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ANALYSIS OF PARAMETERS INFLUENCING IN-PLANT MILK RUN DESIGN FOR PRODUCTION SUPPLY

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Abstract

In-plant milkrun systems are a transport concept for in-plant material delivery which is becoming more and more applicable especially in the automotive industry. This is due to the system characteristic of providing materials in small lot sizes and with high frequency. As there is a number of different milk run concepts applied and there are several parameters influencing the efficiency and stability of these systems, this paper aims at presenting an overview of common concepts and their properties together with key figures based on an empirical study. The concepts are further analyzed and evaluated with respect to resulting lead times and stability.

1 Motivation

In the automotive industry, in-plant production supply is a critical function in physical logistics, as a shortage of parts at workstations results in an expensive stoppage of the assembly line. The number of automobile derivatives assembled on the same production line is constantly increasing and there are no two cars that are exactly the same, therefore a huge number of different materials need to be supplied to the production line. Considering that the space for material provision next to the assembly line is not sufficient, only a minimal number of bins per material number can be stored there. Therefore, a fast, frequent and reliable in-plant supply process to deliver small lot sizes must be implemented. We assume that in-plant milk run systems are an efficient way to fulfil these requirements (Figure 1) and are being used more and more often.

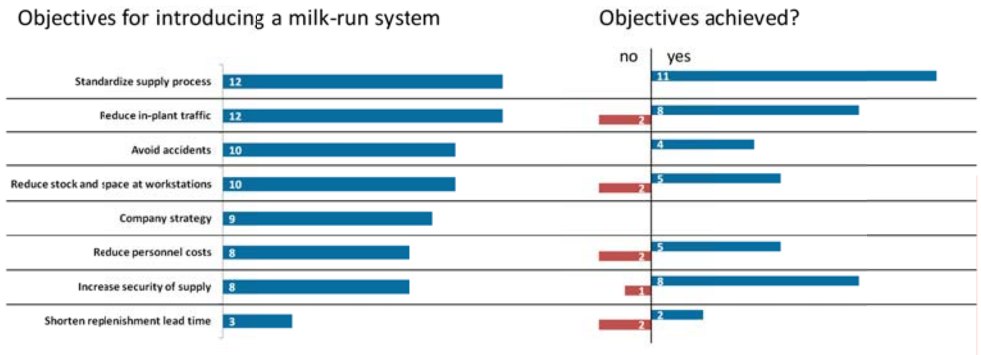


Figure 1: Objectives for introducing a milk run system [1]

An in-plant milk run system is a transport concept to supply various goods to various points of use in one run (cf. Figure 2) [2]. Typically, the milk run is using a fixed route. In some cases, it is operating on a fixed schedule. This system is comparable to a bus system in public transportation. Depending on the size of the system, several milk run trains may be operating from the same material source. Most often, milk-runs are tugger trains consisting of a tugger and from three to five trailers.

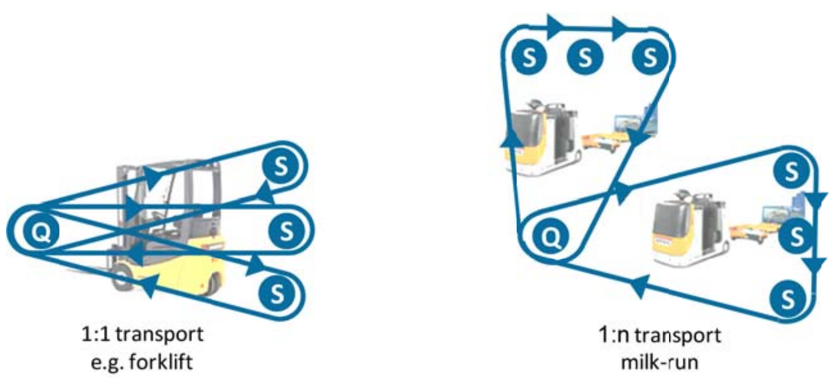


Figure 2: Milk run process in comparison with a forklift process

The milk run concept is used under a number of different general conditions regarding the source of the transported goods, the amount and variety of transported goods, the number of workstations to supply goods and the way in which replenishment orders are generated. Depending on these conditions, different milk run processes are applied.

The decision which milk run concept to use and planning and dimensioning of the system is often based on planners' experience or on the concepts used by other companies. To our knowledge, there exists only a limited amount of scientific literature which describes in-plant milk run processes and their parameters, and these papers discuss only one specific process. Furthermore, the parameters influencing milk run systems are numerous and diverse. Companies operating in-plant milk run systems need to coordinate these parameters when designing a milk run process to ensure fast, stable and efficient material provision [3].

2 Method

In order to support a decision in favour of the milk run concept and dimensioning of a milk run system, this paper presents different typical concepts for in-plant milk run supply based on an ongoing empirical study of a number of automotive companies and suppliers as well as companies from related industries. The conceptual differences are analyzed and typical processes are described in detail. Parameters relevant for dimensioning of a milk run route are presented and different processes are modeled according to these parameters using Methods Time Measurement (MTM). The resulting lead times and replenishment lead times for different transport volumes / throughput per tour are calculated for each concept to enable a quantitative comparison of the concepts. Furthermore, different aspects that influence stability of the processes are analyzed and evaluated. Finally, there is a recommendation given which concept to use and under which general conditions.

3 Milk run Concepts and Processes – Qualitative Analysis

To gain an overview of typical milk-run concepts used in the industry, as well as their parameters and resulting key figures, 21 milk run concepts of major automotive companies and suppliers as well as companies from related industries have been investigated [1]. First of all, the concepts are classified using the criteria described in Table 1.

Table 1: Classification criteria for different milk run concepts

	Criterion	*Values*
General conditions	Material source	Automated storage system Manual storage system Production supermarket Buffer area
	Handling unit	Small load carrier (SLC), e.g. bins Large load carrier (LLC), e.g. pallets Special carrier (e.g. for sequenced provision) Mixed carriers
	Replenishment principle	Kanban

		Reorder level Sequenced orders Demand-oriented
Organizational structure	Route	Fixed route Dynamically planned route Flexible route
	Assignment of vehicle to route	Fixed assignment Flexible assignment
	Milk-run control principle	Tact / Fixed schedule Workload-oriented Permanent On demand
	Integration of loading process	As part of tour Separate loading, buffering of loaded trailers
	Integration of empty bins process	1:1-exchange Pick-up on demand No integration

Figure 3 shows the morphology of the researched milk run concepts according to the above mentioned criteria.

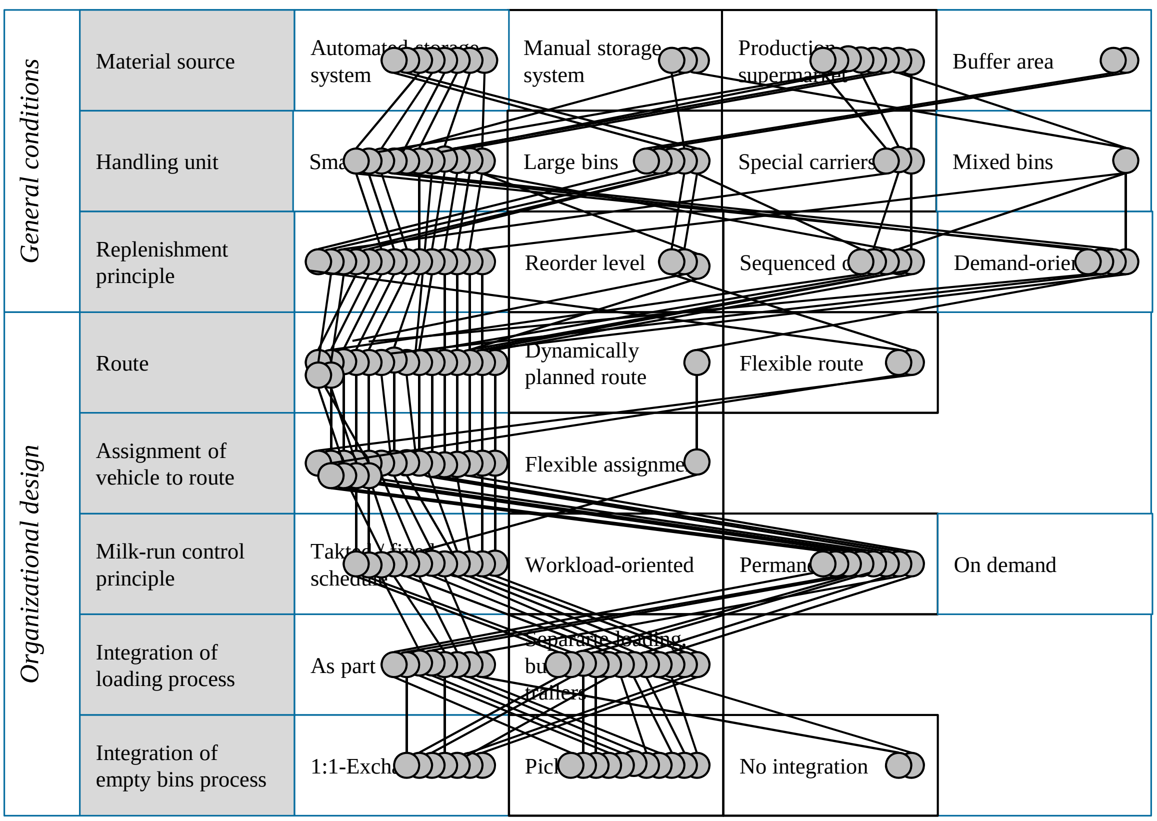


Figure 3: Morphology of typical milk run concepts based on an empirical study

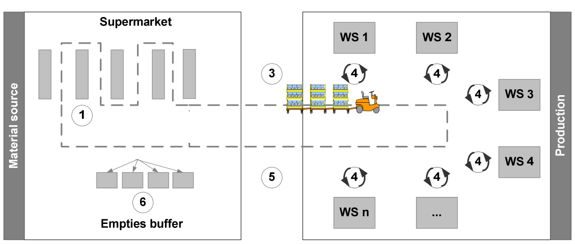
As can be seen, there are no two concepts that are exactly the same, but most share some similarities:

- Almost all concepts are operating on fixed routes.
- Vehicles are assigned to one single route.
- Most small bin processes operate on a fixed schedule; large bin processes run permanently.
- The empty bin process is usually integrated into the milk run.

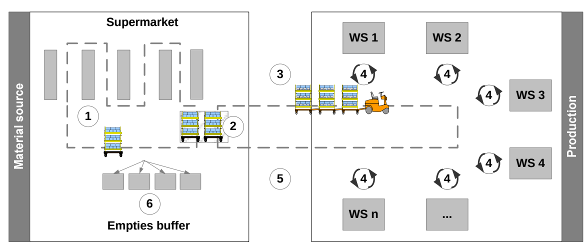
Obviously, the concepts for handling small bins are much more diverse than those for other goods; we therefore focus our further discussions on these concepts.

If we assume that an average number of empty bins required to be picked up by the milk run is the same in case of 1:1 exchange and pick-up on demand (which is plausible, as the number of empty bins to pick up is the same as the number of full bins to supply), and the routes and cycle times need to be defined (even if they are not fixed in the later operating phase) in a planning phase, some major process types can be derived. Different replenishment principles result in different information processes and, therefore, in different lead times, as it is shown below, but physical processes differ only a little (e.g. handling / no handling of kanban cards). If these considerations are taken into account, six major milk run material handling processes can be derived. They are depicted in Figure 4 and described in detail below.

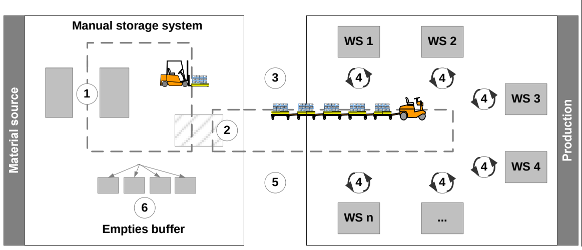
Concept 1: supermarket, self-loading



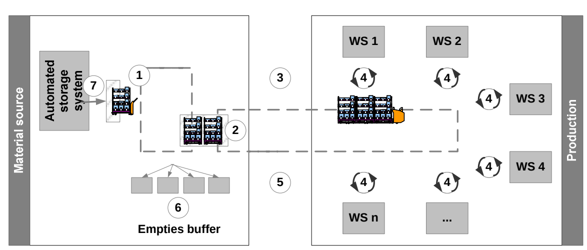
Concept 2: supermarket with pre-picking and buffering



Concept 3: whole pallets milk run, single small bins supply



Concept 4: automated storage system with buffering and manual loading



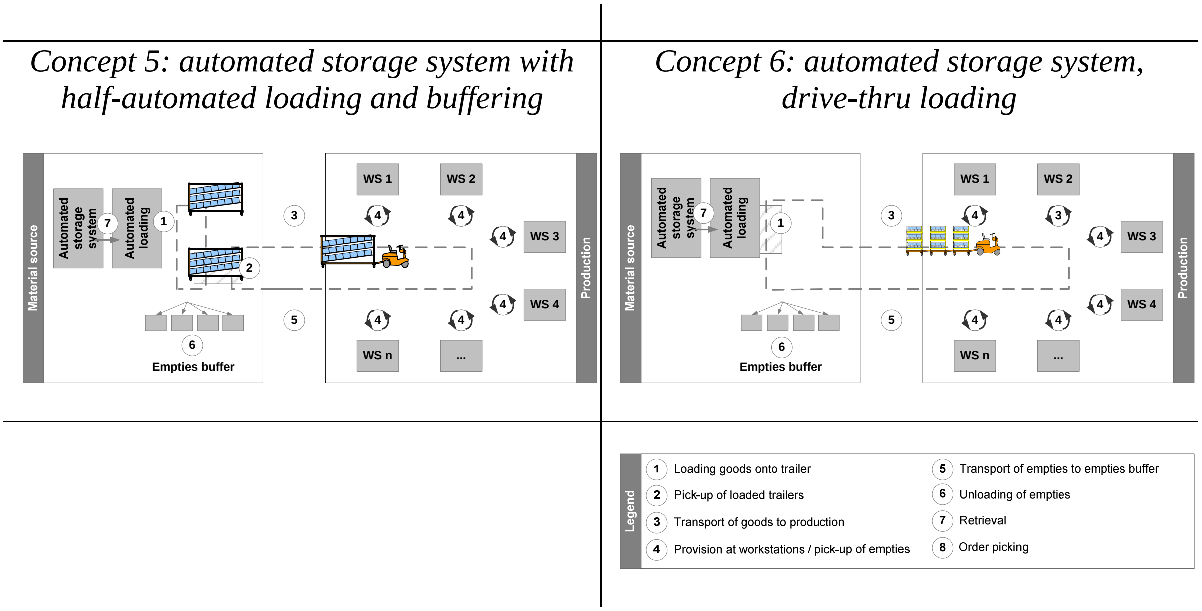


Figure 4: Major milk run concepts

3.1 Concept 1: supermarket, self-loading

A material source for small bins is a production supermarket. A milk run driver himself is loading bins onto his milk run train according to replenishment orders. After finishing the loading, he drives to the production workstations using his fixed route, stops, if he has something to deliver, and unloads the bins at the stations, which ordered the goods, and picks up empty bins. At the end of each tour, the driver unloads the empty bins and waits until he has to start the next tour according to his milk run schedule. The concept provides for orders that are often generated using kanban. In this case, the milk run driver is also responsible for generating the replenishment orders, either by picking up kanban cards, using empty bins as the replenishment kanban, or generating e-kanban orders by scanning empty bins. As there is only one person, who is responsible for the whole process, there are no interfaces in the physical process where time or information may be lost. The process can be implemented without any IT system using kanban cards for example and, therefore, it is simple. On the other hand, it takes little time per tour actually used for delivering material, as loading and order picking in the supermarket consume a significant amount of the available time. Therefore, milk run cycle time for supplying a fixed number of bins per tour is longer than in other concepts.

3.2 Concept 2: supermarket with pre-picking and buffer

This concept is similar to concept 1, but an additional supermarket worker is responsible for loading the milk run train. Depending on the type of information system used, the supermarket worker is either loading the train according to replenishment information given to him by the milk run driver, or according to information from the ERP system. After finishing the loading, he forwards the loaded trailers into a buffer area where the milk run driver picks up the trailers and starts the next tour, similarly to concept 1. As in this system, the supermarket process and the milk run process need to be synchronized, both the supermarket worker and the milk run driver operate according to a fixed schedule. Compared to concept 1, material lead time may be longer because of the buffering. If a kanban system is used, the information flow is also delayed because of the interface between the milk run worker and the supermarket worker. On the other hand, a higher milk run tact may be realized, as the milk run driver is solely responsible for delivering goods. Depending on the time needed for loading the trailers in the supermarket, the supermarket worker may supply more than one milk run train. This "pooling" may lead to engagement of less personnel in large systems. The milk run cycle and the supermarket cycle have to be synchronized in order to create stable lead times and little stock in the buffers.

3.3 Concept 3: whole pallets milk run, single small bin supply

In this case, the milk run train transports whole pallets with small bins (only one material per pallet). A warehouse worker loads the pallets onto the trailers by forklift. The milk run driver picks up the trailers and starts the next tour according to a fixed schedule. He stops at each point of use, checks the available stock and fills up the stock to a defined maximum level. He also picks up empty bins. After finishing the tour, he leaves the trailers with the empty bins at the buffer, loads the leftover full bins (if any) on top of the loaded trailers, provided in the buffer, and starts the next tour. This system requires coordination between the milk run and the loading process; therefore the system usually operates in a fixed tact. Materials are fixedly assigned to trailers, therefore only a limited number of different materials (= number of trailers) can be delivered with one milk run, and the demand per material should be high to ensure that the pallets are almost (but not completely) empty at the end of each tour. No information flow is necessary, i.e. the concept is simple and replenishment lead times are short. As whole pallets are loaded onto the trailer, handling times at the warehouse are short which result in short material lead times.

3.4 Concept 4: automated storage system with buffering and manual loading

The material source for small bins is an automated miniload warehouse. Bins for a milk run tour are retrieved, sequenced and provided for loading at a roller conveyor. A warehouse worker picks up an empty trailer from a trailer buffer and places it next to the conveyor. Then he uses a handling tool to load the bins onto the trailer (several bins at once). Loaded trailers are placed in another buffer area, where the milk run driver picks them up and starts the tour. The milk run driver delivers the bins to each point of use and picks up empty bins. At the end of each tour, he places the trailers with empty bins in a buffer area where another warehouse worker unloads the empty bins. The loading process and the milk run process need to be synchronized in the same way as the retrieval process, this system usually operates in a fixed tact. Demand-oriented or kanban systems are used as the information principle. In the case of kanban, the milk run driver may be responsible for creating kanban-orders. If a kanban system is in use, orders have to be buffered in the IT system for a certain time, until retrieval orders for the whole tour can be triggered. In case of a demand-oriented system, orders are known in advance, retrieval orders can be triggered just in time for the next tour, which results in lower stock levels at the assembly line.

In this system, several routes may be serviced by the same warehouse worker at the same conveyor. As trailers are buffered outside the storage system, and some empty trailers are always available, the risk of congestions of several routes at the conveyor is low.

3.5 Concept 5: automated storage system with half-automated loading and buffering

This system is similar to concept 4, except for the loading process. In this case, the warehouse worker positions the trailer directly in front of the conveyor system. Bins are loaded automatically into the trailer. When the trailer is fully loaded, the warehouse worker puts it in the buffer area where the trailers are picked up by the milk run driver. Similar to system 4, the information flow may be also realized as a kanban system or a demand-oriented system. Compared to system 4, less manual handling is necessary.

3.6 Concept 6: automated storage system, drive-thru loading

The material source is also a miniload warehouse. Bins for a milk run tour are retrieved, sequenced and provided for loading in a flow rack. For loading, the milk run driver positions the milk run train in front of the flow rack. The trailers are also designed as flow racks which exactly fit the loading system (cf. Figure 5). The driver triggers the loading process, and all bins roll onto the trailers simultaneously. This results in a quite short loading time, and, as there is no buffering outside the storage system, in short lead times. On the other hand, the retrieval and milk run process have to be synchronized exactly, as there is no buffer in between. Also, if several milk runs are loaded on the same flow racks, an exact schedule has to be ensured.

Figure 5: Drive-Thru loading concept

4 Parameters and Key Figures

In order to be able to compare the concepts further, it is necessary to determine the times for separate activities of the milk run process, loading process and retrieval process.
In all the milk run processes described above, one tour provides for the same activities: first, bins are loaded onto the milk run trailers. Then, the driver stops at a number of workstations, delivers full bins and picks up empty bins. Afterwards, he stops at a buffer area for empty bins, unloads the bins or places trailers with empty bins there, and drives back to the loading area. Consequently, the milk run cycle time is the sum of the loading time (t_L), stop time (t_S), handling time for the delivery at each stop (t_H), time for handling the empty bins or empty trailers (t_E) and travelling time (t_T) [4].

The travelling time t_T depends on the length of the route, t_S depends on the number of stops per tour (several bins may be delivered to one stop) and t_H depends on the number of bins delivered per tour. These times may vary depending on the chosen milk run technology but are independent from the concepts described above. On the other hand, the loading time t_L and the time for handling the empty trailers / bins t_E on the other hand largely depend on the concept, as loading may mean loading single bins onto the trailers (concept 1), loading the whole batch at once (concept 6) or simply picking up loaded trailers from a buffer (concepts 2, 3, 4, 5). In concept 1, the loading time is also dependent on the number of bins to load per tour, in concepts 2, 3, 4 and 5 - on the number of trailers to pick up and, in concept 6, it is independent from both.

The resulting material lead time comprises the milk run cycle time plus the time for loading the bins onto the trailers, if this is not part of the tour, as well as the time for retrieval from storage and buffer times. The loading time again depends on the chosen concept and the number of bins to load, as bins may be loaded singly (concepts 2, 5), several bins may be loaded at once (concept 4), or all bins may be loaded simultaneously onto the trailer (concept 3). The retrieval time depends on the number of bins to retrieve. For the buffer time, we assume that one tour is buffered; therefore the buffer time is equal to the time needed for loading one tour.

To calculate the replenishment lead time for the different milk run concepts, defined as the time span from signaling a demand until this demand is fulfilled, the information flow has to be taken into account too. If a kanban principle is used, the kanban information has to be transmitted to the material source before the retrieval of bins can be started. If a demand-oriented principle is used, future demand is calculated in advance, and the retrieval process can be started based on this information just-in-time for the next milk run tour.

Figure 6 shows the resulting lead time and replenishment lead time for a milk run concept in combination with kanban and the lead time for a demand-oriented system. In case of kanban, the remaining material at the production line must be sufficient to cover the replenishment lead time, whereas in a demand-oriented system, the moment, when all the material is consumed, can be calculated and therefore only the lead time has to be covered (assuming a 2-bin-principle for both cases). Consequently, stock levels at the production line are generally lower, when a demand-oriented replenishment system is used. Note that the implementation of a demand-oriented system will only be exact, if the calculated stock level in the IT system and the physical stock at the production line are exactly the same, which is only applicable if material consumption is completely stable (no defective products, no rework, no changes in the production sequence etc.). The decision which replenishment principle to use is, therefore, based on production methods etc. but not on the milk run system.

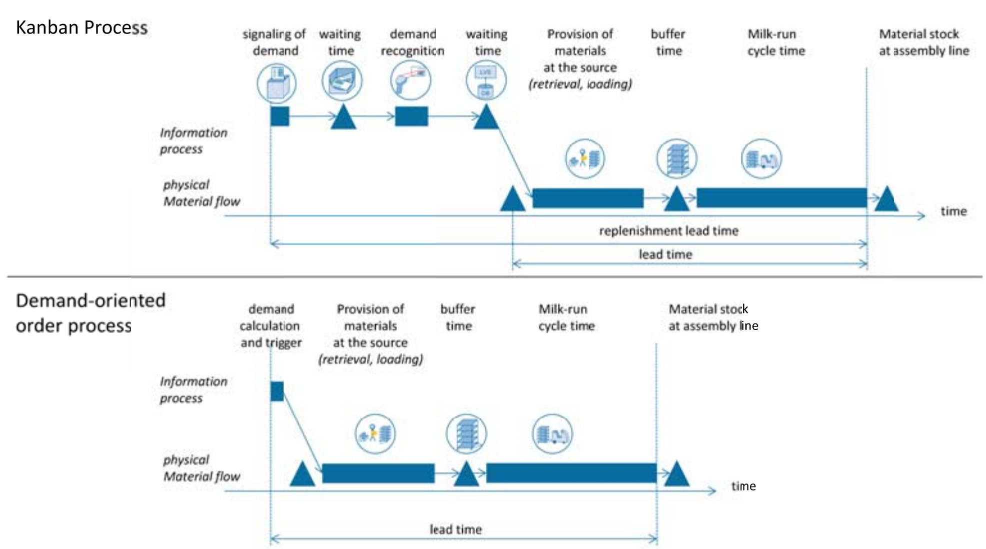


Figure 6: Determination of lead time and replenishment lead time

5 Quantitative Analysis

For a quantitative analysis of different concepts, the processes described above are modeled using MTM time modules. As the concepts mainly differ with regard to the loading process, in order to be able to compare the concepts in a better way, we assume the same travel time for each process. We also assume, that in each concept two bins are provided per stop, with the exception of the "low number of variants" concept (concept type 3; we assume five bins per stop), which only makes sense for a high throughput per material.

With these assumptions, loading time, travelling time, stop time, handling time and unloading time are calculated for different numbers of bins per tour. A safety buffer time of 30 % to handle deviations in the mean number of bins per tour (which may result e.g. from unstable demands) is added to the milk run cycle time. Further loading and handling times at the warehouse are also calculated using MTM modules. To determine the cycle times of the automated systems, a material flow simulation is used.

Based on these calculations, milk run cycle time, material lead time and replenishment lead time can be determined.

The results for 20 and 40 bins per tour are shown in the following tables (Table 2, Table 3). Further results for other throughputs per tour are presented in the appendix. Note that the milk run cycle times differ slightly due to different trailers and tugger trains in the real processes which result in different handling times for the milk run driver.

Table 2: Key figures [min] for different milk run concepts with a mean throughput of n = 20 bins per tour

n=20	*Milk run cycle time*	*Buffer time*	*Loading / handling at source*	*Retrieval*	*Order creation and info. handling*	*Lead time*	*Reple-nishment Lead time*
Concept 1, kanban	34	0	0	0	34	34	68
Concept 2, kanban	23	12	12	0	23	47	93
Concept 3	19	13	13	0	0	45	not relevant
Concept 4, e-Kanban	21	7	7	33	42	68	110
Concept 4, demand-or.	21	7	7	33	0	68	not relevant
Concept 5, e-kanban	22	7	7	33	44	69	113
Concept 5, demand-or.	22	7	7	33	0	69	not relevant
Concept 6, e-kanban	23	0	0	33	46	56	102
Concept 6, demand-or.	23	0	0	33	0	56	not relevant

Table 3: Key figures [min] for different milk run concepts with a mean throughput of n = 40 bins per tour

n=40	*Milk run cycle time*	*Buffer time*	*Loading / handling at source*	*Retrieval*	*Order creation and info. handling*	*Lead time*	*Reple-nishment Lead time*
Concept 1, kanban	57	0	0	0	57	57	114
Concept 2, kanban	36	22	22	0	36	80	116
Concept 3	29	13	13	0	0	55	not relevant
Concept 4, e-Kanban	32	12	12	52	64	108	172
Concept 4, demand-or.	32	12	12	52	0	108	not relevant
Concept 5, e-kanban	35	13	13	52	70	113	183
Concept 5, demand-or.	35	13	13	52	0	113	not relevant
Concept 6, e-kanban	36	0	0	52	72	88	160
Concept 6, demand-or.	36	0	0	52	0	88	not relevant

6 Stability Analysis

Process stability is the minimization of the variation around the desired value of the process performance. A logistics system is stable if it is able to reach the desired values despite of short-term disruptions in the system. Process stability can be achieved by a constant product flow, standardized processes and fixed cycle times under a constant workload. One way to achieve this is to implement certain principles from the well-known Toyota production system, particularly the “Just-in-Time” principle which aims at reducing the mean lead time and the spread of the lead times. This enables constant flow in low lot sizes, reliable replenishment lead times, and low stock levels. To continue and explicitly secure the process against unforeseen disruptions, buffer times and capacity reserves may be additionally planned [5].

Milk run systems in general already fulfill some of these requirements. If the milk run routes are operated in high frequency and are synchronized with the production tact, a continuous flow of material through the system is guaranteed. Additionally, mean lead times and the spread of lead times can be reduced, compared to direct transport with a forklift which transports each pallet one by one, as shown in Figure 7.

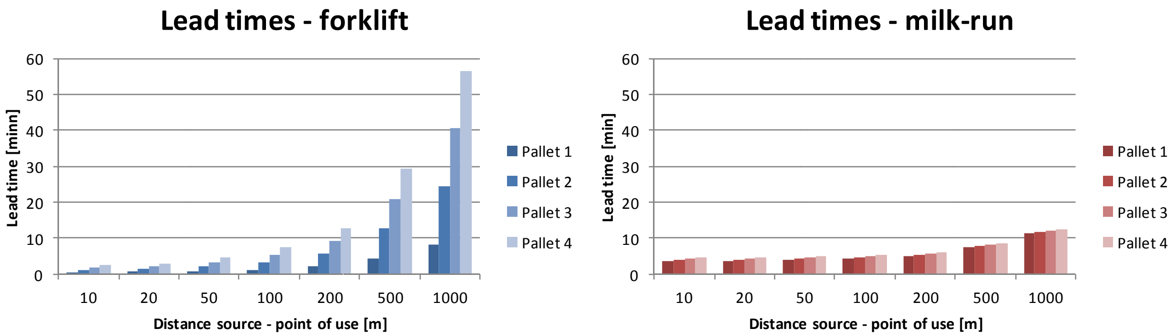


Figure 7: Lead times for 1:1 and 1:n – transport

As stock levels are generally low and exact schedules are defined, deviations from the standard process and errors become obvious fast, it is, therefore, easy to verify whether the dimensioning of the system is correct and standards are adhered.

Still, in each milk run system there are some possible sources of interference and uncertain parameters. These may be classified into external disruptions (which are not caused or influenced by the milk run system) and internal disruptions. Figure 8 shows typical sources of disruption according to our empirical study [1].

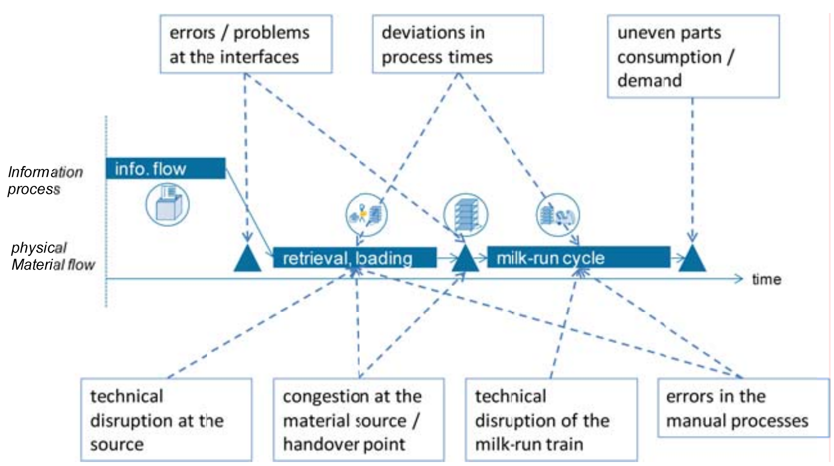


Figure 8: Typical disruptions and deviations in the milk run process

Uneven demand and consequently uneven transport volumes may not be influenced by the milk run system and, therefore, have to be taken into account when dimensioning the system, or may cause an exception process. The other disruptions and deviations shown in Figure 8 are caused by the milk run system itself or can at least be influenced by it. Therefore, the systems differ with regard to the risk of occurrence of a disruption and the chance to handle possible disruptions.

Table 4 compares the risk of the above mentioned disruptions and deviations causing a shortage of materials at the assembly line for each milk run concept.

Table 4: Risk of disruptions and deviations causing shortage of materials

	Concept 1	Concept 2	Concept 3	Concept 4	Concept 5	Concept 6
technical disruption milk run train	low	low	low	low	low	low
technical disruption storage system / loading system	none (manual process)	none (manual process)	low (technical defect forklift possible, storage compartments still accessible, buffering outside storage system)	medium (automated system not accessible, buffering outside storage system)	medium (automated system not accessible, buffering outside storage system)	high (automated system not accessible, no buffering outside storage system)
congestions at the material source	low	low	low	low	low	high
errors / problems at the interfaces in the physical process	medium (manual process, milk run driver responsible for whole process)	high (manual process, shared responsibilities)	high (manual process, shared responsibilities)	medium (half-manual process shared responsibilities)	medium (half-manual process shared responsibilities)	low (highly automated process, milk-run driver is responsible for whole process)
deviations in process time (running out of tact)	high (manual process)	high (manual process)	high (manual process)	medium	medium	medium
deviations in process time causing delays on other routes	low	medium (buffer)	medium (buffer)	medium (buffer)	medium (buffer)	high

7 Evaluation

Regarding cycle time and lead time, concept 3 guarantees the fastest delivery process with relatively high stability and no IT support. Obviously, it can be applied only for a limited number of different materials and high throughput per material; therefore, application is limited. The other concepts may be basically used for providing an unlimited number of different materials because the information which materials to transport is either provided by kanban information, or by a demand-oriented system.

Comparing the supermarket concepts, concept 1 results in a longer milk run cycle time but shorter replenishment lead time for the considered throughputs per tour. If the number of bins per tour is higher, replenishment lead time is shorter in concept 2. In larger systems with a number of different routes, one supermarket worker may be responsible for picking several routes, which results in a “pooling” effect and the system may be operated with a lower number of workers than in concept 1. To ensure stability in this case, the supermarket and milk run process need to be well synchronized. In concept 1, the milk run driver may be able to catch up possible delays without hindering any other routes. Both manual supermarket concepts are usually used in combination with a kanban information principle, often without any IT support.

Half-automated concepts 4 and 5 differ only slightly with respect to times and stability. Concept 6 guarantees a remarkably faster delivery process due to shorter loading time and no buffering. In addition to that, the milk run driver is responsible for the complete process, no warehouse worker are necessary. On the other hand, stable cycle times are critical, as delays on one route directly cause delays on other routes. Moreover, as there is no buffer, technical problems in the automated system directly affect the milk run process.

Obviously, the information principle determines the replenishment lead time comprehensively and the necessary stock levels at the production line, respectively. As mentioned above, the information principle is not determined by the milk run concept, but each concept may be operated with each information principle.

8 Conclusion and Review

During the recent years, milk run systems have become a commonly used transport concept for in-plant material provision. As shown above, diverse concepts are in use. Each concept has some advantages and difficulties. All the concepts differ in resulting cycle times, lead times and stability and each one may be used for a different application.

To research stability and risk of material shortages in the different systems further, a dynamic approach may provide further insights. Additionally, we will also research further, in terms of dimensioning the systems and determining the routes based on the considerations and parameters described above.

Appendix

Table 5: Key figures [min] for different milk run concepts with a mean throughput of n = 30 bins per tour

n=30	*Milk run cycle time*	*Buffer time*	*Loading / handling at source*	*Retrieval*	*Order creation and info. handling*	*Lead time*	*Reple-nishment Lead time*
Concept 1, kanban	50	0	0	0	50	50	100
Concept 2, kanban	30	17	17	0	30	64	94
Concept 3	24	13	13	0	0	50	not relevant
Concept 4, e-Kanban	27	10	10	43	54	90	144
Concept 4, demand-or.	27	10	10	43	0	90	not relevant
Concept 5,e-kanban	28	10	10	43	56	91	147
Concept 5, demand-or.	28	10	10	43	0	91	not relevant
Concept 6, e-kanban	29	0	0	43	58	72	130
Concept 6, demand-or.	29	0	0	43	0	72	not relevant

Table 6: Key figures [min] for different milk run concepts with a mean throughput of n = 50 bins per tour

n=50	*Milk run cycle time*	*Buffer time*	*Loading / handling at source*	*Retrieval*	*Order creation and info. handling*	*Lead time*	*Reple-nishment Lead time*
Concept 1, kanban	68	0	0	0	68	68	136
Concept 2, kanban	43	27	27	0	43	97	140
Concept 3	35	13	13	0	0	61	not relevant
Concept 4, e-Kanban	38	15	15	61	76	129	205
Concept 4, demand-or.	38	15	15	61	0	129	not relevant
Concept 5, e-kanban	41	17	17	61	82	135	217
Concept 5,	41	17	17	61	0	135	not

demand-or.							relevant
Concept 6, e-kanban	42	0	0	61	84	103	187
Concept 6, demand-or.	42	0	0	61	0	103	not relevant

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