

Case Study: An Automated Theft on Mars

An entry in the [MGMWERX Space Case Study Prize Challenge](#)

by Dr. Orion Sky Lawlor, lawlor@alaska.edu, 2020-07-20 (Public Domain)

Background

The year is 2050. Dramatic decreases in rocket launch costs through reusability, and advances in automated mining and material processing or "In-Situ Resource Utilization", have made it economical for tens of thousands of people to live and work on Mars, mostly in Hellas crater.

Tens of thousands of **people** live on the surface of Mars. The first people were scientists and expert technicians, and the population is still highly educated and technically inclined, but now has broadened to include wealthy tourists, management and government personnel, and a variety of other people from Earth. The first decade of this development was very carefully pre-planned from Earth, but with the dozens of countries and hundreds of organizations now involved, operations have now reached a scale that requires substantial local control by people on Mars, with oversight by people and funding agencies on Earth.

Communication between Mars and Earth is limited by the speed of light, which depending on the orbital configuration of the two planets varies from a 6 to 40 minute roundtrip, for the scenario 20 minutes. This is fine for sending written or recorded messages in either direction, but telephone or interactive video between the two planets is not possible.

Shipping people or materials to or from Earth is only feasible when the planets are aligned, which occurs every 2.2 years. This acts as a natural trade barrier that makes many industries on Mars economically feasible at a much smaller scale than on Earth.

The atmospheric pressure in Mars' Hellas crater is only 0.15psi. For the 14psi normal human atmosphere you need a **pressurized habitat**. The hoop stress scales linearly with the habitat diameter, so buildings tend to be relatively small rounded spheres and cylinders, the largest under 100 yards in diameter. Donning a pressure suit is slow and uncomfortable, so adjacent habitats are normally interconnected with short pressurized tubes, and people normally travel in pressurized vehicles that dock directly with pressurized buildings.

Because shipping costs are very high, a huge variety of **industrial production** activities occur on the surface of Mars: preparation of chemical feedstocks from local atmospheric CO₂ and mined water, production of basalt fiber and basalt composites from locally mined basalt rock, production of transparent plastic sheets used for making pressure habitats, preparation of agricultural soil for food from local dusty regolith and atmospheric CO₂ and nitrogen, and production of metals including iron and aluminum. Most industrial production does not occur inside pressurized buildings, but outside on the surface, to reduce fire and atmospheric contamination risk, and enable widespread use of near-vacuum in industrial processes.

Robotic automation is the key enabler for Mars' industrialization: automated robots in a variety of sizes are used to mine rocks, transport materials, and fulfill commercial orders, as well as construct, repair, and maintain most of the infrastructure. But much human labor on Earth and Mars is devoted to designing, programming, configuring, and debugging the robots.

Mars police, fire, and emergency services are all handled by one tiny "security director"

office, which for organizational reasons is a wing of the United States military.

Scenario

Assistant to the Security Director
15-year veteran of Mars

The Hellas Security Director
Just arrived 2 months ago from Earth

I just got word that there's been a weird theft: several tons of mine tailings.

What kind of mine tailings?

Mixed perchlorate salts, mostly calcium and magnesium perchlorate.

Aren't those poisonous?

Yes, very.

How valuable is it?

It's ... not. It costs more to haul it than to buy it.

So why would anybody want to steal it?

Well, it's also a good oxidizing agent.

Do you think they're making more black market oxygen candles?

It's one option, but with the price of oxygen so low¹ nowadays, it doesn't seem likely.

What worries me is the options for perchlorate explosives.

That could definitely be a problem.
But don't you need micronized aluminum
to make explosives from perchlorate?

Perchlorate and aluminum is what the hard rock miners are using now for blasting, and we do track that carefully, but almost anything that burns can be made to explode when finely divided and mixed with perchlorate--it's just a combination of fuel and oxidizer. Before our aluminum smelter came online, they used to blast hard rock here using the charcoal and waste tars from pyrolysis of agricultural waste as fuel, with mixed perchlorate salts as the oxidizer.

If they are making explosives, there are too many options for fuel to track, then?

Yes, way too many: organics or metals would work, anything that burns.

So we really need to figure out who took the perchlorate.

Where did the theft take place?

Directly on the surface of Mars, from the tailing pile behind the regolith classifier.

Incoming dust gets washed with water in a counter-flow setup to remove salts, the resulting brine gets vacuum distilled for the valuable evaporites, and the soil perchlorate salts are most of what's left over. They just stack those in a storage pile.

But if they're still using perchlorate for blasting,
then why is perchlorate building up like that?

Well, the incoming regolith is over half a percent perchlorate by weight, and with the price of food lately they've been pulling in huge quantities of regolith to build soil to get the farms expanded. Even with the new basalt quarry drilling 24.6/7, they don't use that much perchlorate

¹ The natural abundance of oxygen is higher than silicon in most places, so any industrial process that extracts metals will produce ton quantities of oxygen as a byproduct.

tonnage for blasting, so excess tends to pile up; there are hundreds of tons of perchlorate stacked in that stockpile alone. The LIDAR on that storage pile shows the net unaccounted volume change was about 2 tons total over the last week.

Why didn't that volume change show up sooner?

A big pile of materials like that tends to shift around, compact. Shrinking in volume by a cubic meter or two as more material is loaded is pretty typical, not worth the false alarms.

But we'd have detailed telemetry logs in an industrialized area like that.

Sure, I do have the logs here for everyone and everything that got near the pile.

But I've got better than that, I have the culprit impounded.

Who is it?

You mean **what** is it--it's a 1S trash collecting robot. Here are the photos.

That's pretty small to move several tons!

It had made several hundred trips back and forth before it was caught. It took days.

It looks just like the little robots that empty the garbage cans in this office.

Yes, it's the standard 1S chassis, drive motors, manipulator arms, and storage hopper.

This version has knobbier wheels for running outdoors, but that's a common configuration.

What do its tracking data say?

Not much. The impounded robot has been logged as driving back and forth from the perchlorate tailing pile almost every night this past week. It just drives up to the pile, scoops as much perchlorate as it can carry, about 15 kilos, and drives off.

That's clearly not normal behavior for a trash collector.

No, it's not. The forensics guys on Earth are looking over the trash collection parameters we pulled from the robot, and they're not the defaults, but almost every trash collector operator needs to tune the parameters, so that's not too unusual. But this one was reprogrammed to classify white granular solids around the perchlorate pile as highest priority.

Why are we allowing random robots wandering around an industrial area?

Trash collector robots are allowed almost everywhere, or else trash blows in and builds up there. The collector operators usually try to keep them out of the most dangerous areas, to protect the robot, and to keep from getting sued.

Where was it dropping off the perchlorate?

The logs show it offloading after every trip directly into a self-driving recycling dumpster robot, but there isn't a log entry for a dumpster located anywhere near the drop off point. Running with telemetry off is a huge hazard, and a clear sign whoever did this was up to no good.

A ghost dumpster? That's clever, it's like a dead drop.

Yes. We never would have noticed the operation at all, except a tech was using thermal IR to diagnose a conveyor malfunction, and last night she noticed that 1S sneaking away from the tailings pile in the dark and called us.

It was caught in the act? Why wasn't it followed?

Look, "a robot is doing something weird" is a call that I probably get ten times a day, so I routed it to our Earth staff, just like everything that doesn't seem like a time-critical emergency.

Folks on Earth check the transponder logs and common robotics planning data to see what the robot is registered as doing, versus what it actually was doing, and if the two doesn't seem to match up, those Earth techs' knee-jerk reaction is to send "safe stop" to the robot, to give

everybody plenty of time to sort things out.

A trash picking robot picking up the wrong thing as "trash", is actually a pretty common problem. But one packed with perchlorate? That's a totally different kind of problem.

*But as soon as our impounded robot got stopped,
the thieves knew that they needed to vanish.*

Where was the dead drop location?

Do we have video there?

Here's the satellite view. It's in a surveillance dead zone, just behind a berm from a major ground transit road. They picked that spot carefully to avoid records.

But my money is that the "recycling dumpster" was really a recycling dumpster, because the same shell company registered as owning the 1S also is registered as owning one recycling dumpster, navigation sensor mast missing or damaged. And rather than figure out the fiddly process of docking and material transfer, or supervise the loading in person hundreds of times, I'd just buy a used 1S and standard dumpster and let them work.

What else do we know about the shell company?

A name and address would be great!

Well, the corporation doesn't even have a name, just a registration number. And they're legally incorporated on Earth and offshore, in one of those backward jurisdictions where we'd need people on Earth to visit offices in person to get any more information, which they probably wouldn't give us anyway.

This alone is actually pretty common, trash collection is low margin, so the operators don't like revealing much about their contracts.

But they do log all their material transfers, it's the only way to sell anything here.

What other property does the shell company own?

Nothing else on Mars.

Where does the telemetry trail start?

Let's see.

Oh, I do get an address for the 1S from just after it was purchased last week, let me check that.

No, it's Joe the Robot Mechanic, nice guy. He updated my appliances a few years ago.

And he probably fixes and flips a couple hundred robots per week.

By himself? Busy guy!

He is a hard worker, but most of the assembly and cleaning part of his work is done by robots.

And he's probably the last person in the world I'd suspect of stealing explosives for something nefarious.

Would he be able to give us anything useful about the purchaser?

His sale paperwork looks normal, fair price.

The purchase was 100% online, and the 1S drove away on its own, so it's not like he ran their credit card or saw their vehicle. I can ask if he happened to see anything, but selling a robot is pretty fire and forget, especially when you're listing hundreds per week.

He'll probably be upset that one of the robots he fixed was involved in this though.

How about the dumpster?

The dumpster started in the big scrap yard, and was bought the same day last week.

The dumpster's sensor mast had been damaged and scrapped, so the 1S drove itself over to

navigate for it.

Let's see. The two robots bought a couple hundred kWh of electricity to top off the dumpster's internal battery, and the 1S recharged from the dumpster during the day, but they were literally parked outside the crime scene for the last three days. A trash collecting robot parked at a dumpster is not exactly unusual.

Sounds like telemetry is a dead end.

Seems like it so far--having perfect 24.6/7 logs seems like it'd work great for solving crimes, except the criminals also know about it!

Well, we're going to need to find some other way.

What size and type is the perchlorate? Is it a block, or a powder?

It's coarse crystals of the raw perchlorate salts, washed straight from Mars soil. But to work as an explosive, you'd usually grind it to a fine powder, and blend it with your fuel, but either one could be done by any mobile automated materials processor in an hour or less.

How many of those are there?

A few thousand? I could check.

Any chance we could track them all down?

Sure--it'd just take a few weeks.

And they could mix the explosives with a shovel anyway.

So you think the perps are here, on Mars in person?

Well, the purchases, the reprogramming, and the driving around would be easy to do from Earth, that sort of operation is done remotely all the time.

But what does your gut tell you?

I think whoever did this would want really to keep an eye on it, without the lag from Earth.

So we're looking for one person?

No, you'd need somebody to keep an eye on them.

So probably two people.

Yes, if it's an outside organization, they'd probably send two people.

And they probably arrived two months ago in the same transfer window as you.

Ha, maybe we arrived on the same rocket!

Did anybody on the trip seem suspicious?

Hmmm, not really.

But if it's some crazy guy in his basement, our perp could be only one person.

*Could the perchlorate be stored indoors like in a basement then,
or does it need to be stored under vacuum?*

It's the calcium and magnesium salts, so it's very hygroscopic if stored in a humid pressurized area, but any sealed container would be fine indoors.

Sealed containers like shipping containers, barrels, boxes, or cans?

Yes, any of those things.

That doesn't really narrow it down.

How hard is it to detonate?

Technically, it deflagrates, but it's not hard to set off at all--with a fine mix a match or a hot wire could ignite it. But it does need to be mixed with the fuel first.

So there's no point in looking for detonators.

How explosive is it?

When confined, it's approximately as brisant as dynamite.

*So are we talking unauthorized mining, an IED attack,
or a swarm of evil Roombas packing automatic grenade launchers?*

Your guess is as good as mine!

Role Playing Scenario

The instructor plays the role of the moderator, who figures out what actually happens in the scenario. If time permits, continue role playing until the perpetrators are identified or captured. Students get divided into three groups: security staff, industry, and perpetrators. Ideally they would each have separate (virtual) rooms so they can talk among themselves. The instructor can carry messages between them.

| Role | <i>Security Staff</i> | <i>Industry</i> | <i>Perpetrators</i> |
|-------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Overall Goals | Protect everyone Follow the law Avoid embarrassment | Earn profit Maintain privacy & autonomy | See below |
| Specific Goals | Identify and arrest perpetrators Secure or destroy the perchlorate | Protect all industrial infrastructure | Mix explosive Test small amount of explosive Use explosive to achieve goals |
| Common resources | Near real time orbital optical surveillance on demand Variety of industrial vehicles, both vacuum rated and indoor rated | | |
| Resources | Investigation powers Arrest powers (2) On-site personnel, armed (1) Vacuum rated armored vehicle (1) Bomb-sniffing dog (not vacuum rated) | Hundreds of thousands of industrial robots, each of which have many sensors including cameras and accelerometers | (1) Robotic dumpster containing 2 tons of perchlorate salts Previously purchased common industrial materials and robots (2) On-site personnel (1) Nondescript warehouse, pressurized, isolated |
| Support | Earth governments | Earth industrial interests | See below |

The instructor will select a motivation for the perpetrators, and tell only the perpetrators:

1. "Red Mars": eco-terrorists who want to stop the industrialization of Mars with violence. Covertly supported by both local and Earth extremist ecological organizations.
2. "Mars-13": criminals who want to extract a portion of the trillions of dollars in wealth available in space using intimidation, kidnapping, and violence. Covertly supported by eastern european, asian, or central american organized crime.
3. "Mars First": independence activists who want to immediately sever Mars' ties with Earth, by any means necessary. Covertly supported by anarchist organizations and regional independence interests on Earth.
4. "Mars Wildcats": illegal miners, who want to blast a legally protected formation for valuable ore. Covertly supported by extralegal mining interests on Earth.

Goals of the exercise:

- How do mobile and semi-autonomous robots enable new strategies for security staff?
For crime?
- What opportunities are provided by ubiquitous device telemetry to investigate crime?
How will criminals cover their tracks?

- How do we protect people in space, when everyone literally lives in a fragile bubble?

Background Reading

- Davila, Wilson, Coates, Mckay, "[Perchlorate on Mars: A chemical hazard and a resource for humans](#)" 2013 discusses the basics of perchlorate in Mars soil.
- Wu, Breitingner, Baggili, "[IoT Ignorance is Digital Forensics Research Bliss: A Survey to Understand IoT Forensics Definitions, Challenges and Future Research Directions](#)" 2019 surveyed practitioners in digital forensics about the traces available in current Internet of Things (IoT) devices.
- Kouwn, Scanlon, Choo, Le-Khac, "[Digital forensic investigation of two-way radio communication equipment and services](#)" 2018 discusses the extensive forensic traces left on two-way digital radios.
- (Optional) Robinson's "Red Mars" 1993 novel follows the expansion of human civilization to Mars, including the organized opposition to industrialization.

Much of the robotic and industrial background in this scenario had its origin in discussions in [Nexus Aurora](#), an open source space colonization group.