TIMELINE-BASED NETWORK ANALYSIS OF A PUBLICATION SAMPLE RELATED TO PACKAGING VIBRATION TESTING

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Abstract

Records of search queries can often be exported from scientific databases, most of them contain the record of citations, as well. However, it is ineffective to register the citation relationships among publications manually, so the reader might lean on the number of citations when looking for leading publications. One can be interested in trend-setting publications or the primary columns of the discipline in terms of publications. Beneath the conventional literature reviews, helpful solutions are available to assist the reader in similar questions. Network visualizations in bibliographic analyses have long-established practices, offering appealing tools to visualize complex connection systems constituted by different bibliometric couplings. The current paper investigates the direct citation network of a sample drawn from the Web of Science scientific database in the relation of a particular research field concerning road induced vibrations from a packaging testing perspective. The sample consists of 46 publications embracing 28 years as of date. Core publications are identified first, supplemented by qualitative contextual reviews, followed by main path analysis. The assays attempt to estimate the main research topics of the investigated discipline by the given sample.

Key words: Direct citation network, Timeline-based network, Main path analysis, Road vehicle vibration, Packaging vibration testing

1. INTRODUCTION

The aim of the current paper is twofold. Firstly, new methods of literature screening processes are introduced in the form of timeline-based network analysis of bibliographic samples regardless of the topic investigated. For demonstration purposes, an individual sample had been drawn related to packaging vibration testing. The qualitative introduction of core publications and the highlights of underlying approaches from several periods of the discipline are presented. The set of publications is further synthesized via *main path analysis*, a tool to estimate the backbone of a bibliographic sample. For the current paper, individual selection of publications is not utilized; instead, the results from a search query are analyzed.

Therefore, it offers a new kind of estimate regarding *state-of-the-art* of the discipline. Other reviews from within the sample have worked with a higher number of publications.

Goods forwarded by road vehicles are subjected to road induced vibrations. The packaging is applied to those goods to withstand the dynamic loads during transportation. The vibration testing of units, pallets, or other devices under testing (DUT) is a common procedure for packaging testing purposes. A widely used measure to assess the vibration circumstances is the Power Spectral Density (PSD), which can be obtained by the measurement and analysis of road vehicle vibrations (RVV). By shaker testing, a Gaussian signal can be generated from the PSD, but real-world RVV tends to have a non-Gaussian and non-stationary nature over time. Addressing this limitation, different simulation methods evolved, which often encompass unique techniques for the segmentation of RVVs.

The analysis of bibliometric networks gained increasing attention since the early days (van Eck & Waltman, 2014b), and graph illustrations offer appealing solutions for the description and illustration of such systems. Network visualizations are frequent modeling techniques of real-world phenomena or abstract concepts in different fields of interest, such as social sciences, bioinformatics, or the semantic web, just to name a few. As the number of publications increases, they are continuously broadening the state-of-the-art, and more complex bibliometric systems can be obtained needing advanced visualization techniques.

Commonly studied bibliometric relations are co-authorship, co-occurrence-, and citation relations. The latter can be further divided into direct citation -, co-citation-, and bibliographic coupling relations (van Eck & Waltman, 2014a). Co-authorship relations are links among researchers, research institutions, or countries based on the number of jointly authored publications. Keyword co-occurrence is based on the number of documents in which both keywords occur together either in title, abstract, or keyword fields. *Two publications are co-cited if there is a third publication that cites both publications* (van Eck & Waltman, 2014b), which might be interpreted between publications, researchers, or journals. On the contrary to co-citation, *two publications are bibliographically coupled if there is a third publication that is cited by both publications (ibid)* simply speaking, bibliographic coupling describes the overlap in the reference lists of publications. *Direct citation, where articles are linked if one references another, only considers links from within the set* (Boyack & Klavans, 2010).

Different methods are available for visualizing bibliographic networks; three of them are highlighted in (van Eck & Waltman, 2014b). In a distance-based approach, the distance between two nodes approximately indicates the relatedness of the nodes. In the graph-based procedures, the displayed edges indicate the relatedness of nodes. Timeline-based methods make use of publication dates using a dimension representing time, another dimension representing relatedness. In the timeline-based visualization of CitNetExplorer (van Eck & Waltman, 2014a), the vertical dimension is used to represent time, and the horizontal dimension indicates the relatedness of publications. Beneath the direct citation relations, different types of indirect citation relations (*e.g.* co-citation and bibliographic coupling relations) are also considered by the horizontal positioning. (van Eck & Waltman, 2014b)

Another method of citation analysis was proposed by Hummon & Dereian (1989), which technique also explicitly focuses on the flow of time, and it is called *main path analysis* (Nooy *et al.*, 2005). *Pajek* (Batagelj & Mrvar, 2020) software offers network analysis methods providing graph-based visualization, and clustering and main path analysis are also available for bibliometric network analysis (van Eck & Waltman, 2014b). Nooy *et al.* (2005, p.245) explain the idea, that *if knowledge flows through citations, a citation that is needed in paths between many articles is more crucial than a citation that is hardly needed for linking articles*. The main path analysis calculates the extent to which a particular citation or article is needed for linking articles, which is called the traversal count or traversal weight of a citation or article *(ibid)* to find the backbone of a research discipline.

2. METHODS

A sample consisting of 46 documents is drawn from the Web of Science (Clarivate Analytics ©, 2020) scientific database among the *Core collection* on March 15th, 2020, with the term-constellation:

" packag AND vibration AND road AND (simulat* OR test*)"*

applied among the *topic* field. The resulted list of publications is exported in *.txt* format, with the *full record and cited references* metadata. The CitNetExplorer (1.0.0) is used for direct citation analysis, which can use either external[1] or internal citation scores. Internal citation scores -used herein- indicate the number of citations of a publication within the citation network being analyzed, the initial results are presented in Fig 1.a). 26 records were identified as core publications by CitNetExplorer, and those are *drilled down* in Fig. 1.b). Only stand-alone nodes are not considered as core publications in this context. *A core publication is a publication that has at least a certain minimum number of citation relations with other core publications*, where *the identification of core publications is based on the idea of k-cores* (van Eck & Waltman, 2014b). In the current article, the minimum number of citation relations is set to one, resulted in 26 core publications. Reviews presented in the discussion are broken down into periods, describing core publications by the goal of the research, the applied methodologies, and a highlighted finding. The discussion introduces the publications in the following standard manner:
(In line citation) studied the [object or subject of research], via [methodology of research], in order to [goal of research], and concluded *i.a.* [a highlighted finding].

Possible alternative formulations are applied, whereas found necessary to describe better the actual context. The above formulation admittedly cannot represent a record in its full spectrum, and a discussion might supplement it reflecting on research trends.

[1] External citation scores indicate the total number of citations of a publication. Citations from all publications in a bibliographic database (e.g. Web of Science) are counted, including citations from publications outside the citation network being analysed van Eck & Waltman, (2014a).

The source of derived samples is limited to the Web of Science in the case of CitNetExplorer. A list of records also from all databases in Web of Science can be exported, but the exports did not contain cited references. Therefore, the result of the Core Collection is used in this study. The following table summarizes the search results from different databases to estimate the price of this limitation.

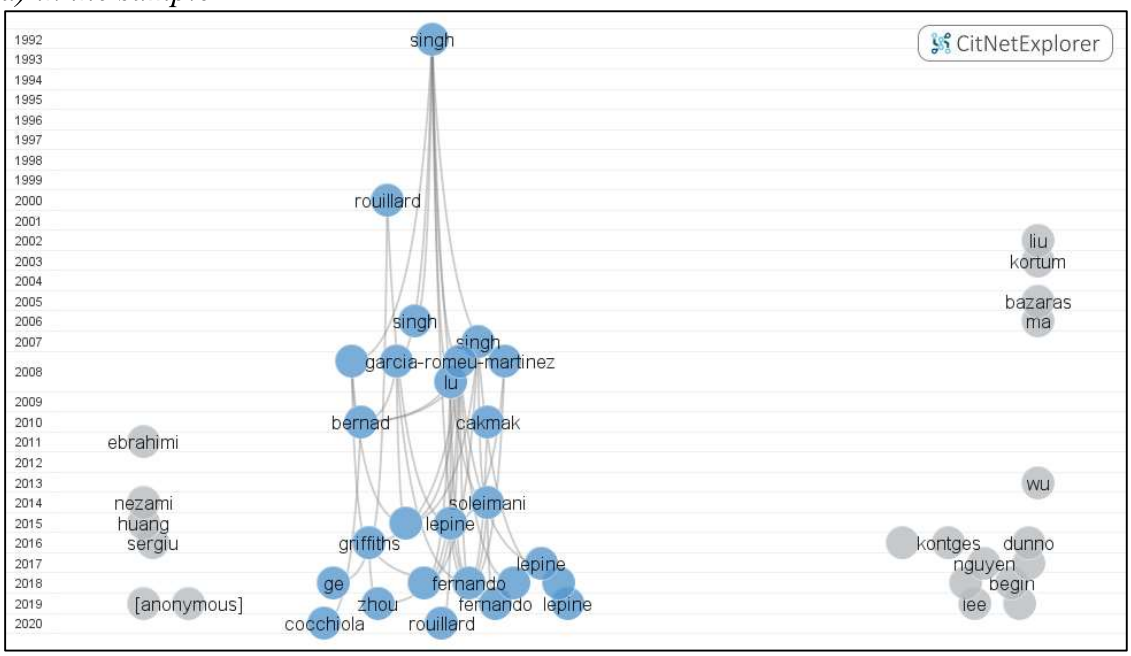
Table 1. Number of records for the same constellation of keywords "*packag* AND vibration AND road AND (simulat* OR test*)*" in different scientific databases without further constraints or filters on March 15th, 2020.

Database	**Web-address**	**Search field description**	**Number of results**
Crossref	https://search.crossref.org/	*Title, author, DOI, ORCID iD, etc.*	813,072
Google Scholar	https://scholar.google.com/	empty search bar	~17000
Dimensions	https://app.dimensions.ai/	*Full data*	2448
Scopus	https://www.scopus.com/	*Article title, Abstract, Keywords*	121
Web of Science	https://apps.webofknowledge.com/	*Topic* (from All Databases)	89*
Web of Science	https://apps.webofknowledge.com/	*Topic* (from Core Collection)	46
Microsoft Academic	https://academic.microsoft.com/home	*Search any topic, author, journal, etc. or any combination of these*	20

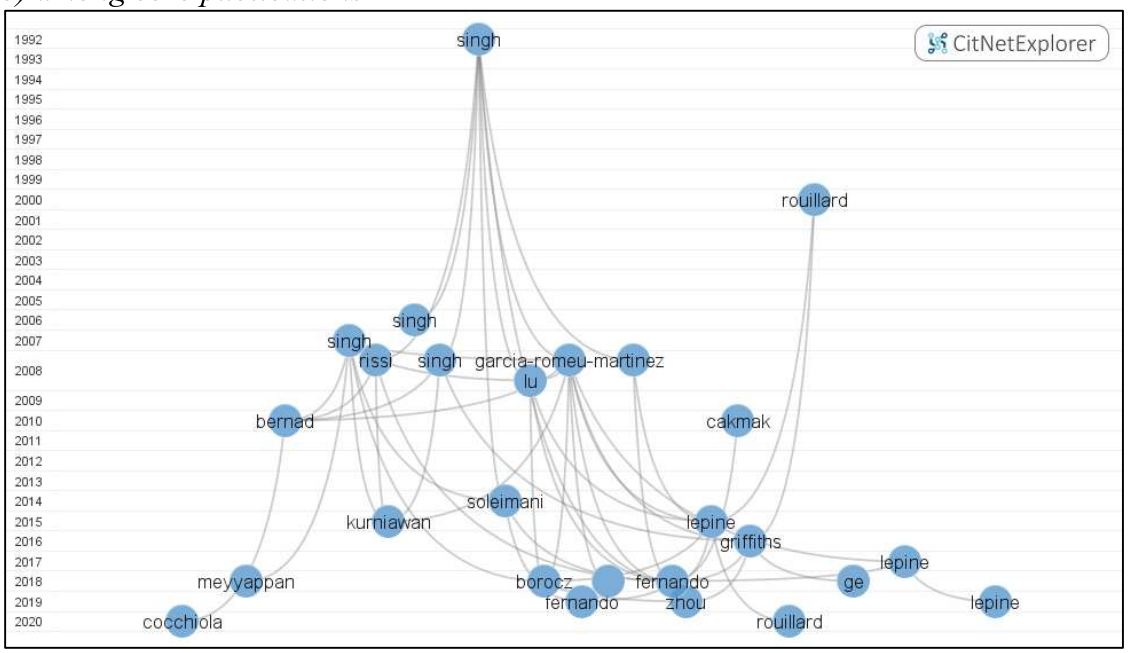
*retrieved on March 16th, 2020.

The exported dataset is read in by CitNetExplorer, and the records are displayed in Fig 1.a), "*drilled down*" to core publications are grouped into one cluster highlighted in Fig 1.b).

Figure 1. The timeline-based network of direct citations within core publications;
a) in the sample



b) among core publications



Source: own analyses in CitNetExplorer

The following section introduces micro-reviews of the core publications. The minimum number of citation links is one, and the connected publications are remarked core publications grouped into one cluster by CitNetExplorer.

3. DISCUSSION

The review of the 26 core publications is arranged in three decades, and the most recent one is divided into half-decades.

3.1. Core publications from 1991 to 2000

Singh & Marcondes (1992) studied the truck vibration levels via measurements to be recommended for package testing and concluded i.a. composite spectrums for simulating tests.

The effect of suspension, the weight of the shipment, and road quality had been compared; the composite spectrums are Power Density Spectrums (subsequently PSD), showing the average levels observed in the studies from data collected over 16 000 km of road conditions.

Rouillard & Sek (2000) the non-stationary nature of road vehicle vibrations (RVV), via measurements and Hilbert-transforms, to enable more realistic simulations of transport vibrations. It concluded *i.a.* how the statistical characteristics of the vibration intensity could be combined with the spectral characteristics of transport vibrations.

Singh & Marcondes (1992) obtained the measurements under a variety of conditions and offered average PSD characteristics. However, a stationary Gaussian time-series can be obtained via inverse Fourier-transform from a given PSD. Rouillard & Sek (2000) emphasized the non-stationary nature of RVVs.

3.2. Core publications from 2001 to 2010

Singh et al. (2006) studied the vibration levels in three directions in trucks as a function of road condition, truck type, vehicle speed, and stacking height (of packages) in Thailand. Measurement and analysis (subsequently MA) of vibration levels were carried out to assist product and package designers to reduce damage in transit by using the recommended vibration test spectrums. It concluded i.a., that an increase in truck speed increased vibration levels and damage to packaged fruit.

Singh et al. (2007) studied the vibration levels in truck and rail shipments in India, via MA and composite spectra in three directions, in order to develop lab-simulated vibration test methods to simulate truck and rail shipments. It was concluded i.a., that the measured vertical vibration levels were more severe than the levels used for existing test methods. There was also a difference between vibration levels in the truck versus rail shipments.

The rail and road transportation environments were discussed, the results of a two years long study were provided incorporating truck and rail transport vibration for the major freight distribution routes in India. It is often cited by subsequent studies in the sample, like by the following record, which itself has the highest internal citation score.

Garcia-Romeu-Martinez et al. (2008) MA study discussed vibration levels for truck transport in Spain as a function of payload, suspension, and speed, to analyze

vibrations occurring during truck transport. It was concluded i.a., that air ride vibration levels were lower than that of leaf spring suspension trailers.
The study has the most internal citations (9), it presents an experiment considering different independent variables, such as:

- the vehicle speeds {[0;40], [40;70], [70;110]} [km/h] intervals,
- the type of suspension {leaf spring-, air ride suspension}, and
- the payload.
  The vibration recorders were mounted
- at the rear and front of the trailer,
- the sampling methods consisted of signal-triggered- and time-triggered acquisition,
- constituted by a GPS+GSM data recorder and a computer.
  Four test conditions had been evaluated:
- 3000 and 0 [kg] payloads for truck semi-trailer with leaf spring suspension and
- 21000 and 3300 [kg] payloads for truck semi-trailer with air ride suspension.

The enticing possibility of a DOE setup (design of experiment) has remained unmined.

Singh et al. (2008) studied the vibration dynamics inside trailers used for less-than-truckload (LTL), via a comprehensive data measurement and video, in order to make recommendations to safely load and transport of LTL shipments. It concluded i.a. that the measured vertical vibration levels are more severe than implied standard levels used for existing test methods. Video footage of load shifting inside the trailer showed that the LTL environment requires blocking and bracing, and the absence of load-restraining methods can result in excessive shifting and damage.

Lu et al. (2008) studied vibration accelerations during truck transport in Japan via extracting shock accelerations and comparing them to video recordings to study the causes of sporadic large shocks. Shocks were caused by road roughness, metal joints, difference in levels on the asphalt-surfaced road, pedestrian crossings, “manholes”, road curves, left and right turns, railroad crossings, etc.

Vibration level results are presented in the form of PSD: examined for shocks, RVV without shocks, and in total. Unfortunately, the method used for shock extraction is not described, only referred to the utilized software.

Rouillard (2008) discussed a signal synthesis approach, utilizing numerical vehicle models in conjunction with measured pavement profiles for packaging optimizations purposes. It was concluded i.a., that the method could be used to produce statistically accurate estimates of the vibratory response.

The numerical simulation is based on a generic linear mathematical quarter-vehicle model described by the coupled two degrees of freedom (2 DoF) second-order differential equation. It could simulate vertical vibration level, vertical body acceleration (in the temporal or spatial domain), from different longitudinal pavement profiles at pre-determined constant speeds. The method provides spectral and statistical estimates to generate vibration test schedules effortlessly for any vehicle type, pavement profile and vehicle speed schedule *ibid*.

Rissi et al. (2008) vibration MA study was conducted in Brazil, in order to provide composite PSD and concluded i.a., that the vertical vibration levels were higher than the lateral and longitudinal levels as expected.

Bernad et al. (2010) studied the dynamics of stacked packaging units, via operational modal analysis (OMA), in order to investigate the non-linear behavior of the paperboard containers and the natural frequencies and modes. The relevance of bending-like modes concerning laboratory testing was emphasized.

The publication introduces OMA in the discipline. The modal analysis of output-only systems first appeared in the 1970s, and significant developments have begun in the 1990s *ibid*. The authors stated that the reviewed studies (for packaging testing purposes) only focused on vertical responses and neglected other vibration modes. *Id*. summarize their motivation that packaging damages might have different reasons apart from fatigue failures, and the responses have closer relationships to the failures instead of the excitation signals.

Cakmak et al. (2010) studied the effectiveness of packaging boxes by different materials, via measurements and shaker testing, to examine the effect of vibration on fresh figs. It was concluded i.a., that the cardboard packaging box was not proper for transporting fresh fig fruits in all road conditions.

The study presents that specifically chosen research objects (here, fresh fig fruits) contribute to a precise formulation of quality indices, or dependent variables in an experiment. Many MA publications deal with dummy masses or just generally reflecting upon *goods transported.*

3.3. Core publications from 2011 to 2015

Soleimani & Ahmadi (2014) studied the truck vibration levels as a function of packages locations in truck bed and suspension via MA and ANOVA.

Apples were packaged in reusable plastic container (RPC), the ANOVA consisted of peak and average
PSD values and acceleration RMS, as affected by:

- S - suspension systems {leaf-spring suspension; air-ride suspension},
- A - RPC position in relation to truck axle {rear; front},
- H - RPC height positions of the container column {bottom; middle; up),
- D - fruit depth in RPC container {top; bottom}.

The investigation was carried out according to a factorial experiment in the form of a multivariate factorial (2x2x3x2) design. Duncan's multiple range tests were used to compare the means. Five replications were conducted for each combination of variables. Twelve acceleration gauges (per truck), each embraced by a spherical shape, had been used. The vibration data results indicated that all independent variables, including the suspension system $S, RPC(H)$, RPC position than truck axle (A) and $RPC(D)$ had significant effects on the average PSD in the range of 0.1–5 [Hz], peak PSD, and RMS of acceleration ($p < 0.05$) *ibid.*

Kurniawan et al. (2015) MA study described vibration levels in two- and three-wheel delivery vehicles in Southeast Asia. It was concluded i.a., that the vibration levels in last leg delivery routes are lower than those measured in truck and container

shipment across road and rail transportation in North America, previously studied by id.

Lepine et al. (2015) review article studied the simulation methods applied in packaging vibration testing. It concluded i.a. that a suitable simulation method should reproduce the three modes present in vehicle vibration, i.e., the non-stationary random, transient, and harmonic components.

The study is organized in the following manner, offering an orientation in packaging testing simulation methods:

- Standardized methods (and accelerated vibration tests),
- Time-history replication,
- Non-Gaussian simulations,
- Non-stationary simulations,
- Transient event simulations,
- Harmonic simulations.

Another conclusion summarizes that there are many methods for simulating non-stationarities; still, no definitive method has been developed and validated to identify and characterize the two other modes of RVVs as of 2015 according to Lepine *et al.* (2015)

3.4. Core publications from 2016 to 2020

Griffiths et al. (2016) introduced a novel method for RVV segmentation and simulation, with decomposing RVVs via discrete wavelet transform (DWT), in order to find Gaussian segments within RVVs in an iterative process. The paper presented the capabilities of the proposed method to simulate RVVs. For the process applied, the reader is referred to ibid. and (Lepine et al., 2015).

Lepine et al. (2017b) studied the performance of a Support Vector Machine (SVM) in contrast to moving Crest factor for detection purposes of shocks buried in RVV via receiver operating characteristics. Synthetized RVVs were created from the dynamic behavior of a specific vehicle. It was concluded i.a., that the SVM is considerably more accurate and reliable in the identification of shocks than the more traditional approach based on the Crest factor.

The synthesized signal was obtained to mirror the real-world vibration behavior of trucks on the model level. Machine learning classifiers can base their prediction on different predictors at the same time, which were inherently used utilizing moving RMS, Crest factor, Hilbert-Huang-transform (HHT), and DWT. It was concluded in (Lepine *et al.,* 2015), that there was room for introducing validated transient event characterization.

Fernando et al. (2018) studied the critical factors of vibration during transport and their implications for fruit quality, and possible improvements. The authors considered the effects of different inner packing methods and different package types in order to synthesize the state-of-the-art. It was concluded i.a., that more precise characterization of mechanical damage induced by shock and vibration, and its reproduction by improved simulation techniques would contribute to the optimization of damage prevention mechanisms.

The review article considered many critical factors for vibration damage to fruits, such as *vibration energy, critical frequencies, acceleration and its transmissibility, package position on truck floor, height in a stack, depth of fruit within a package* (from the top of the corrugated box)*, suspension type or truck type, road conditions, vehicle speed, vibration duration i.a.*.

Wang et al. (2018) investigated the vibration scuffing life curves by an inked transfer device and paperboard via experimental vibration testing in order to develop the G_(rms,e)-N_(a,e) and G_(rms,r)-N_(a,r) scuffing life curves. It was concluded i.a. that the scuffing life curves in the resonance- and non-resonance scuffing state are very different.

Characterization of scuffing level (S) -implying damage rate- was expressed as a percentage of change of the sum of RGB values of the scanned images from the paperboard (A), compared to the maximum total RGB values of a blank card (O). The scuffing life curve in the level of the whole product is given by the relation of $G_{rms,e} - N_{a,e}$, where $G_{rms,e}$ denotes the RMS of the excitation acceleration in the frequency range and $N_{a,e}$ is the total number of zero crossings during the test time; The scuffing life curve on the component level is characterized by the relation of $G_{rms,r} - N_{a,r}$, where $G_{rms,r}$ denotes the RMS of the specimen acceleration in the frequency range, relative to the inclined surface under the specimen, and $N_{a,r}$ is the total number of zero crossings for the relative acceleration during the test time.

Meyyappan et al. (2018) studied electronic components being exposed to vibration risks during their entire lifetime under operational conditions, via a so-called knowledge-based qualification (KBQ) framework in order to map use conditions to accelerated test requirements for solder joint fatigue and socket contact fretting. The qualification requirements via KBQ were compared to standard requirements to verify how well industry standard models reflect field reliability risks.

Electronic components, such as *microprocessors, crystals, capacitors, inductors, transformers, ball grid array packages (BGA), quad flat packages (QFP), and chip-scale packages (CSP)* (Saravanan *et al.*, 2008) are likely to appear in the current sample since packaging has a secondary meaning, for which a representative definition is given in (Shannon, 2019; p.37). *In electronics manufacturing, integrated circuit packaging is the final stage of semiconductor device fabrication, in which the tiny block of semiconducting material is encapsulated in a supporting case that prevents physical damage and corrosion. The case known as "package", supports the electrical contacts which connect the device to a circuit board. In the integrated circuit industry, the process is often referred to as packaging.*

Borocz & Singh (2018) MA study investigated vibration levels in delivery vans in Hungary, in order to simulate package testing for parcel delivery. It concluded i.a. composite PSDs.

Ge & Pan (2018) studied vibration damage rate curves for quantifying abrasion of printed packaging in accelerated random vibration test, via G_rms-N vibration damage rate curves. It was concluded i.a., that the accelerated random vibration formula could be used when vibration damage rate curves for printed packaged products are developed, in order to effectively reproduce the damage in the laboratory, equivalent to the field.

The authors proposed the concept of vibration damage rate curves to characterize progressive damages on printed surfaces. Accelerated random vibration study was conducted to investigate the abrasion of a printed surface between a single axis vibration in the laboratory and the field test per the given Basquin- equation. The paper described the method to obtain vibration damage rate curves based on equal damage between the laboratory and the field. The damage rate r is formulated as the percentage of change, utilizing *optical density* (before/after). The number of cycles N was counted via the *rainflow* cycle-counting algorithm[2].

Fernando et al. (2019) studied the vibration levels and damages to bananas in palletized cartons transported by multi-trailer road trains. The MA was constituted by quantitively estimated damages (MDI). The transmissibility testing in a stacked pallet was accomplished with a vibration simulator table. The research was conducted for the purpose of studying the mechanical damage levels in bananas, influenced by the package height and the stacked position of the pallet.

Mechanical Damage Index (MDI) based on the estimated damage area was derived as an index score for each fruit carton. The ANOVA design consisted of the mean MDI score for each fruit carton, as affected by*:*

- trailer {A; B},
- position of pallet in trailer A {front; rear} and in trailer B {front; middle; rear}
- height of cartons per position {bottom; middle; top}.

The experiment was conducted according to a factorial experiment in the form of a multivariate factorial (2x2x3x3) design. MDI data for each sample banana carton stacked in different positions in the pallets were analyzed for statistical significance by ANOVA and Tukey's HSD test method *ibid.*

Lepine et al. (2019) studied four different Machine Learning Classifiers for the detection of shocks buried in RVV, via ROC- and the specially developed PERFO curves. In order to assess the classifiers' detection accuracy, it was found that obtaining the classifier's optimal operation point (OOP) via synthetic dataset was inadequate. Therefore, the recalibration of classifiers was necessary using this time the measured RVVs. It was concluded after recalibration, that the detection capability of the Decision Tree, 20NN and Bagged Ensemble classifiers are equivalent to random guessing. An area under the curve (AUC) of 0.94 was obtained by the Gaussian SVM providing accurate detections. Accordingly, it can be used to detect shocks buried in RVVs.

The same predictors had been utilized here, as compared to (Lepine *et al.*, 2017b). Beneath ROC (implicitly AUC) statistics, the PERFO curve was introduced as a performance indicator. Furthermore, three other classifiers were evaluated next to the SVM approach. The schematic of the generation synthetic training and validation sets was improved, as well. Another development in contrast to *ibid.* was the validation using real-world RVV measurement.

Zhou & Wang (2019) further studied a previously introduced approach, namely the shock extraction method (subsequently SEM). Three representative RVV

[2] Tatsuo Endo and M. Matsuiski in 1968 devised the rainflow-counting algorithm and enabled the reliable application of Miner's rule to random loadings Westmoreland Mechanical Testing & Research, (2018).

simulations (single-level PSD, three-way split spectral, and wavelet decomposition) was compared to SEM, to assess simulation capabilities based on statistical parameters. The simulations were tested on three measured RVVs, and it was concluded i.a., that the single-level PSD simulation produces the worst, while SEM achieves the best simulation effect.

Statistical parameters incurred in the comparison were max.- and min. acceleration, overall G_{rms} , kurtosis, segment duration, vibration intensity [3] , acceleration probability distribution, moving RMS probability distribution, and PSD plots.

The single-level PSD method as a standard procedure produces a stationary Gaussian signal, which is not discussed here in more detail. The three-way split spectra method splits the original signal into three segments with the lower 70%, middle 25%, and top 5% of (*acceleration level* (Fernando *et al.*, 2018)) data, and each segment is simulated with a stationary Gaussian signal. Griffiths *et al.* (2016) proposed the wavelet decomposition method discussed above.

Shock extraction method has been prior introduced in (Zhou & Wang, 2018), the original signal is decomposed into a series of approximated Gaussian segments and one shock segment. The segmentation is based on the moving crest factor (MCF) and the one-tenth peak (OTP) value. MCF is often used to index transients, but it is *not always reliable and is often not appropriate for signals that contain strong non-stationarities* (Lepine *et al.*, 2017a). Segments are simulated as stationary Gaussian signals, which are concatenated to be the total simulated signal. Fatigue life prediction may also be unrealistic, since suffered damages may vary by the sequence of high- and low- or low- and high-stress fluctuations (Raouf A. Ibrahim, 2017; p.365).

Rouillard & Lamb, (2020) studied multiaxial motions, like heave, pitch, and roll vibrations from many transport vehicles traveling on typical urban and suburban routes, in order to establish the nature and level of the multiaxial vibrations that exist. It was concluded i.a. that the relationships between the moving RMS of the above-given DoFs are not strongly correlated but can be characterized statistically as joint distributions.

The publication reveals a recently unfolding trend that multiaxial vibration testing can be characterized based on multiaxial measurements because the use of lightweight systems such as stretch film is increasing, and those packaging systems are susceptible to lateral forces generated by roll and pitch vibratory motions.

Cocchiola et al. (2020) studied the effect of coplanar sensor spacing on determining the angular acceleration of vehicles. A sensitivity analysis was conducted to determine the effect of misplacement and misorientation of sensors on the angular acceleration calculation; and concluded i.a., that there is a trade-off between compactness of the recording array and the measurement accuracy.

A coplanar six translational acceleration DoF and three angular rate DoF (6a3ω) configuration had been investigated with gauges mounted on a unique L-shaped fixture. Heave acceleration was measured with the onboard accelerometer, whereas angular velocity was measured with an IMU connected to two available external

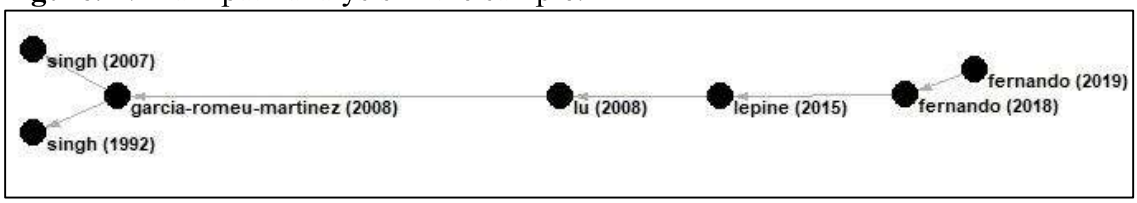
[3] Usually the vibration intensity can be expressed by vibration acceleration RMS value Liu & Zhang, (2012); or in other words G_{rms} is a qualitative measure of intensity of vibration Santhosh M. Kumar, (2008).

channels of the self-contained data recorder. Rouillard & Lamb (2020) used a self-contained data recorder. The study of Bernad *et al.* (2010) considered only the evaluation of translational motions.

4. SYNTHESIS

Twenty-six core publications are identified by CitNetExplorer and discussed in more detail in the prior section. Subjects and methods of studies are highlighted in the script. Research trends and highly referred records have been analyzed. The direct citation network utilizing a timeline-based approach estimates the knowledge transfer in the discipline by the sample. Nooy *et al.* (2005) describe the idea of citation networks as a system of channels transferring information. A junction (article) in this system refers to many other publications and likely synthesize knowledge, implying that a knowledge flow through them. Such a main channel in the current sample is visualized in Figure. 2, and the short thematic connections are described next.

Figure. 2. Main path analysis in the sample.



Source: own analysis in Pajek

Fernando *et al.* (2019) investigated via ANOVA design the mechanical damage to bananas in transport. A discrepancy in PSD curves has been noticed between ASTM testing standard - and recorded signal PSD profiles. *Id*. explained further that PSD peaks can be influenced by the suspension (characteristics and stiffness) in each vehicle, referring to a preliminary study by Fernando *et al.* (2018). *Ibid* cites 113 records in order to discuss and identify the main factors of vibrations and their implications on fruit quality. Transient shocks are discussed as one of those critical factors and *id*. refers to Lepine *et al.* (2015), who also described the shock detection capabilities of the Crest factor. Among standard laboratory vibration testing, the testing times can be accelerated via the Basquin-model -referring again to Lepine *et al.* (2015)-. Another essential review appears, as Lepine *et al.* (2015) synthesize the knowledge of RVV simulations for packaging testing purposes as of date. In the topic of transient event detection, the method of Lu *et al.* (2008) is mentioned *i.a.*. The results from *ibid.* are discussed in the context of other researches, such as (Garcia-Romeu-Martinez *et al.,* 2008), which published MA results of truck transport in Spain as a function of payload, suspension, and speed. Studies from different countries concerning vibration level measurements are taken into account in the introduction, like a study conducted in India (Singh *et al.*, 2007) or in North America (Singh & Marcondes, 1992). Both cited references describe the measurement and analysis of vibrations of shipments during transport.

5. CONCLUSION

The citation networks seem an applicable representation to study the connection of researches, but it does not reveal the context. Visual networks help to identify not only primary researches but offer an orientation when reading publications. In large scale networks, further analysis techniques are available to estimate the main knowledge channels in time, such as the *main path analysis*. Even if the presented methods can only estimate a discipline, it still presents an added value in the preparation- and presentation phase of reviewing the literature. Future research regarding the bibliographic analysis may expand the sample size with different search queries but utilizing the same approach. As a possible alternative to the current approach, other time-independent analyses of citation networks as per decades could be introduced, as well.

Packaging vibration testing has its roots in measurement and analysis of road vehicle vibrations. Studies led to the recognition of RVVs being non-stationary and non-Gaussian stochastic processes, still many available vibration testing standards use average PSD profiles leading to stationary Gaussian simulations. The limitation of prior available testing standards had been addressed in different studies; hence new simulation methods had been established. From this indefinite changepoint, the discipline has reserved the two methodologies, such as *RVV measurement & analysis* and *RVV synthesis*. Here shall be noted that these classes are neither mutually exclusive nor giving up to the total methodology space in the discipline. However, this duality can be discovered through the qualitative analysis of publications. Larger sample sizes may result in different clusters.

The measurement and analysis of vibration levels show increasing interest in the heave, pitch, and roll vibratory motions beneath the translational vibrations. The joint distribution of the 6 DoF measurements and DOE approaches might reveal further significant connections between the vibratory motions and different independent variables, if accountable under RVV circumstances. The contribution of 6 DoF measurements to the improvements in multiaxial shaker testing must be assessed.

The identification of shocks in RVVs has a long track record in the discipline; lately, machine learning algorithms are also implemented to classify *events*. The discipline may face questions regarding the estimation and cross-validation of the distribution(s) of transient events along the journeys if it is applicable. The drivetrain-related harmonic excitation is still a rarely discussed phenomenon in the discipline, which needs further attention in investigating accountable vibrations.

Albeit no universally accepted methods are developed yet beneath the standard approaches, the active strive in empirical observation and description of RVV enables us to understand the real-world phenomena better and indirectly facilitates the presentation of new simulation methods in the packaging vibration testing.

6. REFERENCES

Batagelj, V. and Mrvar, A. (2020) ‘Pajek’. Available at: http://mrvar.fdv.uni-lj.si/pajek/.

Bernad, C., Laspalas, A., González, D., Liarte, E. and Jiménez, M. A. (2010) 'Dynamic study of stacked packaging units by operational modal analysis', *Packaging Technology And Science*, 23(3), pp. 121–133. doi: 10.1002/pts.883.

Borocz, P. and Singh, S. P. (2018) 'Measurement and analysis of delivery van vibration levels to simulate package testing for parcel delivery in Hungary', *Packaging Technology And Science*. Wiley, 31(5), pp. 342–352. doi: 10.1002/pts.2327.

Boyack, K. W. and Klavans, R. (2010) 'Co-citation analysis, bibliographic coupling, and direct citation: Which citation approach represents the research front most accurately?', *Journal Of The American Society For Information Science And Technology*, 61(12), pp. 2389–2404. doi: 10.1002/asi.21419.

Cakmak, B., Alayunt, F. N., Akdeniz, R. C., Aksoy, U. and Can, H. Z. (2010) 'Assessment of the quality losses of fresh fig fruits during transportation', *Journal Of Agricultural Sciences - Tarim Bilimleri Dergisi*. Ankara Univ, Fac Agr, 16(3), pp. 180–193.

Clarivate Analytics © (2020) *Web of Science*. Available at: https://apps.webofknowledge.com/ (Accessed: 15 March 2020).

Cocchiola, G. J., Joodaky, A., Batt, G. S. and Gibert, J. M. (2020) 'The effect of coplanar sensor spacing on determining the angular acceleration of vehicles', *Packaging Technology And Science*. Wiley, 33(2), pp. 83–96. doi: 10.1002/pts.2488.

van Eck, N. J. and Waltman, L. (2014a) 'CitNetExplorer (Leiden University © 2014)'. Leiden, Netherlands: Leiden Univerity.

van Eck, N. J. and Waltman, L. (2014b) *Visualizing Bibliometric Networks*, *Measuring Scholarly Impact: Methods And Practice*. Springer. doi: 10.1007/978-3-319-10377-8_13.

Fernando, I., Fei, J. and Stanley, R. (2019) 'Measurement and analysis of vibration and mechanical damage to bananas during long-distance interstate transport by multi-trailer road trains', *Postharvest Biology And Technology*. Elsevier, 158. doi: 10.1016/j.postharvbio.2019.110977.

Fernando, I., Fei, J., Stanley, R. and Enshaei, H. (2018) 'Measurement and evaluation of the effect of vibration on fruits in transit Review', *Packaging Technology And Science*. Wiley, 31(11), pp. 723–738. doi: 10.1002/pts.2409.

Garcia-Romeu-Martinez, M.-A., Singh, S. P. and Cloquell-Ballester, V.-A. (2008) 'Measurement and analysis of vibration levels for truck transport in Spain as a function of payload, suspension and speed', *Packaging Technology And Science*, 21(8), pp. 439–451. doi: 10.1002/pts.798.

Ge, C. and Pan, L. (2018) 'Vibration damage rate curves for quantifying abrasion of printed packaging in accelerated random vibration test', *Packaging Technology And Science*. Wiley, 31(2), pp. 71–81. doi: 10.1002/pts.2354.

Griffiths, K. R., Hicks, B. J., Keogh, P. S. and Shires, D. (2016) 'Wavelet analysis to

decompose a vibration simulation signal to improve pre-distribution testing of packaging', *Mechanical Systems And Signal Processing*. Academic Press, 76–77, pp. 780–795. doi: 10.1016/j.ymssp.2015.12.035.

Hummon, N. P. and Dereian, P. (1989) 'Connectivity in a citation network: The development of DNA theory', *Social Networks*, 11(1), pp. 39–63. doi: 10.1016/0378-8733(89)90017-8.

Kurniawan, M. P., Chonhenchob, V., Singh, S. P. and Sittipod, S. (2015) 'Measurement and analysis of vibration levels in two and three wheel delivery vehicles in Southeast Asia', *Packaging Technology And Science*, 28(9), pp. 836–850. doi: 10.1002/pts.2143.

Lepine, J., Rouillard, V. and Sek, M. (2015) 'Review Paper on Road Vehicle Vibration Simulation for Packaging Testing Purposes', *Packaging Technology And Science*, 28(8), pp. 672–682. doi: 10.1002/pts.2129.

Lepine, J., Rouillard, V. and Sek, M. (2017a) 'On the use of machine learning to detect shocks in road vehicle vibration signals', *Packaging Technology And Science*. John Wiley and Sons Ltd, 30(8), pp. 387–398. doi: 10.1002/pts.2202.

Lepine, J., Rouillard, V. and Sek, M. (2017b) 'On the Use of Machine Learning to Detect Shocks in Road Vehicle Vibration Signals', *Packaging Technology And Science*, 30(8), pp. 387–398. doi: 10.1002/pts.2202.

Lepine, J., Rouillard, V. and Sek, M. (2019) 'Evaluation of machine learning algorithms for detection of road induced shocks buried in vehicle vibration signals', *Proceedings Of The Institution Of Mechanical Engineers, Part D: Journal Of Automobile Engineering*, 233(4), pp. 935–947. doi: 10.1177/0954407018756201.

Liu, J. and Zhang, Q. (2012) 'Variability in dynamic characteristics of the Sutong cable-stayed bridge under routine traffic conditions', in Biondini, F. and Frangopol, D. M. (eds) *Bridge Maintenance, Safety, Management, Resilience And Sustainability. Proceedings Of The Sixth International IABMAS Conference*. Stresa, Lake Maggiore, Italy: CRC Press, Taylor & Francis Group, pp. 3428–3436.

Lu, F., Ishikawa, Y., Shiina, T. and Satake, T. (2008) 'Analysis of shock and vibration in truck transport in Japan', *Packaging Technology And Science*. Wiley, 21(8), pp. 479–489. doi: 10.1002/pts.841.

Meyyappan, K., Vujosevic, M., Wu, Q., Malatkar, P., Hill, C. and Parrott, R. (2018) 'Vibration-induced failures in automotive electronics: Knowledge-based qualification perspective', *Journal Of Electronic Packaging*. ASME, 140(2). doi: 10.1115/1.4039301.

Nooy, W. De, Mrvar, A. and Batagelj, V. (2005) *Exploratory network analysis with Pajek*. 1st edn. New York: Cambridge University Press.

Raouf A. Ibrahim (2017) *Handbook of structural life assessment*. Wayne State University, USA: John Wiley & Sons Ltd.

Rissi, G. O., Singh, S. P., Burgess, G. and Singh, J. (2008) 'Measurement and analysis of truck transport environment in Brazil', *Packaging Technology And Science*, 21(4), pp. 231–246. doi: 10.1002/pts.797.

Rouillard, V. (2008) 'Generating road vibration test schedules from pavement profiles for packaging optimization', *Packaging Technology And Science*, 21(8), pp. 501–514. doi: 10.1002/pts.840.

Rouillard, V. and Lamb, M. (2020) 'Some characteristics of the heave, pitch and roll vibrations within urban delivery routes', *Packaging Technology And Science*, 33(3), pp. 113–121. doi: 10.1002/pts.2491.

Rouillard, V. and Sek, M. A. (2000) 'Monitoring and simulating non-stationary vibrations for package optimization', *Packaging Technology And Science*. John Wiley & Sons Ltd., 13(4), pp. 149–156. doi: 10.1002/1099-1522(200007)13:4<149::AID-PTS508>3.0.CO;2-A.

Santhosh M. Kumar (2008) 'Analyzing Random Vibration Fatigue', *ANSYS Advantage*, II(3), pp. 39–42. Available at: www.ansys.com.

Saravanan, S., Sakri, M. I. and Mohanram, P. V. (2008) 'Fatigue Prediction of Electronic Packages Subjected to Random Vibrations', *Journal Of Microelectronics And Electronic Packaging*, 5(1), pp. 31–35. doi: 10.4071/1551-4897-5.1.31.

Shannon, R. (2019) *Linear Integrated Circuits*. Waltham Abbey Essex, United Kingdom: ED-Tech Press.

Singh, S. P., Jarimopas, B. and Saengnil, W. (2006) 'Measurement and analysis of vibration levels in commercial truck shipments in Thailand and its impact on packaged produce', *Journal Of Testing And Evaluation*. Amer Soc Testing Materials, 34(2), pp. 104–110.

Singh, S. P., Joneson, E., Singh, J. and Grewal, G. (2008) 'Dynamic analysis of less-than-truckload shipments and test method to simulate this environment', *Packaging Technology And Science*. John Wiley & Sons Ltd., 21(8), pp. 453–466. doi: 10.1002/pts.787.

Singh, S. P. and Marcondes, J. (1992) 'Vibration levels in commercial truck shipments as a function of suspension and payload', *Journal Of Testing And Evaluation*. Amer Soc Testing Materials, 20(6), pp. 466–469.

Singh, S. P., Sandhu, A. P. S., Singh, J. and Joneson, E. (2007) 'Measurement and analysis of truck and rail shipping environment in India', *Packaging Technology And Science*. John Wiley & Sons Ltd., 20(6), pp. 381–392. doi: 10.1002/pts.764.

Soleimani, B. and Ahmadi, E. (2014) 'Measurement and analysis of truck vibration levels as a function of packages locations in truck bed and suspension', *Computers And Electronics In Agriculture*. Elsevier B.V., 109, pp. 141–147. doi: 10.1016/j.compag.2014.09.009.

Wang, L.-J., Wang, Z.-W. and Rouillard, V. (2018) 'Investigation on vibration scuffing life curves', *Packaging Technology And Science*. Wiley, 31(8), pp. 523–531.

doi: 10.1002/pts.2376.

Westmoreland Mechanical Testing & Research, L. (2018) *The history of fatigue testing*. Available at: http://www.wmtr.co.uk/History_Of_Fatigue_Testing.html (Accessed: 1 April 2020).

Zhou, H. and Wang, Z.-W. (2018) 'A New Approach for Road-Vehicle Vibration Simulation', *Packaging Technology And Science*, 31(5), pp. 246–260. doi: 10.1002/pts.2310.

Zhou, H. and Wang, Z. W. (2019) 'Comparison study on simulation effect of improved simulation methods for packaging random vibration test', *Packaging Technology And Science*, 32(3), pp. 119–131. doi: 10.1002/pts.2421.