

Software Stability Model for Dump Truck Scheduling

Dr. Mohamed Fayad
Majid Nabavi

Abstract

The software stability model is applied to a classic dispatching problem, namely: Dump Truck Scheduling. Like many similar problems, the dump truck scheduling problem is NP-Incomplete, therefore the solution set is considered unbounded. A flexible system that can adapt to new facts is desirable when building scheduling systems. In addition, a well-designed system should be applicable to similar scheduling problems.

Problem Statement

A mining company is planning to extract a Porphyry copper deposit, using surface mining method. According to the geological surveys, this deposit has a 240,000,000-ton proven reserve (ore). This ore must be exploited within 20 years and the number of working days per year is 300. A mineral processing facility is under construction close to the pit, to refine and melt the extracted copper at the spot. There is a huge amount of overburden on the reserve that has to be removed and dumped into "waste Dumps". The amount of this overburden (waste) is estimated as 360,000,000-tons.

Production method is the conventional cycle of drilling-blasting- loading-transport. Drilling, loading and transport are day-to-day operations, blasting is done once every 2 months and all other operations are stalled at the day of blasting. These operations are designed in advance and follow the relevant plans, so for every cycle of 2 months that the new blasting operation yields a depot of extracted rocks the loading spots and the volume of rocks to be loaded and transported are predetermined.

The type and size of the machinery is given so the problem here is calculating the necessary number of shovels and trucks, and the daily schedule of trucks in a way that all the transportation goals are achieved by using the minimum possible number of trucks, in other word, the optimum usage of dump trucks' time. In this solution trucks are assigned to the shovels in a way that there is no idle shovel in the mine while dump trucks are lining up in front of another shovel.

For a particular situation that is a period of two months, the amount of ore and waste that must be loaded from each point is given in the following table:

Volume of depots in the pit for 2 months

Loading Point	Type of material	Depot (tonnes)	Working days per month	Total working days	Daily Loading(tonnes)
W1	Waste	1,000,000	25	50	20,000
W2	Waste	550,000	25	50	11,000
W3	Waste	1,500,000	25	50	30,000
P1	Ore	1,200,000	25	50	24,000
P2	Ore	750,000	25	50	15,000

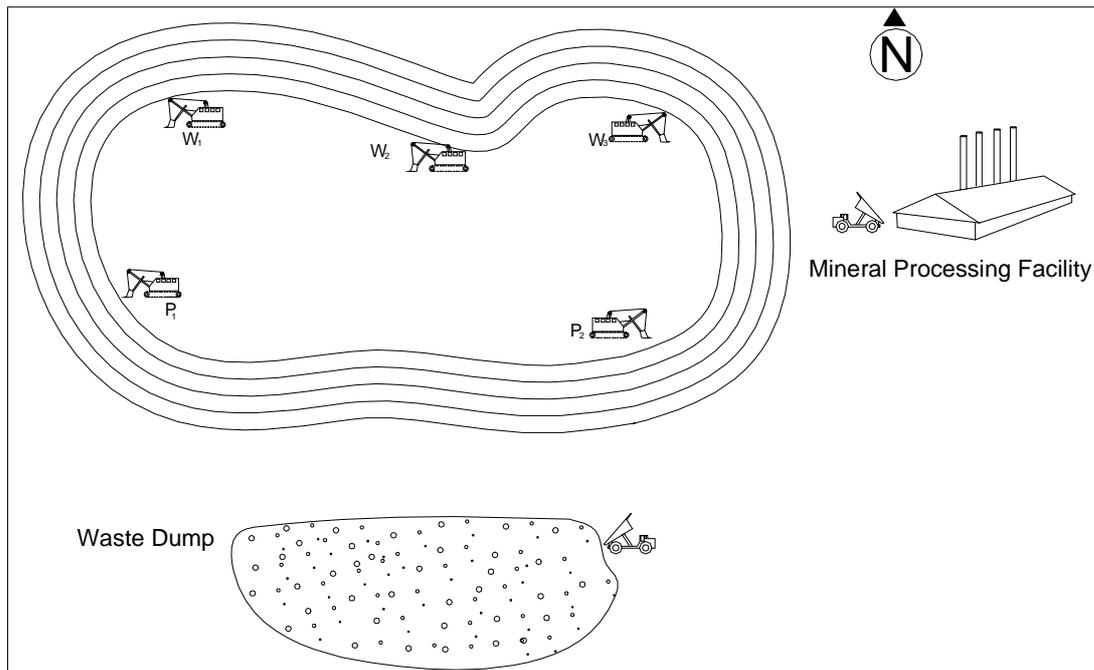


Figure 1: Situation of loading points, mineral processing facility and waste dump

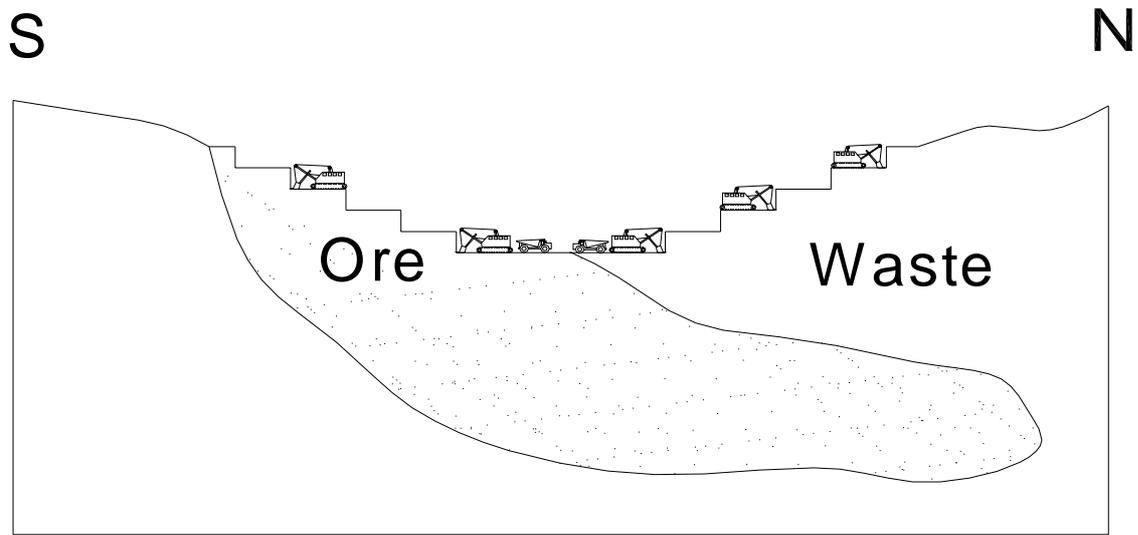


Figure 2: A vertical profile of open pit and the ore body situation.

Dump Trucks and routes

We have to calculate the number of trucks we need and determine the daily schedule for their assignment to loading points. Each dump truck has 120 tones capacity for transporting ore to mineral processing facility or waste to the waste dump. The optimization problem arises here, that we have to decide exactly which loading point the trucks have to go, how many times a day, from which route? Finding the optimum answer for this question can guide us to buy optimum number of trucks and schedule them for right routes. This can contribute to a significant saving in investment and operational costs in this mine.

The possible routes that dump trucks can work in are as shown in figure 3:

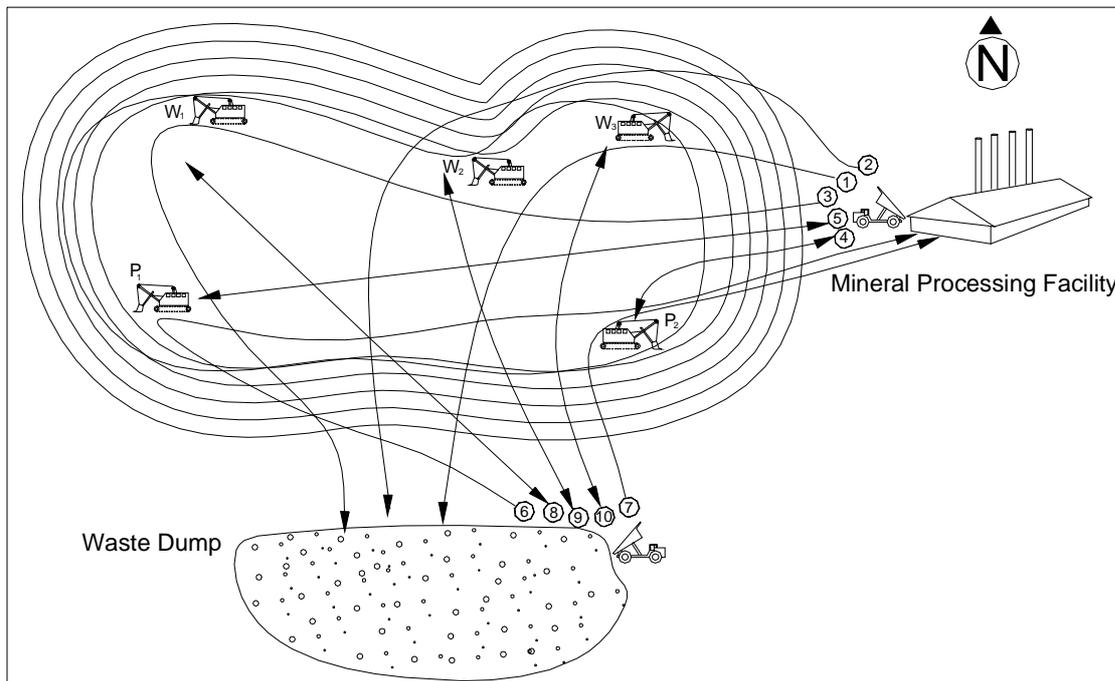


Figure 3: Routes, origins and destinations of materials

10 routes for dump trucks are illustrated in this figure, each is assigned a number, circled at the beginning of the route and they are explained as follows:

Route No.1: Start unloaded from "Mineral processing facility", go to point W3, load waste and go to unload it into the "Waste Dump".

Route No.2: Start unloaded from "Mineral processing facility", go to point W2, load waste and go to unload it into the "Waste Dump".

Route No.3: Start unloaded from "Mineral processing facility", go to point W1, load waste and go to unload it into the "Waste Dump".

Route No.4: Start unloaded from "Mineral processing facility", go to point P1, load ore and return back to unload it into the crusher of "Mineral processing facility".

Route No.5: Start unloaded from "Mineral processing facility", go to point P2, load ore and return back to unload it into the crusher of "Mineral processing facility".

Route No.6: Start unloaded from "Waste Dump", go to point P1, load ore and go to unload it into the crusher of "Mineral processing facility".

Route No.7: Start unloaded from "Waste Dump", go to point P2, load ore and go to unload it into the crusher of "Mineral processing facility".

Route No.8: Start unloaded from "Waste Dump", go to point W1, load waste and return back to unload it into the "Waste Dump".

Route No.9: Start unloaded from "Waste Dump", go to point W2, load waste and return back to unload it into the "Waste Dump".

Route No.10: Start unloaded from "Waste Dump", go to point W3, load waste and return back to unload it into the "Waste Dump".

These routes connect all loading points to both "Waste Dump", and "Mineral processing facility". Now we have to decide which set of these routes are the best solutions for our problem. For example, we can consider a question: is it better that a truck works between point P1 and "Mineral processing facility", transporting ore to the crusher, or that's better to send trucks that have unloaded waste into the "Waste Dump" to load ore from this point? Or a combination of them is a better solution? If so, how many truckloads from each route?

To answer these questions we have to know the time each truck spends to go through these routes. The following figures are calculated according to the manufacturer's information, topographical maps, and design documents:

Route No.	Time for passing the route (min)	Maneuver for loading (min)	Loading (min)	Maneuver for unloading (min)	Unloading (min)	Total cycle (min)
1	13	1	3	1	1	19
2	15	1	3	1	1	21
3	16	1	3	1	1	22
4	8	1	3	1	1	14
5	24	1	3	1	1	30
6	17	1	3	1	1	23
7	15	1	3	1	1	21
8	8	1	3	1	1	14
9	14	1	3	1	1	20
10	23	1	3	1	1	29

A schedule or dispatching system is required to assign the empty trucks to proper destination. This system checks the status of each truck and shovel and as soon as a truck status is "free" assigns it to a shovel that will be free when the truck receives there. If all shovels are busy when the truck receives them, the dispatcher system selects the shovel with minimum waiting time.

Requirements Analysis

The problem is analyzed using Software Stability Model techniques, with UML notation to come up with analysis artifacts: Use Cases, CRC Cards, Class Diagram, Sequence Diagram, and State Transition Diagram. In this section we discuss the traditional and stability model, then review the stability and state transition diagrams and CRC cards.

Class Diagram: The Traditional and Stable Models

The traditional model in figure 4 illustrates how the transport system works. There is extracted "Ore" in "Ore Extraction Openings" and also "Waste" rocks in "Waste Removal Openings", that have to be transported to "Mineral Processing Facility" and "Waste Dumps" respectively. "Dump Trucks" are assigned to these openings according to a "Schedule" and there are "Shovels" to load these "Ore" and "Waste" into these trucks. Every truck continues the daily work until its quota of that day is fulfilled and then stops transport and returns to the parking. Based on the rocks available or considered for loading in every ore extraction opening or waste removal opening, every Shovel works until the daily assigned work is fulfilled.

This model is not stable; most of the objects in the model are industrial objects. If there is any technological change, the model will not be viable. Consider the situation that there are two different kinds of "Ore", "Oxide" and "Sulfide" of a metal, like Copper. These two kinds of ore have to be transported to two different destinations, the "Sulfide" is transported to the "Mineral Processing Facility" for further process and the "Oxide" is piled up in a depot to be processed later.

Another issue may be a situation that there is no more waste rock for removing. In this case, we will miss the objects "Waste", and "Waste Dump" from the model. If we extend the scope of the problem to a general transport system in mining industry, there are transport methods that don't use "Dump Trucks" and mechanical "Shovels". One of these methods is using the combination of "Front-end Loaders", "Semi Mobile Crushers", and "Conveyor Belts". Loaders fill their buckets from materials and feed the semi mobile crusher that crush the rocks to a proper size for conveyor belt, and the extendible conveyor belt moves materials to the destination.

There is still more than identifying industrial objects and business objects in the problem. Looking at the problem statement, we can easily identify the concept of "Transportation" that is the purpose of our activities. Another important theme of the problem, the one that all the efforts are about, is "Efficiency". The concept of efficiency encounters optimization of resource usage, one of our initial goals to provide a time and money saving system. Another important theme of the problem is availability. Consider the relation between different components of the transport system; they are assigned to work together when they are available. The concept of availability is conceived here.

If we group "Industrial objects" to find out about the "Enduring Business Themes" and "Business Objects" we can consider all different types of "Ore" and "Waste" as "Material". The role of "Ore Extraction Openings" and "Waste Removal Openings" that yield "Ore" and "Waste" respectively, is the "Origin" of materials that have to be transported to some "Destination". This

destination can be "Mineral Processing Facility", "Waste Dump", or a "Depot of a different kind of ore" but as far as the transport system concerns, that is a "Destination".

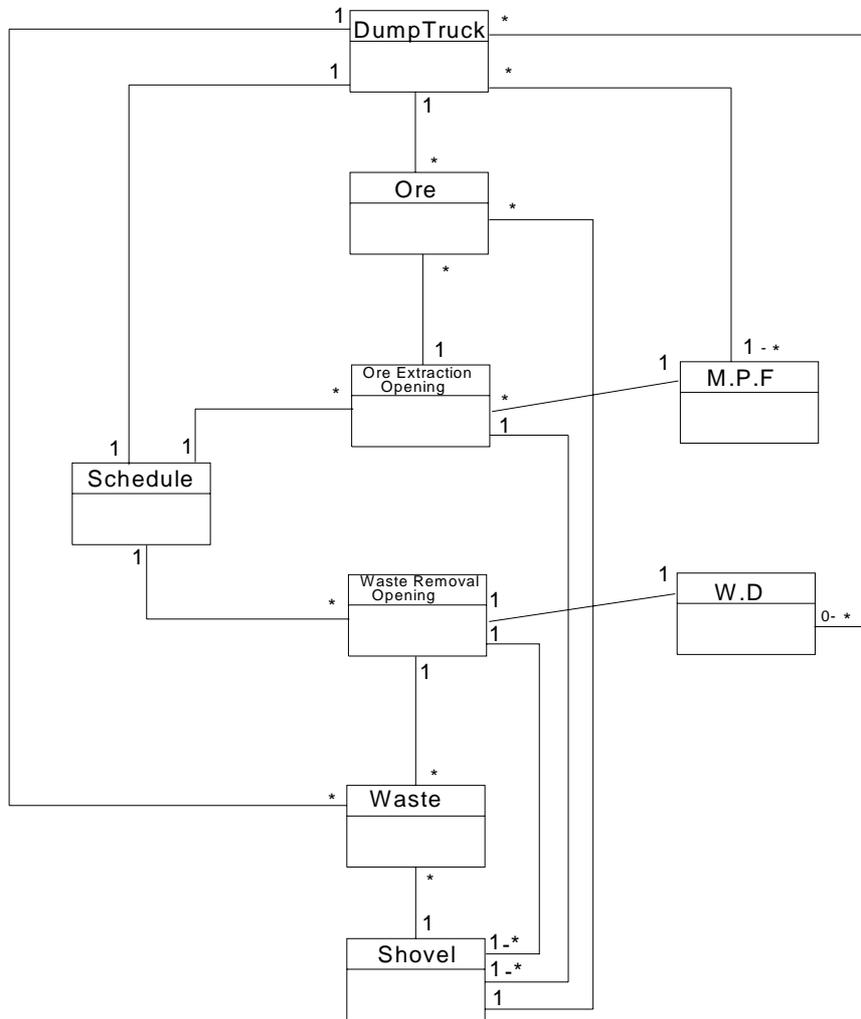


Figure 4: The Traditional model of transport system

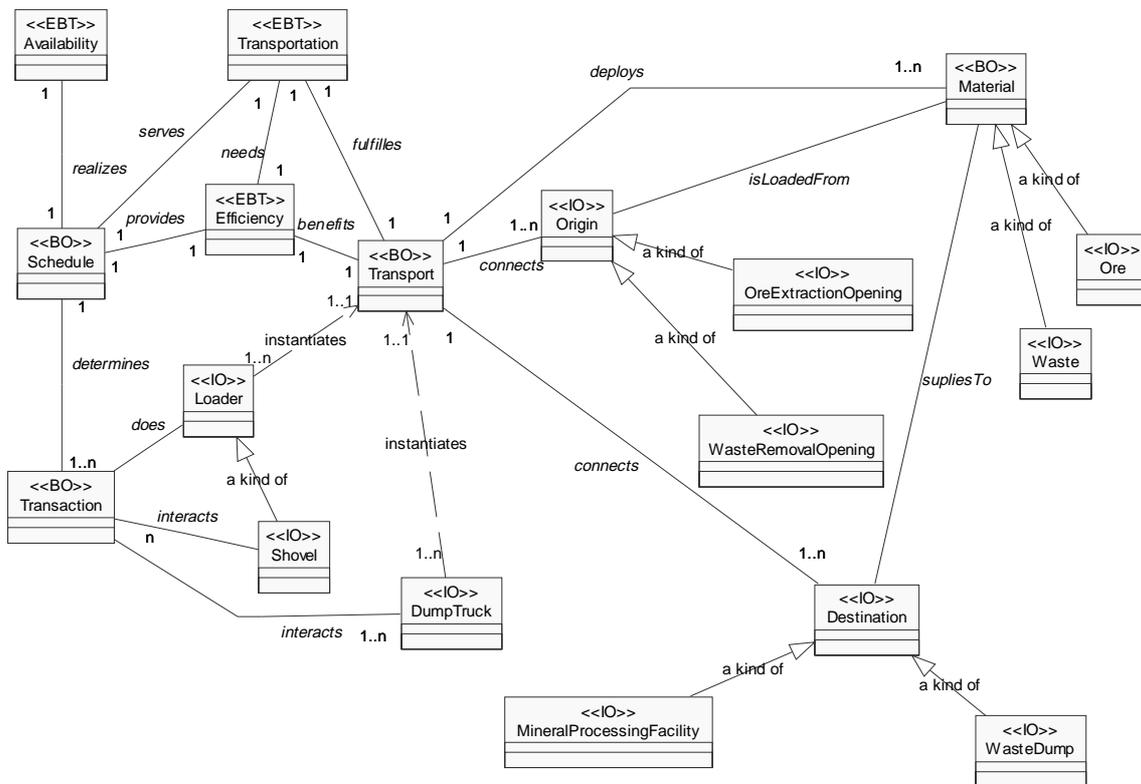


Figure 5: The Stability Model

Sequence and State Transition diagrams:

In sequence diagram transport machines start work by checking the schedule and check their tasks. Schedule assigns tasks by checking the shovels' status and oncoming time, in other word their availability, when the truck will arrive to the loading spot. After assigning task to a truck, they reserve time of the shovel for loading so that no other vehicle is in the same site at the same time. After doing all the steps for loading, materials are supplied to destinations and cycle is finished. Trucks then start another cycle by checking the schedule. The sequence is illustrating interactions between objects within the problem domain.

The state diagram is showing the sequence of states the objects assume during their lifetime. The situation is reflecting the stable model and the major activities are focused.

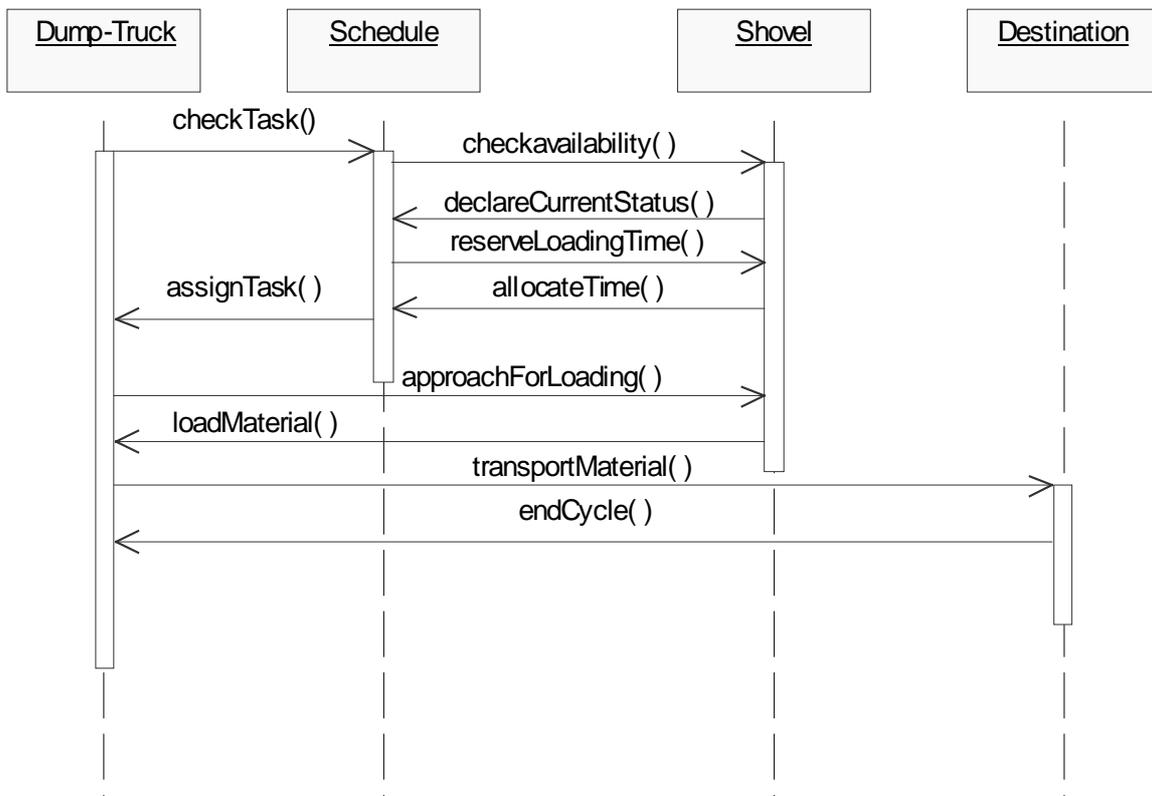


Figure 6: Sequence diagram

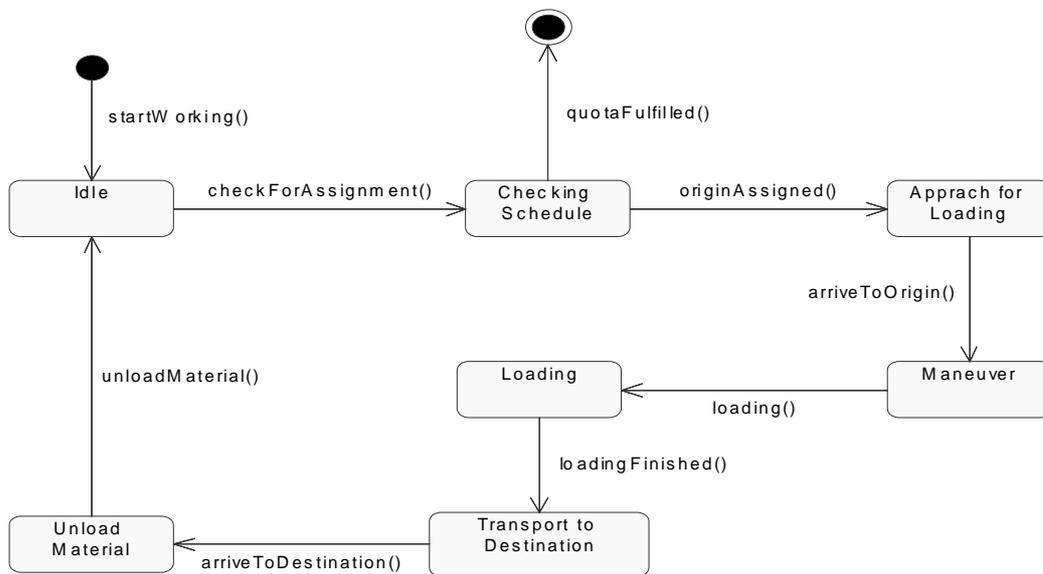


Figure 7: State Transition Diagram for Dump Trucks

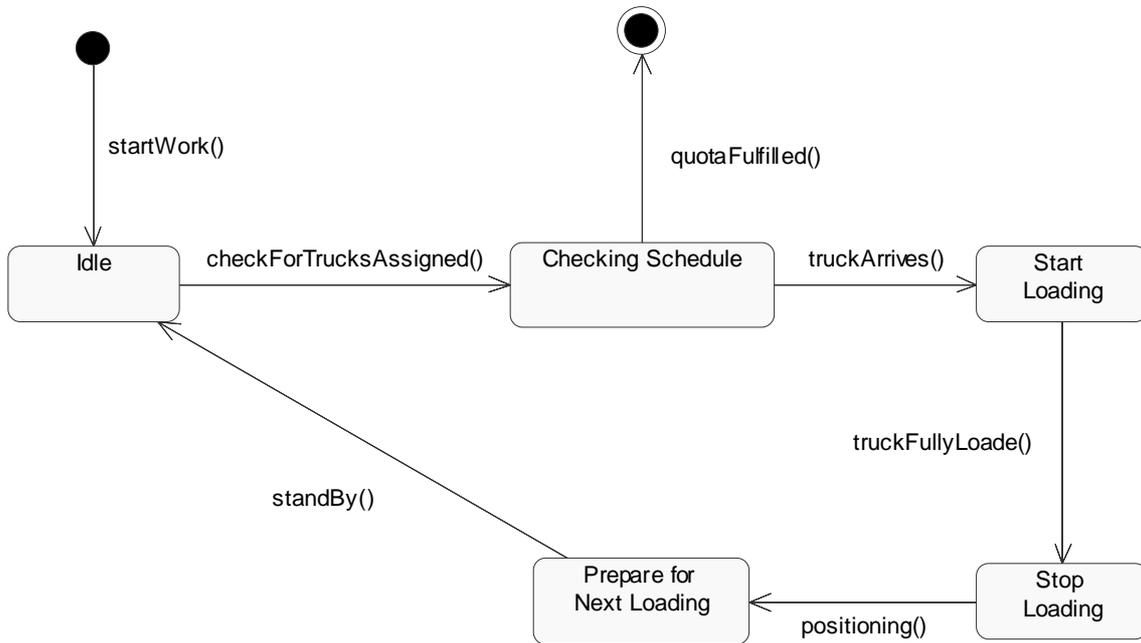


Figure 8: State Transition Diagram for Shovels

CRC cards:

CRC cards display the name of class besides the role of that enclosed in parentheses in the first top column(i.e. Dump Truck(transport materials)). Right column in the second row is the head-column for class responsibilities, which in case of class DumpTruck is “Transport Material”. Collaborations of the class are listed in the right side of the table. The “Clients” column lists the classes that act as “Client” for the class, that are “Transport” and “Availability” in case of “DumpTruck” class. And the last column in the right, lists actions that the class performs to serve the client classes. In the example of “DumpTruck” class, these actions are “transport()”, getAssignment(), interact(), and “declareStatus()”.

Dump Truck (transport materials)		
Responsibilities	Collaborations	
	Clients	Server
<ul style="list-style-type: none"> • Transport Material (to W.D & M.P.F) 	<ul style="list-style-type: none"> • Transport • Availability • Transaction 	<ul style="list-style-type: none"> • transport() • declareStatus() • getAssignment() • interact()

Shovel (Load materials)		
Responsibilities	Collaborations	
	Clients	Servers
<ul style="list-style-type: none"> • Load dump trucks 	<ul style="list-style-type: none"> • Transport • Availability • Transaction 	<ul style="list-style-type: none"> • load() • declareStatus() • getAssignment() • interact()

Schedule (check availabilities and assign tasks)		
Responsibilities	Collaborations	
	Clients	Server
<ul style="list-style-type: none"> • Assign available dump trucks to available shovels 	<ul style="list-style-type: none"> • Transaction • Efficiency • Availability 	<ul style="list-style-type: none"> • assignTask() • trackStatus() • reserveTimeSlots()

Material (Being transported by the system)		
Responsibilities	Collaborations	
	Clients	Server
<ul style="list-style-type: none"> • Provide materials to be transported 	<ul style="list-style-type: none"> • Transportation • Origin • Destination 	<ul style="list-style-type: none"> • suppliesTo() • isLoaded() • yieldMaterial()

Origin (provide point of loading materials)		
Responsibilities	Collaborations	
	Clients	Server
<ul style="list-style-type: none"> • Place of loading 	<ul style="list-style-type: none"> • Material • Transport 	<ul style="list-style-type: none"> • provideMaterials() • declareDistance()

Destination (destination of materials)		
Responsibilities	Collaborations	
	Clients	Server
<ul style="list-style-type: none"> Accept material from dump trucks 	<ul style="list-style-type: none"> Material Transport 	<ul style="list-style-type: none"> demandMaterial() Declareistance()

Efficiency (arrange transport in an efficient manner)		
Responsibilities	Collaborations	
	Clients	Server
<ul style="list-style-type: none"> Optimize utilization of machinery and time 	<ul style="list-style-type: none"> Transport Schedule 	<ul style="list-style-type: none"> estimateTime() reserveTimeSlot() trackAvailability()

Use Cases:

UC1.1- All dump trucks are going to start their work shift. They have to be assigned to different origins of loading to load ore or waste and transport them to destinations.

Actors:

Dump truck, Schedule, Shovel, Ore, Waste.

Roles:

Dump truck: Transports ore to M.P.F or waste to W.D

Schedule: Checks the status of shovels and Assigns dump trucks to the right shovel

Ore: A pre determined amount of that is transported to M.P.F

Waste: A pre determined amount of that is transported to W.D

Types: Transport, Material, Origin, Destination

Interfaces for Types:

Transport: getOreVolume, getWasteVolume, removeWaste, supplyOre,

Material: typeOfMaterial, dailyTonnage, distanceFromDestination

Destination: typeOfMaterial, dailyTonnage

Classes: Schedule, Transport, Transaction, Efficiency, Availability, DumpTruck, Shovel, Ore, Waste, WasteDump, MineralProcessingFacility, OreExtractionOpening, WasteRemovalOpening.

Enduring Business Themes: Transportation, Efficiency, Availability

Business Objects: Transport, Schedule, Transaction, Material

Industrial Objects: DumpTruck, Shovel, Origin, Destination, Waste, Ore.

Attributes:

- Dump_Truck: Travel_Time_Loaded, Trave_Time_Empty, Capacity, ManeuverTime, UnloadingTime
- Shovel: BucketCapacity, LodingCycleDuration, DistanceFromWD, DistanceFromMPF
- MineralProcessingFacility: DailyTonnageOre
- WasteDump: DailyTonnageWaste
- Schedule: Time, Origin, Destination
- Ore: DailyTonnage
- Waste: DailyTonnage

After arriving to the loading point, every truck spends one minute for maneuver and positioning before shovels start loading. The next truck(s) arriving to the same point will line up for loading that takes three minutes for each of them. Schedules have to send dump trucks in a way that the total time they spend in lines is minimized.

UC1.2- A dump truck has arrived to the mineral processing facility and unloaded ore into the crusher of this site. This dump truck will be assigned to a shovel to load either ore or waste. A similar use case would be for a truck that has arrived to the waste dump and is ready to start a new transport cycle.

Actors:

Dump truck, Schedule, Shovel, Ore, Waste.

Roles:

Dump truck: Transports ore to M.P.F or waste to W.D

Schedule: Assign DumpTrucks, checks the materials already transported to destinations plus the material that will be transported by dump trucks in the way and if the volume is enough, stop transport operation.

Ore: A pre determined amount of that is transported to M.P.F

Waste: A pre determined amount of that is transported to W.D

Types: Transport, Material, Origin, Destination

Interfaces for Types:

Transport: getOreVolume, getWasteVolume, removeWaste, supplyOre,

Material: typeOfMaterial, dailyTonnage, distanceFromDestination

Destination: typeOfMaterial, dailyTonnage

Classes: Schedule, Transport, Transaction, Efficiency, Availability, DumpTruck, Shovel, Ore, Waste, WasteDump, MineralProcessingFacility, OreExtractionOpening, WasteRemovalOpening.

Enduring Business Themes: Transportation, Efficiency, Availability

Business Objects: Transport, Schedule, Transaction, Material

Industrial Objects: DumpTruck, Shovel, Origin, Destination, Waste, Ore.

Attributes:

- Dump_Truck: Travel_Time_Loaded, Trave_Time_Empty, Capacity, ManeuverTime, UnloadingTime
- Shovel: BucketCapacity, LadingCycleDuration, DistanceFromWD, DistanceFromMPF
- MineralProcessingFacility: DailyTonnageOre
- WasteDump: DailyTonnageWaste
- Schedule: Time, Origin, Destination
- Ore: DailyTonnage
- Waste: DailyTonnage

The next loading point of this dump truck will be one of the shovels that has finished loading either ore or waste into the previous dump truck by the time this one arrives. In other words, there is no waiting time for loading. If all shovels will be busy loading trucks by the time this one arrives, then the dump truck will go to the shovel with minimum waiting time.

UC1.3- All the materials transport goals for the shift is fulfilled and the operation have to stop.

Actors:

Dump truck, Schedule, Shovel, Ore, Waste.

Roles:

Dump truck: Transports ore to M.P.F or waste to W.D

Schedule: Assign DumpTrucks, checks the materials already transported to destinations plus the material that will be transported by dump trucks in the way and if the volume is enough, stop transport operation.

Ore: A pre determined amount of that is transported to M.P.F

Waste: A pre determined amount of that is transported to W.D

Types: Transport, Material, Origin, Destination

Interfaces for Types:

Transport: getOreVolume, getWasteVolume, removeWaste, supplyOre,

Material: typeOfMaterial, dailyTonnage, distanceFromDestination

Destination: typeOfMaterial, dailyTonnage

Classes: Schedule, Transport, Transaction, Efficiency, Availability, DumpTruck, Shovel, Ore, Waste, WasteDump, MineralProcessingFacility, OreExtractionOpening, WasteRemovalOpening.

Enduring Business Themes: Transportation, Efficiency, Availability

Business Objects: Transport, Schedule, Transaction, Material

Industrial Objects: DumpTruck, Shovel, Origin, Destination, Waste, Ore.

Attributes:

- Dump_Truck: Travel_Time_Loaded, Trave_Time_Empty, Capacity, ManeuverTime, UnloadingTime
- Shovel: BucketCapacity, LadingCycleDuration, DistanceFromWD, DistanceFromMPF
- MineralProcessingFacility: DailyTonnageOre
- WasteDump: DailyTonnageWaste
- Schedule: Time, Origin, Destination
- Ore: DailyTonnage
- Waste: DailyTonnage

The next loading point of this dump truck will be one of the shovels that has finished loading either ore or waste into the previous dump truck by the time this one a/rives. In other words, there is no waiting time for loading. If all shovels will be busy loading trucks by the time this one arrives, then the dump truck will go to the shovel with minimum waiting time.

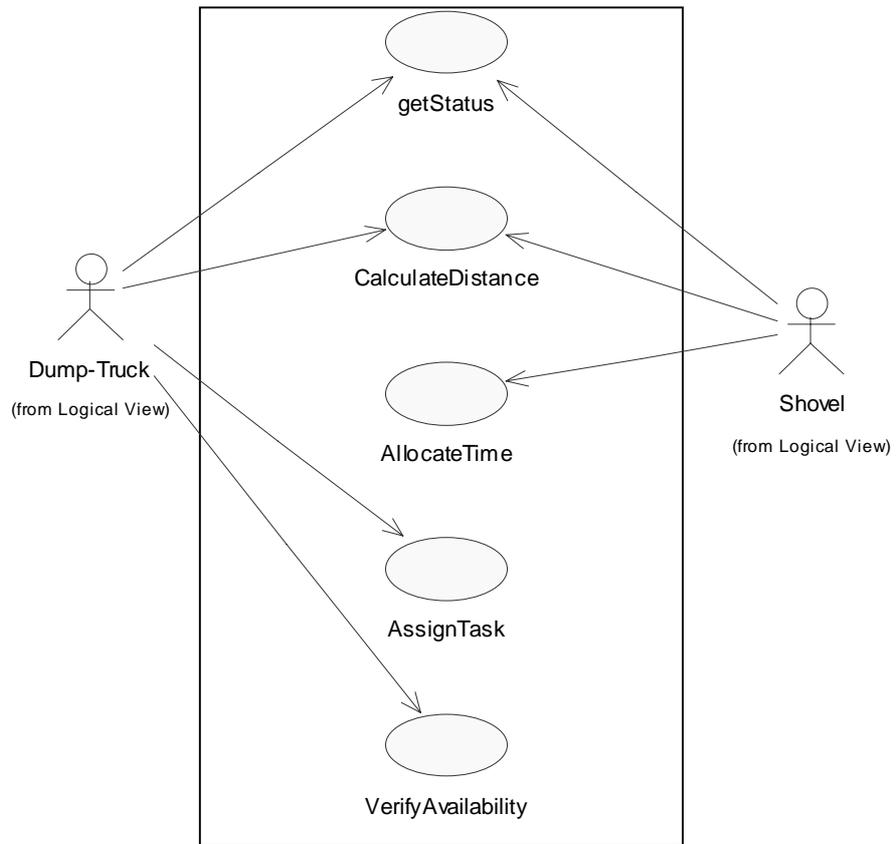


Figure 9: Use Case View