

NEW DESIGN GUIDELINES FOR IN-PLANT MILK-RUN SYSTEMS

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Abstract

Tugger trains became a popular means of supply in material handling intensive production systems. In contrast to forklift trucks they interlink a supermarket with multiple delivery locations along a transport route in a milk-run. But the efficiency gain (higher transport capacity, reduced labor costs) has its price: Compared to forklift trucks, planning and dimensioning of in-plant milk-run systems is more complicated.

The paper discusses features and drawbacks of a recent standardization approach of the Association of German Engineers (VDI) and highlights the variety of technical restrictions which have to be considered when a milk-run system is designed. It shows, that algorithms can *support* the design and dimensioning process. It is, however, not feasible to formulate the design task as an ordinary optimization problem which can be handled by a solver without any further interaction.

1 Background

In the course of the last decade, tugger trains gained increasing popularity as an alternative means of supply in material handling intensive production systems. Large automotive companies were the first, to replace their forklift fleets by a significant lower number of tugger trains to supply their assembly lines. Efficiency was the primary driver of this shift: As a tugger train's transport capacity is two to four times higher compared to a forklift truck, it allowed drastic headcount reductions in supporting logistic operations. Aside of reduced labor costs, improvements in occupational safety are a major advantage of tugger trains.

Thus, the dictum of 'forklift-free plant' began circulating in industry.



Figure 1: A Still tugger train at a Fendt facility

The shift from forklift trucks to tugger trains is, however, by far more than just a replacement of one type of transport vehicle by another. The latter interlink a so-called supermarket (i.e. parts warehouse) with multiple delivery locations (stops, e.g. assembly stations) along a transport route in a milk-run. But at several stops along the assembly line, the demand of articles varies in type, weight and volume over time (due to product variety) – while their delivery is rigidly tied together by the row of trailers and a rather rigid schedule: the implementation of a tugger train system usually aims at a uniform supply process, preferably according to a timetable.

Consequently, a tugger train delivery can rarely be introduced into a production or assembly system without a reorganisation of article dispatching strategies. In fact, a successful implementation of tugger trains implies some ‘lean’ material supply concept. As a contrast to established ‘hands-on’ forklift dispatching strategies, this seems to be a welcomed side effect – but its consequences are occasionally underestimated, particularly by small and medium sized enterprises.

To address such issues the Association of German Engineers (VDI) recently developed the guideline VDI 5586 for ‘In-plant milk-run systems’. It will be officially released as a preliminary version in 2016 and will thus become a point of reference for dimensioning and implementation of in-plant milk-run systems in the years to come.

The VDI 5586 covers two parts: ‘Basics, design and practical examples’ and ‘Planning and dimensioning’. In the former, the variety of options of

- context (e.g. type of carriers, determination and signalling of demands),
- equipment (e.g. type of tug drive and trailer steering) and
- organisation (e.g. assignment of drivers/trains/stops to routes)

is classified. In the latter, basic principles and formulas for dimensioning of milk-run systems are defined. The draft of the latter part was developed under the aegis of the Chair for Logistics Engineering at Technische Universität Dresden. In the following, the details and the limitations of the guideline's dimensioning approach will be sketched and discussed.

2 State of the Art

According to VDI 5586, the desired *average* throughput is the key design figure of a tugger train route. It is measured in standard carriers (usual size 800×1200 or 1000×1200, e.g. EUR-pallets) per time unit (usually hour or shift):

$$\Lambda_R = \sum_H \sum_A \frac{\lambda_{A,H}}{\varphi_{LT}}$$

It is thus derived from $\lambda_{A,H}$ (the throughput per article A to deliver at stop H along the route, measured in article-specific carriers, e.g. bins or boxes, per time unit) and from φ_{LT} (the ratio of article-specific carrier size to standard carrier size, e.g. bins per pallet, resp. 1 for the standard carrier). These values, aggregated from all articles and all stops, yield Λ_R .

Incorporating K_{RZ} (the tugger train transport capacity, again, measured in standard carriers) and η_K (the planned utilisation of its capacity), it yields on the one hand the tugger train start interval (in time units):

$$t_{TA} = \frac{\eta_K K_{RZ}}{\Lambda_R}$$

On the other hand there is the tugger train cycle time (in time units):

$$t_{zyk} = t_F + t_H + t_B + t_E$$

It considers t_F (the driving time according to speed and distance and additional times for gates, curves, ramps etc.), t_H (the time for deceleration, acceleration and any additional operations at the stops, taking into account the probability that the tugger train will halt at a certain stop), t_B (the train loading time, usually at the supermarket), and finally t_E (the unloading and carrier handling time at the stops).

Both values above allow a calculation of the required number of tugger trains:

$$n_{RZ} \geq \left\lceil \frac{t_{zyk}}{t_{TA}} \right\rceil$$

Finally, the number of carriers per route, stop and article is $n_{LT,A,H} = \lambda_{A,H} t_{TA}$. Each stop should provide further space for empty carriers. So, the required buffer space per article

and stop is $q_{A,H} = 1 + \lceil n_{LT,A,H} \rceil$. This leads to a stop's *average* buffer size (measured in standard carriers, too):

$$Q_H = \sum_A \frac{q_{A,H}}{\varphi_{LT}}$$

3 Discussion

The standardisation approach described above is essentially a response to the requirements of planners and operators of in-plant milk-run systems. It is suitable for a quick estimate of the required number of tugger trains. An example in the guideline illustrates it by means of the following two diagrams.

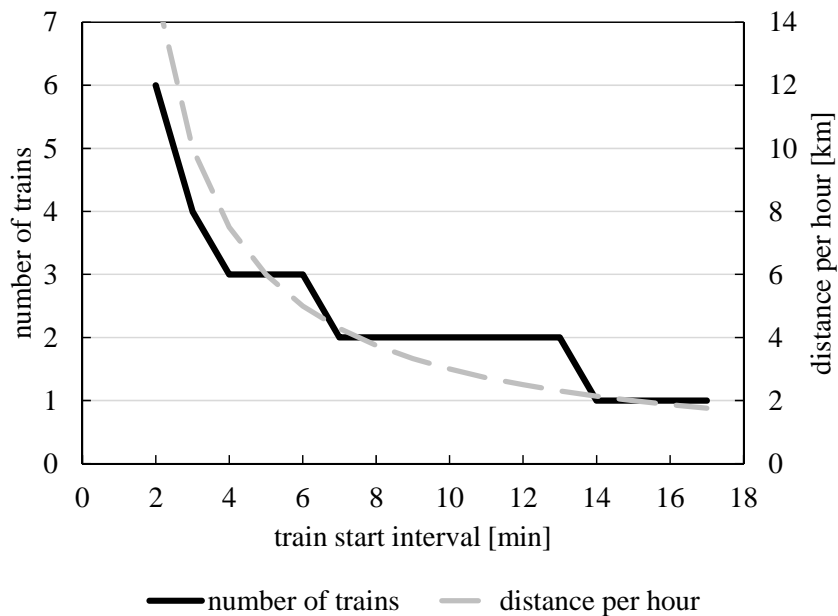


Figure 2: Impact of tugger train start interval on required number of tugger trains and total tugger train travel distance per hour

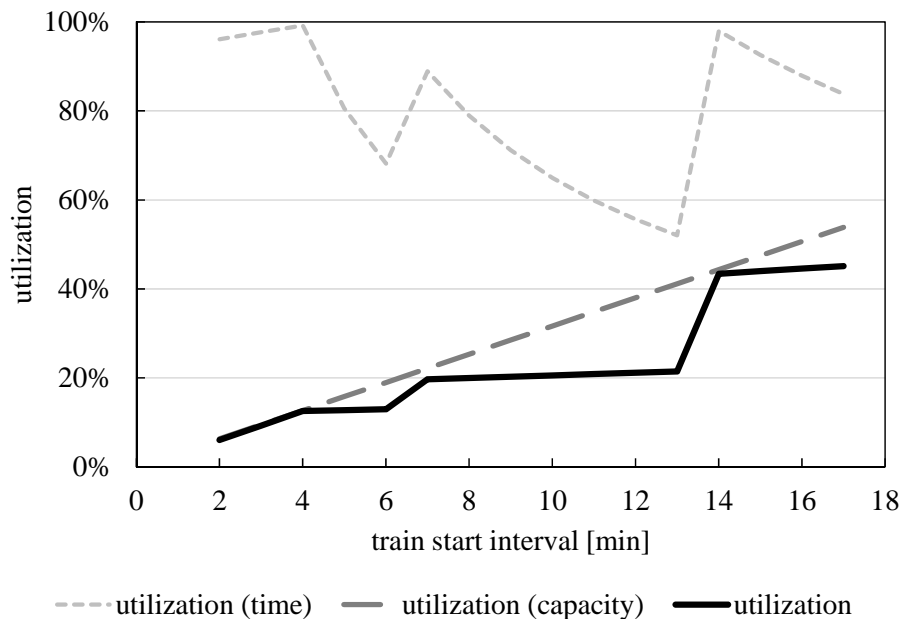


Figure 3: Impact of tugger train start interval on utilization (overall as well as of driver's working time and tugger train's transport capacity)

As a VDI guideline it meets the requirements of early logistics planning stages or tender specifications. Nonetheless, it has several drawbacks.

Obviously, it is based on the assumption of relatively constant demands (resp. throughput). The planned utilisation of the tugger train (i.e. its capacity reserve) is currently the only way to cope with throughput fluctuations. Although levelled demands are generally desired and milk-run systems are particularly suitable in such cases, it is not yet defined what 'relatively constant' specifically means and to what extent demand variability is acceptable. Beyond that, decreased utilisation (or increased milk-run frequency, i.e. increased labor costs) is not the only option to manage variability: another one is increased buffer size at the stops (i.e. increased space requirements) – although milk-run systems are usually associated with the expectation of reduced inventories, which is essentially wrong.

Furthermore, the guideline does not address the following questions:

- How to assign certain sequences of stops to certain routes? In practice there are restrictions in the facility layout (e.g. oneways or curve/turn radius) as well as technological restrictions due to interdependencies between load/carrier, trailer and stop (e.g. weight/shape or left/right side).
- How to configure trains? This is the case when there are different types of trailers; frequently there are at least two, for box pallets and for bins.

- What are the ideal tugger train start intervals? Not necessarily they have to be constant and just demand driven. Sometimes the train schedule has to consider bottlenecks in the layout, where different trains cannot or should not meet.
- How to determine the size and fill level of carriers? Particularly in the case of constant throughput, the supply intervals of different articles should have least common multiples which are large enough to prevent frequent superposition of deliveries.

4 Literature

The questions above are generic for the design of in-plant milk-run systems. They are illustrative but there are further crucial ones.

Generally, the matter is by far not new to the scientific community. CLARKE & WRIGHT (1964) might serve as an example of an early paper. Of course there is a large body of (OR-) literature (e.g. about vehicle scheduling, routing, and dispatching) which addresses relevant aspects – but only a few papers consider specifically *in-plant* milk-run systems. In this respect most relevant are from our point of view e.g. BRUNGS (2012), COSTA et al. (2008), DROSTE & DEUSE (2011), EMDE & BOYSEN (2012), GRUNEWALD et al. (2014), KILIC et al. (2012), SADJADI et al. (2009), SATOGLU & SAHIN (2013) and SATOH (2008).

However, none of them does it in the entirety which is appropriate for direct application in real-world (i.e. industrial) scenarios. In particular the variety of technical restrictions as mentioned in section 3 hinder the development of closed analytical or numerical solutions. Nonetheless, such planning and design problems exist and such questions are asked. Thus, a practicable solution is in fact the algorithmic support of a manual planning tool, which leaves the consideration of complicated or soft restrictions in the responsibility of the user.

5 Outlook

For the specific case of the Daimler AG, the Chair for Logistics Engineering at Technische Universität Dresden therefore developed in 2011/2012 a calculation concept and algorithms for in-plant milk-run systems dimensioning, which were later implemented by Daimler in the ‘DelCa’ (delivery calculation) tool for its internal planning departments. The scope of this tool is, in part, even beyond the scope of the recent VDI guideline. Meanwhile Daimler uses the tool worldwide for assembly line layout and supply planning and it replaced the application of discrete event simulation.

In cooperation with Logsol GmbH, a Dresden based logistics consulting and software company, the algorithms are currently generalised and extended (among others with respect to the questions above). Design target is RoutMan, a web-based in-plant milk-run planning tool for general industrial application. Currently, RoutMan is already used for layout planning, but its functionality shall be extended up to timetable generation for the operational business.

6 References

- BRUNGS (2012): *Der Milkrun in der Produktionslogistik*. Dissertation, Darmstadt : Universität, Institut für Produktionsmanagement, Technologie und Werkzeugmaschinen. – ISBN: 978-3-8440-1125-8
- CLARKE & WRIGHT (1964): Scheduling of Vehicles from a Central Depot to a Number of Delivery Points. In: *Operations Research*, vol. 12 (August 1964), no. 4, pp. 568–581. – DOI: 10.1287/opre.12.4.568
- COSTA, DIAS, OLIVEIRA & PEREIRA (2008): Simulation as a tool for planning a material delivery system to manufacturing lines. In: *Proceedings of the 2008 IEEE International Engineering Management Conference*, pp. 1–5. – ISBN: 978-1-4244-2288-3. – DOI: 10.1109/IEMCE.2008.4618006
- DROSTE & DEUSE (2011): A Planning Approach for In-plant Milk Run Processes to Optimize Material Provision in Assembly Systems. In: *Enabling Manufacturing Competitiveness and Economic Sustainability: Proceedings of the 4th International Conference on Changeable, Agile, Reconfigurable and Virtual production (CARV2011)* (Montreal, Canada, 2. October 2011), ed by. ElMaraghy, pp. 604–610. – ISBN: 978-3-642-23859-8
- EMDE & BOYSEN (2012): Optimally routing and scheduling tow trains for JIT-supply of mixed-model assembly lines. In: *European Journal of Operational Research*, vol. 217 (March 2012), no. 2, pp. 287–299. – DOI: 10.1016/j.ejor.2011.09.013
- GRUNEWALD, VOLLING & SPENGLER (2014): Integrierte Planung von Bestellmengen und Milkruns mit korrelierten Bedarfen. In: *Supply Management Research*, ed by. Bogaschewsky, Eßig, Lasch & Stölzle, pp. 147–163. Wiesbaden : Springer Fachmedien. – ISBN: 978-3-658-06199-9, 978-3-658-06200-2
- KILIC, DURMUSOGLU & BASKAK (2012): Classification and modeling for in-plant milk-run distribution systems. In: *The International Journal of Advanced Manufacturing Technology*, vol. 62 (October 2012), no. 9, pp. 1135–1146. – DOI: 10.1007/s00170-011-3875-4
- SADJADI, JAFARI & AMINI (2009): A new mathematical modeling and a genetic algorithm search for milk run problem (an auto industry supply chain case study). In: *The International Journal of Advanced Manufacturing Technology*, vol. 44 (September 2009), pp. 194–200. – DOI: 10.1007/s00170-008-1648-5
- SATOGLU & SAHIN (2013): Design of a just-in-time periodic material supply system for the assembly lines and an application in electronics industry. In: *The International Journal of Advanced Manufacturing Technology*, vol. 65 (March 2013), no. 1, pp. 319–332. – DOI: 10.1007/s00170-012-4171-7
- SATOH (2008): A Formal Approach for Milk-Run Transport Logistics. In: *IEICE Transactions on Fundamentals of Electronics, Communications and Computer Sciences*, vol. E91-A (November 2008), no. 11, pp. 3261–3268. – DOI: 10.1093/ietfec/e91-a.11.3261