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Auditory Logistic Analysis in Production Planning and Control

103 - Recent Advances in Multimedia Processing, Organization and Visualization beyond Domains and Disciplines

Abstract

Whereas methods for visualization of time-based data have become widely accepted in the fields of data analysis and human computer interaction, analogous approaches in the field of data sonification remain marginally recognized at best. However, sound is intrinsically tied to space and time, which makes it strongly eligible for conveying information based on multivariate time-based data, such as planning and feedback data of manufacturing processes. We propose a sonification model for Auditory Logistic Analysis (ALA) that is derived from the throughput element of the Bottleneck Oriented Logistic Analysis and allows for the displaying of data from several logistic perspectives, which we will apply on two example data sets from a circuit board manufactory and steel production.

Keywords:

manufacturing, logistic analysis, bottleneck identification, data sonification, auditory display, time series, explorative data analysis

1. Introduction

Customers' demand for highly individualized high quality products with short life cycles to be delivered as quickly as possible has brought new challenges to enterprises on a now global market. More than ever before, the efficiency of the logistic performance has become an essential aspect with regards to the economic success of a company. The new challenges surface with an increasing degree of complexity (Windt et al. 2008) for Production Planning and Control (PPC), demanding new methods for logistic analyses. One of these new approaches is the Auditory Logistic Analysis (ALA), which, although still at in its rudimentary state, has provided promising results in two case studies on industrial data sets (circuit board manufactory and steel production). We present two examples in this article.

1.1 Sonification of time-based data

"The best pattern recognition system that we know of is our auditory system". (Bruce Walker according to Feder 2012). The human auditory system is capable of distinguishing between several simultaneous layers or streams of acoustic information. Complex acoustic scenarios can be heard either integrated for example by perceiving the sound of an orchestra as a chord, or else segregated into discrete sounds of individual instruments (Bregman 1994). From an evolutionary perspective,

perception of sound is tied to warning and alarming functions. Therefore the auditory system is particularly sensitive to acoustic changes in the environment (Carlile 2011). In contrast to the human visual system, it allows omnidirectional perception and cannot be switched off. It works complementary to visual perception, "*compensating for deficits in the other's repertoire of localization abilities"* (Neuhoff 2011). While methods for data visualization have become widely accepted in the fields of data analysis and human computer interaction (Aigner et al. 2011; Wainer 2005), analogous approaches in the field of data sonification remain marginally recognized. Sonification is *"the transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation"* (Kramer et. al. 1999). Since an acoustic signal is intrinsically tied to space and time, sonification is an excellent candidate for conveying information based on multivariate time-based data.

1.2 Data analysis in manufacturing

In traditional production, and particularly in the field of job shop manufacturing, the application of conventional statistical methods for the analysis of manufacturing data as a basis for the derivation and implementation of measures, has led to formidable improvements concerning the achievements of the pursued logistic objectives, such as high schedule adherences, low throughput times, low work in process (i.e. inventories), and high utilizations. In order to reduce complexity[1], these traditional approaches generally rely on extremely simplified models, mostly based on averaging that neglect the less significant features and "*signify [...] vital features"* (Nyhuis / Wiendahl 2009). In that process, work systems that most evidently contribute as bottlenecks[2] to the production workflow are identified and appropriate measures are applied. The main levers for adjusting scheduling in production are adjustments of capacities (e.g. number of machines at work systems, number of shifts) and lot sizes, as well as the application of sequencing rules, e.g. the prioritization of specific order processing in work systems that have been identified as bottlenecks (Lödding 2008). Despite its undisputed potential for the improvement of logistic performance, by focusing on the optimization of single (or small groups of interconnected) work systems, these approaches stand rather static and bear only rudimentary capability of identifying dynamic and interdependent fluctuations causing bottlenecks within the overall workflow of the shop floor. Such fluctuations concern, for example, the impact of changes in sequencing rules as well as the impact of the processing of specific product types and processing restrictions. Particularly the continuously increasing demand for highly individualized products in the context of Internet 4.0 (Schlick et al. 2014) and the lot size 1 paradigm (Baum 2013) require new methods for the analysis of dynamics in production workflows (Wiendahl / Worbs 2003) at a higher level of detail.

Therefore recent approaches on the analysis of manufacturing data include more and more advanced statistical methods, such as Knowledge Discovery in Databases (KDD) (Choudhary et al. 2008;

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[1] grade of complexity = number of interconnections / number of elements (Krallmann / Frank 2002)

[2] defined as the difference between planning and actual production (Windt 2001)

Hülsmann / Windt 2007; Windt / Hütt 2011; Windt et al. 2011). These approaches take comprehensive parameter sets of order and operation-related attributes into acount. The recursive and exploratory procedures of KDD include the selection, pre-processing, and transformation of data in order to apply data mining (e.g. pattern recognition or cluster analysis) for evaluation and interpretation. A strong relationship exists between the proceedings of KDD and routines in data sonification (Hermann 2002; Grond et al. 2010), where data is also conditioned and transformed by mapping data parameters to sound parameters. Data sonification is particularly (but not exclusively) suitable for the analysis of chronological events, such as the numerous sequential and simultaneous processes in manufacturing (Iber / Windt 2012; Iber et al. 2012; Iber 2014).

2. Data sonification for the analysis of manufacturing data

Human auditory perception is not only capable of differentiating between spectral characteristics of sound (e.g. pitch, color, harmonicity, …) in their temporal evolution on a high resolution level, but also of localizing the position of a sound in space at a 360° angle on the horizontal plane and to a more limited degree, also on the vertical axis. A conductor of an orchestra should be able to pick out the violinist who played the wrong note by his or her position out of a group of 30 or more string players. From this image of an orchestra, it is only a small step to envision the work systems of a shop floor contributing their data flows to a complex soundscape, where each work system can be localized by the virtual position of the generated sound (Figure 1). While performing the data, the original time is extremely compressed. Depending on the data structure, an evaluation period of 250 days can be compressed on the auditory display to less than one minute of sound.

Apart from the mentioned spatio-temporal attributes, sound has a further quality that predestines it for an application in logistic analysis. Models in logistic analysis distinguish between discrete event and dynamic continuous flow perspectives (Scholz-Reiter et al. 2008), which can also be regarded from a network perspective, cf. Figure 1 (Gudehus / Kotzab). Sound is able to represent both perspectives simultaneously: a periodic sound signal can be considered as the sum of e.g. sinusoids representing the continuous flow perspective, whereas, from a musical perspective, the same sound may be regarded as a sequence of discrete events.

2.1 Throughput element as basis for sonification model

For the development of Auditory Logistic Analysis (ALA) (Iber 2014), we elaborated on a methodical transfer from logistic to sonic parameters in order to investigate the potential of data sonification for the identification of bottlenecks in a production workflow, also with regards to the impact of cross-system dynamics and interdependencies. The developed sonification model is based on the throughput element (Figure 2) of the Bottleneck Oriented Logistic Analysis (BOLA) (Nyhuis / Wiendahl, 2009).

The throughput element describes one discrete operation of an order at a specific work system within its complete processing workflow (consisting of several sequential operations at several work systems). The (horizontal) time axis features two main sections: the interoperation time comprising the time span between the end of the previous process and the start of the actual processing, and the operation time, which includes the work system setup for the operation and the actual processing. The vertical axis of the throughput element indicates the work content of an operation, which is a planning measure used for the scheduling of operations. It is based on the processing time per piece, the number of pieces to be processed, and the time needed for setting up the work system. In an ideal system, the work content of an operation should be equal to the actual operation time (Iber 2014).

In the flow oriented BOLA (Nyhuis / Wiendahl, 2009), the throughput element is the common intersection between an order-oriented perspective, which entails parameters that are relevant for measuring logistic performance (throughput time, schedule adherence), and a resource-oriented perspective which entails parameters that are relevant for measuring logistic costs (utilization, work in process, i.e. inventory). Within a flow diagram depicting the workflow of operations, the resources themselves are modeled as funnels, describing the in- and output situations as well as the maximal capacities of the work systems (c.f. also network scheme in Figure 1). For the identification of throughput time related bottlenecks that endanger the schedule adherence of orders, BOLA analyses the work in process (inventory) and mean throughput times of every work system over a steady state evaluation period.

2.2. Sonification of logistic perspectives

A sonification of these parameters, mapping data values to sinusoidal frequencies where each work system is represented by a discrete audio signal and a spatially arranged loudspeaker[3], provides additional information by the indication of seasonal fluctuations and their sequential impact on succeeding work systems over several work systems and entire shop floors (Figure 3).

While sonifications of the resource-oriented perspective (i.e. work system) use statistically calculated data (average, standard deviation, accumulation, …) providing information about the state of the work systems, sonifications of the order-oriented perspective display every operation discretely compound to complex sounds, which give, for example, evidence about the sequence of orders and at the same time about the state of the work systems. To give an example, in order to analyze the impact of the processing of a specific product group on the overall process workflow, the throughput time of all operations were discretely sonified. Hence, data values were mapped twofold: first on the time axis represented by the duration of the created sinusoid, and second, by a frequency corresponding to the underlying data value. With this mapping, the throughput characteristics of one product group that contributed 23% to the workload of the analyzed work systems ("inner layers") could be clearly distinguished from the overall workflow as well as from the other product groups (Figure 4a). A further parameter mapping in which a fixed frequency ID was assigned to each incoming order, revealed that the "inner layers" product group was presumably prioritized towards the rest of the operations (Figure 4b).

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[3] if there are more work systems than loudspeakers in the setup, virtual sound sources have to be used instead

2.3 Synchronous view

Although sonification of time-based data is predestinated to display parameter values with respect to time, “synchronous view” as an alternative option gives evidence of the complete workflow of an order as a compound sound, so to speak as a characteristic “fingerprint”. This synchronous view supplements the above mentioned order and resource-oriented perspectives by mapping the values of a parameter (e.g. throughput time) of all operations to a spatially distributed sound. By the application of this method to a data set from steel production, characteristic distributions of throughput times could be categorized. Upon further analyses, we could attribute causes, at least for some of the extensive throughput times, to re-allocations of discretely produced material pieces of orders to other orders (Iber / Windt 2012; Iber 2014).

3. Critical discussion and future perspectives

For the Auditory Logistic Analysis (ALA) as a supplement to existing logistic analysis approaches, a set of novel methods has been developed that allow the identification of bottlenecks in manufacturing workflows. ALA can be fully integrated in the methodical proceedings of the Bottleneck Oriented Logistic Analysis (BOLA) (Figure 5). Although functional, the state of these methods, some of which have been introduced in this article, is rather basic and hence needs further refinement. At present, the application of ALA is rather cumbersome. The acoustic information should be more self-explanatory and usable with a clearly lower amount of expert training. One step in this direction might be substituting the compound sinusoidal sounds by instrumental or environmental samples (cf. Hermann 2015). The advantage of such an approach is that it will be easier to distinguish sound sources from each other. The drawback is that is becomes more difficult to balance values among each other in order to be comparable. Since the spatial distribution of sound is an essential attribute of ALA, at least at present, the method is limited to laboratory settings with multi-loudspeaker setups. It will be subject to further experiments to test how far binaural headphone spatializations, combined with head tracking technologies are also suitable in this context.

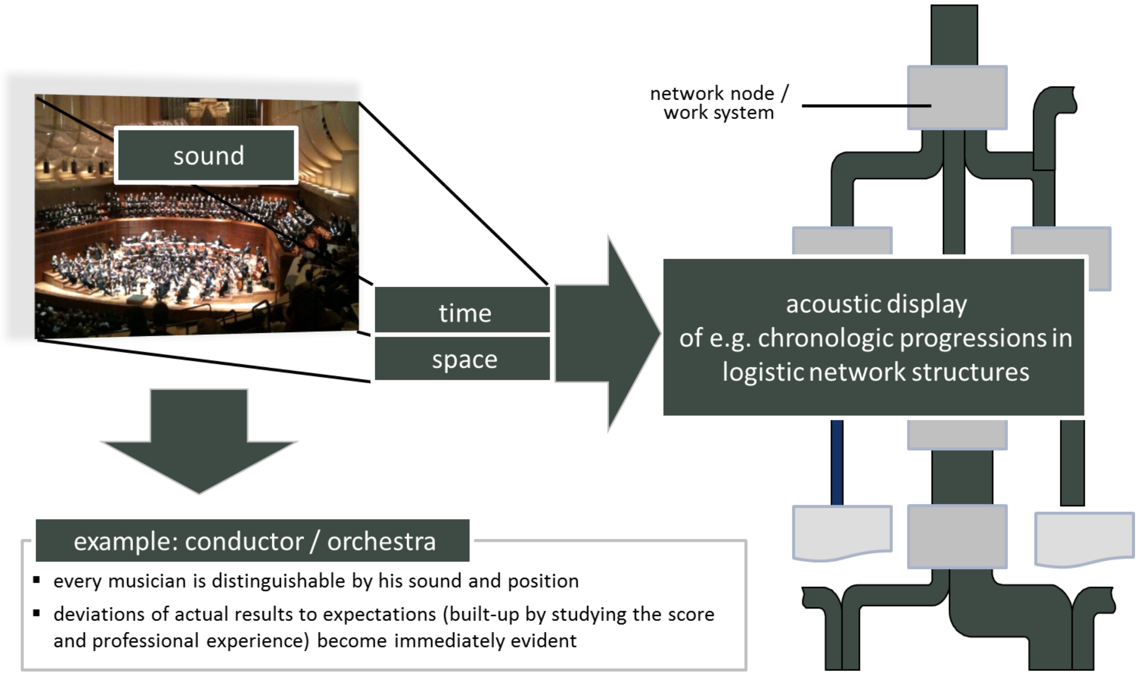


Figure 1: Temporal and spatial coherencies between sound and manufacturing networks (Iber 2014).

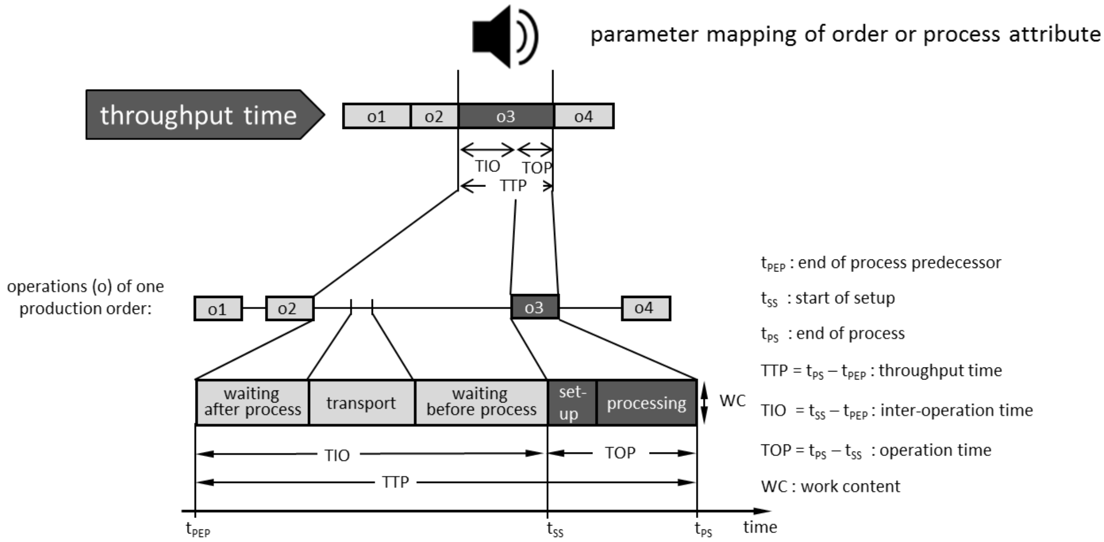
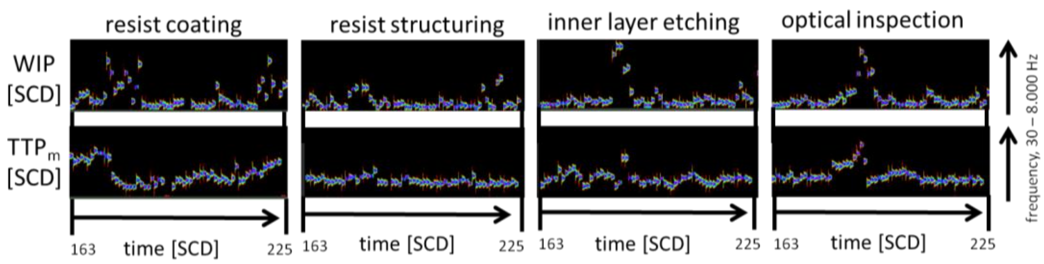


Figure 2: Sonification of throughput element (adapted from Iber et al., 2012)

Throughput element adapted from Bechte (1984); Nyhuis & Wiendahl (2009).



WIP: work in process (inventory), TTP_m: mean throughput time, SCD: shop calender days

Figure 3: Sonifications (spectrograms) of work in process (WIP) and mean throughput times at four succeeding work systems of a circuit board production (Iber 2014).

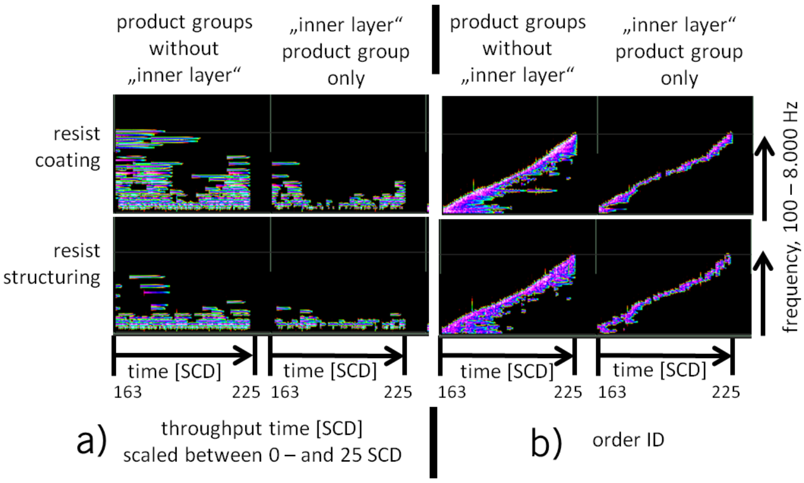


Figure 4: a) Sonification of throughput time mapped as frequency and duration of sinusoidal sound, b) a fixed frequency is ascendingly assigned to each incoming order, serving as order ID. The throughput time is again mapped to the sound duration. Thus the long-lasting frequencies indicate changes of order sequences, in this case for the prioritization of orders of the “inner layer” product group.

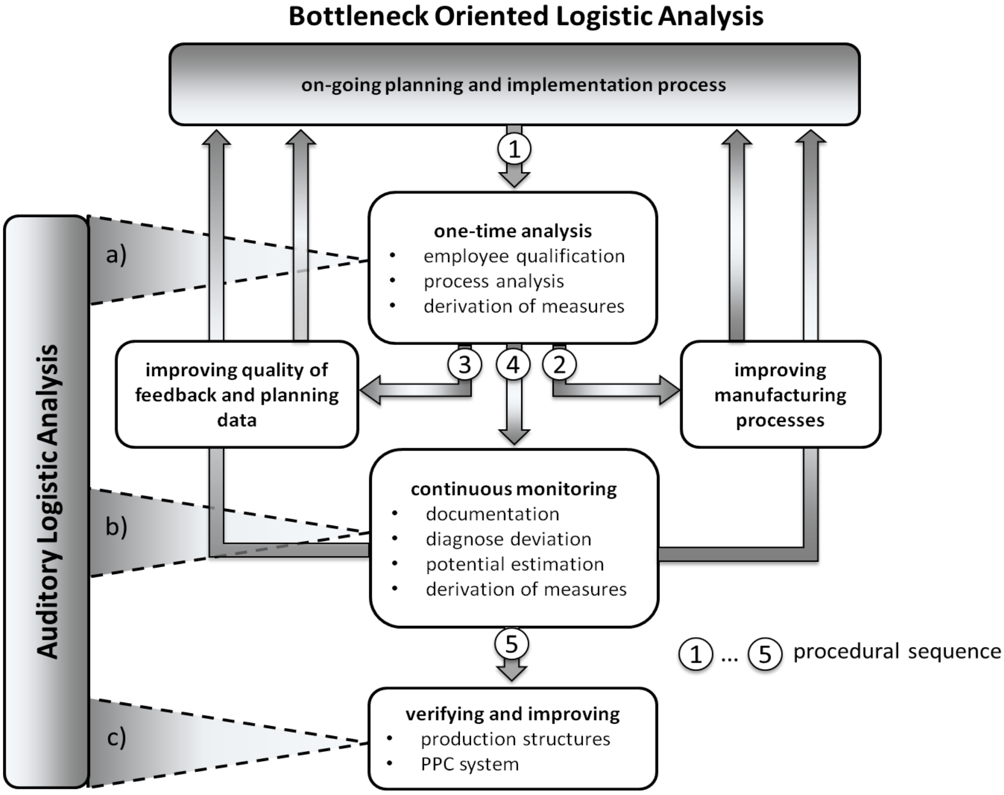


Figure 5: Intersections for the integration of ALA into the proceeding model of BOLA (Iber 2014, adapted from Nyhuis / Wiendahl 2009).

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