The tool switching problem on a flexible machine in a dynamic environment

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Abstract

This paper analyses the tool switching problem in the dynamic environment, where parts to be processed on a flexible machine arrive randomly. As the total number of tools required to process a set of parts on the machine is generally larger than the available magazine storage capacity, tool switches between parts are usually necessary. We assume that tool switching must be made just before the processing of the parts. Since the time required for tool switches can be significant relative to processing time and cause the processing of parts to be delayed, it is desirable to minimize the number of tool switches. Therefore, we present one heuristic algorithm to minimize the total number of tool switches and the proposed heuristic is compared with the KTNS (Keep Tool Needed Soonest) policy on randomly generated problems.

I. Introduction

Tool switching is a key problem at the single flexible machine. As the total number of tools required to process a set of parts on a flexible machine is generally larger than the available magazine storage capacity, tool switches between parts are usually necessary. Before processing a part, all tools required by that part must be loaded on the tool magazine. Since the time required for tool switches can be significant relative to processing time and cause the processing of parts to be delayed, it is desirable to minimize the number of tool switches.

The tool switching problem has received considerable attention from researches. A detailed study was conducted in Bard(1988) and Tang and Denardo(1988). In particular, in the latter paper, the KTNS (Keep Tool Needed Soonest) policy is proved to give an optimal tooling solution for a given part sequence. An extended study presented in Rupe and Kuo(1997) considered that parts often require more tools than the tool magazine can hold, and so tool switches must be made during part processing as well as between parts. In their paper, a slightly modified KTNS policy was proposed and shown to be an optimal policy. Note that most of the studies assumed a static environment, where the sequence of parts to be processed on the machine is determined in advance. For the first time, Matzliach and Tzur(1998) analysed the tool switching problem in the dynamic environment, where parts that need to be processed on the machine arrive randomly. In the paper, it was assumed that tool switching can be made during the part processing. However, we assume that tool switching must be made just before the processing of the parts.

II. Problem description

Consider a single flexible machine with a tool magazine, which can accomodate at most C tools. N parts to be processed randomly arrive at the machine during the production period. All tools required by each part have to be placed in the tool magazine before the part can be processed. M tools required to process a set of parts is generally larger than the available magazine capacity. Therefore, when a certain tool is required, if it is not loaded on the tool magazine, tool switching must occur.

The further assumptions are made as follows:

(1) Each part does not require more tools than the tool magazine capacity.

(2) Each tool fits in one slot of the magazine.

(3) The number of parts and a set of tools required to process them are known at the beginning of production period. But the sequence of parts to be processed is not known in advance.

(4) The tool switching does not occur during processing of the parts.

The objective is to determine the set of tools to be placed on the machine prior to processing each part so that the total number of tool switches is minimized to complete all parts. Since the basic assumption of our model is that future demands are revealed only as they occur, we may use historical data only. There exists the limited informations on the future, that is, the number of parts to be processed and a set of tools required by each part.

III. A heuristic for the dynamic tool switching problem

It can be shown that there exists an optimal solution in which at every instant tools are inserted to the tool magazine only if they are required at that instant, and tools are removed only if there is not enough capacity for the required tools. That is, tool switching is made only if it is necessary. Therefore, a heuristic presented in this paper adopts this rule of no initiated removals.

We use the following definitions:

n instant just after processing the nth arrived part, but before any tools are switched ($n=0, \ldots, N$).

$T(n)$ set of tools required by the nth arrived part. ($T(n) < M$)

$D(t)$ the total number of parts that require tool t.

$W(n)$ set of tools that are present on the tool magazine at instant n. We refer to $W(n)$ as the state of the system.

$B(n)$ the capacity usage of the tool magazine at instant n.

$S(t, n)$ the number of parts in which has used tool t until instant n.

The values of $B(n)$ and $S(t, n)$ are updated at every instant that the heuristic changes the state of the system. For every instant n, the following procedure proceeds:

Procedure

Step 1. Select a tool t not considered yet such that $t \in T(n+1)$.

Step 2. If $t \in W(n)$, then go to Step 6.

Step 3. If $B(n) < C$, then insert tool t into the tool magazine, set $B(n) = B(n)+1$, and go to Step 6.

Step 4. For all $r \in W(n)$ and $r \notin T(n+1)$, compute $P_r = \frac{D(r) - S(r, n)}{N-n}$.

Step 5. Remove the tool r^*, where $r^* = \arg\min P_r$. Break the ties arbitrary. Insert tool ^{t} into the tool magazine.

Step 6. If all tool $t \in T(n+1)$ are considered, proceed to instant (n+1).
Otherwise, go to Step 1.

IV. Computational results

In this section, we test performance of the heuristic suggested in this study. Unfortunately, there is no previous research result on the problem considered here. Therefore, we compare the proposed heuristic with the KTNS (Keep Tool Needed Soonest) policy that is optimal for the static problem. Also, to evaluate the effectiveness of our heuristic, its values are compared with the random solutions, obtained as follows: If there is not enough capacity in the tool magazine for the required tool, one of the tools in the tool magazine is randomly chosen and removed.

For the tests, we generated 160 test problems with the various instance types as displayed in Table 1. Here, R denotes the number of tools required by each part and DU[a, b] denotes the discrete uniform distribution with range [a, b]. For level T of tool magazine capacity, the number of tool slots in the tool magazine is set to equal to the maximum value of R. For level NT, the number of tool slots is equal to 150% of level T.

The computational results are summarized in Table 2. For each type, we report

Table 2. Performance of the proposed heuristic.

N	M	R	C	Random	Proposed	KTNS
30	20	[2, 6]	T	84.7(18.5)*	80.3(12.2)	71.6
			NT	65.6(41.8)	58.6(26.7)	46.4
		[8, 12]	T	126.5(17.8)	123.4(14.9)	107.5
			NT	69.3(48.8)	62.9(35.0)	46.6
	40	[4, 12]	T	171.6(20.3)	163.3(14.5)	142.8
			NT	135.1(50.2)	117.7(30.5)	90.1
		[16, 24]	T	251.1(21.3)	242.1(17.0)	207.1
			NT	172.1(51.5)	153.1(34.9)	113.6
50	20	[2, 6]	T	144.1(19.5)	137.4(14.2)	120.6
			NT	110.7(47.8)	102.0(35.9)	75.0
		[8, 12]	T	206.5(19.3)	199.4(15.1)	173.3
			NT	113.4(57.2)	103.8(43.7)	72.3
	40	[4, 12]	T	283.6(21.9)	271.3(16.6)	233.0
			NT	228.2(55.9)	204.0(39.3)	146.5
		[16, 24]	T	412.6(23.3)	396.0(18.4)	334.6
			NT	271.9(57.3)	250.2(44.7)	172.9
AVERAGE				177.9(35.8)	166.6(25.8)	134.6

*percentage above the value of the KTNS policy

averages over 10 instances in terms of the number of tool switches. As expected, the proposed policy demonstrates a big improvement over the random solution. We observe that the performance of the proposed heuristic is decreasing with N and C.

V. Conclusions

This paper presents a heuristic for the dynamic tool loading problem where all parts to be processed arrives randomly at a single machine. Having no prior rules to compare our heuristic to, we compared it to a random policy and demonstrated its superiority. A further study is needed on developing more efficient policies than the proposed heuristic in this study.

Table 1. Instance types

N	M	R	C
30	20	sparse(DU[0.1M, 0.3M])	T(tight)
50	40	dense(DU[0.4M, 0.6M])	NT(Not Tight)

[References]

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