UNIVERSITY OF MAINE

THE MAINE AGRICULTURAL EXPERIMENT STATION
ORONO, MAINE

Scheduling of Pallet Trucks in Pulpwood Operations

Thomas J. Corcoran

FOREWORD

Operations research techniques have been utilized to solve a variety of operational problems facing both wood-producing and wood-using firms. One technique which has frequently been applied as a decision-making tool is linear programming. While its forms are many, this publication will present but one in hopes it can provide a reasonably simplified and direct means of solving small scale problems concerning vehicle assignments. It must be cautioned, however, that while a degree of emphasis has been placed on methodology in this writing, the problem is always the focal point of the operations research approach. The technique used is, therefore, determined by the nature of the problem rather than the problem fitted to the technique.

The author wishes to extend his appreciation to the management of the St. Croix Paper Company, Georgia-Pacific Corporation and to officials of other concerns for their cooperation in securing the basic data and photographs used in this study and for their review of the material presented herein.

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CONTENTS

SUMMARY

The use of pallets as a means of bundling pulpwood for delivery to Maine's pulpwood markets has steadily increased in recent years. The pallet hauling system represents but one attempt to reduce the costs involved in the transportation of primary forests products.

A pallet operation promotes efficiency in truck usage, since the loading of the pallet is almost completely independent of the pallet truck. To take full advantage of this potential for efficient usage, proper scheduling of pallet trucks and their pallets should be a goal of pulpwood producers.

This study illustrates a method of scheduling pallet trucks utilizing data obtained from pallet operations in Maine. The method, which is based upon a linear programming technique, can be employed in the determination of the minimum number of trucks required to handle a continuous flow of pulpwood in situations involving multi-pickup and multi-delivery points. In addition, the program establishes times and places of pulpwood pickup and delivery for each required truck.

By accurately defining the needs of pallet operations and by insuring optimal arrangements of pickups and deliveries, the costs attributed to the hauling phase of harvesting-marketing activities can be improved. Capital expenses in the form of trucks and pallets are quite high compared to more traditional trucking methods. The woodland operation that engages more trucks than required in its system bears the burden of these capital expenditures as well as increased operating expenses. Even when truck numbers are kept at a minimum required by the pulpwood operating system, the allocation of trucks between pickup and delivery points can affect the operating costs. The method inclusive in this study suggests a means of optimally scheduling pallet hauling that will be in balance with the other fixed harvesting activities. While directed primarily at scheduling pallet hauling, this methodology may well be adaptable to other forms of forest products transportation.

SCHEDULING OF PALLET TRUCKS IN PULPWOOD OPERATIONS

Thomas J. Corcoran[1]

INTRODUCTION

The hauling phase of a pulpwood operation is a critical activity. It normally contributes a large proportion to the total cost of pulpwood harvesting. This proportion naturally varies with the locality, harvesting system, and operating conditions. However, estimates of 20 to 30%[2] are not uncommon. Since the hauling function is so highly represented in the cost of pulpwood, improvements in hauling practices can result in economies to the woodland operation.

There are a great many methods currently used to move pulpwood from its woodland location to its next echelon of use. This study will consider but one of these, namely, the pallet truck operation.

In Maine the use of truck-borne pallets as a method of handling and transporting pulpwood has steadily increased in recent years, especially for larger operations. With the emphasis on increased mechanization for both small and large pulpwood producers, the potential of pallets incorporated in a mechanized system should not be overlooked.

It is the purpose of this paper to present a method whereby the number of pallet trucks required to handle a continuous flow of pulpwood can be determined for situations involving multi-pickup points and multi-delivery points. This determination will also establish times and places of pulpwood pickup and delivery for each required pallet truck. The methodology involves the use of an operations research technique which will provide those in control of woodland operations with an optimum design for pallet truck scheduling.

PALLET TRUCK OPERATIONS

Pallet truck operation involves the use of pallets, which, when loaded with pulpwood, can be winched on to a truck bed and the pulpwood subsequently delivered at the pulp mill or some intermediate delivery point. As practiced on pulpwood operations in Maine, the pulpwood is normally hand loaded onto the pallet after being yarded in either four-foot, log, or tree length form. In the latter two forms the bucking into pulpwood lengths takes place at the landing and the loading is normally accomplished in conjunction with the bucking process.

Pallets vary widely in their design and consequently in their cord capacity. Pallets have been manufactured which have capacities ranging from 1 to 12 cords. One common type in use on larger pulpwood operations in Maine is illustrated in figures 1 and 2. The average load on this type of steel rack is 8.5 cords. The pallet truck is equipped with power take-off, coupled to the forward mounted winch, and with pallet runs on the truck bed.

The pallet truck system allows the loading of these pallets with

Figure 1. A loaded pallet in initial stages of being winched aboard a pallet truck.

Figure 2. A loaded pallet in final stages of being winched aboard a pallet truck.

pulpwood at the landing without tying up the prime mover during this loading process. The use of pallet trucks is especially applicable where truck-to-stump operations are impossible or not practical. Since the loading of the pallet is almost completely independent of the pallet truck, the efficiency of truck usage can be greatly enhanced. The use of truck-borne pallets where conditions are not prohibitive also has other advantages which provide for possible increases in production volumes as well as reductions in unit costs of delivered wood. These include:

(1) a more effective handling of pulpwood because of the bundling effect of pallets;

(2) a lessening of truck maintenance requirements because the trucks are not exposed to terrain extremes inherent in direct from-the-stump hauling;

(3) an increase in all-weather operating capacity because trucks will normally utilize improved roadways; and

(4) the suitability of pallets to hand-loading techniques since the pallets are loaded at ground level.

It should be noted, however, that the pallet and the pallet truck represent a greater investment and pallets, themselves, add more weight to the truck's payload than would be the case in more traditional trucking practices.

The unloading procedure, which is usually mechanized to some degree, depends upon the type of installation at the delivery location. After delivery the empty pallet is returned by the pallet truck to a woodland landing where another loaded pallet can be picked up.

OPERATIONS RESEARCH METHOD

Pulpwood producers are constantly called upon to make decisions concerning their harvesting activities. A harvesting system can be quite complex. It is composed of a number of component operations such as felling and bucking, skidding, loading, hauling, and unloading. Each component has its own equipment and personnel arrangements and its own unique problems or areas of needed decisions. In many mechanized operations these decisions are further confounded by the dependency of one component operation upon the efficient fulfillment of another component operation.

In linkage of one component to another a balance must be established to ensure the efficiency of the overall harvesting system. The best possible meshing of all component activities is the basic aim of an operation research approach, and is often measured in terms of minimized costs or maximized profits.

Operations research can be defined as an orderly process of obtaining, assembling, and organizing the knowledge af an operational system in conjunction with the application of scientific techniques to problems involving that system with the intent of providing optimum solutions to the problems as recognized. "The results of operations research are organized facts which facilitate management decisions."[3]

While it is the basic aim of operations research to provide the best possible decisions for as large a segment of the total operating system as possible, practical considerations quite often require a sequential optimizing of the components of the system accompanied by adjustments to the overall approach.

The hauling component is but one phase of a pulpwood harvesting operation. When the hauling method is fixed, only activities within that type of hauling are subject to scrutiny. Such is the case

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for pallet truck scheduling. When this scheduling is practiced with the best possible efficiency, it can be said to be "phase-optimal" relative to all other fixed factors of the harvesting system. The obtaining of phase-optimality in the scheduling of pallet trucks does not reflect upon the adequacy of any hauling method, landing location, points of delivery, or other harvesting procedures in regards to the overall operating system. It does, however, provide for the objective of this study in that the pallet-truck requirements are balanced with the prescribed flow of pulpwood being loaded upon pallets at landing locations. In addition, the time and place of pickup and delivery combinations are so arranged and defined that the cost incurred in the movement of all pallet trucks utilized to meet the schedule is at a minimum.

DETERMINATION OF SCHEDULE COMBINATION

The use of a continuous time scale reflects the duration of engagement in work activities not on the traditional clock scale, but on a continuum of time periods. For example, the ninth period on the continuous scale would mean that nine periods of work had been accomplished. Based upon an 8-hour work day and using periods of an hour's duration, this would place the ninth continuous hour at the second hour of the second day of work. The continuous time scale is not affected by variations in the length of the work day. Time rates such as those associated with crew productivity and in pallet truck travel can be readily adapted to this continuous scale. The basic data (appendix A) used in the scheduling situation about to be developed, suggested time periods of 15 minutes duration. Figure 3 illustrates the relationship between clock scale and the continuous scale with increments set at 15 minutes.

The situation involves four woodland locations and two points of delivery. At each woodland location a harvesting crew continuously produces four-foot pulpwood from the stump and loads it at the location's landing onto a pallet. When the pallet is fully loaded with 8.5 cords of pulpwood, the pallet is ready for pickup and subsequent delivery to the nearest delivery station. With each pickup of a loaded pallet, an empty pallet is deposited by the pallet truck. This situation, which will be viewed through 40 continuous periods, is illustrated in figure 5.

The basic data, transposed into time periods expended in producing loaded pallets at the various landings and in travel

Figure 3

	Continuous Scale	Clock Scale
Start of first day	0	8:00 A.M.
	1	8:15
	2	8:30
	3	8:45
	4	9:00
	:	:
	:	
	14	11:30 A.M.
	15	11:45
Start of lunch hour	16*	12:00 Noon
	17	1:15 P.M.
	18	1:30
	:	:
		:
		:
		:
	:	:
	30	4:30 P.M.
	31	4:45
End of first day	32**	5:00
Into the second day	33	8:15 A.M.
	34	8:30

* The 16 period can also be interpreted at 1:00 P.M. of the same day
** The 32 period can also be interpreted at 8:00 A.M. of the next day
Figure 3. Continuous time scale compared to the traditional clock scale through one work day into another with an allowance of one hour for lunch.

between landings and delivery stations, are presented in tables 1 and 2 respectively.

If production activities were conducted before initiating the scheduling sequence, the period when the first loaded pallet at each landing would be ready for pickup must be based upon a judgment as to how far each crew's production has progressed.

The basic principle of the scheduling routine is to use as few trucks and pallets as possible and yet retain the continuous nature of the harvesting operation. This can be accomplished by returning those trucks which have completed a delivery to landings where a new pickup can be made. A truck, upon arriving at a landing, will deposit an empty pallet and pick up the new pallet when it is fully loaded. However, there must be sufficient time between the period when a delivery is made and the period when a loaded pallet will be ready for pickup at the landing to allow for travel

Figure 4. A harvesting crew continuously produces four-foot pulpwood and loads it at the location's landing onto a pallet.

between the two points and at the same time not jeopardize the continuous nature of the operation. Waiting time is restricted to trucking phase, not the other phases of the production operation.

Table 3 presents a composite of activity periods affecting the

TABLE 1

Periods when loaded pallets are ready for pickup with points of subsequent delivery.

	Delivery Station Destination	
Woodland Landing*	To D_1	To D_2
	(period number)	(period number)
L_1 (16)	0, 16, 32	
L_2 (18)	8, 26	
At		
L_3 (19)		15, 34
L_4 (20)		20, 40

* Figures in parentheses indicate crew productivity rates in periods per loaded pallet.
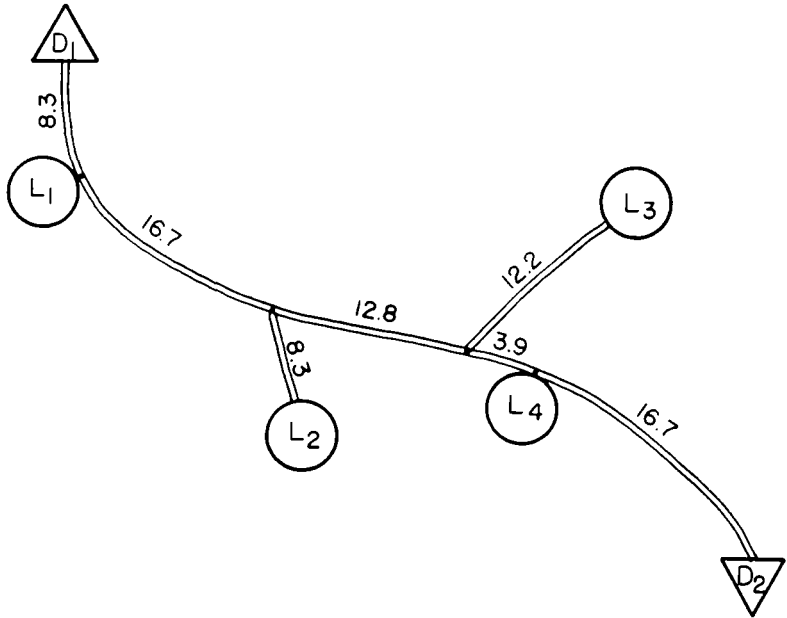
Figure 5. Schematic representation of the locations of the woodland landings (L₁, L₂, L₃, and L₄) and delivery stations (D₁ and D₂) including roadways and mileage figures considered in the scheduling situation.

TABLE 2

Distance and periods of one-way travel between woodland locations and delivery points.

		To			
		D_1		D_2	
Woodland Landing	Miles	Periods*	Miles	Periods°	
L_1	8.3	2	50.1	7	
L_2	33.3	5	41.7	6	
From					
L_3	50.0	7	32.8	5	
L_4	41.7	6	16.7	3	

° includes the assignment of one period on load trip for pallet pickup activities or on return trip for pulpwood removal activities at delivery point.

hauling phase. For each period when a load is ready for pickup at a landing, a determination of the feasibility of a return trip from a delivery station can be made. The feasibility of a round trip is registered in the matrix, page 14.

TABLE 3

Composite of Activity Periods Affecting the Hauling Phase

	I	II	III	IV	V	VI	VII	VIII	IX
A. Period when load ready	0	8	15	16	20	26	32	34	40
B. Landing where load located	L_1	L_2	L_3	L_1	L_4	L_2	L_1	L_3	L_4
C. Periods expended between L & D	2 7	5 6	7 5	2 7	6 3	5 6	2 7	7 5	6 3
D. Delivery station for load	D_1 D_2	D_1 D_2	D_1 D_2	D_1 D_2	D_1 D_2	D_1 D_2	D_1 D_2	D_1 D_2	D_1 D_2
E. Period when load arrives	2 -	13 -	- 20	18 -	- 23	31 -	34	- 39	- 43

Columns for Row E

		I	II	III	IV	V	VI	VII	VIII	IX
	I									
	II	5								
	III	7								
Rows	IV	2	2							
for	V	6	6							
Row A	VI	5	5	6	5					
	VII	2	2	7	2	7				
	VIII	7	7	5	7	5				
	IX	6	6	3	6	3	6	6		

These round trips have been indicated by placing the periods expended in the return trip in the appropriate cell of the matrix. The blank cells indicate the combinations which are impossible under the requirements of the situation. A description of this process of completing the matrix from information in table 3 appears in appendix B.

Since there are alternative possibilities of return trips in respect to the pickup of a given loaded pallet, a decision must be made as to the allocation of feasible trips to the various landings where loaded pallets are ready to be accepted. The efficiency of this allocation depends upon the obtaining of a maximum number of round trips in the scheduling period, as well as keeping the total cost of hauling at a minimum.

Because labor costs, usage charges for vehicles and pallet, and the operating costs of load trips are fixed within the scheduling period, the total hauling cost can only be varied by the operating costs of return trips. For the scheduling situation these return trip costs are considered as a linear function of the time periods expended in the return trip. Therefore, cost minimization can be interpreted as minimization of return trip time.

The linear programming technique provides a method of meeting the objectives of efficient allocation.

LINEAR PROGRAMMING TECHNIQUE

Linear programming is a technique by which a problem is reduced to a quantitative basis and solved mathematically. Formally defined, it is a mathematical technique by which the value of non-negative variables, presented as a linear function, are optimized after being subjected to linear restrictions.[4] Through the imaginative use of linear programming techniques, a complex problem whose solution is obscured in a maze of alternatives, may well be cleared up. The resulting answers can be relied upon to be the optimized and mathematically precise solution to the problem as posed.

The linear programming model used in the allocation process of the scheduling situation is presented in appendix C. This model which is an adaption of the basic Assignment Model[5] is solvable by computer or hand methods. Many of today's better known computer manufacturers have canned programs" for linear programming models of this sort.

With situations not complex enough to require the services of a computer, hand methods can prove quite satisfactory and equally reliable. Appendix D illustrates the solution of the scheduling model by hand methods.

RESULTS AND DISCUSSIONS

According to the linear programming solution, the maximum number of return trips that can be achieved in the scheduling situation is six. Therefore, six of the nine loaded pallets can be handled by return trips of trucks already in service. This means that only three trucks are required to maintain the continuous nature of the system. In addition, one pallet must be assigned to each landing location prior to the start of scheduling sequence. Table 4 presents the assignments of the trucks during the operating periods. The return trips in the assignments were so allocated that the total time spent in return trips was a minimum. This minimum total time was 26 periods or approximately 6.5 hours.

Excess trucks assigned to a hauling system represent needless expenditures of capital and operating dollars. This does not mean

[4] Doty, W. K. 1954 An Introduction to the Application of Linear Programming to Industrial Engineering. Purdue University M.S. Thesis (unpublished).

[5] Churchman, C.W., R. L. Ackoff, and E. L. Arnoff. 1957. Introduction to Operation Research. New York: John Wiley and Sons, Chapter 12.

Vajada, S. 1958. Reading in Linear Programming. New York: John Wiley and Sons, Chapter IX.

Dantzig, B. G. and D. R. Fulkerson. 1954. Minimizing the Number of Tankers to Meet a Fixed Schedule. Nav. Reg. Log. Quarterly 1: 217-222.

TABLE 4

Truck assignments during 40 continuous period scheduling system

		Original Assignment			Round-Trip Assignment	
Truck Number	Pick-up Location	Pick-up Time & Day	Delivery Destination	Pick-up Location	Pick-up Time & Day	Delivery Destination
1	L_1	8:00 A.M. (1st)	D_1	L_2	10:15 A.M. (1st)	D_1
				L_1	1:00 P.M. (1st)	D_1
				L_1	8:00 A.M. (2nd)	D_1
2	L_3	11:45 A.M. (1st)	D_2	L_2	3.30 P.M. (1st)	D_1
				L_4	10:00 A.M. (2nd)	D_2
3	L_4	2:00 P.M. (1st)	D_2	L_3	8:30 A.M. (2nd)	D_2

that spare trucks are inadvisable. The decision to hold some trucks in reserve in case of changes in operating procedures or breakdown of trucks in service is a separate undertaking not in the realm of this study. However, to include an extra truck in the system would require the allocation of additional capital dollars in the form of this truck directly to the pulpwood operation and would not necessarily reduce the requirements for spare trucks. In addition, a rise in the overall operating costs attributed to labor, maintenance, fuel, etc., would more than likely result from the increase in truck usage.

Substantial changes in operating procedures or productivity rates could necessitate a new scheduling. The scheduling method utilizes those known factors that affect production of pulpwood. These factors were considered as production standards, and while they need not be constants, they should be relatively stable. However, even when variability exists, decisions must be made on problems of scheduling. The model presented in this study represents a way of solving the scheduling problem. It uses only the ingredients that should be considered in any method of scheduling or directing pulpwood movements. In other words, it solves the problem as posed — a problem which requires some insight whether it is posed solely in the mind of a timber producer or for the model and directed into a desk calculator or computer.

The method utilized in this study need not be confined to scheduling situations involving only pallet trucks, but could be adapted to other transportation activities.

APPENDIX A

Basic Average Data

Pulpwood on loaded pallet		8.5 cords
Pickup of loaded pallet at landing		8.8 minutes
Drop and spot empty pallet	2.0 minutes	
Winching of loaded pallet on truck	2.2 "	
Delay in pickup process	4.6	
Unloading pallet truck at delivery station		9.0 minutes
Scaling of cordwood	4.0 minutes	
Unloading of pallet	3.2 "	
Delay in unloading process	1.8	
Pallet truck speed (Loaded & unloaded)		0.030 hours mile
Productivity rate from stump to loaded pallet		1.88 cords hour
Crew rates at L_1	2.13 cords hour	
Crew rates at L_2	1.89 "	
Crew rates at L_3	1.79	
Crew rates at L_4	1.70	

APPENDIX B

Determination of Round Trip Feasibility

The period represented in row A — column I of table 3 indicates when a pickup can be made at L_1. None of the periods presented in row E under any column constitutes a feasible return to make this pickup at L_1 (period 0), because all deliveries have occurred after time period 0. This is registered in the matrix by the absence of any return trip figures under column I-IX of row I. Since no round trip is feasible for this load, a truck must be allocated to the system. The period represented in row A — column II of table 3 indicates when a pickup can be made at L_2. The truck that picked up the loaded pallet at L_1 (period 0) and arrived at D_1 (period 2) can return by period 7 to L_2 in time to make this pickup at period 8. No other periods in row E, except that under column I, are feasible. This is registered in the matrix in Row II by the return trip time (5) under column I and blank cells under all other columns. This process was continued for the remaining time period of row A in table 3, registering the results in the matrix.

When more than one return trip figure appears in a row of the matrix, it indicates alternative choices of return trips to pick up a given loaded pallet. For example, the pallet ready at L_4 (period 20) can be picked up by the truck at any of four delivery stations: D_1 (period 2), D_1 (period 13), D_2 (period 20), and D_1 (period 18).

APPENDIX C

Scheduling Model for Pallet Operations

$$\text{Minimize } Z = \sum_{i=1}^{m} \sum_{j=1}^{n} t_{ij} \, x_{ij}$$

Subject to:

$$\sum_{j=1}^{n} x_{ij} = a_i = 1 \text{ for all i's}$$

$$\sum_{i=1}^{m} x_{ij} = b_j = 1 \text{ for all j's}$$

Where:

$i =$ denotes the combination of period and landing location of pallet pickup.

$j =$ denotes the combination of period and pallet truck at delivery location.

$x_{ij} =$ the number of pallet trucks at the jth combination which can be re-directed to accept pallet from i^{th} combination.

$t_{ij} =$ time of return trip in periods.

$a_i = 1 =$ total number of pickups to be accomplished at the ith combination.

$b_j = 1 =$ total number of trucks to be re-directed from the jth combination.

$m =$ number of pickups during scheduling period.

$n =$ number of deliveries during scheduling period.

APPENDIX D

Solving Scheduling Model by Hand Methods

Steps for solving scheduling problem starting with original matrix as developed from table 3:

1. Eliminate any row or column of the original matrix that is co-pletely void of return trip values.

2. Place all other rows and column in a new matrix without altering the relative position of these rows and columns.

3. Assign a positive M value to all void cells of the new matrix. This M value can be interpreted as a high value of unknown quantity whose magnitude is such that it will not enter into solution until all other minimizing considerations are satisfied.

4. If new matrix is not square (equal number of rows and columns) complete the square by adding appropriate number of rows or columns.

5. Assign a value of zero (0) to all cells the dummy row (s) or column (s) added in step No. 4.

6. Select the smallest value and subtract it from all others. If a dummy row or column was added, the value subtracted will be zero and the new matrix will be unaltered. Any value subtracted from an M value, except the M value itself, can be considered as not sufficiently affecting the magnitude of M. Therefore, the M value remains the same (when the subtraction is M minus M then the value becomes zero).

7. Place in the appropriate rows and/or columns the minimum number of straight lines that will cover all zeros. One line will cover a complete row or column.

8. From the remaining uncovered values select the smallest value and proceed as follows:

    a) subtract this value from all uncovered values

    b) retain as is those values covered by one line

    c) add the subtracted value to those values covered by two lines

9. Repeat steps No. 7 through 8 until unique zero value can be selected for each row and column. Remember a selected zero represents the row which it is in as well as the column it is in. The number of unique zeros selected cannot exceed the number of rows or the number of columns in a square matrix. The position of these zeros in the final matrix traced back to the original matrix indicates the return trips that are optimal to the scheduling situation. The values that these zeros represent in the original matrix are in aggregate the minimized time spent in return trips.

NEW MATRICES

Initial°

	I	II	III	IV	V	VI	VII	VIII
II	(5)	M	M	M	M	M	M	0
III	7	M	M	M	M	M	M	0
IV	2	(2)	M	M	M	M	M	0
V	6	6	M	M	M	M	M	0
VI	5	5	(6)	5	M	M	M	0
VII	2	2	7	(2)	7	M	M	0
VIII	7	7	5	7	(5)	M	M	0
IX	6	6	3	6	3	(6)	6	0

Final°°

	I	II	III	IV	V	VI	VII	VIII
II	(0)	M	M	M	M	0	0	1
III	2	M	M	M	M	0	(0)	0
IV	0	(0)	M	M	M	0	0	3
V	1	1	M	M	M	0	0	(0)
VI	0	0	(0)	0	M	0	0	0
VII	0	0	4	(0)	4	0	0	3
VIII	3	3	0	3	(0)	0	0	1
IX	M	M	M	M	M	(0)	0	M

°Values in parentheses were obtained from positions indicated in final matrix.

°°Unique zeros for row and column indicated by parentheses.