

1. Tables and Figures

1 Tables

Table 1 Routes distance and cycle time

Stations	Length [m]	CT [min]
1	544	21.76
2	516	20.64
5	436	17.44
4	451	18.04
3	514	20.56
6	210	8.4
OC - PS	280	11.2

Table 2 Example of Daily record of AGV journey's efficiency

Trip n	Total time	Blocked 1	Blocked 2	Blocked 3	Blocked 4	Break	Total time stopped	CT (wo stops)	OEE (w stops vs wo stops)	OEE (w stops vs theoretical)	Time waiting
Trip 1	00:43	00:17	00:02	00:12	00:00	00:00	00:31	00:12	28%	28%	00:00
Trip 2	00:18	00:04	00:00	00:00	00:00	00:00	00:04	00:14	78%	67%	00:00
Trip 3	00:18	00:03	00:03	00:00	00:00	00:00	00:06	00:12	67%	67%	00:00
Trip 4	00:14	00:01	00:00	00:00	00:00	00:00	00:01	00:13	93%	86%	00:00
Trip 5	00:15	00:02	00:00	00:00	00:00	00:00	00:02	00:13	87%	80%	00:00
Trip 6	00:12	00:00	00:00	00:00	00:00	00:00	00:00	00:12	100%	100%	00:00
Trip 7	00:17	00:04	00:00	00:00	00:00	00:00	00:04	00:13	76%	71%	00:00
Trip 8	00:15	00:02	00:00	00:00	00:00	00:00	00:02	00:13	87%	80%	00:00
Trip 9	00:12	00:00	00:00	00:00	00:00	00:00	00:00	00:12	100%	100%	00:00
Trip 10	00:17	00:01	00:03	00:00	00:00	00:00	00:04	00:13	76%	71%	00:00
Trip 11	00:16	00:02	00:02	00:00	00:00	00:00	00:04	00:12	75%	75%	00:00
Trip 12	00:14	00:02	00:00	00:00	00:00	00:00	00:02	00:12	86%	86%	-

Table 3 Summary of AGV journey's efficiency

Day	OEE			Total time used			Load capacity used		
	AGV 1	AGV 2	AGV 3	AGV 1	AGV 2	AGV 3	AGV 1	AGV 2	AGV 3
1	72%	91%	90%	100%	29%	46%	29%	80%	45%
2	75%	91%	85%	100%	44%	43%	22%	100%	49%
3	86%	63%	80%	100%	58%	10%	24%	100%	50%
4	68%	70%	72%	100%	70%	34%	24%	80%	67%
5	79%	85%	72%	100%	68%	55%	35%	78%	51%
6	69%	86%	73%	100%	84%	75%	33%	78%	42%
7	77%	92%	95%	100%	84%	87%	40%	69%	31%
8	73%	80%	78%	100%	63%	71%	29%	86%	43%
9	74%	83%	76%	100%	60%	55%	27%	88%	49%
10	76%	81%	81%	100%	62%	45%	24%	88%	51%
Average	75%	82%	80%	100%	62%	52%	29%	85%	48%

Table 4 Results from positioning tests

Zones	Left inf comer		Right sup comer		AGV 1			AGV 2			AGV 3		
	X 1	Y 1	X 2	Y 1	No of times at zone	Time at zone	Time stopped	No of times at zone	Time at zone	Time stopped	No of times at zone	Time at zone	Time stopped
1	62	40	86	23	427	00 03:11:13	00 02:24:15	2463	00 03:52:20	00 03:09:56	0	00 00:00:00	00 00:00:00
2	63	15	84	-4	860	00 00:23:41	00 00:12:36	807	00 00:17:58	00 00:15:08	4488	00 03:57:03	00 03:22:30
3	85	24	115	-4	1248	00 03:30:28	00 02:42:33	1150	00 02:56:52	00 01:32:35	4846	00 03:27:36	00 02:06:11
4	0	0	0	0	0	00 00:00:00	00 00:00:00	0	00 00:00:00	00 00:00:00	0	00 00:00:00	00 00:00:00
5	0	0	0	0	0	00 00:00:00	00 00:00:00	0	00 00:00:00	00 00:00:00	0	00 00:00:00	00 00:00:00
6	0	0	0	0	0	00 00:00:00	00 00:00:00	0	00 00:00:00	00 00:00:00	0	00 00:00:00	00 00:00:00
7	0	0	0	0	0	00 00:00:00	00 00:00:00	0	00 00:00:00	00 00:00:00	0	00 00:00:00	00 00:00:00
Min x-y speed					Total control time	00 07:22:22		Total control time	00 07:17:07		Total control time	00 07:31:21	
					Total time stopped	00 05:56:03		Total time stopped	00 05:02:13		Total time stopped	00 05:29:00	
2.5					Start	71.47	6.35	Start	75.78	17.57	Start	82.74	3.71
					End	111.48	2.3	End	104.2	0.64	End	93.37	20.3

Table 5 AGV 1 workload calculation

Area	Output / shift - Demand	Output / shift - Max	Shift prod.	Material 1	Material 2	Material 3	Material 4	Material 5	Boxes per shift	Boxes per trolley	No. of trolleys	Trolley per AGC	Loops per shift	AGC	CT	Total time
AGV 3																
Oil Coolers	356	385	3	Steelwork					30	8	4	2	2	Charlotte	8.4	16.8
			Parts per product													
			Parts per shift	712												
			PPB -->	24												
			Total boxes -->	30	0	0	0	0								
Mods 1 - 5	180		2	Sidemembers					60	8	8	2	4	Charlotte	24	96
			Parts per product	2												
			Parts per shift	360												
			PPB -->	6												
			Total boxes -->	60	0	0	0	0								
AGV 2																
5R	240		2	Sidemembers	Tanks	Gaskets			98	6	17	3	6	Lucy	24	144

			Parts per product																
			Parts per shift	480	480	480													
			PPB -->	10	10	300													
			Total boxes -->	48	48	2	0	0											
6R	175		2	Sidemembers	Tanks	Gaskets													
			Parts per product																
			Parts per shift	350	350	350				72	6	12	3	4	Lucy	24	96		
			PPB -->	10	10	300													
			Total boxes -->	35	35	2	0	0											

Area	Output / shift - Demand	Output / shift - Max	Shift prod.	Material 1	Material 2	Material 3	Material 4	Material 5	Boxes per shift	Boxes per trolley	No. of trolleys	Trolley per AGC	Loops per shift	AGC	CT	Total time	
OC - Press shop	288		3	Gallery plates	Inner fins	Bottom plate											
			Parts per product	25	22	1			179	12	15	1	15	Emily	12	180	
			Parts per shift	7200	6336	288											
			PPB -->	65	100	200	1000										

		Total boxes -->	111	64	2	2	0						
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Table 6 Workload result

AGC	OEE	Total usage time	Workload
AGV 3	82%	292.68	68%
AGV 2	80%	141.00	33%
AGV 1	75%	128.00	30%

Table 7 IoT positioning systems

System	Location of supplier	Type of tracking	Accuracy	Tags power source	Tag battery life	Data extraction	Cost (6 AGCs)	Increase +1 cart	Annual cost	Comments
IoT1	Spain	UWB	0.5 m	Internal battery	3 years	Yes	£ 65,00	£ 115	-	
IoT2	Germany	UWB	0.5 m	2xAA battery	3 years	Yes	£ 35,000	£ 79	£ 10,000	Annual soft cost (€11.000)
IoT3	France	UWB	0.5 m	Internal battery	10s – 5 years 1 s – 1 year	Yes	€ 21,000	£ 73	£ 1000	Trial kit £ 3000
IoT4	US	UWB	1 m	Internal battery	6 days	Yes	£ 115,000	£ 192	-	
IoT5	UK	UWB Gateway	8m	-	-	Yes	£ 150,000	-	-	-
IoT6	Estonia	UWB	0.5 m	Internal battery	-	Yes	-	-	-	
IoT7	Germany	UWB	0.5 M	Internal battery	-	Yes	£ 26,000	-	-	
IoT8	Germany	BT Beacons	8 m	cr2032 battery	1 Year	Yes	£ 26,000	£ 10	£ 10,000	Annual soft cost (€11.000)
IoT9	UK	RFID - EPS WiFi	> 1m	24v (1.5W)	1 Year	Yes	£ 100,000	£ 150	-	

2. Figures

Figure 1 Caption: AGVs flowchart

Figure 1 Alt Text: A diagram that shows the routes of two Autonomous Guided Vehicles (AGVs) moving across the factory floor

Figure 2 Caption: Spaghetti chart map

Figure 2 Alt Text: A map of the factory floor showing the continuous flow line tracing the path of one AGV in real time

Figure 3 Caption: Heatmap results

Figure 3 Alt Text: a map of the factory floor that depicts in colour (red) where AGVs stop indicating possible problems in their routing which require investigation.

Figure 4 Caption: IoT Positioning within Alpha

Figure 4 Alt Text: A map of the factory floor showing where Internet of Things (IoT) antennas have been placed to cover the areas AGVs are operating.

Figure 5 Caption: IoT-AGV Positioning system

Figure 5 Alt Text: A map of the factory floor showing where IoTs antennas should be placed to cover the whole factory and create a cyber-physical manufacturing system

Figure 1: AGVs flowchart

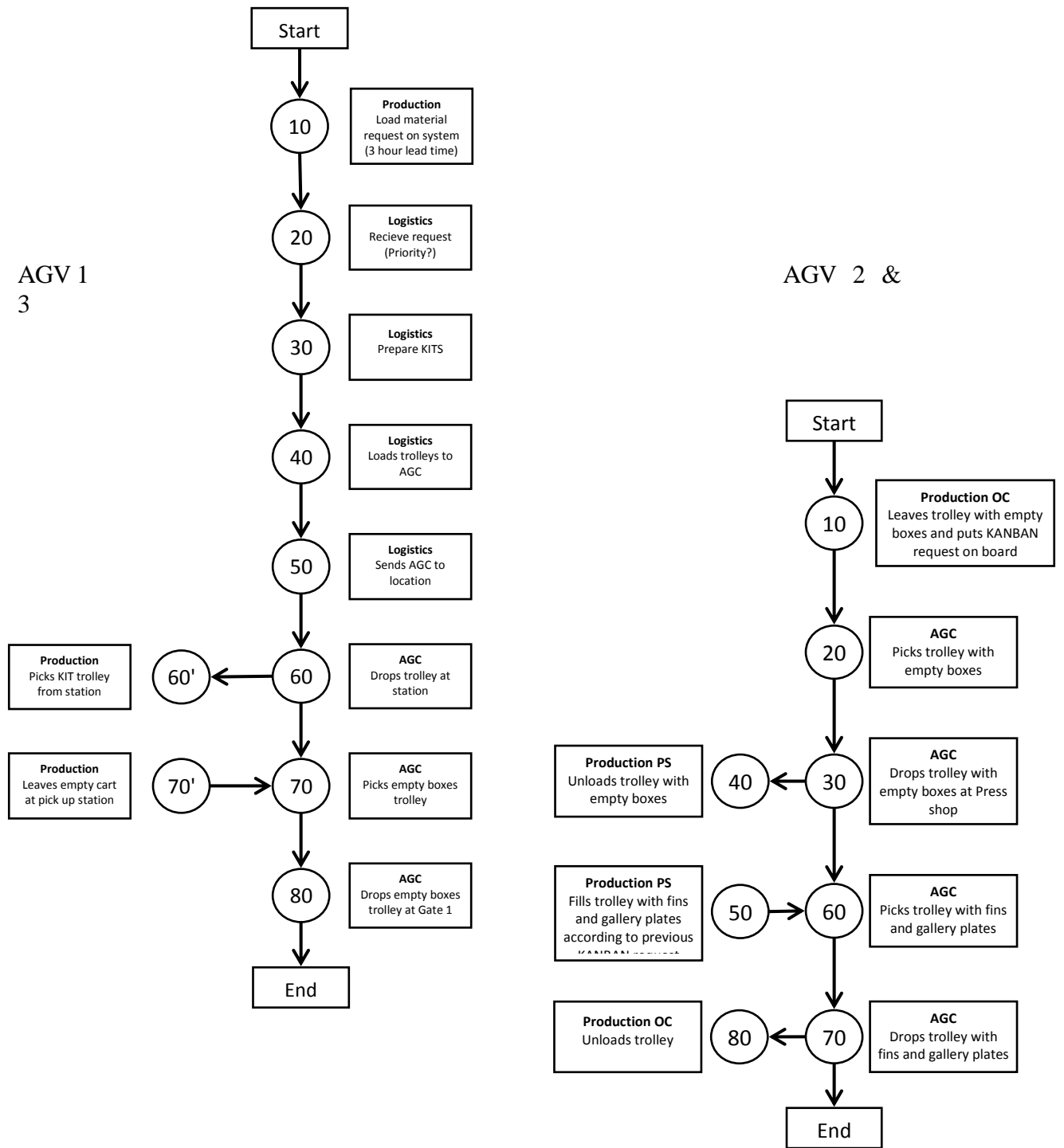


Figure 2. Spaghetti chart map

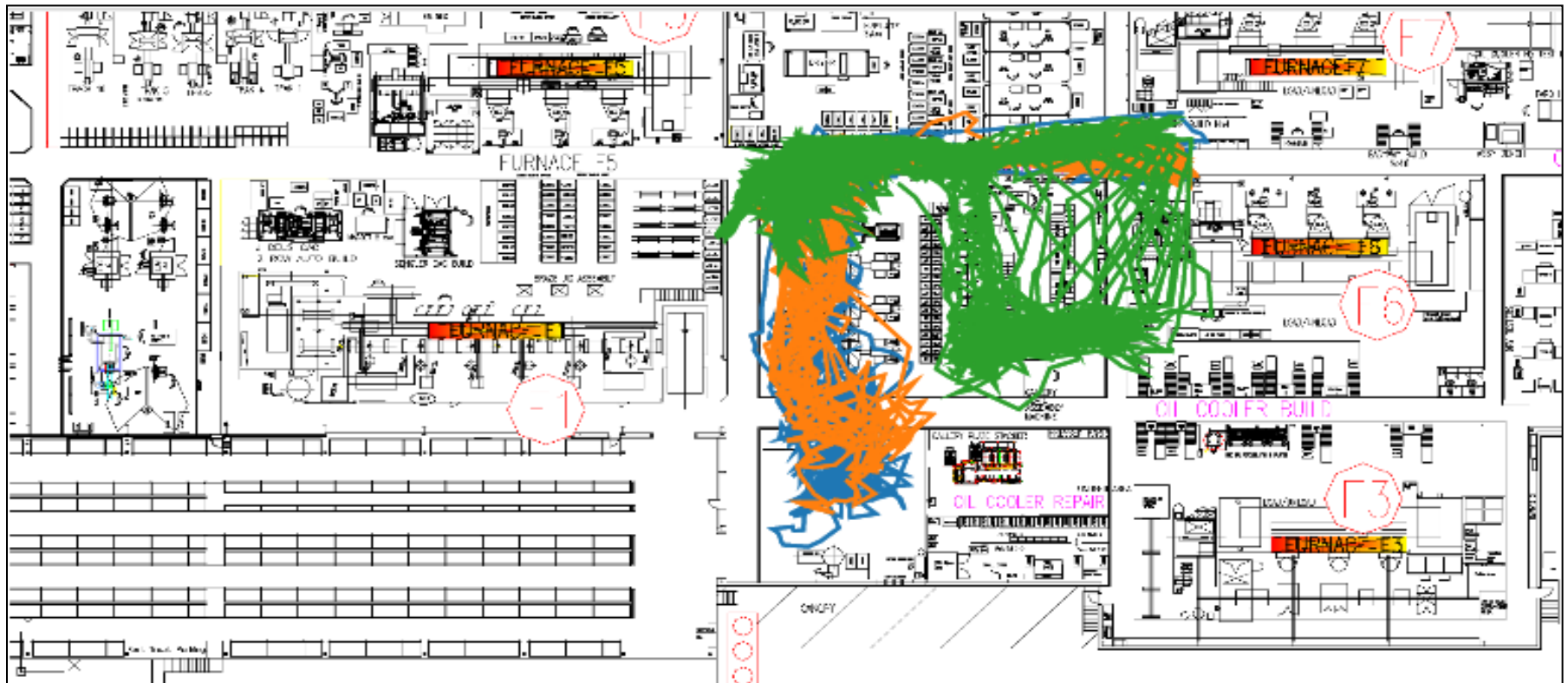


Figure 3. Heatmap results

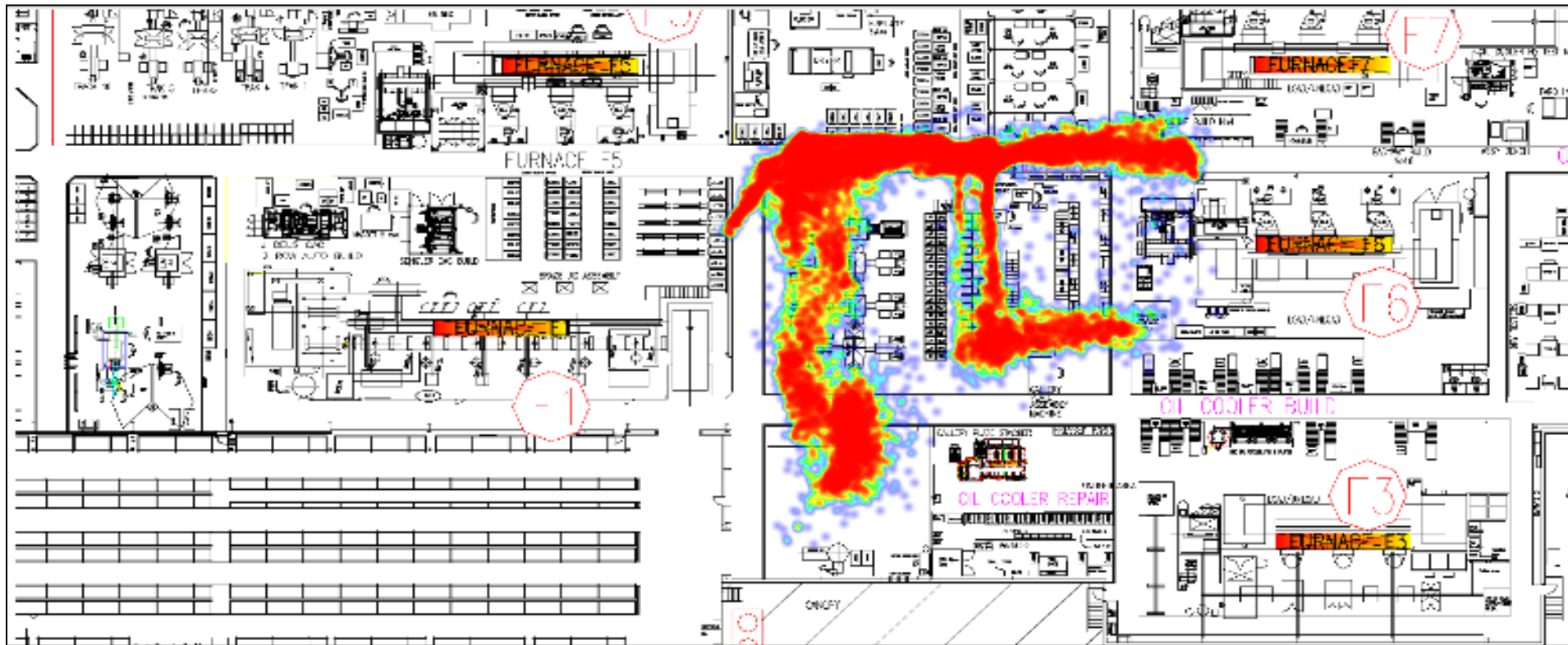


Figure 4. IoT Positioning within Alpha

