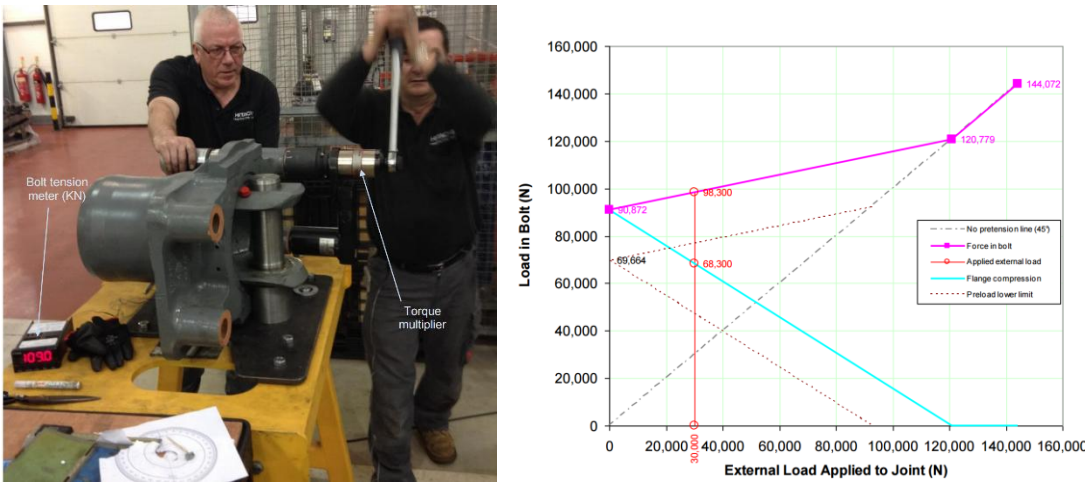


Figure 6 – M16 bolt reuse projects generally allowed providing torque tightening is replaced with angle tightening procedure.

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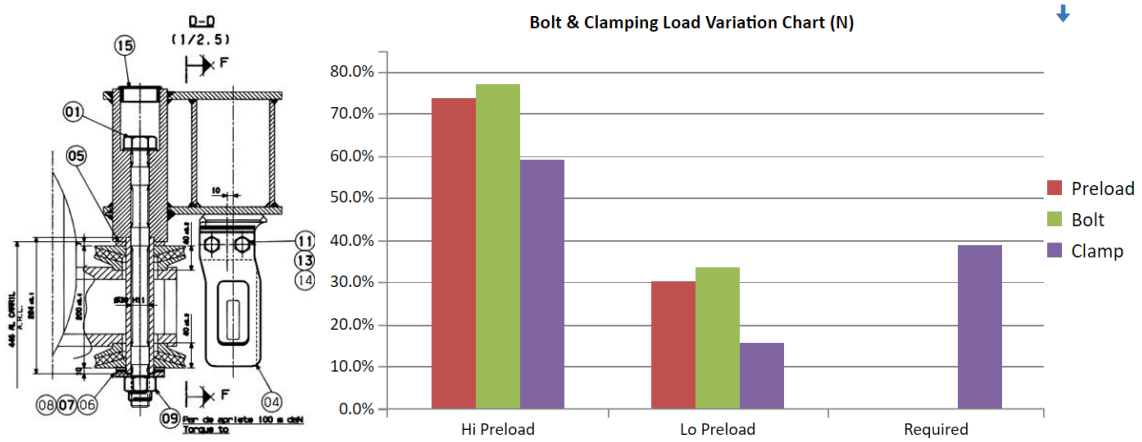


Figure 7 – M30 Bolt replacement showing BoltExpert load variation chart.



Figure 8 – Train lift accident investigation due to screw jack wear and deficiency in safety nut design as dynamic loading not accounted for. Bonus insurance case reports and structural repair of permanently deformed bodyshell.



Figure 9 – Line buffer stop fails to arrest low speed train. Bent bolt indicates that bolt was not sufficiently tightened to provide clamping force. Bonus crash assessment of train/buffer collision and structural repair of damaged bodyshell.

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Figure 10 – Bolt design calculations for theme park equipment. Failure to predict impact loads. Bonus visits to the Disney back lot to witness Snow White on a 'fag' break.

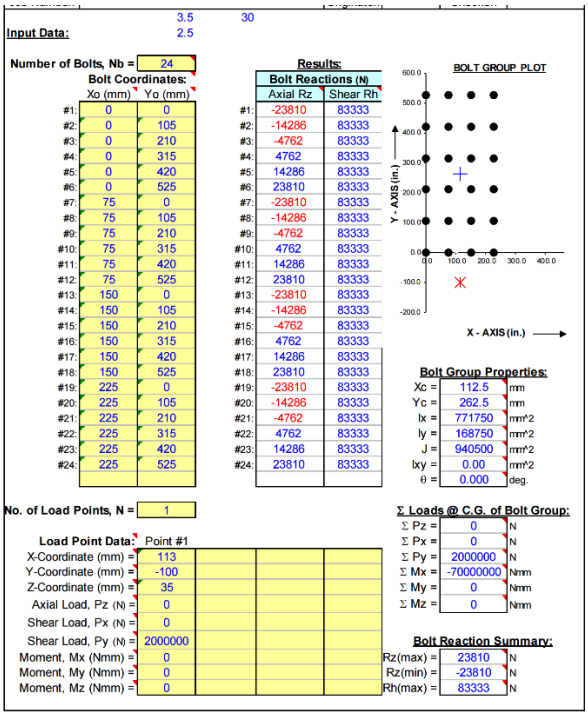
Reviewing the case studies, it is possible to place each into one of the following categories:

1. **Missing bolts** – Scatter in bolt pretension means some bolt joins slip under shear loads providing a mechanism for loosening in high vibration environments.
2. **Under estimating bolt loads** – effect of resonance, strain gauged bolts and on track testing. Digital signal processing of test results in the frequency domain can illuminate the problem.
3. **Not following tightening procedure/maintenance procedures** – Bolt not pretensioned at all. Over tightening a good tug after the torque wrench has clicked for good measure.
4. **Inadequate slip strength** - Solutions include surface preparation or introducing pins, dowels, or spiral dowel bushings.
5. **Bolt reuse/life extension** - Determining if bolts can be reused by switching to angle tightening procedures.
6. **Bolt replacement** – Using cheaper bolts now they are all failing.
7. **Fatigue** - Utilising the good fatigue resistance of bolts compared to welds.
8. **Design strength of bolt groups** – check that design requirements are satisfied. Using classical calculations or finite element methods
9. **Ultimate strength of bolt groups** – failure assessments to determine bolt loadings.
10. **Unconventional use of a bolt** – A bolted joint that allows slip on the clamped interface.

When an investigation begins it becomes clear that generally bolting is rarely well understood in the service environment and it is almost treated as some kind of black art. Certainly the design intent of the bolt is lost, and all kinds of rumours and madcap theories abound.

The author advocates digitally capturing all records pertaining to bolts, including design, testing, manufacturing, installation, and maintenance data. This information would be accessible for anyone needing to investigate a failure. Though few companies currently take advantage of digitisation, the technology is readily available.

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Input Data:

	3.5
	2.5

Number of Bolts, Nb = 24

Bolt Coordinates:

	Xo (mm)	Yo (mm)
#1:	0	0
#2:	0	105
#3:	0	210
#4:	0	315
#5:	0	420
#6:	0	525
#7:	75	0
#8:	75	105
#9:	75	210
#10:	75	315
#11:	75	420
#12:	75	525
#13:	150	0
#14:	150	105
#15:	150	210
#16:	150	315
#17:	150	420
#18:	150	525
#19:	225	0
#20:	225	105
#21:	225	210
#22:	225	315
#23:	225	420
#24:	225	525

Results:

Bolt Reactions (N)

	Axial Rz	Shear Rh
#1:	-23810	83333
#2:	-14286	83333
#3:	-4762	83333
#4:	4762	83333
#5:	14286	83333
#6:	23810	83333
#7:	-23810	83333
#8:	-14286	83333
#9:	-4762	83333
#10:	4762	83333
#11:	14286	83333
#12:	23810	83333
#13:	-23810	83333
#14:	-14286	83333
#15:	-4762	83333
#16:	4762	83333
#17:	14286	83333
#18:	23810	83333
#19:	-23810	83333
#20:	-14286	83333
#21:	-4762	83333
#22:	4762	83333
#23:	14286	83333
#24:	23810	83333

BOLT GROUP PLOT

Y - AXIS (in.)

X - AXIS (in.)

Bolt Group Properties:

Xc =	112.5	mm
Yc =	262.5	mm
Ix =	771750	mm^2
Iy =	168750	mm^2
J =	940500	mm^2
Ixy =	0.00	mm^2
θ =	0.000	deg.

No. of Load Points, N = 1

Load Point Data: Point #1

X-Coordinate (mm) =	113
Y-Coordinate (mm) =	-100
Z-Coordinate (mm) =	35
Axial Load, Pz (N) =	0
Shear Load, Px (N) =	0
Shear Load, Py (N) =	2000000
Moment, Mx (Nmm) =	0
Moment, My (Nmm) =	0
Moment, Mz (Nmm) =	0

Σ Loads @ C.G. of Bolt Group:

Σ Pz =	0	N
Σ Px =	0	N
Σ Py =	2000000	N
Σ Mx =	-70000000	Nmm
Σ My =	0	Nmm
Σ Mz =	0	Nmm

Bolt Reaction Summary:

Rz(max) =	23810	N
Rz(min) =	-23810	N
Rh(max) =	83333	N

http://www.excelcalcs.com/repository/machines/bolts-and-threads/boltgrp.xls/ version 2.5

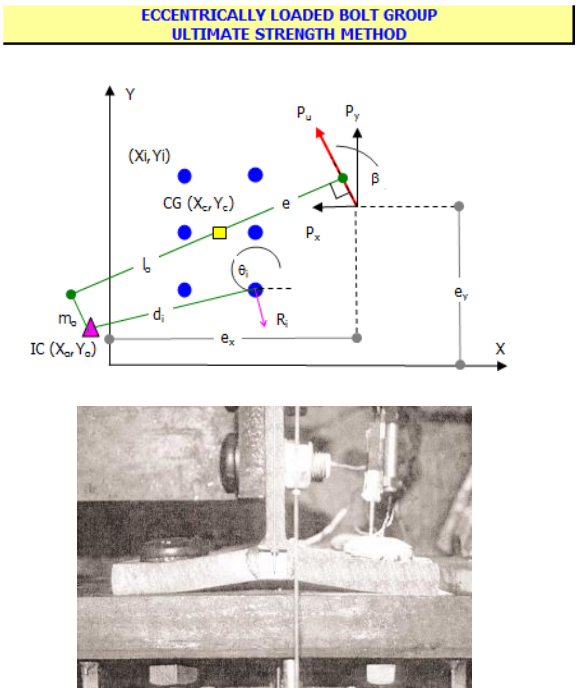
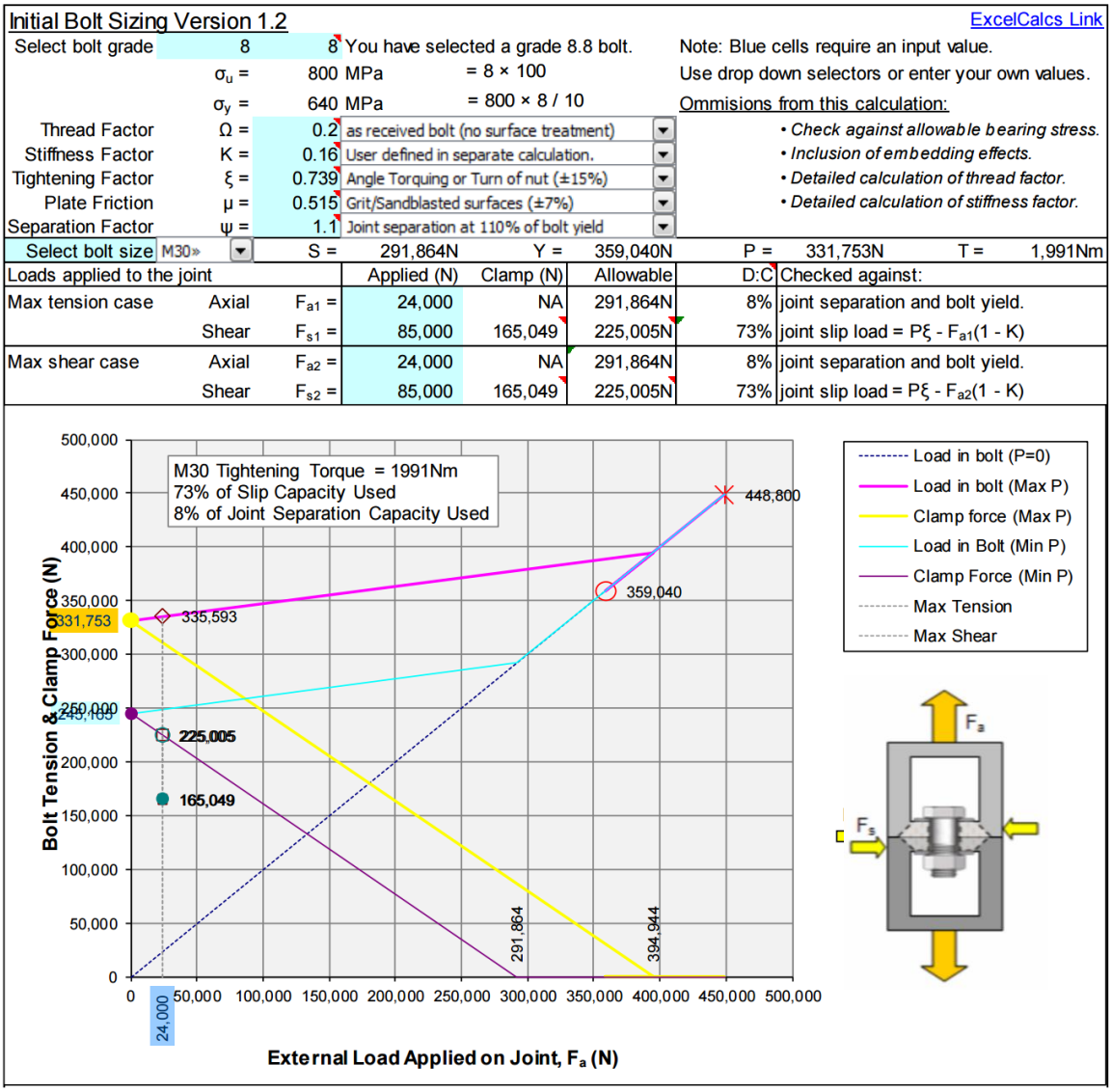


Figure 11 – ExcelCalcs for bolt group assessment.

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http://www.excelcalcs.com/repository/machines/bolts-and-threads/quick-and-dirty-bolt-sizing-calculation.xls/ Version 1.2

Figure 12 – ExcelCalcs for bolted joint assessment.

ExcelCalcs features a software add in for Excel called “XLC” that makes Excel into a calculation pad for engineers. It can display mathematical equations that show the method behind the numbers and verify the formulas in the cells. Excel is the most common software (Mathcad, Mathematica and Maple have symbolic algebra features but are not accessible by everyone). This way, engineering knowledge can be shared widely.

ExcelCalcs is a site that offers more than 1500 calculations for various engineering topics, including bolting, publishing about 10 new calculations each month. Each calculation has a system to track changes and can serve as an internet reference point. You can follow calculations that you have an interest in and use them to standardise the technical approach to common engineering problems. It is a great learning resource and calculations are shared with an expert community, consisting of 80,000 registered members, who give their own review comments and feedback. The author publishes calculations on ExcelCalcs regularly and the same calculations are used time and time again for new bolting investigations and studies.

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Figure 13 – BoltExpert shows that this joint fails under the "Loads" Tab as the required preload is greater than the minimum preload and this joint will be prone to slip and vibrational loosening.

The BoltExpert web app was made in the early days of the development of ExcelWraps. WrapCreator is an Excel add-in that turns a workbook into a standalone web application. We used the knowledge accumulated at ExcelCalcs to m a web application for assessment of bolted joints. It works on any device including your smart phone and aids understanding joints mechanics and disseminates bolting knowledge to a layman. It checks for different possible issues and points out problems. Some key features are:

- Summary page showing pass/fail status of joint aspects.
- Simple drop-down inputs for bolt, clamped material, friction, tightening method.
- Checks for issues like embedding, thermal effects, vibration loosening and bolt stress.
- Repeatable analyses and bolt knowledge sharing.

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6 2014 - ExcelWraps Production Workflow Capture

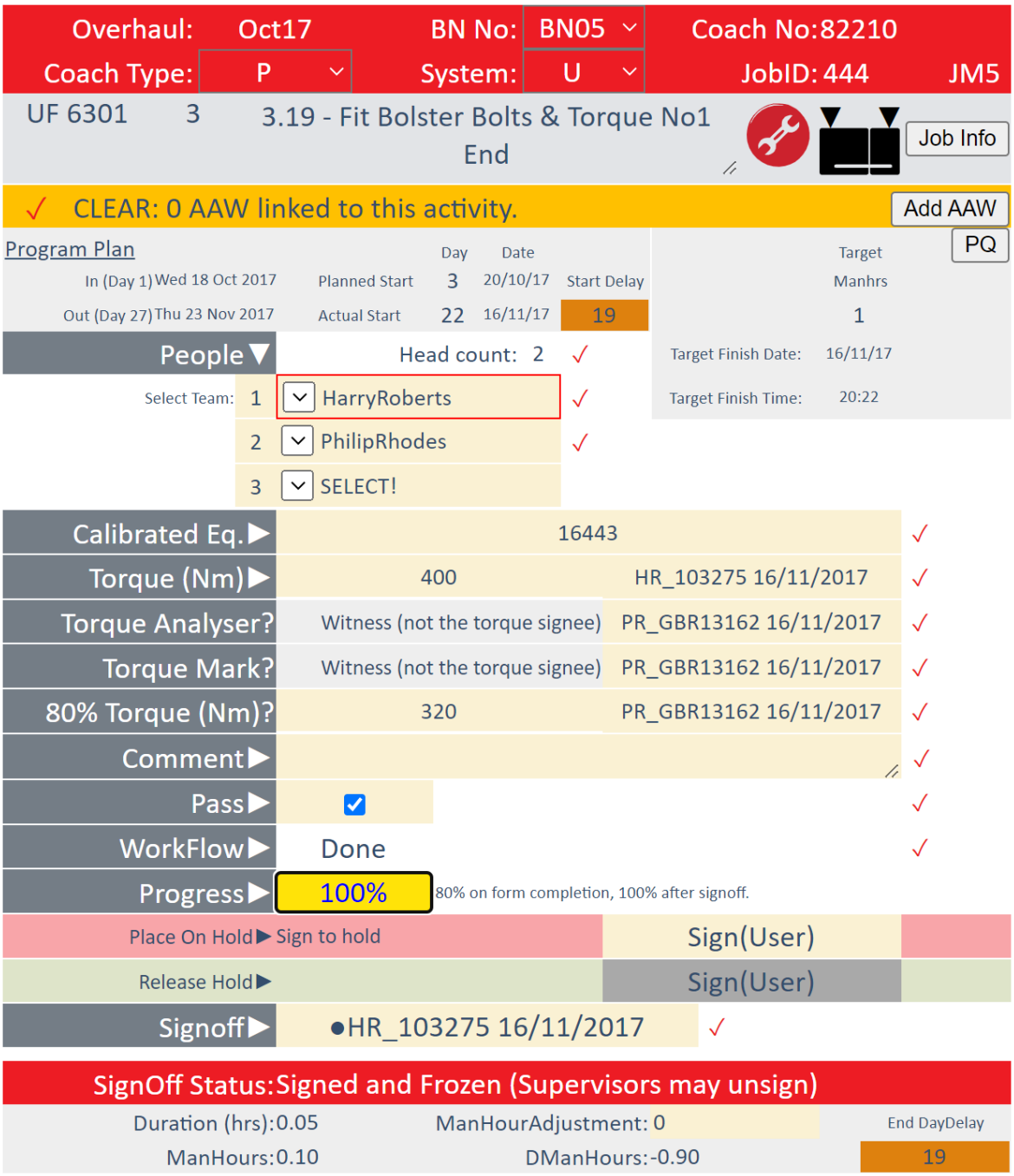


Figure 14 – Excel used to design the production workflow for attachment of underframe equipment, capturing torque wrench serial number and digital signatures for the operator and the buddy checks. Only people with the specified competence can sign. All this data is stored in an online database.

ExcelWraps is used to created web apps to digitise production data. The benefits are:

- **Eliminates paper** – any Excel user can create them.
- **Provides easy access to captured data** – filtered tables and charts from database records.
- **Competence** - Ensures only qualified personnel can complete tasks.
- **Compliance** – Guarantees success of quality assurance audits.
- **Time and Motion** – task timing tracked for project management where the full project is mapped on a Gantt chart and compared with the base plan.

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ExcelWraps creates a morphing signoff sheet so that a single wrap can capture data for any job using web app show and hide logic. This is not a one-to-one replacement of paper workflows it is a one-to-many replacement. This make setting up an ExcelWraps production workflow system very quick to roll out. In about 10% of jobs custom ‘wraps’ can be appended to the signoff wrap so that a special layout can be used for complex jobs (e.g. brake checks can follow a layout mirroring the axle positions on a train). The morphing signoff sheet must be completed correctly to achieve 100% progress on a job.

Several wrap solutions are linked to make a comprehensive solution. For example:

a) A separate wrap solution for a calibrated tool databases can be linked to created drop down selection of ‘in-calibration’ tools.
b) A wrap solution for document control can be linked so that only the latest issue of a job can be followed.
c) A wrap solution for production/client queries so that they can be easily raised and monitored.
d) A wrap solution for unplanned work or arising work (AW) keeps track of an expanding work scope. It requires an “instruction to proceed” with a client’s digital signature to avoid any argument over additional work at the end of a contract.

ExcelWraps has a library of 30 such solutions that are freely available for clients to use and customise.

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	OH	Unit	Car	System	Station	JobNo	Task	Competence	RemHrs	Team	SignOff	AW	Comment	Start	LastModified
	co(May1	co(BN2	eq(B)	eq(U)				ne(mech)							
sum									0.0			10			
	May19	BN21	B	U	3	U~ 0105	Underframe Mounted Equipment - Examine (Air Conditioning Module)	Staff	0	DavidEvans AndzejRyt	AndzejRyt	0		15/05/2019 12:21:56	15/05/2019 13:22:18
	May19	BN21	B	U	3	U~ 0105	Underframe Mounted Equipment - Examine (Brake Module)	Staff	0	DavidEvans AndzejRyt	AndzejRyt	0		15/05/2019 12:22:50	15/05/2019 13:23:06
	May19	BN21	B	U	3	U~ 0105	Underframe Mounted Equipment - Examine (Static Converter Module)	Staff	0	DavidEvans AndzejRyt	AndzejRyt	0		15/05/2019 12:23:30	15/05/2019 13:23:47
	May19	BN21	B	U	3	U~ 0105	Underframe Mounted Equipment - Examine (Control Equipment Module)	Staff	0	DavidEvans AndzejRyt	AndzejRyt	0		15/05/2019 12:24:34	15/05/2019 13:24:53
	May19	BN21	B	U	3	U~ 0105	Underframe Mounted Equipment - Examine (Battery Box Module)	Staff	0	DavidEvans AndzejRyt	AndzejRyt	0		15/05/2019 12:25:21	15/05/2019 13:25:41
	May19	BN21	B	U	3	U~ 0105	Underframe Mounted Equipment - Examine (Auxiliary Equipment Module)	Staff	0	DavidEvans AndzejRyt	AndzejRyt	0		15/05/2019 12:26:00	15/05/2019 13:26:15
	May19	BN21	B	U	1	UB 0105	Retractable Hydraulic Buffer - Examine Non Drivers Side	Mech	0	AndzejRyt	MarkBrennan	0	done by andy ryt	16/05/2019 08:19:01	16/05/2019 09:19:20
	May19	BN21	B	U	1	UB 0105	Retractable Hydraulic Buffer - Examine Drivers Side	Mech	0	AndzejRyt	MarkBrennan	0		16/05/2019 08:19:41	16/05/2019 09:20:00
	May19	BN21	B	U	1	UB 0108	Vestibule Buffer - Overhaul	Mech	0	BenKnox-Leet EricPanther GeorgeCarroll PhilipRhodes KeithWard	GeorgeCarroll	0		07/05/2019 18:40:51	11/05/2019 07:17:34
	May19	BN21	B	U	1	UB 0108	Vestibule Buffer - Refit	Mech	0	KeithWard GeorgeCarroll	KeithWard	1		09/05/2019 12:21:31	09/05/2019 13:25:56
	May19	BN21	B	U	1	UB 0108	Vestibule Buffer - Remove	Staff	0	GeorgeCarroll PhilipRhodes	PhilipRhodes	0		07/05/2019 09:12:58	07/05/2019 10:13:26
	May19	BN21	B	U	1	UC 0115	Drophead Buckeye Coupler - Overhaul	Mech	0	KeithWard GeorgeCarroll	KeithWard	0		09/05/2019 12:26:27	09/05/2019 13:27:55
	May19	BN21	B	U	1	UC 0124	Coupler Pins - Examine No1 End - Diameter of Pin MM	Mech	0	AndzejRyt DavidEvans	DavidEvans	0		07/05/2019 18:22:41	07/05/2019 19:23:26

Figure 15 – MyWraps report to show all overhaul jobs on the underframe, on unit B21 and coach B. It shows how the morphing signoff wrap is used many times over to cover all the jobs.

Overhaul: May19
Unit: BN21
Coach: B
Job Matrix Ver.: 15

System:	Air	Brakes	Carbody	Diesel	Battery	HVAC	Interior	Cater	Doors	AWS	U'frame	Toilets	Safety	Test	Misc.
	A	B	C	D	E	H	I	K	O	S	U	W	Z	Multi	~
Progress: 100.00%		100%	100%		100%	100%	100%		100%		100%	100%	100%	100%	
		Go	Go		Go	Go	Go		Go		Go	Go	Go	Go	
															AAW 2

Figure 16 – A wrap dashboard showing % completion of all systems on coach B and the number of additional arising work tasks (AAW) added to the work scope. The "Go" button opens the list of remaining jobs on that system.

OVERHAUL: May19 Start Date: 02/05/2019 Matrix: 15
UNIT: BN21 Day: 1223.43 27 20%

		AVERAGE UNIT PROGRESS:	100.00%		0	296	
ORDER	COACH	COACH No.	PROGRESS	RAG	Live AW	All AW	
PMK	B [TOE]	12222	100.00%		0	23	Live AW All
PMK							Live AW B
PMK	C [TO]	12461	100.00%		0	27	Live AW C
PMK							
PMK	D [TO]	12441	100.00%		0	24	Live AW D
PMK							
PMK	E [TO]	12476	100.00%		0	24	Live AW E
PMK							
PMK	F [TOD]	12323	100.00%		0	28	Live AW F
PMK							
PMK	H [SV]	10330	100.00%		0	41	Live AW H
PMK							
PMK	K [POP]	11244	100.00%		0	32	Live AW K
PMK							
PMK	L [POD]	11321	100.00%		0	21	Live AW L
PMK							
PMK	M [PO]	11421	100.00%		0	28	Live AW M
PMK							
PMK	P [DVT]	82227	100.00%		0	38	Live AW P
PMK							
		All [Rake]	100.00%		0	10	Live AW Rake

Figure 17 – A wrap unit dashboard to show the overhaul % completion of each coach on the unit and 296 arising work tasks raised. Clicking % progress takes you to the individual coach dashboard.

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It is easy to see that all work is 100% complete and that there are no remaining jobs to be completed. The final digital signature can only be completed when all jobs are finished, and this provides a “certificate of conformance” so the client can return the train back into passenger service safely.

The internet allows your production workflows to be used by your sub-contractors. This means that all the relevant information for your project is gathered in your database and automatically reports on the progress of a subcontractor. In one case where both the main contractor and the sub-contractor had an ExcelWraps system, the subcontractor maintained their own records and scripts are used to transfer the information to the main contractor’s system automatically.

At the end of a contract a pdf copy of all wraps is bound in a single pdf volume. This is very important to clients who need a universally accessible record of the work done with no dependency on ExcelWraps at all. As the main contractor, with an ExcelWraps system, you have the added advantage of database access to create reports about every job, every measurement and every KPI and compare them over an entire fleet of trains.

7 2022 - ExcelWraps Integration with Digital Torque Wrenches

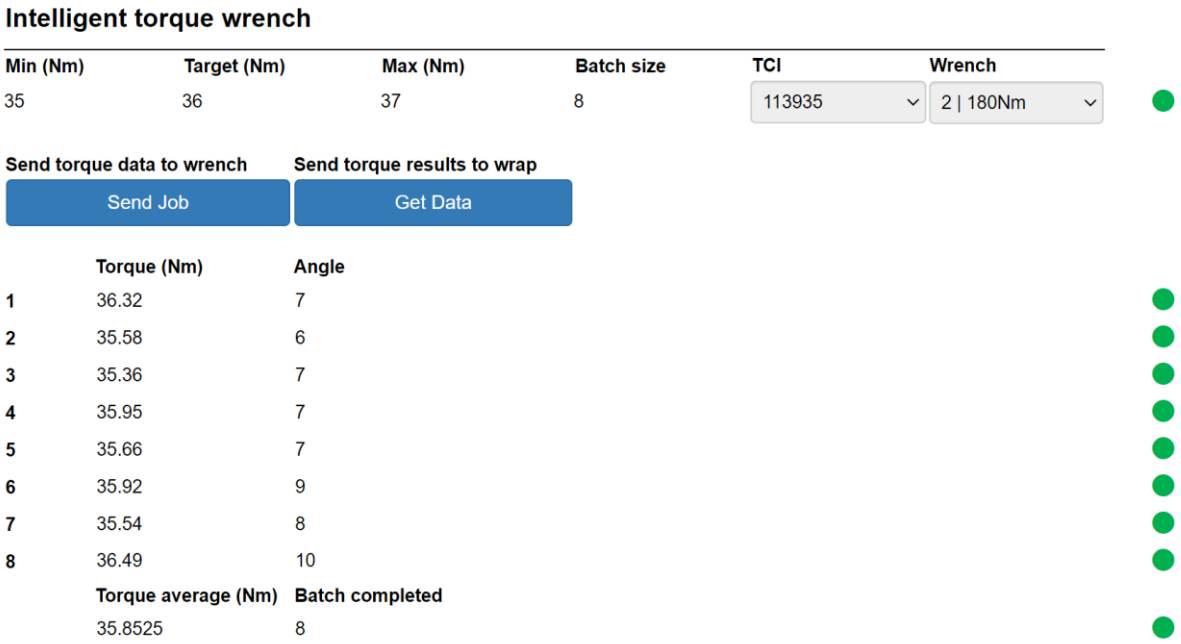


Figure 18 – Extract of a wrap production workflow dealing with the records for fastening of 8 bolts. The tightening method to apply a snug torque then apply a turn through a specific angle.

API connectors were implemented to exchange data between any websites. In the first case we used the API connect to talk to digital torque wrench website. This allows the production workflow wrap to:

“Send Job” – Sends program the smart wrenches.

“Get Job” – Retrieves tightening information for 8 bolts.

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Formatted key-value pairs 1	JSON object keys	JSON object values w/o ""
"id":"113935"	id	113935
"ip":"192.168.0.101"	ip	192.168.0.101
"port":"4546"	port	4546
"adapterId":"0"	adapterId	0
"adapterLength":"0"	adapterLength	0
"angleMaximum":"360"	angleMaximum	360
"angleMinimum":"5"	angleMinimum	5
"angleThreshold":"17.5"	angleThreshold	17.5
"auditAngle":"0"	auditAngle	0
"batchSize":"8"	batchSize	8
"control":"1"	control	1
"cycleEndTime":"7"	cycleEndTime	7
"finalAngleTarget":"180"	finalAngleTarget	180
"mode":"1"	mode	1
"parameterSetId":"1"	parameterSetId	1
"parameterSetName":"36N	parameterSetName	36Nm x 8
"rotationDirection":"1"	rotationDirection	1
"tciSerial":"113935"	tciSerial	113935
"torqueFinalTarget":"36"	torqueFinalTarget	36
"torqueMaximum":"37"	torqueMaximum	37
"torqueMinimum":"35"	torqueMinimum	35
"torqueThreshold":"17.5"	torqueThreshold	17.5
"optionalParams":{"contract	optionalParams	"contract":"C180541100","sub_cwo":"

wrenchapipostholder - this is the JSON job string sent to the Crane server	{"id":"113935","ip":"192.168.0.101","port":"4546","adapterId":"0","adapterLength":"0","angleMaximum":"360","angleMinimum":"5","angleThreshold":"17.5","auditAngle":"0","batchSize":"8","control":"1","cycleEndTime":"7","finalAngleTarget":"180","mode":"1","parameterSetId":"1","parameterSetName":"36Nm x 8","rotationDirection":"1","tciSerial":"113935","torqueFinalTarget":"36","torqueMaximum":"37","torqueMinimum":"35","torqueThreshold":"17.5","optionalParams":{"contract":"C180541100","sub_cwo":"B800XH0399","sub_type":"KH-244 - pos 2","sub_no":"63UA201","job_no":"540","wrapid":"1049533"}}

Figure 19 - Wrench programming is simplified using Excel templates. Data is concatenated into a single JSON block and sent to the digital torque wrench website who directs the program to the appropriate wrench.

wrenchapiholder - this is the JSON result string received from the Crane server	{"optionalParams":{"job_no":"540","sub_cwo":"B800XH0399","wrapid":"1049533","sub_no":"63UA201","sub_type":"KH-244 - pos 2","contract":"C180541100"},"port":"4546","ip":"192.168.0.101","results":[{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"154","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"36.32","torqueFinalTarget":"36","angleMaximumLimit":"360","dateTimeOfLastChangeInPSetSettings":"2000-01-01:00:00:00","finalAngleTarget":"180","batchCounter":"1","vinNumber":"","angle":"7","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighteningStatus":"1","timeStamp":"2023-10-26:08:01:36","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"155","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"35.58","torqueFinalTarget":"36","angleMaximumLimit":"360","dateTimeOfLastChangeInPSetSettings":"2000-01-01:00:00:00","finalAngleTarget":"180","batchCounter":"2","vinNumber":"","angle":"6","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighteningStatus":"1","timeStamp":"2023-10-26:08:01:51","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"156","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"35.36","torqueFinalTarget":"36","angleMaximumLimit":"360","dateTimeOfLastChangeInPSetSettings":"2000-01-01:00:00:00","finalAngleTarget":"180","batchCounter":"3","vinNumber":"","angle":"7","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighteningStatus":"1","timeStamp":"2023-10-26:08:14:03","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"157","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"35.95","torqueFinalTarget":"36","angleMaximumLimit":"360","dateTimeOfLastChangeInPSetSettings":"2000-01-01:00:00:00","finalAngleTarget":"180","batchCounter":"4","vinNumber":"","angle":"7","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighteningStatus":"1","timeStamp":"2023-10-26:08:14:18","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"158","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"35.66","torqueFinalTarget":"36","angleMaximumLimit":"360","dateTimeOfLastChangeInPSetSettings":"2000-01-01:00:00:00","finalAngleTarget":"180","batchCounter":"5","vinNumber":"","angle":"7","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighteningStatus":"1","timeStamp":"2023-10-26:08:14:38","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"159","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"35.92","torqueFinalTarget":"36","angleMaximumLimit":"360","dateTimeOfLastChangeInPSetSettings":"2000-01-01:00:00:00","finalAngleTarget":"180","batchCounter":"6","vinNumber":"","angle":"9","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighteningStatus":"1","timeStamp":"2023-10-26:08:14:58","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"160","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"35.54","torqueFinalTarget":"36","angleMaximumLimit":"360","dateTimeOfLastChangeInPSetSettings":"2000-01-01:00:00:00","finalAngleTarget":"180","batchCounter":"7","vinNumber":"","angle":"8","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighteningStatus":"1","timeStamp":"2023-10-26:08:15:14","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"},{"torqueMinimumLimit":"35","pSetNumber":"2","tighteningId":"161","torqueControllerName":"crane","torqueMaximumLimit":"37","torque":"36.49","torqueFinalTarget":"36","angleMaximumLimit":"360","dateTimeOfLastChangeInPSetSettings":"2000-01-01:00:00:00","finalAngleTarget":"180","batchCounter":"8","vinNumber":"","angle":"10","channelId":"1","torqueStatus":"1","peakTorque":"","angleStatus":"1","angleMinimumLimit":"5","cellId":"1","tighteningStatus":"1","timeStamp":"2023-10-26:08:15:30","secondaryStatus":"","batchSize":"8","batchStatus":"2","jobNumber":"0"}],"slot":"4546","id":"113935"}

Figure 20 - Tighten data for 8 bolts is sent from the digital torque wrench website as a JSON block. This data is split and inserted into the relevant wrap workflow records and will be kept along with all other measurement and data related to the job.

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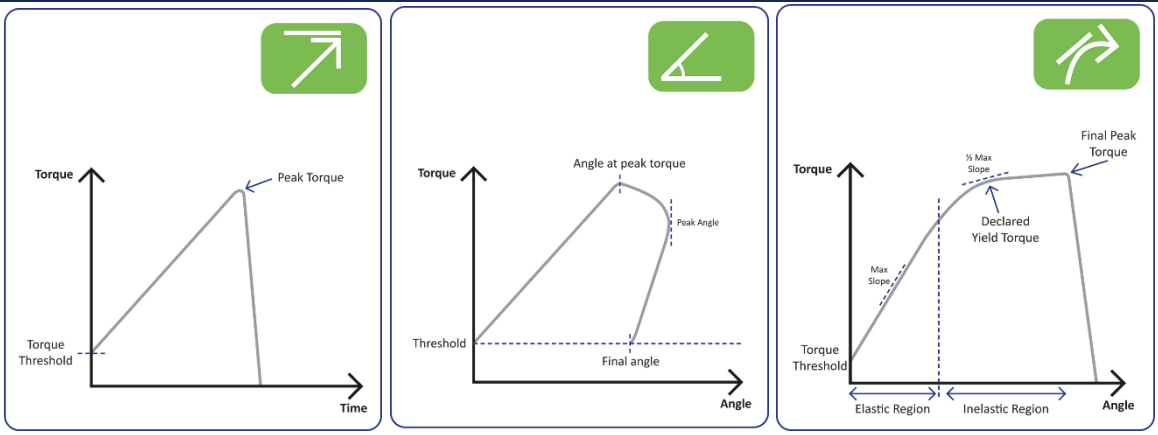
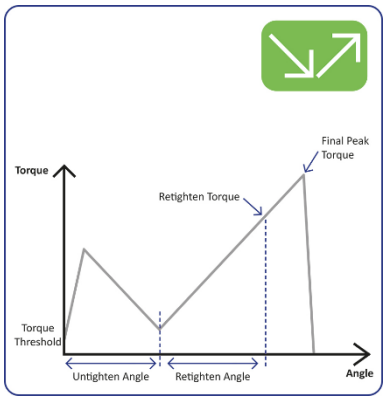


Figure 21 – Tightening modes of digital torque wrenches Peak Torque, Angle and Yield modes are shown above. Many other modes are available like Click Mode, Pulse Mode, Audit Mode, MoveOn Mode, MoveOn Advanced Mode, Force Mode.

Relevant digital torque wrench modes, listed in order of tightening accuracy, are:

- **Peak torque tightening** - on unlubricated bolt gives a tightening accuracy factor of ±35% and ±25% for lubricated bolts.
- **Angle tightening** – a tightening accuracy factor of ±25%.
- **Yield tightening** – a tightening accuracy factor of ±8% although the use of this method is suitable for joints carrying high shear load with low tension loads.



Digital torque wrenches can also be used in a "retightening" mode for recovery of embedding losses. Embedding losses occurs over the first few hours of tightening as the contact surfaces in the joint settle. This may account for around 5% to 10% depending upon material and joint configuration. Retightening can recover these losses.

Figure 22 – Retightening mode can be used to reduce bolt embedding losses.

Tightening accuracy factor and recovery of embedding losses is managed by the BoltExpert app (or calculations in the ExcelWraps repository). They calculate the variation of pretension due to accuracy of the tightening mode. Usually, the bolt with the least pretension needs to be checked for joint slip, as this provides a mechanism to drive bolt vibrational loosening (this can be seen in the "bolt and clamping load variation chart" in Figure 13).

Digital retention of the tightening mode and the tightening records of each bolt means that we are always clear of any bolt's history. This will avoid all the confusion at the start of a bolt investigation.

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8 Failure Incident Reporting



NIR 4014 Concluding: Class 331 - Yaw Damper Bracket (New Design) Bodyside Cracks **Defect Date:** 09/01/2024 10:00
Class: 331 (EMU)
Description: Whilst undergoing servicing at Blackpool Train Servicing Point on 09/01/24, cracks have been found in the vehicle body above wheel 13A on unit 331104 within the vicinity of the new yaw damper bracket assembly. Following previous NIR 3757 - "Class 1...

NIR 4006 Initial: Class 710 defective driver's seat **Defect Date:** 05/12/2023 10:30
Class: 710 (EMU)
Description: The back of the driver's seat collapsed backwards after securing bolts at the base had sheared, pictures attached. The driver was falling backwards as a result of this and sustained minor injuries arresting their fall.

NIR 4004 Initial: Class 397 broken traction link (drag link) to axle box bolts. **Defect Date:** 27/11/2023 12:58
Class: 397 (EMU)
Description: During a Light Maintenance (LM) exam and underframe inspections following reports in service of excessive vibration, it was found that both bolt heads connecting the traction (drag) link to the axle box, had sheared on 473005 vehicle at wheel positio...

NIR 4003 Initial: Class 170 Cracked Alternator Body Mounts **Defect Date:** 24/11/2023
Class: 170 (DMU)
Description: Class 170638 suffered from cracks on the alternator body where the mounting brackets are fitted, on all 3 vehicles. These cracks were highlighted by Alstom at Central Rivers on a C4 overhaul, under contract by Porterbrook, and advised to CrossCountry...

NIR 3984 Initial: HST Power Car Drive Link Failure **Defect Date:** 14/09/2023 09:08
Class: 43 (Loco)
Description: 43304 was the leading power car working 1V50 Edinburgh – Plymouth on 14/09/23, on arrival at York there was report of brake pressure gauge for Bogie 2, reading 0 bar. There was no other allegation against the train, and the train continued in servic...

NIR 3947 Concluding: ART17TH MEWP Oscillating Axle **Defect Date:** 10/04/2023 05:40
Class:
Description: MEWPs: The type of Mobile Elevated Working Platforms (MEWPs) involved in the derailment events at Carstairs is the Manitou Art17. Five of these machines were hired to SPL Powerlines from Torrent Trackside. • T141408 • T142118 (2nd and 3rd Derailm...

NIR 3918 Complete: HST Trailer Vehicle Catering PSU Fixing Anomalies **Defect Date:** 13/01/2023 02:30
Class: Mk 3 (LHCS)
Description: ScotRail staff identified fixings discrepancies in the Wabtec supplied documentation for refit of the underframe mounted catering power supply unit (PSU): TI-140306-650-M Issue A. On investigation, Wabtec identified a deficiency in specific Wabtec en...

NIR 3899 Complete: Class 395 Gearbox torque reaction link fixings **Defect Date:** 18/10/2022
Class: 395 (EMU)
Description: On 18th October, during routine maintenance on 395008, Hitachi identified that one wheelset had both gearbox torque reaction link lower fixings missing. One bolt was fully missing and so likely to have come loose. The other bolt was sheared, likely d...

NIR 3895 Initial: Class 720: Axle Earth End Housing Failure **Defect Date:** 04/10/2022 12:10
Class: 720 (EMU)
Description: At 0010 on 04/10/22 it was reported that by a driver that 720537 had a detached axle end earth return assembly had detached. Upon inspection it was found that the M8x8 bolt used to mount the equipment was missing. This was traced back to the bolt h...

Figure 23 – Bolting related incidents on UK railway held on the National Incident Register. Typically, there are 2 to 3 bolting related incidents every month.

A digital register that can be searched quickly is an essential safety service in the UK railway industry. ExcelWraps technology can easily create an incident register. The first step would be to design an incident reporting form in Excel so that they can be saved in a database, and we can generate reports to monitor any number of incidents until they are resolved. This is an important tool used to record service problems and it is used to inform other train operating companies and maintain a record of how they are resolved.

9 Conclusion

In summary bolt failure investigation has 3 stages and all are improved using digital technologies in design, testing, manufacture, installation, and maintenance.

1. Assess the bolt group loading - determine loads on each bolt working together. Use ExcelCalcs calculations, FEA models, or load testing with sensors.

2. Assess the bolted joint - evaluate if the joint can withstand the loads based on factors like bolt properties, clamped materials, friction, tightening method, thermal effects. ExcelCalcs, the BoltExpert app and joint testing.

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3. Review bolt history - extract digital records capturing the complete bolt history, including manufacturing, batch testing, tightening processes, supplier changes, and failure incident records.

To try these digital technologies, scan the QR code to get my contact details and ask for:

a) **Bolt Expert App** – we are happy to give you access.
b) **ExcelWraps** - Send a spreadsheet we'll wrap it for you (e.g. a production workflow form or layout your own failure incident form).
c) **See it in action** - Arrange a site visit to see production workflow wraps with API connector integration to digital torque wrenches.

10 Epilogue

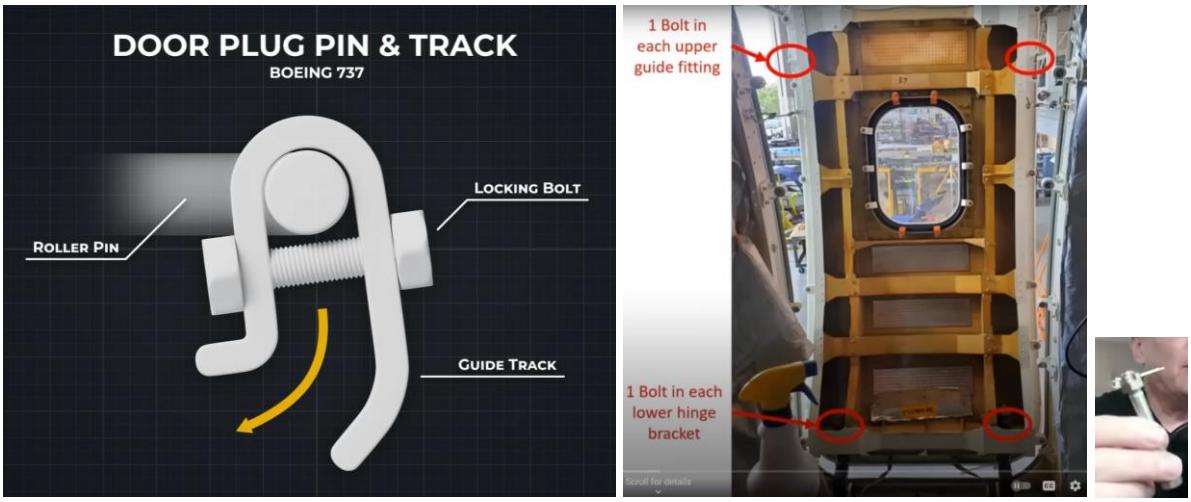


Figure 24 - Boeing 737 door plug track and locking pin with cotter pin locking device.

Regarding the Boeing 737, an update on January 25th: Alaskan Airlines CEO said that numerous loose bolts were found after a fleet check. If they had digital records a fleet check would not have been necessary, the information could have been immediately available by searching digital records.

Boeing's subcontractor, Spirit AeroSystems, makes fuselages and door plugs in Wichita, Kansas, and sends them to Seattle, Washington, for final assembly. The door plugs are not fully installed at first, because Boeing takes them out to adjust interiors for customers and fixes them when they put them back. Misunderstanding between the companies could cause door plugs to be moved wrongly, resulting in improper installation. Spirit AeroSystems quality assurance records indicate that work has been done on the plug door seal, but the Boeing quality assurance system had no records of this. It is possible that they may have skipped their door installation checks altogether. There are also whispers that Boeing may have failed a fuselage pressure test but just reset the pressure switches without alerting anyone. Boeing has also had significant layoffs, particularly reducing the number of quality assurance staff, which has led to confusion over what has been checked and not checked. All these whispers match the author's experience of the chaos around all failure investigations. It's still early and the investigation is continuing but the root cause is likely to be one of these:

1. Locking bolts never fitted
2. Only two bolts fitted.
3. Cotter pins not fitted and vibrational loosening leading to loss of locking bolts.

Regarding the digital technology described in this paper, Boeing and Spirit AeroSystems should have had a clear view of work that had not been completed, particularly if both companies shared data automatically using an API connector.

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