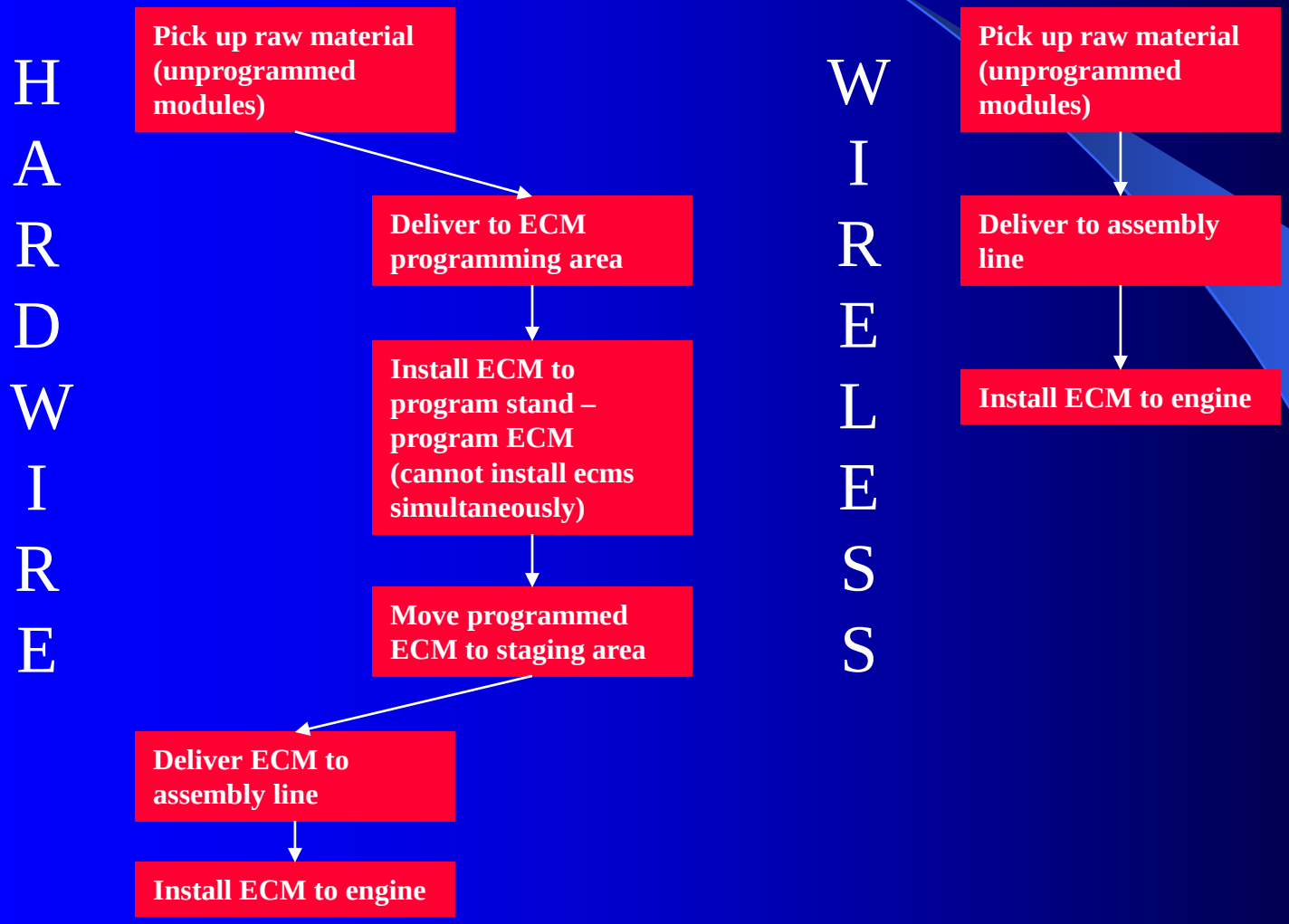
A Manufacturing Study:

Hardwire Programming vs Wireless

Background

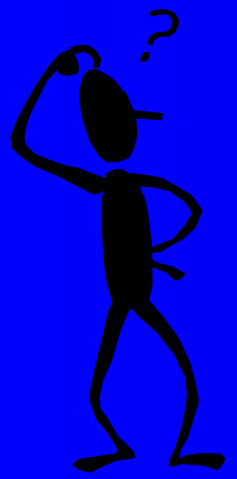
- Cummins, Inc. – Columbus, IN
  - Diesel Engine Design and Manufacture
  - Engines are electronically controlled and require an engine control module (ECM)
- Current Manufacturing Method (HARDWIRE)
  - Program individual ECMs on a programming stand
    - To program 15 modules simultaneously, 15 stands are required
  - Utilize labor resources to staff the programming area
- Proposed Manufacturing Method (WIRELESS)
  - Program multiple modules simultaneously with one set of hardware
  - Eliminates labor in programming area
  - Eliminates assembly and material handling operations

Pictorial Method Comparison



Objective

- Determine if wireless programming is a benefit over the current manual programming method
  - Will it save the company money to implement the wireless solution?
- If yes, at what point (i.e. how many modules need to be programmed simultaneously to make economic sense [2, 3, or4]?)



Example - More is NOT necessarily better

- Assume the following data
  - 1 - hardwire = 2 minutes
  - 1 - wireless = 2.5 minutes
  - 2 - wireless = 3 minutes
  - 3 - wireless = 3.2 minutes
  - 4 - wireless = 8.5 minutes

- Improvement is seen for 2 and 3 modules
- Degradation in efficiency is seen at 4 modules

*****Important Note - This is NOT ACTUAL data**

Statistical Model

- One-Way ANOVA
- 5 Factor levels

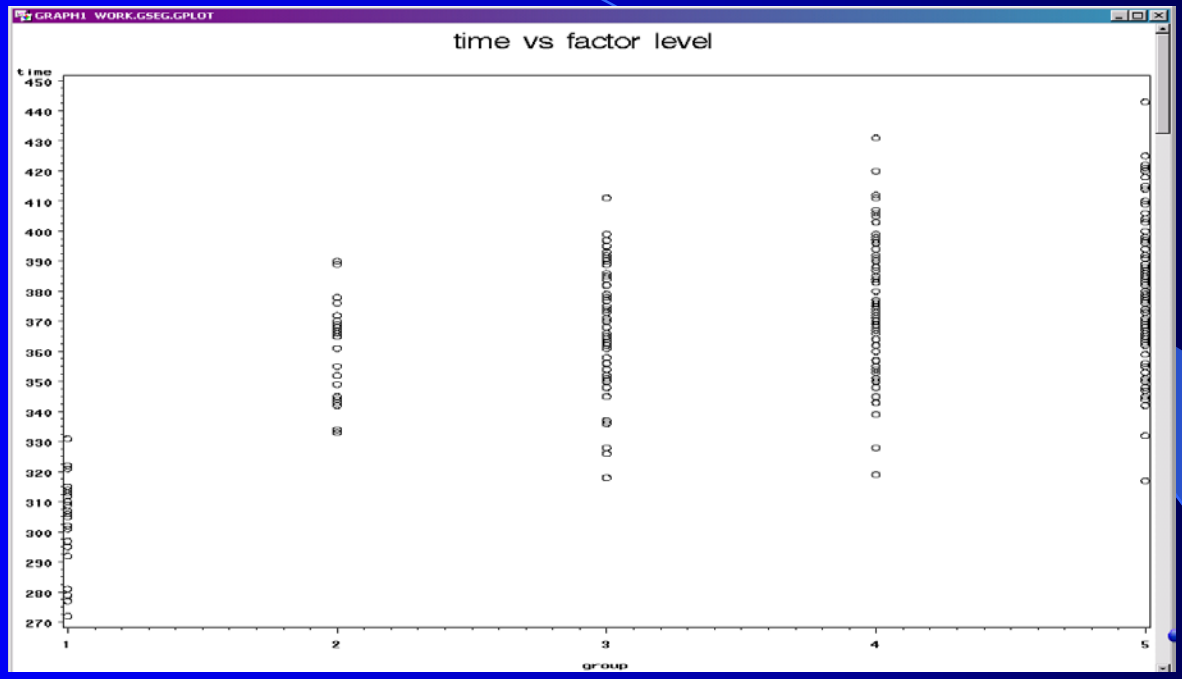
Treatments	Description	# of Obs
Group 1	One Hardwired Module	28
Group 2	One Wirelessly Programmed Module	28
Group 3	Two Wirelessly Programmed Modules	56
Group 4	Three Wirelessly Programmed Modules	84
Group 5	Four Wirelessly Programmed Modules	112

- Compare overall programming time (seconds) versus factor level

Plot of Data

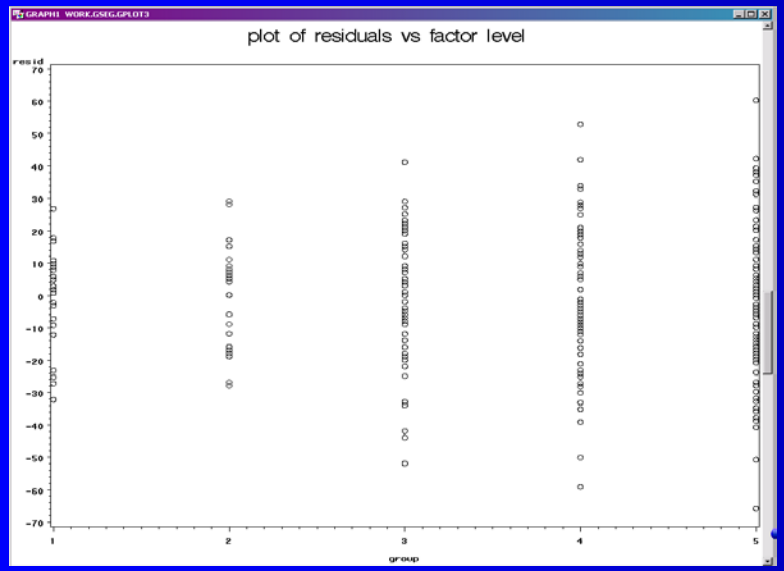
X-Axis – Group

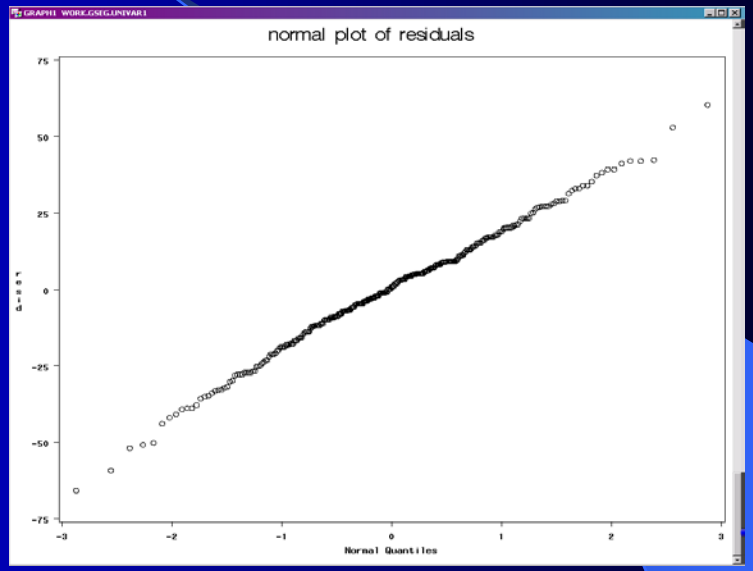
Y-Axis – Time



- Remarks
  - Single wireless module requires more programming time than single hardwire module
  - Amount of time required to program multiple modules increases *slightly* as modules are added

Validation of assumptions





- Variance appears to increase as modules are added
- Residual distribution is reasonably normal

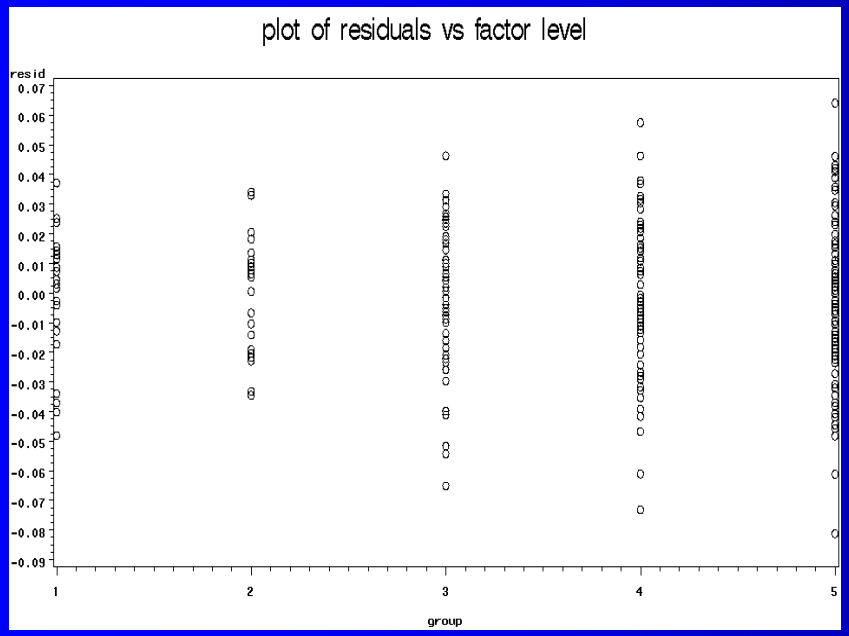
Homogeneity of Variance

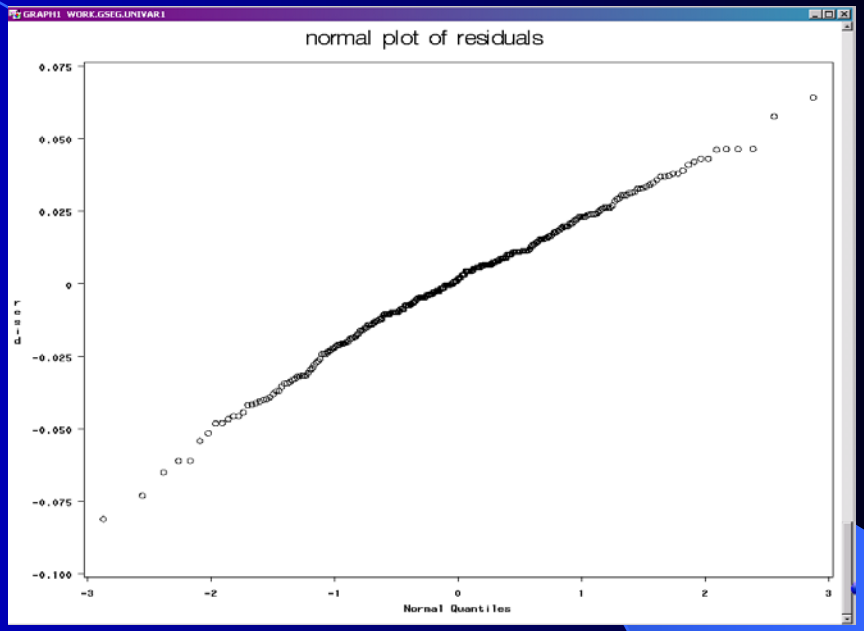
Levene's Test for Homogeneity of log(time) Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
group	4	1149.7	287.4	1.89	0.1122

- Homogeneity of variance is preserved
- Low p-value and graph still suggests further investigation to determine if transformation is needed

Log Transformation





- Residual plot
- QQ-plot

Log Transformation

Levene's Test for Homogeneity of log(time) Variance

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
group	4	0.000609	0.000152	0.71	0.5835

Raw Data

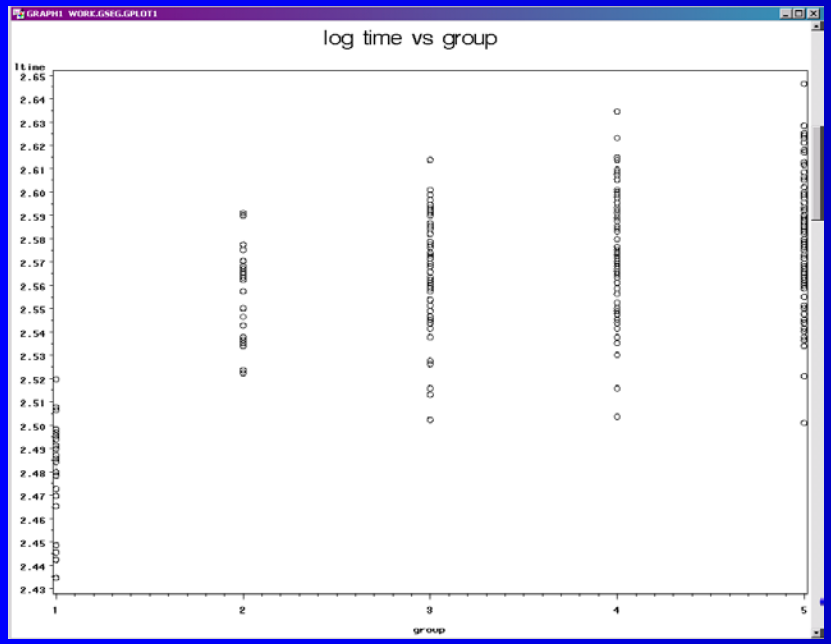
Level of group	N	time Mean	time Std Dev
1	28	304.142857	14.2457642
2	28	360.785714	14.9427479
3	56	369.857143	19.3854946
4	84	378.083333	21.4741135
5	112	382.732143	21.3207940

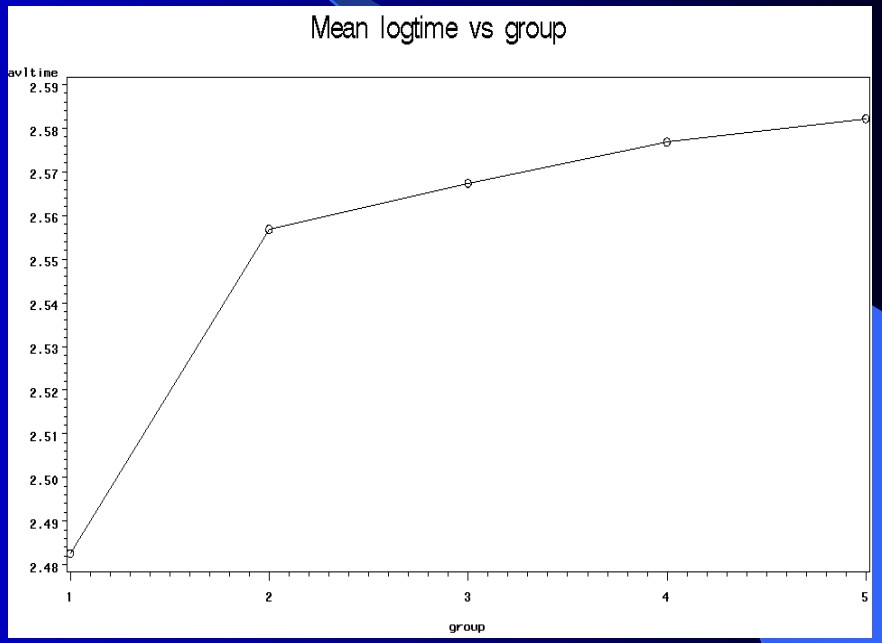
Transformed Data

Level of group	N	ltime Mean	ltime Std Dev
1	28	2.48260847	0.02066967
2	28	2.55688876	0.01804142
3	56	2.56743466	0.02316147
4	84	2.57689020	0.02481512
5	112	2.58221991	0.02440015

- Various transformations tested – log appeared to give the best results
  - Resulted in higher Levene number (0.1122 to 0.5835)
  - Assumption of constant variance more believable
  - Normality between the residuals

Transformed Data
(Log Transformation)





GLM Output

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	0.23642396	0.05910599	107.22	<.0001

- Conclusion: At least one group mean time is different from the others.

Tukey Comparison

Tukey	Mean	N	group
A	2.582220	112	5
B A	2.576890	84	4
B C	2.567435	56	3
C	2.556889	28	2
D	2.482608	28	1

- Hardwire (group 1) is clearly different than all wireless groups
- It is difficult to determine how different the other groups (wireless) are from each other
  - There are some similarities

Estimate and Contrast

- Contrast

	DF	Contrast SS	Mean Square	F Value	Pr > F
Wired Vs One Wireless	1	0.07724587	0.07724587	140.13	<.0001
Wired Vs Two Wireless	1	0.13431570	0.13431570	243.66	<.0001
Wired Vs 3 Wireless	1	0.18666994	0.18666994	338.64	<.0001
Wired Vs 4 Wireless	1	0.22226266	0.22226266	403.21	<.0001

- Estimate

Treatment 1	Treatment 2	Estimate (log seconds)	Treatment 1 Est. Time (seconds)	Treatment 2 Est. Time (seconds)	MeanTime difference (seconds)
Hardwired	1 – Wireless	-0.074	304.14	368.88	56.7
Hardwired	2 – Wireless	-0.084	304.14	369.75	65.5
Hardwired	3 – Wireless	-0.094	304.14	377.88	73.7
Hardwired	4 – Wireless	-0.099	304.14	383.55	78.4

Conclusion

- Wirelessly programming 1 module takes more time than with hardwire process → not beneficial.
- Wirelessly programming 2 or more modules takes more overall time, but produces more output → beneficial.
  - In this case, 4 modules makes the most sense
- Further investigation is warranted
  - There will be a point when the capacity of the wireless system is exceeded