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Markov decision processes and ship handling: an exercise in aggregation

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MARKOV DECISION PROCESSES AND SHIP HANDLING:
AN EXERCISE IN AGGREGATION

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Summary. Operational planning in a general purpose ship terminal is treated. The decisions to be taken concern the weekly manpower capacity and the assignment of manpower and equipment to ships. As a Markov decision problem the model is very big and aggregation is desirable. As a check simulation is used, which leads to an iterative aggregation-disaggregation approach.

Zusammenfassung. Diese Arbeit beschäftigt sich mit operationelle Planung in ein Schiffterminal für Stückgutbehandlung. Wöchentlich muss entschieden werden über Arbeitspotential und täglich über Zuteilung von Arbeitskräfte und Material. Das Markoffsche Entscheidungsmodell für dieses Problem ist sehr gross und man muss an Aggregation denken. Als Überprüfung wird dabei Simulation benützt und das führt zu einem iterativen Aggregation-Disaggregation Verfahren.

1. Introduction.

Quite a substantial amount of theoretical research has been done in the area of aggregation in Markov decision processes (Whitt [4], Mendelssohn [2]). Little, however, has been reported on practical experience. The sparse reports on practical use are concerned with problems in which grid size is a measure for the level of aggregation (Mendelssohn [1], Veugen, Van der Wal and Wessels [3]). Realistic planning problems, for instance in the area of production planning, have a tendency to be so complicated that aggregation via sensible grids does not diminish action and state space sufficiently for numerical analysis. In such case the question may arise how to use a form of aggregation which affects the structure of the problem and next, what kind of corrections can be made. It is not very likely that this topic can be treated very generally: probably approaches will be highly dependent on the specific structure of the problem on hand.

In this paper we consider, as an exercise, the production planning problem in a general purpose ship terminal. In that case the production planning problem is a dynamic assignment problem. Manpower and hardware (cranes, fork trucks, etc.) have to be assigned dynamically to ship's holds under some constraints. What is shown in the sequel is a view in passing of work in progress. It is not a definitive answer but it gives an idea of the complexity of the problem and of possible approaches.

The next section is devoted to a short problem description. In section 3 a highly aggregated model is given. In section 4 the results of section 3 are used for a simulation of the real assignment process. In section 5 it is indicated how the simulation results can be used as feedback for the aggregated model.

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2. The ships handling problem.

At a ship terminal in a see harbour ships arrive according to a Poisson process. The terminal has N berths (in the example N = 12). If all berths are occupied, then arriving ships proceed to a terminal of a competiting firm. In fact, we have introduced a first simplification here, since only unloading ships are able to take refuge with a competitor. Each ship has a number of holds (usually up to 5) in which work has to be done. The stevedore has to assign workcrews and equipment to holds under the restriction that two crews cannot work simultaneously on the same hold. So crew assignment is a question of 0 - 1 decisions. Constraints are:

a) The allowed handling time of a ship is expressed in the time required for handling the so called heavy hold, i.e. the hold which requires most work.

b) Work forces are only available during 16 hours a day from Monday till Friday (8.00 - 24.00) and during 8 hours on Saturday (8.00 - 16.00).

c) There are restrictions on the available numbers of crews for the various working periods, the general rule being that the day shift (Saturday excluded) is twice as strong as the evening shift (including the shift on Saturday).

d) The available number of cranes is fixed (27 in the example). Since each crew needs a crane, also the number of crews in each working period is limited.

e) The available work force can be split up in
   - 15 crews who are always available (10 for the day shift and 5 for the evening shift) and who are always paid, also if there is no work to be done;
   - a variable number of crews which can be hired at relatively short notice but always according to the 2 : 1 restriction for day and evening shifts. The hiring of these extra crews takes place according to a complicated system which will be simplified here in such a way that at the beginning of each week a constant number of extra crews can be hired for the whole week. Also the costs are complicated. In the example, the first 15 extra crews are somewhat more expensive than the contracted work force, and they still give 60% of the costs if they are not hired. Above these crews more can be hired at higher rates but without any financial obligation if they are not taken.

f) Other equipment than cranes does not give extra constraints, since fork trucks etc. can be hired at very short notice.

g) Some prior knowledge about arriving ships is available.

This system has interesting medium and long term planning aspects. However, in this paper we confine ourselves to short term planning. In the description as given so far, short term or operational planning boils down to the following two decisions: the weekly decision of how many extra crews to hire and the hourly decisions of how to assign the crews to the holds. For simplicity we take as unit of time a period of 8 hours (one shift): the work in a hold for a crew is measured in these units and crew assignments are made for a whole shift.

3. An aggregated model for the weekly decisions.

When formulating the planning process as a Markov decision process, it quickly becomes clear that the state space should be highly dimensional, the state should contain the remaining number of units of work in each of the holds of each ship in the terminal (so, for 5 holds per ship and 12 berths this already gives a 5×12-dimensional contribution), and further the number of crews available, the time instant within the week, and the information about ships to come. The information about expected ships might consist of estimated arrival times for the next week plus information about the amount of work involved.

The usual form of aggregation would imply the choosing of another time unit, however, even with 2 shifts (a day) as time unit the state space would remain huge. Therefore we have to consider a more structural form of aggregation. A base for aggregation might be the distinction between the two types of decision: the weekly manpower capacity and for each shift the crew assignment. It seems sensible to try to take decisions with respect to manpower capacity on the basis of relatively rough data on manpower requirement and to take assignment decisions for a given manpower capacity. So, let us try to construct a model for the analysis of capacity decisions. A consequence of such a hierarchical set-up for the decisions is that the capacity model should already contain estimations of the effects of the assignment decisions.

For the capacity model the time unit may be one week, with decisions taken on Saturday immediately after the only working period. As unit of work can be taken the number of shifts one crew would need to handle one standard ship. So, as a further simplification, the work in all ships is considered as equal. The information about the numbers of ships to be expected in the forthcoming week is reflected by one of five numbers (9, 13, 17, 21, 25) representing the Poisson arrival process with mean 16. This makes the state space 2-dimensional: remaining amount of work, information. This state space is even rather small, however, it allows the possibility to experiment with other information structures, for instance the expected numbers of arriving ships for each of the next two weeks. The decisions to be allowed may be represented by the number of standard ships which can be handled in one week by the manpower. So the decisions with respect to manpower capacity are also taken in units of standard ship equivalents.

The only remaining difficulties are the determination of the transition probabilities and the one-stage costs. A detailed description would require much space, therefore, we confine ourselves to a rough outline of the difficulties. For costs and transitions it is necessary to know how many ships balk and therefore it is necessary to know how many real ships (occupied berths, not standard ship equivalents) are there at the decision moment and how is the arrival and departure process. The number of ships can be estimated by multiplying the number of standard ship equivalents by a fixed factor, 3/2 for instance. This factor is related to the assignment policy and the same holds for the departure process. Nevertheless, after some assumptions, real numbers can be filled in. Cost factors are manpower capacity and ships turned away. By standard successive approximation the resulting Markov decision process with average costs criterion can be solved efficiently. Table 1 gives the optimal decision rule for an example.

	0	1	2	3	4	5	6	7	8
9	10	10	10	11	12	13	14	14	14
13	12	13	14	15	16	17	17	17	16
17	16	17	18	19	20	20	20	20	20
21	20	20	20	20	20	20	20	20	20
25	20	21	21	22	22	21	21	21	20

Table 1. For each number of ship equivalents present at the beginning of the week (between 0 and 8) and each number of ships expected (between 9 and 25) this table gives the manpower capacity in standard ship equivalents.

The lack of monotonicity in optimal decisions might be explained by the fact that if many berths are occupied at 16.00 h on Saturday then quite a number of the arriving ships will be lost during the weekend and the beginning of the next week, in which case increasing the capacity does not sufficiently influence the number of balking ships.

4. Simulation of the assignments.

It is not clear beforehand whether the solution of the aggregated model for the capacity problem makes it possible to make an assignment fitting the side conditions like allowed handling time. Worse still, it is not clear beforehand whether the parameters of the aggregated model are realistic, so also the value of computed turn-away rates, weekly costs, and crew utilization are dubious. Therefore, the resulting capacity policy is used for the simulation of the detailed handling process.

This detailed handling process still requires decisions to be taken, viz. the assignments. This difficulty is avoided by introducing a simple assignment rule. In this paper we only give one assignment rule, however, the procedure as described in the next section can also be executed for other assignment rules which seem sensible. By comparing the results for different assignment rules a comparison of the different rules can be obtained leading to the choice of a standard rule.

Here we adopt the rule that crews are assigned to all heavy holds first (a ship may have more than one heavy hold). If there are more crews available than there are heavy holds, then the holds which, if not served, become heavy after the shortest time get a crew. If there are less crews than heavy holds, then first the ships with the least number of heavy holds get one assignment. Among the ships with an equal number of heavy holds the lightest ones are preferred. As soon as all ships have one assignment, an extra crew is assigned to each ship with 2 heavy holds, etc.

There may be more crews than holds in some period, this is a source for idleness of manpower. On the other hand, there may be more heavy holds than crews, which is a source for delay compared to the minimal handling time of the ship.

In the simulation (100 weeks in the example) one can measure the average delay of the ships, the average idleness of the crews, and the balk rate of arriving ships.

For the capacity policy of table 1 we display in table 2 some of the simulation results. The average amount of work per ship is taken to be 8 units (shifts). The amount of work in the heavy holds varies between 2 and 8 units with an average of 4 and the number of nonempty holds varies between 1 and 5 with an average of 3.

	Week-end	Mo		Tu			We			Th			Fr			Sa		Total
		D	E	N	D	E	N	D	E	N	D	E	N	D	E	N	D	
Arrivals	373	71	75	78	92	76	88	80	72	78	91	67	73	70	82	89	65	1620
Balking	21	16	4	7	6	1	1	5	5	0	2	0	0	0	0	0	2	70
Departures		142	155		182	143		165	127		165	114		145	117		91	1546
Delay days		17	179		23	195		32	146		26	111		14	57		82	882
Idle days		98	23		169	29		252	56		357	71		387	87		43	1572

Table 2. Number of arrivals, etc. for the various periods in the week for the 100 weeks simulation. D stands for the day shift: 8.00 - 16.00, E for the evening shift 16.00 - 24.00 and N for the night period 0.00 - 8.00.

As we see the balk rate and the number of delay days are higher in the beginning of the week and idleness increases towards the end of the week. This because of the relatively long period during the weekend in which ships arrive but are not served. We also see that, due to the 2 : 1 ratio of the sizes of day and night shifts, delay is large in the evenings whereas idleness is large in the morning.

5. Feed-back of the simulation results.

Summarizing the simulation results displayed in table 2 we observe a balk rate of 4.3% an average delay of .57 days or 7.1% and an average idleness of 11.3%. These data deviate considerably from the data used in the original model where idleness was only .2%, the balk rate only .6% and delay had been assumed not to appear. Only the multiplier 3/2 which translates ships equivalents into occupied berths turned out to fit remarkably well.

Having noticed all this the next step in the analysis is to feed back the simulation results into the original model. The question is how. One has to be careful.

In a first attempt we have fed back the idleness results as follows. For each of the possible numbers of arriving ships (9, 13, 17, 21, 25) an idleness fraction has been deduced from the simulation. The simulation did not contain enough information to obtain these fractions as a function of the decision, much less of both the number of arriving ships and the decision. That the balk rate has been estimated too low originally is an immediate consequence of the underestimation of the idleness. Since the preassumed departure process and the observed departure process in the simulation are very similar, the balk rate will increase automatically if the idleness is increased. So we did not feed back the increased balk rate explicitly. After feeding back the idleness another optimization can be performed, and the new optimal strategy resulting from it can be tested again via simulation. In our experiment we repeated this procedure several times. It turned out that idleness kept increasing (to above 20%), so clearly this was not the right way to feed back the simulation results. What we ignored in this first attempt is that the idleness fraction will decrease if less capacity is assigned and will increase if more capacity is assigned. So a better way to feed back the idleness might be to assume that in the neighbourhood of the optimal decisions idleness is a linear function. These linear functions might be estimated by simulation using strategies neighbouring the optimal strategy. This experiment will be performed shortly.

We expect that this way of feeding back, possibly after some further refinements, will lead to an iterated aggregation-disaggregation approach which is suited very well for the analysis of this specific problem. But in our opinion this way of attacking a problem will be useful in many other situations as well.

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