Topic: Reducing Automobile testing time using Lawler's Algorithm
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INTRODUCTION

Mercedes-Benz Group AG (Mercedes-Benz), is a leading German car manufacturer. It designs, develops, and sells elite and luxury automobiles, vans, trucks, and buses. The firm also provides financing, leasing, automobile subscription, car rental, fleet management, insurance brokerage, digital charging and payment systems, and new mobility services. It is present in 93 locations globally, throughout Europe, North and Latin America, Asia, and Africa. The corporation sells and maintains automobiles in practically every country on every continent. The company is based in Stuttgart, Germany. Mercedes has been a pioneer in innovation and safety technologies, which are to this date used by other car manufacturers as well [1].

Fig 1. Mercedes models [2]

The company has about 172,425 employees globally with around ~1,400 employees in the United States. The company even though being a manufacturer of luxury cars, is one of the most sold car companies in the world. It has a market share of ~3% in the global market. The logo of Mercedes is an iconic part of the company that signifies luxury and quality. It was made by Gottlieb Daimler (one of the co-founders of Mercedes Benz). It symbolizes the use of the products on land, sea, and air [4].

Fig 2. Mercedes Logo [4]

Mercedes-Benz Cars offers vehicles in every passenger car sector, including urban compacts, adaptable SUVs, attractive sports cars, and luxury sedans. Mercedes-Benz Cars are accelerating the methodical development of alternative drives, to electrify the complete lineup [5]. Most Mercedes cars are made in Germany in the regions of Affalterbach, Berlin, Bremen, Hamburg, Kamenz, Kolleda and Arnstadt, Rastatt, and Sindelfingen. In addition to Germany, Mercedes is also built in the United States (Alabama), France (Hambach), Romania (Sebes and Cugir), China (Beijing), and South Africa (East London) [6].

BACKGROUND

The company began in 1886 by Karl Benz who patented the first modern automobile (The Motorwagen). It was a three-wheeled vehicle. The project was funded by his wife, Bertha Benz. Later in 1926, Karl Benz, Gottlieb Daimler, Wilhelm Maybach and Emil Jellinek founded Mercedes Benz. The name comes from Emil Jellinek's daughter whose name was Mercedes It was first named Benz & Co. and later after the merger the company was known as Mercedes Benz (the name that is still used today. Mercedes has also had great achievements in the field of safety and performance. The company has 30,090 patents to date. The company has been ever-growing since its inception and many of its technologies are being used by other automobile manufacturers as well [3].

With the increase in the demand for vehicles, the company must manufacture a greater number of cars each day to meet the demands. The work presented in this paper involves the reduction of tardiness in the vehicle testing process. For this, Mercedes-Benz used a process called as "**multi-point inspection**" method. Through this method, the technicians perform quality checks of important components and systems. This includes checks of the system and components, fluid, and tire & brakes. This process makes a thorough diagnostic test and inspection of the entire vehicle to ensure that everything is in working order. This inspection started for vehicles that are 2009 and newer. Based on the current standards, a multi-point inspection is done every 10,000 miles or 12 months of driving [7].

Mercedes uses artificial intelligence and machine learning very effectively to give its customers a unique experience. Moreover, in production facilities, Mercedes have been trying to completely digitalize their production setup using intelligent and energy-efficient robots. There is active research going on that is called – **"Active Research Environment for the Next Generation of Automobiles"** (ARENA2036). Here, the main focus is to make high-tech production concepts that involve the support of HRC (Human-robot cooperation) [8].

Fig 3. AREUS facility in Mercedes-Benz Europe [8]

In the EU, Mercedes-Benz has been building automation tools for production in the project – **"Automation and Robotics for European Sustainable Manufacturing"** (AREUS). These components are used for production facilities and work on an energy-efficient system. This project involves "green electricity" being supplied to the production robots which means that some of the energy that is being used can be recovered and some can be temporarily stored [8].

RESEARCH OBJECTIVE/PURPOSE

When a vehicle is manufactured by an automobile company, there are many tests and quality checks are carried out to authenticate the performance of the car. Most of these tests and quality checks are time-consuming and require a lot of money to perform. Moreover, the testing of these cars requires intensive manual labor since these vehicle models are hand-made. Factory machines are not programmed with the technology to produce such types of cars. It ensures that the model being designed meets all the requirements set by the company and is ready to get into the production stage.

The work presented in the section solves the problem of vehicle testing schedules using Lawler's algorithm. Since the process is time-consuming, the advised method takes into consideration the available time and points out the tardy job/lateness that can either be removed or the processing time can be reduced by efficient means. This method would curb the problem for technical planners to use fewer resources and utilize all the time by simultaneously working on multiple testing. This method in the long run will help companies to save money, time, and resource workload.

CHALLENGES/ PROBLEMS RELEVANT TO THE ASSIGNED SECTOR

1. **Issues in supply chain and operations:** Due to the recent Ukraine and Russia wars, there have been disruptions in the supply chain in the automobile industry. Most production of automobiles requires natural gas. Russia has been the largest exporter of the said commodity. However, Mercedes is certain that it will be switching to renewable energy from gas in the long run. Other major automobile manufacturers had to also cut ties with Russia, which resulted to stop the supply of energy [9].

2. **Chip supply shortage:** Mercedes's battery suppliers are China's CATL and South Korea's SK Innovation, LG Chem, and Farasis. There has been a huge shortage in the chip supply that has caused problems in the production of electric vehicles and high-end luxury cars. Some of these devices are the main components in the electrical systems that control the main functions of the vehicle. This happened mainly due to COVID-19 restrictions and increased consumer demand. This is leading to late deliveries because certain functions would not exist without the microchip [10].

3. **Reduced sales:** During the pandemic, buying a car was the least concern of the people. Even for those who could buy cars, it was near to impossible due to the restrictions set by the government. Post-pandemic, car manufacturers have increased their prices to break even from the losses caused to the pandemic. Hence, sales of luxury cars like Mercedes have reduced. However, the companies are trying to make profits through subscription-based models and are adopting newer methods to make income [11].

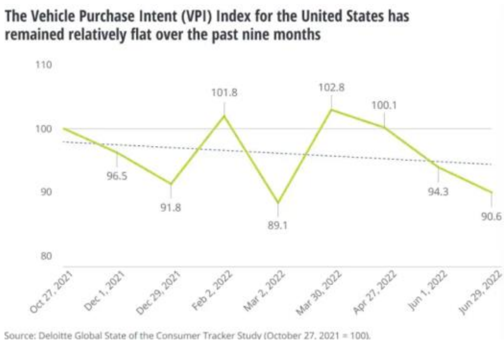


Fig 4. Reduced purchasing intent in the US over the past 9 months [9]

4. **Engine and wire damages:** Due to excessive heat in the summer, the wires in the vehicle can get cracked and damaged. This is mainly because the heat from outside combined with the engine heat is causing the wires to get brittle. Moreover, Mercedes wiring is covered with plastics making it difficult for technicians to examine the problem. These also have huge costs to repair. Moreover, there are oil leaks and failure of the engine when the car reaches the 100,000-mile mark [12,13].

5. **Transmission issues:** Even though Mercedes has been equipped with a robust 5-speed transmission system. Customers have always complained about the transmission fluid being leaked. This damages the control module and forms cracks in the wiring. There may also be cases of poor shifting in the valve body [12].

6. **Rusting:** Most automobile face problems of rusting. Metal parts of the car rust rather quickly than usual. Mercedes-Benz too has such problems, especially in their older models of cars [10].

7. **Failure of Electrical sensors:** Sensors like brake monitor sensor is often seen to malfunction in Mercedes-Benz cars. These sensors go off and will keep alarming until they have been replaced. These sensors monitor when the brake pads reach minimum wear thickness [13].

8. **Electric Vehicle (EV) technicians:** As the world shifts to more renewable energy options, it has become a major issue for companies to try to switch from regular diesel engines to electric vehicles. This is mainly because fewer people are skilled in handling EV components. Moreover, EV components are expensive to produce and there are short supplies of powertrain batteries [14].

RESEARCH METHODOLOGY/ APPROACHES TO SOLVING THE ISSUES

According to Ludwig, Jeremy, et al [15], it is necessary to have scheduling systems to ensure solving vehicle testing efficiently.

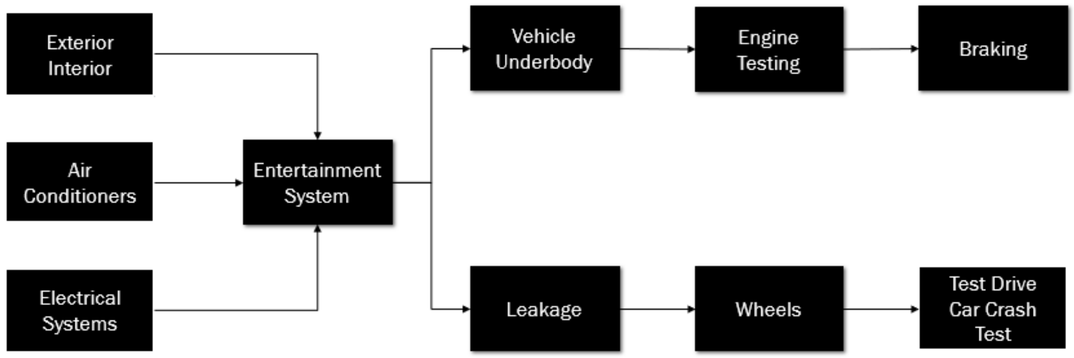
Lawler's Algorithm:

1. Set the value of k (k= number of unscheduled jobs/ numbers of available spaces)
2. Calculate the value of τ

$$\tau = \sum_{i=1}^{n} P_i$$

3. Create a pool, having no followers/ successors
4. Create a cost/ penalty/tardiness pool
5. Select a job having minimum tardiness and place the job in the last position
6. Update the value of k, τ, Pool
7. Proceed until you get the optimal schedule
8. Follow the "Backward scheduling procedure"

Network Diagram:



The description of each job is given below:

Jobs	Job Description
Exterior and Interior checking (Job 1)	Checking of indicators, horns, flashes, lighting, seats, seat belts, dashboard, steering wheel, and oil tanks (Functional checks)
Air conditioners check (Job 2)	Checking of airbags, air quality sensors, dust filters, heating sensors, oxygen, and CO2 sensors
Electrical Systems (Job 3)	Check of wirings, spark plugs, speedometers, control modules, warning buzzers, level sensors, and distance sensors [16]
Entertainment system (Job 4)	Check the display unit, web accessibility, clock, display bracket, remote controls, headphones, and DVD unit [16]
Vehicle underbody (Job 5)	Covers, shields, wheel frames, door beams, bulkheads, rear frames, mirrors, side frames, and floor tunnels [17]
Leakage check (Job 6)	Poly vee belt, suspension joints, rubber joints, axle joints, track rod, drag link ends, engine oil, and filtering system [17]
Engine testing (Job 7)	Engine chains, filter caps, assembly brackets, crankshaft, mounts, engine valves, guide tubes, oil pan, bearings, gears, exhausts, camshafts, auxiliary parts, cleaners, and shields [17]
Wheel check (Job 8)	Wheel bolts, alloys, dampers, wheelhouse, liners, flare, paddle switches, bolts, and clamps [17]
Braking test (Job 9)	Brake pads, brake switch, parking brake actuator, control module, and brake lights [17]
Test Drive/Car crash testing (Job 10)	Check safety sensors and components, create the crash environment to perform a crash simulation with a human dummy, and durability tests abiding by the United States standards

There are 10 jobs in the car testing plant. Each job performs quality checks in a specific area. Each job has a specific processing time and due dates depending on the number of expert technicians available in the manufacturing plant. The work presented here assumes that there is only 1 machine that will be performing all the tasks related to car testing. The following network is performed using Lawler's algorithm which means that there is a precedent in the workflow of each task. Each task in the network diagram can be considered a job and machines can be considered by expert technicians. The objective function is to minimize maximum tardiness ($\min(T_{max})$). This will help automobile manufacturers to increase their production capacities which can help increase sales and meet demands. It will also reduce company costs since these vehicles are hand-made and time-consuming to build.

Depending on each job and task a schedule has been made, on which Lawler's algorithm will be applied to find the optimal schedule and objective function. Since in this problem we are assuming that there is only 1 expert technician (Machine) doing each job, thus the set time is put accordingly. According to [18], it takes about 3-6 months for building the car. Assuming that 80% of the time is taken to build the vehicle the rest 20% is required for testing the car. This leaves us with days (maximum value) for each car. There are 7-10 cars that are tested simultaneously in the testing bench of a Mercedes facility. Hence, we assumed 8 cars to be tested for this problem. Depending on the work and testing standards the processing time and due dates are assigned.

Jobs	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10
Pi	14	25	32	29	28	30	38	36	25	31
Di	18	28	26	20	30	37	35	32	35	37

(Here, Pi = Processing time and Di = Due Date)

EXPECTED RESULTS/ FINDINGS

Using Lawler's algorithm to solve the $10/1/T_{max}$ and find the optimal schedule.

Jobs	J1	J2	J3	J4	J5	J6	J7	J8	J9	J10
Pi	14	25	32	29	28	30	38	36	25	31
Di	18	28	26	20	30	37	35	32	35	37

Number of jobs = 10
Number of machines = 1

Applying Lawler's Algorithm,

Cycle 1

K = 10
τ = 14 + 25 + 32 + 29 + 28 + 30 + 38 + 36 + 25 + 31 = 288
Pool = { J_9 , J_{10} }

Jobs	9	10
τ	288	288
Di	35	37
L	253	251

Thus, we use backward scheduling procedure and place Job 10 in the last

									J10

Cycle 2

K = 9
τ = 288 – (Processing time of Job 10) = 288 – 31= 257
Pool = { J_8 , J_9 }

Jobs	8	9
τ	257	257
Di	32	35
L	225	222

Thus, we use backward scheduling procedure and place Job 9 in the last before Job 10

								J9	**J10**

Cycle 3

K = 8
τ = 257 – (Processing time of Job 9) = 257 – 25 = 232
Pool = { J_7, J_8 }

Jobs	7	8
τ	232	232
Di	35	32
L	197	200

Thus, we use backward scheduling procedure and place Job 7 in the last before Job 9

							J7	**J9**	**J10**

Cycle 4

K = 7
τ = 232 – (Processing time of Job 7) = 232 – 38 = 194
Pool = { J_5, J_8 }

Jobs	5	8
τ	194	194
Di	30	32
L	164	162

Thus, we use backward scheduling procedure and place Job 8 in the last before Job 7

						J8	**J7**	**J9**	**J10**

Cycle 5

K = 6
τ = 194 – (Processing time of Job 8) = 194 – 36 = 158
Pool = { J_5, J_6 }

Jobs	5	6
τ	158	158
Di	30	37
L	128	121

Thus, we use backward scheduling procedure and place Job 6 in the last before Job 8

					J6	**J8**	**J7**	**J9**	**J10**

Job 4 and Job 5 have precedence already and hence we will be following the same
The processing time was = 158 – (Processing time of Job 6) = 128

			J4	**J5**	**J6**	**J8**	**J7**	**J9**	**J10**

Cycle 6

K = 3
τ = 128 – (Processing time of Job 4 and Job 5) = 128 – (29+28) = 71
Pool = { J_1, J_2, J_3 }

Jobs	1	2	3
τ	71	71	71
Di	18	28	26
L	53	43	45

Thus, we use backward scheduling procedure and place Job 2 in the last before Job 4

		J2	J4	J5	J6	J8	J7	J9	J10

Cycle 7

K = 2
τ = 71 – (Processing time of Job 2) = 71 – 25 = 46
Pool = { J_1, J_3 }

Jobs	1	3
τ	46	46
Di	18	26
L	28	20

Thus, we use backward scheduling procedure and place Job 2 in the last before Job 4 and subsequently put Job 1 in the first

J1	J3	J2	J4	J5	J6	J8	J7	J9	J10

(Optimal Schedule)

Jobs	J1	J3	J2	J4	J5	J6	J8	J7	J9	J10
Pi	14	32	25	29	28	30	36	38	25	31
Ci/Fi	14	46	71	100	128	158	194	232	257	288
Di	18	26	28	20	30	37	32	35	35	37
Li	-4	20	43	80	98	121	162	197	222	251

Tardiness/Lateness = max (0, $(c_i - d_i)$)
Lateness (Li) = $c_i - d_i$

$$L_{max} = 251\ units$$

CONCLUSION

With the increase in the demand for production as well as an increase in the costs of testing vehicles' performances, Lawler's algorithm is a very powerful tool for scheduling and finding out tardiness. Implementation of both ongoing processes in Mercedes with Lawler's algorithm will prove to be more efficient and optimal. The overall time and costs can be saved that in turn will help in building the profits of the vehicle. Through Lawler's algorithm we are able to reduce the lateness and find the most optimal schedule. This will improve the overall efficiency in the production facility.

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