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A PERIODIC LOADING POLICY FOR A FLEXIBLE TRANSFER LINE: DEVELOPMENT AND SIMULATION ASSESSMENT*

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Abstract: The modelling and control of a flexible transfer line is considered in this paper. The transfer line is able to produce a number of various products concurrently; it involves considerable set-up times between different product groups and has limited interprocess buffer capacity.

The proposed control methodology is hierarchical in nature. At upper levels production orders are aggregated in groups with the aim of reducing system set-up times while satisfying demand. At lower levels, given a set-up configuration, dispatching of parts into the system is performed based on the concept of periodic loading.

Simulation results have shown that when the system is controlled by the suggested scheme, the work-in-progress level is reduced by 50% and part waiting time by 93% as compared to the current system control practices. It was found that doubling the capacity of two critical workstations may result in a 70% increase in productivity.

Keywords: Flexible transfer line, system productivity, simulation.

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1. INTRODUCTION

The task of production scheduling is the allocation of the machines, personnel and support systems of a manufacturing system over time so as to best meet a set of objectives. This problem has been approached by a number of methods (including both optimisation techniques as well as heuristic approaches) by the operational research community. The problem of scheduling for a flexible transfer line, however, is reduced to designing an effective input policy, since the sequence of the jobs may be determined only when they are loaded into the system. In this paper, a hierarchical optimal loading policy for a real flexible transfer line is developed and assessed by the use of simulation.

2. SYSTEM DESCRIPTION AND PRODUCTION CHARACTERISTICS

The system under consideration is a flexible transfer line which manufactures heaters of variable length and height. Raw material comes in coils of specified width. Heaters of different heights require coils of corresponding width and their length is determined at the initial stage of the production. A variety of heater types is produced, consisting of one or more basic heater bodies.

In order to produce a basic heater body, the raw material is cut and formed (in the press machine) so that an elementary part of the heater is created. Then, special rings are placed in every other part (at the ring-placer) and two parts are grouped together to form the main body of a basic heater (at the alignment station). The body is consequently spot welded (at the spot welder) and bound to a meander (at the meander spot welder), followed by lengthwise and transversal binding of the body edges in two welding machines. Then, each basic heater goes through a set of three subsequent secondary operations which are: deburring, corner rounding and finishing. Finally, inlets and outlets are inserted to the body to produce the simplest type of heater (at the final assembly). Other heater types may be produced by assembling a number of basic heaters at the final assembly. This is the end of the automatic transfer line; heaters are then forwarded to the testing area, where they are tested and reworked if it is necessary. The heaters are painted and packed in the final production stage. In this paper, however, we will mainly deal with the automatic transfer line. In the automatic transfer line heaters are transferred from one work station to the next by a conveyor with constant speed and of specific length.

Operation times are proportional to the length of the heater in the press machine, the body and meander spot welder and the length welder. On the other hand, height affects mainly the traversal welding and the finishing time. Finally, the heater type affects only the final assembly operation time. The testing area operation time is insensitive to the kind of heater tested.

Whenever a coil of raw material has been used up or when it is decided to change the height of the produced heater, a new coil is placed in the press machine; this is a very time-consuming setup activity which is performed manually. In addition, set-up time is also required at the final assembly when the heater type changes.

The produced heater bodies are tested in order to identify deficiencies. This is a manual operation which also identifies the station from which the deficiency has originated. The heater bodies produced from this machine have the same deficiency until the proper action of tuning the station is taken. Tuning of the station means that production stops, corrective action to remove the cause of the deficiency is taken and all the defective heater bodies are re-worked.

The current production schedule attempts to maximise the throughput of the system by loading it to its maximum capacity. This is attempted by feeding the system continuously. The current production policy is characterised by its fixed planning horizon which is set to a working week and by the fact that the orders are satisfied from the stock, i.e. the system produces heaters which are used to replenish the inventory. The current production schedule also attempts to minimise the setup time by avoiding as much as possible the operations which require a long setup time. Thus, heaters of the same height are produced during the planning horizon (i.e. no change of coil occurs during the working week). Instead, changing of the coil is postponed until the end of the week and takes place during the weekend when the system is idle.

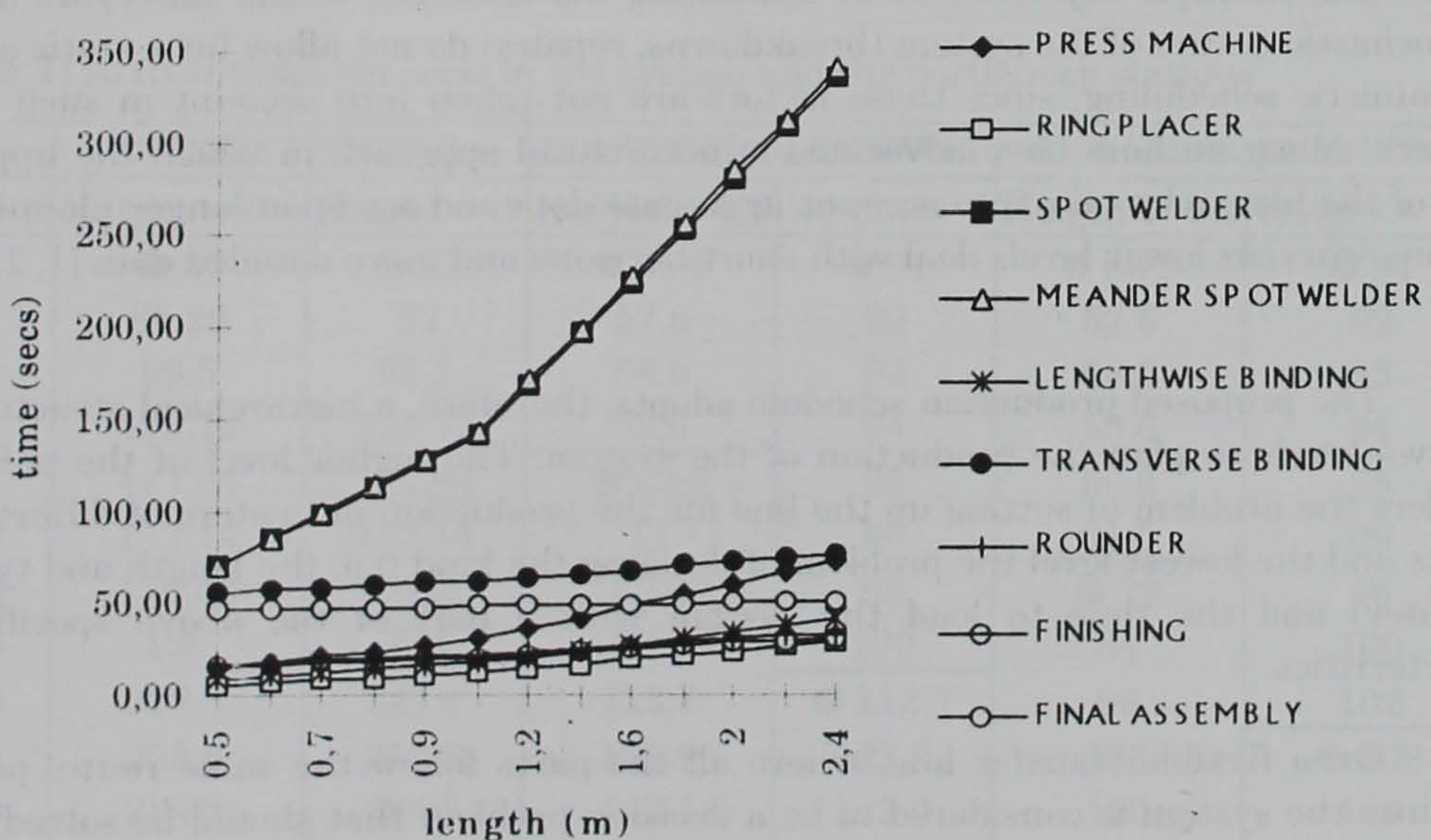

Figure 1: Processing time for heaters of height 0.6m.

Static analysis of processing time demand reveals that the required work-load on body and meander spot welders is greater than that imposed on the rest of the stations and it increases with bigger lengths. As a result, these two stations are the system's bottleneck machines (Fig. 1). Bigger heights only affect traverse welder and press processing times, whereas types affect the final assembly machine but not to the extent needed for changing the bottlenecks of the system. Therefore, balance of the current transfer cannot be achieved by designing an appropriate part mix. The work-load of the testing area is fixed and may be the bottleneck of the overall production for a specific kind of heaters.

3. DEVELOPMENT OF A PERIODIC LOADING POLICY FOR THE CURRENT SYSTEM

The objective of this study is to develop and assess with the help of a simulation model, a system loading policy which would optimise current system performance and suggest and evaluate ways to increase system productivity through additional investment.

System performance measures are considered to be the system production rate for each kind of heater, the average work-in-progress, the average flow time, the utilisation of the stations and the number of defective parts produced before identifying the problem in the testing area. The policy proposed attempts to optimise the above objectives while satisfying demand requirements.

The multiple objectives to be optimised, the existence of the conveyors and the stochastic nature of the system (breakdowns, repairs) do not allow for a static and deterministic scheduling, since these factors are not taken into account in such an approach. Many authors have advocated a hierarchical approach in which the upper levels of the hierarchy take into account aggregate data and act upon longer planning horizons whereas lower levels deal with short horizons and more detailed data [1, 2, 3, 4, 5].

The proposed production schedule adopts, therefore, a hierarchical structure with two levels to plan the production of the system. The higher level of the policy considers the problem of setting up the line for the production of heaters of different heights and the lowest level the problem of deciding the kind (i.e. the length and type of heater) and the time to load the system with a part of the above specified characteristics.

On a flexible transfer line, where all the parts follow the same route, part entry into the system is considered to be a decision problem that should be solved at the lowest level. The question of which part to process next at a released machine is not relevant for this case, because the parts are transferred by a conveyor in which the heaters keep the sequence specified by their entry. In any case, since one of the objectives is to minimise the work-in-progress, the solution to such a problem is not expected to affect performance measures considerably, as the parts waiting in front of a station are very few.

As mentioned before, the planning of heater production of different heights is performed at the higher level of the hierarchy. Line setups are considerable and therefore settingup the line for different heights should be a decision taken less frequently than system entry decisions. Thus, the length and type of the heater are used as control variables for short-term scheduling, while the height is used for medium-term scheduling.

The policy suggested at the higher level was to group the orders by their delivery time by using aggregated demand data and then split them in groups of the same height taking into account the line productivity. In this paper we will concentrate on the development of the policy in the lower level.

There is no reason to load the system with more parts than it is able to produce because otherwise parts tend to accumulate within the systems resulting in system congestion and blocking of the machines given its limited buffer capacities. In a flexible transfer line with a distinct bottleneck the production rate of the transfer line equals the production rate of the bottleneck machine. Therefore, as far as the automatic line is concerned, the periodic loading of the line at a period inversely proportional to the production rate of the bottleneck station for the particular kind of heater is suggested. As a result, it is expected to reduce the work-in-progress and flow time of the heaters produced. Table 1 shows the time intervals at which the formation of a new elementary part of the heater has to take place, as well as the bottleneck stations which determine the productivity of the system.

Table 1: Arrival times (in secs) in the system and the bottleneck stations

(mm)	CURRENT SYSTEM		DOUBLE PRODUCTIVITY		TRIPLE PRODUCTIVITY	
	Height = 0.6	Height = 1	Height = 0.6	Height = 1	Height = 0.6	Height = 1
500	❷ 87	❷ 91	❶ 56.6	❶ 91	❶ 56.6	❶ 91
600	85.29	92	57.6	92	57.6	92
700	99.5	99.5	58.6	93	58.6	93
800	113.72	113.72	59.6	94	59.6	94
900	127.94	127.94	❷ 63.9	95	60.6	95
1000	142.14	142.14	71	96	61.6	96
1200	170.59	170.59	85.3	98	❸ 72	98
1400	199	199	99.5	100	84	100
1600	227.4	227.4	113.7	❷ 113.7	96	102
1800	255.8	255.8	127.9	127.9	108	❸ 108
2000	284.3	284.3	142.1	142.2	120	120
2200	312.6	312.6	156.3	156.3	132	132
2400	341.2	341.2	170.6	170.6	144	144

Bottleneck stations: ❶ transverse binding ❷ meander and body spot welder ❸ press machine

The output rate of the automatic line is the feeding rate of the testing area which has a fixed production rate. As a result, the number of parts accumulated in front of the testing area is a function of the difference of the two production rates. The policy, although it considers mainly the automatic line, tries to minimise the average number of parts waiting in the testing area. This is achieved by appropriately controlling the kind of heater (basically its type) to be produced by mixing the kinds of heaters in the line entrance. Kinds of heaters which render the automatic line dominant are interchanged with the kinds of heaters for which the testing area is the crucial station.

4. INCREASED SYSTEM PRODUCTIVITY AND ITS IMPLICATIONS

In order to increase the productivity of the system, it is necessary and sufficient to improve the productivity of the crucial machines: the body and meander spot welders. Technologically, it is only possible to double, or triple their productivity. Both these cases were evaluated with the help of a simulation model.

It is interesting to note that the bottleneck stations depend on the length of the heaters produced. Figure 2 shows the main stations that are substantially affected by the change of length and affect productivity when it increases. Thus, in the current system, the body and meander spot welders are system bottlenecks (Fig. 2a). When body and meander spot welder productivity is doubled, traverse binding becomes the new bottleneck machine of the system for short-length heaters, while the body and meander spot welders remain the bottleneck for longer heaters (Fig. 2b).

When body and meander spot welder productivity is tripled, traverse binding is again the bottleneck machine for short-length heaters, while the press machine becomes the bottleneck for longer heaters (Fig. 2c).

5. SIMULATION AND RESULTS

The system was modelled with the use of a domain specific simulation tool to the necessary level of detail. System performance was evaluated under the proposed control schemes and for various realistic demand and system configuration scenarios, namely, the existing system and a system with increased (double and triple) productivity of the crucial stations. The obtained simulation results for the existing system demonstrate that system productivity and machine utilisation are identical under the current and the proposed production policy.

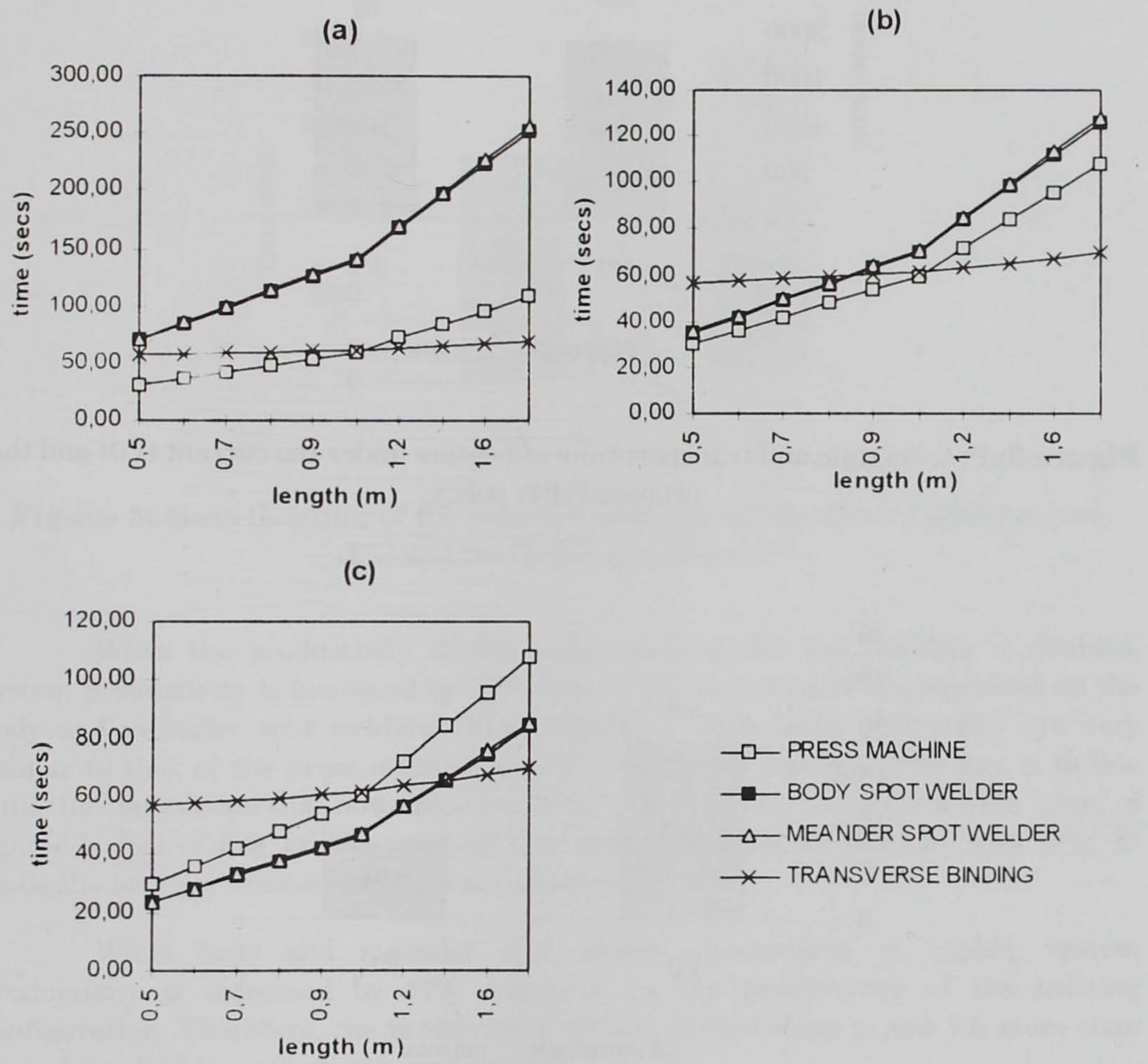

Figure 2: Operation times of important stations under three system configurations:
(a) current system
(b) system with double productivity
(c) system with triple productivity
The heater height is 0.6m for all the alternatives

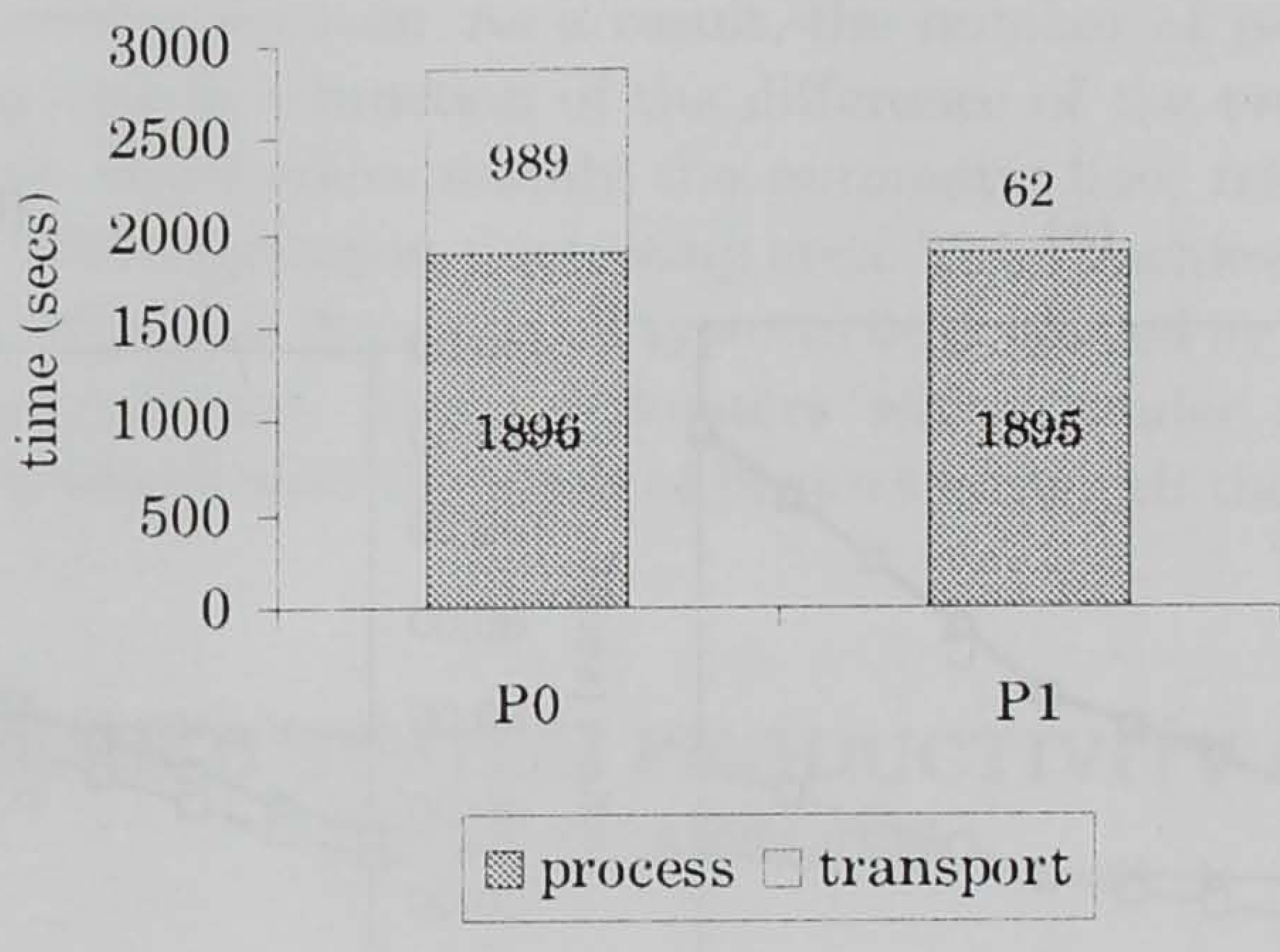

Figure 3: Process time and transport time of heaters under the current (P0) and the proposed (P1) policy

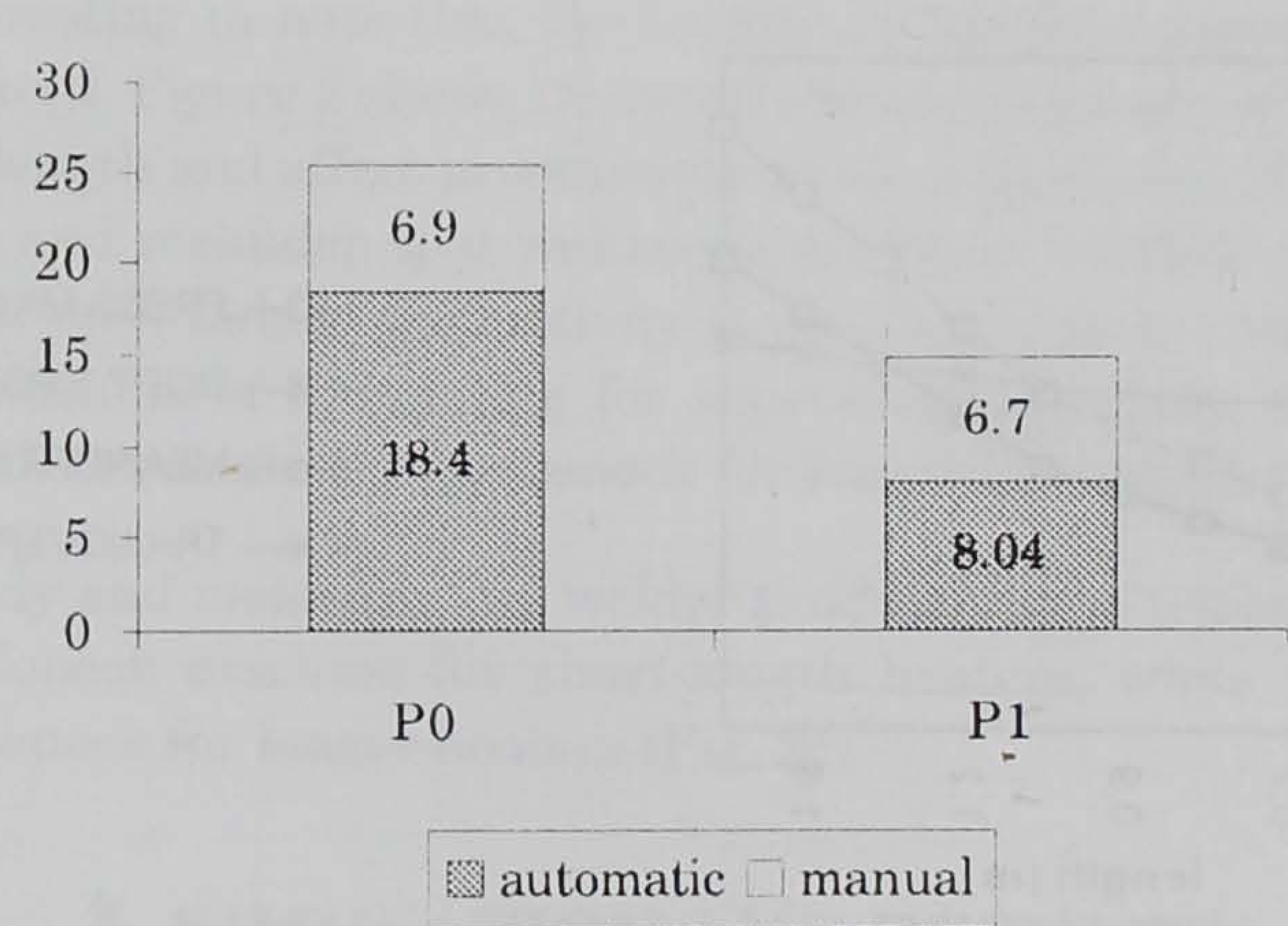

Figure 4: Average number of heaters in the manual and automatic line under the current (P0) and the proposed (P1) policy

Furthermore, the same machines appear to be the system bottleneck under both schemes. Thus, the body and meander spot welders are bottleneck machines operating at full capacity, while the press machine and the traverse binding have a considerable utilisation rate (about 50%).

The mean flow time, however, is reduced under the proposed policy by 67% (Fig. 3) a fact which is attributed to the minimum number of parts on the conveyor. As a consequence, under this policy, no blockage of machines is observed. Finally, the average number of bodies in the system is reduced by 45%, which practically means that the average work-in-progress for the proposed policy is minimised (Fig. 4).

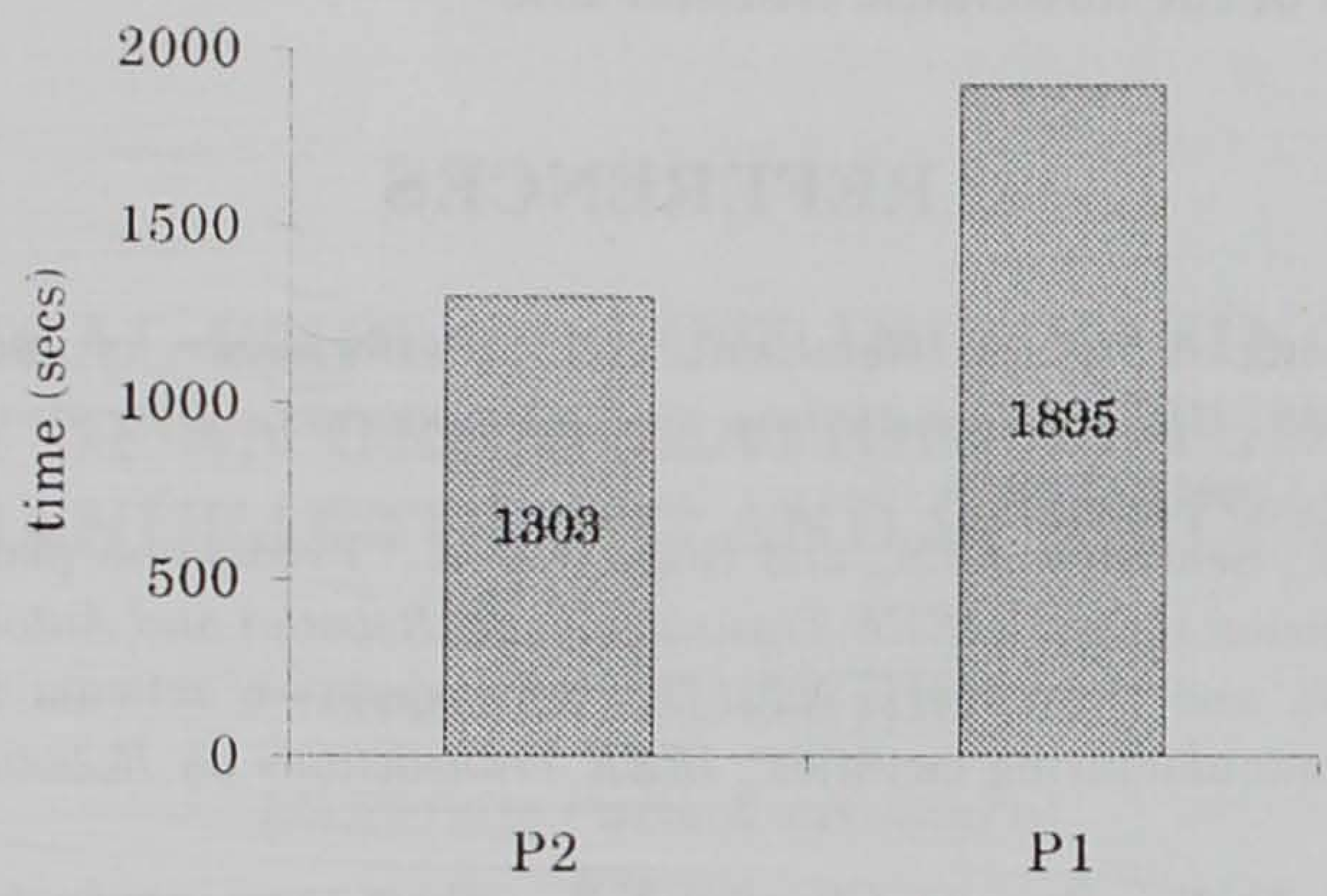

Figure 5: Mean flow time of the proposed policy under the current configuration (P1) and the double capacity (P2)

When the productivity of the body and meander spot welders is doubled, system productivity is increased by 70%. Due to the reduction of the workload on the body and meander spot welders, their utilisation rates under this policy are very similar to that of the press machine and the transverse binding. This fact is in line with the observation that now these machines are the bottlenecks for a wide range of heater bodies (Table 1). The average flow time is further reduced by 67% (Fig. 5) while the average work-in-progress is still minimum.

When body and meander spot welder productivity is tripled, system productivity is increased by 77% compared to the productivity of the existing configuration. Therefore, the productivity of this configuration is just 7% more than that of the double productivity configuration.

6. CONCLUSION

In this paper a real flexible line with limited buffer capacity which produces different kinds of heaters has been studied through simulation under the current and a periodic loading policy and different configurations have been evaluated.

The way the current system is controlled results in unsatisfactory values of system performance measures, while the proposed production control policy, which is hierarchical in nature, optimises these measures.

The periodical input policy respects the line production rates by introducing parts into the system at a rate proportional to the line production rate. Thus, the policy achieves the minimisation of the number of heaters in the system and the defective parts as shown by the simulation results. Also, simulation findings suggest that additional investment is justified to double the productivity of the current bottleneck stations of the automatic transfer line.

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