Analytics at GM, Briefly

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GM Analytics Team

About GM (ending 2019)

- 111 years, $137B revenue, 7.7M sales, 164,000 employees, 6 continents, 75 languages
- More: gm.com and statista.com/topics/2480/general-motors/

Chief Data and Analytics Office (CDAO)

- About 150 employees
- Many data analysts and data scientists
- Work on data collection, access, reporting, analysis and modeling
- Many other GM organizations use STEM talent (e.g., Engineering, Design, Marketing, Finance)

Advanced Analytics Center of Expertise (AACE)

- About 45 people, mostly Masters and PhDs
- Projects in Manufacturing, Maintenance, Product portfolio, Quality, Future Businesses, Warranty, Service Parts, Healthcare, Residual Value, OnStar, Safety, Marketing, Supply Chain, and more

“Math” Career Path

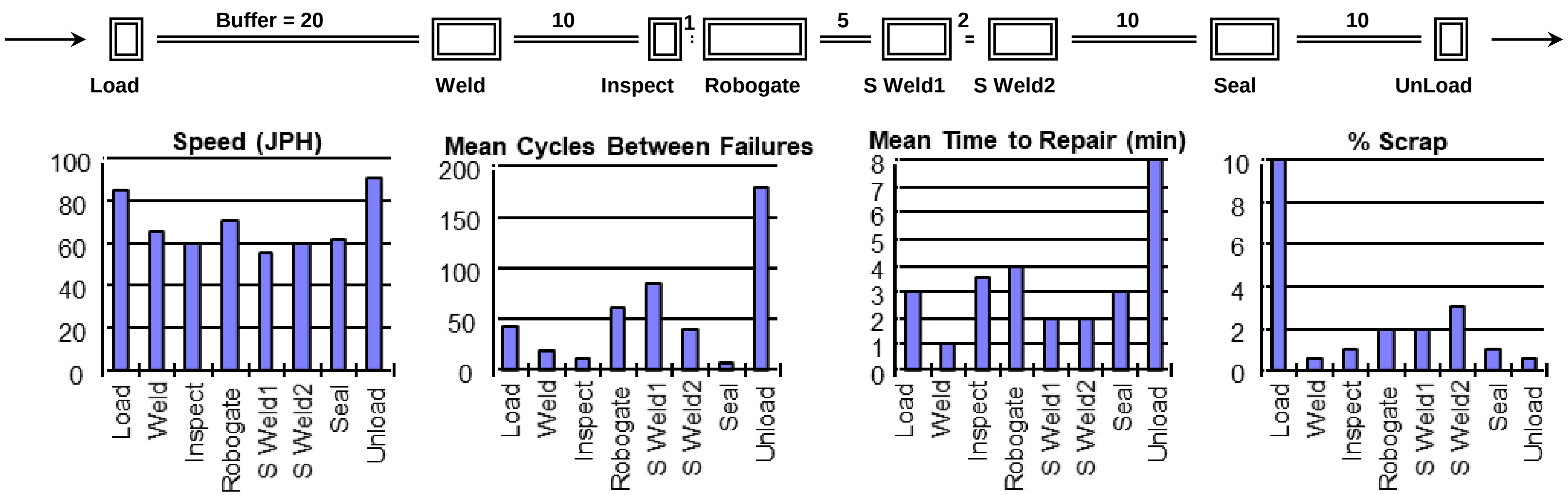
Levels and advancement

- Typically start at level 6 (Data scientist) and advance to level 9+ (Fellow) and/or management.
- Considers project contribution, impact ($), mentoring, teamwork, professional profile, project identification, leadership and go-to expertise.

Great work environment

- Bright interesting collaborative colleagues
- Diverse projects
- Potential for huge impact
- Values professional growth
- Supportive, safe, diverse and inclusive
- Remote work (evolving)
- Global opportunities

Example project: Increasing Production Throughput



Description

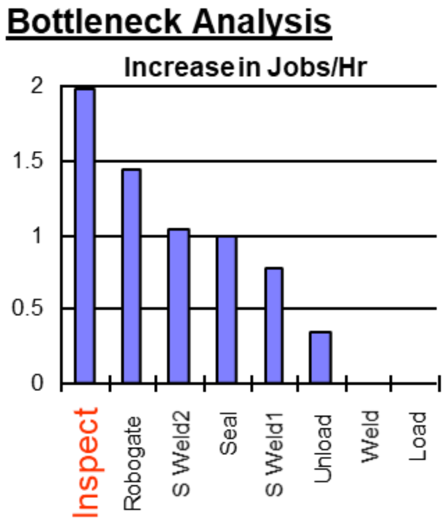
- Parts moves though a line of stations separated by buffers
- Stations have different speeds (constant)
- Stations randomly fail with random repair times (Exponential)
- Stations scrap parts (fixed rate)

Interactions

- Starving … no parts in input buffer
- Blocking … no space in output buffer

Only bottleneck improvements increase throughput, where is it??

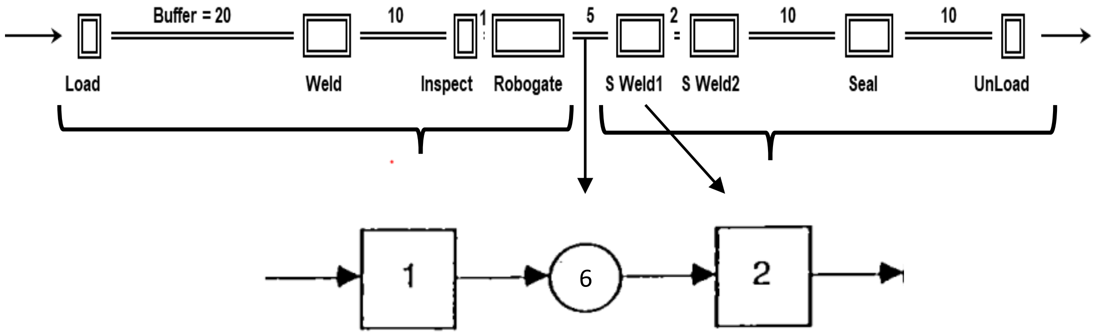
Need model to find bottleneck!



Solution Approach

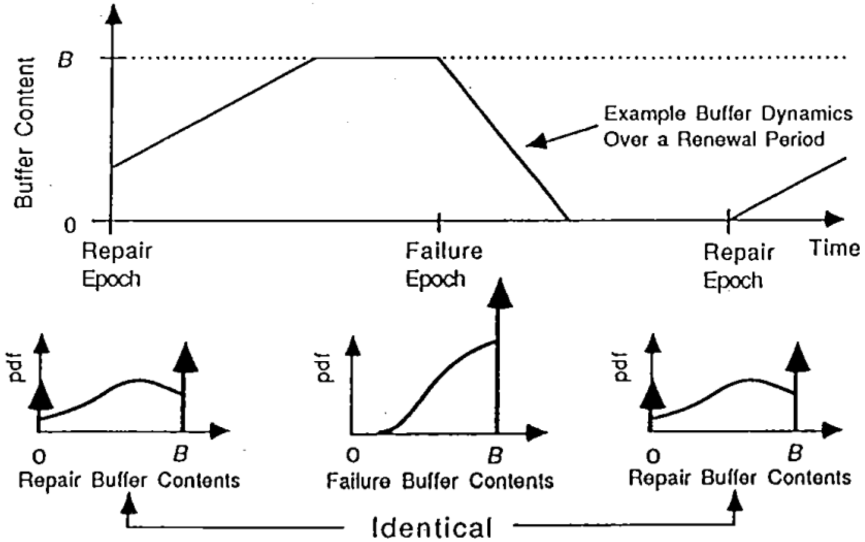
System Model

- Model as upstream aggregate station a each buffer
- Analyze two station problem using the next downstream station
- Aggregate into one station and estimate aggregate parameters
- Repeat with next buffer until done
- Repeat going in reverse but now using aggregate upstream station
- Repeat down and up until converge
- Calculate throughput from one last aggregation of all stations



2-Station Model (steady-state, no scrap, constant speeds)

- Assume exponential failure and repair distributions
- Assume a buffer distribution form at a repair epoch (lucky guess)
- Analyze all buffer evolutions (8 cases) to give distribution at next repair epoch
- Equate the two distribution to calculate distribution parameters
- Calculate aggregate parameters (MTTR, MCBF, Speed)



Case 1: Speed 1 > Speed 2 and buffer partially full at repair, buffer fills before next failure, next failure is Station 1, and buffer empties before repair.

Result (one of 8 cases)

$$\delta = S_1 - S_2,$$

$$\lambda = \lambda_1 + \lambda_2, \qquad \hat{\lambda}_1 = \lambda_1 f_1^{sb} = \frac{\lambda_1 S_2}{S_1},$$

$$\theta_1 = \frac{\lambda_1}{\lambda_1 + \lambda_2}, \qquad \hat{\theta}_1 = \frac{\hat{\lambda}_1}{\hat{\lambda}_1 + \lambda_2},$$

$$\theta_2 = \frac{\lambda_2}{\lambda_1 + \lambda_2}, \qquad \hat{\theta}_2 = \frac{\lambda_2}{\hat{\lambda}_1 + \lambda_2},$$

$$\hat{S}_1 = \frac{S_1 \mu_1}{\mu_1 + \lambda_1}, \qquad \hat{S}_2 = \frac{S_2 \mu_2}{\mu_2 + \lambda_2},$$

$$r = \frac{\lambda}{\delta}, \qquad r_1 = \frac{\mu_1}{\hat{S}_2}, \qquad r_2 = \frac{\mu_2}{\hat{S}_1},$$

$$f_1^{SB} = \frac{S_2}{S_1} \text{ for } S_1 > S_2, \qquad f_2^{SS} = \frac{S_1}{S_2} \text{ for } S_1 < S_2,$$

$$\tau = \frac{1}{\lambda} + \frac{\theta_1}{\mu_1} + \frac{\theta_2}{\mu_2}, \qquad \hat{\tau} = \frac{1}{\hat{\lambda}} + \frac{\hat{\theta}_1}{\mu_1} + \frac{\hat{\theta}_2}{\mu_2}.$$

Case 1: $S_1 > S_2$ and $\alpha_2 \neq 0$

$$\alpha_2 = -\frac{r - r_1 + r_2}{2} + \sqrt{\left(\frac{r - r_1 - r_2}{2}\right)^2 + \theta_2 r (r_1 + r_2)},$$

$$\alpha_3 = -\frac{r - r_1 + r_2}{2} - \sqrt{\left(\frac{r - r_1 - r_2}{2}\right)^2 + \theta_2 r (r_1 + r_2)},$$

$$\hat{a}_2 = \frac{(\alpha_2 + r_2)(\alpha_2 + r)}{\alpha_2 - \alpha_3},$$

$$\hat{a}_3 = \frac{(\alpha_3 + r_2)(\alpha_3 + r)}{\alpha_3 - \alpha_2},$$

$$P_0 = \frac{\hat{\theta}_1 \alpha_2 \alpha_3 (\alpha_2 - \alpha_3)}{\hat{\theta}_1 r r_2 (\alpha_2 - \alpha_3) + \alpha_3 \left((\alpha_2 + r_2)(\alpha_2 + \hat{\theta}_1 r) + \theta_2 \alpha_2 r\right) e^{\alpha_2 B} - \alpha_2 \left((\alpha_3 + r_2)(\alpha_3 + \hat{\theta}_1 r) + \theta_2 \alpha_3 r\right) e^{\alpha_3 B}},$$

$$\frac{P_B}{P_0} = \frac{\left(\hat{\theta}_2(\alpha_2 + r_2) + \theta_2 r\right) e^{\alpha_3 B} - \left(\hat{\theta}_2(\alpha_3 + r_2) + \theta_2 r\right) e^{\alpha_3 B}}{\hat{\theta}_1 (\alpha_2 - \alpha_3)},$$

$$p(x) = \hat{a}_2 P_0 e^{\alpha_2 x} + \hat{a}_3 P_0 e^{\alpha_3 x}.$$

$$\frac{E(T^U)}{P_0} = \frac{r}{\lambda}\left[\frac{r_2}{\alpha_2 \alpha_3} + \frac{(\alpha_2 + r_2) e^{\alpha_2 B}}{\alpha_2(\alpha_2 - \alpha_3)} - \frac{(\alpha_3 + r_2) e^{\alpha_3 B}}{\alpha_3(\alpha_2 - \alpha_3)}\right],$$

$$\frac{E(T^{SB})}{P_0} = \frac{(\alpha_2 + r_2 + \hat{\theta}_2 r) e^{\alpha_2 B} - (\alpha_3 + r_2 + \hat{\theta}_2 r) e^{\alpha_3 B}}{\hat{\lambda} \hat{\theta}_1 (\alpha_2 - \alpha_3)},$$

$$\frac{E(T^F)}{P_0} = \frac{\theta_2 r r_2}{\mu_2 (\alpha_2 - \alpha_3) \alpha_2 \alpha_3}\left[\alpha_2\left(1 - e^{\alpha_3 B}\right) - \alpha_3\left(1 - e^{\alpha_2 B}\right)\right],$$

$$\frac{E(T^E)}{P_0} = \frac{r_1(r_2 + \theta_2 r)}{\mu_1 \alpha_2 \alpha_3} + \frac{r_1(\alpha_2 + r_2 + \theta_2 r)}{\mu_1 \alpha_2 (\alpha_2 - \alpha_3)} e^{\alpha_2 B} - \frac{r_1(\alpha_3 + r_2 + \theta_2 r)}{\mu_1 \alpha_3 (\alpha_2 - \alpha_3)} e^{\alpha_3 B},$$

$$\frac{E(T^{FB})}{P_0} = \frac{\hat{\theta}_2(\alpha_2 + r_2) + \theta_2 r}{\mu_2 \hat{\theta}_1 (\alpha_2 - \alpha_3)} e^{\alpha_2 B} - \frac{\hat{\theta}_2(\alpha_3 + r_2) + \theta_2 r}{\mu_2 \hat{\theta}_1 (\alpha_2 - \alpha_3)} e^{\alpha_3 B},$$

$$\frac{E(T^{FS})}{P_0} = \frac{1}{\mu_1}.$$

$$\frac{E(T^C)}{P_0} = \frac{E(T^U)}{P_0} + \frac{E(T^F)}{P_0} + \frac{E(T^E)}{P_0} + \frac{E(T^{FB})}{P_0} + \frac{E(T^{SB})}{P_0} + \frac{E(T^{FS})}{P_0} + \frac{E(T^{SS})}{P_0}$$

Throughput = $1/E(T^C)$

Example Highlights

- Started about 1987
- Year to derive equations, validate equations, and document (Top Secret in GM)
- Months to validate and pilot (as a team)
- Years to fully productionize and distribute (25 plants, special task force, still in use)
- Added simulation (now fast enough) to model complex scenarios (rework, splits and merges, feeder lines)
- Saved over $2B over ~18 years (mostly increased sales, reduced overtime, and cheaper line designs)
- Won 2005 Informs Edelman Achievement Award (finally published results!)
- References:

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