Configuration and control of suppliers’ safety buffers in automotive Just-In-Sequence-Production via a dynamic mathematical model

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Abstract
In Just-In-Sequence (JIS) production, there is a high risk to disrupt the Original Equipment Manufacturer’s (OEM) production, if the module is built not until the final JIS-call is received by the supplier. To proactively reduce the risk, safety buffers might be built up on the suppliers’ side. Because the information on the OEM’s real production sequence is fraught with uncertainty, it is of vital importance, which variants in which amount should be presently provided in buffer (long-term coverage in case of supplier’s production breakdown), and how the criticality of a call can be evaluated in order to decide about its delivery on production or on taking from buffer (short-term coverage if there is a supplier’s production backlog).

This research provides a mathematical model that aims at a high guaranty of supply. Concretely, a heuristic, stepwise approach is be presented. In each stage, buffer setup resp. buffer use is planned, to come as close as possible to the target buffer configuration on the one hand and to ensure the short-term coverage on the other hand. The situation is modeled as an integer linear problem (ILP). In case that there is no solution found in a given time, or, if there exists no feasible solution, a shift to a priority rule based approach is done which is derived from the ILP formulation.

The model describes a useful decision support to the self-dependent and demand-oriented organization of buffers on the supplier’s side. The model evaluation was successfully done by means of selected scenarios.

Keywords: Just-In-Sequence production, buffer stock control, optimization model

1. Introduction and problem description
The higher the amount of module variants as e. g. seats, cable harnesses, or fuel tanks in large-volume automotive production, the more the Just-In-Sequence supply concept becomes relevant (Wagner and Silveira-Camargos (2011)). Given the required store capacities, there are clear advantages compared to e. g. KANBAN-control (Schröder (2004), p.11).

Not until the final assembly of a completely defined car is started by the OEM, the delivery call on the required module variant is transmitted to the supplier or a 3rd party logistics provider (3PL), providing him with the necessary information about variant (article code) and sequence position. In the following the term 3PL is used without any restriction. Then the 3PL produces the delivery unit with a lead time of about 240 minutes (Rumpelt (2009), p.26). The information on short notice and the high variety of variants result in a 3PL’s module production by a make-to-order final assembly.

On the one hand, the OEM avoids storage capacity costs, but on the other hand, there is the risk to disrupt the production, if only one supplier fails to deliver (Wagner and Silveira-Camargos (2012)). To reduce the risk, safety buffers might be established to instantiate a by-pass-concept in case that a problem appears in the 3PL’s production, which increases the risk of delivery failure. On principle, such a concept is reasonable, if there is a high amount of variants, but not to the extent, that the variants are car-individual. However, OEMs try to avoid safety buffers especially in the case of supplied modules (Lieberman and Demeester (1999)).

So, there is the option to self dependently build up buffers on the 3PLs’ side. Thereby, an additional benefit is generated to the OEM by supporting process stability, and not least, the 3PL increases its competence to successfully participate in automotive JIS-Supply-Networks. Additionally, there might be a financial necessity, because high costs arise, if a JIS-delivery fails and the OEM’s production is disrupted.

In this work, we focus on an integrated JIS-concept with by-pass-buffer, where normally the 3PL produces the module on call (see Figure 1). It clearly differs from a 2-step JIS-concept, where the
complete production is based on forecast data. So, each module is stored and just sequenced on call (Tempelmeier (2012), p.83 and p.100). The higher the amount of variants and the higher the uncertainty of the forecasts, the higher is the risk related to process failure or to storage waste. Additionally, each module needs a double handling.

**Figure 1:** Integrated JIS-Concept with self-dependently controlled safety-buffer by 3PL

The further conditions in this situation are as follows:

- Buffer storage is restricted to a production volume of about one shift. Given a daily time of production up to 3 shifts, there is an adequate optimization potential.
- The real OEM-sequence is known with a lead time of about 240 minutes.
- Buffer configuration is planned based on forecast data given by the OEM related to article code and its quantity per date. Normally, these data contain no sequence information, or such an information is highly uncertain because of changes on the part of the OEM, that are e. g. caused by other supply chain delivery problems or the OEM production process itself (Meißner (2009), p.58).
- So, the variants’ distribution related to the timeline of a day is uncertain. For an overview to commonly used call (forecast) types in German automotive industry see Grill-Kiefer (2010), p. 359 or Ostertag (2008), p. 31.

Summarized, we have the following requirements to the integrated JIS-Concept and its buffer:

- The 3PL’s ability to supply must be ensured by means of a safety buffer to by-pass a production breakdown (long-term coverage) resp. a gradually accumulated production backlog that also may put the OEM’s production at risk (short-term coverage).
- The capital lockup caused by the buffer warehouse stock should be as low as possible.
- The buffer’s planning and control must be based on the calls and call forecasts, i. e. the amount of each variant in the buffer and its use must be determined in a dynamic and context-sensitive manner.
- Additionally, the following assumptions are made in terms of the concept’s practical handling:
  - There is direct access to each unit in buffer. The smallest lot size is one unit.
  - To calculate days of inventory of each variant (i. e. how long the stock of a variant – probably meets the OEM demand), work schedules of OEM and 3PL are available.
  - 3PL produces each variant without retooling.
  - The initial buffer buildup is done in an additional shift without OEM-supply.
- The following shows the research objective that results from the requirements mentioned above. Afterwards the related concept will be presented.

### 2. Objective

To meet the requirements mentioned above, a dynamic and context-sensitive buildup and use of the buffer must be realized. When a 3PL production breakdown happens, each call, starting with the first still pending call, must be delivered from buffer. So, the target buffer configuration must be continually adapted, because the initially uncertain forecast data will be transformed into real calls during the working day. As a result, there are concrete residual amount of calls related to the actual day and first information about the variants’ distribution related to the timeline of a day. See figure 2.
The central challenge doesn’t actually consist in determination of the target buffer configuration, but in permanent adaption of the buffer amounts taking account of changes related to the required variant, to the buffer capacity and to the actual production backlog associated with the buffer use for calls. So, the main objective consists in making decisions to meet the target buffer configuration as close as possible under these conditions.

As a consequence, the operational objectives of this research are as follows:

1. Develop a measurement to quantify the criticality of a variant and thus a decision criterion to determine its amount in target buffer configuration, i.e. if and how the variant’s amount has to be changed.
2. Develop a measurement to quantify the criticality of a still pending (i.e. open) call and thus a decision criterion to decide if it shall be produced on call or be delivered from buffer.
3. Determination of adequate input variables related to the mentioned decision criteria.

3. The concept of buffer planning and control

3.1 Functional logistic concept

Input variables:
- Delivered calls related to the day by means of call date.
- Calls, which are already received, but still to be produced by 3PL (open calls, actual backlog of production); related to the day by means of call date.
- Quantity of planned OEM-calls for each variant (call forecast) per date related to the actual day and the following days.
- Residual amount for each variant related to the actual working day, i.e. the difference between call forecast and delivered calls. Residual amounts at the end of a working day aren’t taken into account one day later. It is assumed that call forecast will be adjusted daily. If necessary, residual amounts related to the following working day must be added (see below).
- Fixed buffer capacity as total amount of modules. Identically equal to the amount of calls that must be delivered from buffer in case of a 3PL’s production breakdown, and also to the planning horizon of the target buffer configuration. See also figure 2 above.
- Classification of variants into fast mover (X-parts) and slow mover (Z-parts).
- Special value representing Z-parts’ planning horizon in working days.
- Threshold values representing the 3PL’s standard production backlog the 3PL’s maximum allowed production backlog, respectively. A backlog always exists because of the natural delay between call and 3PL production.
- Actual amount of a variant in buffer.
- Variant-dependent value representing the maximum storage duration.
- Variant-dependent tolerance parameter to express the allowed percentage difference between actual and target buffer stock of inventory. The absolute lower and upper tolerance values for each variant result from multiplying the tolerance parameter by target buffer stock. The lower tolerance value represents a range reduction that is accepted, if the target buffer configuration can’t actually be realized. Reversely, by the upper tolerance value one takes into consideration, that the call forecast remains uncertain. The following figure illustrates this aspect, given $x(V_j, t)$ as the target buffer amount.
of variant $V_j$ at the time $t$. and $TO(V_j, t)$ as the tolerance parameter of variant $V_j$ at the time $t$.

$$TO(V_j, t) \times x(V_j, t)$$

$$TO(V_j, t) \times x(V_j, t)$$

buffer stock of a variant

**Figure 3**: Illustration of tolerance values given the target buffer amount of a variant

Target buffer configuration: Dynamic and context-sensitive buildup to be prepared for a 3PL production breakdown at the time $t$.

The planning horizon is given by the amount of calls that should be deliverable from buffer to by-pass a production breakdown (long-term coverage)

The amount of open calls determines the known demand for buffer modules.

Calculation of residual amounts for each variant related to the actual day. If the buffer capacity exceeds the corresponding sum plus the amount of open calls, the following day’s forecast data are proportionally anticipated. By this, the uncertain demand for buffer modules is given. As a consequence, a pseudo call sequence must be determined to get a base to calculate the target buffer inventory. To simplify matters, we assume that the variants’ frequency of appearance correspond to its rate in the residual amount. That means, if a variant has a 50 percent rate in the residual amount, each second call in pseudo sequence is related to that variant.

Setup and reduction (use) of buffer inventory:

Setup of buffer corresponds to placing an order for modules that must be dispatched additionally to the OEM-JIS calls by the 3PL. If such an order is required, depends on the criticality of a variant and its difference between actual and target buffer amount. Planning a buffer order must take into consideration the actual production backlog, so that the short-term coverage is not subject to a risk. Concurrently, the order has also a priority to realize the long-term coverage. So, these aspects have to be traded off against each other.

Reduction of buffer corresponds to the delivery of a JIS-call from buffer. For one thing, this happens if the buffer inventory of a variant exceeds its target amount. This also becomes relevant, if the short-term coverage becomes critical because of a high backlog. At last, a module’s durability in stock might be restricted.

Elements to decide on the buffer inventory’s setup and reduction:

X-parts’ criticality of open calls is measured by production backlog. If the maximum allowed production backlog is exceeded, open calls are delivered from buffer till such time as standard backlog is reached, assumed a sufficient stock amount.

If the actual buffer amount of a variant exceeds the upper tolerance value, open calls are delivered from buffer, assumed that there are adequate JIS-calls.

How much a variant may put the OEM’s production at risk determines its criticality related to the buffer inventory. Given the corresponding buffer amount and the pseudo sequence, it becomes obvious, at which time the OEM’s production would be disrupted in case of a 3PL’s production breakdown.

If a variant’s buffer amount falls below the lower tolerance value, the difference must be balanced by dispatching buffer orders. At the same time the maximum allowed production backlog must be taken into consideration.

Special handling of slow movers: For Z-part variants the buffer amount of modules should be equal to the sum of known and forecasted calls. That corresponds to the 2-step JIS-concept and it is justifiable in this context because slow movers pose a special risk, when a 3PL production breakdown appears, shortly before a call on a Z-part is transmitted. The handling in more detail:

Z-parts’ planning horizon to determine target buffer amounts is extended to several working
days.

If \( k \) is the positive difference between the forecasted amount and the actual buffer inventory of a variant, a corresponding buffer order for \( k \) modules is dispatched directly. Tolerance parameter is set to 0. Corresponding buffer orders are dispatched with highest priority and should be realized independent from production backlog.
A JIS-call on a Z-part will always be delivered from buffer.

3.2 Mathematical Model

3.2.1 Problem type

The basic type of the problem considered in this work, corresponds to a non-deterministic and dynamic optimization problem (Hillier and Lieberman (2004)). The decisions mentioned above are made in stages with each receipt of a call. Additionally, decisions from early stages influence decisions in later stages. Depending on whether buffer modules were built, they can later be used for a JIS-call or to by-pass a production breakdown. Because the input changes with each call, the problem can also be characterized as online-optimization problem (Grötschel et al (2001)).

In this work, a heuristic, stepwise approach will be presented. In each stage, buffer setup resp. buffer use is planned, to come as close as possible to the target buffer configuration on the one hand and to ensure the short-term coverage on the other hand.

The situation is modeled as an integer linear problem (ILP). To solve a definite model, commercial solvers are available, such as IBM ILOG CPLEX Optimization Studio (IBM (2011)) or MOPS (Suhl (1994)). These are adequate for this work, given the mean amount of variables and restrictions. An empirical analysis was done in this work by means of the latter.

In case that there is no solution found in a given time, or, if there exists no feasible solution, a shift to a priority rule based approach is done which is derived from the ILP formulation.

3.2.2 Variables and declarations

- \( PUK \): Buffer capacity
- \( S_{Ti} \): \( i \)-th sequence call related to working day \( T \) (consecutively numbered day of the year); \( i \in \{1, \ldots, m\} \), \( T \in \mathbb{N} \). In general, \( T \) indicates the actual working day. Consequently, \( T-1 \) indicates the day before, \( T+1 \) the following day.
- \( t \): Point in time (day and time)
- \( V_j \): Variant ordered by OEM; \( j \in \{1, \ldots, n\} \)
- \( V(S_{Ti}) \): Variant ordered by call \( S_{Ti} \)
- \( s(S_{Ti}) \): Status of \( S_{Ti} \). Values: delivered, open.
- \( F(V_j, T) \): OEM\’s forecast related to working day \( T \) and variant \( V_j \)
- \( R(V_j, T) = F(V_j, T) - \left\lfloor V(S_{Ti}) = V_j ; s(S_{Ti}) = \text{`delivered'} \right\rfloor \): Residual amount related to working day \( T \) and variant \( V_j \)
- \( KL(V_j) \): Classification of variant \( V_j \). Values: X, Z
- \( PLHZ \): Planning horizon related to Z-parts, given in working days

\[
P(R(t) = \bigcup_{T} \{ S_{Ti} : s(S_{Ti}) = \text{`open'} \} \quad \text{Production backlog at time } t.
\]

\[
OA(V_j, t) = \bigcup_{T} \{ S_{Ti} : V(S_{Ti}) = V_j ; s(S_{Ti}) = \text{`open'} \} \quad \text{Amount of open calls (production backlog) related to the variant}
\]

- \( PRR_{\text{max}} \): Maximum allowed production backlog
- \( PRR_{\text{norm}} \): Standard production backlog
- \( TO(V_j) \): Tolerance parameter of variant \( V_j \). Domain \([0, 1]\)
- \( KR(V_j) \): Criticality of \( V_j \) related to its amount in buffer inventory (long-term coverage). Domain \([0, 1]\).

x(Vⱼ, t): Target buffer amount of variant Vⱼ at the time t, according to calculation of target buffer configuration at the time t.

Ist(Vⱼ, t): Actual buffer amount of variant Vⱼ at the time t. Measures to build up or use the buffer that are started but not finished yet, must be taken into account

MHD(Vⱼ, t): Buffer amount of variant Vⱼ at the time t with exceeded maximum duration of storage.

y(Vⱼ, t): Buildup amount of variant Vⱼ, planned by the system at the time t in order to build up the buffer. Domain: N

y(Vⱼ, t): Reduction amount of variant Vⱼ, planned by the system at the time t in order to reduce the buffer. Domain: N

3.2.3 Derivation of target buffer configuration

Calculation of target buffer amounts

The amount of each variant is calculated by a percentage share of the buffer capacity.

The percentage share A(Vⱼ) of a variant Vⱼ in the buffer shall correspond to the variant’s percentage related to the residual amount of the actual day and if necessary of the following day. PLH spans one shift and thus less than a daily production.

If \( \sum_{j=1}^{n} R(V_j,T) \geq PUK \), then: \( A(V_j) = \frac{R(V_j,T)}{\sum_{j=1}^{n} R(V_j,T)} \)

Else: \( A(V_j) = \frac{\sum_{j=1}^{n} R(V_j,T)}{PUK} \cdot \frac{R(V_j,T)}{\sum_{j=1}^{n} R(V_j,T)} + \left( \frac{\sum_{j=1}^{n} R(V_j,T)}{PUK} \cdot F(V_j,T+1) \right) \left( \frac{1}{\sum_{j=1}^{n} F(V_j,T+1)} \right) \)

With this, we calculate: \( x(V_j,t) = \left( \left\lfloor A(V_j) \cdot PUK \right\rfloor \right) \)

Because the values for \( x(V_j,t) \) of Z-parts are calculated in a different manner (given as absolute values, see below), it is possible, that one has \( \sum_{j=1}^{n} x(V_j,t) \geq PUK \). Then, the X-parts’ amounts are reduced stepwise by one, starting with the variant with maximum \( A(V_j) \).

If, on the other hand, \( \sum_{j=1}^{n} x(V_j,t) < PUK \), the X-parts’ amounts are increased stepwise by one, starting with the variant with maximum \( A(V_j) \).

Determination of the pseudo sequence (PS)

Given: \( A(V_j) \)-values for each variant.

Initialization: Set \( PS[1]=V_j \) for \( V_j \) with highest \( A(V_j) \)-value for all \( j \)

Iterations: For \( i=1 \) to \( PLH - 1 \) do

Calculate percentage shares in \( PS \) by: \( AS(V_j) = \frac{\text{#Positions in } PS \text{ with value } V_j}{i} \) for all \( j \)

Select \( V_j \) with \( \max_j \{A(V_j) - AS(V_j)\} \)

Set dimension of \( PS \) to \( i+1 \) and set \( PS[i+1] = V_j \).

If there are \( r \) open calls, the first \( r \) positions of \( PS \) are set to the corresponding values and iterations start with \( i = r+1 \).

Calculation of criticalities based on the pseudo sequence

We have \( PS \) and the actual buffer amounts \( Ist(V_j, t) \).

We calculate the amount of positions with value \( V_j \) in \( PS \) for each \( V_j \).
Is it less than $Ist(V_j, t)$, so we set $KR(V_j)=0$.

Else, we search for the position (index) in $PS$, which has no backup given the actual buffer amount (denoted a “problem position”) and we have

$$KR(V_j) = 1 - \frac{\text{problem position of } V_j \text{ in } PS}{\text{PLH}}$$

I. e., the sooner the problem position of $V_j$ appears, the higher is its criticality.

### Special handling of Z-parts

$$KR(V_j) = 1 \quad \forall j \quad \text{with } KL(V_j) = Z$$

$$x(V_j, t) = R(V_j, T) + \sum_{l=1}^{PLHZ} F(V_j, T + l)$$

(with extension of planning horizon)

### 3.2.4 Formulation of optimization model

#### Decision variables

The central decision in $t$ concerns, which amounts of each variant with a detected actual-target buffer-difference should be built up or decreased, or even must be decreased given the actual values of $MHD(V_j, t)$ and $PRR(t)$.

With $y^u(V_j, t)$ and $y^d(V_j, t)$ we denote the corresponding amounts to reduce the given difference.

#### Objective values and resulting objective function

Objective value “by-pass a production breakdown” (long-term coverage): It is measured by the difference between $x(V_j, t)$ and $Ist(V_j, t)$, which must be minimized, anticipating actual values of $y^u(V_j, t)$ and $y^d(V_j, t)$. Ideally, there is no difference for each variant. Given the model restrictions (see below for more details), this seems to be unlikely. Thus, there must be a trade-off between the variants, whereby more critical variants should receive preferential treatment. To evaluate the objective value, we build the sum of difference values for each variant, with each summand weighted by the variant’s criticality. So, we get:

$$\sum_{j=1}^{n} KR(V_j) \cdot \left[ x(V_j, t) - \left( Ist(V_j, t) + y^u(V_j, t) - y^d(V_j, t) \right) \right]$$

Objective value “production coverage” during standard operation (short-term coverage): The $PRR(t)$–value should be minimized, which is taken into consideration by means of two model elements:

$PRR(t)$–value considered in terms of an objective value: Each order to build up the buffer needs a part of the production capacity. I. e. with each buffer order, the delivery of JIS-orders is retarded. So, given a buffer buildup planning and assumed that there are no external influences on the $PRR(t)$–value, there is a JIS-call, which is handled after the buffer orders, resulting in a production backlog increased by

$$\sum_{j=1}^{n} y^u(V_j, t) - y^d(V_j, t) .$$

So, we have to minimize $PRR(t) + \sum_{j=1}^{n} y^u(V_j, t) - y^d(V_j, t)$. Of course, orders to build up and to decrease the buffer neutralize each other. In the operative implementation these order types should be adequately mixed, so that $PRR(t)$ doesn’t exceed the value assumed in this context

$PRR(t)$–value considered in terms of restriction: Additionally, we aim at a minimum realization of the objective value. This leads to (R3) in the restriction system mentioned below.

Objective function: Both objective values enter the objective function. They are linearly connected with different weights $c_k$. So, a lower value in the short-term coverage can be compensated by a higher value related to the long-term coverage and vice versa. $PRR(t)$ is just a constant value related to the objective value „production coverage“. So it is not explicitly considered in the objective function.
MIN \( c_1 \cdot \sum_{j=1}^{n} KR(V_j) \cdot (x(V_j,t) - \left( Ist(V_j,t) + y^u(V_j,t) - y^d(V_j,t) \right)) \) + \( c_2 \cdot \sum_{j=1}^{n} y^u(V_j,t) - y^d(V_j,t) \)

Restrictions

The new amount of a variant in buffer should not come below the lower tolerance value and should not exceed the upper tolerance value:

(R1) **Lower tolerance value rule:**
\[ Ist(V_j,t) + y^u(V_j,t) - y^d(V_j,t) \geq x(V_j,t) - x(V_j,t) \cdot TO(V_j) \quad \forall j \]

(R2) **Upper tolerance value rule:**
\[ Ist(V_j,t) + y^u(V_j,t) - y^d(V_j,t) \leq x(V_j,t) + x(V_j,t) \cdot TO(V_j) \quad \forall j \]

For Z-parts one has \( TO(V_i) = 0 \). So, both restrictions are reduced to \( Ist(V_i,t) + y^u(V_i,t) - y^d(V_i,t) = x(V_i,t) \). This becomes substantially clear together with restriction (R8), formulated below. So, the values of \( y^u(V_i,t) \) and \( y^d(V_i,t) \) are given deterministically.

**PRR(t)-value as restriction:**
\[ (R3) \quad PRR(t) + \sum_{j=1}^{n} y^u(V_j,t) - \sum_{j=1}^{n} y^d(V_j,t) \leq PRR_{max} \]

If \( PRR_{max} \) is exceeded, there must be more orders to decrease the buffer than buffer buildup orders (criticality of the short-term coverage must be reduced):

\[ (R4) \quad \sum_{j=1}^{n} y^d(V_j,t) - y^u(V_j,t) \geq \min \left\{ \sum_{j=1}^{n} OA(V_j), PRR(t) - PRR_{norm} \right\}, \text{if} \ PRR(t) \geq PRR_{max} \]

Sum of actual buffer amounts plus buildup orders and minus reduction orders must not exceed \( PUK \):

\[ (R5) \quad \sum_{j=1}^{n} Ist(V_j,t) + y^u(V_j,t) - y^d(V_j,t) \leq PUK. \]

Given an initialized buffer, this restriction implies that the amounts to increase and decrease the buffer should be balanced.

Buffer modules that exceed the maximum duration of storage must be used as JIS-calls as soon as possible:

\[ (R6) \quad y^d(V_j,t) \geq \min \left\{ OA(V_j,t), MHD(V_j,t) \right\} \quad \forall V_j \]

For each variant, the reduction orders are restricted by suitable open calls:

\[ (R7) \quad y^d(V_j,t) \leq OA(V_j,t) \quad \forall j \]

The buffer reduction of Z-parts must take place with each JIS-call (substitution of (R6) and (R7) for Z-parts):

\[ (R8) \quad y^d(V_j,t) = OA(V_j,t) \quad \forall j \text{ with } KL(V_j) = Z \]

Technically induced restrictions: The absolute value \( x(V_j,t) - Ist(V_j,t) + y^u(V_j,t) - y^d(V_j,t) \) integrated in the objective function is substituted by an artificial variable \( z(V_j,t) \) and the restrictions are extended as follows (Grant and Boyd (2008)):

\[ (R9) \quad z(V_j,t) \geq x(V_j,t) - Ist(V_j,t) + y^u(V_j,t) - y^d(V_j,t) \quad \forall j \]

\[ (R10) \quad z(V_j,t) \geq -x(V_j,t) + Ist(V_j,t) + y^u(V_j,t) - y^d(V_j,t) \quad \forall j \]

Remark: Both variables \( y^u(V_j,t) \) and \( y^d(V_j,t) \) may have a positive value, e. g. when the buffer amount has to be increased, and simultaneously some modules exceed the maximum duration of storage.
4. Implementation und consequences

4.1 Details of implementation

4.1.1 Model elements in ILP-implementation

Restriction (R6) is implemented as “lower bound” for the variables \( y^d(V_j, t) \).

Restriction (R7) is implemented as “upper bound” for the variables \( y^d(V_j, t) \).

Especially restriction (R7) ensures, that \( y^d(V_j, t) \) are constrained. So, there are no arbitrarily high values, which would clearly improve the value of the objective function. On the other hand, it influences the satisfaction of (R1) and (R2), so that an excess stock can’t be reduced as stated, despite the slowdown induced by the tolerance parameter. If there is no buildup order and there are no sufficient open calls available to satisfy the limit given by (R2), we adapt \( TO(V_j) \), so that a corresponding reduction is possible given the available open calls. For variants with \( Ist(V_j, t) > x(V_j, t) \) we set: \( Ist(V_j, t) + y^u(V_j, t) - y^d(V_j, t) \leq x(V_j, t) + x(V_j, t) \cdot TO(V_j) \) ⇒

\[
\frac{Ist(V_j, t) - OA(V_j, t) - x(V_j, t)}{x(V_j, t)} \leq TO(V_j)
\]

(R3) and (R4) are especially interdependent to the restrictions (R1), (R2), (R6), (R7). Here we potentially need an adaption of the right hand side (and therewith a softening of the short-term coverage. Alternatively, an adaption of the right hand sides in (R1), (R2) is possible.

The same holds true for (R5), especially, if buffer is already built up completely. Analogously, we could adapt the right hand sides of (R1) and (R2), if required. Alternatively, we can permit a temporary increase of \( PUK \).

4.1.2 Heuristic model version

As an alternative to the adaption of right hand sides in the model restrictions, a problem relaxation is presented. For this purpose, priority rules are introduced, which determine the values of the decision variables, based on the ILP’s objective function and restrictions.

Determinations of target buffer configuration, pseudo sequence, and criticalities are maintained.

We apply the rules in a chronological order, which implies a ranking of the objective values in the general model.

Firstly, we focus on the Z-parts. After this, we take measures concerning the short-term coverage, and then concerning the long-term coverage.

The rules are applied in the following order:

1. Determination of z-parts’ values for \( y^u(V_j, t) \) and \( y^d(V_j, t) \), by applying of (R1), (R2), and (R8), that are deterministically given in this case.
2. Application of (R6) to consider the modules’ durability adequately.
3. Corresponding to (R4), we update \( y^d(V_j, t) \) in increasing order of \( KR(V_j) \)-values, considering (R2), and succeeding (R1), as far as possible.
4. In decreasing order of \( KR(V_j) \)-values, we set – if necessary – \( y^u(V_j, t) \), so that (R1) is met, or we set – if necessary – \( y^d(V_j, t) \), so that (R2) is met. In the latter case, we also consider (R7).

We adapt the order in a manner, that after the determination of a buildup-order, we search for variants with reduction orders (with respect to (R7)) as long as the buildup and reduction amounts are balanced. By this, we take into consideration (R3) and (R5) as far as possible.

Quantities set in steps 1 – 3 must be included. If there are not enough reduction orders, buildup orders are just set in that volume, that (R3) and (R5) are satisfied.

5. As far as capacity is left, we can repeat step 3, then focusing on the target value or even the upper tolerance value.
4.1.3 Recommendations to the operative implementation
Calculation of buffer orders shouldn’t be done after each JIS-call, but after receipt of a set of JIS-calls, to be able to detect a trend.
With each planning, measures that are not yet realized will be replaced.
Measures, that were started, are matched to the measures of the new planning.
If there are no forecast data, no buffer planning will be done. Then, we focus only on the short-term coverage.
After the by-pass of a production breakdown, modules that are still in production are connected to open calls or to buffer orders and are finished as such.

4.2 Evaluation and outlook
The mathematical model presented in this work shows in each step the ideal configuration of the safety buffer and derives decisions on the change of the actual buffer amounts. This is based on the concurrent objectives of long-term and short-term coverage and specific restrictions and conditions.
The corresponding integer linear model normally contains about 100 variables. The amount of restrictions results from a factor applied to the amount of variables. Models of this size can be handled by commercial solvers. If not, or if there is no feasible solution, a heuristic approach based on priority rules was also presented. There is no evaluation of the approximation quality related to a theoretical optimum. But it is substantially obvious, that the given objectives with respect to the conditions are adequately taken into consideration.
So, the model describes a useful decision support to the self-dependent and demand-oriented organization of buffers on the 3PLs’ side. The model evaluation was successfully done by means of selected scenarios.
Future work is planned in the following areas:
Alternatives to the deduction of pseudo-sequence (e. g. empirical assessment of the variant’s distribution related to a working day) and performance measurement
Integration of sequence-oriented forecast data (e. g. end of paint-job) into the pseudo-sequence.
Simulation of the model based on real data including the use of buffer buildup and decrease.
Dynamic determination of objective function’s weight parameters $c_1$ und $c_2$ (e. g. increase of $c_2$ for the short-term coverage the closer $PRR(t)$ comes to $PRR_{max}$).
Anticipation of future calls to improve the possibility to adequately adapt the buffer configuration, also in case of a low $PRR(t)$-value.
Time-shared combination of integrated JIS-concept and 2-step JIS-concept.

5. References


