Basic Zone Control Performance Determination in FTS Design

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This paper presents procedure for estimation of vehicle control zone blocking times as an only a small part of system and elementary subsystems performance variables calculation in a flexible transport system (FTS) design. Procedure is a final step of an Integral analytical model (IAM) for FTS design and performances determination*, whose general algorithm is shown. Some results of sensitively analyses performed by IAM are also presented. Proposed analytical modeling strategy substantially increases the level of accuracy of system and elementary subsystem performance predicting.*

Key words: *flexible transport systems (FTS), zone control, elementary subsystems (ESS), system performances, performance variables, and Integral analytical model.*

1. INTRODUCTION

Flexible transport systems (FTS) are the best adopted for solving the transport problems in a great number of fields. FTS are classified as complex transport systems with different interactions of elements, so analysis of the whole system and selection of solutions for the given design task can only be done by modeling. Major aspects of any system research problem are given in [1].

The FTS design problem could be reduced to the isolation and optimization of the knot points or elementary subsystems (ESS), resources whose capabilities seriously limit the overall system performances. Knot point or elementary subsystem (ESS) represents a place of performing technological operations, material flow decelerates because of transshipment, or temporary stops, transportation flows are branching or collecting, the transportation and technical state of cargo changed, or material temporary stocks [2,3]. By definition ESS is the subsystem which is unable to be further decomposed without disturbing given function and which is suitable for optimization in system analysis. The basic aim for introducing notion ESS is to define boundaries in such manner to enable optimization of elementary subsystem in a most appropriate way.

By identification and optimization of ESS variables it is possible to obtain component, subsystem and system variable values that assure optimal system performances achieving or, in other words, all ESS variable values should be determined on the system level based on design requests.

This is a crucial issue of *Total Performance Design* (TPD) approach developed at Faculty of Mechanical Engineering, Belgrade [4]. The basic idea of the procedure TPD – Total Performance Design [4] is to coordinate methods of operations research, at the system level, and the methods of optimization at the component level. Specially, in the case when the standard components are capable to be modified (reengineering process) or where it is reasonable to make a new design (construction) of the component. In both cases, for the design process of a component, the system requirements should be treated as a design task. In the following text, a pragmatic model approach at the system level is presented, which in one integrated planning instrument that combines simulation model and multiattributive evaluation methodology. The approach is based on the following concept: a simulation model developed is combined with a formal evaluation procedure to initiate an iterative solution finding process. The results of the simulation may at any point in time be submitted to a formalized evaluation procedure containing multi goal structure. The procedure not only allows evaluation of indicators of system performance, but also the relating of these indicators to more general concepts of utility, such as influence of the system into the working and climatic conditions or fatigue and possibility of injury.

The proposed planning process consists of the iterative applications of simulation and evaluation to planning alternatives [3,4,5,6], by designer together with decision-makers (Figure1).

Simulation models represent a complex system, but they do not generate optimal solutions, they only describe the consequences of given solution alternatives. The solution of the planning problem is approached experimentally by an iterative process of learning about the behavior of the system modeled under different conditions and isolation of the knot points (elementary subsystem). The experimental character of the simulation corresponds specifically with the iterative decision process. Evaluation and selection of alternatives remain outside of the simulation model. A formalized evaluation model based on the utility theory has been developed [2,3]. In this model a

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complex object of evaluation is decomposed into its independent dimensions by means of a goal hierarchy. The evaluation model receives the data from the simulation model and evaluated them by using multi goal structures. It allows an iterative approach to successively "better" solutions. This makes the solution finding process as a learning process, in which through iterative application of simulation and evaluation a design that is acceptable to all participants is approached.

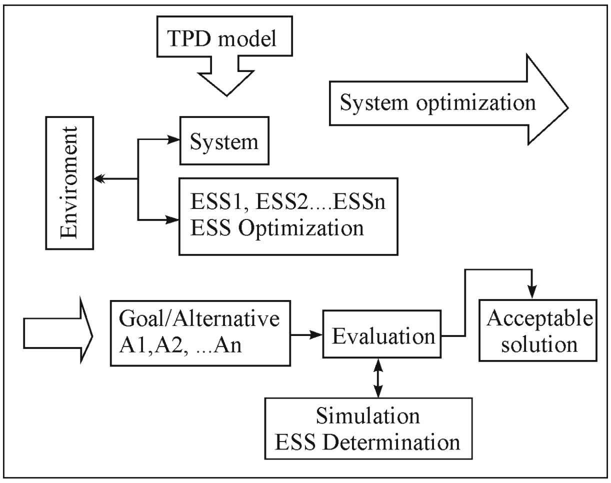

Figure 1. TPD procedure

FTS cover today a very wide range of transport tasks in a great number of fields: automotive industry, motor and gear box industry, machine industry, warehouses, distribution centers, flexible production systems, and in hospitals, posts, airports, etc. Due to the great importance of FTS it is necessary to develop a methodology of their design on the system level, by obtaining large amounts of new information necessary for providing required criteria for attaining the desired project results [4,7].

The FTS elementary subsystems (ESS) are: [8]:

1. Workstations: machine tools; flexible cells; automatic welding stations; assembly stations; input/output zone of automatic warehouse; palletization and depalletization stations, etc.
2. Transportation path crossroads.
3. Pickup stations.
4. Delivery stations.
5. Central buffer. If any machine tool has its own buffer, central buffer is not necessary.

The FTS variables are: System layout (with control zone configurations in the guided path network); flow path; location of pickup and delivery stations; fleet size; average transporter speed; dispatching rules.

The ESS variables are: ESS location; ESS design and construction solution; average handling speeds and transportation distances of implemented transport devices; guided path configuration in ESS control zone or in the part of the ESS representing pickup and/or delivery station (with or without spur); buffer capacity of ESS control zone; ESS input storage capacity; ESS output storage capacity.

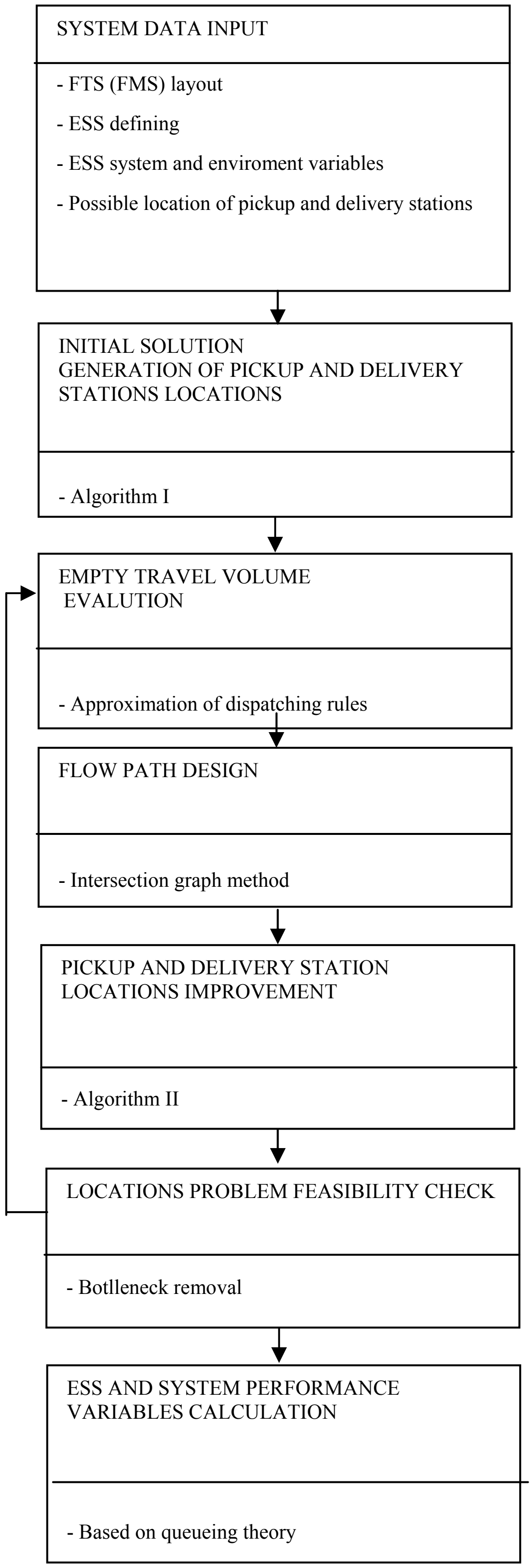

Figure 2. IAM algorithm

The system performance variables are: System throughput (number of unit load completed); mean job flow time; average transporter utilization; FTS (and flexible manufacturing system (FMS)) floor area; overall transport path length; optimization criteria value of the optimal flow path model.

The ESS performance variables are: Mean number of transporters in the ESS control zone; control zone mean transporters travel time (including blocking, i.e. control zone transporter waiting time); mean number of parts in the ESS input queue; mean part waiting time in ESS input queue; mean number of parts in the ESS output queue; mean part waiting time in workstation output queue. The ESS design solutions and their specific variables are given in [9].

2. LITERATURE REVIEW

Flow path design problem was first studied by Gaskins and Tanchoco [10] as a zero one integer linear programming problem. They modeled flexible transport system (AGVS) as node and arc network, where the nodes represent fixed pick-up/delivery stations and aisle intersection and arcs are guide paths connected with the nodes. The objective was to find direction of arcs, which will minimize the total travel of loaded vehicles. The problem was solved with the multipurpose optimization system computer package using a direct search algorithm. Goetz and Egbelu [11] extended the Gaskins and Tanchoco [10] model by studied optimal flow path network as well as the location of pick-up/delivery stations simultaneously.

The problem is solved using integer programming (mathematical programming software). Kaspi and Tanchoco [12] formulated AGVS flow path problem as a zero-one integer programming problem. They first introduced computationally efficient branch and bound procedure for solving the problem using backtracking depth-first search technique. For the first time large realistic size problems could be successfully treated. Sinriech and Tanchoco [13] developed so-called ‘intersection graph method’ for AGVS optimal flow path designing. The zero-one integer-programming problem formulated by Kaspi and Tanchoco [12] were solved using an improved branch and bound procedure. Proposed accelerated method becomes particularly powerful when dealing with specific changes of input dates. Sun and Tcherney [14] presented a modeling approach to determine the AGVS optimal flow path which takes into account, for the first time, the impact of empty vehicle flows. They formulated problem by two analytical models based on mixed integer linear programming. The problem was solved by a very effective branch and bound algorithm based on a depth-first search.

The second main FTS design problem is the location of departmental pickup and delivery stations determination problem.

Montreuil and Ratliff [15] introduced the pickup and delivery point location problem for block layouts. The method generated possible location of pickup and delivery points and chose the best locations. Kiran and Tansel [16] discussed optimal pickup point location on guided path networks. Pickup point may represent any point where material exits or enters the system. As it was already mentioned Goetz and Egbelu [11] discussed the flow path and location of pickup and delivery points problems. Sinriech and Tanchoco [17] dealt with the optimal placement of pickup and delivery points in a single loop system. The developed method based is on finding the best single loop first and then choosing the corresponding locations. Finally, Kim and Klein [18] presented two heuristic algorithms for the location of pickup and delivery points. The first algorithm generates initial solutions by exploiting the structural feature of departmental layouts. The second algorithm takes an iterative search approach to reach a final solution by comparing relative locations of pickup and delivery points among departments. The algorithm is based on procedure developed by Armor, G.C., Buffa, E.S. [19].

All models deal with bi-directional flow path network and do not take into consideration empty travel volume. Kosanić [20] and Kosanić and Zrnić [21] discussed optimal location of pickup and delivery point and uni-directional flow path network simultaneously.

The third problem is ESS and FTS performances obtaining. Just a few references deal with this complex problem. In the paper of Tanchoco at al. [22] the effectiveness of CAN-Q (Computerized Analysis of Network of Queues) in the determining the required number of AGV vehicles for a specific application is compared to a simulation-based method (AGVSim). CAN-Q is the queueing-theory-based model, which for the specific number of vehicles gives basic system performance (of flexible manufacturing system and transportation subsystem - AGV): average machine utilization, number of unit load completed a mean job flowtime.

CAN-Q does not take in to consideration empty travel volume, and pickup and delivery point locations are fixed. Wysk at al. [23] used spread-sheet analyses along with CAN-Q to estimate the required number of vehicles in an AGVS serving the flexible manufacturing system. The other authors obtained ESS and system performances only by simulation: Mahadevan and Narendran [24], due to investigated required number of vehicles in the AGVS, or (Ozden, M. [25]), due to main system performance evaluating.

The FTS structure analyses and all elementary subsystems variables are given in Zrnić and Kosanić [9].

3. INTEGRAL ANALYTICAL MODEL FOR FTS DESIGN AND PERFOR-MANCES DETER-MINATION (IAM)

Integral model simultaneously optimizes the most of the system variables, and evaluates system and ESS performances avoiding potential bottlenecks. It represents combination of optimization and queueing theory models. General algorithm of IAM is given in Figure 2.

Model first simultaneously optimizes location of pickup and delivery stations and unidirectional flow path accounting empty travel as an approximation of the applied combination of dispatching rules [21].

Optimal pickup and delivery stations problem is solved using two heuristic algorithms developed by Kim and Klein [18].

In each iteration of second algorithm flow path design problem is solved using so-called ‘intersection graph method' developed by Sinriech and Tanchoco [13]. However, in each iteration of 'intersection graph method' empty vehicle flow is taken into account for the first time as an approximation of the applied combination of dispatching rules (procedure based on improved model originally developed by Malmborg [26], Kosanić [1]).

Possible departmental pickup and delivery station locations depend on design solution of elementary subsystems. Some characteristic machine tool workstation and pickup and delivery station ESS design solutions the model can treat are given in Table 1 and Table 2. The model can also experiment with two paletization and depaletization station ESS design solutions.

It is also important to note that construction characteristics of ESS of FTS and their influence on system performance are not being discussed in details in the literature and that IAM has this possibility.

IAM also assures removing of vehicle congestion in station and crossroad control zones.

After optimization of locations of stations and flow path Integral model calculates all system and ESS performance variables.

4. BASIC ZONE CONTROL PERFORMANCE DETERMINATION

Basic zone control performances determination is a small part of an ESS and system performance variables calculation and involves estimation of mean number of vehicles (transporters) in the ESS control zone and control zone mean vehicle (transporter) travel time (including blocking, i.e. control zone transporter waiting time).This procedure is represented below.

This part of Integral model is based on considerably improved control-zone model originally developed by Malmborg [26].

Estimates of the vehicle blocking times are obtained by modeling the control zones as finite customer population single server queueing model - M/M/1//M [27]. Population of possible users is finite and equal to actual number of vehicles, M. A vehicle (customer) is either in the system (control zone) or outside the system and in some sense "arriving". All vehicles act independently of each other, and the system is self-regulating.

The arrival rate and the service rate are

$$\lambda_j = \begin{cases} \lambda(M-j), & 0 \le j \le M \\ 0, & \text{otherwise} \end{cases}$$

$$\mu_j = \mu, j = 1,2,\ldots . \tag{1}$$

The arrival rate is equal to the number of vehicles entering a control zone in some time period. A service rate is equal to the reciprocal value of the t_k, time necessary for a vehicle to travel through a control zone including the expected load transfer time.

The state probabilities are

$$p_j = p_0 \prod_{i=0}^{j-1} \frac{\lambda(M-i)}{\mu}, \quad 0 \le j \le M. \tag{2}$$

Thus,

$$p_j = \begin{cases} p_0 \left(\dfrac{\lambda}{\mu}\right)^j \dfrac{M!}{(M-j)!}, & 0 \le j \le M. \\ 0, j > M \end{cases} \tag{3}$$

Probability that the system is empty is

$$p_0 = \left[\sum_{j=0}^{M} \left(\frac{\lambda}{\mu}\right)^j \frac{M!}{(M-j)!} \right]^{-1} . \tag{4}$$

For obtained steady state probabilities of control zone k, mean number of vehicle waiting to enter a zone, K_k is

$$K_k = \sum_{j=2}^{M} (j-1) p_{k,j} . \tag{5}$$

The time necessary for a vehicle to travel through control zone k including blocking time can be estimated as

$$w_k = t_k' + \sum_{j=1}^{N-1} \left[(j-0.5) t_k'' p_{k,j+1} \right]. \tag{6}$$

Expression (1.6) is slightly different from an equation given in Malmborg [26] and assumes that the current vehicle in service is half completed when an arriving vehicle is blocked from using the zone. The time t_k'' is a time necessary for a vehicle to exit from control zone i.e. to travel through a zone including load transfer time (if load transfer exists) starting from a top of a waiting zone. This time for transport path crossroad control zone and pickup or delivery control zone depends on spur configurations i.e. pickup and delivery station locations (i.e. machine tool workstation ESS design solution). The times t_k' and t_k'' for crossroad control zone represent mean times for all input crossroad sections.

The total time required per unit time to accomplish all transport tasks is

$$voz = \sum_{i=1}^{W} \sum_{j=1}^{W} \sum_{k \in Z_{ij}} m_{ij}' w_k , \tag{7}$$

where m_{ij}' is a material flow intensity between workstations i and j (including empty travel).

Transport path crossroad control zone and pickup or delivery control zone configuration is presented in Figure 3.

It is important to emphasize that Integral model as it is shown allowed simultaneously the optimization of location of pickup and delivery stations and flow path through direct mutual influence these two FTS design variables and third variable, dispatching rules for specific values of other variables, chosen design solutions of ESS, fleet size and average vehicle speed. First two variables together with others influence sequence of operational parameters of the ESS and system: distances between departmental pickup and delivery points, traffic intensity on aisles, vehicle blocking in control zones (due to the congestion induced by imbalances in the material flows), and space utilization Kosanić [20], Zrnić and Kosanić [9]. The given parameters influence the ESS performance variables and system performance variables.

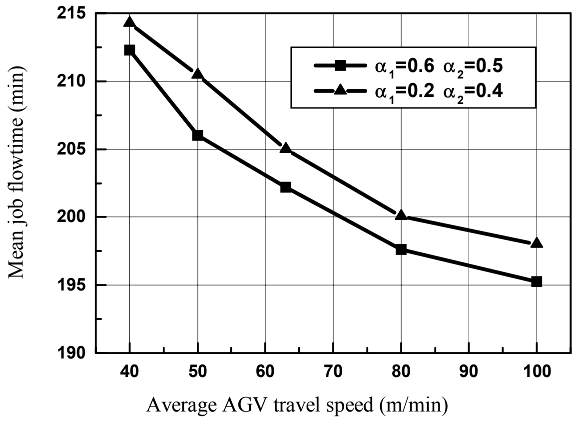

Figure 5. Mean job flowtime vs.average AGV travel speed

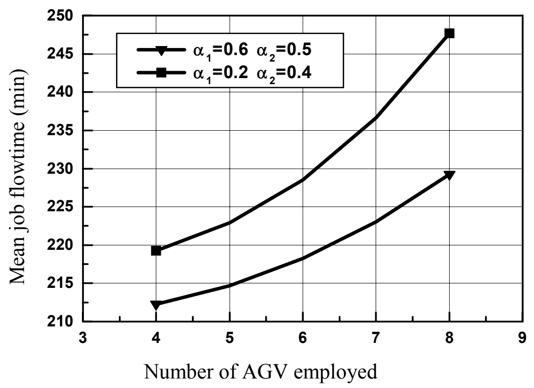

Figure 6. Mean job flowtime vs. number of AGV employed

For any possible combination of design solution of ESS and ESS and system variable values by a given model, it is possible to optimize system performances and perform any kind of sensitive analyses.

An example for the FMS consisting of automatic warehouse, palletization and depalletization station, and 7 machine tool work stations (of a first type given in Table 1), Figure 4, influence of the average AG vehicle travel speed to the mean job flowtime is given in the Figure 5, and influence of the number of AGV employed to the mean job flowtime is given in the Figure 6.

Mean job flowtime as a function of the number of AGV employed and their average travel speed is given in Figure 7.

Mean job flowtime as a function of the average AG vehicle travel speed and the main roller conveyer speed of the input/output automatic warehouse ESS is given in Figure 8.

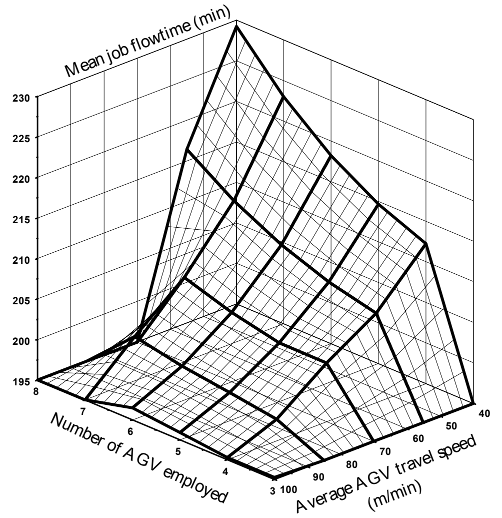

Figure 7. Mean job flowtime vs. number of AGV employed vs. average AGV travel speed

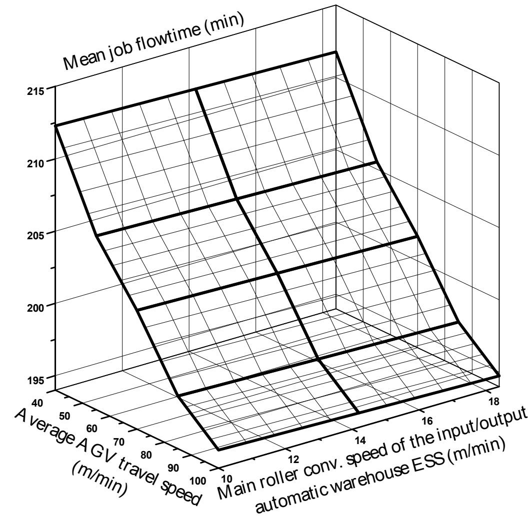

Figure 8. Mean job flowtime vs. average AGV travel speed vs. main roller conveyer speed

5. CONCLUSION

The aim of paper was to point out estimation of basic zone control performances and the basic aspects of *Integral analytical model for FTS design and performances determination* based on Total Performance Design (TPD) approach. TPD enables total control of the system and ESS performances, assuring subsystem and component variables values determination on the system level, along with all potential bottlenecks removing.

General algorithm of IAM is roughly described, procedure for estimation of vehicle control zone blocking times as only a small part of system and ESS performance variables calculation is shown and some results of sensitive analyses performed by IAM are presented.

It is important to emphasize that proposed analytical modeling strategy enables simultaneously the optimization of locations of pickup and delivery stations and flow path network, accounting empty travel as an approximation of applied combination of dispatching rules. Model allowed application of 10 possible design solutions of machine tools ESS and corresponding solution of buffers, pickup and delivery station and two palletization and depalletization station ESS design solutions. Proposed analytical modeling strategy substantially increases the level of detaility of system and ESS performance predicting.

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ОДРЕЂИВАЊЕ ОСНОВНИХ ПЕРФОРМАНСИ ЗОНСКЕ КОНТРОЛЕ У ПРОЈЕКТОВАЊУ ФТС-А

Ненад Косанић

У раду је изложена процедура за процену времена блокирања возила у контролним зонама, која представља мали део поступка за одређивање вредности променљивих перформанси система и елементарних подсистема у пројектовању флексибилних транспортних система (ФТС). Процедура је завршни корак Интегралног аналитичког модела (ИАМ) за пројектовање и одређивање перформанси ФТС-а, чији је генерални алгоритам, такође, представљен. Предложена стратегија аналитичког моделирања знатно побољшава ниво тачности предвиђања перформанси система и елементарних подсистема ФТС-а.

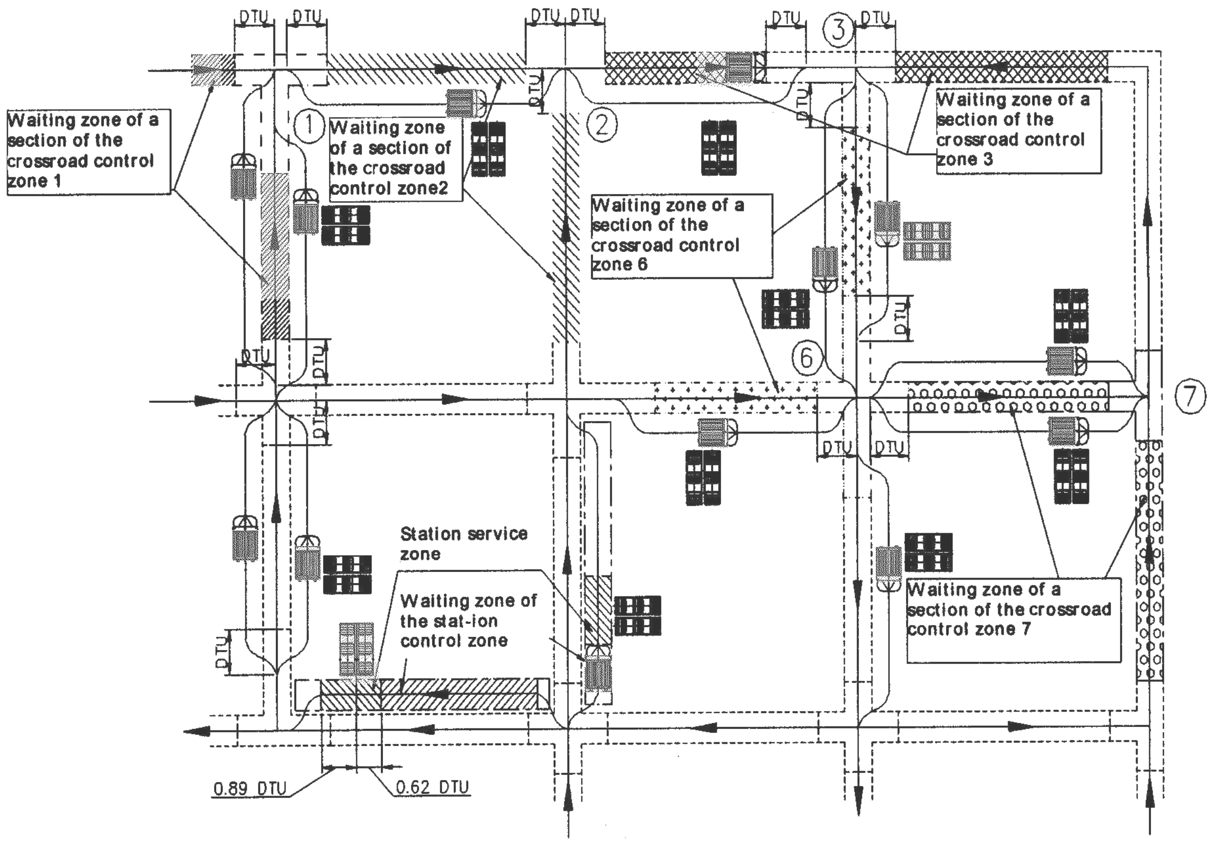


Figure 3. Control zone configuration

Table 1. Some characteristic machine tool workstation ESS design solutions

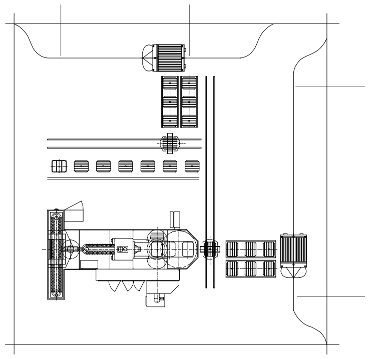
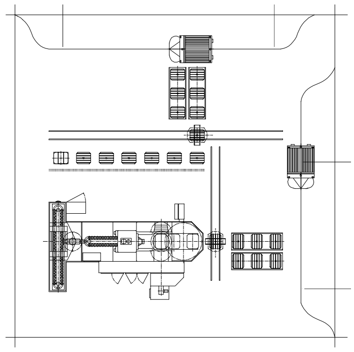
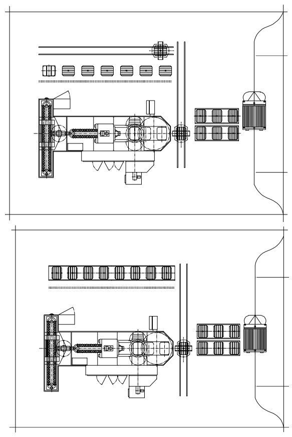
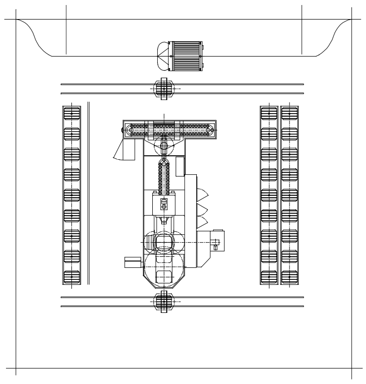
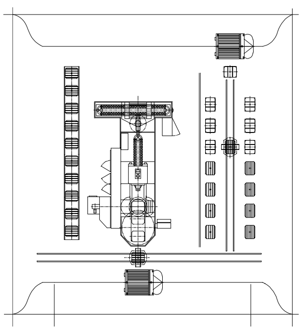
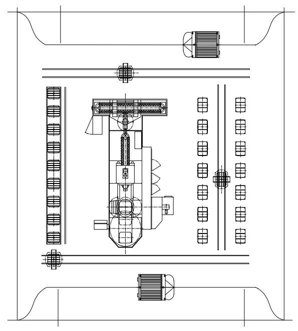
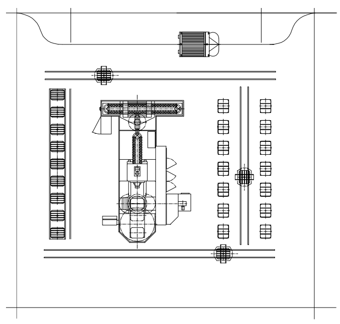
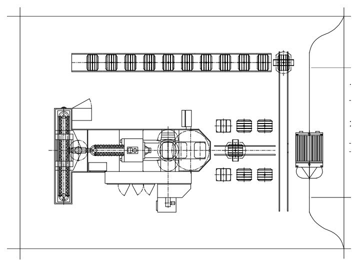
Machine tool workstation and pickup or delivery (or pick-up/delivery) station ESS design solutions	1.1 	1.2 
Design solutions specifies		
Input and output queue design solutions	parallel roller conveyers	parallel roller conveyers
Buffer design solution	pallet pull	pallet pull
Pickup and delivery stations are separated	yes	yes
Number of possible layouts	8	8
Queuing discipline /buffer	FIFO/FIFO or PRI	FIFO/FIFO or PRI
Layout shape	quadratic	quadratic
Design solution weaknesses	- difficult delivery of input queue reject unit loads - station locations are mutually dependable	- difficult delivery of input queue reject unit loads - station locations are mutually dependable
Application recommendations	- high unit load arrival and service rates	- high unit load arrival and service rates
Machine tool workstation and pickup or delivery (or pick-up/delivery) station ESS design solutions	2.1 	2.2 
Design solutions specifies		
Input and output queue design solutions	parallel roller conveyers	roller conveyer
Buffer design solution	pallet pull/roller conveyer	roller conveyer
Pickup and delivery stations are separated	no	no
Number of possible layouts	2 (4 for two possible buffer locations)	4 (8 for two possible buffer locations)
Queuing discipline /buffer	FIFO/FIFO	FIFO/FIFO
Layout shape	rectangular	quadratic
Design solution weaknesses	- small input and output queue capacities - difficult delivery of input queue reject unit loads - access to buffer is possible only with one side	- high unit load transfer time
Application recommendations	- low unit load arrival and service rates - high processing times	- high and higher unit load arrival and service rates

Table 2. Some characteristic pickup and delivery station ESS design solutions

Machine tool workstation and pickup or delivery (or pick-up/delivery) station ESS design solutions	3.1 	3.2 
Design solutions specifies		
Input and output queue design solutions	pallet pull	pallet pull
Buffer design solution	roller conveyer	roller conveyer
Pickup and delivery stations are separated	yes	yes
Number of possible layouts	8	2 (4 for two possible buffer locations)
Queuing discipline /buffer	FIFO or PRI/FIFO	FIFO or PRI/FIFO
Layout shape	quadratic	quadratic
Design solution weaknesses	- location of the pallet pull station is fixed (location is dependable of the spur direction) - access to buffer is possible only with one side - long service time for input queue unit loads	- high investments costs (three transport trolleys) - long service time for input unit loads queue (possible PRI queue discipline)
Application recommendations	- high and higher unit load arrival and service rates	- high unit load arrival and service rates
Machine tool workstation and pickup or delivery (or pick-up/delivery) station ESS design solutions	3.3 	3.4 
Design solutions specifies		
Input and output queue design solutions	pallet pull	pallet pull
Buffer design solution	roller conveyer	roller conveyer
Pickup and delivery stations are separated	no	no
Number of possible layouts	2 (4 for two possible buffer locations)	2 (4 for two possible buffer locations)
Queuing discipline /buffer	FIFO or PRI/FIFO	FIFO or PRI/FIFO
Layout shape	quadratic	quadratic
Design solution weaknesses	- high investments costs (three transport trolleys) - long service time for input queue unit loads – long unit load transfer time in pickup/delivery station control zone	- small input and output unit load queue capacity - long service time for input unit loads queue - long unit load transfer time in pickup/delivery station control zone -restricted buffer acc.
Application recommendations	- high unit load arrival and service rates	- low unit load arrival and service rates

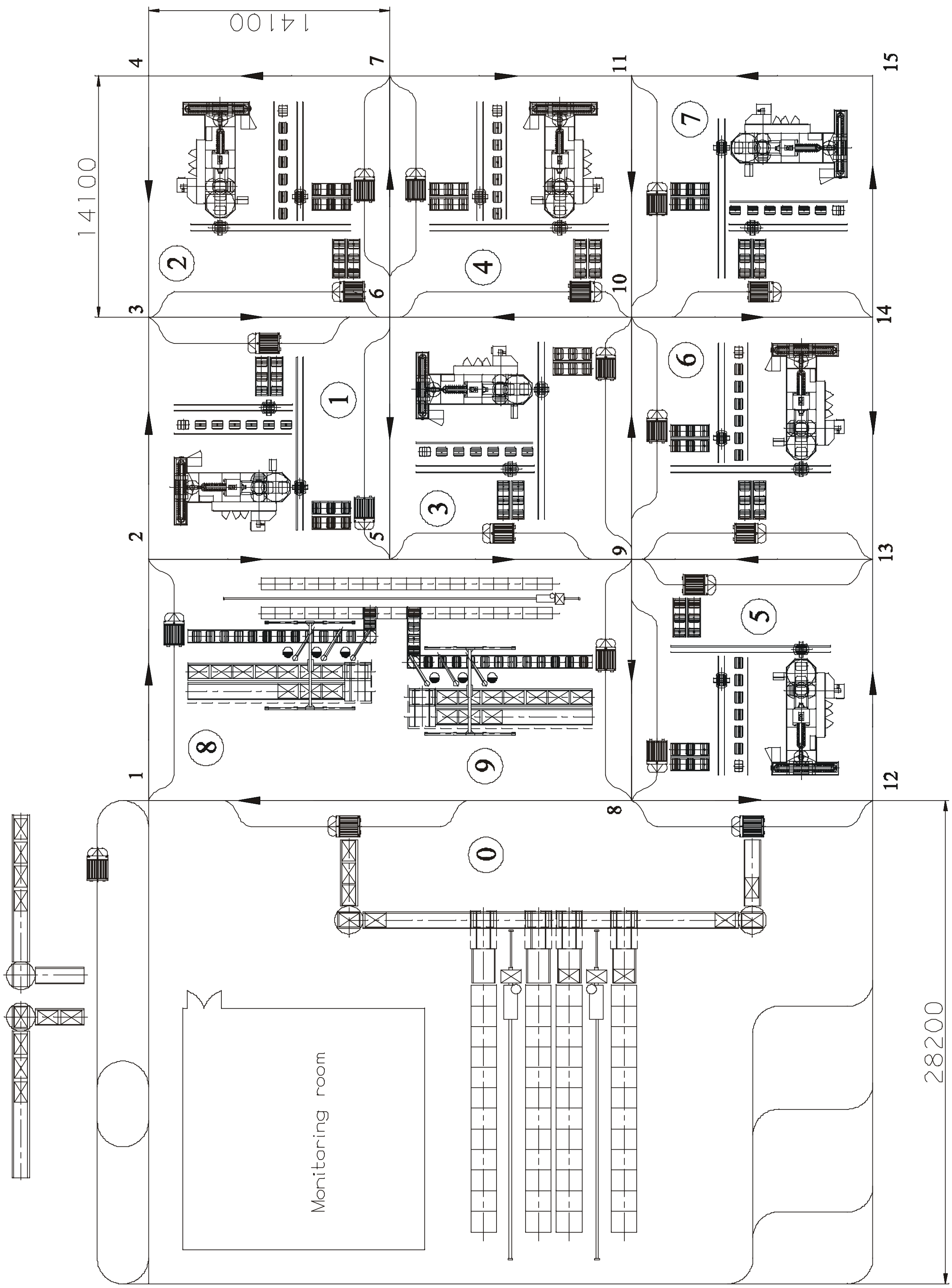


Figure 4. FMS example layout