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LAMPIRAN

Lampiran 1. Dokumentasi simulasi *Toyota production system*



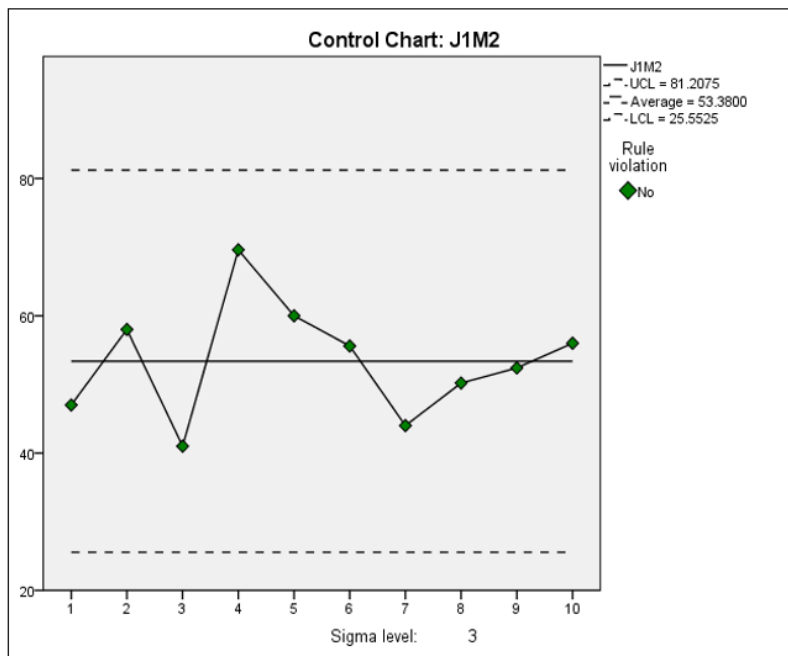
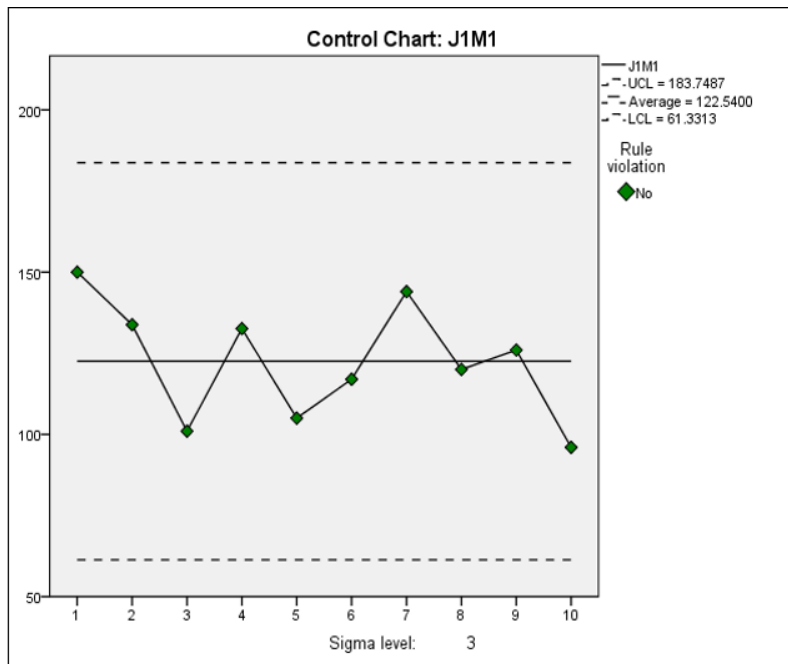
Lampiran 2. Kelonggaran Berdasarkan Faktor yang Berpengaruh

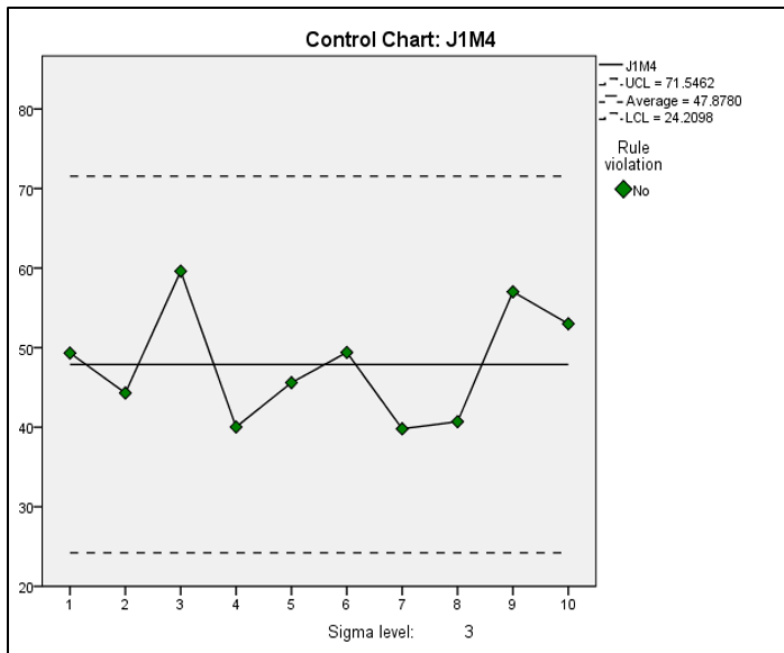
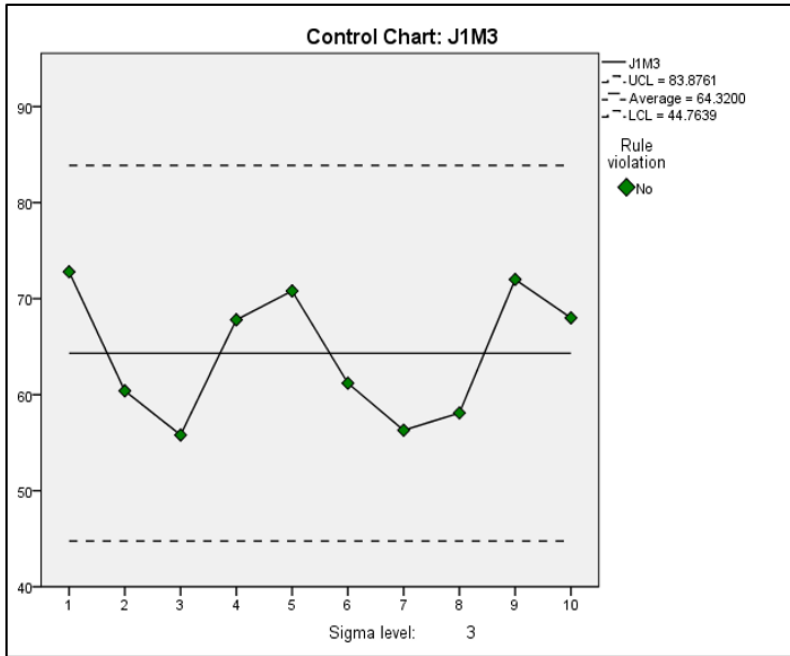
Faktor	Contoh Pekerjaan	Ekivalen Beban	Kelonggaran (%)	
			Pria	Wanita
A. Tenaga yang dikeluarkan				
1. Dapat diabaikan	Bekerja di meja, duduk	tanpa beban	0,00-6,0	0,00-6,0
2. Sangat ringan	Bekerja di meja, berdiri	0,00-2,25 kg	6,0-7,5	6,0-7,5
3. Ringan	Menyekop, ringan	2,25-9,00	7,5-12,0	7,5-16,0
4. Sedang	Mencangkul	9,00-18,00	12,0-19,0	16,0-30,0
5. Berat	Mengayun palu yang berat	18,00-27,00	19,0-30,0	
6. Sangat berat	Memanggul beban	27,00-50,00	30,0-50,0	
7. Luar biasa berat	Memanggul karung berat	dias 50 kg		
B. Sikap kerja				
1. Duduk	Bekerja duduk, ringan		0,00-1,0	
2. Berdiri diatas dua kaki	Badan tegak, ditumpu dua kaki		1,0-2,5	
3. Berdiri diatas satu kaki	Satu kaki mengerjakan alat control		2,5-4,0	
4. Berbaring	Pada bagian sisi, belakang atau depan badan		2,5-4,0	
5. Membungkuk	Badan dibukukkan bertumpu pada kedua kaki		4,0-10,0	
C. Gerakan kerja				
1. Normal	Ayunan bebas dari palu		0	
2. Agak terbatas	Ayunan terbatas dari palu		0-5	
3. Sulit	Membawa beban berat dengan satu tangan		0-5	
4. Pada anggota-anggota badan terbatas	Bekerja dengan tangan diatas kepala		5-10	
5. Seluruh anggota badan terbatas	Bekerja di lorong pertambangan yang sempit		10-15	
D. Kelelahan mata *)			<u>Pencapaian baik</u>	<u>Buruk</u>
1. Pandangan yang terputus-putus	Membawa alat ukur		0,0-6,0	0,0-6,0
2. Pandangan yang hamper terus-menerus	Pekerjaan-pekerjaan yang teliti		6,0-7,5	6,0-7,5
3. Pandangan yang terus menerus dengan fokus tetap	Pemeriksaan yang sangat teliti		7,5-12,0	7,5-16,0
4. Pandangan terus menerus dengan fokus berubah-ubah	Memeriksa cacat-cacat pada kain		12,0-19,0	16,0-30,0
5. Pandangan terus-menerus dengan konsentrasi tinggi dan fokus tetap			19,0-30,0	
6. Pandangan terus menerus dengan konsentrasi tinggi dan fokus berubah-ubah			30,0-50,0	
E. Keadaan suhu tempat kerja **)			<u>Kelelahan normal</u>	<u>Berlebihan</u>
1. Beku		Suhu (°C) dibawah 0	dias 10	dias 12
2. Rendah		0-13	10-0	12-5
3. Sedang		13-22	5-0	8-0
4. Normal		22-28	0-5	0-8

Lampiran 3 Tabel Penyesuaian menurut *Westinghouse*

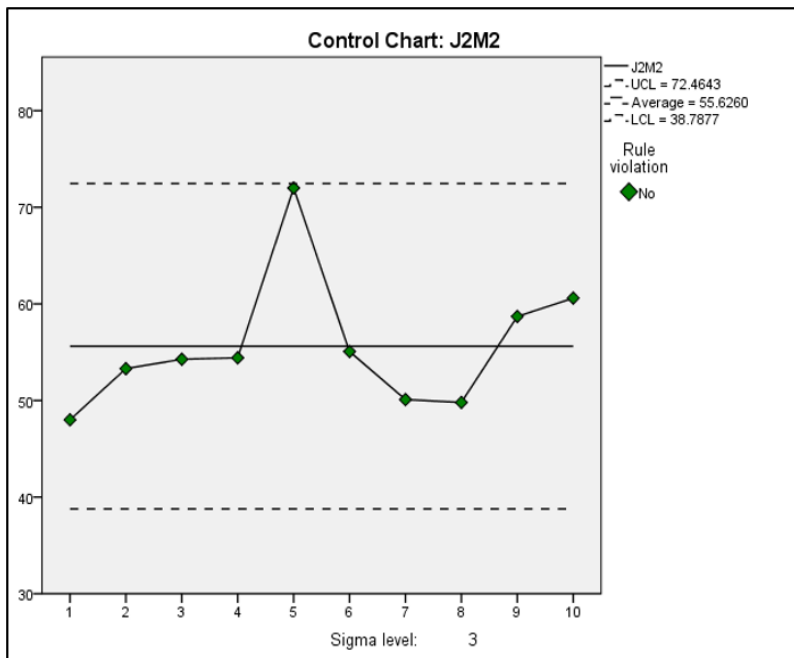
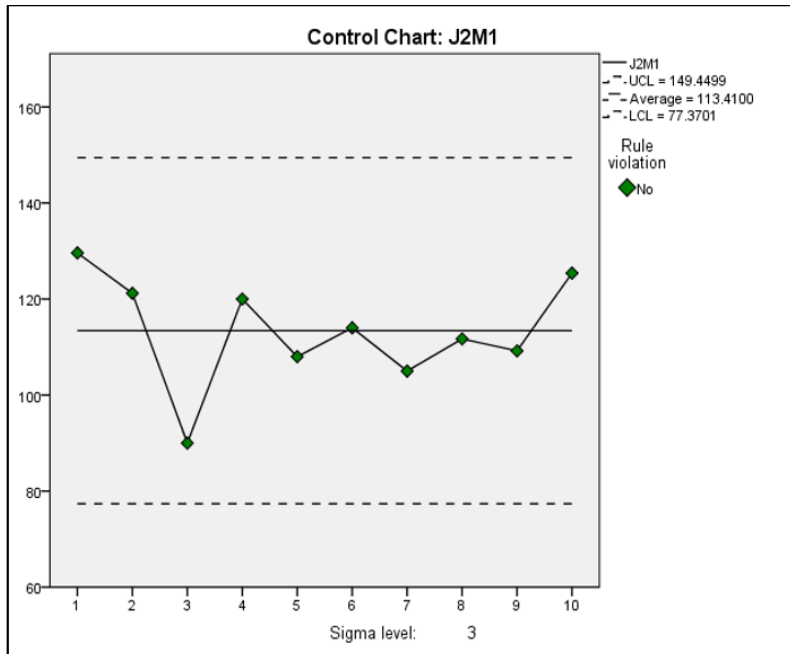
Faktor	Kelas	Lambang	Penyesuaian
Keterampilan	<i>Superskill</i>	A1	+0.15
		A2	+0.13
	<i>Excellent</i>	B1	+0.11
		B2	+0.08
	<i>Good</i>	C1	+0.06
		C2	+0.03
	<i>Average</i>	D	0.00
	<i>Fair</i>	E1	-0.05
		E2	-0.10
	<i>Poor</i>	F1	-0.16
F2		-0.22	
Usaha	<i>Superskill</i>	A1	+0.15
		A2	+0.13
	<i>Excellent</i>	B1	+0.11
		B2	+0.08
	<i>Good</i>	C1	+0.06
		C2	+0.03
	<i>Average</i>	D	0.00
	<i>Fair</i>	E1	-0.05
		E2	-0.10
	<i>Poor</i>	F1	-0.16
F2		-0.22	
Kondisi Kerja	<i>Ideal</i>	A	+0.06
	<i>Excellent</i>	B	+0.04
	<i>Good</i>	C	+0.03
	<i>Average</i>	D	0.00
	<i>Fair</i>	E	-0.03
	<i>Poor</i>	F	-0.07
Konsistensi	<i>Ideal</i>	A	+0.04
	<i>Excellently</i>	B	+0.03
	<i>Good</i>	C	+0.01
	<i>Average</i>	D	0.00
	<i>Fair</i>	E	-0.02
	<i>Poor</i>	F	-0.04

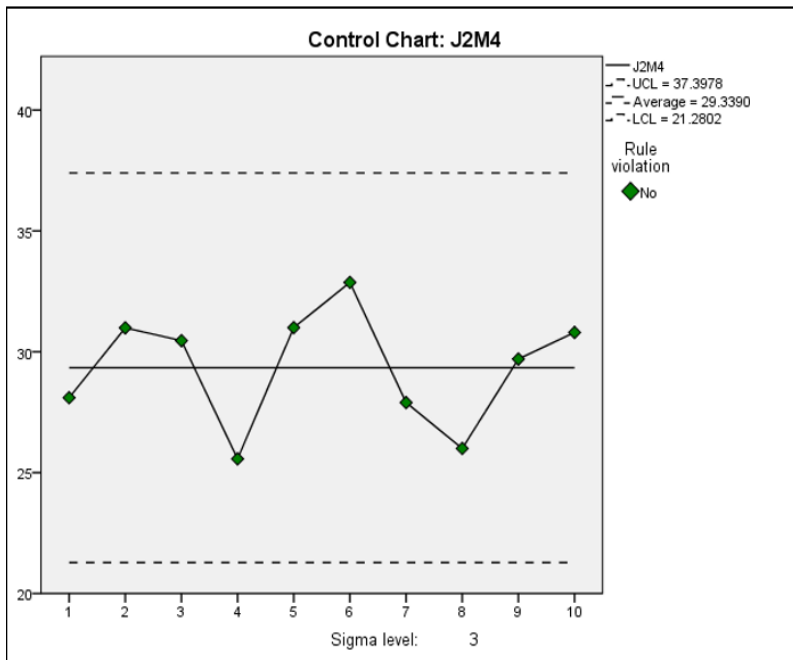
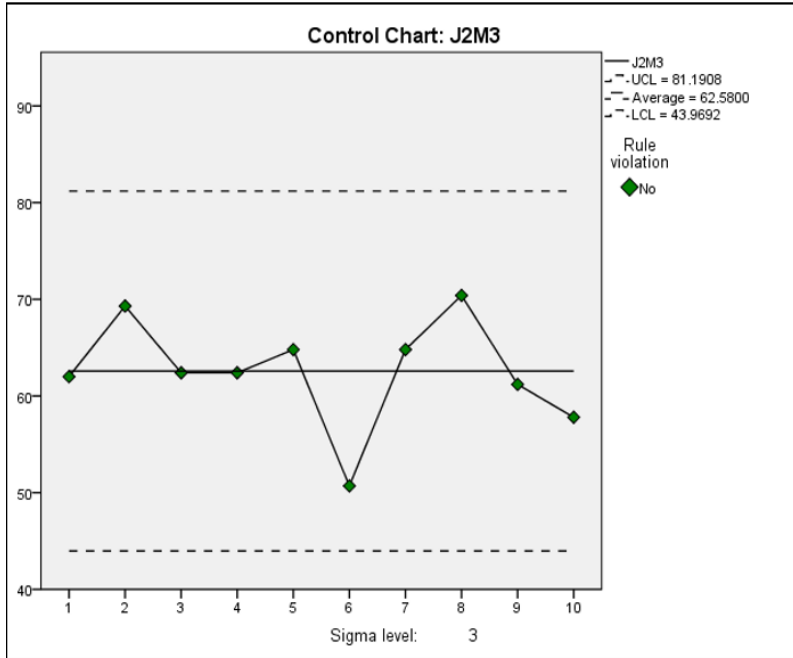
Lampiran 4. Uji Keseragaman Data Tiap Mesin (Dalam Satuan Detik)

Pick Up

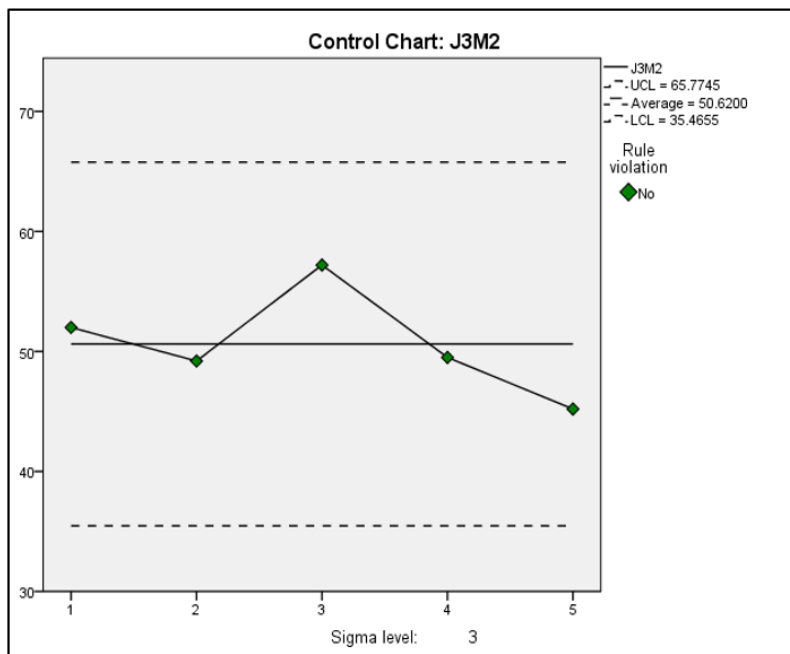
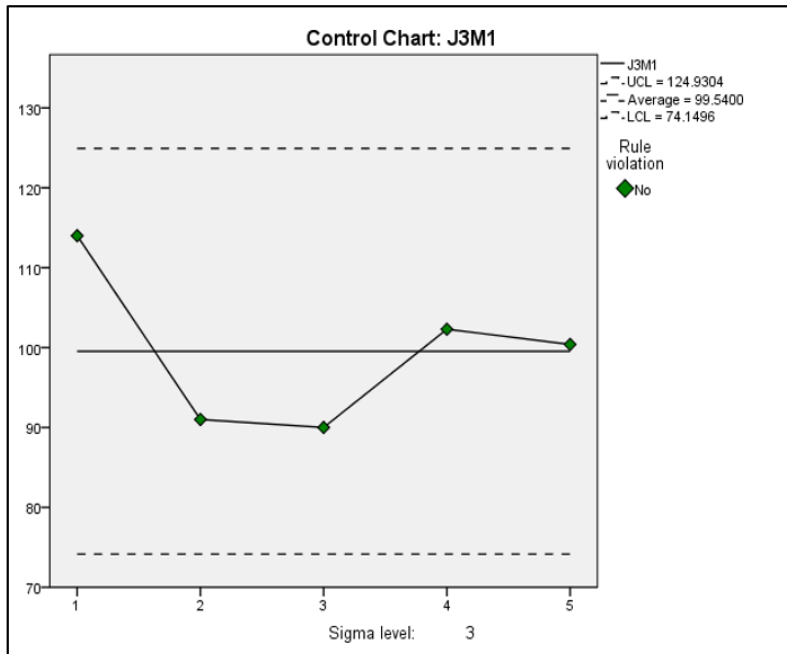


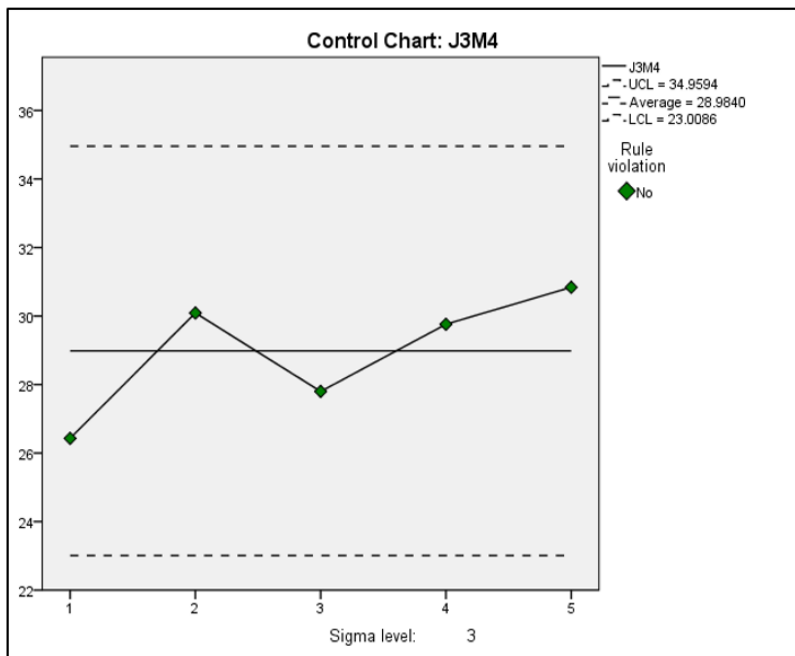
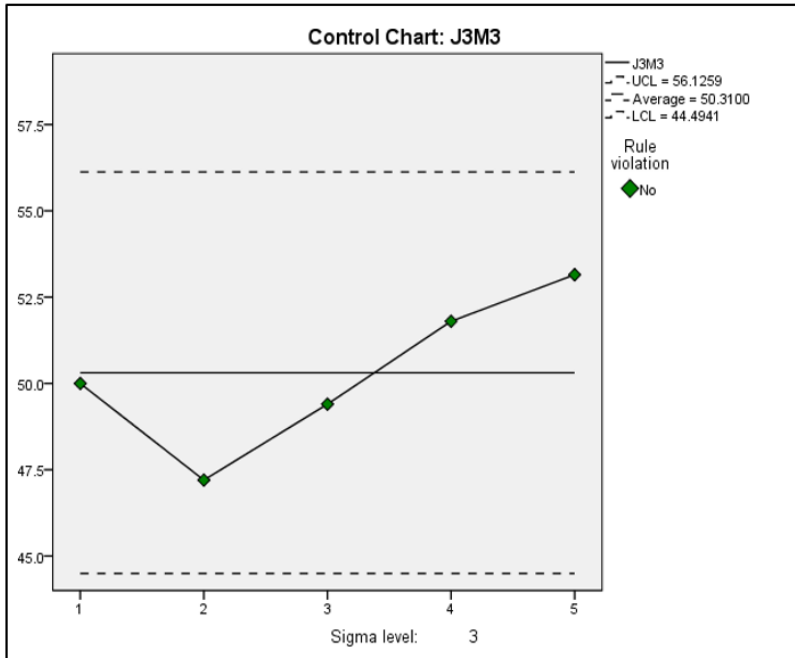
MPV



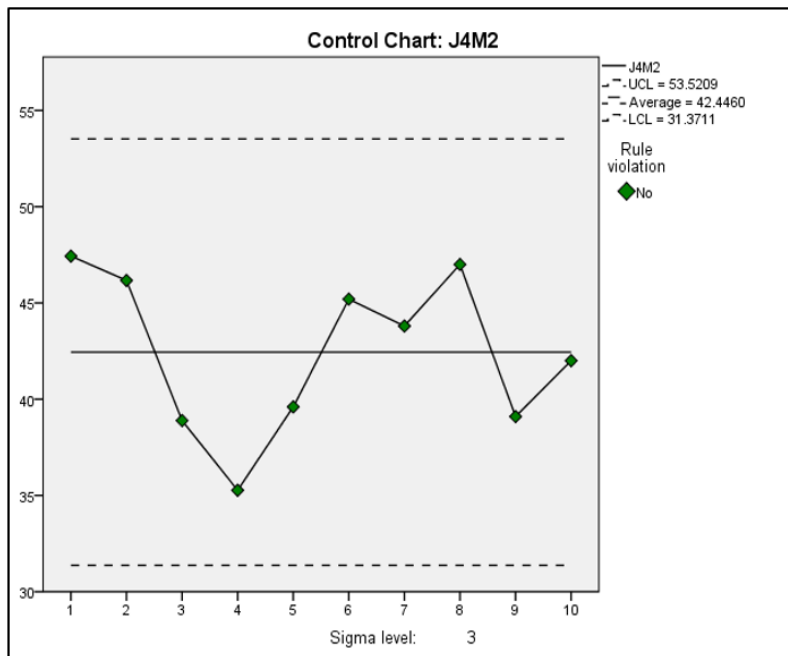
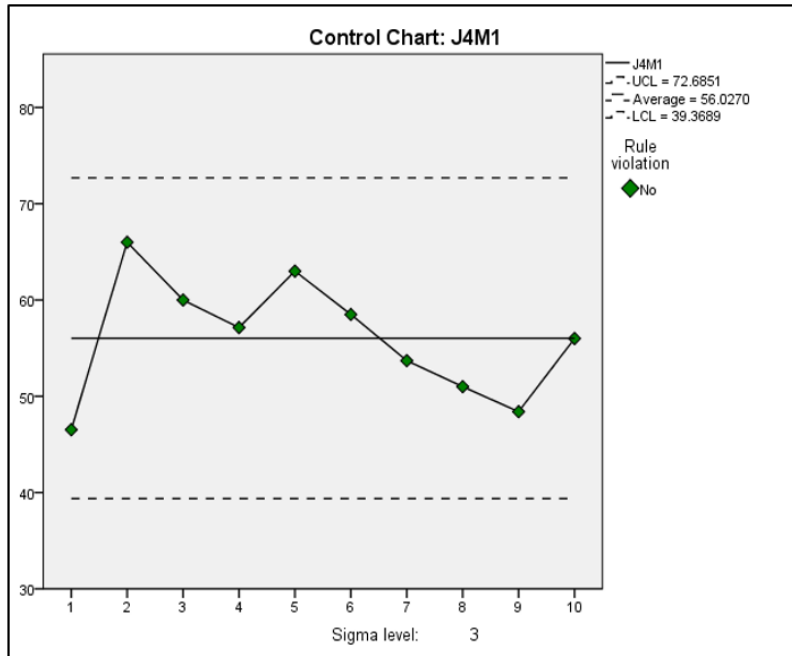


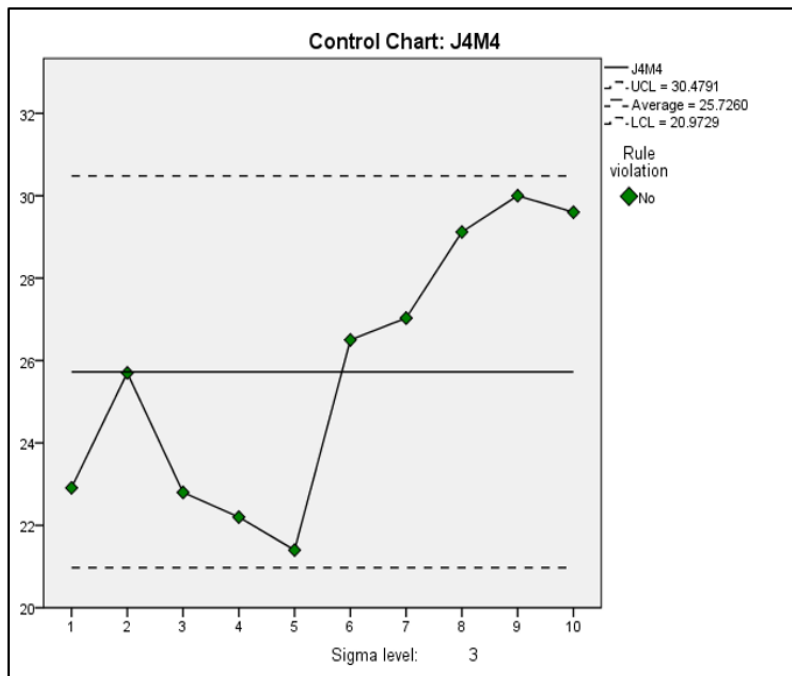
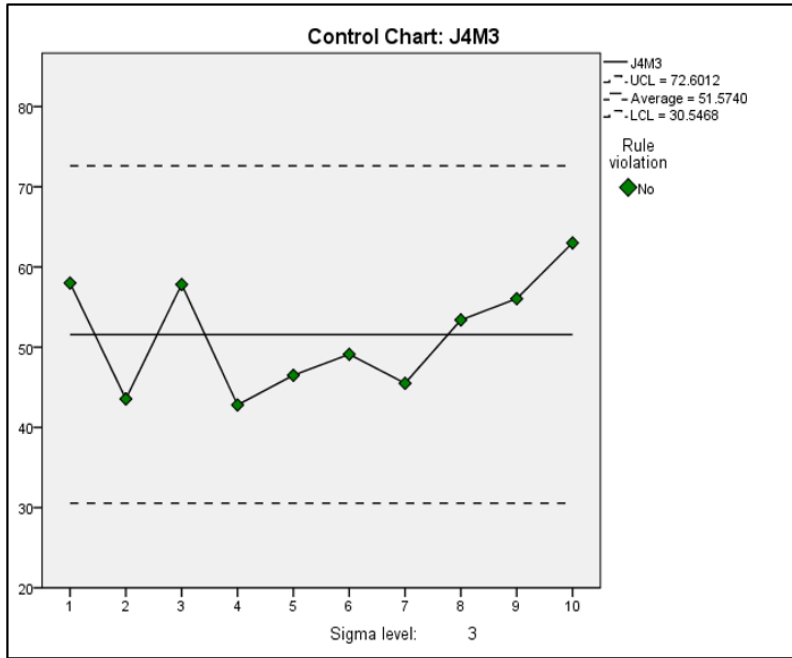
Double Cabin



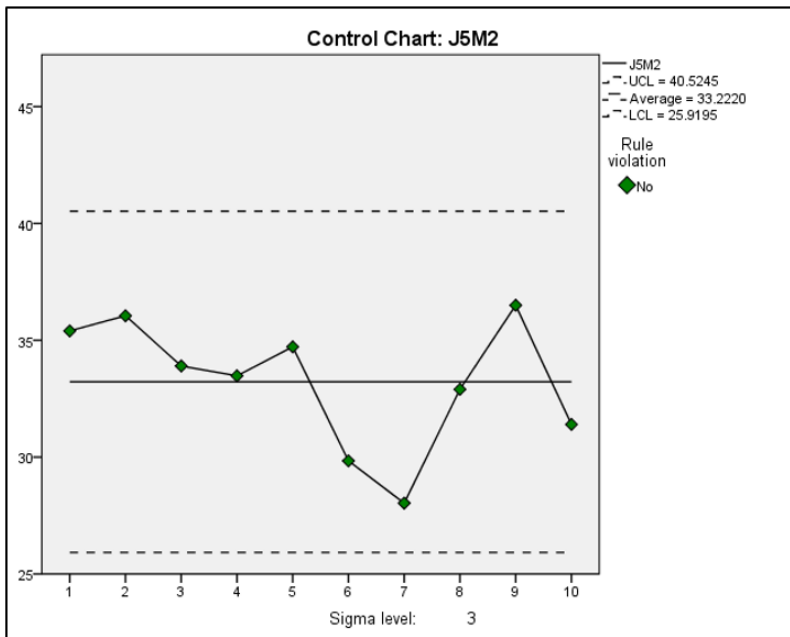
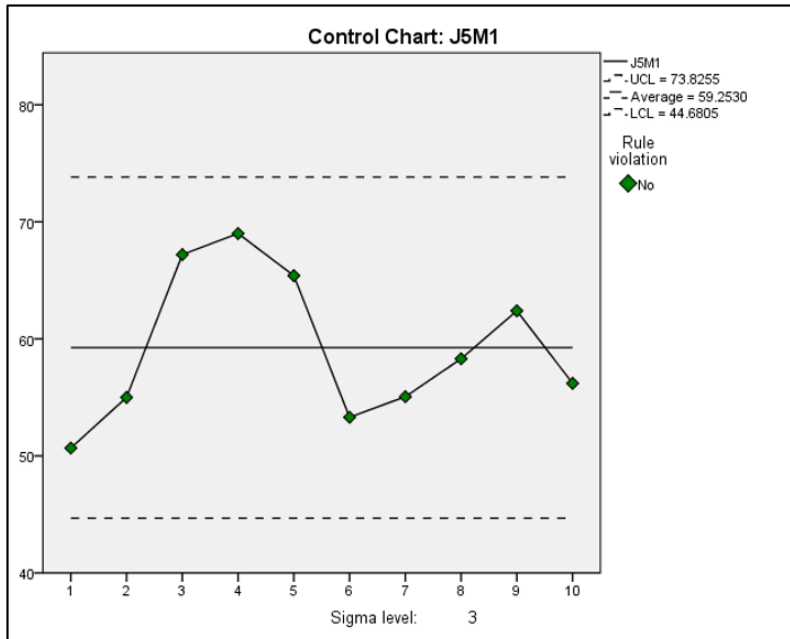


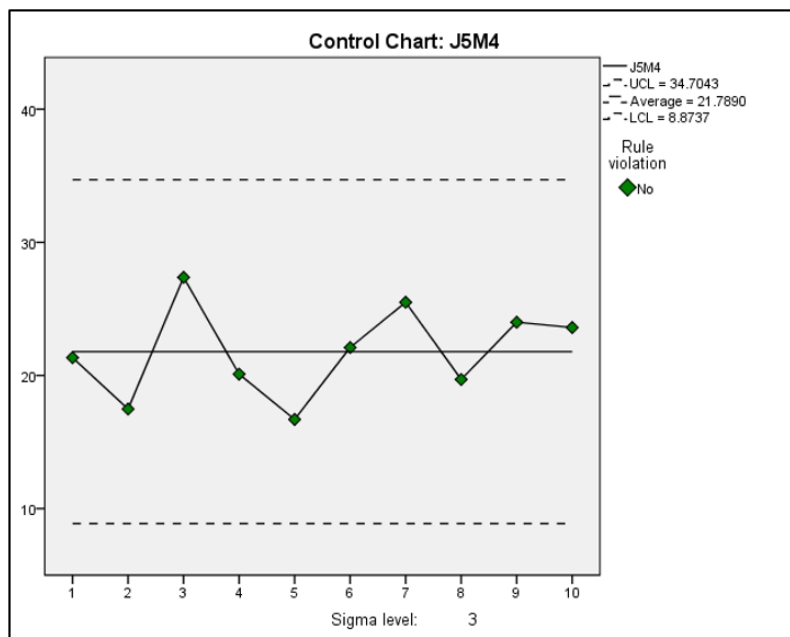
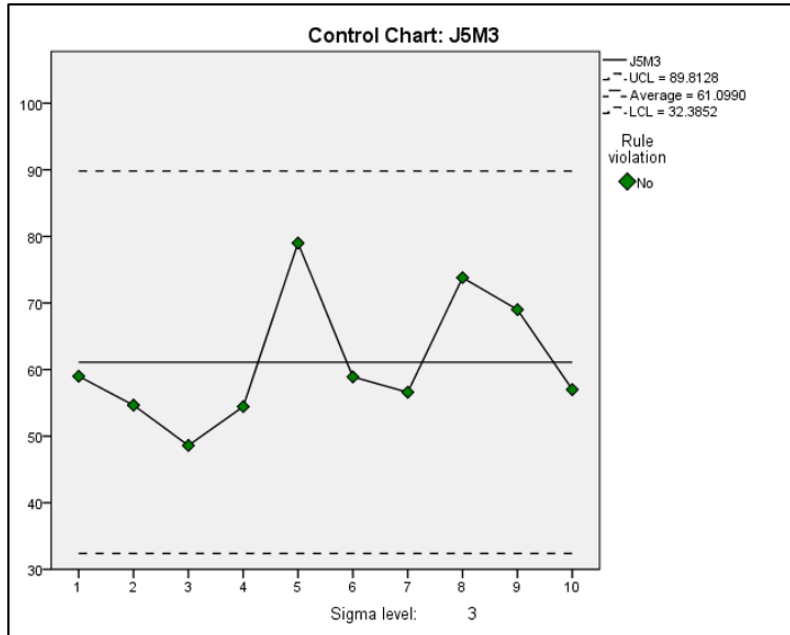
Truck Mixer



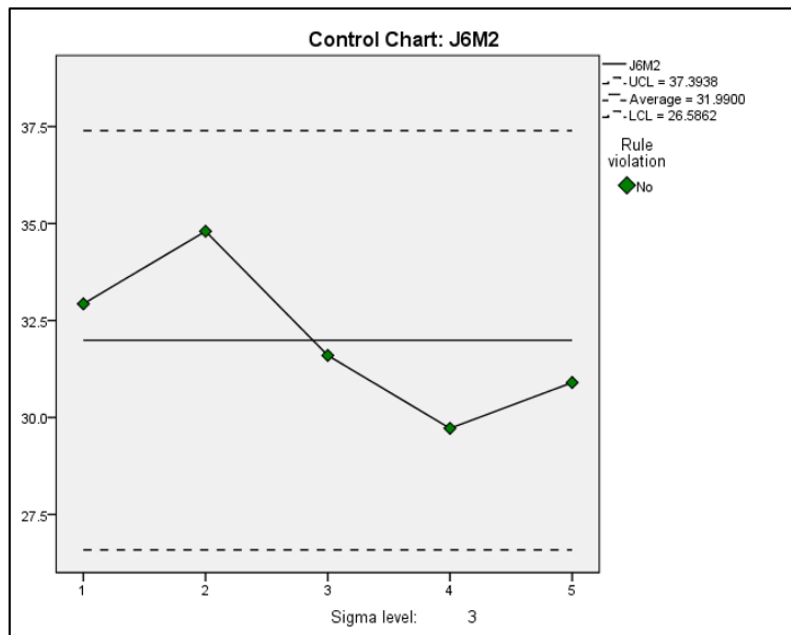
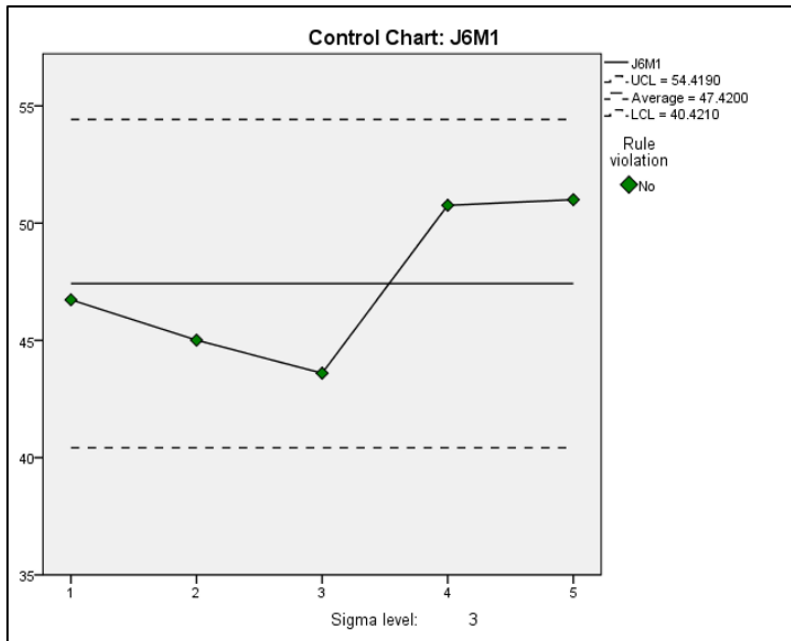


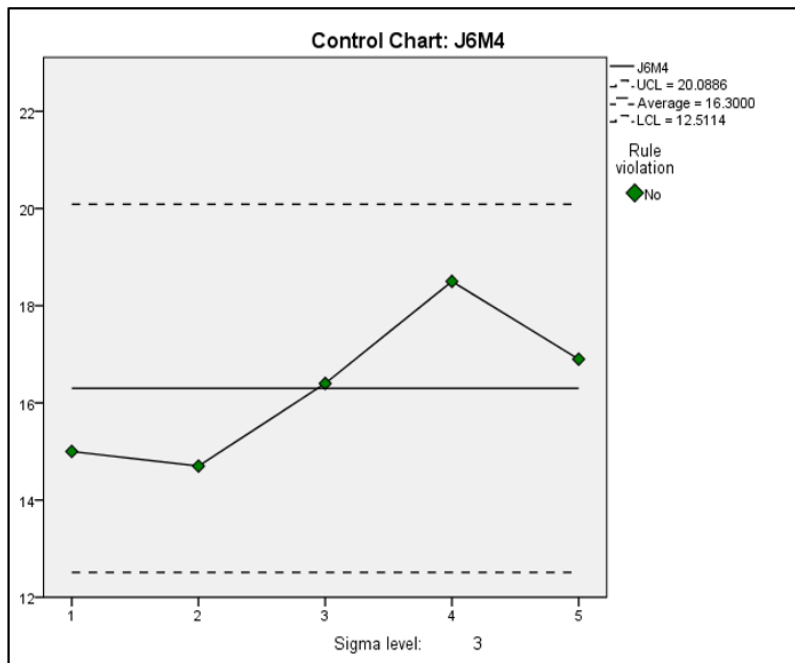
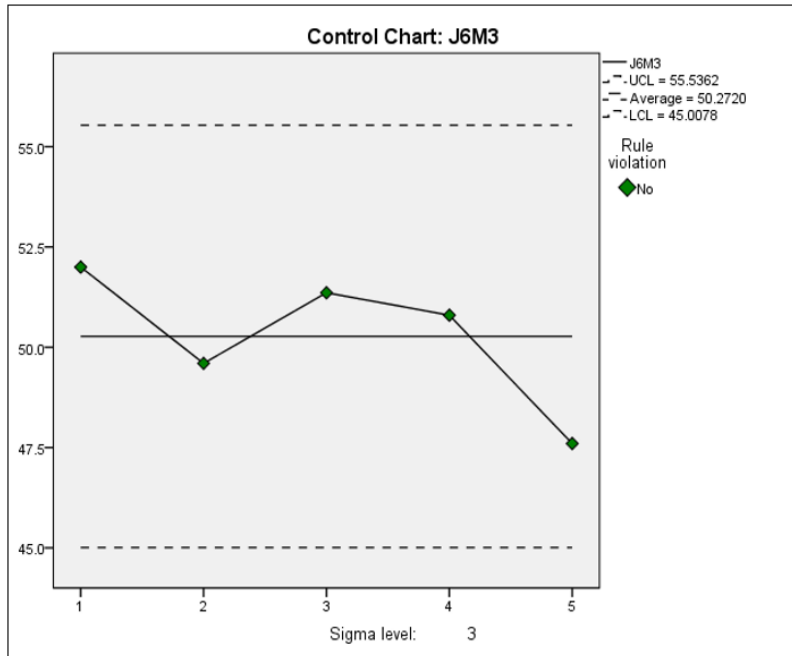
Excavator





Truck Silinder Roller





Lampiran 5. Uji Kecukupan Data Setiap Mesin/Work Station (Dalam Satuan Detik)

PICK UP								
	WS 1	X ²	WS 2	X ²	WS 3	X ²	WS 4	X ²
1	150	22500	47	2209	72.8	5299.84	49.32	2432.462
2	133.8	17902.44	58	3364	60.4	3648.16	44.3	1962.49
3	101	10201	41	1681	55.8	3113.64	59.61	3553.352
4	132.6	17582.76	69.6	4844.16	67.8	4596.84	40.03	1602.401
5	105	11025	60	3600	70.8	5012.64	45.6	2079.36
6	117	13689	55.6	3091.36	61.2	3745.44	49.4	2440.36
7	144	20736	44	1936	56.3	3169.69	39.8	1584.04
8	120	14400	50.2	2520.04	58.1	3375.61	40.7	1656.49
9	126	15876	52.4	2745.76	72	5184	57.02	3251.28
10	96	9216	56	3136	68	4624	53	2809
N	10		10		10		10	
$\sum xi$	1225.4		533.8		643.2		478.8	
$(\sum xi)^2$	1501605.2		284942.4		413706.2		229230.3	
$\sum xi^2$	153128.2		29127.3		41769.9		23371.2	
$n \sum xi^2$	1531282.0		291273.2		417698.6		233712.4	
$n \sum xi^2 - (\sum xi)^2$	29676.8		6330.8		3992.4		4482.1	
SQRT	172.3		79.6		63.2		66.9	
K/S	3445.4		1591.3		1263.7		1339.0	
$(K/S)/\sum xi$	2.8		3.0		2.0		2.8	
N'	7.9		8.9		3.9		7.8	

MPV								
	WS 1	X ²	WS 2	X ²	WS 3	X ²	WS 4	X ²
1	129.6	16796.16	48	2304	62	3844	28.1	789.61
2	121.2	14689.44	53.3	2840.89	69.3	4802.49	30.99	960.3801
3	90	8100	54.27	2945.233	62.4	3893.76	30.46	927.8116
4	120	14400	54.42	2961.536	62.4	3893.76	25.57	653.8249
5	108	11664	72	5184	64.8	4199.04	31	961
6	114	12996	55.07	3032.705	50.7	2570.49	32.87	1080.437
7	105	11025	50.1	2510.01	64.8	4199.04	27.9	778.41
8	111.7	12476.89	49.8	2480.04	70.4	4956.16	26	676
9	109.2	11924.64	58.7	3445.69	61.2	3745.44	29.7	882.09
10	125.4	15725.16	60.6	3672.36	57.8	3340.84	30.8	948.64
N	10		10		10		10	
$\sum xi$	1134.1		556.3		625.8		293.4	
$(\sum xi)^2$	1286182.8		309425.2		391625.6		86077.7	
$\sum xi^2$	129797.3		31376.5		39445.0		8658.2	
$n \sum xi^2$	1297972.9		313764.6		394450.2		86582.0	
$n \sum xi^2 - (\sum xi)^2$	11790.1		4339.5		2824.6		504.3	
SQRT	108.6		65.9		53.1		22.5	
K/S	2171.6		1317.5		1062.9		449.2	
$(K/S)/\sum xi$	1.9		2.4		1.7		1.5	
N'	3.7		5.6		2.9		2.3	

DOUBLE CABIN								
	WS 1	X ²	WS 2	X ²	WS 3	X ²	WS 4	X ²
1	114	12996	52	2704	50	2500	26.43	698.5449
2	91	8281	49.2	2420.64	47.2	2227.84	30.09	905.4081
3	90	8100	57.2	3271.84	49.4	2440.36	27.8	772.84
4	102.3	10465.29	49.5	2450.25	51.8	2683.24	29.76	885.6576
5	100.4	10080.16	45.2	2043.04	53.15	2824.923	30.84	951.1056
N	5		5		5		5	
$\sum xi$	497.7		253.1		251.6		144.9	
$(\sum xi)^2$	247705.3		64059.6		63277.4		21001.8	
$\sum xi^2$	49922.5		12889.8		12676.4		4213.6	
$n \sum xi^2 - (\sum xi)^2$	249612.3		64448.9		63381.8		21067.8	
$n \sum xi^2 - (\sum xi)^2$	1907.0		389.2		104.4		66.0	
SQRT	43.7		19.7		10.2		8.1	
K/S	873.4		394.6		204.4		162.4	
$(K/S)/\sum xi$	1.8		1.6		0.8		1.1	
N'	3.1		2.4		0.7		1.3	

Truck Mixer								
	WS 1	X ²	WS 2	X ²	WS 3	X ²	WS 4	X ²
1	46.53	2165.041	47.43	2249.6049	58	3364	22.91	524.8681
2	66	4356	46.17	2131.6689	43.55	1896.603	25.7	660.49
3	60	3600	38.89	1512.4321	57.82	3343.152	22.8	519.84
4	57.14	3264.98	35.27	1243.9729	42.8	1831.84	22.2	492.84
5	63	3969	39.6	1568.16	46.5	2162.25	21.4	457.96
6	58.5	3422.25	45.2	2043.04	49.12	2412.774	26.5	702.25
7	53.7	2883.69	43.8	1918.44	45.5	2070.25	27.03	730.6209
8	51	2601	47	2209	53.4	2851.56	29.12	847.9744
9	48.4	2342.56	39.1	1528.81	56.05	3141.603	30	900
10	56	3136	42	1764	63	3969	29.6	876.16
N	10		10		10		10	
$\sum x_i$	560.3		424.5		515.7		257.3	
$(\sum x_i)^2$	313902.5		180166.3		265987.7		66182.7	
$\sum x_i^2$	31740.5		18169.1		27043.0		6713.0	
$n \sum x_i^2$	317405.2		181691.3		270430.3		67130.0	
$n \sum x_i^2 - (\sum x_i)^2$	3502.7		1525.0		4442.6		947.3	
SQRT	59.2		39.1		66.7		30.8	
K/S	1183.7		781.0		1333.1		615.6	
$(K/S) / \sum x_i$	2.1		1.8		2.6		2.4	
N'	4.5		3.4		6.7		5.7	

EXCAVATOR								
	WS 1	X^2	WS 2	X^2	WS 3	X^2	WS 4	X^2
1	50.67	2567.449	35.4	1253.16	59	3481	21.34	455.3956
2	55	3025	36.05	1299.603	54.65	2986.623	17.48	305.5504
3	67.2	4515.84	33.9	1149.21	48.6	2361.96	27.37	749.1169
4	69	4761	33.48	1120.91	54.44	2963.714	20.1	404.01
5	65.4	4277.16	34.72	1205.478	79	6241	16.7	278.89
6	53.3	2840.89	29.84	890.4256	58.9	3469.21	22.1	488.41
7	55.06	3031.604	28.03	785.6809	56.6	3203.56	25.5	650.25
8	58.3	3398.89	32.9	1082.41	73.8	5446.44	19.7	388.09
9	62.4	3893.76	36.5	1332.25	69	4761	24	576
10	56.2	3158.44	31.4	985.96	57	3249	23.6	556.96
N	10		10		10		10	
$\sum xi$	592.5		332.2		611.0		217.9	
$(\sum xi)^2$	351091.8		110370.1		373308.8		47476.1	
$\sum xi^2$	35470.0		11105.1		38163.5		4852.7	
nxi^2	354700.3		111050.9		381635.1		48526.7	
$n\sum xi^2 - (\sum xi)^2$	3608.5		680.7		8326.3		1050.7	
SQRT	60.1		26.1		91.2		32.4	
K/S	1201.4		521.8		1825.0		648.3	
$(K/S)/\sum xi$	2.0		1.6		3.0		3.0	
N'	4.1		2.5		8.9		8.9	

ROLLER SILLIDER								
	WS 1	X ²	WS 2	X ²	WS 3	X ²	WS 4	X ²
1	46.73	2183.693	32.93	1084.385	52	2704	15	225
2	45.01	2025.9	34.8	1211.04	49.6	2460.16	14.7	216.09
3	43.6	1900.96	31.6	998.56	51.36	2637.85	16.4	268.96
4	50.76	2576.578	29.72	883.2784	50.8	2580.64	18.5	342.25
5	51	2601	30.9	954.81	47.6	2265.76	16.9	285.61
N	5		5		5		5	
$\sum xi$	237.1		160.0		251.4		81.5	
$(\sum xi)^2$	56216.4		25584.0		63181.8		6642.3	
$\sum xi^2$	11288.1		5132.1		12648.4		1337.9	
$n \sum xi^2 - (\sum xi)^2$	56440.7		25660.4		63242.0		6689.6	
SQRT	224.2		76.4		60.2		47.3	
K/S	15.0		8.7		7.8		6.9	
(K/S)/ $\sum xi$	299.5		174.8		155.2		137.5	
(K/S)/ $\sum xi$	1.3		1.1		0.6		1.7	
N'	1.6		1.2		0.4		2.8	

Lampiran 6. *Codingan Tabu Search*

```
▶ import numpy as np
import pandas as pd
from itertools import permutations

processing_times = np.array([
    [32.94, 15.24, 5.35, 15.01, 7.96, 2.55],
    [14.35, 7.48, 2.72, 11.41, 4.46, 1.72],
    [17.29, 8.41, 2.7, 13.86, 8.21, 2.7],
    [12.87, 3.94, 1.56, 6.92, 2.93, 0.88]
])

num_jobs = processing_times.shape[1]
num_machines = processing_times.shape[0]
tabu_tenure = 5
max_iterations = 100

# Fungsi untuk menghitung makespan
def calculate_makespan(solution):
    schedule = np.zeros((num_machines, num_jobs))
    for i, job in enumerate(solution):
        for j in range(num_machines):
            if i == 0 and j == 0:
                schedule[j, i] = processing_times[j, job]
            elif j == 0:
                schedule[j, i] = schedule[j, i - 1] + processing_times[j, job]
            else:
                schedule[j, i] = max(schedule[j - 1, i], schedule[j, i - 1]) +
    return schedule[-1, -1]
```

```

▶ def get_neighbors(solution):
    neighbors = []
    for i in range(num_jobs - 1):
        for j in range(i + 1, num_jobs):
            neighbor = solution.copy()
            neighbor[i], neighbor[j] = neighbor[j], neighbor[i]
            neighbors.append(neighbor)
    return neighbors

# Algoritma Tabu Search
def tabu_search():
    initial_solution = list(range(num_jobs))
    best_solution = initial_solution
    best_makespan = calculate_makespan(best_solution)
    tabu_list = []
    all_solutions = set()

    for perm in permutations(initial_solution):
        current_solution = list(perm)
        makespan = calculate_makespan(current_solution)
        all_solutions.add((tuple(current_solution), makespan))
        if makespan < best_makespan:
            best_solution = current_solution
            best_makespan = makespan

    tabu_list.append(tuple(current_solution))
    if len(tabu_list) > tabu_tenure:
        tabu_list.pop(0)

    return best_solution, best_makespan, all_solutions

```

```

▶ # Menjalankan Tabu Search
best_solution, best_makespan, all_solutions = tabu_search()

# Menyiapkan data untuk DataFrame
data = []
for solution, makespan in all_solutions:
    row = list(np.array(solution) + 1)
    row.append(makespan)
    data.append(row)

# Membuat DataFrame
columns = [f'Job {i}' for i in range(1, num_jobs + 1)] + ['Makespan']
df = pd.DataFrame(data, columns=columns)

# Simpan DataFrame ke file Excel
df.to_excel('hasil_tabu_search.xlsx', index=False)

print("\nSolusi optimal:")
print(f"Urutan job: {best_solution}, Makespan: {best_makespan}")

```



```

Solusi optimal:
Urutan job: [4, 0, 3, 1, 2, 5], Makespan: 101.18999999999998

```


Lampiran 6. *Output* Perhitungan Penjadwalan dengan Algoritma *Tabu Search*

Urutan Job						Makespan (Waktu)
Pertama	Kedua	Ketiga	Keempat	Kelima	Keenam	
5	1	4	2	3	6	101,19
1	4	2	5	3	6	101,36
1	5	4	2	3	6	101,47
1	4	5	2	3	6	101,47
1	3	4	2	5	6	101,62
1	4	2	3	5	6	101,62
1	4	3	2	5	6	101,62
5	1	4	2	6	3	101,85
1	4	5	2	6	3	102,13
1	5	4	2	6	3	102,13
1	4	2	5	6	3	102,13
6	1	4	2	5	3	102,21
1	4	6	2	5	3	102,38
1	4	2	6	5	3	102,38
1	6	4	2	5	3	102,38
5	1	3	4	2	6	102,48
5	1	4	3	2	6	102,48
4	1	2	5	3	6	102,71
1	4	5	3	2	6	102,76
1	5	4	3	2	6	102,76
1	5	3	4	2	6	102,76
1	3	5	4	2	6	102,76
1	3	4	5	2	6	102,76
1	4	3	5	2	6	102,76
4	1	5	2	3	6	102,82
4	1	2	3	5	6	102,97
4	1	3	2	5	6	102,97
5	6	1	4	2	3	103,07
6	5	1	4	2	3	103,07
1	2	4	5	3	6	103,23
5	1	6	4	2	3	103,24
5	1	4	6	2	3	103,24
6	1	4	5	2	3	103,35
6	1	5	4	2	3	103,35
4	1	5	2	6	3	103,48
4	1	2	5	6	3	103,48

1	2	4	3	5	6	103,49
6	1	4	3	2	5	103,5
6	1	3	4	2	5	103,5
6	1	4	2	3	5	103,5
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1	4	6	2	3	5	103,67
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1	6	4	3	2	5	103,67
1	4	6	3	2	5	103,67
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4	1	6	2	5	3	103,73
6	4	1	2	5	3	103,77
4	6	1	2	5	3	103,77
1	2	4	5	6	3	104
6	1	2	4	5	3	104,08
1	6	2	4	5	3	104,08
1	2	6	4	5	3	104,08
4	1	3	5	2	6	104,11
4	1	5	3	2	6	104,11
1	2	4	6	5	3	104,25
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5	1	3	6	4	2	104,53
5	1	6	4	3	2	104,53
5	1	3	4	6	2	104,53
3	1	4	2	5	6	104,6
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4	6	1	3	2	5	104,85
6	4	1	3	2	5	104,85

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4	1	6	3	2	5	105,02
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1	2	6	4	3	5	105,37
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5	3	1	4	2	6	105,46
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4	5	6	3	1	2	113,71
3	5	4	6	1	2	113,71
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