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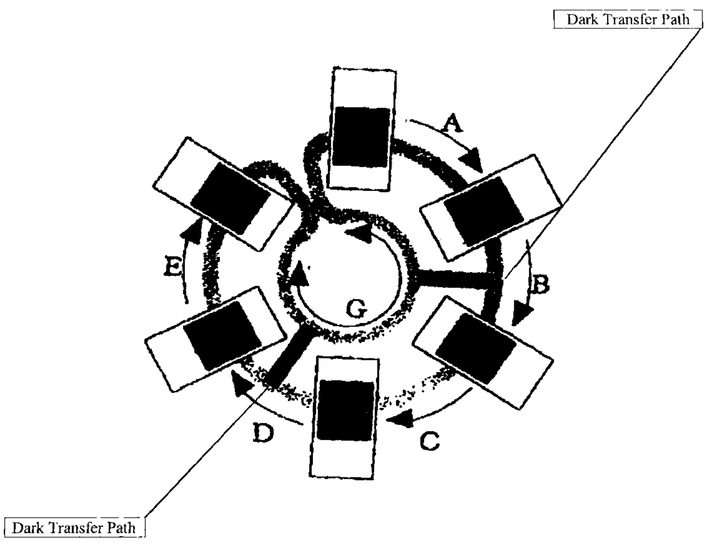
(54) Title: PRODUCTION LINES UTILIZING AUTO GUIDED PALLET AND PRODUCTION LINE DESIGN SUPPORT SYSTEM



Transfer path combining Job Type and Flow Type transfer paths

(57) Abstract: The present invention is a new manufacturing system which is small one that can mount on a desk and the like. The inventors call it a DTF (Desk Top Factory) such as to mean a small factory. In the present application is described what "DTF" aims at and two main items are described in this report. 1) A manufacturing system having an automatic guided pallet (what is called "AGP") as an automatic transport system. This AGP system is in harmony with an advantage of conventional two transfer systems of manufacturing lines that is, a flow shop type (what is called "assembly line"), which is suitable for a mass-manufacturing, has the advantage of being able to minimize the distance transferred between each process in the system and a job shop type (there is much to need a batch working) has an advantage of enabling traffic (go and return) between each process. The present invention develops an Automatic Guided Pallet (AGP) that is suitable for one-by-one operation and can traffic (go and return) between each process. The present system can be used in a flexible manufacturing system where the volume of production is relatively low and there are a wide variety of products to be made. 2) A manufacturing line design support system. One embodiment is that firstly, an operator inputs system design requirements of a manufacturing line design such as a working time of each process, an operating rate, plant and equipment cost and the like, furthermore, the weight (importance) of each of the above requirements is inputted. Secondly, the system outputs some candidates, respectively. Finally, the system allows the construction of the optimum manufacturing line by simulations.

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Production Lines Utilizing Auto Guided Pallet and Production Line Design Support System

This application claims priority to U.S. provisional application No. 60/387,347 filed June 7, 2002 under 35 U.S.C. §119 the entire disclosure of which is also hereby incorporated by reference.

Background

[0001] **Flow Type and Job Shop Type Productions, and U-Shaped Production Line**

The conventional concept of a production method and workflow associated with the production method can be summarized into the following two categories:

[0002] **Flow Type:** Work pieces are transferred one by one on a belt conveyer wherein each work piece is passed from one machine to another corresponding to each production step. The transfer can be performed at high-speed. The slowest machine in the production line determines the productivity tack. For this reason, to improve productivity, slower and lower priced machines are run in parallel to catch up with the productivity tack of a costly system (Workflow choice of Ford).

[0003] **Job Type:** In the Job Type production method (hereinafter referred to as the "Job Type"), production progresses in a manner that transfer motions follow the order of process steps. This requires a long transfer time; therefore, the system usually performs batch processing by keeping work pieces in stock. To increase productivity of this production method, it is imperative to increase the number of work pieces processed per batch. It is also imperative to speed up the process of the machine with a heavy workload or run multiple machines in parallel (Workflow choice of semiconductor fabrications).

[0004] These two production methods are highly applicable not only to manual operations or manual transfer systems but also to automated production lines or automated transfer systems.

[0005] In contrast, a U-shaped production line maximizes the use of manual labor, which is particularly effective in producing different quantities of many different types of products. The U-shaped production line is a Flow Type production method wherein an operator carries a work-piece from one machine to another to get a specific job done using each machine (usually a simple jig) and a product is made as he or she goes around the U-shaped production line.

[0006] Other than the above, there is the Volvo method in which a main work piece does not move but an operator moves a machine toward the work piece during manufacturing. This workflow may be effective in some cases.

[0007] It is a rule of thumb to increase output to improve productivity in the Flow Type or Job Type production method. In the U-shaped production line, on the other hand, an increase in productivity is accomplished by a reduction in the investment on plant and equipment, not an increase in output. In other words, the focuses of this concept are: (1) letting an operator work more efficiently and increase the workload per operator, thereby directly minimizing facility-related expenses; and (2) switching the type of machine, or scaling down of production output so as to run different types of machines in parallel, or by reducing losses from poor arrangements and logistics, thereby reducing the total amount of investment on plant and equipment. Even though an additional step of batch processing is required for overcoming problems such as exorbitant costs, facility, or production tack, an operator can easily operate the Job Type's automated transfer vehicle; and an operator can easily provide the motion of an automated transfer vehicle; therefore, it is possible to have a Job Type concept introduced in a part of the workflow as long as the travel distance is small. It is also possible to combine the advantages of both the Flow Type and the Job Type production methods.

[0008] The U-shaped line workflow is very effective for production of a variety of machines that make products and for products with a short life cycle. PCT application No. 02-03229 proposes a concept called the "Desk Top Factory" (hereinafter referred to as "DTF") that is an ultra-small precision production line. However, the DTF has a serious cleanliness problem that disqualifies the method for production lines in which manual labor must be eliminated as much as possible.

[0009] Usually, the term "productivity" means throughput per hour. More importantly, it is the throughput per "monetary value" in a practical sense. In this age, "productivity" should be defined in view of management as the production cost per "total cost of ownership" (hereinafter referred to as TCO) wherein the monetary value is the sum of the investment of plant and equipment and running costs, which includes indirect costs such as costs of investment, training, environmental infrastructure construction, and scrap value, which is the final value of a product.

[0010] The above U-shaped production line has many merits in view of TCO. The plant and equipment investment comprises a desk, mechanical parts stacking shelves, basic jigs and standalone machines of minimum requirement. The energy preparation required for facilities is minimal as well. Particularly, machines are configured with a standard specification, which yields a highly advantageous scrap value of the system. However, the U-shaped production line incurs higher training costs, human resource management costs, and clean environment conservation costs than a regular production line. The quality assurance cost may also be higher than that of automated production line.

[0011] Nonetheless, it is commonly known that the U-shaped production line provides excellent productivity in view of the TCO. It appears that the largest advantage is that the U-shaped production line has a very small management risk associated with output variations and product life cycles.

Policy for Production Line Construction

[0012] When one analyzes productivity on a TCO basis, one must find equilibrium for the following elements taking trade offs into account.

[0013] 1) Materialize Flow Type and Job Type motions (transfer cost optimization).

[0014] 2) Share expensive equipment with multiple product lines (cost and productivity tack to be shared).

[0015] 3) Increase the operating time of expensive equipment rather than increasing the number of pieces of equipment.

[0016] 4) Reduce the total cost of plant and equipment required for manufacturing the product.

[0017] 5) Minimize the land area, factory running cost, environmental infrastructure construction cost (reduce foot print).

[0018] 6) Maximize productivity per hour for a limited production quantity.

[0019] 7) Facility's recycling capability, disposal cost, and product scrap value.

[0020] 8) Eliminate motions and layout that include redundancy that deteriorates product quality (technical points such as contamination, vibration, and the like).

[0021] Prints 3), 4), 5), and 6) must be balanced with an estimated output, a product life cycle strategy, a scrap value, presence or absence of incumbent equipment as a whole for evaluation.

[0022] Based on the above, a proposal on the method of arranging the production facility and transfer is provided to make the following possible: (1) to improve productivity independent of scaling up by (2) analyzing the cost of plant and equipment on a TCO basis.

Summary of the Invention

The present invention is a new manufacturing system which is small and that can mount on a desk and the like. The inventors call it a DTF (Desk Top Factory) such as to mean a small factory.

In the present application is described what "DTF" aims at and two main items are described in this report. 1) A manufacturing system having an automatic guided pallet (what is called "AGP") as an automatic transport system. This AGP system is in harmony with an advantage of conventional two transfer systems of manufacturing lines that is, a flow shop type (what is called "assembly line"), which is suitable for a mass-manufacturing, has the advantage of being able to minimize the distance transferred between each process in the system and a job shop type (there is much to need a batch working) has an advantage of enabling traffic(go and return) between each process. The present invention develops an Automatic Guided Pallet (AGP) that is suitable for one-by-one operation and can traffic (go and return) between each process. The present system can be used in a flexible manufacturing system where the volume of production is relatively low and there are a wide variety of products to be made. 2) A manufacturing line design support system One embodiment is that firstly, an operator inputs system design requirements of a manufacturing line design such as a working time of each process, an operating rate, plant and equipment cost and the like, furthermore, the weight (importance) of each of the above requirements is inputted. Secondly, the system outputs some candidates of an optimum manufacturing line. Then the system performs simulations of the candidates, respectively. Finally, the system allows the construction of the optimum manufacturing line by simulations.

Requirements of Transfer in DTF (Factory Desktop) Layout

[0023] A review of the U-shaped production line wherein the Job Type layout and the Flow Type layout are combined found the following requirements for transfer motions thereof:

[0024] 1) The sequence goes to the next step based on a Flow Type workflow.

[0025] 2) To provide Job Type transfer when it is necessary in view of plant and equipment costs and production capacity.

[0026] 3) To provide interactive random access transfer motion separate from the basic transfer motion.

[0027] Of the above, at least, step (3) has not been described in the prior art; however, according to the invention Automatic Guided Pallets (AGPs) loaded with mechanical parts or supplemental materials are taken in the manner in which this sub-transfer motion skillfully cuts into the main workflow, whenever it is necessary. If the equipment were fully automated, a machine that picks up the above components would have been required; however, in the U-shaped layout, the cost for the pick-up machine is zero. The hardware required for transfer motions for the U-shaped layout is about the same as that required for the Job Type. Nonetheless, knowing that the transfer route cannot be planned in advance, and this requires the software of the U-shaped layout greatly different from that of the Job Type, it is inferred that this layout may require an advanced software algorithm.

Brief Description of the Figures.

Figure 1 shows a prior art basic Flow Type Production system.

Figure 2 shows a prior art Multiple-Intake of Flow Type Production.

Figure 3 shows a prior art Job Type transfer path.

Figure 4 shows a dual common path system.

Figure 5 shows a transfer system having both the Flow Type and Job Type transfer paths.

Figure 6 shows a transfer system having both the Flow Type and Job Type transfer paths.

Figure 7 shows an alternate embodiment of the embodiment shown in Figure 7.

Figure 8 flows a flow chart of the system of the present invention.

Figure 9 shows an arrangement candidate.

Figure 10 shows a final transfer network.

Fig. 11-1 is a flow diagram.

Fig. 11-2 is a diagram of an Auto Guided Pallet (AGP).

Fig. 11-3 is an orbit modification unit.

Detailed Description of the Invention

Fusion of Flow Type and Random Access of Job Types according to the invention

[0028] Figure 1 illustrates the topology of Flow Type transfer. This is a very typical transfer system represented by free flow belt conveyers and the like. We provided the so called "return path" in Figure 1.

[0029] In a Flow Type layout, the overall productivity tack is controlled by the slowest step; as a result, one must adjust the system to create uniform productivity tack distribution throughout the steps. Nonetheless, one may not be very successful in balancing the productivity tack. In addition, in the case where "(cost of a slow process) << sic, is much less than (a costly high speed process)," it may be necessary to run the slow process in parallel. There are two ideas for doing this: (1) to set up a parallel line by completely branching shops; and (2) to provide "multiple-intake" (fukusuu-dori) motions (See Figure 2).

[0030] In contrast, a Job Type layout requires a topology in which job shops are linked to a passage in parallel. Figure 3 illustrates the arrangement in which job shops are arranged in parallel to a transfer path such that a work piece can be transferred from one given job shop to another of one's choice. To increase throughput of the system, that is, to efficiently handle simultaneous transfer needs, multiple transfer paths may be provided or a transfer path is formed in a loop.

[0031] The Job Type transfer system has a topology comprising a common path and branch lines for taking work pieces into machines, however, multiple transfer vehicles can be released in the topology by imposing one-way traffic onto the common passage. Fused random access is thus provided for the Job Type layout.

Fusion of Job Shop Transfer Path and the Flow Transfer Path

[0032] Figure 5 illustrates the topology of the transfer path equipped with both the Flow Type transfer path and the Flow Type transfer path. The white transfer path in Figure 1 is re-arranged in a white circular path in the order of A – F in Figure 5; the gray transfer path (transfer path G) in Figure 5 is the transfer path of Figure 4 as it stands.

[0033] Now, assume that work pieces move along each transfer path as marked with arrows. Work pieces are basically forwarded to the next step from transfer paths A-E. As a result, a transfer motion cannot be deviated from given destination; however, the transfer path G can provide a selective transfer motion from one step to another.

[0034] Herein, the transfer path G can provide the same function as the transfer path F, therefore, we eliminated transfer path F and the task is accomplished by an alternate means in which two steps share the same route illustrated by the topology of Figure 6. In another view, the topology shows that branching and merging functions were added to obtain the random access function utilizing the return path in a Flow Type layout (See Figure 7).

Layout

[0035] In the Desk Top Factory, process steps are allocated in a manner such that attention is paid only to productivity and multiplying steps are allocated to a machine (increasing machine capabilities) such that machine layout and transfer motion between machines is designed as an independent phase. The possibility of utilizing both the Job Type and the Flow Type functions has been discussed. Below, a machine is discussed that works independent of scale up of output.

[0036] The flow chart for generating a layout is outlined as follows:

[0037] **Step 1: Identify Seeds of Technology and Needs**

[0038] 1) Clarify required steps.

[0039] 2) List all machines required for each step.

[0040] 3) Identify output, space, and investment value required for each step.

[0041] 4) List the steps that a machine having multiple capabilities can process.

[0042] **Step 2: Determining Number of Machines**

[0043] 1) Input space size, investment, and production capacity, etc.

[0044] 2) Compute required number of machines and steps that can be performed by multiple functions of a machine.

[0045] 3) Compute multiple samples and obtain multiple results that can generally fulfill the requirements of 1). List output, investment value, latency of each machine, and the investment value of the latency per machine.

[0046] **Step 3: Compute Rough Layout**

[0047] 1) Input weighted transfer distance index.

[0048] 2) Compute all combinations of arrangement of equipment selected in Step 2 through permutations to gauge all transfer distance indices, and further select multiple combinations with best scores of transfer distance indices.

[0049] **Step 4: Set Sub Route for Jobs**

[0050] 1) Add the path to jobs at the point, which is not the Flow Type transfer path to the result selected in Step 3.

[0051] **Step 5: Simulation**

[0052] 1) Simulate at different transfer duration, transfer cost, and the like.

[0053] 2) Simulate to estimate how many transfer vehicles can be introduced.

[0054] 3) Compute cost, space, and output.

[0055] **Step 6: Program Creation**

[0056] 1) Create a program for the production line selected by simulation.

[0057] **Step 7: Analysis on Equipment Used for Actual Production**

[0058] 1) Make products in the selected production line.

[0059] 2) Check the transfer vehicle via a monitor screen to collect data for the machine used in an actual production line.

[0060] 3) Analyze bottlenecks based on the data collected above.

[0061] 4) Provide feedback from the analysis to improve the production line.

[0062] Decisions are made following the above sequence. Multiple candidates are selected for every step; a mechanism in which the interactive designer can "initiate steps" by making his or her own decision and "re-edit" the workflow or layout utilizing personal experience.

[0063] It is often the case that a large amount of data must be processed to roughly screen almost infinite candidates through permutation. A generic algorithm (hereinafter referred to as "GA") needs to be introduced to increase screening efficiency hereinafter. In Step 4, which comes next, a sub route is set up. Figure 6 illustrates an example of the "sub route", a dark transfer path. Figure 6 eliminates transfer paths that are not actually required for the process. The layout of this stage is adjusted to some extent, followed by simulation to ensure the analysis. Following a simulation, a designer can further improve efficiency of the system to finally produce an actual layout and a transfer control program.

[0064] Then, the program is downloaded to a machine and final adjustment is provided by comparison of differences in results from the simulation and from the actual production machine used for production and bottlenecks are analyzed using the machine in the production line.

Optimizing Layout – Conventional Concept (Specific Examples)

[0065] Herein the author discusses a way to map the layout in which productivity is optimized utilizing the transfer path that accommodates both the random access transfer function and the flow transfer function is discussed.

[0066] This discussion assumes the following example for processing:

[0067] **Machine A** Assembly (Hands for three parts)

[0068] Cost 0.5 Tack 10

[0069] **Machine B** Coating (Adhesive coating at a given point is possible)

[0070] Cost 0.5 Tack 15

[0071] **Machine C** First In-First Out Oven (Adhesive can be annealed for a given period)

[0072] Cost 1.0 Tack 5

[0073] **Machine D** Cooling (Cooling after annealing)

[0074] Cost 0.5 Tack 5

[0075] **Machine E** Metering

[0076] Cost 3.5 Tack 3

[0077] **Transfer Time** Tack 1

[0078] (Cost: 1 million yen; Tack: seconds)

[0079] Assume that the above five machines assemble three mechanical parts (b, c, and d) on a main work piece (a) in that order. Among them, two mechanical parts (b and c) require steps of adhesive coating, annealing, and cooling. Also assume that metering is required for a work piece in progress after assembling the main work piece and the final product. To describe this easily, assume that all parts are supplied in a given arrangement. Table 1 shows how the steps are arranged.

[0080] Table 2 shows the results of the process steps carried out in the Flow Type layout in a conventional manner.

[0081] Given the condition, metering constitutes 71% of the total cost of 19.5 million yen wherein the capacity usage ratio of the metering step is 20%. The value of the machine cost multiplied by the capacity usage ratio (hereinafter referred to as "investment value usage") is 5.8 million yen in total. This means that only the 5.8 million yen portion of the 19.5 million yen investment is utilized.

[0082] The following formula shows the ratio at which the monetary value of the investment is utilized (hereinafter referred to as "investment value usage ratio"):

[0083] $\{\Sigma\ (MT / Ct * \text{Machine Cost})\}\ /\ \text{Total Cost}.$

[0084] The above formula provides an index that expresses the monetary value of the investment per unit time during which the investment is effective. This index takes into account the cost of machine, when the total capacity usage ratio could not fully express time. Even though increasing the capacity usage ratio of an inexpensive machine does not improve the numerical value of the index, increasing the capacity usage ratio of an expensive machine greatly improves the index.

[0085] The numerical value of the index is less than 30% in an arrangement in which machines are arranged in the order of progression of process steps. The calculation assumes 24-hour operation of the system; the index is 10% when the machine operates for 8 hours, which means that the effective investment value is only 10%.

[0086] To push the "investment value usage ratio" above 90%, additional machines must be installed to balance out the tack for each machine. That the productivity tack of each machine cannot be balanced unless output is increased becomes an apparent problem herein.

[0087] Moreover, the numerical values in the tables assume that the line length is 34 units per 19 units, which is the basis for the clean room investment calculation herein. The dimension of one unit is 500 mm x 1000 mm and the cost of clean room construction is 400,000 yen / m^2.

[0088] "Idle monetary value" is another unique indicator of our creation and is expressed as follows:

[0089] (1 – Investment Value Usage Rate) x Equipment Cost

[0090] This indicator is believed to be useful when one tries to find a bottleneck for cost of each unit of machine, however, the "idle monetary value" means about the same as "investment value usage rate" when the total production line is considered.

[0091] The "machine per product" is the cost of machine per product assuming annual output.

Detailed Description of the Invention

Optimizing Step Layout – DTF-like Concept

[0092] Up to 5.1, the optimization of a production line of conventional technology has been evaluated based on the new index "investment value usage rate." As is described above, it is understood that productivity does not improve in the conventional sense unless output increases.

(As long as the equipment specifications are fixed, it is impossible to balance the productivity tack where output is very small).

[0093] It is important to pay attention to the importance of expressing the number of machines required as a ratio as a means to improve the "investment value usage rate." Accepting this concept (e.g. 1/2 unit, 1/3 unit) allows applying the investment value usage rate of a large output to a small output. Note that a simulation indicates a use of 0.85 units of Machine A, 1.25 units of Machine B, 0.44 units of Machine C, 0.44 units of Machine D, and 0.25 units of Machine E provides an investment value usage rate of 100%, which is equal to a time capacity usage rate of all machines of 100%.

[0094] Now let us check whether the idea of counting the number of machines in terms of non-integers is viable. Assume that one adopts the Job Type functions utilizing the Flow Type layout as described in 4.2 where the same machine serves different steps. Assume also that the unit of machine required to perform a step is 1/2 or 1/3 for our convenience. Machines that are used in the above processing example can be expressed in a non-integer form as follows:

[0095] **Machine A** 1/3, 2/3, 1, 4/3

[0096] **Machine B** 1/2, 1, 3/2

[0097] **Machine C** 1/2, 1, 3/2

[0098] **Machine D** 1/2, 1, 3/2

[0099] **Machine E** 1/4, 2/4, 3/4

[00100] Note that the same machine requires different tooling and different mechanical hands. (Toll selection is difficult in the case below.)

[00101] The fractions that provide a 100% investment value usage ratio as mentioned above are as follows:

[00102]	**A**	0.85 units	1 unit
[00103]	**B**	1.25 units	3/2 units (3 units for 2 steps)
[00104]	**C**	0.44 units	1/2 units (1 unit for 2 steps)

[00105]	**D**	0.44 units	1/2 units (1 unit for 2 steps)
[00106]	**E**	0.25 units	1/4 units (1 unit for 4 steps)

[00107] Computing the investment value usage ratio again using the above fractions yields a capacity usage ratio of over 90%.

[00108]	Investment value usage ratio	91%
[00109]	Equipment cost	8 million yen
[00110]	Output	133,000 units of product
[00111]	CR investment value	1.6 million yen
[00112]	Idle value	650,000 yen
[00113]	Equipment per product	5 yen

[00114] The result of the computation shows that a output of 133,000 products can be obtained at 1/2 cost in a 2/3 area, in other words, the same rates optimized for an output that is four times larger can be applied to this case. (This projection does not assume the effect of the DTF technology where the objective of the technology is miniaturization of the machine itself, but it assumes the use of incumbent existing machines for all criteria in comparison. The author expects much better results if the DTF effect is taken into consideration during evaluation.)

[00115] Although the author did not describe in detail herein, another advantage of expressing the usage of machine per product in fractions is a great reduction in inventories in a production line.

Key Technologies in Pursuit of The Idea

[00116] 1. How many steps can a machine serve?

[00117] 2. How flexibly can a work piece be transferred?

[00118] Means of (1) and (2) can be pursued theoretically, however, this limits cost, refining of processes, maintenance, and the like. In other words, the equipment design limits the possibility of providing the functions of (1) and (2). As a result, one needs to evaluate in advance the capabilities and risks that are associated with execution of steps listed in Table 1.

[00119] The invention proposes the DTF robot as a solution to issue (1) and the AGP transfer system as an answer to issue (2).

[00120] Robots of the DTF Type require a lower manufacturing cost than those that are adopted in the automated assembly line of conventional technology. The DTF robots under development can be characterized as follows:

[00121] Configuration that can make a significant cost reduction possible.

[00122] Enhanced tooling flexibility of a perpendicular-motion robot.

[00123] Enhanced linearity (in a single direction) of a perpendicular-motion robot.

[00124] Cleanliness of a joint robot.

[00125] Assurance of the installation area to work area ratio of a joint robot.

[00126] Direct-drive capability of the XY positioning mechanism to ensure absolute precision.

[00127] Herein, (2) and (5) are very important when one intends to impart multiple functions to the robot and they are even more important for the DTF robot which is a product of miniaturization.

[00128] The AGP transfer system (Figure 8) is a novel automated transfer system having an orbit. It intends to provide a degree of freedom of an automated vehicle and the high speed of a belt conveyer and a transfer rod.

[00129] These elements are described in Japanese patent application numbers 2002-113660 and 2002-150750.

[00130] The aims of JP No. 2002-113660 are weight reduction and compactness, this AGP can transfer a work with stability, the structure of (Auto Guided Pallet) AGP can be easily fed without generating dust and the like while keeping the clean degree of environment of these work area.

[00131] This application explains one preferred embodiment of an Auto Guided Pallet. As shown in Fig. 1 of 2002-113660, the main components of AGP 2 are wheels 6 which are on two parallel rails 3, motor which drives the wheels 2, a battery, which can storage, drives the motor, a portion 9 which can put a work 4 and which are removable to AGP 2, a no-contact type feeding means 11a and a control circuit.

[00132] Also, no-contact type feeding means 11b is arranged between the rails 3 and faces the no-contact type feeding means 11a of the AGP 2.

[00133] In regard to Japanese application No. 2002-150750, the aim is to meet a change of rail arrangement or system more easily.

[00134] This application explains the system has station controller 6 corresponding to station 5.

[00135] An AGP 2 provides with communication means to connect with the station controller 6 through the station 5.

[00136] The station 5 arranges between the station controller 6 and the AGP 2 in order to ensure the communication.

[00137] The station controller 6 can communicate with the others.

[00138] Also, the station controller 6 has a data transferring means which can transfer (receives and gives) data, a communication means which communicate with the AGP 2 through the station 5, memory means which memorizes a process (routine) program to control the AGP 2 and an implement means to run the process (routine) program.

Selection of Type and Number of Machines

[00139] To select a desirable machine type and the number of machines, proposed sample parameters such as output (running time), machine design, space, and a tolerable amount of investment must be generated. At this stage, parameters are selected independent of the transfer system and the machine layout. That is, when one intends to perform the task by software, the software must include both analytical and integral tools.

[00140] The analytical tool can be characterized in that an operator can easily calculate the investment value, investment value usage ratio, and usage ratio of each machine by manually entering the number of machines required for each type. The resulting analysis may suggest the need for multiple functions or multiple number of machines to balance out the productivity tack.

[00141] On the other hand, for an integral tool, an operator inputs data regarding the type of machine, recognition of machine functions, and the cost of each machine. The data are processed following the instructions below:

[00142] Minimum space.

[00143] Minimum cost.

[00144] Optimal investment value; variable output.

[00145] Guaranteed output: variable investment value.

[00146] The requirement “minimum space” tentatively determines the number of machines required and the type of machine that accommodates all possible multiple functions.

[00147] The instruction "minimum cost" compares the cost of giving possible multiple functions to a machine with the cost of dedicating a single function of the machine. This comparison is done for all combinations thereof. Then, the type and the number of machines is determined using the configuration sic, combination of the lowest cost.

[00148] To optimize the investment value, one multiplies functions to eliminate as many machines as possible (while reducing expected output) until the cost of the combination matches the given investment value. (Multiple) combinations that provide largest outputs are selected.

[00149] When optimizing the output, the combinations that ensure the required output and investment values are searched to identify the combinations that meet the required output. Multiple combinations at the lowest cost are selected. In addition, when multiple machines are required for all types, an alternate manufacturing method, in which half of the original requirement is output by parallel running of two production lines, should be proposed at the same time.

[00150] Generating software to perform steps (3) and (4) may seem difficult at first. However, the factors that are used in this permutation are the type of machine and the machine's possibility of having multiple functions. Since the number of combinations is very small, it is most likely that one can evaluate all combinations. Table 3 shows the results of this permutation.

Rough Estimate of Machine Arrangement

[00151] To determine a tentative order of machine arrangement based on the type and the number of machines obtained in 5.3, one shuffles the order of the machine arrangement to select the quickest and least costly method to give to a designer. However, it is difficult for a computer to find the transfer time and the cost of transfer machines for all of the combinations resulting from "permutation" within a realistic time. In addition, this "permutation" involves more than mathematics: it also involves simulations that need to be performed for all combinations to find a desirable machine when there are multiple machines having multiple functions and one has to decide which machine best suits the target process. This calculation is very time consuming.

[00152] To remove the redundant transfer motions without depending on simulations, the process of roughly estimating desirable arrangement in the initial stage is required. A new index called the "non-dimensional transfer distance" is introduced to accomplish the task herein. In this

process, the "non-dimensional transfer distance" for all arrangements resulting from permutation of the combination including machines having multi-functions. Finally, the arrangement that has the highest score is selected.

[00153] Scores are given according to the simple rule described below. Here, an estimated arrangement is compared with an actual arrangement. Points are given for each shift that must have been made from the original or estimated arrangement. The sum off all points earned is deemed the score of the machine arrangement.

[00154] The following is an example of the scoring rule:

[00155]	1 shift from right to left	5/n
[00156]	1 shift from left to right	-5/n
[00157]	3 or more shifts from left to right	3/n
[00158]	Shifts to the right after 2 shifts to the left	30
[00159]	Shifts to the right after 4 shifts to the left	50

[00160] This scoring system, under the concept illustrated in Figure 7, is based on the understanding the following: (1) the routing going through the machine is advantages in case of the left shift: (2) the highest transfer efficiency is obtained specifically at one shift; and (3) when a work piece is returned along a return line, path, the longer the distance, the better. (The scores are set based on the policy that a higher score is better. Shifting from right to left or vice versa yields the same result.)

[00161] The scores thus computed are statistically analyzed and the best scores are selected. (For example scores higher than 3 σ.)

[00162] The arrangements that are not worth evaluating are thus eliminated through this rough screening process.

Determining Transfer Network and Motions

[00163] The candidates arrangements obtained in 5.4 are arranged in a ring-like shape. Herein, the order of steps is assumed to be ABCDBCE and the candidate arrangement is assumed to be ABCDE (See Figure 9).

[00164] When the line diagram as illustrated in Figure 9 is prepared, one determines the transfer network as illustrated in Figure 10.

[00165] At this stage, one writes a program for motions required for the transfer network and simulates the program. The schematics of automated programming of each station will be as follows: "confirm the vacancy of the next station; upon confirmation of a vacancy of the next station, declare 'occupancy' for both the incumbent and the target station; as soon as the work piece starts leaving the incumbent station, and dismiss the occupancy of the incumbent station."

[00166] Nonetheless, when the transfer network is required of a piston motion at the dead end where there is nowhere else for a robot to go, the number of machines that can be placed in the "dead end to/from blind alleys" (the number of junctions) may be computed in advance such that one can keep some stations, in addition to the target station, in the blind alleys.

[00167] A similar program is generated for all stations.

Tuning through Simulation

[00168] All the arrangement candidates obtained in 5.4 are simulated to obtain an actual productivity tack for each arrangement herein. Each arrangement candidate is simulated for its actual tack and transfer duration and the data further processed to select a few candidates. The average output cycle is a function of evaluation and the arrangements with the highest average output cycle are selected as final candidates.

[00169] The simulation simultaneously outputs the following parameters in the form of averaged numerical values.

[00170] The capacity usage ratio of a module.

[00171] The latency occurred after completion of a job due to auto guided pallets (hereinafter referred to as AGPs") queued for discharging.

[00172] The ratio of AGPs that go through a module without being worked on.

[00173] The results are utilized for analysis of bottlenecks described in the following section.

Improvement of Bottlenecks by Simulation

[00174] Regarding modules having a low capacity usage ratio with reference to the results of 5.5, the modules are classified into the following three, four categories based on the causes of such low ratios.

[00175] (1) The module that has many AGPs that only passes therethrough without performing any job.

[00176] (2) A module having a large number of queues that needs to be discharged.

[00177] (3) A module having a large number of queues due to the absence of intake motion.

[00178] (4) A module having a large number of queues due to the presence of many redundant two-way motions allocated to one rail.

[00179] To solve the problems of (1) and (2), addition of a dummy station following the step in question is proposed for the module. In this way, AGPs of (1) passes quickly and queues of (2) waiting for discharge do not need to be synchronized with other steps thereby speeding up the data processing of the module.

[00180] Regarding (3), linking of the previous step to a bypassing path is proposed. In this way, AGPs can be taken from the bypassing path.

[00181] Regarding (4), three lanes on a path are proposed to increase throughput of the overall traffic.

[00182] The designer uses his or her own judgment on these proposals and interactively makes changes in accordance with the proposals. He or she optimizes the final shape of the transfer network and its productivity by calculating the number of AGPs that can be placed in the production line.

Modification by Manual Mode

[00183] When one thinks that a layout should be changed during simulation, one should change the layout and check the productivity, cost and the like of the new layout in the manual mode. A perfect layout cannot be obtained as yet by an automated layout utilizing automated programming. Therefore, human thinking is inevitable for the change and improvement in the manual mode.

Summary

[00184] Introducing AGPs allows the step-to-step transfer motions in the fused or "combined" Flow Type – Job Type layout. This method can balance out the productivity tack of a machine without depending on scaling up of output. One can flexibly create a layout to meet various requirements that are represented by multiple visits to an expensive machine, limited installation area, and prioritizing minimization rather than optimization of investment value for a small output.

[00185] It is difficult to determine a layout that matches this requirement by human thought only because the order of steps and the workflow do not match each other. A computer may provide a "round-robin" evaluation of data. Nonetheless, the volume of data that must go through "round-robin" evaluation is very large and it is impossible even for a computer to provide an accurate evaluation, in the form of a simulation. To resolve this issue, a basic evaluation is provided to select initial candidates, which are then evaluated through simulations. Further, the computer-assisted layout is imperfect and some improvement such as addition of transfer paths may be required. It is inevitable, therefore, that the method of designing a production layout involves human-computer interactions. To make this new concept work, it is important to provide an analyst to diagnose where the bottleneck of a process exists.

[00186] Figure 11 illustrates the above concept.

[00187] **Table 1 Step vs. Machine (Example)**

1	Micrometering of **a**	Machine E
2	Attach **b** on **a**	Machine A
3	Bonding	Machine B
4	Annealing	Machine C
5	Cooling	Machine D
6	Micrometering	Machine E
7	Attach **c** on **ab**	Machine A
8	Micrometering	Machine E
9	Bonding	Machine B
10	Annealing	Machine C
11	Cooling	Machine D
12	Attach **d** to **abc**	Machine A
13	Micrometering	Machine E

[00188] **Table 2 Configuration in an Ideal Flow Type Line**

Line length	13 X U
Cost	19.5 million yen
Productivity Tack	15
Annual output	133,000 units/month

Step	Capacity Usage Ratio %
1	20
2	67
3	100
4	33
5	33
6	20
7	67
8	20
9	100
10	33
11	33
12	66
13	20

[00189] **Table 3** **Balance Among Steps**

	Case	A	B	C	D
	Machine E	1 unit	1 unit	1 unit	2 units
	Machine A	1	2	4	7
	Machine B	1	3	5	10
	Machine C	1	2	4	7
	Machine D	1	1	2	4
	Machine E	1	1	1	2
	Machine A	1	2	4	7
	Machine E	1	1	1	2
	Machine B	1	3	5	10
	Machine C	1	1	2	4
	Machine D	1	1	2	4
	Machine A	1	2	4	7
	Machine E	1	1	1	2
	Total	13	21	34	65
Investment Value Usage Rate		30%	76%	93%	96%
Investment Value (Million yen)		19.5	23	31	60
CR Investment Value		2.6	4.1	7.6	13
Idle Value (Million yen)		13.65	5.52	2.17	2.4
Output (Thousand units)		133	400	667	1333
Value per Machine (yen)		12.2	4.8	3.9	3.8

[00190] **AGP: Advantages List:** ***Compact intelligent transfer vehicle changes common sense of production systems.***

[00191] The Auto Guided Pallet system with advantages of the Flow Type and Job Type production methods of the present invention can be optimized utilizing a variety of parameters such as productivity tack, footprint, capacity usage ratio, facility cost, etc.

[00192] Can configure an efficient production line while minimizing the line inventories.

[00193] No need for arranging machines in the order of the process steps:

[00194] Concentration of workload on an expensive high-speed machine

[00195] (A laser scan micrometer provides metering for three steps that are in a shuffled order in the demonstration.)

[00196] The productivity tack is balanced by arranging machines that require a long cleaning time in parallel.

[00197] The main work piece and mechanical part pallets can be transferred on the same path.

[00198] A clean transfer ensured by non-contact power supply = power supply at every station that are spread apart.

[00199] Home sensing accuracy of ± 0.5 mm requiring no special alignment for marking, manual work, or image inspection.

[00200] Read-write non-volatile memory capable of reading and writing pallet IDs.

[00201] Windows-based monitoring capability for transfer vehicles taking a complex routing.

[00202] Transfer and layout design support tools that meet various types of optimization.

[00203] While foregoing description and drawings represent the present invention, it will be obvious to those skilled in the art that various changes may be made therein without departing from the true spirit and scope of the present invention.

WHAT IS CLAIMED IS:

1. A manufacturing line having an automatic transport system comprising:

an input means for inputting design conditions and the importance of each of said design conditions, said design conditions being a manufacturing line's design that is comprised of an environment of work area and transfer paths connected among said work area;

a calculation means from which candidates of an appropriate manufacturing line are outputted by being calculated from said design conditions and said importance;

a simulation means which simulates said some candidate of said manufacturing line respectively; and

an output means which generates and outputs a program or programs of an optimized manufacturing line.

2. The manufacturing line having automatic transport system according to claim 1, wherein said design conditions include:

required working steps for said manufacturing line;
working time of each of said required working steps;
outputted products of said line;
working space available in said work area;
transfer paths connected among said working area; and
investment value.

3. The manufacturing line having automatic transport system according to claim 1, wherein said simulation means simulates a transfer duration among said working area and usage rates of said working space.

4. A manufacturing line design support system comprising:

inputting at least one system design requirement of a manufacturing line design from a group consisting of working time of each process, an operating rate, plant cost or equipment cost;

inputting and applying a weighting factor of importance to said design requirements;
outputting potential candidates of an optimum manufacturing line;
performing performance simulations on said outputted candidates; and
displaying a resultant construction design of the optimum manufacturing line.

5. An automated production line system comprising:

a work area for automated guided pallets(AGP);

automated guided pallets(AGP);

a flow type (FT) control system to guide the automated guided pallets(AGP) around the work area;

a job type (JT) control system to control the specific function performed on the automated guided pallets(AGP) when the automated guided pallets(AGP) are placed at a job site in the work area;

a system controller which harmonizes the functions of the flow type (FT) control system and the a job type (JT) control system so that the two systems wok together at the same time in the work area to optimize output.

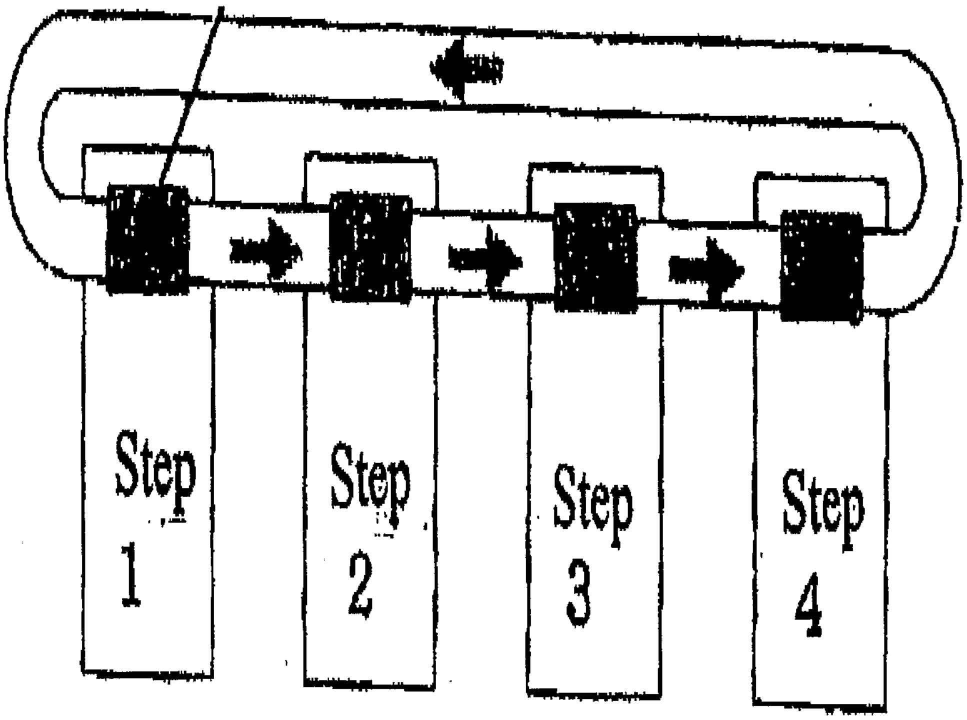


Figure 1 Basic flow of Flow Type Production (utilizing pallets)

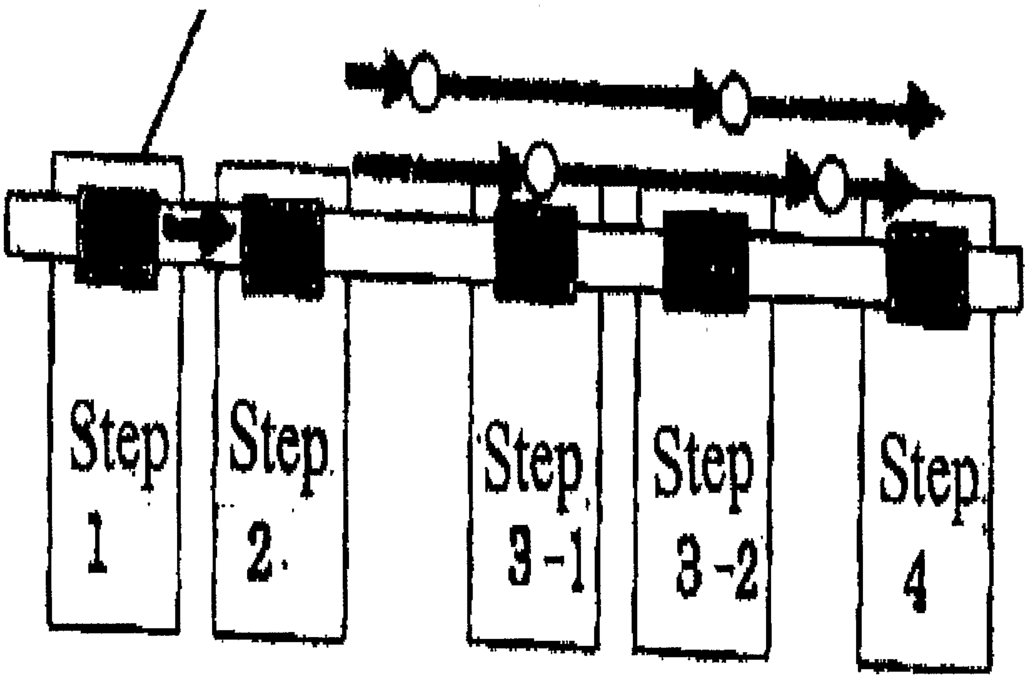


Figure 2 Multiple-Intake of Flow Type Production

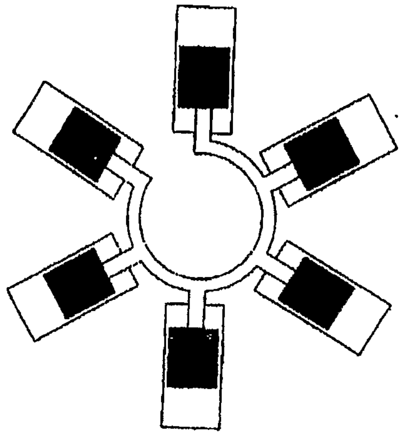


Figure 3 Job Type transfer path

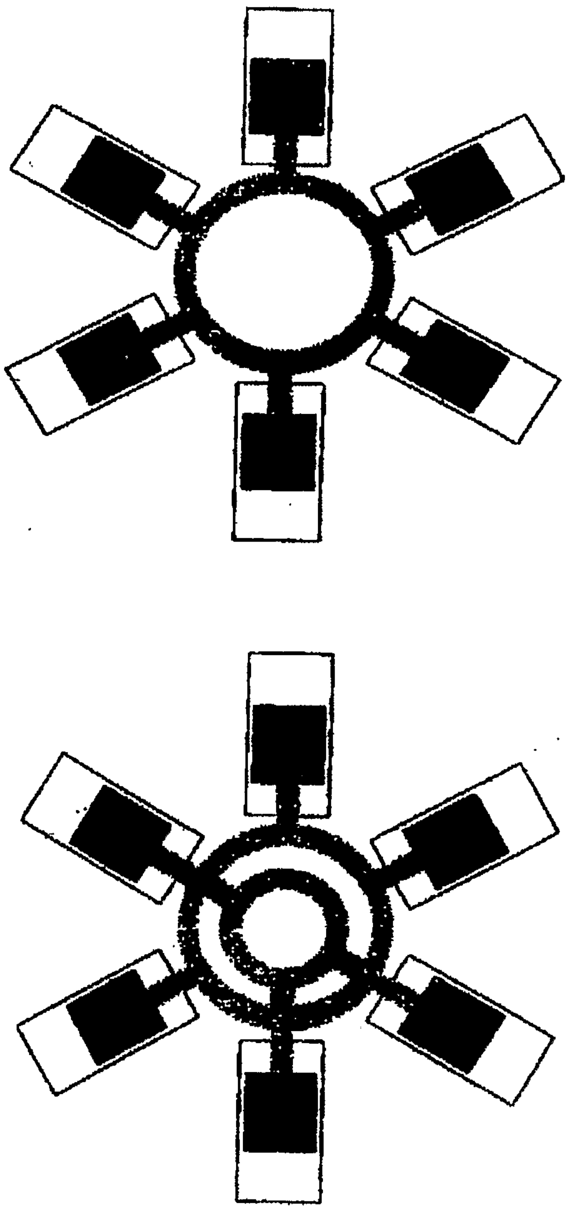


Figure 4 Speeds up production by taking a loop shape or Speeds up production by creating a dual common path (to provide simultaneous transfer motions)

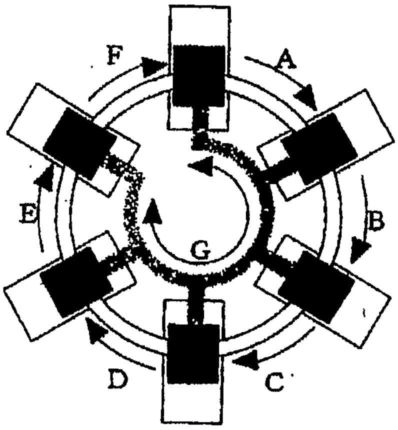


Figure 5 Transfer system having both the Flow Type and the Job Type transfer paths.

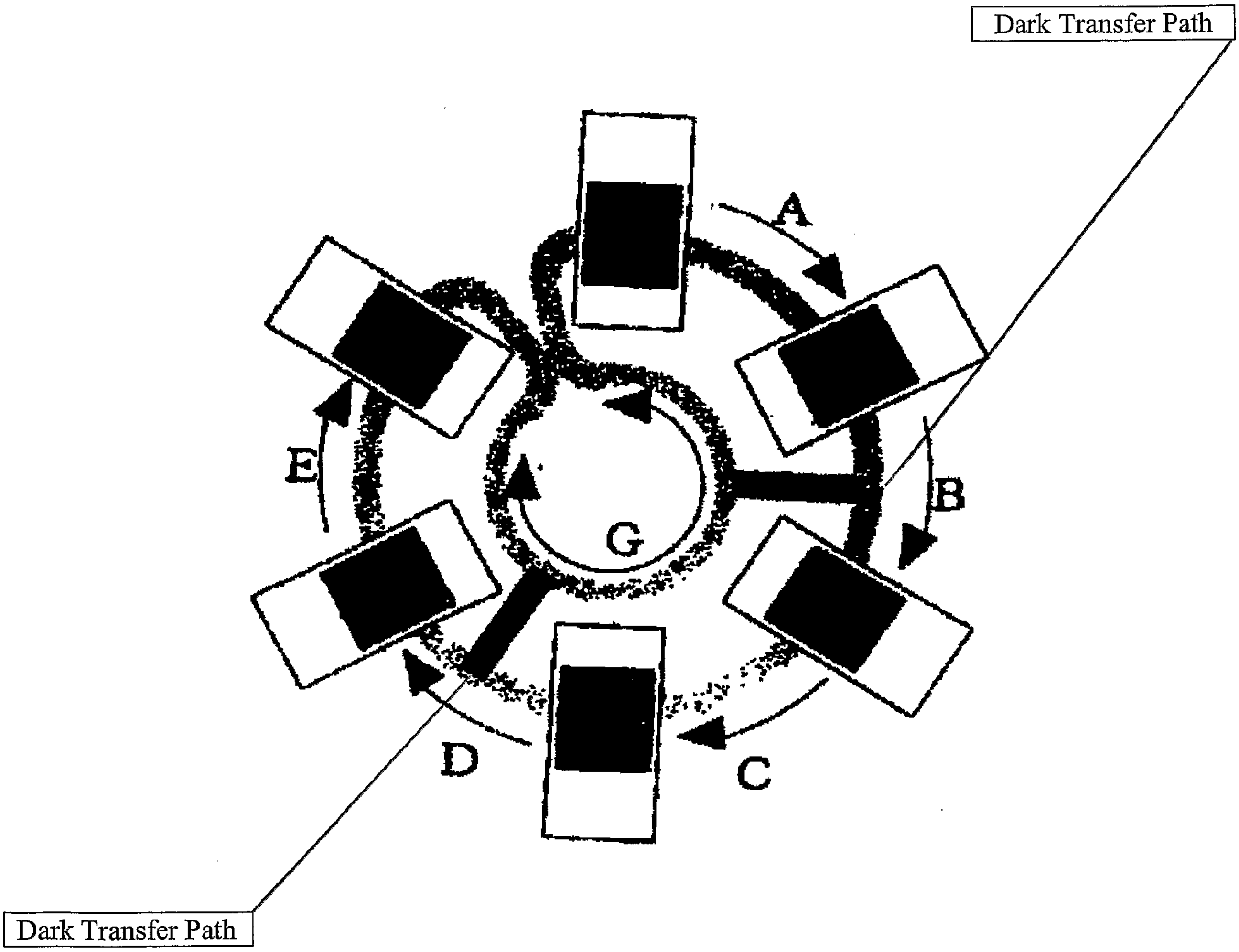


Figure 6 Transfer path combining Job Type and Flow Type transfer paths

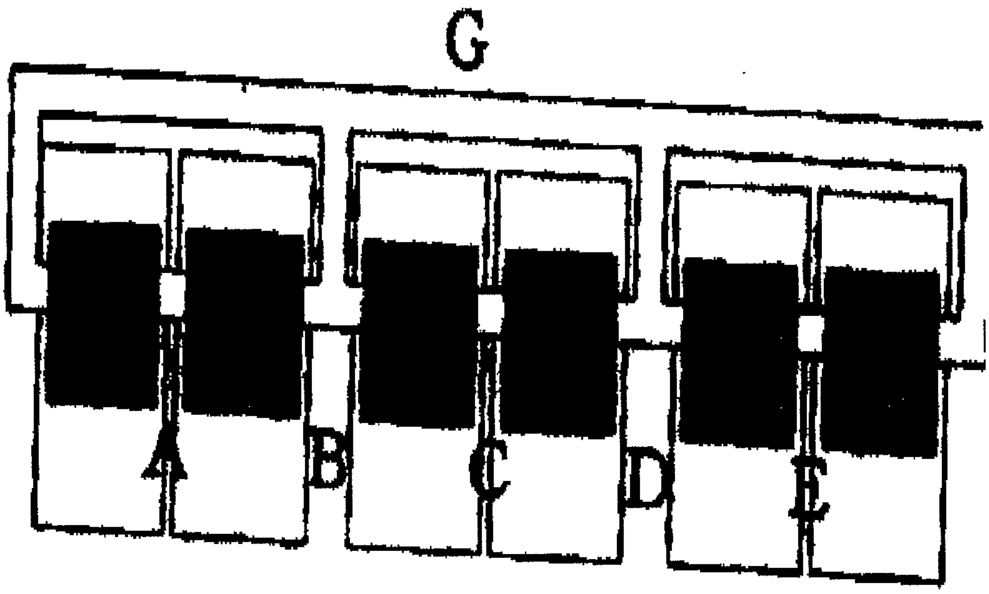


Figure 7 Modified arrangement of Figure 7

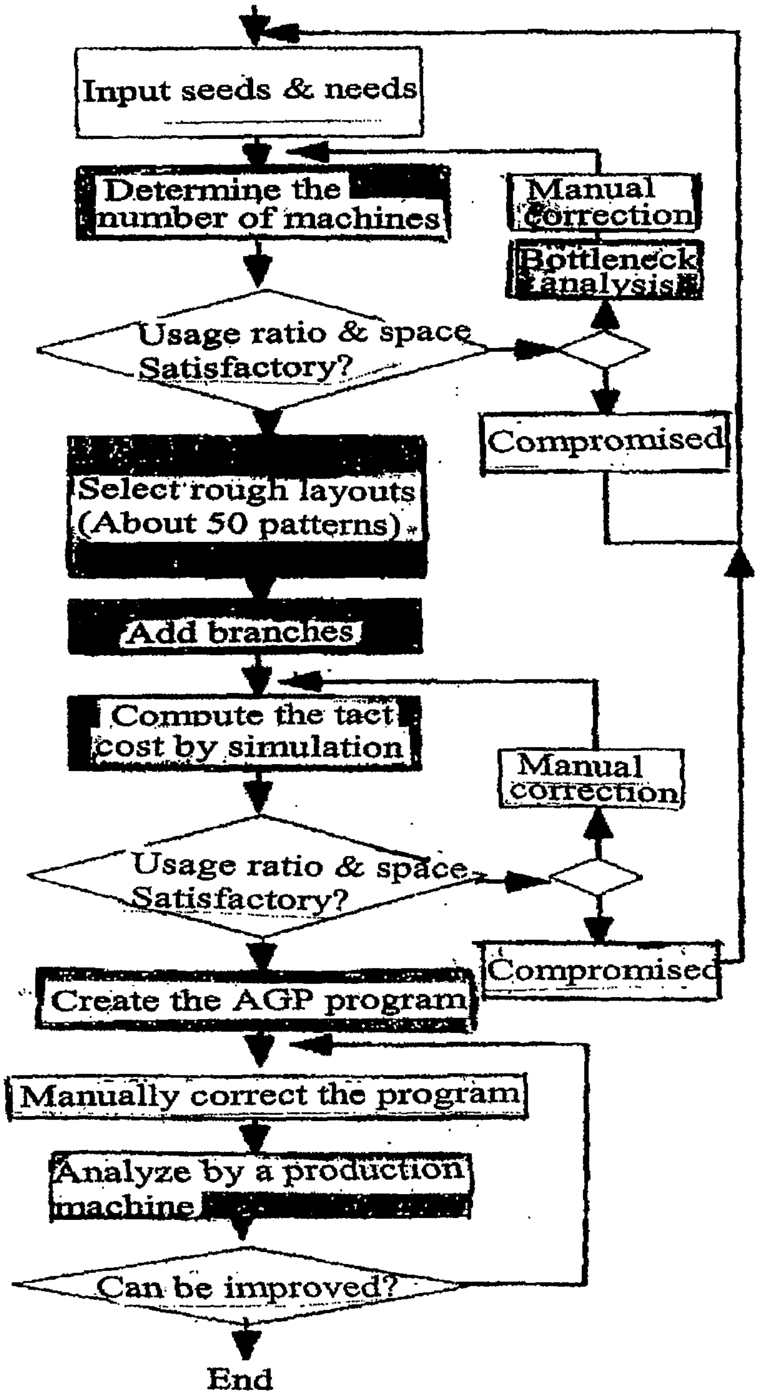

Input seeds & needs
Determine the number of machines
Manual correction
Bottleneck analysis
Usage ratio & space Satisfactory?
Compromised
Select rough layouts (About 50 patterns)
Add branches
Compute the tact cost by simulation
Manual correction
Usage ratio & space Satisfactory?
Compromised
Create the AGP program
Manually correct the program
Analyze by a production machine
Can be improved?
End

Fig. 8

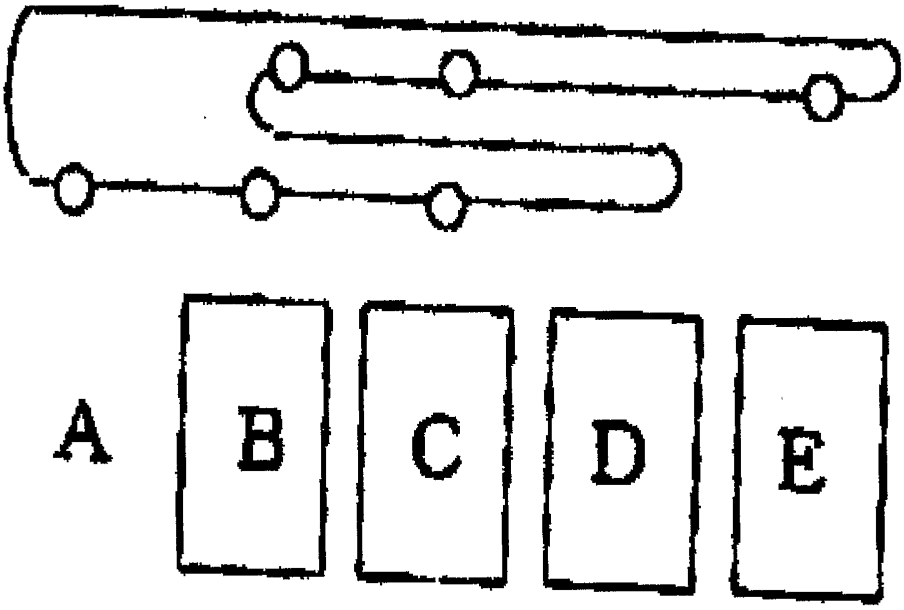


Figure 9 Arrangement Candidate

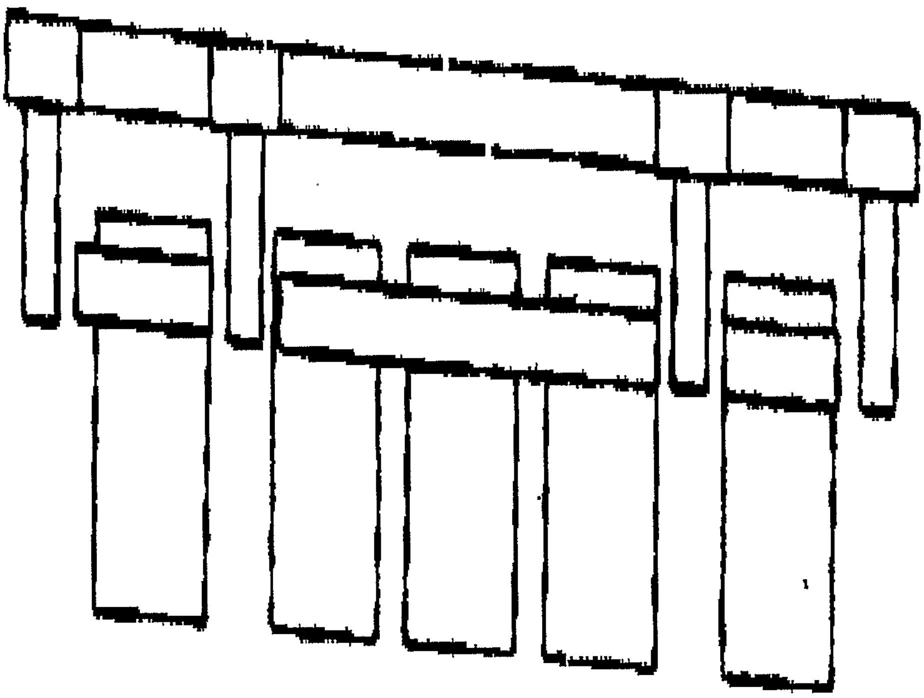
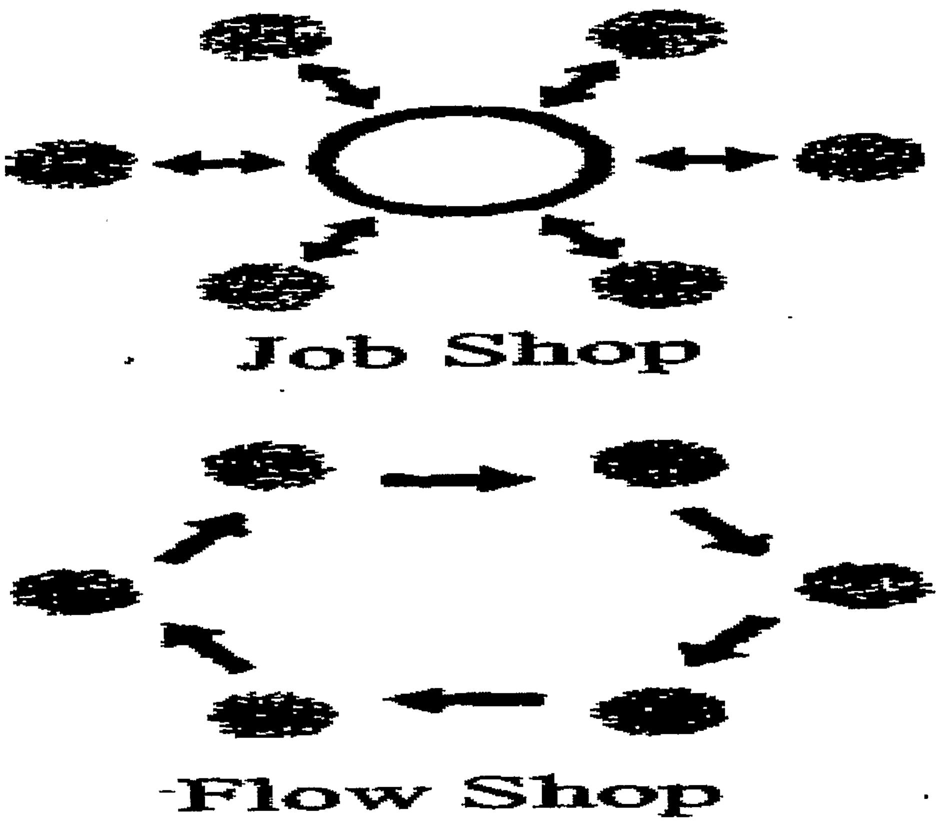


Figure 10 Final Transfer Network

Figure 11-1



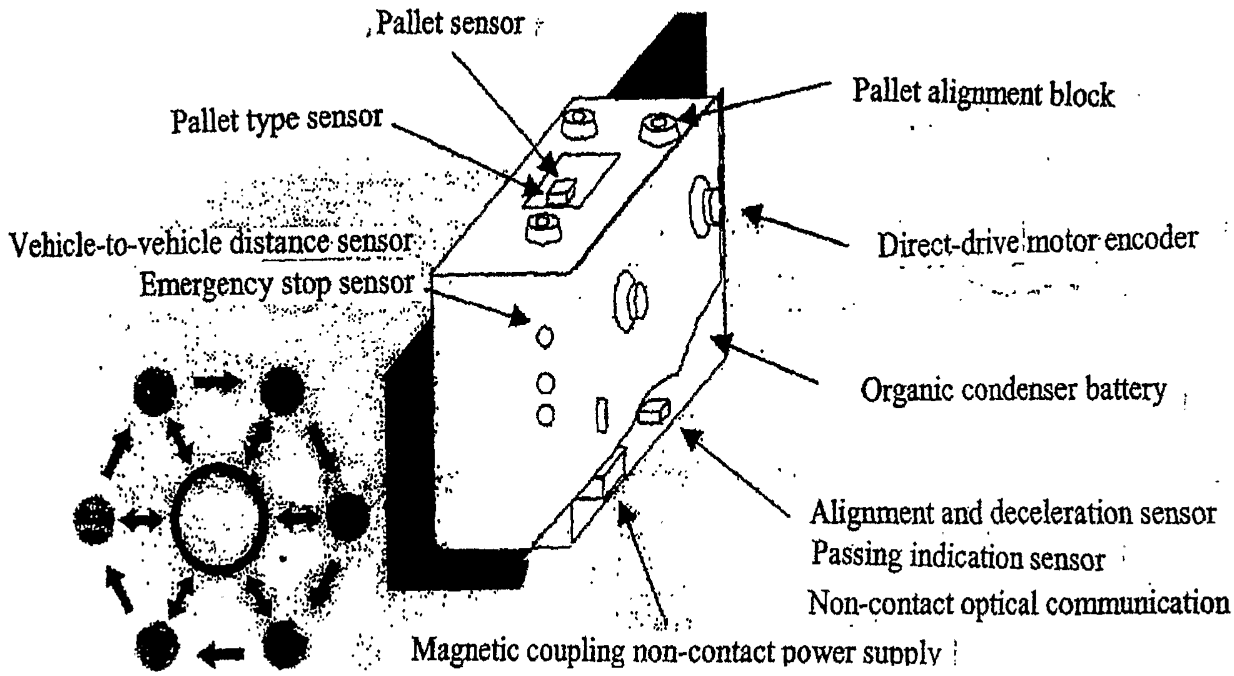


Figure 11-2 AGP Conceptual Diagram

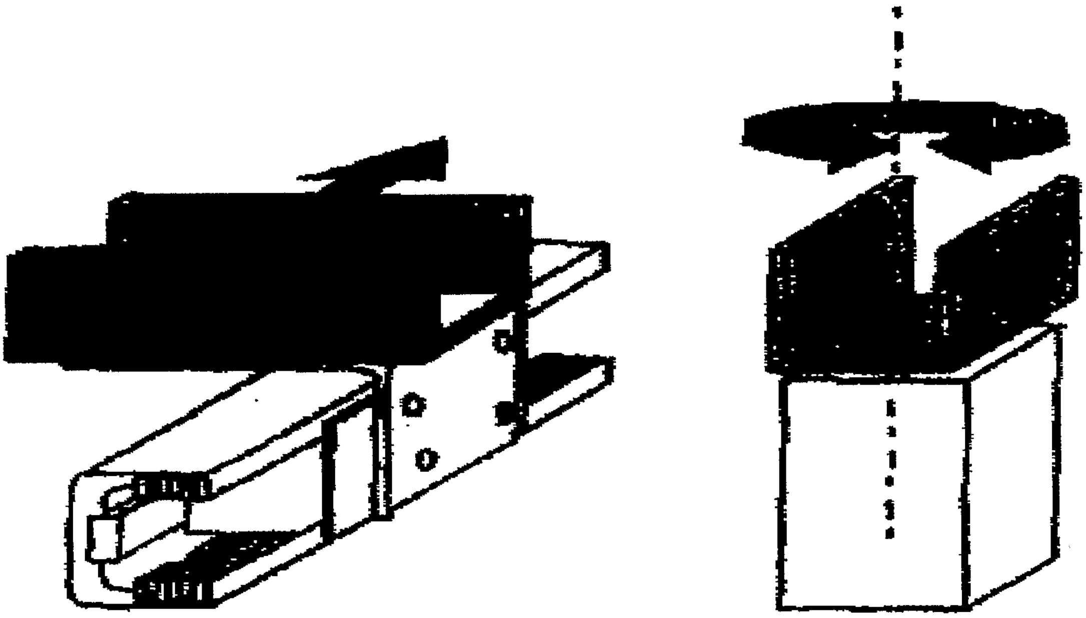


Figure 11-3 Orbit Modification Unit for slide and rotary types