SOLVING WOOD CHIP TRANSPORT PROBLEMS WITH COMPUTER SIMULATION

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Efficient chip transport is the key to marketing wood chips produced in the field. Yet efficiency is an elusive objective because of constantly changing harvesting location and other factors. Ideally, one should alter the amount and organization of transport equipment as chipping rate, distance to mill, mill quota, or other factors change. But the high cost of trucks and vans requires that most loggers decide upon a combination of men and machines that best fits their average conditions. Although contract haulers or truck rental and leasing arrangements are often available to help adjust to unforeseen needs, the problem of "how much" still remains. The "seat-of-the-pants" calculations and actual trials currently employed are always confusing, and many good alternatives are not considered because of the practical and economic difficulties of assembling the desired equipment under the proper conditions.

In an effort to alleviate this situation, we describe here a chip transport model or simulator that will allow a logger to realistically and economically determine the best way to get his daily trucking job done. Two examples illustrate the use of this model. Although designed for problems unique to chip trucking, the simulator can be used for almost any sort of wood trucking system.

THE ADVANTAGES OF SIMULATION

This simulator is a computer program that dynamically models all the essential actions and reactions of real chip transport systems. Everyone is familiar with model bridges and airplanes and their advantages in developing efficient and practical real structures. Our simulator is a model in the same sense but is concerned with the "structure" of men, equipment, and work rules.

As with any model, its main advantage is its ability to predict how a similar configuration of the real system will perform. But chip transport system simulation has several other related advantages.

First, the incredible speed of computers allows us to compress months of simulated activity into a few minutes of real time, and many different system alternatives and configurations can be examined in a fraction of the time and cost of one real experiment.

Second, simulation is flexible: the kinds of systems modeled are limited only by the user's imagination. In contrast to a bridge, which once designed and built will not be changed, a chip transport system must be able to respond to external changes in order to stay profitable. Thus, the simulator should be used each time some significant factor changes. These factors may range from distance to market to the availability of more economical trucks and trailers.

Third, the simulator allows a user to visualize the interactions of entire systems. For example, the time that one operation or piece of equipment must wait for another often suggests what changes to make. But the principal criterion for identifying system improvements is cost. Because the simulator constructs a cost record for each process and piece of equipment, cost effective changes are easily seen.

The simulator cannot tell the logger what is best in one step. It predicts how the real system will perform under a specific set of conditions: conditions such as the number of trucks and vans available, truck and van costs per hour, driving time to the mill, truck starting times each morning, and the value of a van of chips. If the logger is not satisfied with predicted profits or production under the specified conditions and work rules, he can change those conditions under his control and run the simulator again and again.

In effect, this simulator is a crystal ball for discovering unsuspected opportunities. But achieving all the advantages of this powerful tool depends a great deal on its proper use. There are two major requirements. First, a user must become familiar with the model, because studying

the model can uncover things he didn't understand about his real system as well as make him aware of any model limitations. Obviously, the model is not the "real world" but the user should be satisfied that its limitations are acceptable. If not, the model should be changed to conform to his expectations.

Second, a user must test the simulator against his own experience. If the model correctly predicts system performance under known conditions, the user will feel more confident in adopting its recommendations under new, untried situations. Of course, some caution is necessary: several small changes from known conditions are safer than one large change. For example, one would have more confidence in the results predicted by adding one more van than in the results predicted by adding four more vans and two new trucks, unless the intermediate changes had also been tested.

THE CHIP TRANSPORT SIMULATOR

This simulator is written in GPSS, or General Purpose Simulation System, developed by IBM.[1] Originally limited to their equipment, it is now available on most medium and large computers.

Although any computer language requires some effort to learn and apply, this language is especially oriented toward the users. As a result, it is the most widely used simulation language today. No computer program can claim to fulfill all demands placed on it, but we have attempted to provide a great deal of flexibility. And the use of GPSS has made it intrinsically easy for any other user to modify the program to his own needs.

The program itself is available to any interested individual or organization and is documented. For copies, write to:

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North Central Forest Experiment Station
Forest Hill Road, Michigan Technological Univ.
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118 Old Main Bldg.
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[1] *International Business Machines, Inc. 1971. General Purpose Simulation System V Users Manual. SH20-0851. 422 p. White Plains, New York.*

Our model has five interactive segments corresponding to the real system's division of activity: (1) a chipper, (2) trucks and vans, (3) setout trucks, (4) a mill yard, and (5) records.

The Chipper

This segment models the functions of a chipper, filling empty vans with chips, closing them, and moving the chip spout if necessary. A logger must provide the following information for this segment: (1) the time required to fill a van, (2) the time required to close a full van, (3) the time required to move the chip spout, and (4) the number of slots for empty vans in front of the chip spout.

Note that the time required to fill a chip van lumps all the felling, skidding, and chipping activities into what can be termed a "black box". That is, if we say that the chipper fills a van in 35 $\pm$ 10 minutes, we mean that van filling time can vary from 25 to 45 minutes due to unspecified variation in felling, skidding, and chipping rates. This time estimate says nothing about how this rate is achieved, just that it *is* achieved. This is not to say that felling and skidding are unimportant, but the purpose of this simulator is to find the *best combination of men, trucks, vans, and rules to optimize trucking activity for the observed chipping rate.*

The question of slots for vans under the chipper's spout is also important in this model. Some chippers have chip spouts that can be moved to fill more than one van without moving vans and thus have several "slots". Other chippers have only one "slot" and, once a van is filled must wait for it to be removed and another empty moved into place. This feature greatly affects the use of trucks, vans, and setout trucks and will be discussed in the trucking segment.

Trucks, Vans, and Setout Trucks

These two segments have the job of moving full vans from chipper to mill. The number of trucks, setout trucks, vans, and hauling distance are the major factors affecting productivity.

Three different trucking situations are identified in this model and are distinguished primarily on how setout trucks, if

used, interact with the highway trucks. In the first, a setout truck is never used; in the second, setout trucks are used only when necessary because the incoming highway trucks can do much of the handling; and in the third, setout trucks are used exclusively for van handling. In addition, the model distinguishes between chippers with only one slot in front of the spout and chippers with two or more slots.

The logger must provide the following information for the trucking segment:

(1) number of trucks
(2) truck cost per hour including labor
(3) number of vans
(4) van cost per day
(5) number of setout trucks
(6) setout truck cost per day
(7) truck travel time, loaded and empty, to and from the mill
(8) time required for a truck or setout truck to hook up to and unhook from a van
(9) time required for a truck or setout truck to move between the empty van storage area, full van storage area, and slots at the chipper
(10) For the setout truck when there are two or more slots:
a. The number of empty vans in slots which the chipper must have in reserve
b. The number of slots that can be occupied by full vans before they "get in the chipper's way"

The Mill Yard

This segment models all the actvities at the mill yard that determine how much time the logger's own trucks spend there being weighed, unloaded, and waiting for these services because of the competition from other trucks arriving at the yard.

Although all these activities can be modeled in great detail, they are usually beyond the control of the logger. As a result, this segment is modeled similar to the chipper and lumps all activities into the time required to complete all mill yard activities and start on the return trip to the landing. The logger must specify this time.

The Record Segment

This segment starts and stops the other segments each day according to the schedule provided by the user and prints a daily summary of each segment's activities. The following information must be provided by the user:

1. Time each segment starts work each day.

2. Time each segment quits for the day:
   a. After achieving a production quota?
   b. After a specific elapsed time?

How to Use the Simulator

Each user must provide all the above statistics for his conditions. Equipment and decision rules can be chosen for his existing operation or for any system he wishes to examine. Time data are a bit more complicated. At one extreme, he can make rough estimates based on his experiences; at the other, he can make elaborate time studies of each operation.

Rough estimates may give some feel for the sensitivity of the model to certain operations. For example, a proportionately large error in estimating the time to move the chip spout from one van to another would probably have little effect on overall model accuracy while a small proportionate error in estimating travel speed to the mill could be serious. So data collection effort should be allocated to those data requirements that are most critical.

With his set of data, the user can then "run" the model for a desired length of time or until a desired production quota is reached. At this point the report of how much was produced, at what cost, and other features describing machine utilization and interaction can be examined for clues on how to improve system performance.

Many kinds of chip trucking problems can be solved using this simulator: What is the best combination of trucks and vans? How many setout trucks should I buy? Should I lease or buy additional trucks and vans? Can I alter work schedules to increase production or reduce costs? Is there an optimum truck and van size? How are hauling costs affected by distance to market? What effect does distance to mill have on the number of trucks and vans needed? The following examples of the use of our model

should give some idea on how the whole process works.

EXAMPLE NUMBER 1--A CASE STUDY

A timber producer has a full-tree chipping operation that annually produces nearly 30,000 tons of aspen chips for a hardboard plant more than 3 hours driving time away. To deliver his quota of eight loads a day, he developed (without benefit of simulation) a system using four trucks and eight vans plus one setout truck at the landing. At 6 a.m. all trucks begin their first trip to the mill with vans filled the previous day. At 7 a.m. the chipper and setout truck begin to fill the remaining four vans to be hauled that afternoon. When these four have been filled, the chipper is idle about 2 hours until one of the first four vans returns from the mill. The first four vans are then filled for the next morning's haul.

Because the chip spout was not very flexible, the single full van had to be pulled away and an empty van positioned before chipping could resume. Thus, although the chipper filled a van in an average of 28 minutes, another 26 minutes were consumed by the setout truck in removing the full van and bringing another empty, a total of 54 minutes. Given a 9-hour workday, his system was operating very near capacity considering refueling, normal maintenance, and knife changing. Even if his production quota were raised by the mill, his operation could not have supplied much extra wood without major changes.

Although there were many possible changes the logger could have considered, such as designing a more flexible chip spout, working a longer day, or even adding another shift, he chose to see if he could reduce the setout truck's van handling time. A simple suggestion was to add another setout truck. With a second setout truck already waiting with an empty van, it could move in as soon as the first setout truck removed the full van.

Thus the problem we examined with the simulator was this: would the addition of another setout truck be a cost-effective way to increase production? To answer this question, the logger ran a time study of his operation. The results of his study were as follows:

Record Segment

Chipper work day--Begin at 7 a.m. and work until eight vans are filled with chips.

Truck scheduling--All trucks begin at 6 a.m. from garage, travel to landing for first full van, complete two round trips and finish at garage for night.

Cost and value (dollars).

Trucks, including labor	21.00/hour
Vans, each	1.80/hour
Setout trucks, each	1.80/hour
Chipper, including labor	50.00/hour
Value of chips	250.00/van

Chipper Segment	*minutes*
Fill the van	28
Close the van	5

Trucking and Setout Truck Segments	*minutes*
Travel time on landing from van storage to chipper or return	5
Back into the slot	7
Move out of the slot	3
Hook up to a van	10
Drop a van	7
Travel time on highway:	
Garage to landing--empty	47
Landing to mill--loaded	187
Mill to landing--empty	192
Mill to garage--empty	145

Mill Segment

Time spent in mill yard activity	54

Although we show only average times for simplicity's sake, the data varied as would be expected in any real operation. Our model includes this variation, an important feature of any simulation.

Using these time data, 2 weeks of operations were simulated: the first week with one setout truck, and the second week with two. Instead of changing the production quota, however, we simply compared the times for both weeks that would have been available for more chipping if the mill would have purchased the wood and if additional vans and trucks were acquired. The results were as follows:

	One setout truck	*Two setout trucks*
Chipper time per day--all activities required to fill eight vans	8.99 hr	8.92 hr
Chipper time per van:		
Filling vans	28.43 min	28.43 min
Waiting for another empty van	25.63 min	10.22 min
Total	54.06 min	38.65 min
Chipper time per day waiting for trucks to bring more empties	1.78 hr	3.77 hr
Additional production if chipper was used to fill vans	1.97 vans	5.85 vans
Net revenue per trip	$ 25.52	$ 22.76
Net revenue for eight trips	$204.16	$182.08
Net revenue if additional vans were filled and hauled to market	$254.43	$315.23

The simulator demonstrated that even if more chips could be sold, the use of a single setout truck could allow daily revenue (excluding felling, skidding, and all other costs) to increase by only 25 percent. On the other hand, adding an inexpensive second setout truck would enable daily net revenue to increase by 54 percent. This happened because the second setout truck reduced the time that the chipper spent waiting for another empty van from 26 to 10 minutes. And this reduction in wasted time increased the time available for more chipping from 1.78 hours to 3.77 hours per day.

Although the net revenue per trip is less for the second week because of the second setout truck's cost, total profits could be larger.

Admittedly, this is a fairly simple problem and simulation may not even have been required. Yet this actual case allowed the logger to see how realistic simulation can be and he is now interested in trying simulation on the more complex aspects of his operations. (The Appendix contains the two summaries of cost and activity provided by the simulator for this example.)

EXAMPLE NUMBER 2--A HYPOTHETICAL CASE

A second example represents a general problem faced by all chip truckers: How many trucks and vans do I need? This question can be answered easily by simulation but there are really two different answers depending on the size of the logger's market for chips. If he can sell all the chips he can produce, he will get one answer. But if he is limited to a quota, the best combination of trucks and vans will be different.

Our logger has a full-tree chipping operation located about 50 minutes from the mill. His chipper can fill a van in about 28 minutes and works a 10-hour day. But unlike our first example, there are three slots for vans in front of his movable chip spout. This means that the chipper may not have to wait for another empty van. If the single setout truck has already placed another empty van in an adjacent slot, only the chip spout has to be moved.

Incoming trucks first try to drop their empty vans in a slot at the chipper. If these are already occupied, they will drop the van at the storage area if there are full vans ready to haul to the mill. If not, they will stay attached to the van and wait for a slot to open. Other features of the operation such as costs, mill yard activity, and the operation of a single setout truck are similar to the first example.

This logger would like to know, given the current chipping rate and distance to the mill, how many trucks and vans should he use.

Using the information describing his operation, we used the simulator to operate the system for 20 different combinations of trucks and vans (table 1). Four items are displayed: (1) average number of trips per day, (2) gross revenue per day, (3) truck, van, setout truck, and chipper cost per day, and (4) net revenue per day (excludes felling and skidding costs).

To emphasize the point made earlier, how one looks at this information depends on the situation.

The Logger can Sell as Much as He Produces

In this case the logger is concerned with net revenue per day. As each van is added, both the chipper and trucks spend less time waiting. But like most good things, the improvement can only go so far.

Table 1.--*Simulated gross revenue, cost, and net revenue per day for several truck and van combinations*
(In dollars)

Vans (number)		Trucks (number) 4	5	6	7	8
4		(14.5)[1]				
	G	3,625				
	C	1,447				
	N	2,178				
5		(15.5)	(17.40)			
	G	3,888	4,350			
	C	1,465	1,665			
	N	2,422	2,685			
6		(15.85)	(18.60)	(20.05)		
	G	3,963	4,650	5,013		
	C	1,483	1,683	1,883		
	N	2,480	2,967	3,130		
7		(15.90)	(19.05)	(21.75)		
	G	3,975	4,763	5,438		
	C	1,501	1,701	1,901		
	N	2,474	3,062	3,537		
8			(19.10)	(22.10)		
	G		4,775	5,525		
	C		1,719	1,919		
	N		3,056	3,606		
9				(22.10)	(24.25)	
	G			5,525	6,063	
	C			1,937	2,112	
	N			3,588	3,951	
10					(24.40)	(24.60)
	G				6,100	6,150
	C				2,130	2,305
	N				3,970	3,845
11					(24.50)	(24.45)
	G				6,125	6,113
	C				2,148	2,323
	N				3,971	3,790
12					(24.50)	(24.50)
	G				6,125	6,125
	C				2,166	2,341
	N				3,959	3,784
13						(24.40)
	G					6,100
	C					2,359
	N					3,741

[1]Number in parentheses = average number of trips per day; G = gross revenue; C = cost; and N = net revenue.

For example, with five trucks, the addition of an eighth van doesn't help at all because the maximum productive potential of these five trucks in a 10-hour day was reached with seven vans. The eighth van merely increases costs.

However, the productive capacity of the chipper has not been achieved yet. Five trucks and 7 vans can only move 19 vans per day while the chipper could theoretically produce 24 (600 min/day ÷ 25 min/van). To reach this point, more trucks and vans must be added.

The best combination under these conditions is found at 7 trucks and 11 vans. Net revenue is at a maximum because the productive capacity of both chipper and trucks has been reached.

The Logger is Limited to a Quota of 20 Trips per Day

It should be apparent that because gross revenue is now limited to $5,000 (20 trips, $250/trip), the logger must find that combination of trucks and vans that can reach this goal at minimum cost. Note also that in table 1, truck, van, setout truck, and chipper cost for each combination is fixed whether the equipment is used to its potential or not.

Therefore, the best combination under a quota is the cheapest combination that can meet or exceed the quota. In this case it is six trucks and six vans. No smaller number of trucks regardless of vans can make 20 trips per day and adding a seventh or eighth van or more trucks is futile because we are not interested in wasted chipper time now, just minimum cost. Net revenue under this combination is $3,117 and no other can achieve the quota and earn more.

This example, though simple, shows the ease with which production functions can be determined by simulation.

APPENDIX.--ACTUAL SIMULATOR REPORTS OF THE CHIP TRUCKING OPERATION USED IN THE EXAMPLE

One Setout Truck

System Characteristics

Chipping

Chipper cost per hour including labor: $49.80

Number of slots: 1

Daily quota of vans to fill and haul to mill: 8

Estimated average time to fill a van with no waiting for wood (minutes): 28

Trucking

Number of trucks: 4

Number of vans: 9

Truck cost per hour including labor (each): $21.00

Van cost per hour (each): $1.80

Van capacity (tons): 25

Value of a van delivered to the mill: $250.00

Estimated average time to haul a van from landing to mill (minutes): 187

Setout trucks

Number of setout trucks: 1

Setout truck cost per hour: $1.80

Setout truck operating rules:

a. Setout truck will move an empty van to the chipper when more than 0 slots are open.

b. Setout truck will move a full van to the storage area when less than 0 slots are open.

Production and cost statistics

General

Total days simulated: 5

Total trips completed to mill: 40

Average number of trips completed per day: 8

Total revenue earned (all trips): $10,000.00

Total cost incurred (all trips): $8,978.96

Net revenue (all trips): $1,021.04

Gross revenue per trip: $250.00

Total cost per trip: $224.47

Attributable to:

Chipper: $55.96

Trucks: $146.01

Vans: $20.25

Setout trucks: $2.25

Net revenue per trip: $25.53

Chipper activity

Average chipper time per day--all activities (hours): 8.99

Average time per day spent waiting for vans to fill (hours): 5.00

Trucking activity

Average trucking time per day--all activities (hours): 13.90

Average round trip time--all activities (minutes): 417

Productive time per trip: 406

Nonproductive time per trip waiting for: 11

A slot to open: .00

Its own attached van to be filled: .00

Its reserved full van to get to the storage area: .00

Its turn to be weighed full or empty: 2.00

Its turn to be dumped: 9.00

Setout truck activity

Average number of empty vans brought to the chipper: 5.20

Average number of full vans brought to the storage area per day: 8.00

Average time per day spent in an idle status (hours): 1.81

Two Setout Trucks

System characteristics

Chipping

Chipper cost per hour including labor: $49.80

Number of slots: 1
Daily quota of vans to fill and haul to mill: 8
Estimated average time to fill a van with no waiting for wood (minutes): 28

Trucking
Number of trucks: 4
Number of vans: 9
Truck cost per hour including labor (each): $21.00
Van cost per hour (each): $1.80
Van capacity (tons): 25
Value of a van delivered to the mill: $250.00
Estimated average time to haul a van from landing to mill (minutes): 187

Setout trucks
Number of setout trucks: 2
Setout truck cost per hour: $1.80
Setout truck operating rules:
Setout truck will move an empty van to the chipper when more than 0 slots are open.
Setout truck will move a full van to the storage area when less than 0 slots are open.

Production and cost statistics

General
Total days simulated: 5
Total trips completed to mill: 40
Average number of trips completed per day: 8
Total revenue earned (all trips): $10,000.00
Total cost incurred (all trips): $9,089.55
Net revenue (all trips): $910.45
Gross revenue per trip: $250.00
Total cost per trip: $227.23
Attributable to:
Chipper: $55.50
Trucks: $146.98
Vans: $20.25
Setout trucks: $4.50
Net revenue per trip: $22.77

Chipper activity
Average chipper time per day--all activities (hours): 8.92
Average time per day spent waiting for vans to fill (hours): 5.00

Trucking activity
Average trucking time per day--all activities (hours): 13.90
Average round trip time--all activities (minutes): 419
Productive time per trip: 407
Nonproductive time per trip waiting for: 12
A slot to open up: .00
Its own attached van to be filled: .00
Its reserved full van to get to the storage area: .00
Its turn to be weighed full or empty: .00
Its turn to be dumped: 12.00

Setout truck activity
Average number of empty vans brought to the chipper per day: 6.20
Average number of full vans brought to the storage area per day: 8
Average time per day spent in an idle status (hours): 7.92

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