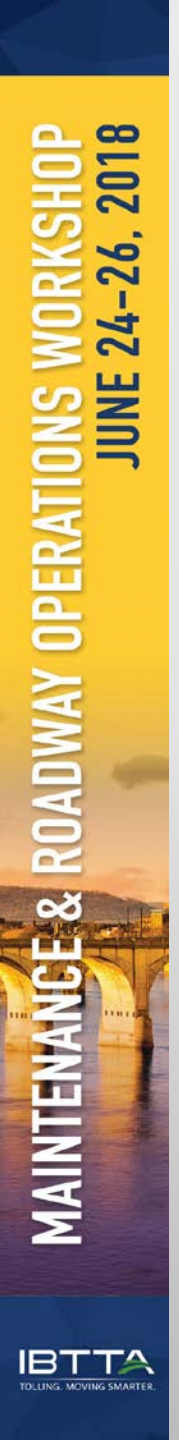


Structural Monitoring as an Internet of Things (IOT) Service – Results from a Pilot Study

Tom Golecki, PE, SE – Intelligent Infrastructure Systems

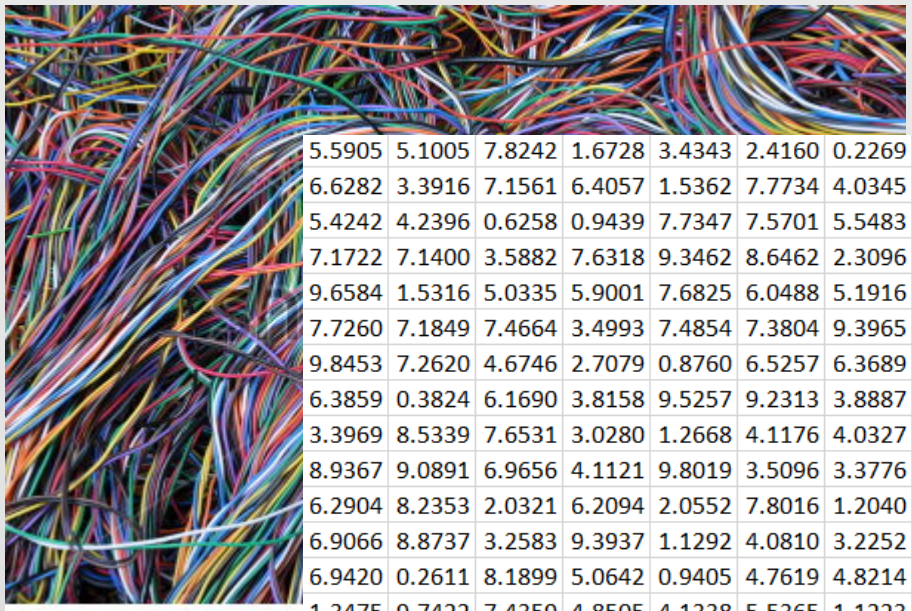
Marielle Lafaire – machineQ

Nathan Dubbs, PhD, PE, P.Eng. – BDI

Presentation Outline

- Background
  - SHM – what is it and what are the challenges?
  - LoRaWAN
- SHM as an IoT concept
- Pilot study
  - Background
  - Implementation
  - Results
- Lessons learned and takeaways

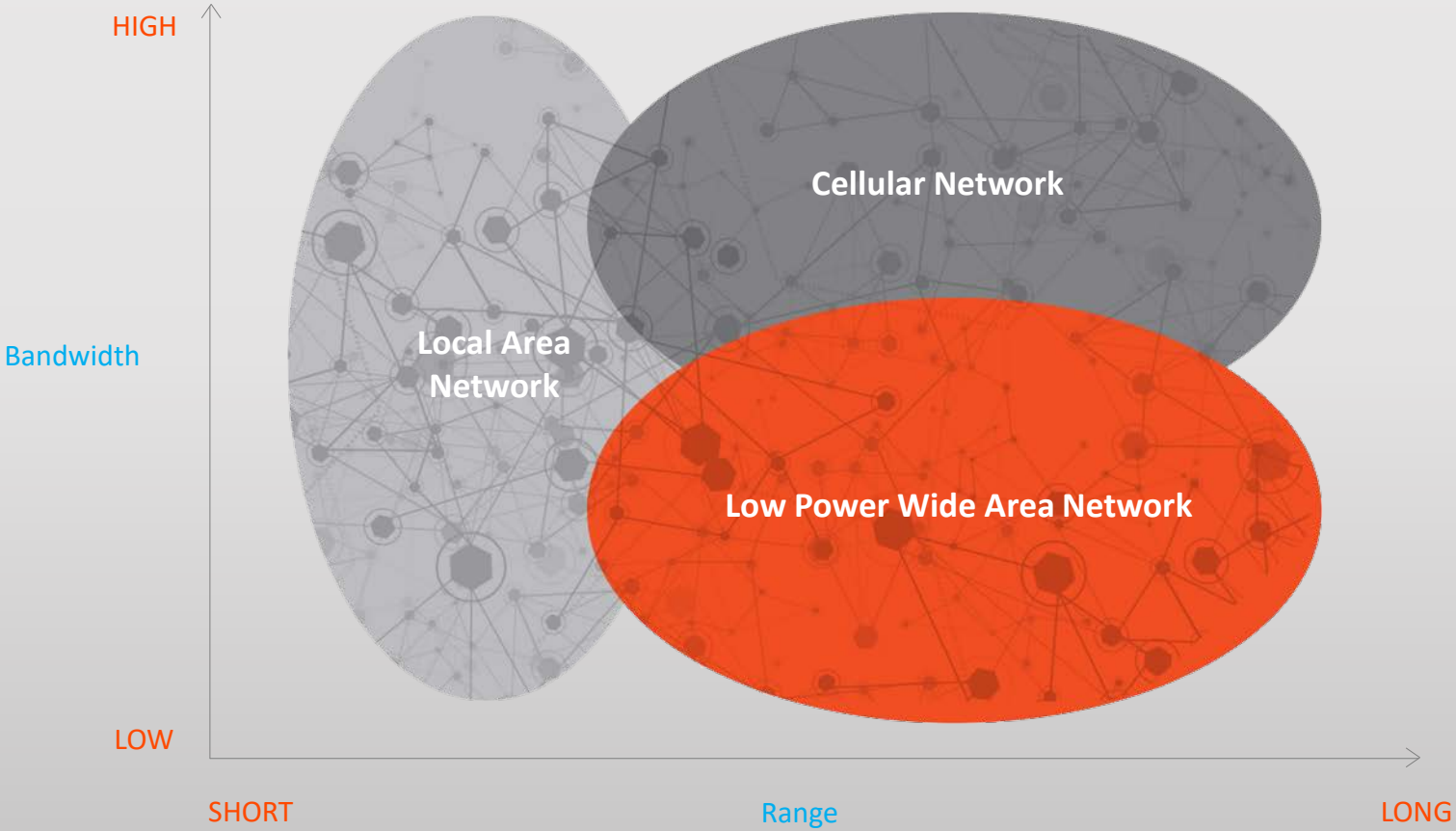
What is SHM?



5.5905	5.1005	7.8242	1.6728	3.4343	2.4160	0.2269	8.8698	7.3121	4.8574	3.7757	6.0903	4.5198
6.6282	3.3916	7.1561	6.4057	1.5362	7.7734	4.0345	1.2755	5.1210	0.2400	9.8250	8.5851	2.0477
5.4242	4.2396	0.6258	0.9439	7.7347	7.5701	5.5483	5.9391	2.5446	5.3469	3.0240	7.2104	9.9396
7.1722	7.1400	3.5882	7.6318	9.3462	8.6462	2.3096	2.3077	6.9720	4.5750	8.4106	0.6974	9.0160
9.6584	1.5316	5.0335	5.9001	7.6825	6.0488	5.1916	3.8944	0.7245	4.0456	9.2842	0.4677	3.7502
7.7260	7.1849	7.4664	3.4993	7.4854	7.3804	9.3965	3.1522	9.9602				
9.8453	7.2620	4.6746	2.7079	0.8760	6.5257	6.3689	3.7305	0.9812				
6.3859	0.3824	6.1690	3.8158	9.5257	9.2313	3.8887	6.3992	6.9507				
3.3969	8.5339	7.6531	3.0280	1.2668	4.1176	4.0327	4.2678	2.1309				
8.9367	9.0891	6.9656	4.1121	9.8019	3.5096	3.3776	6.5552	5.9877				
6.2904	8.2353	2.0321	6.2094	2.0552	7.8016	1.2040	7.9518	1.8701				
6.9066	8.8737	3.2583	9.3937	1.1292	4.0810	3.2252	9.3896	7.1608				
6.9420	0.2611	8.1899	5.0642	0.9405	4.7619	4.8214	9.3425	7.1982				
1.3475	9.7422	7.4359	4.8505	4.1338	5.5365	1.1223	5.2305	5.2744				
0.7105	9.6855	0.3389	1.0627	6.2929	9.7358	0.8077	5.4111	0.0332				
2.4879	5.2573	1.5464	4.4814	1.5434	7.3418	7.1065	2.8894	5.9301				
4.8806	0.5442	8.8814	7.4864	4.0070	7.5222	5.3851	3.8514	2.7796				
0.5032	5.7743	2.6378	3.7788	7.0992	9.5575	8.3568	1.6358	2.7462				
3.7995	8.9394	0.0235	0.7410	9.3749	3.3457	6.8230	4.6104	5.5121				
7.6816	4.3359	9.1206	3.2301	6.0165	7.4965	5.0991	3.0734	9.6539				
1.9919	8.3661	2.6191	8.5035	5.8549	4.5181	2.0378	9.3443	1.5600				
5.3267	1.7532	4.7363	6.5180	3.6541	8.9651	7.0992	5.9953	8.7220				
3.9037	2.0890	4.9729	7.3593	1.1705	3.4569	2.1625	2.1446	7.1341				
2.5581	7.3798	6.6014	1.2227	1.2729	8.0715	4.9046	3.8031	3.6451				
6.6205	2.8403	0.8297	6.6254	6.1352	3.1217	8.5815	0.6526	8.2484				
3.1790	2.6619	1.7514	3.3509	3.2704	5.5721	9.5443	9.6358	9.7887				
7.4549	7.7787	4.8166	5.7672	5.6348	7.0661	6.3784	1.5853	8.3604				
2.3159	8.3557	1.3715	3.3837	6.3098	5.6430	0.4818	3.8850	8.3389				

SHM Need: We need to better fit within the constraints and needs of the end users and deliver actionable info

LoRaWAN: Filling the Connectivity Gap



- Low Power Wide Area Network (LPWAN) Internet of Things
- Cellular Network Traditional M2M
- Local Area Network Short Range Communication

LoRaWAN Advantages

Long range
// Connection up to 30 miles line of sight
// Deep indoor coverage

Low power
// 20 years of battery life
// Low maintenance

Low cost
// Lower costs compared to other connectivity options
// Network operators do not need to amortize the cost of licensed spectrum

Standardized
// A global standard ensuring interoperability and streamlined adoption

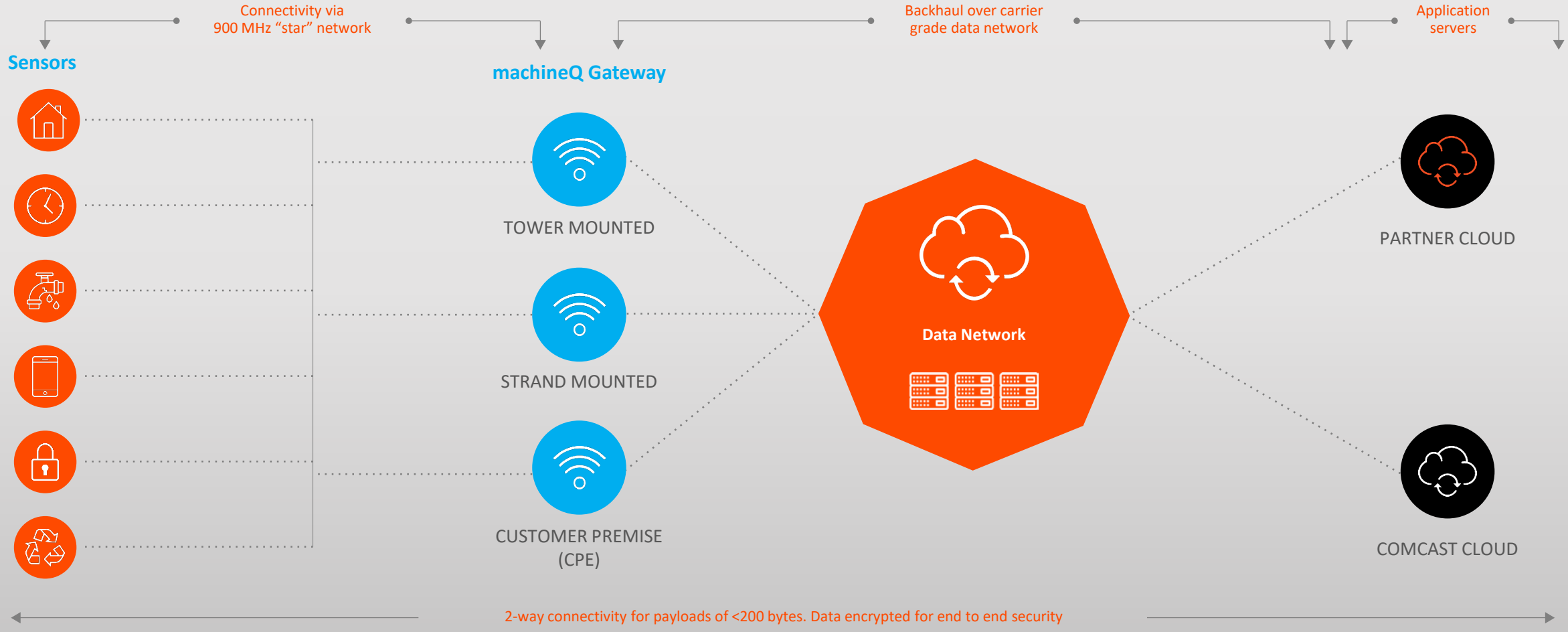
High capacity
// Supports millions of messages per gateway

Secure
// AES 128 encryption of data for the highest level of security
// Data is only accessible to those with the encryption keys

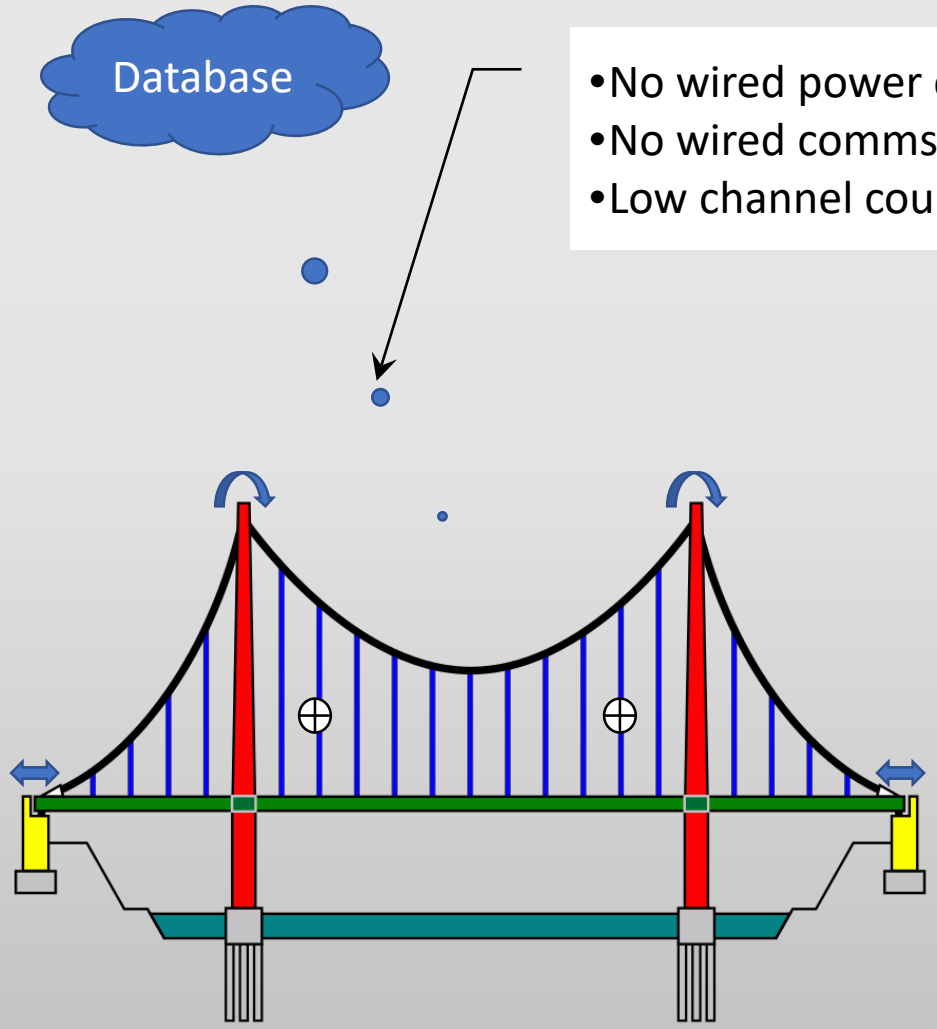
Multi-tenant
// Optimized for many users and use cases
// Allows for third party users

Geolocation
// Significantly reduced costs and embedded geolocation abilities in every sensor

machineQ Network Architecture



SHM as an IoT Concept



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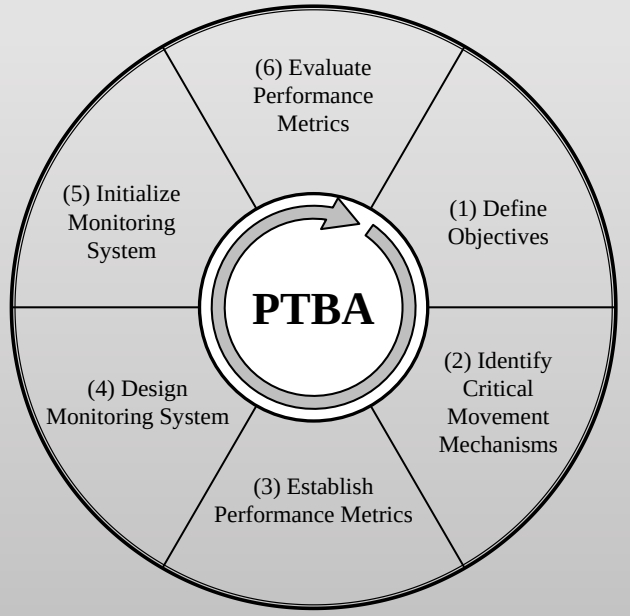
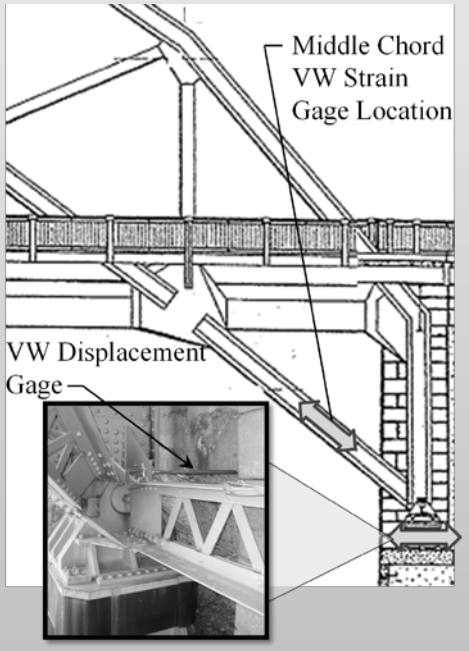
- Battery power
  - If it can last as long as an inspection cycle – it can be maintained by inspectors
- Wireless communications
  - Without hard-wired comms, now no need for conduit
- Low spatial/temporal resolution
- Potential applications
  - ***Movement system performance***
  - Crack growth
  - Mechanical system performance on movable structures
  - Roadway operations (weather)
  - Short span or otherwise small structures
  - Long-term load distribution
  - Really any traditional sensing where low spatial/temporal resolution and low power draw is an option

Pilot Study – Wired SHM for Bearing Performance

- Wired SHM
  - Conduit
  - Enclosures
  - Wired power/comm
  - Dedicated servers with IT support
- SHM infrastructure was included as part of larger IT infrastructure upgrade
- Expansion bearing performance is a key performance metric

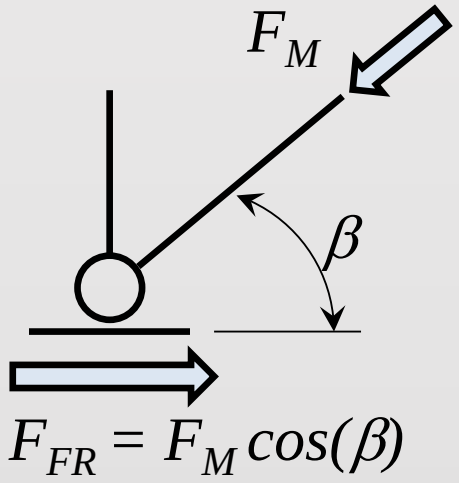


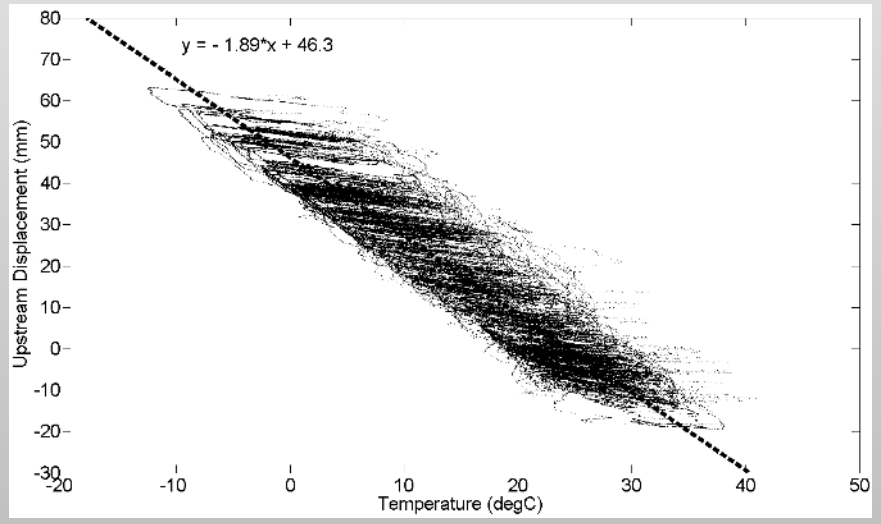


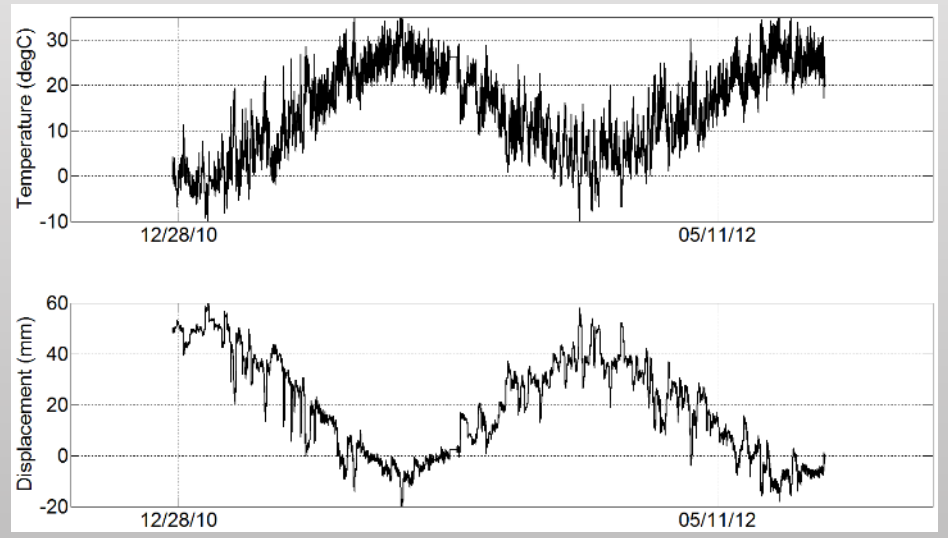
Yarnold, M.T. and Dubbs, N.C. Bearing Assessment using Periodic Temperature-Based Measurements. In *Transportation Research Record: Journal of the Transportation Research Board,* No. 2481, Transportation Research Board of the National Academies, Washington, D.C., 2015, pp. 115-123

Pilot Study – Wired SHM benefits

- After one year of monitoring, the following observations were made:
  - Span was expanding and contracting to within 98% of simple $\Delta\delta=\alpha*L*\Delta T$ calculation
  - Friction coefficient
    - Manufacturer specification was 0.04 to 0.11
    - Measured value was 0.07







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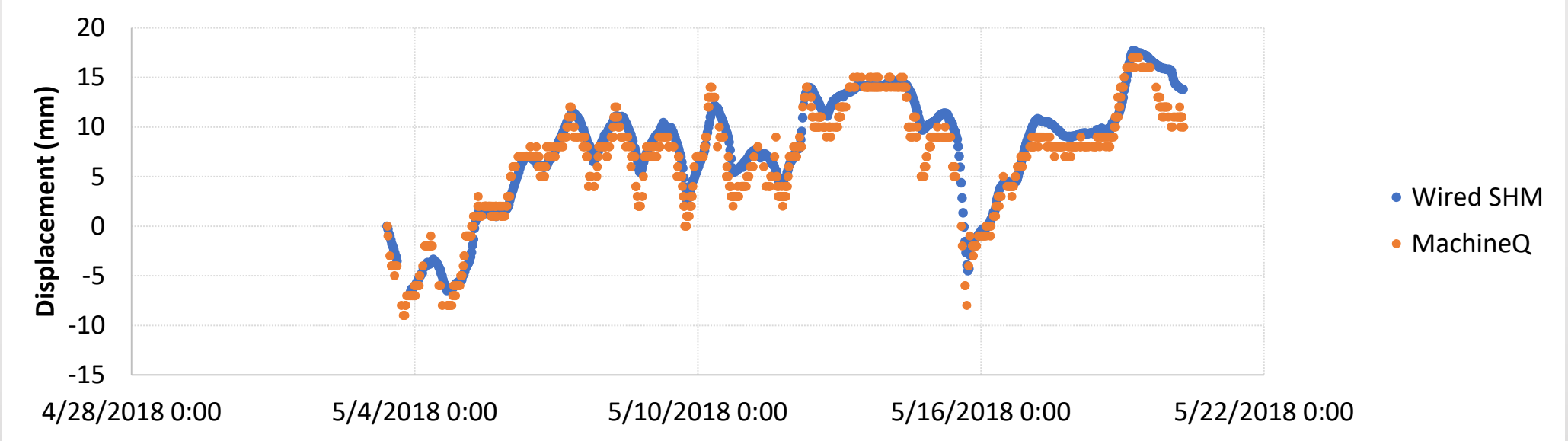
Pilot study – IoT duplicate instrumentation

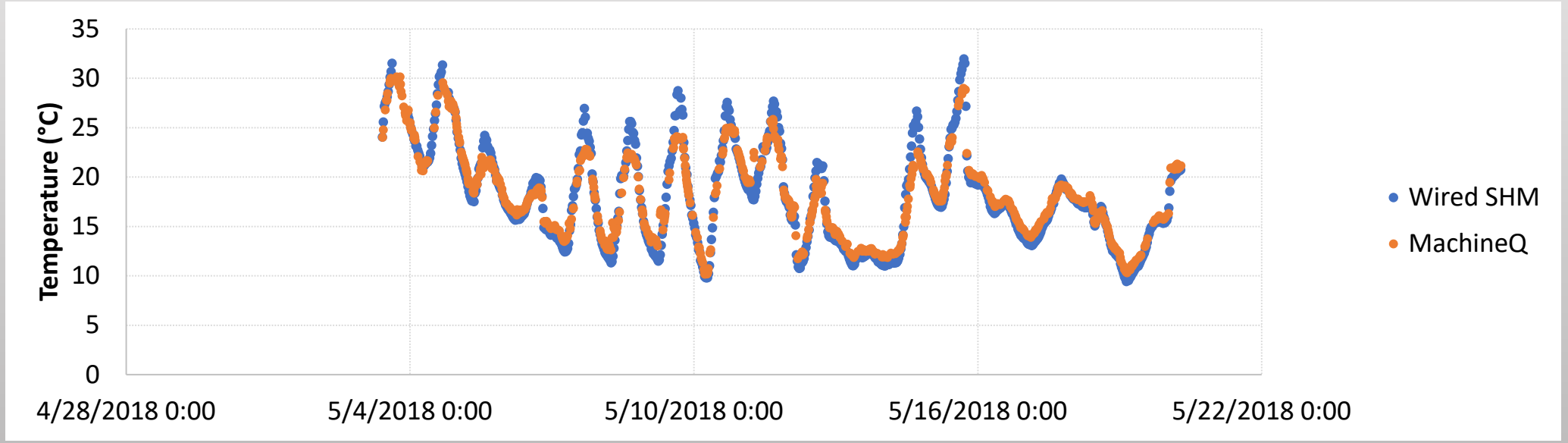
- Ultrasonic Displacement

- Temperature & Humidity

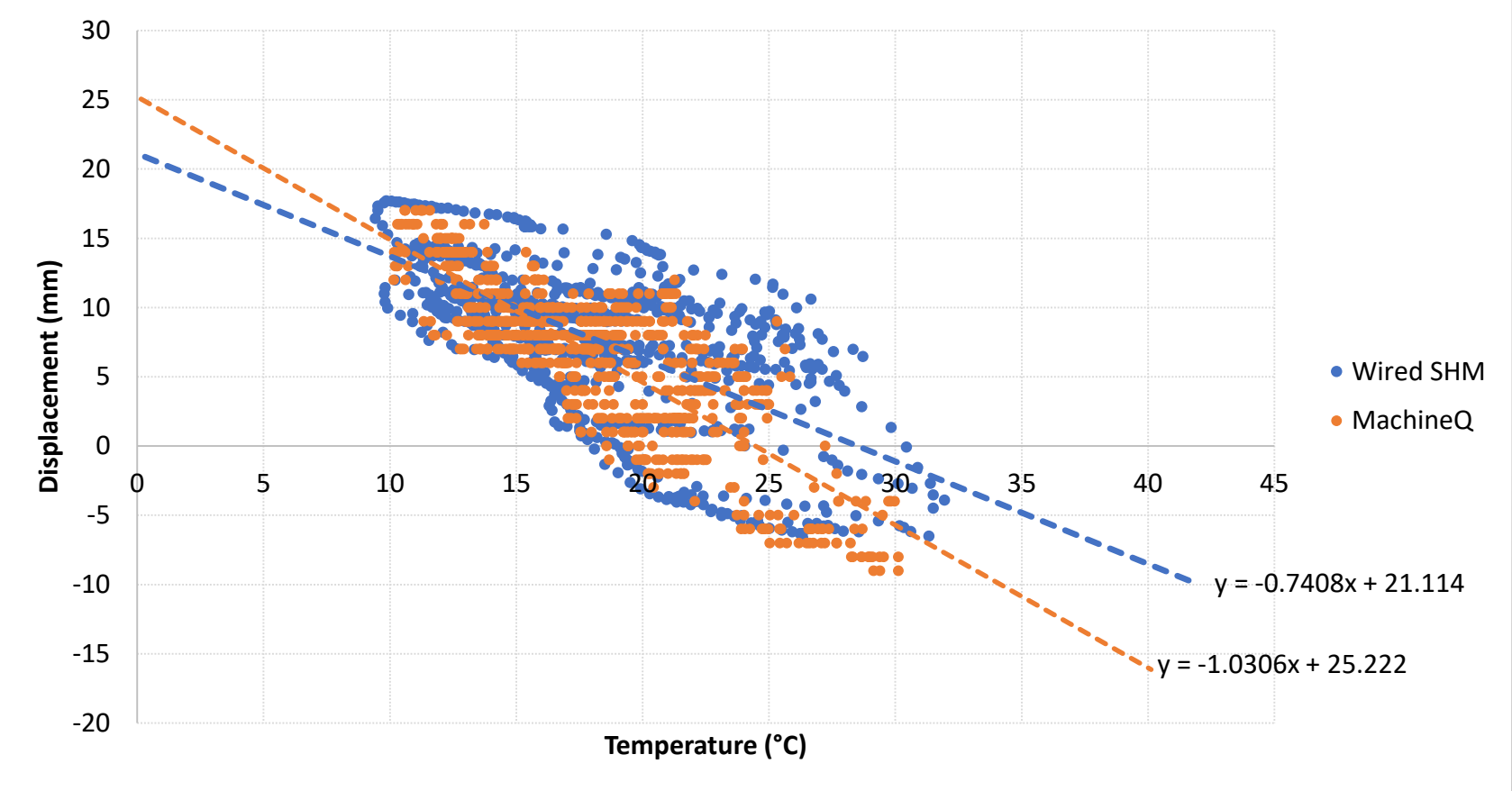
- Vibrating Wire Strain

Pilot study – comparison of measurements





Pilot study – comparison of measurements



Pilot study – comparison of costs

	Wired	IoT
Sensors		
Strain	$ 212.00	$ 630.00
Displacement	$ 480.00	$ 597.00
Temperature	0*	$ 576.00
Data acquisition		
Datalogger	$ 3,600.00	0**
Network peripherals	$ 350.00	0**
Data access fees		
Annual Sensor Data Access	$ -	$ 240.00
Annual Storage and Backup	$ -	$ 27.00
Infrastructure, Maintenance, IT		
Gateway	***	$ 650.00
Monthly licensing/cellular fees	***	$ 34.98
Software	$ 2,700.00	$ -
Total cost - onetime	$ 7,342.00	$ 3,453.00
Recurring annual fee - Y2+	$ -	$ 419.76

Caveats / Assumptions

- This is an illustrative example and not meant to be a formal cost proposal.
- The cost for a wired 3 channel system is the same up through 32 channels with exception of additional sensor costs
- Costs weren't included for in-house IT needs.
- The pilot bridge had network equipment installed as part of a larger IT construction project – the owner did not pay a fixed fee for this monitoring system
- IT infrastructure includes items such as switches, fiber optic, conduit, servers, etc. and is a simple estimate.

*Wired sensors often have thermistor integrated

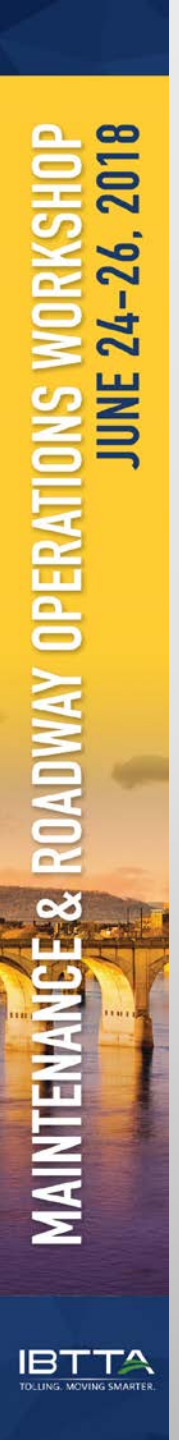
**IoT sensors and DAQ are combined

***Wired SHM costs to consider:

- Conduit
- Enclosures
- IT Infrastructure (servers, switches, UPS, fiber, etc.)
- IT staff

Lessons learned and takeaways

- The good
  - The actual sensing mechanisms between wired and IoT are the same – the difference is in how the data gets from the bridge to your computer.
  - For a simple targeted (low channel count, low frequency transmissions) monitoring system, IoT provides a compelling alternative to traditional wired systems.
- But keep in mind…
  - Power in the vicinity of the bridge is still a requirement
  - Sensors largely require line of sight to gateway
  - Interpretation of data and translation into actionable information is still a requirement in either monitoring approach
  - This will not be a feasible solution for systems required fast (>20Hz) sampling speeds (fatigue studies, load tests, vibration monitoring)



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