Investigating the link between human fatigue and manufacturing assembly quality

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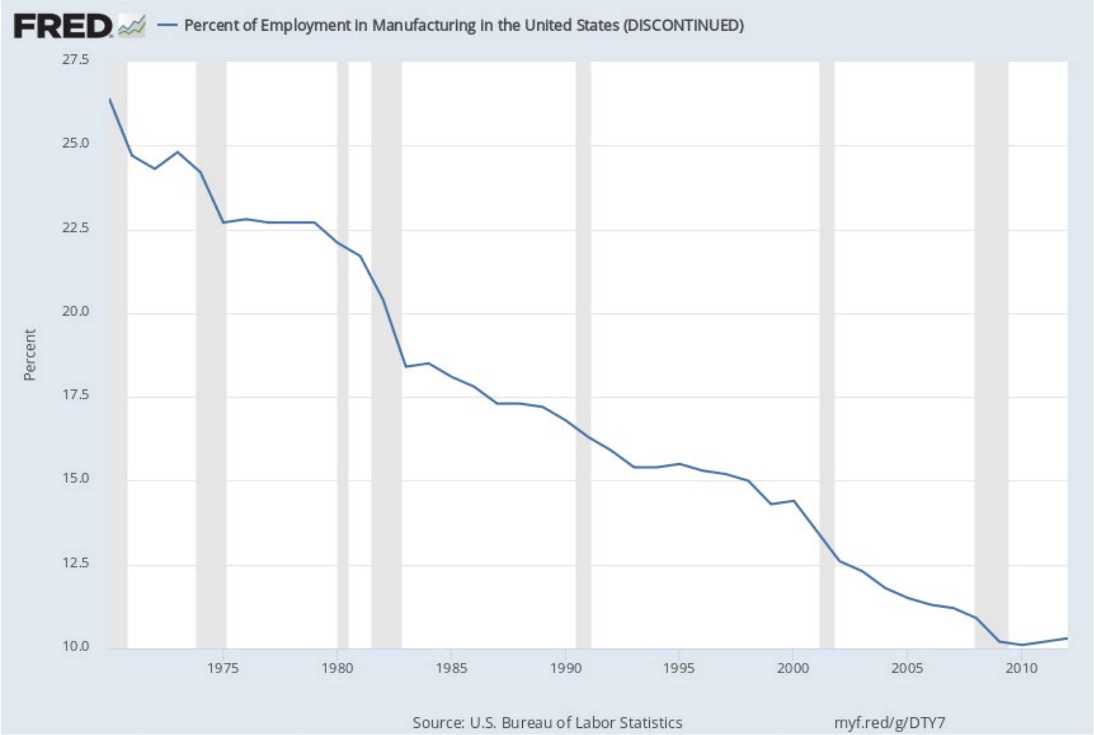
Human workers in manufacturing



[https://fred.stlouisfed.org/series/USAPEFANA, 2020-07-28]

Steady decline in #employees in manufacturing.

A change in the nature of work

- *"computer-controlled systems … results in the reduction of number of seafarers working in ships."* [1]
- Data collected … indicate the number accidents is increasing and are mostly caused by the people on board" [1]
- Fewer people → longer hours → heavy paperwork → new procedures → more complex tasks.
  - (Hard work → complex work).

[1] Bal, E., Arslan, O., & Tavacioglu, L. (2015).
Prioritization of the causal factors of fatigue in seafarers and measurement of fatigue with the application of the Lactate Test.
Safety Science, 72, 46–54. http://dx.doi.org/10.1016/j.ssci.2014.08.003

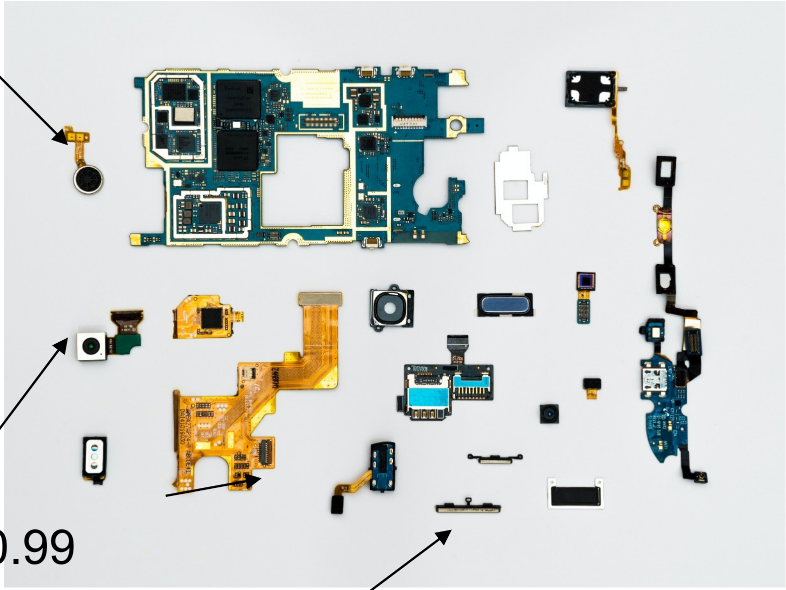
Purpose

- Investigate the relationship between manufacturing quality and human fatigue.
- Why:
  - Manufacturing quality is a competitive requirement.
  - Humans are integral part of manufacturing.

Fatigue = Decreased performance due to prolonged exposure
Quality = The likelihood of a defective product.

Assembly quality (simplified)

Microphone 0.99



Camera 0.99

Button 0.99

- Defect accumulation in assemblies
- Chance of defect
  - Total = 0.99*0.99*0.99
  - 0.97

Method

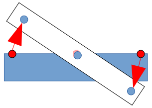
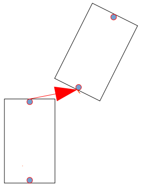
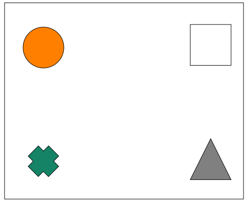
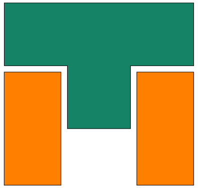
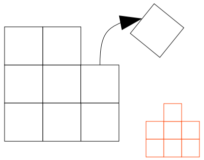
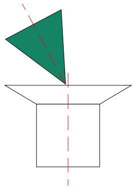
- How do we measure fatigue?

Fatigue factors
- Time of day
- Day of week
- Previous workload
- ...

→ Individual fatigue state →

Quality output
- Assembly tolerance
- Chance of failure
- Chance of injury
- ...

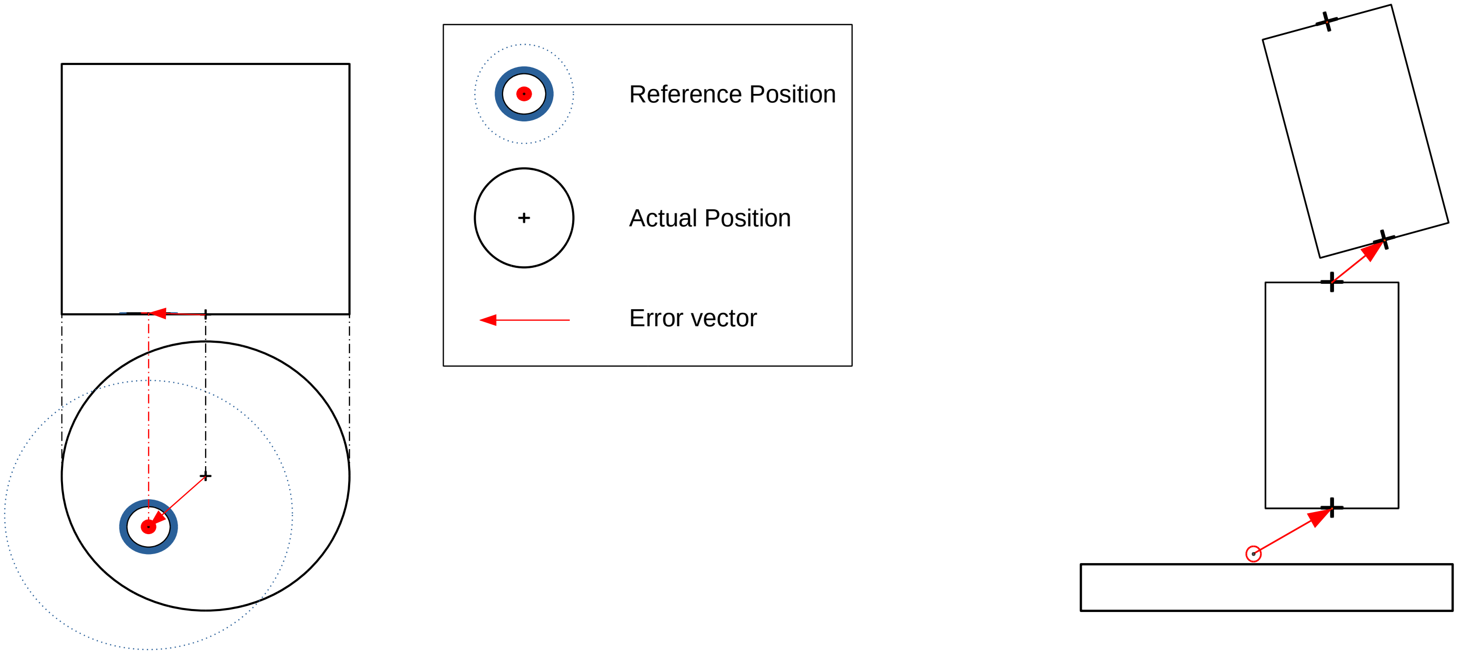
How did we measure? (Video demonstration)

Placement	Stacking	Sorting	Joining	Removal	Drilling
					
Repeatable	Repeatable	Random	Random	Current Prototype	Current Prototype

Increase in task complexity

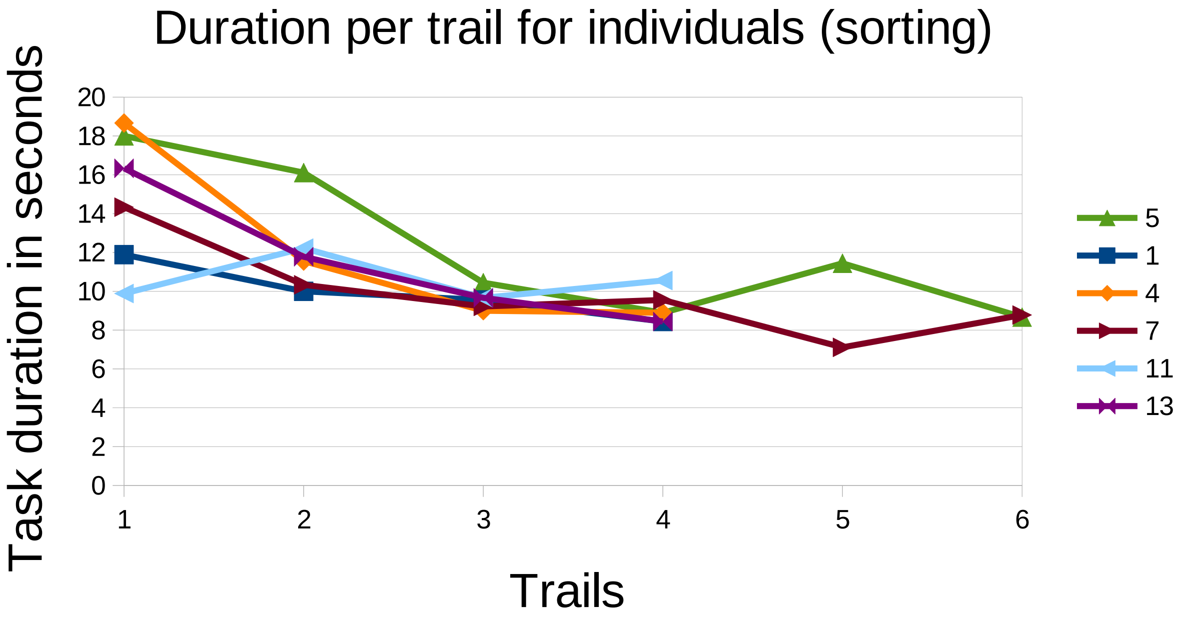
Dimensional error

- The difference between the reference and actual position.



Learning: Duration

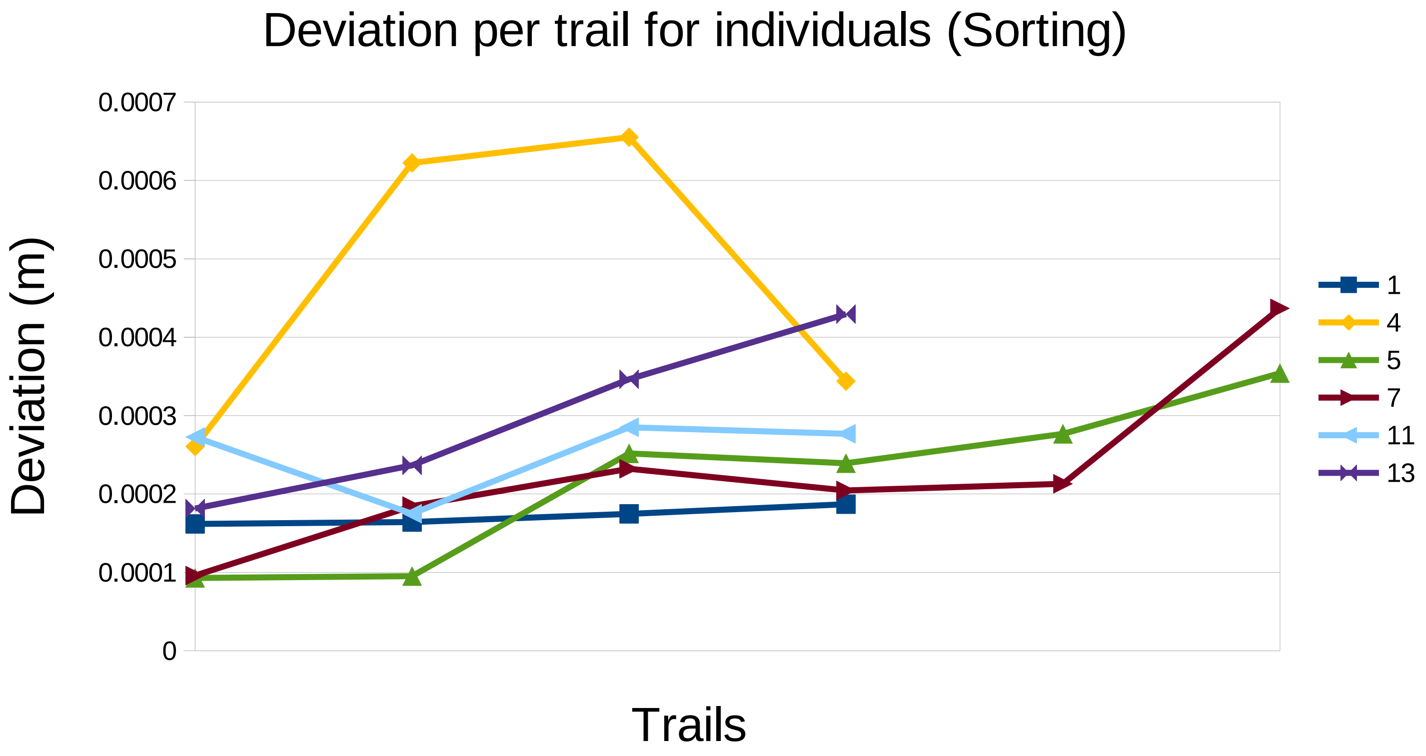
- Known phenomena [2]



Learning decreases task duration

[2] Fruggiero, F., Fera, M., Lambiase, A., Maresca, P., & Caja, J. (2017).
The role of human fatigue in the uncertainty of measurement.
Procedia Manufacturing, 13, 1320–1327. https://doi.org/10.1016/j.promfg.2017.09.092

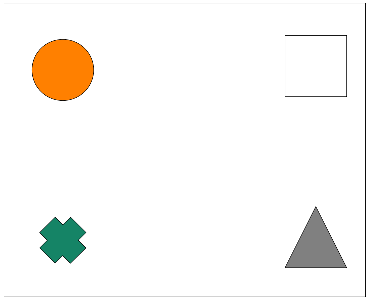
Learning: Deviation

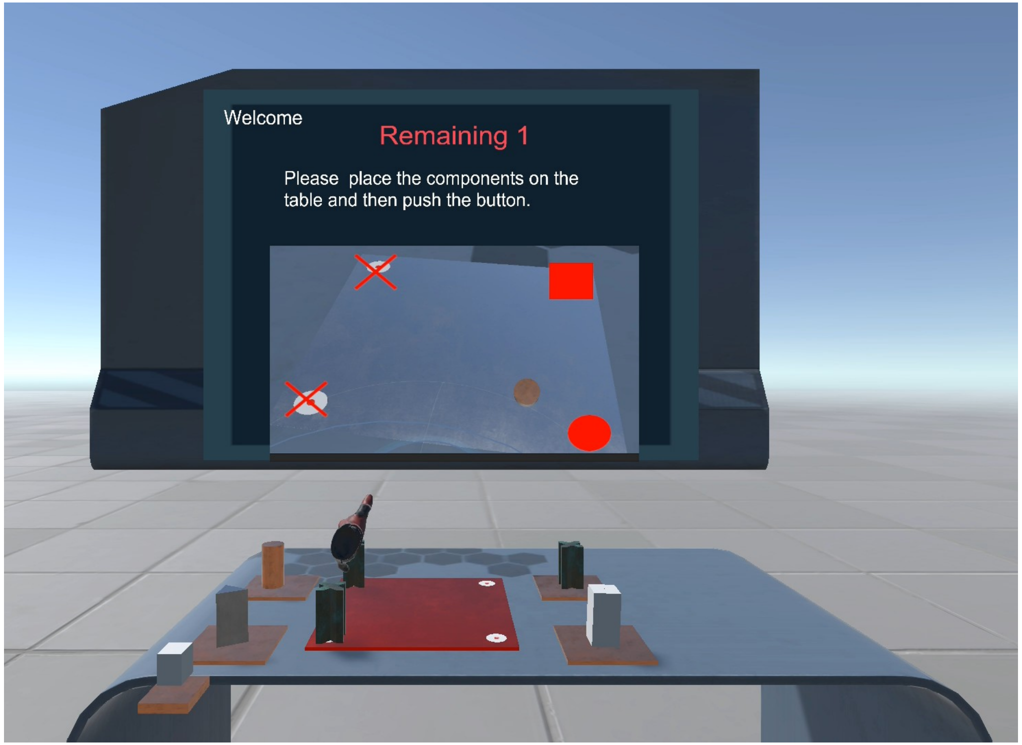


Learning increases assembly deviation

Discrete error

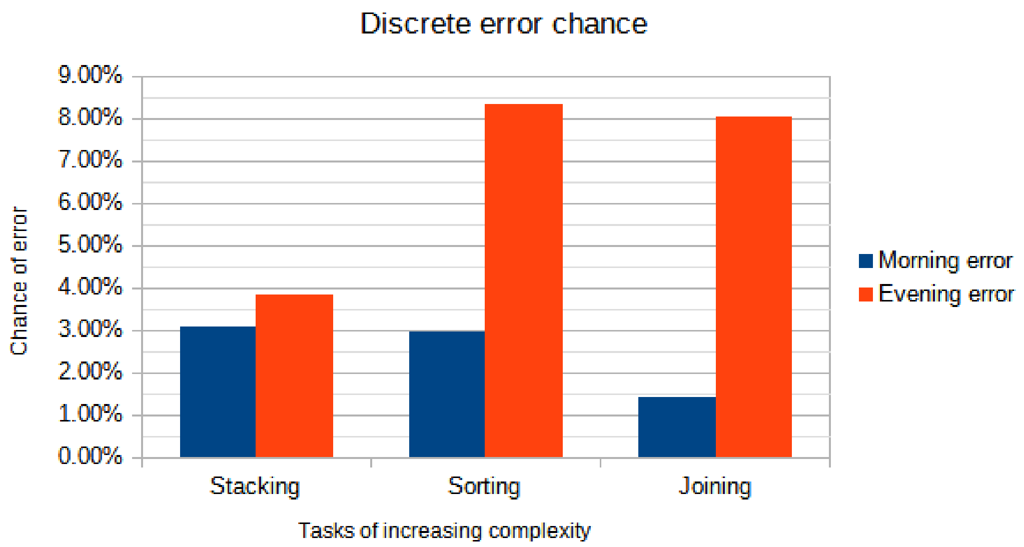
- Does the formula match?
  - Error in judgment
  - Injury





Time of day

- Increased chance of discrete errors later in the day. [3]
- Morning error is constant
- Random tasks have higher evening Error chance

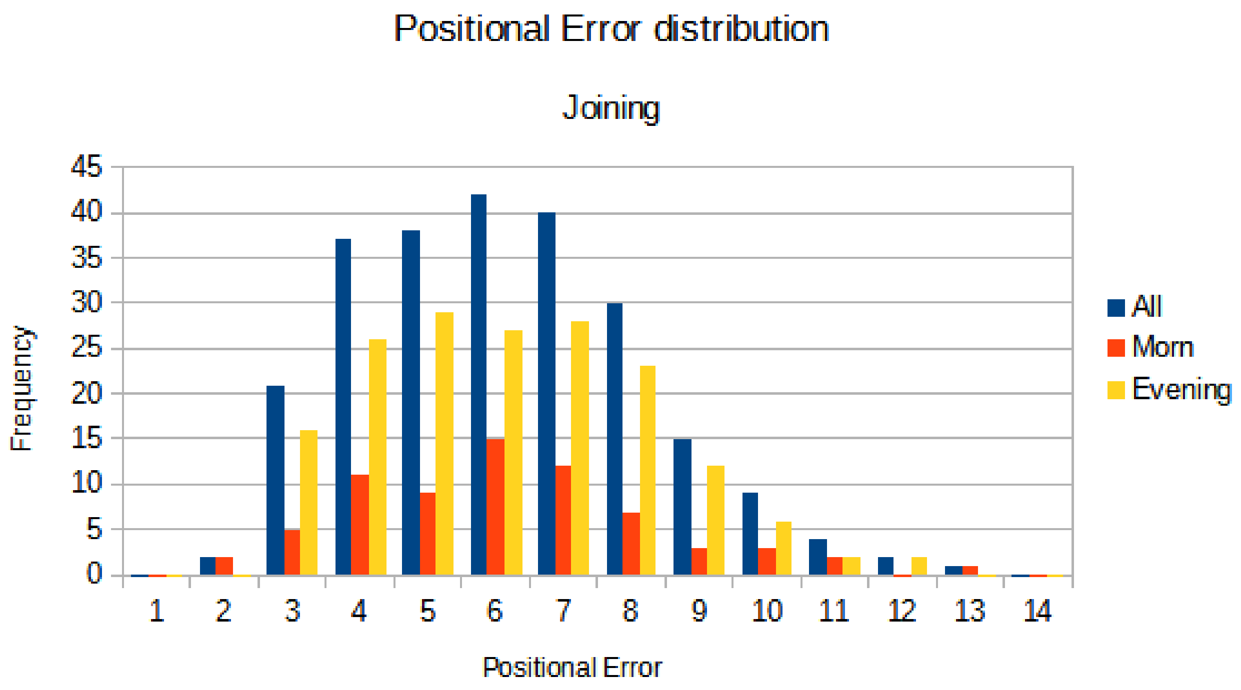


Placement task omitted due to learning/introduction errors

[3] Folkard, S., & Lombardi, D. A. (2006). Modeling the impact of the components of long work hours on injuries and “accidents.” American Journal of Industrial Medicine, 49(11), 953–963. https://doi.org/10.1002/ajim.20307

Fatigue has little effect on dimensional error

- Time of day
- Number of trials



Experimental validation

- We have confidence in the experiments ability to measure because we observed:
  - Learning reduces task duration [2].
  - Discrete error increase rates later in the day [3].

Experimental Findings

- We also found that:
  - Task complexity increases the discrete error later in the day.
    - Random vs Repeatable
  - Time of day has little effect on dimensional error.
  - Learning can negatively effect dimensional error deviation.

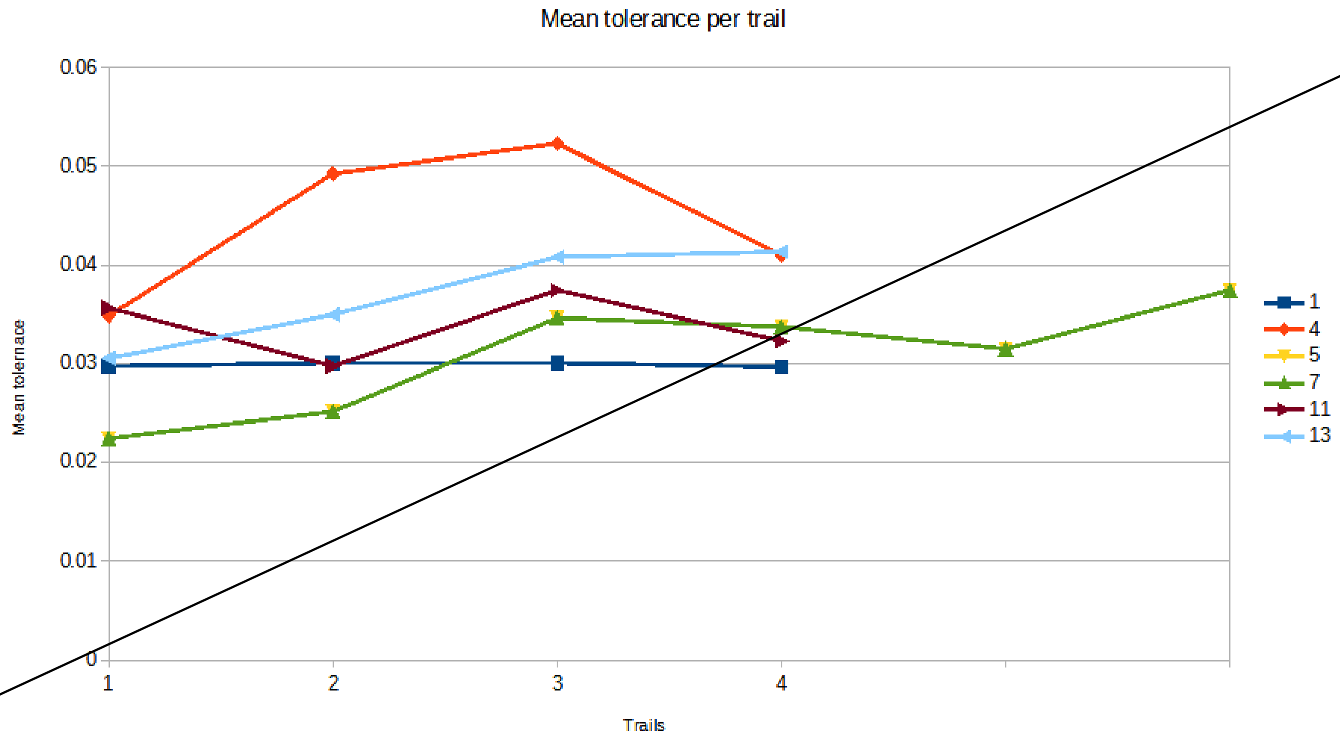
Conclusion

- Scheduling should consider quality, not only make-span [1].
- More relevant models of human fatigue are necessary [4].

[4] Kolus, A., Wells, R., & Neumann, P. (2018). Production quality and human factors engineering: A systematic review and theoretical framework. Applied Ergonomics, 73(October 2017), 55–89. https://doi.org/10.1016/j.apergo.2018.05.010

Thank you!

Learning: Mean



Outline

- Humans in manufacturing
- Human fatigue
- Quality in manufacturing
- Experimental design
- References (Table)

Human fatigue

- Decrease in ones performance due to prolonged exposure.
- Examples:
  - Physical fatigue (time-under-tension)
  - Cognition (recognizing patterns)

$$3x^2 + x - 54$$

Solve using ...

Human fatigue domains

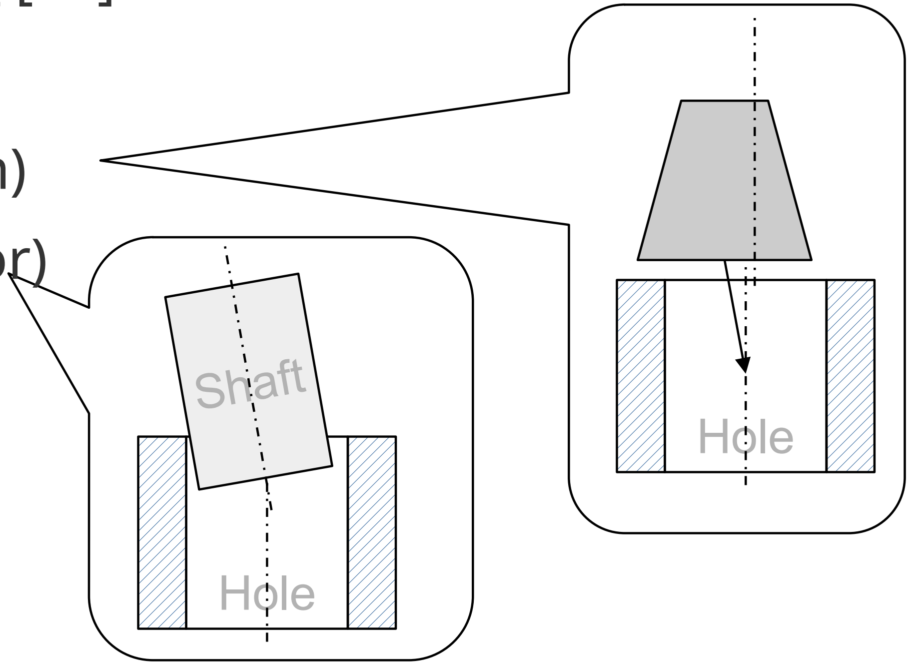
- Airplane pilots [1,14,15]
- Long distance drivers [18,19,21,23]
- Marine [7,10]
- Manufacturing [2,3,4,8,24,25,26,27]
- General workplace [5,6,9,11,12,13,16,17,20,22]

Human fatigue literature

- Studied for safety (2000's)
  - "Many of the industrial disasters of the last few decades, including Three Mile island, Chernobyl, Bhopal, Exxon Valdez, and the Estonia ferry, have occurred in the early hours of the morning." [8] (2005)
- Studied for throughput rate (2010's)
  - [9] Modeled duration taking HF into account (2009)
- Studied for quality (2018+)
  - The mistaken belief that Human Factors are strictly orientated towards safety has limited its contribution to performance aspects. [27]

Production quality (risk)

- The likelihood of a **defective** product.
- Quality has been broadly noted as being of strategic importance in manufacturing [26].
- How can we measure it?
  - Discrete errors. (Cognition)
  - Dimensional errors. (Motor)

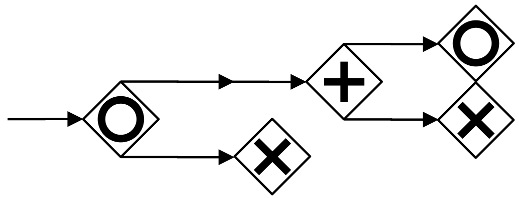


Fatigue factors (from literature)

- Task complexity
- Time of day
- Previous workload

Task complexity

- Cognitive demand of a task.
- More complex tasks generate lower reliability and higher probability error. [7]
- Decision making [24, 16, 10, 13, 21, 26, 7, 5, 6]
  - Judgment, Cognition, Logic, Computer-controlled



Schematic = high cognitive load

Fatigue accumulation

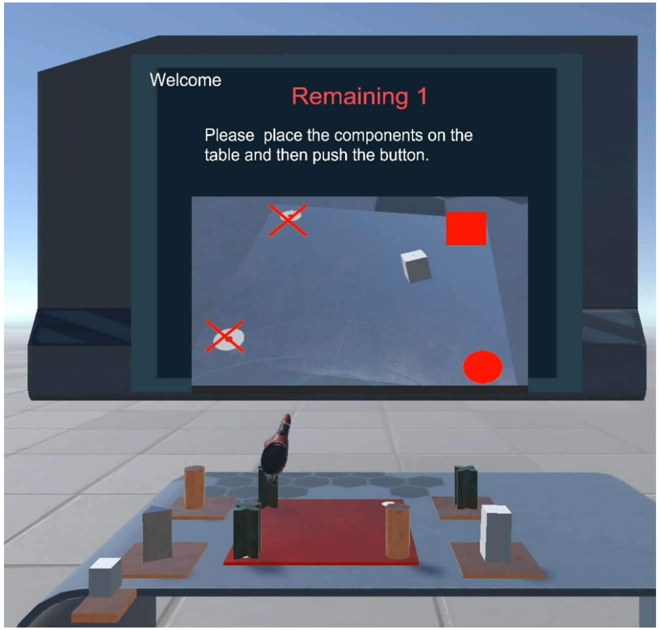
- Short term [8,9,29,15] (Time on task)
  - Hours on duty
  - Shift duration
  - Time since last break
- Medium term[8,14,9,15,10,7,16]
  - Successive shifts (days of week)
  - Weekly work hours
  - "slept significantly more on non-workdays than on workdays" [14]

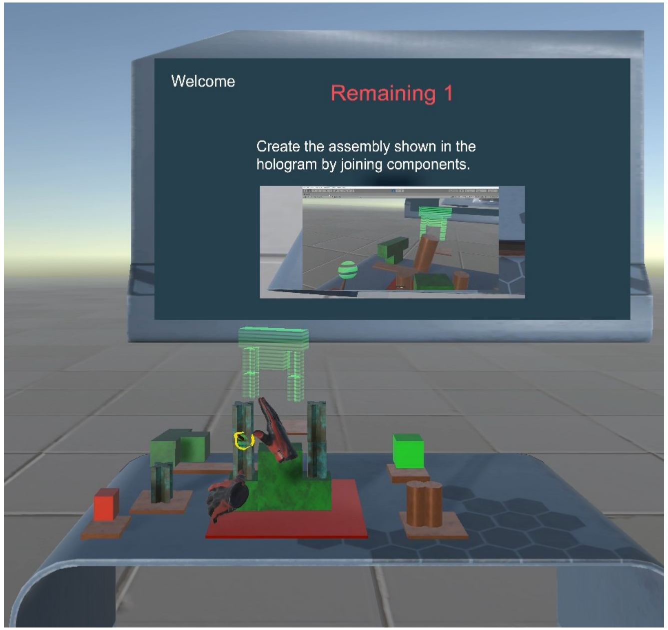
Experimental Design

- Video demonstration
- What was recorded.
- What was analyzed

Discrete error

- Does the product match the recipe?





Experimental Factors

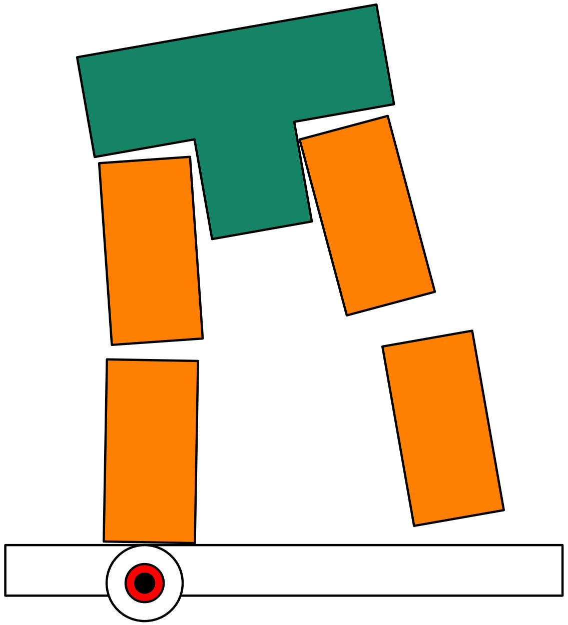
- Time-of-day → Measure
- Task complexity → Estimate
- Error (discrete) → Measure
- Error (Tolerance) → Measure

Nuisance

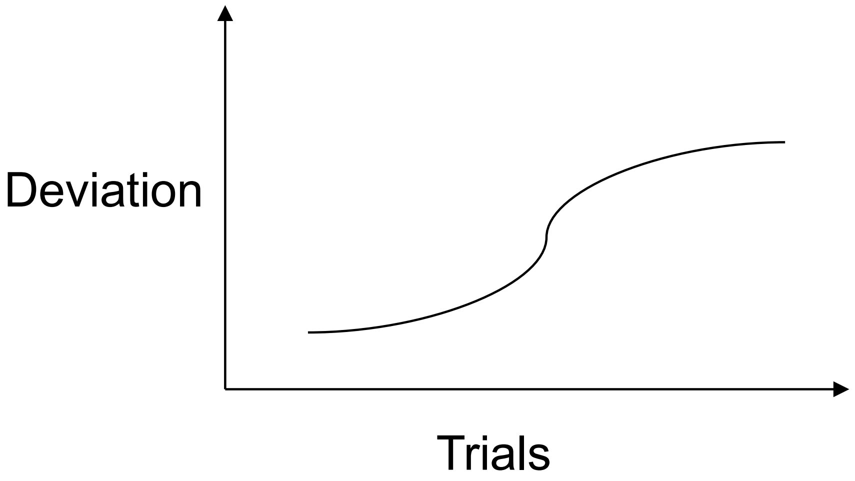
- Ergonomics → Controlled via table height calibration
- Learning* → Gather sufficient trails to eliminate effect
- Forgetting → Trails in one continuous week no weekends
- Task order, previous workload → constant
- Fatigue accumulation, Time since last break → constant
- Fatigue accumulation, week-long → Investigate

Underestimation in joining errors

- Only considered cognition errors, not dimensional errors.



Dimensional errors can cause assembly to topple over



Future

- Large volumes of data is being generated in manufacturing and we need to determine
  - what data is relevant and
  - how we can use it.

References

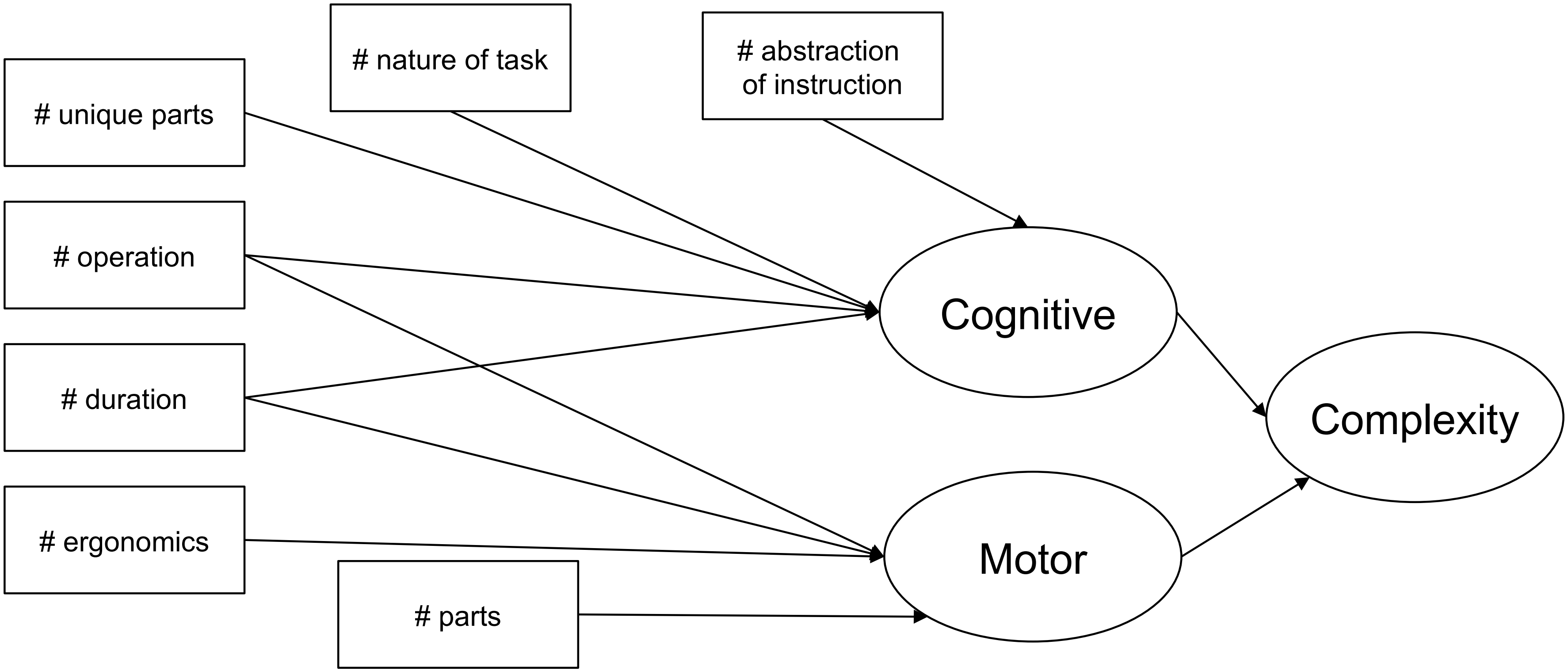
	Title	Domain	Year	Link	M
1	Eye movement and fatigue detection in visual inspection of civil aircraft	Manufacturing	2020		S
2	Heuristic approaches for scheduling manufacturing tasks while taking into account accumulated human fatigue	Manufacturing	2019	https://doi.org/10.1016/	A
3	Workforce scheduling: A new model incorporating human factors	Manufacturing	2012	10.3926/jiem.451	A
4	Maintenance and work-rest scheduling in human-machine system according to fatigue and	Manufacturing	2017	10.5829/idosi.ije.2017.	A
5	Feasibility study of physiological parameter registration sensors for non-intrusive human f	-	2019	ERDev2019.18.N363	-
6	The role of human fatigue in the uncertainty of measurement	Manufacturing	2017		M
7	Common patterns in aggregated accident analysis charts from human fatigue-related groundings and collisions at sea	Marine	2015	10.1080/03088839.201	C
8	Modeling the impact of the components of long work hours on injuries and "accidents"	Engineering	2006		a
9	Updating the "Risk Index": A systematic review and meta-analysis of occupational injuries and work schedule characteristics	Multiple	2017		m
10	Prioritization of the causal factors of fatigue in seafarers and measurement of fatigue with the application of the Lactate Test	Marine	2015	**http://dx.doi.org/10.1**	s
11	A grey–box identification approach for a human alertness model	None	2019	http://dx.doi.org/10.101	S
12	Fatigue and measurement of fatigue: A scoping review protocol	Medical	2019		N
13	Working Time Society consensus statements: A multi-level approach to managing occupational sleep-related fatigue	None		10.2486/indhealth.SW-	N
14	Pilot test of fatigue management technologies	Transport	2005	10.3141/1922-22	Ir
15	Fatigue in aviation: A systematic review of the literature	Aviation crew, shifts	2020	10.1016/j.ergon.2020.1	Ir

References

16	How should a bio-mathematical model be used within a fatigue risk management system to determine whether or not a working time arrangement is safe?	Fatigue models	2017	
17	Predictions from the Three-Process Model of Alertness	Sleep shift management	2004	
18	Detecting Driver Drowsiness Based on Sensors: A Review	Transport	2012	
19	A driver fatigue recognition model based on information fusion and dynamic Bayesian network	Transport	2010	
20	A Smart Health Monitoring Chair for Nonintrusive Measurement of Biological Signals	Electronic sensors	2012	
21	Review of Fatigue Management Technologies for Enhanced Military Vehicle Safety and Performance	Review of commercial pr	2013	
22	A critical review of existing mathematical models for alertness	Mostly transport but not	2007	
23	Various Approaches for Driver and Driving Behavior Monitoring: A Review	Driving	2013	
24	A survey of the prevalence of fatigue, its precursors and individual coping mechanisms among U.S. manufacturing workers	Manufacturing	2017	
25	A data-driven approach to modeling physical fatigue in the workplace using wearable sensors	Manufacturing	2017	
26	Production quality and human factors engineering: A systematic review and theoretical framework	Manufacturing	2018	
27	Examining the fatigue-quality relationship in manufacturing	Manufacturing	2020	
28	The effect of dynamic worker behavior on flow line performance	Manufacturing	2009	http://dx.doi.org/10.101
29	Predicting driver drowsiness using vehicle measures: Recent insights and future challenges	Transport	2009	

Decomposing task complexity

- Emphasis should be on human, not design



Human error table

Task	Morning error	Evening error	# morn	# even	Morn error	Ev error
1	22.22%	14.88%	27	168	6	25
2	2.96%	3.67%	135	354	4	13
3	2.99%	8.36%	134	371	4	31
4	1.41%	8.06%	71	186	1	15