CASE STUDY

Aircraft, Passenger, Cargo, and Crew Scheduling

MemComputing

MemComputing worked with the Defense Innovation Unit to optimize the scheduling of a fleet of military aircraft and its payload in minutes. Learn more about this challenging problem and how MemComputing is poised to transform real-time scheduling for both military and commercial airline applications.

Introduction

In December 2022, a large storm crippled a major US airline due to its outdated scheduling software. As a result, they canceled over 15,000 flights nationwide, stranding thousands of passengers [1]. Not only did this draw bad press, but it could cost the airline between $600 million and $700 million, according to estimates from Bank of America airline stock analyst Andrew Didora [2].

Their crew scheduling system, which has been in use since the 90s, was simply incapable of handling the scale of schedule changes required to match crew members with available aircraft at the time of this incident. Unlike other large US airlines that use a “hub and spoke” model, its reliance on point-to-point operations made it more susceptible to scheduling catastrophes. [3]

As the CEO of the airline pointed out, “We had aircraft that were available, but the process of matching up those Crew Members with the aircraft could not be handled by our technology. In our desired state, we have a solver that would be able to do that very quickly and very accurately. Our system today cannot do that. As a result, we had to ask our Crew Schedulers to do this manually, and it’s extraordinarily difficult.” [4]

While this airline was pointed out for its legacy systems, the Wall Street Journal indicated that the airline industry, in general, is slow to embrace new technology. “The airline sector has been among the slowest to adopt cloud-based and analytics technologies that could help solve complicated transportation network problems.” [5].

MemComputing has demonstrated its ability to provide optimal solutions to aircraft scheduling problems with various industry partners but cannot share the details due to NDAs. However, we were recently put to the test by the Defense Innovation Unit (DIU) on a similar problem for the military. The work was unclassified because they provided simulated airlift data representing military aircraft, passenger, cargo, and crew scheduling, but it was not actual data. This data is considered sensitive, so we will not share the exact data.

Case Study

The speed and efficiency of moving military personnel and equipment can be the difference between mission success and failure. It’s critical that the development and execution of logistics schedules is rapid, optimal, and resilient to ensure the safety of our troops and to establish strategic/tactical advantages.

The DoD employs fleets of aircraft across multiple service branches to transport personnel and cargo across the world. One branch alone moves hundreds of thousands of passengers and millions of pounds of cargo annually. It is reported that the DoD uses 75 million barrels of fuel annually to support its global logistics chain. Considering that airlift missions are scheduled primarily using a manual process that is both inefficient and rigid, they experience unavoidable operational costs and inefficiencies, which could put the warfighter at risk.

So, we took on this challenge to show the performance of our MEMCPU Platform™ when solving real-world airlift scenarios faced by the DoD today. The simulated data they provided represented only a fraction of the number of airlift requests that they actually face. However, even at that number, 93 airlifts, the problem is already intractable for current technology. We set out to demonstrate that our MEMCPU Platform can provide optimal solutions in minutes.

Generating an optimal recovery solution in just a few minutes will provide increased visibility for both commercial and military airlines and can be run continuously as conditions change. This enables the airline to rapidly communicate updated information to its crews and passengers while dramatically reducing down-time to resume operations and avoid catastrophic meltdown. The cost savings will be significant, as this solution is poised to enhance the real-time scheduling for both military and commercial airline applications.

The Problem

Military airlift missions are currently scheduled by a logistics team who primarily use a manual process. The problem data is highly simplified, but we will show even with simplified data, the problem is intractable for current best-in-class solutions.

This problem assumes:

- There are 122 airbases/airports where passengers and cargo are located.
- There are only 2 types of aircraft available.
- Each aircraft identifies capacities such as the number of passengers, the number of cargo pallets, the cruising speed, and the maximum number of hours of continuous flight.
- There is a table identifying the different aircraft of each type, the current location, when and where and for how long the aircraft need to be off of service for maintenance.

There are business rules that must be adhered to for the safety of the crew. These include:

- The maximum number of hours the crew can be active: 13 hours
- The minimum down time after completing their active day: 15 hours
- The minimum time on the ground between different legs: 1.5 hours

There are then 93 airlift requests over a 2-week timeframe. Each request identifies:

- The priority of the specific request from 1 to 3, with 1 being the highest.
- The departure location.
- The earliest pickup date.
- The latest pickup date.
- The latest drop-off date
- The destination.
- The number of passengers.
- The number of pallets.
- Whether the largest of the 2 planes is required.

The goal is to create a schedule that successfully books all priority 1 requests with as many priority 2 and priority 3 requests as possible while minimizing the overall flight time. Passengers and containers of an airlift request can be distributed over different aircrafts and/or the same aircrafts can do multiple flights carrying only part of the passengers and cargo if necessary.

The Problem Continued

The problem is combinatorial:

- As the number of airlift requests grow sequentially (1 by 1), the number of possible scheduling configurations grows exponentially.
- State-of-the-art techniques require a brute force method where they must compute every schedule permutation to determine which specific schedule is optimal.
- Compute time for state-of-the-art techniques grows exponentially to check each scheduling configuration.
- At scale, this problem would take years or worse for today's methods to compute an optimal solution.

As mentioned, these problems are being solved every day, just not optimally. That is, the problems must be simplified further and using heuristics, or short cuts, and an approximate solution can be determined. However, these shortcuts lead to inefficiencies that could produce conflicts and certainly lead to increased costs, with the possibility of failing entirely and be unable of providing a schedule as seen during the December 2022 case.

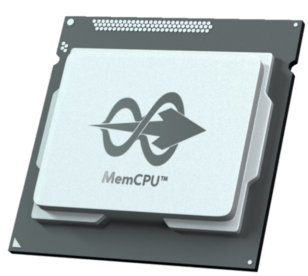
MemComputing's Approach

MemComputing offers a revolutionary method for solving combinatorial optimization problems. Using a physics-based approach, our proprietary circuit design leverages unconventional computational memory to overcome classical computing bottlenecks and solve once intractable problems at unprecedented speed and scale. The MemComputing circuit is so efficient that the MEMCPU Platform, an emulation of the circuit, provides optimal solutions in minutes for problems that are intractable for today's state of the art technologies.

The MEMCPU Platform is programmed by a suitable mathematical formulation that identifies all variables, all constraints and the objective function identifying the optimization goals. The MEMCPU Platform natively supports optimization problems formulated using Integer Linear Programming (ILP). The specifications for the methods date back to the 1970s. These methods are familiar and used in industry by operations research personnel, mathematicians, and data scientists. There are commercially available ILP solvers, and we will compare our solution to the best-in-class commercial solver using the same ILP formulations.

The MEMCPU Platform works by solving the ILP in one massively parallel computing cycle. The dynamics of our circuit naturally converge to the first feasible solution (i.e. solution that satisfies all constraints) of the problem. Since there may be many feasible solutions to a problem, the MEMCPU Platform will continue processing to identify other feasible solutions with better objectives, if there are any.

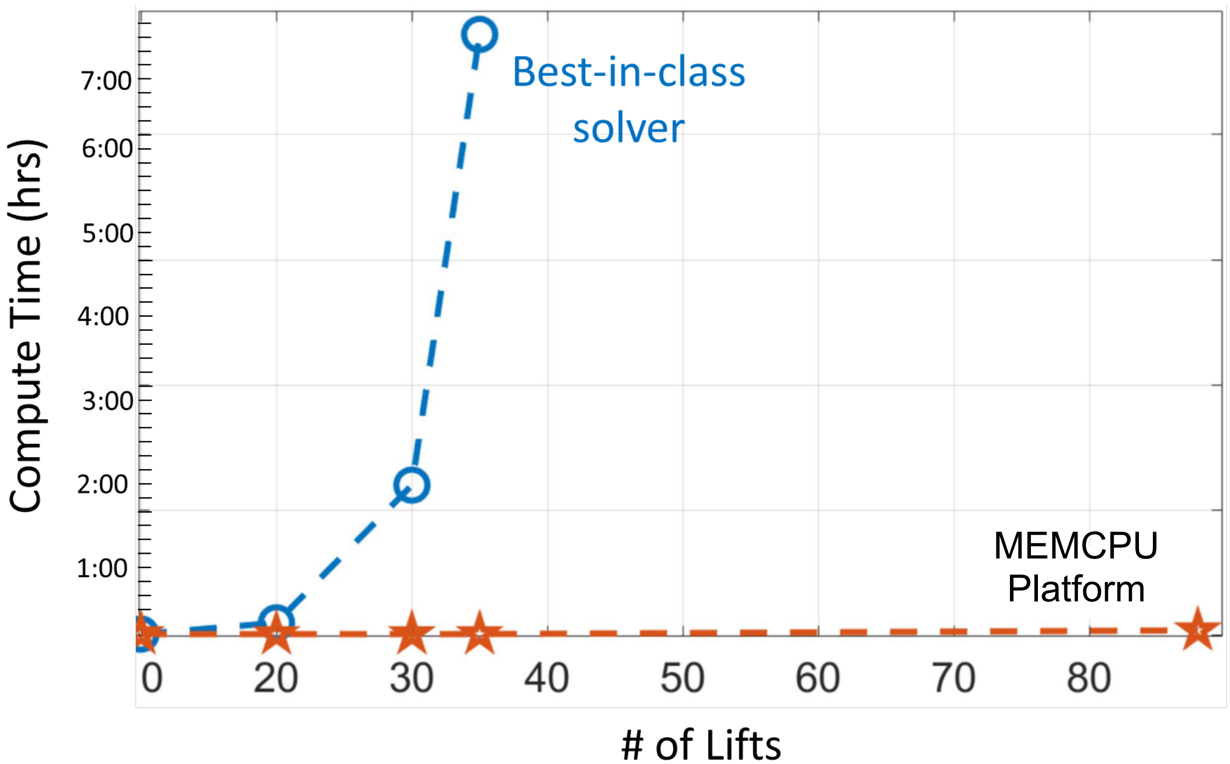
This process is unique to MemComputing and represents a completely novel and efficient form of computation. Further, the larger and more complex the problem, the better our technology performs. This is validated in several peer-reviewed and case studies, where MemComputing demonstrates an exponential speed-up when solving hard combinatorial optimization problems [6]. Note that where the emulation of our circuit takes minutes to solve these problems, the hardware implementation or MEMCPU Integrated Circuit will solve these same problems in real-time (microseconds) with ultra-low power consumption.



While the MemComputing team is expert in developing these mathematical models, it is very teachable to those already familiar with the ILP standards. Therefore, MemComputing can be contracted to build the entire solution for you from the ground up. However, MemComputing will also work with your team to build the solution, while teaching them the nuances of the most effective way to build the mathematical models to take full advantage of the MEMCPU Platform. Often it is best to work together on multiple problems where MemComputing does less and less of the modeling as your team gains experience and takes on the process.

Results & Comparisons

Using Integer Linear Programming (ILP), we developed multiple problem sets using the data provided by the DIU, scaled from 10 lift requests up to the full set of 93 lift requests. We then ran head-to-head comparisons between the MEMCPU Platform and the best-in-class ILP solver. The following plot demonstrates the results.



The x-axis represents the number of lift requests, while the y-axis shows the time it took to solve the problem and find a scheduling solution. While the leading ILP solver (blue) can solve small problems relatively quickly, the exponential nature of the problem becomes apparent at 30 lift requests. At 35 lift requests, it takes over 7 hours to run. At this point, we stopped the testing of the current best-in-class technology.

The MEMCPU Platform, on the other hand, solved every instance within minutes, including the full-scale problem of 93 requests. The scaling for the MEMCPU Platform is linear. Calculating an optimal schedule for 100 lift requests takes approximately 1.5 minutes. (1,000 requests will take 15 minutes, and 10,000 aircraft schedule requests would take 150 minutes (or 2.5 hours).

Results Continued

Compared to the December 2022 Event
Let's extrapolate this data as it would relate to the recent challenges that were faced by one airline and covered so broadly in the news. We have taken statistical data for that airline [7] and used it to extrapolate how MemComputing could apply a similar solution to that problem.

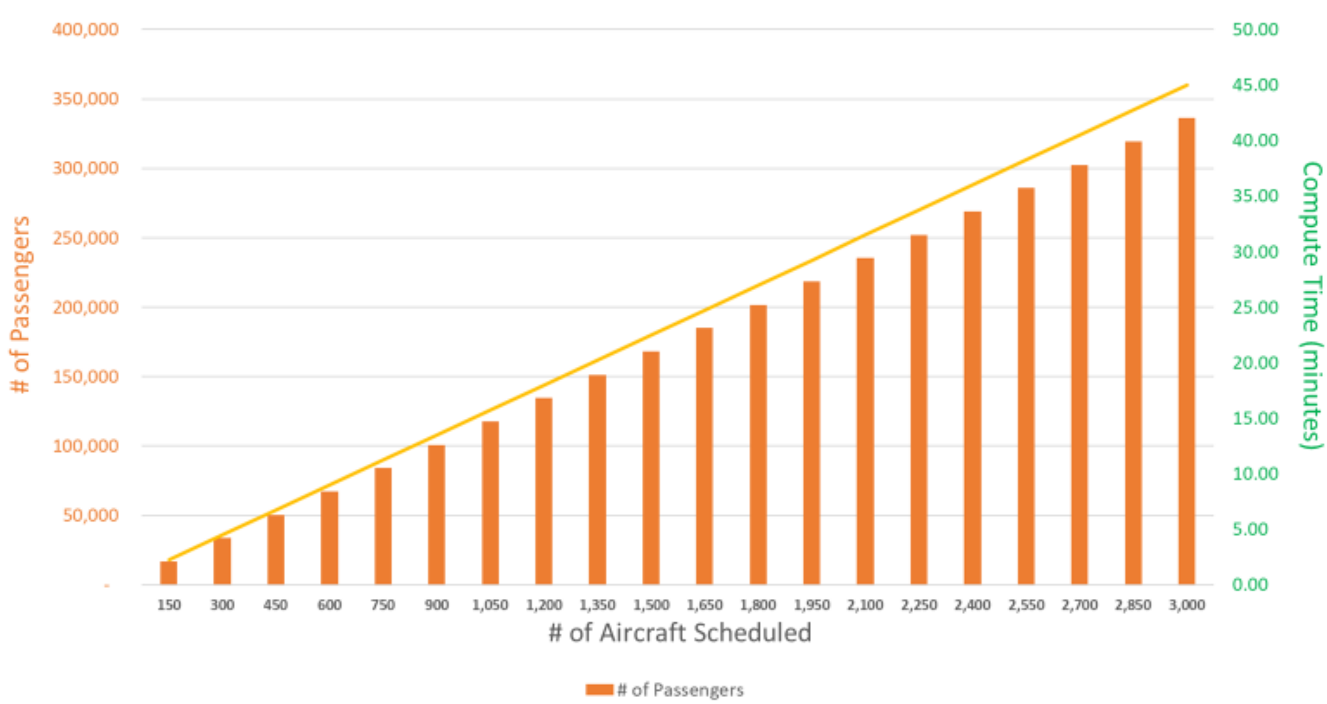
These statistics were pulled from 2021.

# of Aircraft	741
Avg. # of flights per day	3,000
Avg. Passenger load	78.5%
Total Passengers for 2021	122,718,544

From this, we calculated;

Avg. # of Passengers per day	336,215
Avg. # of Passengers/flight/day	3,000

Using these numbers, we extrapolated the following from our case study data,



This indicates it would take our solution 45 minutes to compute an optimal schedule for 3,000 flights in a given day.

Results Continued

Apply this to the recent scheduling issue due to weather

According to data from FlightAware [8], this airline experienced the following impact on its flights:

Date	Flights with issues	% Cancelled	% Delayed
12/25/2022	90%	42%	48%
12/26/2022	87%	71%	16%
12/27/2022*	86%	64%	22%
12/28/2022*	61%	61%	**
12/29/2022*	24%	24%	**

* Data is incomplete for the day as it was collected on 12/27/2022 at 7PM EST.

** Data for 12/28/2022 and 12/29/2022 only shows flights canceled as of 12/27/2022

What our data implies is that since it takes MemComputing 45 minutes to generate a schedule for the day; this program can be continually rerun during the day as new data comes in and a new optimal schedule can be delivered in minutes.

This is especially helpful if there are just some number of planes that have equipment issues and whose passengers need to be re-accommodated. When there are weather issues that affect a great number of planes, especially the widespread issue experienced in December of 2022, passengers in the affected areas will certainly be delayed until the weather has improved. However, MemComputing's solution could have re-routed aircraft and planes that were not in affected areas but might have been headed to those areas. Passengers that needed to travel to those areas would, again, be delayed. However, passengers on those planes that were connecting to unaffected areas could have been accommodated by those planes.

While the data for this case study did not include weather data, it is trivial to add that to our mathematical model. This can include data that predicts the period of time that an airport will be closed. Thus, as the schedules are readjusted, it will be aware of when those airports are open, and the passengers can begin to be accommodated. It just requires up to date and accurate data.

Conclusion

This case study confirms the fact that generating an optimal solution for problems of this nature is intractable for the current best-in-class technology because the compute time scales exponentially as the number of requests grow sequentially. It would take years of compute time on the fastest supercomputers. Thus, current solutions used by the military and commercial airlines can only provide an approximation.

However, MemComputing demonstrates a new computing paradigm that scales linearly on these problems and provides an optimal solution in minutes. Therefore, as the problem grows, MemComputing's compute time grows by fractions of a second. The solution demonstrated scales well beyond the size of the case study. To that matter, the data were extrapolated using statistics from a current commercial airline. It would take 45 minutes to generate an optimal daily schedule for 3,000 aircraft and 336,215 passengers. Further, as the day progresses, if the schedule is impacted because of electromechanical issues with an aircraft or multiple aircraft, as well as airport closures due to weather or other issues, it takes only minutes to run a new optimal schedule. Thus, fewer passengers will be impacted. With fewer problems, there will be less of a financial impact and articles written about such incidents may positively describe how the company recovered vs. negatively call out where the company failed.

Note that for commercial flights there are other scheduling challenges, such as scheduling the flight crew, the flight attendants, food service, etc. The scaling capability of the MemComputing solution makes it possible to combine all scheduling aspects for the most efficient and optimal solution.

In general, MemComputing demonstrates an efficiency improvement that is greater than 40%. For this case study, the DoD indicated they use 75 million barrels of oil annually. At the time of this writing, a barrel of JET A fuel is $135 per barrel in the United States. That is $10,125,000,000.00 ($10.1B) per year. Let's assume that MemComputing cannot deliver its typical efficiencies and our solution can only provide a 10% savings for the military. That still represents a savings of $1,012,500,000.00 ($1B) annually.

Finally, let's consider the same for the commercial airline we have been discussing. In 2021, the airline consumed 1,668,000,000 (1.7B) gallons of fuel [9]. At current prices [10], that equates to $5,899,716,000. A 10% savings annually is $589,971,600 ($589M). As we've said, our solutions typically deliver a 40% savings, but assuming 1⁄4 of that savings is still more than five-hundred million dollars annually.

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