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Modified Petri Net Model Sensitivity to Workload Manipulations[1]

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Introduction

The purpose of this research is to investigate modified Petri nets (MPNs) as a workload modeling tool. This paper describes the results of an exploratory study of the sensitivity of MPNs to workload manipulations in a dual task.

Petri nets have been used to represent systems with asynchronous, concurrent and parallel activities (Peterson, 1981). These characteristics led some researchers to suggest the use of Petri nets in workload modeling where concurrent and parallel activities are common. Petri nets are represented by places and transitions. In the workload application, places represent operator activities and transitions represent events. MPNs have been used to formally represent task events and activities of a human operator in a man-machine system. For example, Madni, Chu, Purcell and Brenner (1983) used MPNs to model the tasks underlying the identification and reaction to a lube oil leak in a ship propulsion system. Madni and Lyman (1983) used a MPN to model the checkout and start-up procedure for a Cessna 182 light aircraft. White, MacKinnon and Lyman (1984) formulated a MPN for POPCORN, a complex computer simulation at NASA-Ames for workload research. These descriptive applications demonstrate the usefulness of MPNs in the formal representation of systems. It is our general hypothesis that in addition to descriptive applications MPNs may be useful for workload estimation and prediction.

This paper reports the results of the first of a series of experiments designed to develop and test a MPN system of workload estimation and prediction. This first experiment is a screening test of MPN model general sensitivity to changes in workload. Positive results from this experiment will justify the more complicated analyses and techniques necessary for developing a workload prediction system.

Our analytical work with MPNs has exposed three critical issues that are relevant for workload applications of MPNs, viz., task complexity, level of task representation detail, and activity and event classifications.

MPNs differ according to task complexity such as a relatively linear task such as identifying an oil leak and taking appropriate action in comparison to a circular task with many goals and repetitions such as the POPCORN simulation. In POPCORN, An large number of trade offs between offensive and defensive strategies are possible throughout the course of one experimental trial. The critical areas for workload estimation often involve circular type tasks such as the activities of a aircraft or automobile operator. The experimental task to be described below is complex and circular in nature, but is programmed so that the necessary information for MPN development can be obtained.

Level of task representation refers to the level of detail of the task that is being modeled. For example, using Madni and Lyman's (1983) task, the start-up and checkout procedures for the Cessna plane can be simply modeled as follows: enter the plane, start the engine and then take off, (a two activity and three transition MPN). Alternatively each muscle movement of the pilot in each activity leading to take off could be modeled (a very large MPN). The level of task representation issue is important because on the one hand a detailed map of the task is required to obtain adequate sensitivity to workload changes. On the other hand, there are limitations on the measurement techniques that can accurately partition task components for a MPN model with the necessary level of detail. For example, with the current level of technology it is not possible to know precisely when shifts of attention occur between task elements. The MPN derived from the task we have devised represents a compromise on the level of detail issue. It is intended to be a task designed to elicit most of the information needed for analysis in MPN terms. Additional information can be obtained via control experiments designed to measure specific mental processes that cannot be measured with the experimental task alone.

Activity and event classification schemes refer to the classification of events and activities in terms of general workload categories. If activities and events can be categorized in terms of workload then it is not necessary to estimate the workload contribution of each individual event and activity. The classification analysis is an area of advanced work and will be conducted in the next stage of this research.

Method

Subjects: Eleven UCLA undergraduate volunteers served as subjects. Each subject participated in a two hour experimental session.

Materials: The entire experimental procedure was conducted on a Televideo 803 computer with a mouse controller.

Procedure: A dual task similar to Derrick and McCloy's (1984) composed of a tracking task and a vowel insertion task was devised. The tracking task was a standard compensatory tracking task with a cursor moving along the horizontal axis driven by a random forcing function. The subject was instructed to try to keep the cursor near the center of the line with a mouse controller. Easy and hard levels of difficulty were introduced by changing the forcing function parameters. A vowel insertion task was incorporated into the tracking task by using the cursor itself as the stimulus letter. It was presented as a consonant that was replaced randomly at intervals of three to seven seconds. The subjects were instructed to mentally insert the letter "A" between the consonant that was currently displayed and the previous one. This consonant-vowel-consonant combination might or might not form an English word. The task of the subject was to indicate whether it was a word or not by means of switches located as part of the mouse controller. The cognitive load of the vowel insertion task was manipulated by increasing the number of vowels that the subject must sequentially insert. For example, with three vowels to insert ("A", "E", & "I") the subject was required to make three lexical decisions and therefore three key press responses. On a comparative basis, one vowel represented a low cognitive load and three vowels represented a high cognitive load.

The one versus three vowels, and hard versus easy tracking tasks were crossed to form four conditions. Thus each subject conducted two four-minute trials in all four conditions, viz., high cognitive load---low tracking load, high cognitive load---high tracking load, low cognitive load-low tracking load and low cognitive load---high tracking load. The order of the conditions was counterbalanced and each subject was given two minutes of practice in each condition.

Subjects performed the task individually and with the CRT screen at eye level. They were instructed to keep the cursor at the center of the horizontal bar using the mouse controller. They were told to press one switch on the mouse when the consonant-vowel-consonant (CVC) was an English word and press another switch on the mouse if the CVC was not a word. After each condition the subject rated her/his level of workload on ten scales of workload level and task difficulty that are in use for the POPCORN task at NASA-Ames, with the exception that the skill-, rule-, and knowledge-based scale was replaced by an scale on automaticity.

Two control conditions were conducted to obtain measurements for certain parameters of the MPN. The control conditions were used to estimate the length of time necessary for certain mental process which cannot be derived by the data available from the experimental conditions. The first experiment obtained a simple reaction time to the change of consonants that are used in the vowel insertion task. This task generated an estimate of the initial start-up and response activities involved in the vowel insertion task. The second control task combined the tracking task and a two choice reaction time. The cursor was displayed as the letter "T" and was replaced by an "X" or and "O" every three to five seconds. Each "X" or "O" was displayed for one half second. The subject depressed one key if it was and "O" and another key if it was an "X". This procedure provided an estimate of letter identification time and the decision processes involved in selecting the appropriate key to press. The subjects performed each control condition with both levels of tracking difficulty. The control conditions were randomly mixed with he experimental conditions.

Each subject generated an individual difference bias rating for the bipolar rating scales. The procedure was the same one as used at NASA-Ames in which subjects rated which of two scales is more important. Each possible comparison of the ten scales was rated. Because the subjective rating scales differ in importance and meaning for each subject, the individual bias information was considered important for accurate workload estimation. This information can be used to weight the ratings. However, only the unweighted rating scores were used in the analyses reported below.

<u>Modified Petri Net of the Dual Task:</u> The MPN for the experimental task is displayed in Figure 1. Figure 1a displays the net for the entire task. Figures 1b, 1c and 1d display the subnets for tracking and vowel insertion. Table 1 presents the activities and events for each experimental task.

Results and Discussion

The preliminary analyses were conducted to verify that the experimental manipulations were effective in changing workload. A 2 (high versus low cognitive load) by 2 (hard versus easy tracking) analysis of variance was conduced on each of the ten ratings, the residual mean square error (RMS) measure and the percent correct on the lexical decision measure.

The anova on the RMS error of the tracking showed a significant main effect for the tracking condition ($F=95.18$, $p<.001$) and vowel insertion condition ($F=8.16$, $p<.05$), with the hard levels of difficulty having the greater RMS error. The anova on the Percent Correct of the vowel insertion showed a significant main effect for the vowel insertion condition ($F=27.40$, $p<.001$). However, the hard level of vowel insertion demonstrated the better performance. This can be explained by the fact that the second and third letters for the vowel insertion ("E" and "I") created much fewer english words compared to inserting the letter "A". Thus, the subjects may have been biased into responding NO for most of the second and third vowel insertions and this strategy paid off. A more appropriate comparison , then, would be to compare the percent correct of the first vowel insertion of the hard level (the letter "A") and the percent correct of the easy level (the letter "A"). This analysis showed no main effects.

Table 2 shows the F values of the anoves conducted on the unweighted workload rating scales. Two of the ten scales showed a main effect for the tracking condition, while 8 of the ten showed main effects for the vowel insertion condition. These results indicate that the experimental conditions did indeed manipulate workload.

Anoves were also conducted the output of the MPN simulations of the experimental trials. The data derived was the number of times each transition fired, the total amount of time each place was activated, and the number of times each place was activated.

Because the activities represented by places 6, 7, 8, & 9 were not directly observable, the estimation of these activity times involved the inclusion of data obtained in the control conditions. These derivations were more complicated and were unavailable for the analyses reported below.

Table 3 shows the F values for the anoves on the transitions and Table 4 shows the F values for the anoves on the places of the MPN simulation. Transitions 1 and 4 were not tested since they did not vary across conditions. The main point of these two tables is that the transitions and places that modeled the tracking components showed main effects for the tracking condition, and the ones that modeled the vowel insertion showed main effects for the vowel insertion condition. This indicates that the MPN model appropriately represented the experimental task.

However, a more important question is whether the MPN represented the workload involved in the task. It is possible that other components of the task, which were not possible to model the the MPN, were more important contributers to the workload involved in the task. Thus, it was necessary to demonstrate a relationship between the MPN parameters and the subjective workload ratings. To do this, a canonical correlation was conducted between the MPN parameters and the workload ratings. The results of the canonical correlation showed that the first four eigenvalues were significant. This indicates that four underlying factors of the MPN parameters are highly related to four underlying factors of the workload ratings.

Summary and Future Directions

The results of the canonical correlation indicated that MPN model of the experimental task represented the task components that influenced subjective workload. Thus, the goal of this experiment was achieved by this demonstration that the MPN model was sensitive to workload changes.

The next stage of this research will involve generating a classification scheme that will group events and activities that are similar in their contribution to task workload. Workload values for each class of events and activities can then be derived. This will allow testing of MPN model simulations for their prediction capability of the workload of a task.

FOOTNOTES

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[2]The order of the first two authors is arbitrary.

Table 1

Transitions and places of MPN Model of Experimental Task

Transitions	Places
T_1-Start	P_1-Vowel insertion activity
T_2-Cursor leaves task boundaries	P_2-Tracking activity
T_3-Restart	P_3-Wait (2 seconds)
T_4-Consonant Changes	P_4-Monitor (cursor)
T_5-Lexical decision process complete	P_5-Lexical decision activity
T_6-Letter identification complete	P_6-Letter identification
T_7-Lexicial decision complete	P_7-Lexcial decision
T_8-Response decision complete	P_8-Response decision
T_9-Response complete (continue with next vowel)	P_9-Response
T_{10}-Cursor moves	P_{10}-Monitor (tracking) and calculate move
T_{11}-Cursor passes mark	P_{11}-Move to compensate
T_{12}-Monitor & calculate complete	
T_{13}-Cursor passes mark	
T_{14}-Move completed	

TABLE 2

WORKLOAD RATINGS

F VALUES

	TRACKING	VOWEL INSERTION	INTERACTION
OVERALL WORKLOAD	3.19	15.32**	0.77
TASK DIFF.	3.51	36.22***	0.39
STRESS	9.31*	17.35**	0.01
FRUSTRATION	4.97*	30.93***	0.04
PHYSICAL EFFORT	2.29	0.01	0.49
MENT/SEN EFFORT	3.22	23.14***	0.27
FATIGUE	0.50	0.04	4.41
AUTOMATICITY	4.28	13.27**	0.69
TIME PRESS	1.06	54.50***	1.11
PEFORMANCE	3.69	11.89**	0.34

*p <.05
**p <.01
***p <.001

Table 3

TRANSITIONS

F VALUES

	TRACKING	VOWEL INSERTION	INTERACTION
T_2	6.15*	1.12	16.98**
T_3	6.15*	1.12	16.98**
T_5	1.91	0.60	0.45
T_6	1.91	0.60	0.45
T_7	2.18	107.73***	4.21
T_8	2.18	107.73***	4.21
T_9	2.18	107.73***	4.21
T_{10}	6.18*	2.62	17.30**
T_{11}	9.22*	0.05	3.08
T_{12}	37.81***	0.31	1.60
T_{13}	71.22***	0.08	16.24**
T_{14}	37.63***	0.26	1.57

* $p < .05$
**$p < .01$
***$p < .001$

Table 4

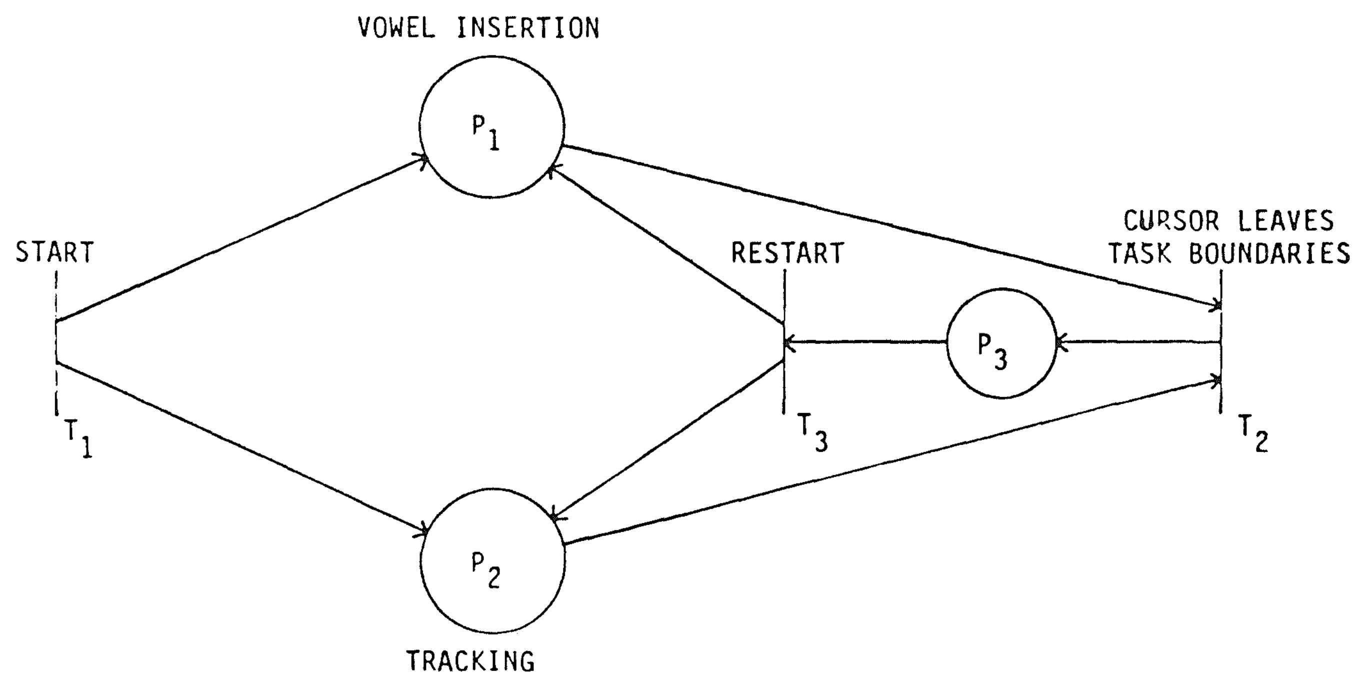
PLACES

F VALUES

	TRACKING	VOWEL INSERTION	INTERACTION
TOTAL TIME			
P_1	5.54*	2.17	17.20**
P_2	5.54*	2.17	17.20**
P_3	5.54*	2.17	17.20**
P_4	0.27	31.99***	8.42*
P_5	2.88	26.80***	14.05**
P_{10}	43.34***	0.34	0.20
P_{11}	26.93***	0.09	0.10
FREQUENCY			
P_1	3.40	1.40	13.80**
P_2	3.40	1.40	13.80**
P_3	6.15*	1.12	16.98***
P_4	2.41	0.47	0.51
P_5	1.91	0.60	1.52
P_{10}	36.65***	0.29	1.50
P_{11}	31.38***	0.53	1.20

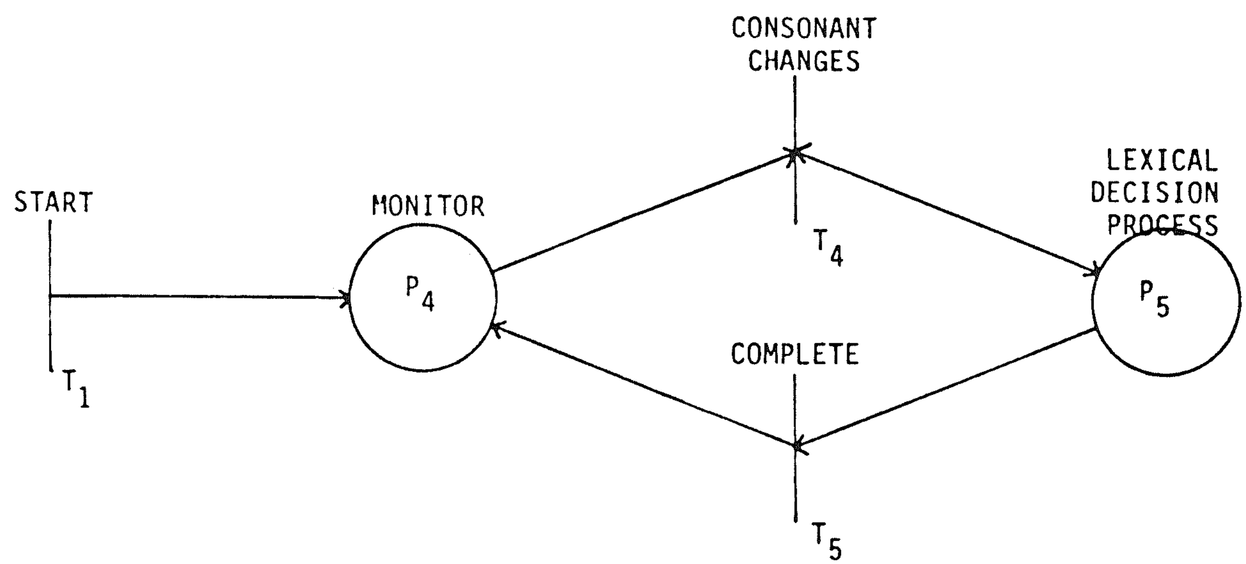
* $p < .05$
**$p < .01$
***$p < .001$

FIGURE 1A



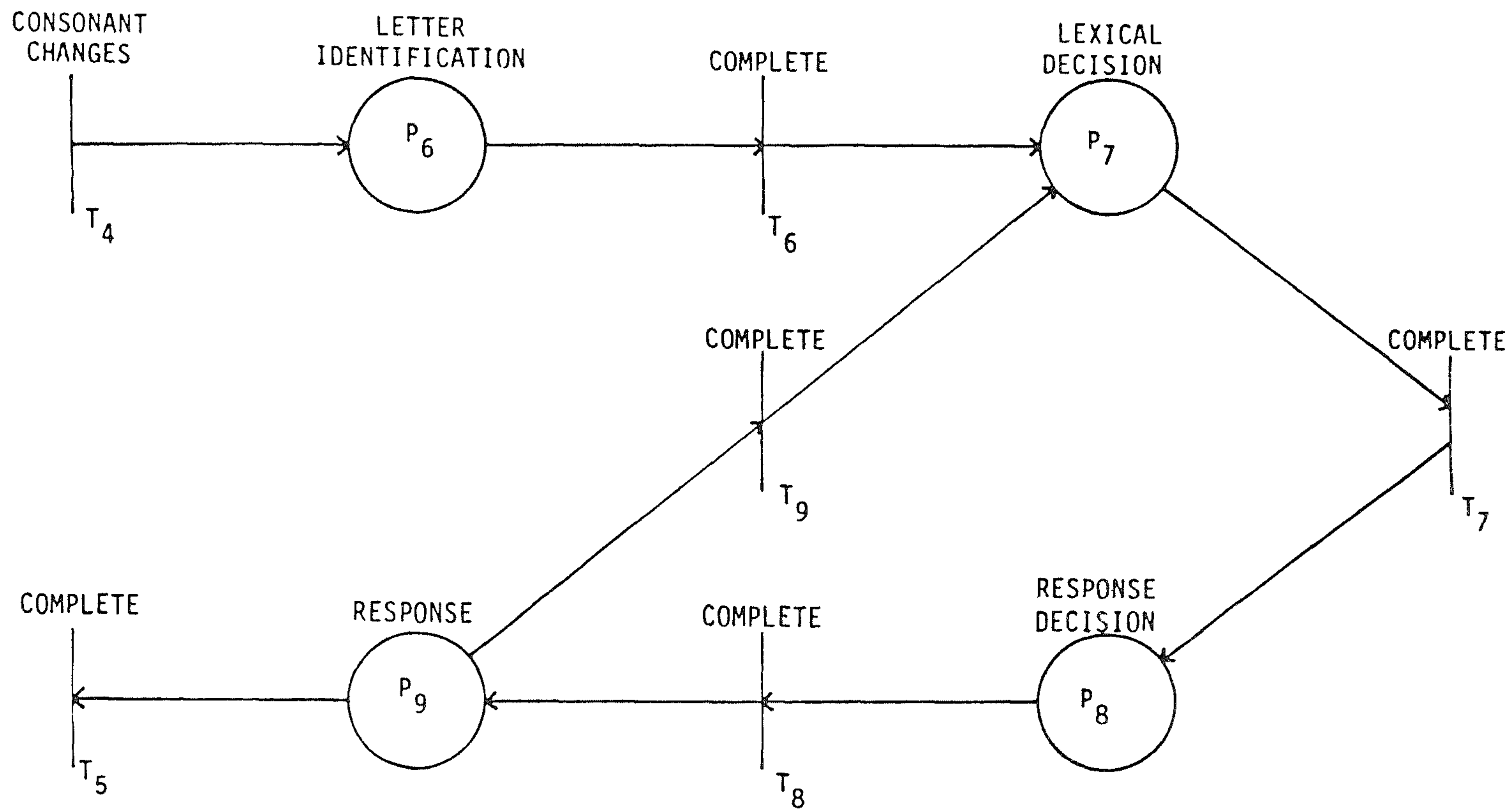
MPN OF DUAL TASK

FIGURE 1B



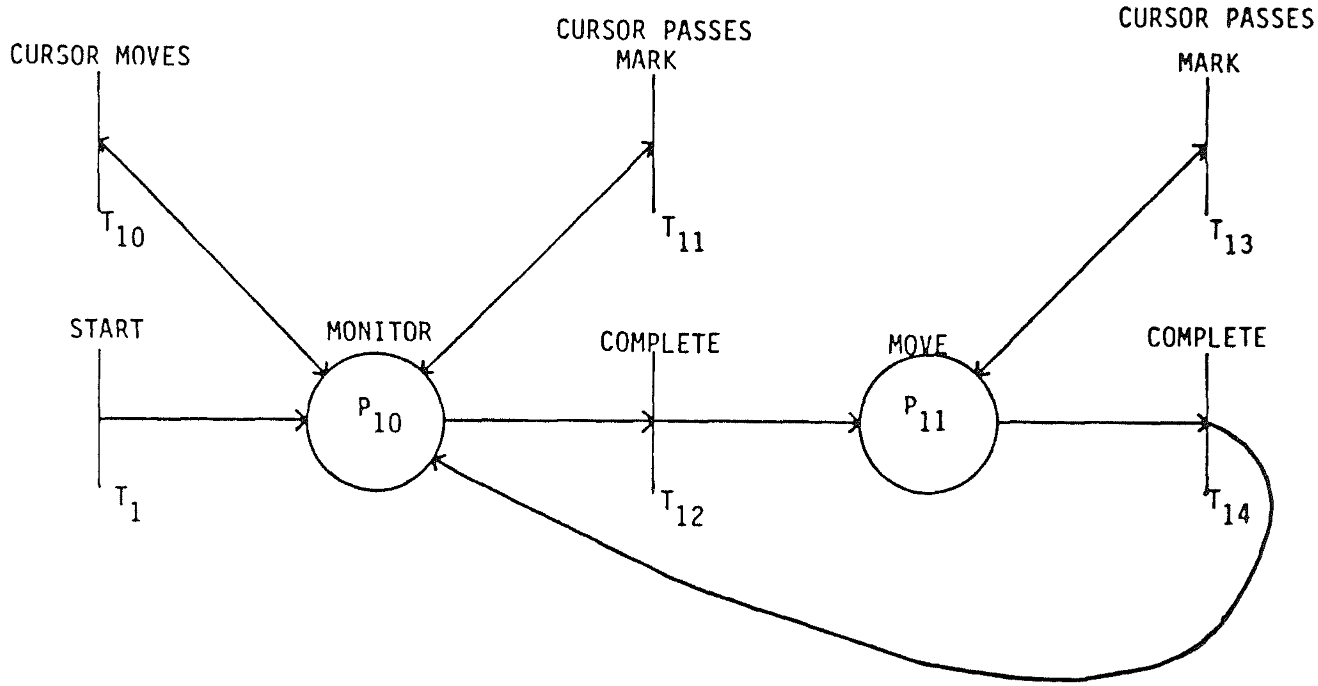
MPN SUBNET OF VOWEL INSERTION ACTIVITY

FIGURE C



MPN SUBNET OF LEXICAL DECISION ACTIVITY

FIGURE 1D



MPN SUBNET OF TRACKING ACTIVITY

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