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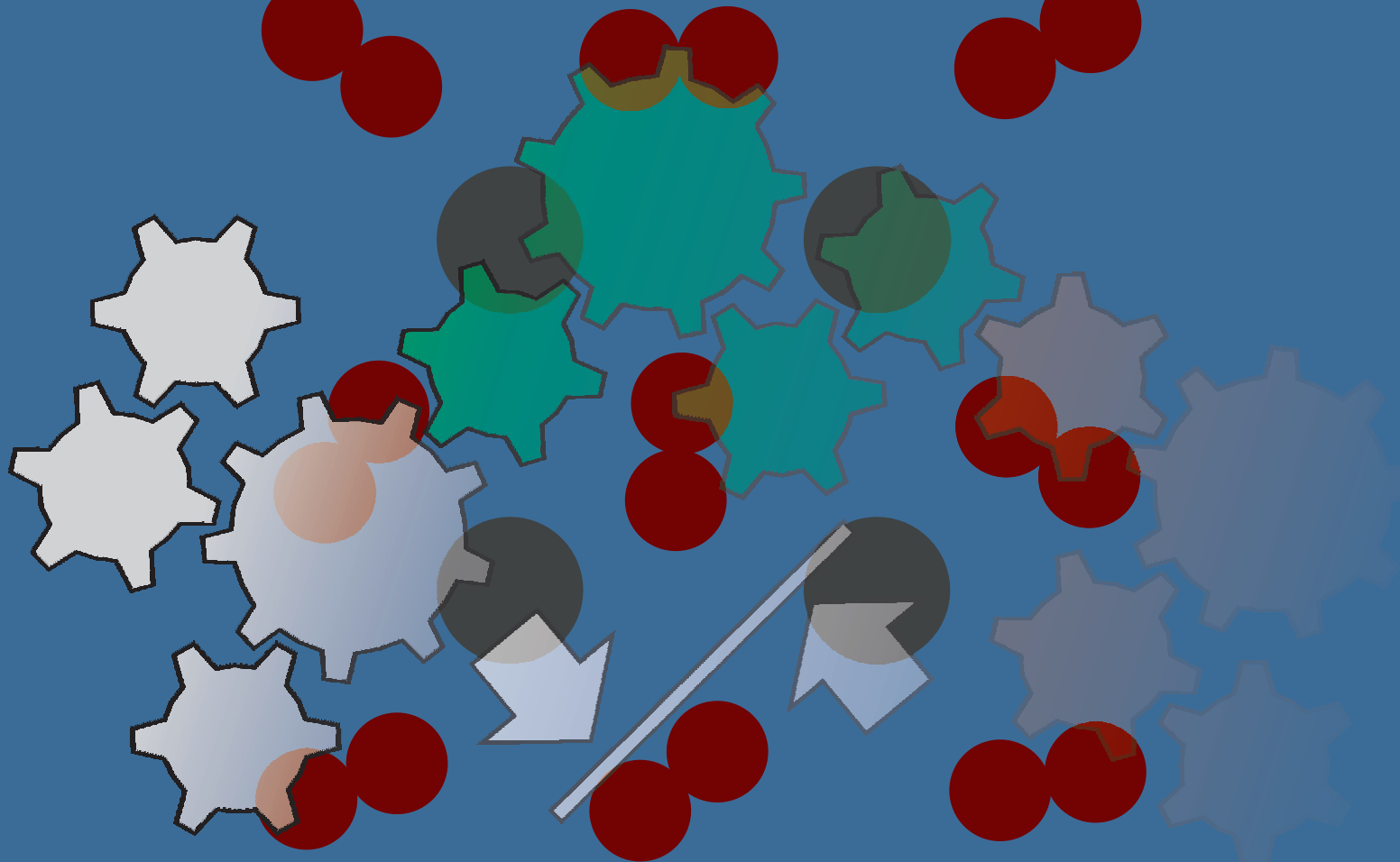

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PROBLEM PREDICTION DURING TRIP IN AND TRIP OUT PROCEDURES WITH ARTIFICIAL NEURAL NETWORKS

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Abstract: In recent times, the adaptation of artificial intelligence (AI) technologies has been spread in the petroleum industry. Such methods as Artificial Neural Networks (ANN), Fuzzy Logic, or Evolutionary Computing have the potential to improve the currently applied methods in every sector of the industry. They provide an advanced encroachment of the complex physics of downhole parameters, which directly add to their modeling ability compared to the traditional empirical and analytical methods. In this study, the development of a feed-forward neural network is presented. The purpose of the development is to predict the possible problems in case of a drilling operation, during running in and pulling out of the hole (RIH & POOH), based on the data acquired during the drilling of the hole.

1 Introduction

1.1 Artificial Neural Networks

Neural networks are a set of algorithms modelled loosely after the human brain that is designed for pattern recognition. They interpret sensory data through a kind of machine perception, labelling, or raw clustering input. The pattern recognition is done on numerical data, which is contained in vectors. To make this possible, real-world data must be translated, be it images, sound, text, or time series.

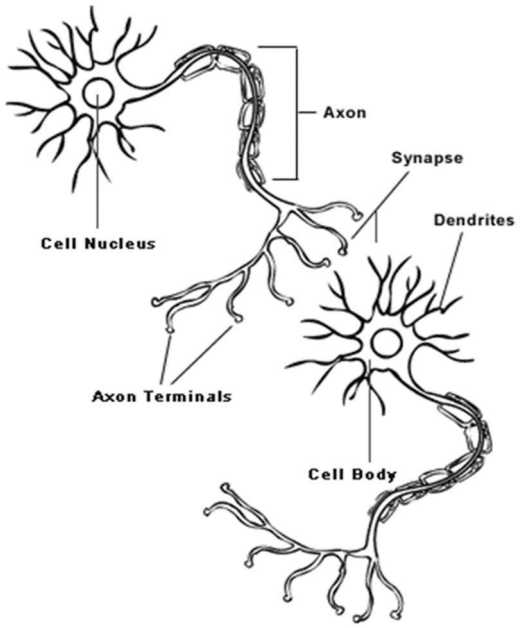

Figure 1 Structure of biological neurons [1]

Each neuron (Figure 1) is a processing tool of our brain. Each neuron will try to stimulate other neurons via its axon terminals and tells whether a terminal should be active or remain inactive. By doing that repeatedly across multiple neurons (the human brain has around 100 billion neurons), our brain can process complex things and solving problems.

Deep learning is the name that is used for networks that are composed of several layers ("stacked neural networks") [2] (Figure 2). The layers are made of nodes, where computation happens. The nodes are loosely patterned on the human brain's neurons, which fire when sufficient stimuli have encountered A node, combines input from the data with a set of coefficients, or weights, that either amplify or dampen that input. With this, significance can be assigned to the input concerning the task the algorithm is trying to learn, e.g., which input is the most helpful in classifying data without error. The sum of the input-weight products is passed through the so-called activation function of a node. The activation function modifies the signal to determine whether and to what extent it should progress further through the network to affect the outcome, e.g., an act of classification. If the signals pass through, the neuron has been "activated" (Figure 3).

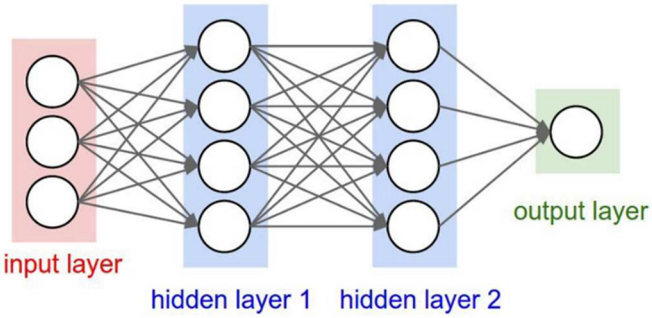

Figure 2 Model of a neural network [3]

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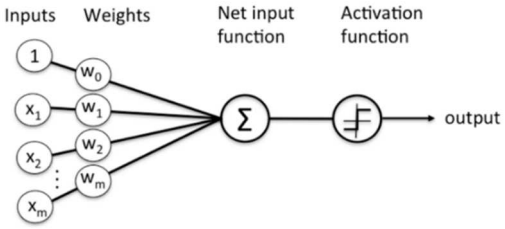

Figure 3 Working model of a node [4]

A node layer is a row of those neuron-like switches that turn on or off as the input is fed through the net. Each output of a layer is simultaneously the input of the subsequent layer, starting from an initial input layer receiving the data.

1.1.1 Working mechanics of neural networks

At the highest and simplest representation, a supervised neural network can be presented as a black box with two methods, learn and predict, as follows (Figure 4).

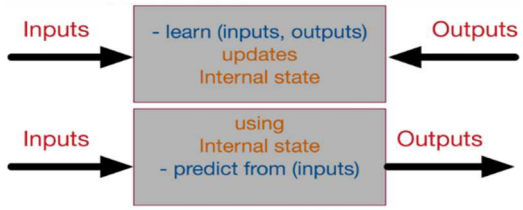

Figure 4 Neural network as a black box

The "learning" process takes the inputs and the desired outputs and updates its internal state accordingly, so the calculated output gets as close as possible to the desired output. The "predict" process takes an input and generates, using the internal state, the most likely output according to its past "training experience". That is the reason why machine learning is sometimes called model fitting. The training procedure of a feed-forward neural network is presented in detail in the following flowchart (Figure 5):

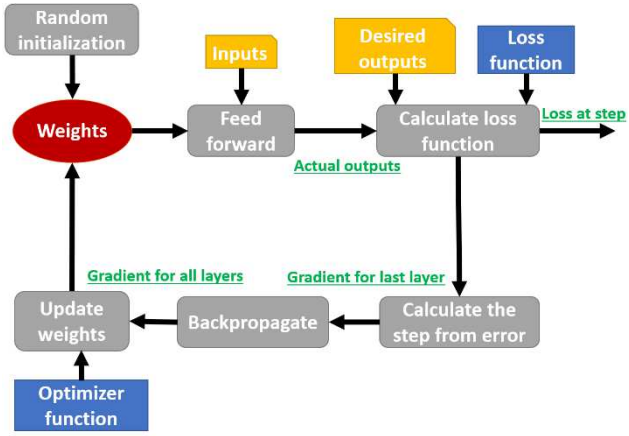

Figure 5 Training procedure of feedforward neural networks

The input parameters which are given to the neural network to process are called features. The nodes have a weight for each feature and a bias term as well. The weights and the bias term together make up the regression parameters. These regression parameters are then passed to an activation function, which decides whether the result is significant enough to "fire" the node, producing the output. The first step of training is to give an initial value for each regression parameter. It is very likely to perform poorly with these random initial values, but the training will essentially punish the network for poor performance.
After the first guess of the network (output calculated with the initial weights), the decision to make is how to modify the weights to reach a better result. In order to do this, first, the level of error needs to be measured. This is done by the application of a so-called loss function, which indicates the severity of error for the current parameters. As a result, the actual goal is to find the minimum of the loss function (Figure 6). The way how this minimum is reached is a question of the optimization method, but to apply any of them, the gradient of the error is needed at the given point corresponding to actual regression parameters. Based on the chosen method, a step is calculated (1), which will improve the result.

$$w_{new} = w_{old} + step \quad (1)$$

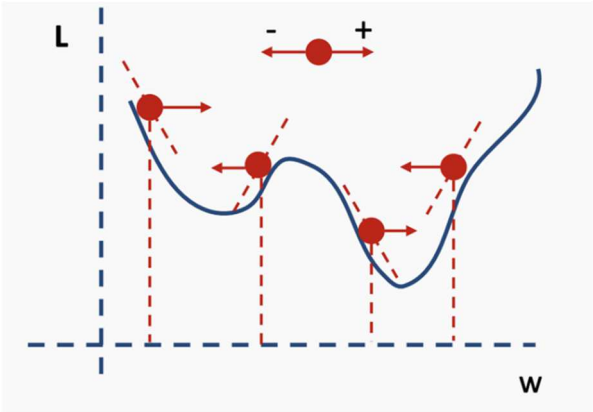

Figure 6: Finding minimum of loss function L(w)

Backpropagation is the learning mechanism of a neural network. It can be considered as the messenger, which tells the network whether a mistake was made or not during the prediction. The development of backpropagation was one of the most important milestones in the field of artificial neural networks.

During prediction, a signal is propagated through the nodes of the artificial neural network to the output layer, where the "decision is made". After the generation of the output, its error is propagated back through the network in such a way, that the parameters of the network can be altered accordingly.

During the backpropagation process, the derivatives for the different parameters in the network are determined, which is needed for the optimization. So backpropagation is the prerequisite of optimization.

1.1.2 Configuration parameters of ANNs

There are several configuration parameters that need to be set for a feedforward network to ensure successful results.

Activation functions

The activation function is analogous to the build-up of electrical potential in biological neurons, which is "fired" when the so-called activation potential is reached. This behaviour is mimicked by the artificial neural network with the application of probability. So a neural network without any activation function is actually a linear regression model, which is limited in the set of functions it can approximate. The selection of the activation function can greatly alter how the firing occurs in the network. The activation function should do two things:

- ensure non-linearity,
- ensure that gradients remain large through the hidden unit.

To perform backpropagation on the network, the activation function is required to be differentiable, so the gradients of error (loss) can be calculated with respect to the weight,s which are then updated using gradient descent.

Loss functions

Several functions can be used to estimate the error of a set of weights in a neural network. However, a function where the space of candidate solutions maps onto a smooth (but high-dimensional) landscape, on which the optimization algorithm can reasonably navigate via iterative updates to the model weights, is preferred [5].

Optimization methods

During the training of the artificial neural network, the goal is to decrease the loss with each epoch. This can be achieved by finding the minimum of the loss function with the optimization of the weights in the network. To achieve this, different optimization methods can be utilized.

Initialization methods

The initialization of network weights is an important and often overlooked characteristic of developing neural networks. Poor initialization of network weights can be the source of many issues which can deteriorate the performance. Because of the inherent way the gradient updates are calculated, a model initialized with all zeroes would learn nothing, as the weights would stay zeroes.

Feature normalization

Feature normalization involves normalizing features before applying the learning algorithm. This is the rescaling of the feature generally done during the preprocessing. According to Ioffe and Szegedy [6], gradient descent converges much faster with feature scaling than without it.

Feature standardization

With feature standardization, the values of each feature in the data will have zero-mean (when subtracting the mean in the numerator) and unit-variance. This method is widely used for normalization in many machine learning algorithms (mostly those that involve distance-based methods). The general method of calculation is to subtract the mean of each feature from the actual value and divide the result by the standard deviation of the given feature.

1.2 Application of ANNs in drilling problems prediction

It is drilling a well that accounts for most of the investments in the oil and gas industry. Thus, it is crucial to avoid any complications, accidents during the construction of a well. Predicting these problems some time ahead they would occur may save a lot of money and reduce non-productive time substantially, as it allows a proactive reaction rather than remediating the occurred problem, which is more than often not successful. The prevailing trend in the century is using ANNs to predict such problems. Borozdin et al. [7] summarized the drilling problems and assigned a value to them based on the possibility of using a neural network to predict them.

Most of the drilling problems that occur during drilling are stuck pipe, lost circulation, and gas, water, or oil kicks. Thus, this work focuses on these problems regarding the applicability of ANNs.

In this decade, several works were devoted to predicting stuck pipes. Ferreira et al. [8] developed an automated decision support algorithm to avoid drilling operations. This earlier work compared real-time data with historical data and required an engineer to detect the cases when action needed to be taken. Naraghi et al. [9] used an active learning method (ALM) to predict the probability of the drillstring being stuck using the surface mechanical parameters of 150 drilled wells. Salminen et al. [10] developed a model that compared the real-time data with the expected trends calculated using torque and drag software and trend analysis. This way, they were able to predict stuck pipe events with sufficient time ahead to prevent them.

Murillo et al. [11] used adaptive fuzzy logic and ANNs to predict stuck pipe incidents. One hundred eighty-five data sets were generated from drilling and mud reports that consisted of the measured and vertical depths, GPM, WOB, RPM, BS, drillcollar length, ROP, torque and drag, chloride filtrate, PV, YP, MW, and gel strength. To reduce the number of variables, dimensionless groups were introduced. Discriminant analysis was used to produce discriminant functions as output curves. 75% of the data was used to train the ANN, while 25% was used to test it. Using the ANN introduced less error in predicting the occurrence of the sticking than the fuzzy logic model.

Jahanbakshi et al. [12] used a dataset of 214 samples that were divided into a 70:30 ratio randomly to train and test their ANN. The data included mud properties, BHA

length, seconds the pipe was still, and different hole sizes. In their work, a feed-forward backpropagation model was used with one hidden layer. After optimization, it was found that the ANN provided the best results with the transit transfer function and 18 neurons in the hidden layer. The ANN showed 82.15% accuracy in predicting sticking cases.

Alshaikh et al. [13] compared three machine learning models to predict stuck pipe, namely decision trees, support vector machines, and ANNs. In their work, a dataset of 9 historical stuck pipe occurrences was used. The parameters contained were the surface drilling parameters, their average of the previous 12 timesteps, and the rate of change of the given parameter. The output was the probability of being stuck. According to their results, which were validated using nested cross-validation, the ANN was 96.88% accurate in predicting stuck pipe incidents with a precision of 94.28%, which means that in 6 out of 100 cases, there was a false alarm.

2 Methods

There are multiple reasons to pull the drillstring out of the hole and to run a new assembly, namely:

- reaching the total planned depth,
- changing BHA (running new rotary assembly, changing malfunctioning downhole tools, bits called bittrip or roundtrip),
- hole conditioning before cementing and open-hole geophysical measurements (it involves pulling out of the hole and running in again, then circulating mud).

Tripping in and out of the hole may pose several risks, downhole problems that can be traced back to the condition of the well, mud, and mudcake as well as the well geometry and well stability. The most common issue is the pipe becoming stuck in the well. The sticking mechanisms include the following:

- Loose or unconsolidated formations collapsing into the borehole and packing off the drillstring.
- Differential sticking due to high-pressure difference and/or thick mudcake.
- Mobile formations behaving in a plastic manner, squeezing into the wellbore.
- Reactive formations swelling into the wellbore.
- Drillstring vibration causing caving that packs off the drillstring.
- Keyseating occurs when the rotating drillpipe wears a groove into the borehole wall making tripping of the larger diameter tools out of the hole challenging.
- Under-gauge holes develop when the bit starts to wear. Running a new bit poses the risk of jamming in the under gauge section.
- Hole cleaning problems preventing the removal of cuttings from the borehole, packing off the drillstring.

All these sticking mechanisms have their early warning signs. This can be avoided or successfully mitigated. To do so, the drilling and formation parameters must be closely monitored. As there is a connection between the formation and the surface mechanical drilling parameters the latter can be used to approximate the formation parameters. Several authors worked hard to develop mathematical models to describe the drilled formations based on the surface drilling parameters with limited success. This is where the power of the ANNs proves very useful.

The aim of this section is to develop a feed-forward artificial neural network that can recognize critical points of an open-hole section, where some kind of sticking may occur during tripping in and out of the hole. The neural network should also be able to provide an early warning sign to prolong the time window for any reaction to make. To develop the network, the surface mechanical drilling parameters are used exclusively which can be monitored at all times at the rig site:

- Measured depth (MD)
- Rate of penetration (ROP),
- Weight on bit (WOB),
- Revolution per Minute (RPM),
- Flow rate (FR),
- Torque (TQ),
- Standpipe pressure (SPP),
- Mud weight in and out (MW),
- Mud temperature in and out (TMP),
- Total gas content (TGAS).

Using these surface drilling parameters, the artificial neural network is trained and tested on the data of 3 drilled wells. 65% of the data is used to train and 35% is used to test the neural network. As a result, the ANN will be able to point out critical points along the trajectory of the well, where the stuck pipe may occur during tripping in and out, also providing an early warning sign for the driller to react faster.

2.1 Development environment

The presented development is done in Java language, with the use of the deeplearning4j library. When considering large-scale server-side applications, Java is the most favored, the deeplearning4j library makes it possible to develop artificial neural networks in Java or to import (even retrain) models from Pytorch, Tensorflow, or Keras and deploy them in JVM Microservice environments, mobile devices, IoT, and Apache Spark.

2.2 ANN development

During the development process of the neural networks, an iterative approach was applied, which included the generation and the training of several networks with a static, common base configuration and changing "case" configuration. The changing configuration contained the number of hidden layers (1, 2

,3), the overall number of hidden neurons (12 and 15), the number of training epoch (200, 400, 600, 800), the size of data batches(30, 50, 100, 250, 500), the learning rate (1e-4, 5e-4, 1e-3, 5e-3) and weight decay (1e-7, 5e-7, 1e-6, 5e-6, 1e-5, 5e-5, 1e-4) applied for the optimization function. This resulted in 3360 models for both trip-out and trip-in procedures.

The applied activation function was ReLU in the hidden layers, sigmoid in the output layer, and hyperbolic tangent in the input layer.

ReLU is the simplest non-linear activation function, which performs well in most applications, as it avoids and rectifies the vanishing gradient problem. Most of the deep learning models use ReLU nowadays. However, ReLU should only be used within hidden layers of a neural network. For the output layer, the activation function should be sigmoid for binary classification, hyperbolic tangent for multiclass classification, and linear for a regression problem.

The zero-centeredness issue of the sigmoid function can be resolved by using the hyperbolic tangent function. Because of this, the hyperbolic tangent function is always preferred to the sigmoid function within hidden layers. However, the hyperbolic tangent still suffers from the other problems plaguing the sigmoid function, such as the vanishing gradient problem.

Sigmoids suffer from the vanishing gradient problem. They are not zero-centered; gradient updates go too far in different directions, making optimization more difficult. Sigmoids saturate and kill gradients and also have slow convergence. Sigmoids are still used as output functions for binary classification but are generally not used within hidden layers. A multidimensional version of the sigmoid is known as the softmax function and is used for multiclass classification.

The applied loss function was mean squared logarithmic error. The adaptive moment estimation method was applied as the optimization method. Adaptive Moment Estimation (Adam) [14] is a method that computes adaptive learning rates for each parameter. In addition to storing an exponentially decaying average of past squared gradients. Adam also keeps an exponentially decaying average of past gradients similar to momentum. Whereas momentum can be seen as a ball running down a slope, Adam behaves like a heavy ball with friction, which thus prefers flat minima in the error surface.

The applied initialization method was the Xavier method, which is a simple heuristic for assigning network weights. With each passing layer, the variance should remain the same. This keeps the signal from exploding to high values or vanishing to zero. So the weights should be initialized in such a way that the variance remains the same for both the input and the output. The weights are drawn from a distribution with zero mean and a specific variance. The normalization and standardization are done by the default data initialization module of deeplearing4j.

2.3 *Model evaluation*

During the training process, only the first well's data was used, as it had the most problems during the trip in and trip out processes. The data of the two other wells were used as a validation check to give feedback on how well a network can be utilized for new wells.

For the evaluation of the generated and trained models, so-called confusion matrices were used. Each row in the matrix represents the instances in an actual class while each column represents the instances in a predicted class (Figure 7):

	Predicted Positive	Predicted Negative
Actual Positive	True Positive (TP)	False Negative (FN)
Actual Negative	False Positive (FP)	True Negative (TN)

Figure 7 Confusion matrix

With the parameters of the confusion matrix the following indicators (2), (3), (4), (5) are calculated:

$$Recall = \frac{TP}{TP + FN} \quad (2)$$

$$Precision = \frac{TP}{TP + FP} \quad (3)$$

$$F1\ score = \frac{2TP}{2TP + FP + FN} \quad (4)$$

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (5)$$

The F1 score is the harmonic mean of precision and sensitivity.

The evaluation process consisted of the following steps:

1. Eliminate the models which gave a worse than 0.5 value for any of the indicator parameters on the training dataset.
2. Search for the models which resulted in the best indicator parameter values on the training dataset.
3. Search for the models which resulted in the best indicator parameter values for the validation datasets.
4. Eliminate models, where overfitting is indicated (indicator parameters have high values in case of training dataset and low values in case of training dataset).
5. For each generated model calculate the ratio of the calculated and best values for each indicator parameter.
6. Select the model with the best calculated / best ratio values.

Unfortunately, the amount of data for the third well in case of build-in problems was not sufficient for the evaluation.

3 Results

The best model for the trip-out procedure is summarized in Table 1. The high ratio values in the case of the two validation datasets suggest, that the model gave exceptionally good results compared to all the built models. On top of that, the actual values are also high (averaging above 0.8), which means, that the model performs well outside of the training dataset. The somewhat low recall ratio in the case of the training dataset is because of an overfitted model, which resulted in a recall value of 1 for the training set but very low values for the validation sets. The network has the highest hidden layer number and hidden neuron number among the provided options, which indicates high nonlinearity between the input and output parameters. Both the batch size and the epoch number are just the second highest within the given range. This is an indication of the optimal setup because neither the increase nor the decreasing of training cycles or training batches would improve the performance of the model.

Table 1 Best model for trip-out procedure

Trip out procedure		
Layer number	3	
Hidden neurons	5	
Epochs	600	
Batch Size	250	
Learning rate	1,E-03	
Weight decay	1,E-06	
Training Dataset		
Indicator	Actual	Ratio
Accuracy	0,9112	0,980312
Precision	0,8579	0,895886
Recall	0,7253	0,7253
F1 Score	0,786	0,941881
First Validation Dataset		
Indicator	Actual	Ratio
Accuracy	0,8502	0,980312
Precision	0,8147	0,895886
Recall	0,8293	0,7253
F1 Score	0,8219	0,941881
Second Validation Dataset		
Indicator	Actual	Ratio
Accuracy	0,9122	0,939463
Precision	0,908	0,909606
Recall	0,6781	0,78921
F1 Score	0,7764	1

The best model for the trip-in procedure is summarized in Table 2. As it was stated before, in the case of the third well, there were not enough positive occurrences (which is fortunate from the perspective of the drilling procedure) for the evaluation. The presented model provided the best average ratio values for both the training and validation datasets. Unfortunately, the actual values are low especially in the case of the precision and F1 score, which means that the model overpredicted the number of positive occurrences for the validation set. The reason for this could be the relatively low occurrence of failure during the build-in procedures of the second well. The batch size, the learning rate, and the weight decay are all one of the extreme values, which indicates, that the optimal model was not found.

Table 2 Best model for trip-in procedure

Trip out procedure		
Layer number	2	
Hidden neurons	6	
Epochs	600	
Batch Size	30	
Learning rate	5,E-03	
Weight decay	1,E-04	
Training Dataset		
Indicator	Actual	Ratio
Accuracy	0,9739	0,993066
Precision	0,931	0,931
Recall	0,8882	1
F1 Score	0,9091	0,977948
Validation Dataset		
Indicator	Actual	Ratio
Accuracy	0,6945	0,729364
Precision	0,1047	0,985876
Recall	0,7143	0,7143
F1 Score	0,1826	1

4 Conclusion

The presented results show that the described methodology is sufficient to develop such neural networks which can predict the possible problems during the trip-in and trip-out procedure at an acceptable level.

The indicator parameters reached high values in the case of both procedures considering the training dataset. The significance of this result lies in the fact that the drilling procedure consists of a series of build-in and out sessions. With every session, the accuracy of a neural network can be improved, so each session will be safer than the previous.

With the evaluation of the validation dataset, the applicability of a pre-trained model is tested. For the trip-out procedure, the results were really promising, the

indicator parameters showed accuracy levels way above the acceptable level.

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FRESH METHOD: 3D BIOPRINTING AS A NEW APPROACH FOR TISSUE AND ORGAN REGENERATION

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Keywords: FRESH, bioprinting, hydrogel, 3D printing
Abstract: Over the last decade, techniques of additive manufacturing of biomaterials have undergone a transformation, from a fast prototype tool used in research and development, to a viable approach in the production of customised medical devices. The key to this transformation is the ability of additive manufacturing to precisely define the structure and properties of a material in three dimensions, and to adjust those properties to unique anatomical and physiological criteria based on the medical data obtained by Computed Tomography (CT) and Magnetic Resonance Imaging (MRI).
The 3D bioprinting technique was developed as a solution to provide temporary and ubiquitous support of structures during the printing process. In general, integrated 3D printing may be understood as a building chamber that is filled with bearing materials, where biomaterials, cellular spheroids, cell-laden hydrogels and other materials (bioinks) are deposited using a syringe-based extruder. In particular, FRESH 3D bioprinting is a revolutionary technology, which may bring a fast and efficient advancement to medicine thanks to the ability to print new tissues from live cells.

1 Introduction

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2 3D bioprinting techniques

There are several 3D bioprinting techniques which are currently used in the fabrication of 3D tissues. The following three basic approaches are the most frequently used (Figure 1):

1. Extrusion-based bioprinting.
2. Inkjet bioprinting.
3. Laser-assisted bioprinting.

The extrusion-based bioprinting is a technology based on using jets and the printing process requires mechanical pressure for the controlled and continuous extrusion of bioinks through the syringe jet. Materials may be extruded in three ways, in particular using the air (pneumatically), a piston, or a screw. The most promising properties of this technology include the universality of the choice of materials within a wide range of bioinks and the high-precision production of chemically relevant tissues or organs. Optimisation of the jet diameter is the main parameter of the printing process for a particular hydrogel. A low-diameter jet for viscous hydrogel requires high pressure, and high extrusion pressure increases the shearing stress of cells. At a higher shearing stress, cellular damage may occur and this may reduce the life cycle of the

cells after the printing. The pneumatic approach provides reduced cellular damage due to a lower shearing stress during the printing process [2][3].

The inkjet bioprinting is a 3D bioprinting technology which is based on a conventional process of ink printing. It is a contactless printing process in which bioink droplets are deposited onto a hydrogel substrate or a culture dish under computer control. The common methods can be further classified into thermal and piezoelectric actuator methods based on the droplet actuation mechanism [4].

In the thermal technology, heating causes gasification and formation of bubbles. Inflated bubbles force the ink out of a narrow nozzle and onto the substrate. In piezoelectric technology, droplets are generated by the transient pressure from a piezoelectric actuator. The piezoelectric method does not use heat and does not cause orifice clogging, thus allowing droplets to remain directional while maintaining a regular and constant size [5].

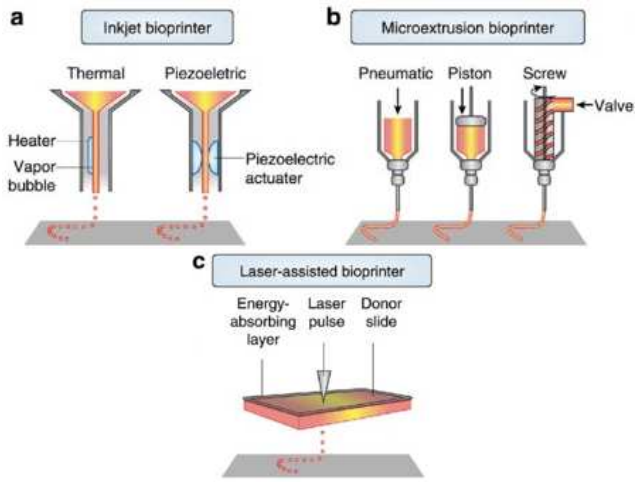

Figure 1 Basic principles of 3D bioprinting [6]

The third method is the laser-assisted bioprinting. This technology consists of directing laser impulses through the layers of materials containing also bioink onto a substrate. The substrate is coated with a layer of titanium or gold that absorbs the laser energy to avoid cellular damage. The lower section of the layers contains cells and a biomaterial, which together form a high-pressure bubble following the evaporation induced by a laser impulse. The bubble propels the bioink layer and forms droplets in order to facilitate depositing bioink onto the substrate [7].

3 Commonly used materials for bioprinting

The 3D bioprinting of tissues or organs is usually carried out using hydrogel materials (Figure 2). Hydrogels are materials capable of holding a mass of water. The development of first hydrogels dates back to 1950s, when contact lenses were developed. Hydrogel is a hydrophilic polymer material holding a great amount of water while maintaining its structure thanks to chemical or physical cross-linking of the individual polymer chains. Hydrogels also exhibit high elasticity, similar to tissue elasticity, as they contain large amounts of water [8].

Hydrogels possess many attractive properties which are suitable for the application of hydrogels as tissue scaffolds. For example, they are biocompatible and typically biodegradable, majority of them having specific cell-bonding sites which are necessary to adhere, proliferate, grow and differentiate. Furthermore, some of these biomaterials may easily be cross-linked when present in modified forms [9].

Figure 2 3D printing of anatomical structures from hydrogel

Bioinks are solutions from biomaterials that contain encapsulated living cells and are the basis of bioprinting. It is important that such materials contained in biomaterial solutions protect cells from mechanical deformation during the printing process, provide them with nutrients and allow them to proliferate [10].

Collagen is a major building block found in mammalian cells, specifically in the extracellular matrix, making it an attractive material for applications in biomedical engineering, tissue engineering and regenerative medicine. it has similar physicochemical properties to tissues and, due to its biocompatibility, is widely used in both in vivo and in vitro applications. Type I collagen has been applied using the FRESH method and is the most common type of collagen. It represents up to 90% of collagen in the skin, tendons, bones and elsewhere in organisms [11].

Gelatin Gelatin is produced by denaturing collagen, for example, from the bones, tendons or skin of animals by acidic or basic hydrolysis. Due to its properties such as thermosensitivity and the ability to form a hydrogel at lower temperatures depending on the concentration, it is one of the most commonly used natural polymers. In addition to biocompatibility, biodegradability, the

advantages of gelatin include low antigenicity, the absence of harmful by-products, easy processing and low costs. All these properties, and in particular its cellular affinity, make it a universal material for applications in tissue engineering and bioprinting [11].

Hyaluronic acid (HA) is a hydrophilic linear anionic polysaccharide composed of 1,3-β-D-glucuronic acid and 1,4-β-Nacetyl-D-glucosamine. It is a major component in the extracellular matrix (ECM), where it plays a crucial role in maintaining cartilage homeostasis by regulating cellular functions and the production and retention of matrix components. It is found in most tissue binders in all living organisms. HA is currently used as a lubricant and in healthcare to prevent postoperative adhesions. Because HA is naturally present in tissues, it can be used to encapsulate cells [12][13].

Alginate is a natural polysaccharide - a natural anionic polysaccharide refined from brown seaweed and is similar to the glycosaminoglycans found in the native ECM of the human body [12].

Chitosan has been studied in recent years for various tissue engineering applications due to its biocompatibility, biodegradability, low immunogenicity and also cationic nature. Thanks to these properties, it is a promising bio-material for tissue engineering applications. The higher degree of deacetylation of the chitin chain promotes the biocompatibility of these hydrogels [10].

4 The principle of the FRESH 3D bioprinting

FRESH (Freeform Reversible Embedding of Suspended Hydrogels) technology is based on the principle of extruding biomaterial from the reservoir syringe in its liquid form into a support bath, where the biomaterial must polymerize rapidly. This polymerization process occurs by rapid crosslinking of the polymer molecules, and this crosslinking mechanism depends on the type of 3D printed hydrogel (Figure 3) [9].

FRESH uses a thermoreversible support bath, which allows the deposition of hydrogels in 3D biological structures of the desired shape. The benefit of the FRESH method is the storage and insertion of hydrogels or bioinks, which have been 3D printed in a second hydrogel support bath, which retains the desired shape during the printing process and significantly improves print fidelity [13].

The support bath and thus the hydrogel is placed in a container of the desired size, consisting of gelatin particles which act as a Bingham plastic during the printing process. This means that at low shear stresses they behave like a solid body, but at higher shear stresses they flow like a viscous fluid. When the needle nozzle moves through the bath, there is little mechanical resistance; nevertheless, the hydrogel is expelled from the nozzle and stored in the bath held in place. In this step, the gelatin suspension is maintained at 22 °C in order to preserve its rheological properties. Soft materials that would collapse when printed in air are therefore easily maintained in the intended 3D geometry. The whole process takes place in a sterile, aqueous, buffered medium biocompatible for the cells used [9].

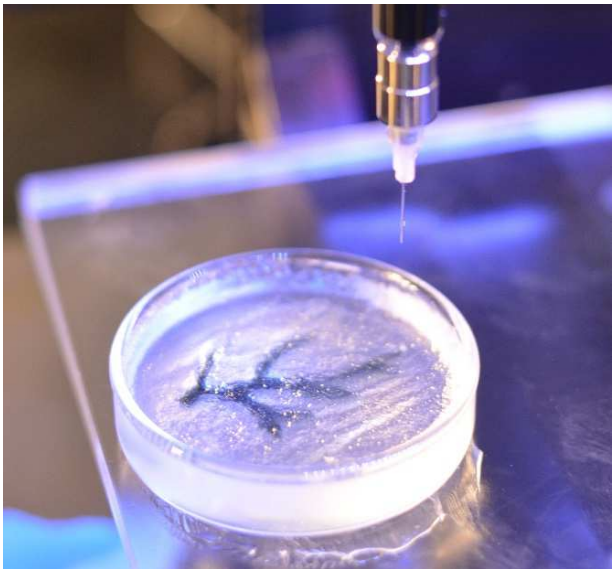

Figure 3 FRESH 3D printing technique

Once the entire 3D structure is FRESH printed, the temperature is raised to a cell-friendly 37 °C; this causes that the gelatine support bath melts for used printed cells in bioink in a non-destructive manner. FRESH therefore enables direct 3D printing of biologically relevant hydrogel inks, including alginate, fibrin, type I collagen, and Matrigel, within a support bath designed to be removed afterwards [14].

The most common material selected for use as a supportive bath is gelatin. It is also suitable due to its biocompatible properties, because it is never possible to remove 100% of the support bath from the extruded structure. Even because of its origin in collagen, it is able to bind to polysaccharides and other ECM proteins. Thus, the residual amount of support bath does not adversely affect cell integration, but may increase cell adhesion.

5 Conclusions

The main challenge in tissue engineering and regenerative medicine is the production of functional tissues and organs to compensate for a limited number of transplant donors. Until now, most 3D bioprinted tissue constructs were relatively small when compared to tissues or organs that need to be replaced. This is partially caused by the problems associated with 3D bioprinting of soft materials and cells. Therefore, FRESH printing has the potential to become the technology for manufacturing models which will facilitate complete fabrication of tissues based on patient-specific anatomical data.

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EFFICIENCY MODEL FOR THE PROLIFERATION OF SECONDARY MARKET SUPPLY CHAIN – WITH REFERENCE TO THE INDIAN GARMENT CLUSTER

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Keywords: secondary market, reverse supply chain, retail garment business, supply chain performance, supply chain practices
Abstract: The growth of secondary market in retail garment trade has been a major boost to economic growth in developing nations. This paper highlights the importance of effective forward and reverse supply chain the garment sector as driver for this booming secondary market. A conclusive research technique has been adapted to study the supply chain practices followed in the garment business those in the primary and secondary market. Structural equation modelling is used to validate and test the proposed model for supply chain performance. Cluster sampling method was incorporated. Owners of garment manufacturing firms in and around Coimbatore, Tirupur, Salem, Bargur and Bengaluru region would form the respondent group. A structured questionnaire was given to them to understand their supply chain practices, supply chain flow velocity and flow efficiency and its impact on their business performance. The firms operating under uncertain circumstances in the secondary supply line have adopted practices which lead to appropriate velocity and efficient flow of money, material and information which has been proved through the testing of the model. The velocity and efficiency in the supply line has improved the performance thereby ensuring a more sustainable business for the firm operating in the secondary markets. This study has contributed in understanding the various dimensions of best supply chain practices and its effect on the flow velocity and flow efficiency of the money, material, and information in the secondary market garment supply chain. An assessment of the results of the study has opened a window to the operations of the secondary garment supply chain line in the Indian cloth market which have been more or less camouflaged under the primary market operations. The outcome of the research also shows that these secondary market players have evolved their own strategies to sustain in volatile and uncertain circumstances. These strategies have proved to be very effective in minimizing wastage and increasing profitability of the manufacturing firms. The implications of this study is bound to give much needed support and leverage to the frail and underperforming secondary garment cluster which is a major contributor of Gross Domestic Product and employment ratio.

1 Introduction

The Indian garment value chain has spread across organized and unorganized segments increasing overall competitiveness (Sudeshna Chattopadhyay and Sarmishtha Sen, 2018). Recent studies have shown that retailers focus more on delivering value to their customers through their strong supply chain to win over their immediate competitors. The supply chain management (SCM) has gotten extremely basic to oversee the hazard and complexities of worldwide sourcing. A completely coordinated supply chain is required for the organization to pick up the most extreme advantages. The goals of the supply chain and its performance should be comprehended to assemble the best supply chain. Performance's estimations give a way to deal with distinguish the achievement and capability of supply chain management systems. One significant part of the supply chain management is to choose the correct source of supply in the worldwide business condition that can bolster the corporate system. In opposition to the traditional ill-disposed connections, powerful supply chain management in the new rivalry proposes looking for cosy connections in the long haul with a fewer number of partners.

Reverse supply chain takes place in the opposite direction to regularize the flow of material, money, and information. The reason being either to recycle, return, or repair a product. Returns of material were generally accepted for maintaining the reputation of the firm through customer satisfaction which in turn helps the firm to maintain its market reputation and thus achieving sales turnover. Recycling was favourable in two ways; to reduce the raw material requirement which in turn minimizes the cost involved and likewise helps in the disposal of damaged materials. Reverse supply chain solves two vital purposes: creating high – value recovery and low – to no value recovery. Value creation in the second life retailing has thus lead to the growth of secondary garment market.

This study was carried out in the western region of Tamilnadu and Karnataka state of India, predominantly in Coimbatore, Bargur and Tirupur districts which are well known for their garment manufacturing clusters and have been nick named as the Manchester of India. Much of the garment manufacturing firms are located in sub-urban towns and in rural villages in this region. The products manufactured in these remote locations depend heavily on logistics and supply chain to reach the consumers on time to meet the growing demand. The manufacturing firms located in Coimbatore and Tirupur are facing problems due to bulk storage, rising inventory cost, labour shortage and disruption in the supply chain network. The present economic condition due to the pandemic situation has led to stagnation and piling up of large quantity of stock. Because of the uncertainty that exists in the functioning of the supply chain back to its original capacity, has been a cause of concern for many of these firms. The huge stocks at the go-downs have been subject to damages and have increased the wastage. This situation has curtailed the cash flow at every node of the supply chain. Under normal circumstances these products which fail quality test and show minor variations in terms of the product consistency make their way into reprocessing units and land up in the secondary markets for sale. A continuous supply to the secondary markets is a strategy that has been followed by many of these garment manufacturing firms over the years to minimise the loss caused due to improper product output, to ensure cash flow and profitability. The products obtained from these primary manufacturers have to go through reprocessing and land up in the hands of agents and dealers who in turn pass it on to the secondary retail cloth merchants and street markets. The current pandemic situation has strangulated the supply chain of these secondary markets because of nil demand and low purchasing power of the lower middle-class segment who are consumers for these products. This unforeseen situation has disrupted material, money and information flow within the secondary supply chain leading to closure of many of these reprocessing units, dealers and agents. The skilled labour force which have come down to work in these manufacturing units and secondary line of operations have migrated to their native locations in the north of India leaving a void for skilled labour. Many of these secondary markets discussed in this paper have found ways to customize their strategies to survive and sustain in this uncertain period. Careful observation and a vivid reading of the literature has prompted the researcher to narrow down to study certain variables pertaining to the secondary market supply chain. The variables impacting this study on secondary supply chain are supply chain practices, supply chain performance, flow efficiency, flow velocity and business performance.

2 Literature review

2.1 Reverse supply chain

Fleischmann et al. (2000) features the developing significance of Reverse Supply Chain Management (RSCM) essentially on understandings for abundance items and broadened maker obligations. As understandings for overabundance items are related to item returns, which can be exceptionally high in certain ventures encountering returns at more than 50 percent of deals, broadened maker obligations manage expecting organizations to successfully deal with the whole existence of the item. The secondary market an extension of the primary market and contributes to the second level in the value chain process. Reprocessed products are sold in secondary markets for additional revenue, often it is offered to a market segment where the purchasing power is comparatively low and shows less importance to branded commodities.

The presence of secondary markets of remanufactured variants of items and the cannibalization impact of the secondary market on the new items decides the main concern of Reverse Supply Chain Management (RSCM) activities in the various enterprises. As supply chain members improve their relationship management and create trust, they search for chances to improve supply chain execution estimates, for example, cost, quality, speed, flexibility, and sales turnover (Selnes and Sallis, 2003). With regards to supply chain frameworks, recent works show that trust diminishes process duration (Handfield et al., 1998) and builds flexibility, stock turnover, and satisfaction rates. Handfield and Bechtel (2002) found that trust in a supply chain relationship can improve provider responsiveness. Improvement in characteristics like responsiveness, reliability, practicality, exactness, and critical thinking are identified with upgrades in the performance of the supply chain. It tends to be concluded that a nearby working connection among manufacturers and their suppliers that incorporates trust will decidedly influence the performance of the supply chain. (Mahour et al.,2019)

Fleischmann et al. (2000) base the developing significance of Reverse Supply Chain Management (RSCM) fundamentally on understandings for overabundance items and broadened manufacturer duties. As agreements for overabundance items are related to item returns, which can be extremely high in certain enterprises encountering returns at more than 50 percent of sales, broadened manufacturer duties manage expecting organizations to adequately deal with the whole existence of the item.

Research on the reverse supply chain has been increasing ever since the 1960s and research on technical aspects and models on reverse co-ordinations started to emerge in leading publications during the 90s. Rogers and Tibben-Lembke (2001) shed new light into the current

comprehension of reverse co-ordinations, some of which were broad and included supportability, income upgrade, and cost decrease. Carter and Ellram (1998) clarified that three basic intra authoritative exercises that crash into reverse co-ordinations: promise to natural issues, moral principles, and arrangement business visionaries who embrace an ecologically neighbourly way of thinking.

Traditional forward supply chain functions in such a way as to satisfy a customer as a final destination. Whereas, the reverse supply chain starts its operations right from the customer as an initial focal point. Guide and Van Wassenhove (2009) in the concept of Reverse Supply Chain had considered five interconnected processes: product acquisition (procuring used products), reverse logistics (movement of the used products from the market to sorting factory), product testing, recovery operation and remarketing.

Guidini (1996) had explained that the reverse supply chain helps in recapturing and recovering the value of the used products and thereby intends in the development of a new market which leads to lower pollution levels in the environment (Lee et al., 1995). Huge consideration is being given for reverse logistics because of considering its benefits and enhanced value creation.

2.2 Growth of secondary market supply chain

Reverse supply chain has emerged as one of the major driver for the growth of the secondary markets in the textiles industry. The secondary garment market is booming and could overtake fast fashion, according to ThredUP's annual resale report (2020). Secondary garment market has just released its annual fashion resale report, and the market is booming. ThredUP reports that, over the past three years, secondary markets had grown 21 times faster than apparel retail. The secondary garment market, currently worth $24 billion, is expected to reach $51 billion in five years. Growing numbers of shoppers are willing to buy secondary garments as the stigma associated with used clothing disappears. Millennials and boomers do the most second hand shopping, but Gen Z'ers (18-24) are the fastest-adopting group. More than 1 in 3 Gen Z'ers will buy secondary garments in 2019. Overall, 64 percent of women say they're willing to buy used apparel, shoes, and accessories, compared to 45 percent in 2016. Most exciting is that this secondary market is stealing revenue from fast fashion, an industry that is notoriously unsustainable. In fact, ThredUP suggests that the resale market will overtake fast fashion if it continues to grow at this rate. Moreover, the secondary garment market doesn't just involves sale of used cloths, but includes the products which were produced as excess goods or surplus and goods with mild defects.

2.3 Cases of efficient secondary textile market in India

2.3.1 Bargur

Bargur (Barugur/Barguru) also called mini-Surat is a town panchayat and taluk located in the Krishnagiri district, Tamilnadu, State of India. The economy here is well known for the textile trade, granite imports, mango cultivation, and export-oriented processing industries. Not only that, but the main importance of this town also comes from its secondary markets for garments. Customers from various towns and metro cities flood to this town to buy garments that are branded but find their way to this secondary market.

A shopkeeper named Mr. Hari having a textile outlet in the Bargur market for nearly a decade was interviewed. He narrated the risks and rewards that one can get it from the industry. From the narration, it was inferred that most of the products were purchased from Delhi, Agra, Mumbai, Surat, Chennai, Kochi to Chickpet. Based on the different trends and fashion in the market. The market trends are being updated to the suppliers through the agents and the agencies. The market had seen goods from various places and through various sources. Bargur market is also called a grey market as it sells smuggled goods through its efficient hidden supply chain. The market is also a hub for reprocessed garments. The interviewee vetoed to talk more about the smuggled goods and its supply chain. The Bargur market mostly had people who are interrelated within a community. It was very difficult for a person to go and find the traces of the supply chain and their suppliers. The supply of goods also included rejected goods from various ports and manufacturing units and re-processing units. The Bargur market had a very special element that is the credit purchasing of materials. The credit was given by most of the suppliers as the business was carried out within a close-knit community, the market itself holds as a guarantee for the purchases made by the shopkeepers.

The maximum credit time duration was approximately 60days. Only a few shopkeepers who faced financial crunch informed their market leaders well in advance and sold their products on credit. If there were issues in the payment the market leaders would take appropriate actions to get back the dues. The shopkeepers preferred to go as a group for the purchase of stocks as they get an extra discount for the bulk orders. They pay a certain amount for the order confirmation and pay the balance when the goods are received. The logistics are taken care of by the suppliers. The goods reach the place within the stipulated time in most of the cases. The suppliers are connected through the agents and agencies who act as intermediate for the sales. These agencies and agents receive a certain percentage of the amount as a commission from the suppliers after the sales and final amount later the due is paid. The damaged goods are collected at a point and are given at a very minimal cost to the roadside vendors. The

roadside vendors usually get the goods once a month from the collection point. The unsold goods are returned to the suppliers and are exchanged for the latest goods in the market.

Bargur's Secondary Market Supply Chain Flow Chart

Manufacturers ⟶ Middlemen (Agents/Agencies) ⟶ Wholesaler/Retailer ⟶ Street Vendors

The Bargur market witnesses customers mainly from metro cities like Bangalore and Salem who are brand conscious. They come down to Bargur to purchase formal wear and casual wear. The market witnesses around 2000 to 2500 customers flowing in every day. The sales are up to 15% to 25% of the investment daily. The market has shopkeepers who sell in bulk quantities and do not prefer retail sales. The shops are of various sizes and are mostly owned by private players and very few are run in government leased buildings. The shopkeepers preferred to do transactions in cash as most of their dealings are covert. The return on investment is high in the industry when compared to other industries. This market thrives on low investment and enjoys high returns as compared to the primary market for garments.

2.3.2 Chickpet

Chickpet (Chikkapete), Bengaluru's core commercial area for more than 250 years is one of the oldest shopping destinations in India, which is popular for saris that find takers even among the Mysore royal family. It is well known for wholesale and retail apparel shops. Chickpet is popular among the people for its variety of sarees, silver, and gold jewelry which are available at an affordable rate. The shops here have an average size of 100 sq. ft., the outlets enjoy 15% to 20% of return on investment, irrespective of the economic conditions.

Interviewing a shop owner in the market named Mr. Kailash, it was understood that the shop keepers in Chickpet mostly purchase their stocks from bigger markets like Delhi, Agra, Mumbai, Surat, etc similar to Bargur based on the variety. Moreover, the shopkeepers themselves are updated with the current fashion trends. Chickpet shopkeepers purchase the rejected and damaged apparel from the manufacturers who produce for leading brands. Goods that lack quality, the ones which are varied from the ordered colors, which differ in size are being purchased. These manufacturers who manufacture for brands are said to hold a maximum of 50,000 units of damaged and rejected pieces on an average per day. These pieces are sent out of their unit through agents and agencies who act as middlemen between the manufacturer and the wholesale/retail shop keepers.

These agents are said to have a commission on the sales volume. Once, the goods reach the wholesaler/retailer the payment is made directly to the manufacturer and it's the manufacturer who pays the agent a commission. Few transactions happen on a credit basis as well, for which the agent is held liable for surety. The credit terms are being fixed based on the firm's reputation and assurance given by the agent. Delay in payment will lead to higher interest rates and vice versa. All the agreements, terms, and conditions are framed orally and not in written format. The important thing to be noted is that it is very little or sometimes zero bad debts in these supply chain formats. The agency also acts as an official mediator between the two parties. The manufacturer sends the bill to the agency who then adds a certain percentage and then sends the agency's bill to the wholesaler/retailer. The wholesalers/retailer makes the payment to the agency and the agency settles to the manufacturer. The agreement, terms, and conditions are in a written format when an agency is involved, but the sad truth is that the bad debts ratio is slightly higher compared to the involvement of agents. The astonishing fact is that there is no loss in the whole chain of process and everyone connected in the chain will be able to take back his whole investment. Though the shops in the Chickpet market are closely connected and are nearby. They manage to sell their goods as expected. The shop keeper sells a minimum of 5 pieces per order and not less than that and their accounts are still maintained through books of accounts and ledger despite the growth of technological advancements. The customers for this Chickpet market are mostly retailers from other parts of India and women entrepreneurs who sell online and offline. The shopkeepers at Chickpet do accept the unsold goods from their customers but they don't return cash instead a new set of products is offered.

Chickpet's Secondary Market Supply Chain Flow Chart

Manufacturer ⟶ Agent ⟶ Wholesaler/Retailer
Manufacturer ⟶ Agency ⟶ Wholesaler/Retailer

2.3.3 Tirupur (Kadarpet)

Tirupur a small city located on the banks of Noyyal River in Tamil Nadu and is the fifth largest urban agglomeration. It is positioned at the center of the South Indian Peninsula, about 450 kilometers southwest of the state capital Chennai. Tirupur was an agricultural town with irrigated farms. During the 1970s those farmers became the owners of various textile related units. The step by step growth of the textile industry paved the way to an interwoven network of small scale units to grow into a big giant and thus made the city grow as a major textile hub. Tirupur is now a major hub for textile and knitwear

contributing to almost 90% of total cotton knitwear exports from India. It has therefore transformed into a large employment generating industry for over six lakh people.

By interviewing a domestic textile manufacturer Mr. Mohammed Shafi, who is in this field of textiles for more than 25 years, it was understood that he had customers coming from varied parts of India like Hyderabad, Bengaluru, Mumbai, Delhi, etc. It was fascinating to know that each customer approached with a bulk order quantity which comes close to around fifty lakh pieces per order. Primarily, their customers are acquired through marketing activities carried out by themselves and also through agents/agencies. The agencies help manufacturers to get orders from customers. Agencies are found to act as middlemen between the manufacturer and wholesaler/retailers. Acquiring customers through agencies act as an assured platform in terms of payment guarantees. The wholesalers or retailers are given a maximum of 45 days credit period based on trustworthiness, however, if it's a new client they had to make an advance payment. If their repayment crosses 45 days, interest is being calculated accordingly. The manufacturer is the one who pays the commission to the agency. Transportation of goods is taken care of by the manufacturers, themselves through their regular logistics service providers. Each piece is sent out along with price tags. Defective pieces are collected separately and are sent to a separate secondary market.

Kadarpet's Secondary Market Supply Chain Flow Chart

Manufacturer ⟶ Agent ⟶ Wholesaler/Retailer
Manufacturer ⟶ Agency ⟶ Wholesaler/Retailer

Mr. Mohammed narrated that there arise situations where a huge volume of material around one lakh pieces had been rejected by the customer. To overcome losses those rejected pieces were sent directly to Kadarpet (secondary) market. He states that regular customers for these secondary markets are generated through word of mouth. The customers are responsible for the lot they purchase in these markets. No returns would be encouraged. These secondary domestic market's design requirements keep changing twice a month. Therefore designs are all predicted and procured in these markets. This market exists because of cash to cash transactions. No credit would be encouraged. The return on investment will be around 15% to 20%. The manufacturers like Mr. Mohammed usually send the defective or rejected pieces to these secondary market through agents or brokers.

Interviewing a secondary market stockiest Mr. Mohammed Arham, it was astonishing to know that there were around 10,000 to 20,000 companies in Tirupur who were regular garment (rejected/surplus pieces) suppliers to the secondary market like Kadarpet. Therefore, he stated that the retailers had a wide variety of suppliers to choose from. Few retailers will be regular customers for a specific garment manufacturing company. Predominantly, these secondary markets receive products that were rejected by quality control, surplus production of garments, order cancellations, delayed orders, stock clearance, etc. Since shopping had become a hobby these days, these markets enjoy huge profits serving the middle class. The interviewee had more than 23 years of experience in this field and he is a stockiest had both wholesalers and retailers as his customer base. He stocks all kinds of garments for boys, girls, men, women, and kids. Therefore a large number of retailers and wholesalers who deal with secondary markets would turn up. He procures rejected and surplus garments from multiple garment manufacturing companies which are placed at Tirupur. He also had customers who would redesign the procured products and then sell them to the wholesalers/retailers. The business runs in cash and no credits are encouraged. Brokers are being involved and they work as middlemen between the stockiest and the wholesaler/retailer and get paid in the form of commissions. The stockiest is a taxpayer and his warehouse is a Goods and Service Tax registered firm. The goods once sold are not being accepted whereas goods can be exchanged with a new set of goods but this applies only with the regular customers. He makes a point that not all the roadside shops sell defective pieces, they sell unfamiliar branded pieces. The stockiest calls attention to the Kadarpet market where there is a wide variety of products found which would suit every need of the customer. He articulates that this is the business that runs on the principle of "low investment, high returns". He also states that these secondary markets are the place where an ample number of employment opportunities are being generated.

Kadarpet's Secondary Market Supply Chain Flow Chart

Manufacturer ⟶ Stockiest ⟶ Wholesaler/Retailer
Manufacturer ⟶ Stockiest ⟶ Broker ⟶ Wholesaler/Retailer

2.4 Objectives

- To understand the functioning of reverse supply chain and its contribution to the growth of the secondary market in the garment business.
- To find out the supply chain practices followed in the retail garment business.
- To propose, validate, and test a suitable model to find the impact of supply chain practices on the performance of the business.

3 Methodology

The research design is conclusive in nature. The sampling frame consisted of firms in the secondary market supply chain and distribution network. This research intends to prove that the best supply chain practices followed in the secondary market helps to improve the supply chain flow efficiency and velocity of the firm which in turn helps to have better supply chain performance, better supply chain performance helps in achieving the overall business performance. A cluster sampling method was incorporated. Owners of garment manufacturing companies, dealers for secondary market and agents were selected as the target respondents for this research as their involvement decides the functioning of the supply chain to the secondary market. A structured questionnaire was developed, purified and administered to the target respondent group for primary data collection. A pilot study was conducted on the respondents to test the reliability of the instrument for use in a large-scale data collection. A reliability of 0.7 (Cronbach alpha) demonstrates sufficient instrument reliability for data collection (Nunally 1978). The Cronbach alpha value for the constructs were greater than 0.7 which is sufficiently reliable. The instrument was administered to a total of 500 respondents out of which 250 were garment manufactures, 150 were dealers and 100 were commission agents. Sample size adequacy calculation makes use of many thumb rues. However, the most prudent way to determine a sample size adequacy will be to make use of power analysis. For this purpose, G* power 3 software is used. A post hoc sample size calculation for PLS Path modelling makes use of four constants – effect size, significance level, power of the test and number of predictors. The effect size is a measure of the strength of the effects being studied in the research. According to Cohen (1978) the value of effect size is 0.02 for small effects, 0.15 for medium effects and 0.35 for large effects. Most researches usually study the largest relationships between constructs. The significance level is also known as type I error. It is the probability of rejecting a correct hypothesis. The commonly used value for α is 0.05. The power of a test (1-β) is the probability of not accepting wrong hypothesis. The usually accepted minimum value of (1-β) is 0.8. Any lower values will indicate a test that is not powerful enough. The number of predictors is the number of indicators contained in the most complex construct in the proposed path model. These four constants are fed into the software to analyze the deviation of R squared value from zero. The resultant output contains the required sample size satisfying the input conditions along with the actual testing power of the sample size. A post hoc calculation after the purification of the constructs is conducted to yield the net power of the sample being studied.

F tests - Multiple Regression: Omnibus (R^2 deviation from zero)

Analysis:	Post hoc: Compute achieved power		
Input:	Effect size f^2	=	0.03
	α err prob	=	0.05
	Total sample size	=	500
	Number of predictors	=	5
Output:	Noncentrality parameter λ	=	15.000000
	Critical F	=	2.232261
	Numerator df	=	5
	Denominator df	=	494
	Power (1-β err prob)	=	0.862113

The effect size shows the precision of the sample size for the research (Figure 1). Since the research is in the area of social science, the effect size is fixed at a 0.03 which is a medium level. The α value describes the significance level and is at 5 percent level of significance. Using the combination of responses from 500 respondent and 5 independent constructs, we obtain the power of the test as 0.86. This clearly indicates that the theory will be true 86 percent of the time and the sample size of 500 respondents is sufficient to prove this theory.

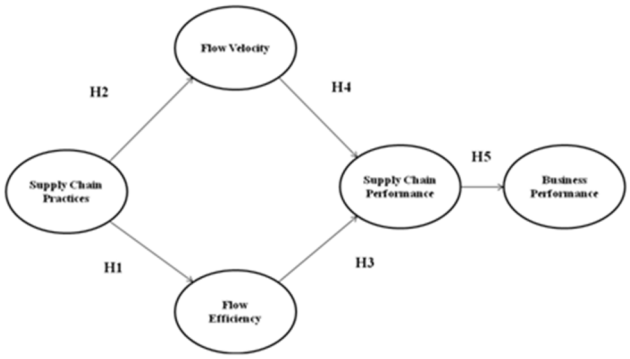

Figure 1 Conceptual model

4 Empirical data and results

4.1 Constructs to examine the efficiency of secondary supply chain

4.1.1 Supply chain management practices

Donlon (1996) portrays the most recent advancement of SCMP, which incorporates provider association, re-appropriating, process duration pressure, and nonstop procedure stream, and IT sharing. With more noteworthy client esteem and upper hand being the superseding goals of supply chain management (Wisner, 2003), it is battled that coordinated SCMP of the firm, for example, key

collusions or formal provider advancement systems, data sharing (IS), data quality (IQ), can affect relative serious quality. Few supply chain management practices were considered for the study namely strategic supplier partnership (SSP), customer relationship, Information Quality, Information Sharing, Lean Retailing Strategies, and Postponement (Gawankar et al., 2013).

4.1.2 Flow velocity

Supply chain velocity is up tied with the adverse speed of response of the supply chain to face the market changes. Supply chain velocity is especially required in the event of disruption for response and recovery. Chris Clark (2007) had proposed the top five tips for accelerating supply chain velocity, namely: scrutinize sourcing activities, continuously improve your systems, increase fulfillment flexibility and reduce cycle times, replace inventory with date, seek out smaller or niche vendors.

4.1.3 Flow efficiency

Goedhals-Gerber, L. (2016) had identified 12 major factors which influence the supply chain efficiency in South Africa, by conducting personal interviews with the field experts for measuring three parameters across a supply chain, namely: reliability, speed, and cost. Similarly in this study, Leila Louise, Goedhals-Gerber (2010) had identified few constructs for measuring service attribute which in-turn help in the flow of efficiency as quicker information flow, real-time information on demand, better planning of procurement, manufacturing, and sale, crating partner relations in a supply chain and better operational factors.

4.1.4 Supply chain performance

Curiosity over performance measurement and management had prominently gained importance over the last 20 years (Taticchi and Balachandran, 2008; Gopal and Thakkar, 2012). The constructs which were considered for the study were Supply Chain Flexibility, Supply Chain Integration, Responsiveness to Customers, Product Innovation, Partnership Quality and Supplier performance (Shradha Ashok Gawankar, Sachin Kamble, and RakeshRaut, 2017).

4.1.5 Business performance

Business performance is a lot of execution the executives and expository procedures that empower the administration of an organization's presentation to accomplish at least one pre-chosen objectives. (Thilini R. Ariyachandra, Frolick, Mark N.,(2006)). A business performance management, observing project three essential exercises — a determination of objectives, combination, and mediation screens a unique framework with questions and requires cautious usage to effectively create business effectiveness.

5 Results and discussion

5.1 Hypothesis testing

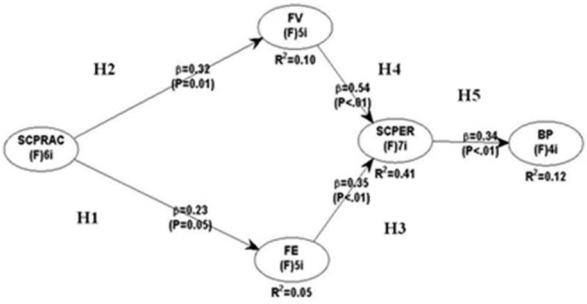

Figure 2 Hypothesis testing

Table 1 Relationship between the independent variable and dependent variable of Primary Market's Reverse Supply Chain

Hypotheses	P-value	Beta	R^2
Hypothesis 1(SC Practices*Flow Efficiency)	0.05	0.023	0.05
Hypothesis 2(SC Practices *Flow Velocity)	0.01	0.032	0.10
Hypothesis 3(Flow Efficiency*Supply Chain Performance)	<0.01	0.35	0.41
Hypothesis 4(Flow Velocity* Supply Chain Performance)	<0.01	0.054	0.41
Hypothesis 5(Supply Chain Performance* Business Performance)	<0.01	0.34	0.12

H1: Better supply chain practices in the secondary market leads to better flow efficiency.

From the above table (Table 1), it's evident that just supply chain practices don't lead to better flow efficiency. The significance value is 0.05 which proves the proposed hypothesis doesn't satisfy the condition. Hence, it's understood that many other factors are being included in achieving efficiency in a supply chain.

H2: Better supply chain practices in the secondary market leads to better flow velocity.

From the above table (Table 1), it's evident that better supply chain practices lead to better flow velocity. The significance value is 0.01 which is less than 0.05 proves the proposed hypothesis.

H3: Better supply chain flow efficiency in the secondary market leads to better supply chain performance.

From the above table (Table 1), it's evident that better supply chain flow efficiency leads to better supply chain performance. The significance value being <0.01 which is less than 0.05 proves the proposed hypothesis.

H4: Better supply chain flow velocity in the secondary market leads to better supply chain performance.

From the above table (Table 1), it's evident that better supply chain flow velocity leads to better supply chain performance. The significance value is <0.01 which is less than 0.05 proves the proposed hypothesis.

H5: Better supply chain performance in the secondary market leads to better business performance.

From the above table (Table 1), it's evident that better supply chain performance leads to better business performance. The significance value is <0.01 which is less than 0.05 proves the proposed hypothesis.

6 Conclusion

This study has contributed in understanding the various dimensions of best supply chain practices and its effect on the flow velocity and flow efficiency of the money, material, and information in the secondary market garment supply chain. The firms operating under these uncertain circumstances in the secondary supply line have adopted practices which lead to appropriate velocity and efficient flow of money, material and information which has been proved through the testing of the model. The velocity and efficiency in the supply line has improved the performance thereby ensuring a more sustainable business for the firm operating in the secondary markets. An assessment of the results of the study has opened a window to the operations of the secondary garment supply chain line in the Indian cloth market which have been more or less camouflaged under the primary market operations. The outcome of the research also shows that these secondary market players have evolved their own strategies to sustain in volatile and uncertain circumstances. These strategies have proved to be very effective in minimizing wastage and increasing profitability of the manufacturing firms. This research looked very closely into the functioning of the secondary market supply line in few recognized cities and towns like Tirupur, Bargur and Chickpet. There are other locations where this study could have been extended to get a very broad perspective on the strategies adopted by these firms. This study could also be extended to focus on the risk mitigation techniques, sustainability practices and technology adaptability pertaining to the secondary market. The growth of the secondary markets has contributed immensely to the socio-economic fabric of the nation. This research is helpful for academicians and researchers to conceptualize and frame new models to understand supply chain in the present scenario. The paper also aims to help the apparel sector to understand and efficiently develop and run their supply chain. The paper aims to give insights to government policy makers to alter and frame tax laws and other incentive schemes to encourage the growth of the secondary market.

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DESIGN AND ANALYSIS OF A PAPER SHREDDER MACHINE

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Keywords: shredder machine, design, cutting blade, CATIA
Abstract: A paper shredder machine is a device that can shred documents such as paper and plastic into small strips or shreds. Private companies use it to shred confidential private documents or other sensitive documents into small strips or rubble. Thus, these machines help secure information effectively and waste to the environment. The article offers an alternative to the design and calculation of a shredder model. In addition, the options for optimizing the cutting blade and evaluating the strength of machine parts are also discussed to ensure the reasonable of the model. The analysis results are carried out with CATIA software. The results can serve as a prerequisite for an optimal model of the shredder that will go into series production in the future.

1 Introduction

A paper shredder machine is a device that can shred documents such as paper and plastic into small strips or shreds. Private companies use it to shred confidential private documents or other sensitive documents into small strips or rubble. Thus, these machines help secure information effectively and waste to the environment [1,2]. Depending on the intended use, shredders can be divided into household shredders and industrial shredders. Therefore, paper shredders are often classified as consumer shredders as they are the most used by consumers. In the office or at home the paper shredder consists of two small cutting shafts fitted with alternating cutting blades, compact design for easy moving of rooms. Help keep office space more organized and tidy when waste documents are released immediately. By limiting the number of landfills, documents and paper can be more easily transported to the recycling center after destruction, which helps protect the environment [3-6]. Nowadays, the demand for document shredders is increasing day by day. Using a paper shredder becomes easier when you can use a paper shredders at home. Many different design techniques have been explored for shredder machine designs for various purposes [7-11]. The article offers an alternative to the design and calculation of a shredder model. In addition, the options for optimizing the cutting edge and evaluating the strength of machine parts are also discussed to ensure the reasonable of the model. The analysis results are carried out with CATIA software. The results can serve as a prerequisite for an optimal model of the shredder that will go into series production in the future.

2 Method and problem statement

The design problem is to build a model of a paper shredder, the parts of which meet the requirements for size and performance, besides the resulting products are pieces of paper. High-security scrap paper. A seen in Figure 1 a paper shredder machine consists of three main parts: base frame; cutting system; transmission system. Cutting system includes shaft, blade, washer, gear. Drive system: Motor drives the cutting system, auxiliary gear.

Working principle: Electric motor (1) converts into mechanical energy, transmits torque to main shaft (2), gear (3) on main shaft transmits torque through gear (4), shaft (5) rotates. The two axes rotate in opposite directions. Evenly distributed blades (6) are attached to each shaft. Alternating blades cut paper into pieces of equal size

DESIGN AND ANALYSIS OF A PAPER SHREDDER MACHINE

Tran Thanh Tung; Luong Thi Hong Ngoc; Nguyen Xuan Quynh; Tran Vu Minh

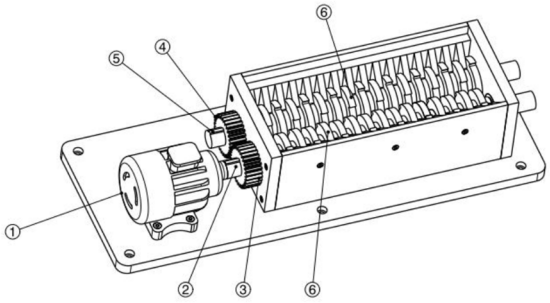

Figure 1 The 3D prototype of the paper shredder machine

Design calculation of shredder details:

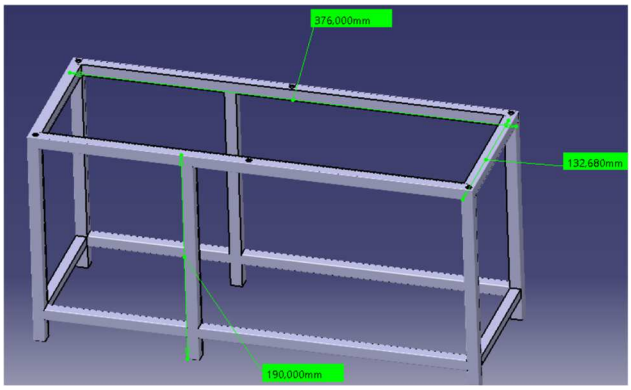

Figure 2 The tripod

Dimensions (Figure 2): 376x132.68x190 (mm)
The weight of the shredder is 12 kg.
The vibration force acting on the tripod is: P = 120 N.

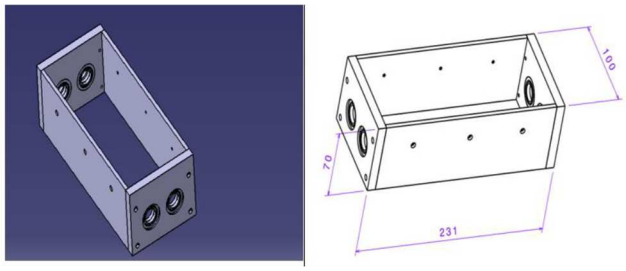

Figure 3 The frame

Frame: Supporting parts for shafts, blades and gears, fastened with bolts.

The frame (Figure 3) has dimensions of 231x100x70 mm, with length(l) = 231 mm, width(w) = 100mm and height(h) = 70 mm

2.1 Blade design

The cutting system consists of a shaft, cutting blade, washer and gear. The blade is a blade with 3 cutting edges, circular hole design with a diameter of 18 mm, mounted on the main shaft and the spindle moves together. The optimized cutting blade design concentrates tension, mass thereby reducing the load on the shaft.

Figure 3 shows the original unmodified 3D design of the blade. The cutting blade is a circular blade with three cutting edges with a round hole in the middle that attached to the spindle and moves the spindle. This blade is used to cut paper in the vertical direction. However, there was a problem of stress concentration at the bend.

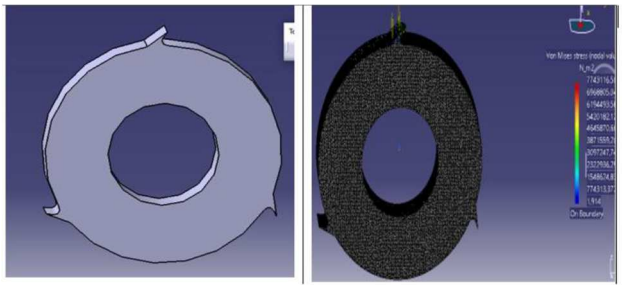

Figure 4 Original blade with stress distribution

Figure 4 shows the modifications in the blade design. Therefore, some modifications have been made, stress concentration problem was solved by creating a tangent in a side edge. However, although stress reduction has been fixed to avoid blade breakage, the mass is heavier than the blade at the first time m = 0.049 kg (Figure 5).

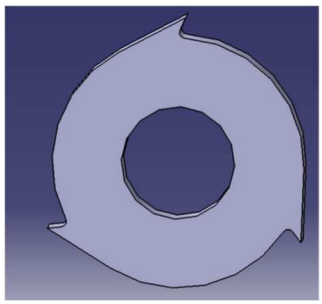

Figure 5 Blade redesigned the first time

Figure 6 shows in this revision, the weight of blade has been reduced. In the first, two blades are made with a circle of diameter d = 40 mm and with a single center. In the design the size has been reduced to m = 0.047 kg, instead of a radius of 20 mm with a common center, this blade is designed in such a way that it creates arcs of 20 mm radius and are three different arcs. whose center is the vertex of an equilateral triangle, is the center of the hole attached to the major axis. Blade thickness equal to 6 mm, made of steel and distance from blade to center r equal to 21.75 mm.

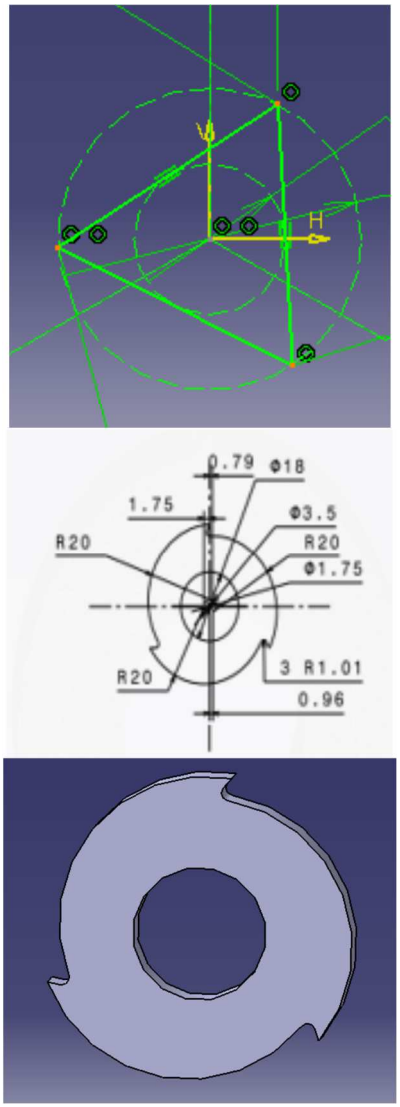

Figure 6 Final design shape cutting blade

2.2 The power calculation

The engine speed can be determined from the shear stress of the paper and the amount of paper. Shear stress is the result when a force is applied to a product that cause shear deformation of the material in a plane parallel to the direction of force application. When cutting paper, the shear stress value of the blade is greater than the allowable shear stress value of the paper

Shear stress is express by (1):

$$\tau = F/A \qquad (1)$$

where
τ : shear stress (N/mm^2)
F : Force applied, combined force of two blades (N) (2)
A : Cross-sectional area(mm^2)

$$F = (M \times a)/r^2 \qquad (2)$$

M : Paper cutting torque (N-mm)
r : Radius of the tool from the center, based on Catia software (mm)
a : Distance between two cutting shaft centers, a = 37 mm

We have (3):

$$\tau = (M \times a)/(r^2 \times h \times t) > \tau_g \qquad (3)$$

$\tau_g = 250$ Kpa , allowable shear stress of paper.

Then (4)

$$M > (\tau_g \times r^2 \times h \times t)/a = (250 \times 10^{-3} \times 21.75^2 \times 297 \times 0.3)/37 = 284.79 = \text{(N-mm)} = 0.28479 \text{ (N-m)} \qquad (4)$$

t is the thickness of 10 sheets of A4 paper which size is 210x279 (mm)
ω: angular speed(rad/s); take M = 0.5(N-m)
Power of the required torque transmission shaft (5):

$$P = M \times \omega = 0.5 \times 120 = 60\ W \qquad (5)$$

2.3 Spidle design

The spindle is the rotating machine element and is used to transmit power from one part to the other. Components such as blades and gears are mounted on it. The shaft has a diameter of d = 18 mm, the universal joint and the circular hole of the blade are 18H7/r6. Calculation and selection of materials for the working shaft to ensure durability.

The blade is mounted on the shaft, the shaft is subjected to the force of the knife's gravity causing bending. When the shaft is subjected to bending, the bending stress is given by (6):

$$\sigma_b = (M_b y)/I = (M_b(d/2))/(\pi d^4/64) = 32M_b/\pi d^3 \qquad (6)$$

In which
σ_b : bending stress (N/mm2)
M_b : bending monent (N-mm)
d : diameter of shaft (mm)
I : moment of inertia of the cross-section about the neutral axis (mm^4)

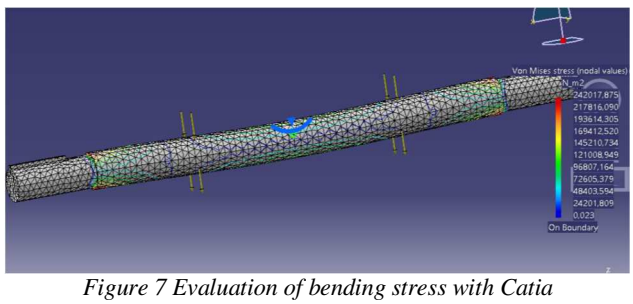

Figure 7 Evaluation of bending stress with Catia

The shaft is not only bent, but is also subjected to torque when driven by the rotating motor, which creates torsional

stress (Figure 7). The torsional shear stress is given by the formula (7):

$$\tau = M_t\, r/J \qquad (7)$$

where:
τ : torsional shear stress at the fibre (N/mm2).
M_t : applied torque (N-mm).
r : radial distance of the fibre from the axis of rotation (mm).
J = polar moment of inertia of the cross-section about the axis of rotation (mm4).

When the shaft rotates to transmit torque, the power transmitted by the shaft (8)

$$P = (2\pi n M_t)/(60\times 10^6) \qquad (8)$$

n: number of revolutions of the shaft (rpm), ω= 120 rad/s so n = 1145 rpm.

And then we have (9)

$$M_t = (P\times 60\times 10^6)/2\pi n = (60\times 10^{-3}\times 60\times 10^6)/2\pi\times 1145 = 500.1 \text{ (N-mm)} \quad (9)$$

Steel is usually chosen as the material for the shaft construction. Assume that the material of the shaft is steel with the permissible plastic limit Syt = 250 Mpa.
According to maximum shear stress theory (10)

$$\tau_{max} = (16/\pi d^3)(\sqrt{M_b^2+M_t^2}) = (16/\pi 18^3)(\sqrt{139^2+500.1^2}) = 0.45\ MPa \quad (10)$$

We have τ_{max} < ½ (Syt) and therefore shaft ensures strength

2.4 Blade system

As can be seen in Figure 8, the blades are evenly distributed, the cutting edge of the blades makes an angle of 40 degrees

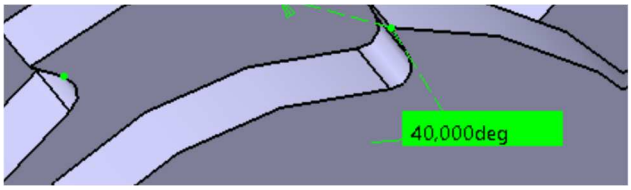

Figure 8 Angle between the two cutting edges of the two blades

When all the blades (2) are applied to the paper first then an equal force, immediately followed by the blade (1). Thanks to this distribution, only half of the cutting edges interact with the shredded paper. With such arrangement, the noise of paper tearing will be greatly reduced. Alternating distribution of cutting blades, evenly distributing cutting forces to each cutting edge as shown in Figure 9.

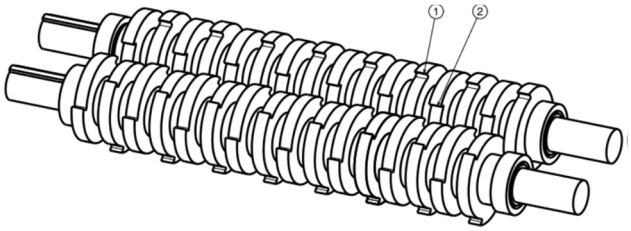

Figure 9 Blade system

The advantage of alternating cutting edges is to reduce the load on the gear when there is a large force, as all blade have cutting edges that are applied to the paper so that the gear will last longer. It also cuts a large amount of paper smaller.

3 Result and discussion

The machine model is completely assembled and simulated on Catia software as shown in Figure 10. The machine model proposed in the study can destroy 10 sheets of A4 paper at the same time, shredding paper in the form of shreds has a high level of security. In addition, the machine can also destroy other materials such as plastic in small form. and medium, CD… Blade is designed to reduce stress concentration and tool weight, helps to reduce the stress on the spindle

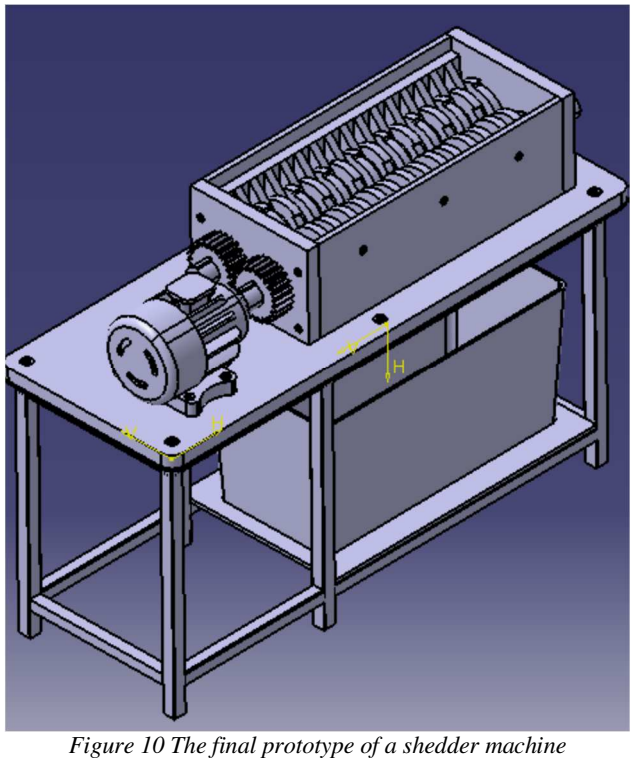

Figure 10 The final prototype of a shedder machine

4 Conclusion

The paper presents an alternative to the design and calculation of a shredder model. The shredding machine performance results also indicate that the machine could be very useful in the office or at home for shredding medium

sized paper. The machine is therefore recommended for use by small and medium scale entrepreneurs working on recycled plastic. In addition, the options for optimizing the cutting edge and evaluating the strength of machine parts are also discussed to ensure the reasonable of the model. The analysis results are carried out with CATIA software.

The results can serve as a prerequisite for an optimal model of the shredder that will go into series production in the future.

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CATALYST PROCESSING AND RECYCLING
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CATALYST PROCESSING AND RECYCLING

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Keywords: statistics, auto catalyst, environment, precious metals
Abstract: Discussed auto catalysts contain interesting quantities of platinum noble metals, palladium and rhodium according to the type of auto catalyst, thereby becoming a possible source of these metal aims to acquaint themselves with catalysts in general, their history and last but not least the possibilities of processing and obtaining noble metals for further use. The article deals with knowledge at the theoretical level of use of methods in processing depleted catalysts. It is pyrometallurgical and hydrometallurgical methods. The platinum group metals (PGMs) palladium, platinum, and rhodium represent the key materials for automotive exhaust gas treatment. Since there are currently no adequate alternatives, the importance of these metals for the automotive industry is steadily rising. The high value of PGMs in spent catalysts justifies their recycling. The state-of the-art technology is to melt the ceramic carrier and collect the precious fraction in a liquid metal bath. As the feed material has quite high melting points, huge amounts of energy are required for this process. Hydrometallurgical treatments of the spent catalysts offer the possibility to recycle the PGMs with less energy and time demands. Moreover, automotive catalysts contain further valuable materials to improve the exhaust gas treatment. These compounds, like cerium oxide, cannot be recovered in pyrometallurgical processes.

1 Introduction

Since the 1950s, all major car manufacturers began to devote to reducing the proportion of toxic substances in the exhaust gases and it is that road transport is involved in more than 90% in the overall environmental pollution. The effort of car manufacturers for reduction in emission production is supported by legislation since the late 1960s is supported by legislation when the first emission standard has been adopted by the exhaust limit values in the California In Europe, the first emission standard began in 1971, when it is clear that the share of products based on power equipment based on the combustion process will also have an increasing trend to completely exhaust fossil energy resources, the only way to reduce the share of toxic substances in Flue gas is to streamline combustion process and simultaneously eliminate the toxic impact of imperfect combustion products by chemical procedures. The catalyst life is estimated at 128,000 km, depending on how combustion engine use. Since the catalyst contains noble platinum metals whose occurrence in the environment is limited, at the end of its life, platinum metals are obtained from the exhausted car catalysts. In addition to positives that brings the catalyst in reducing the amount of exhalation in the air, it also has a negative impact on the environment in the form of release of platinum metal particles. The high price of these metals led to intensive research activities to substitute them. Nowadays no cheaper materials are available that offer similar properties for these kinds of catalytic reactions. Based on the facts that every new car has to be equipped with a catalytic converter and the number of car registrations is steadily increasing, the demand for platinum group metals (PGMs), particularly platinum, will grow continuously. Taking into account that one catalytic converter contains approximately from 1 g up to 15 g of PGMs, it could be easily supposed that this field represents the main application for palladium, platinum and rhodium

The recycling itself for dealing with the amount of authors. Nowadays this is a very busy theme with respect to the environment. Authors *Alexandra Končalová and Alena Dubcová* are focused *on the development of recycling in the waste management concentrate the development of waste recovery in the Slovak Republic with emphasis on its regional differences* [1]. Authors *DengyeXun, Han Hao, Xin Sun, Zongwei Liu, Fuquan Zhao* at article titled *End-of-life recycling rates of platinum group metals in the automotive industry: Insight into regional disparities* [2] talk about the unavailability of

natural resources in relation to precious metals and the need for recycling materials that contain these rare metals. They are also dealing with regional differences in recycling materials that mentioned rare metals contain. Authors *George Asimellis, Nikolaos Michos, Ioanna Fasaki, Michael Kompits*, in article titled *Platinum group metals bulk analysis in automobile catalyst recycling material by laser-induced breakdown spectroscopy [3]* have developed an application to detect noble metals in the catalyst. The application is based on a laser-induced spectroscopy. A true catalytic catalyst form in powder form was used to develop the application. This method requires approximately 1.5 minutes of the sample examination. The accuracy of noble metals can determine with a 3 percent deviation. Authors *Yunji Ding* and colleagues in article *Highly efficient recovery of platinum, palladium, and rhodium from spent automotive catalysts via iron melting collection* [4] designed a high-efficient technology to restore platinum, palladium, and rhodium by iron collection. Thanks to the same cubic structure focused on the structure, it is used as a collector because iron and noble metals can form a continuous solid solution. Another authors from recycling car catalysts are *Lucas Gonçalves da Silva, Rodolpho Faria Dias de Almeida, Vinícius Marinho Silva Faustino, Pedro Américo Almeida Magalhães Júnior [5].* Many authors deal with different options and recycling methods of car catalysts in their studies. In article *Platinum Recovery from Hydrometallurgical Residue of Waste Automotive Catalysts Processing by High-Temperature Smelting Process [6],* authors *Chuan Liu, Shuchen Sun* describe the hydrometallurgical method of recycling at high temperature. This method is also described in our article.

2 Auto catalyst history

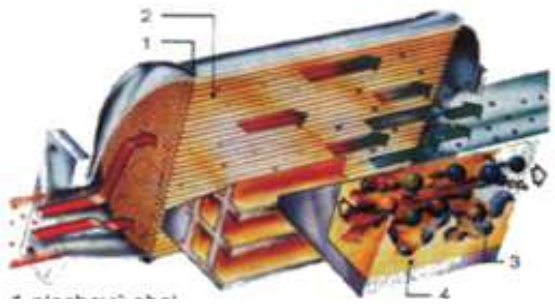
Although the environmental pollution affects a number of factors such as. Discharge of harmful substances to air from individual production undertakings, oil mining, agriculture, waste disposal and so on. With the development of the automotive industry, the production of exhaust exhausts discharged into air is gradually increased, and the environmental pollution was increasingly in increasingly. For this reason, a solution started to remove this pollution. At the same time, the effort to reduce the environmental pollution legislatively treated through emission standards. The development and installation of a technical equipment called the catalyst into the exhaust system was achieved reduction in emission by means of transport. In the 1970s, he started to install the car catalyst. In 1974, started in the UK first production of automotive catalysts in the world. A year later, the first US catalysts appeared. In 1976, as the first used today used a three-way catalyst with a lambda probe was Volvo. In 1985, the first cars with exhaust catalysts, at that time used in the US for several years, receives to Europe [7].

2.1 The importance and division of automotive catalysts

Automobile catalyst is a technical device mounted in the exhaust system of the car. It is defined as a substance that reduces the activation energy needed to respond and accelerates it. After completion of the reaction, the catalyst has the original chemical composition of the catalyst to convert toxic agents such as carbon monoxide, HC_x hydrocarbons, and NO_x nitrogen oxides, resulting from an imperfect combustion process in the engine cylinders, almost harmless substances such as carbon dioxide CO_2, nitrogen N_2 and water steam H_2O, with noble metal - platinum, rhodium and palladium that have catalytic effects. The outer side catalyst reminds the conventional exhaust silencer. The interior construction of the catalyst is very different from structurally. It consists of a steel shell, a ceramic, or a metal carrier on which noble metals are applied as platinum, rhodium, palladium, metal fibre and the lambda probe are also part of the catalyst, serving the correctness of the mixed fuel mixture (Figure 1). The most important part of the catalyst is its active part, ceramic or metal carrier on which are applied - steamed noble metals Platinum, Rhodium, Palladium [7].

Division of catalysts:

- **Oxidizing** - when oxidation is changed - oxidizes CO_2 and C_x H to H2O and CO_2.
- **Reducing** - nitrogen NO_x ingredients are reduced to N_x and CO_2 during combustion, exhaust gases are introduced back into combustion space. Cooled are bred back into the combustion chamber and thereby reducing N_x emission.
- **Three-way** - It can dispose of all three harmful substances CO, $C_xH_yNO_y$.
- **Self-regenerating** - the most unique type with perovskite structure [8].



1. Metal cover
2. Pores
3. Metal catalyst
4. Ceramic substrate

Figure 1 View of the catalyst [8]

3 Methods of processing used catalysts

Stronger legislation Ticking emission limits of exhaust gas vehicles and automotive industry status Guarantee

stable interest in new catalysts, and also increasing interest after platinum, rhodium and palladium. For the same reasons, it is also interested in amortized catalysts. The catalyst operating temperature is about 250 ° C. The metal carrier base catalysts reach this temperature under a short period of time than ceramic catalysts. This is an important factor because when the catalyst is heated to operating temperature, a large amount of exhaust emissions is produced. At extreme temperatures, metal catalysts have better physical and chemical properties than ceramic catalysts. The unique cylindrical and corrugated construction allows them to better withstand excessive vibration and constant repetition of temperature changes.
Along with stricter exhaust emission limits, the content of platinum, palladium and rhodium in automotive catalytic converters is also increasing. The two-way catalyst contains 0.04% by weight of platinum and 0.015% by weight of palladium, the three-way catalyst contains 0.08% by weight of platinum, 0.04% by weight of palladium and 0.005-0.007% by weight of rhodium. palladium and rhodium economically significant. Properly organized, the collection and recycling of auto catalysts can be, and indeed are, a significant secondary source of platinum, palladium, and rhodium in advanced western economies [9].

Figure 2 shows a general technological procedure for the technological processing of catalysts.

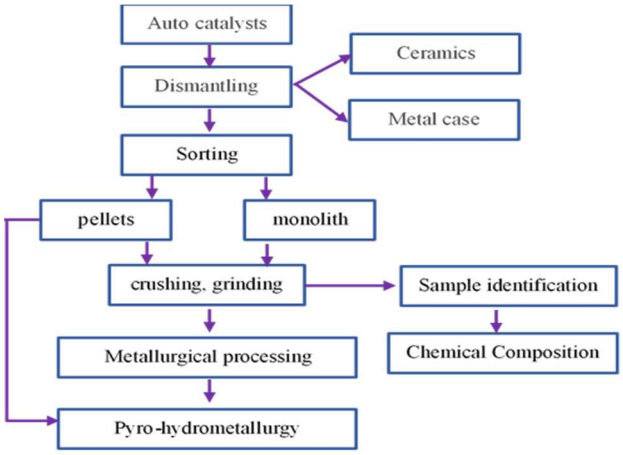


Figure 2 Exhausted catalyst processing technology scheme [8]

We can divide the processing of exhausted catalysts into two basic methods:

1. Pyrometalurgical method.
2. Hydrometalurgical method.

1. Pyrometallurgical method:

There are many ways to recover precious metals from depleted auto-catalysts. Pyrometallurgical methods for the recycling of platinum metals use as a collector the collection of metals, especially iron and copper. The pyrometallurgical method can be divided into 2 parts:

- **Plasma melting:**

In the recycling of catalysts by plasma melting, the catalyst is subjected to crushing and grinding, the batch is supplemented with a mixture of Fe + FeO, melted in a plasma furnace at a temperature exceeding 2000 ° C. This is followed by the separation of the molten slag and the next iron-containing phase with concentrated platinum metals. The iron alloy is then dissolved in an aqueous solution of sulfuric acid with aeration. Undissolved platinum metals are filtered off, the filtrate is neutralized.

- **Melting in EOP (electric arc furnaces):**

When melting with copper, the catalyst is, after mechanical treatment, including crushing and grinding, together with copper carbonate, silica, calcium oxide and iron oxide in a special electric furnace at temperatures of 1600-1800 degrees Celsius.

The melt is divided into slag and an alloy of platinum metals with copper. The copper alloy is dissolved in an aqueous sulfuric acid solution using air as an oxidant. Copper carbonate is recovered by precipitation with sodium ash. The cooled solution is filtered.

In recent years, pyrometallurgical methods have focused on smelting with copper as the collecting metal and on plasma smelting technology, which uses iron as a collector. It is necessary to use hydrometallurgical processes to obtain precious metals from an alloy with a collecting metal. We can therefore speak of these recycling technologies as combined processes. The process of recycling platinum metals pyrometallurgically is shown in Figure 3 [10].

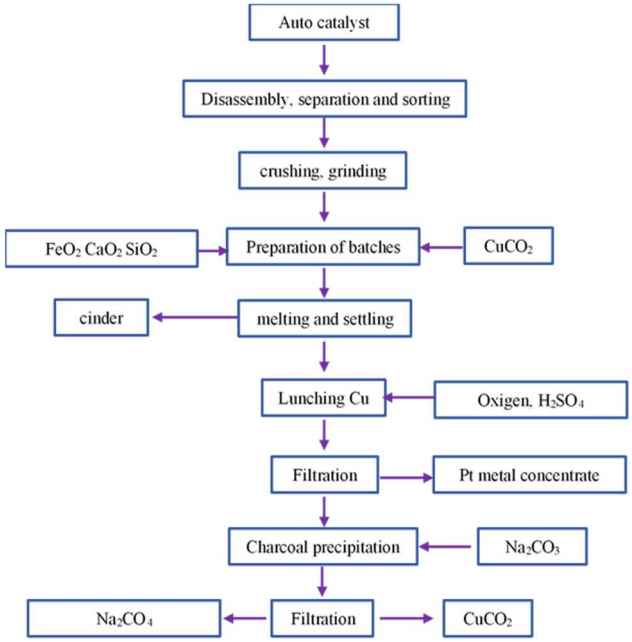


Figure 3 Recycling diagram for pyrometallurgical procedure [8]

2. Hydrometallurgical methods:

A number of processes have been designed and patented for the processing of auto catalysts. In hydrometallurgical processing, the noble metals leached with salivic acid and subsequently the leachate containing noble metals are purified by chemical precipitation or cementation. The pure leachate is further processed into metal, into a chemical concentrate of precious metals or by other methods (adsorption, ion exchange, extraction). The disadvantages of hydrometallurgical methods are the loss of metals, especially rhodium in wastewater, and the problem is also the formation of aluminium sulphate as a by-product.

The hydrometallurgical treatment of catalysts is preceded (during the treatment of catalysts by acid leaching and chlorination) by calcination at a temperature of approx. 500 - 600 ° C, where organic residues of petrol and oils are burned. Unburned carbon residues of gasoline and oils stick to the pores of the catalysts, preventing the penetration of leaching solutions into the pores and thus reducing the yield of the obtained metals.

The catalyst in the form of pellets is dissolved in sulfuric acid after mechanical treatment. to obtain an almost neutral solution (catalyst is in excess). The leachate from the leaching of catalysts is treated by cementation with aluminium in the presence of tellurium dioxide. The resulting aluminium sulphate is used to treat water. The solid phase from the cementation is mixed with insoluble residues from the primary leaching and dissolved in HCl + CL2. Platinum metals are deducted from this solution by sulphur dioxide in the presence of Te, which acts as a collector. The reduced solution is filtered hot, the platinum metals and, after cooling, the lead chloride are filtered off. Hydrochloric acid HCl is recycled. The procedure for treating the catalyst by acid leaching is shown in FIG

Hydrometallurgical methods include acid leaching of whole pellets, or selective leaching of noble cocci. This is followed by refining of the extract and its processing, most often by pressure reduction or precipitation. They are among the most excited. In addition to the above-diluted conventional technological procedures, research work is aimed at discovering alternative methods. Fast, accurate and correct quantitative determination of platinum metals in automotive catalysts is a must for laboratory researchers and industrial practitioners [11].

4 Import and demand of valuable metals in the world

The metals from the platinum group are used in many different industries, for example dental, jewellery, and chemicals. Nevertheless, the most important use is based on their catalytic properties. Approximately 50% of platinum and palladium are used as automotive and industrial catalysts. In case of rhodium, an even higher percentage (around 80–90%) is used as an alloying element in the active layer of different catalysts. The high required amount of 300–900 kg of treated ore to obtain approximately 1 g of PGM is responsible for the high prices. On average, the contents in the ore of Pt and Pd are 5–10 times higher than Rh and Ru and around 50 times higher than Ir and Os.

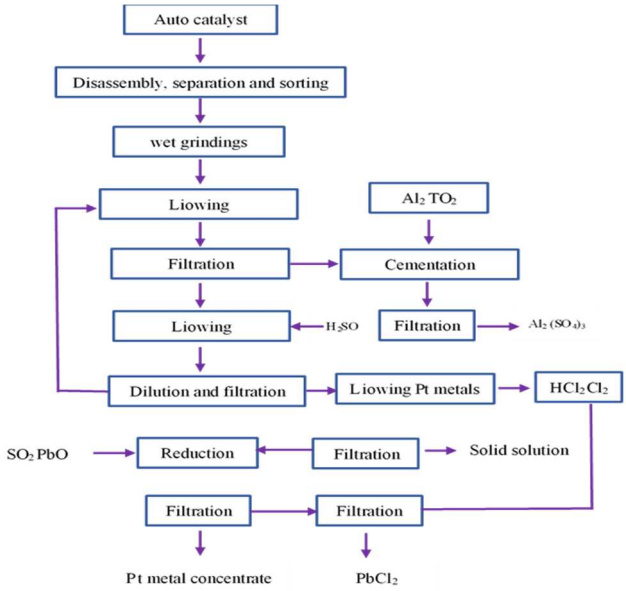


Figure 4 Hydrometallurgical method processing scheme [8]

Additionally, the regional limitation of ore bodies leads to a strong dependence on mainly South Africa and Russia as PGM suppliers. Based on the strong discrepancy in supply and demand of PGM's around the world, recycling of catalysts is mandatory and meaningful from the ecological and economical point of view. Based on the high prices of PGM, the industry is forced to improve the efficiency of catalysts, which is done by improving the wash coat technology. By using rare-earth elements, like cerium oxide, the surface can be increased and the ability to supply oxygen is secured. As a side effect, cerium as an additional critical element is introduced into the recycling circuit of catalytic converters, forming a further valuable component and forming a major challenge for common pyrometallurgical converter recycling [12].

First, like shown in Fig. 5, a strong discrepancy of suppliers (mainly Africa and Russia) and consumers (Europe, China, Japan, and North America) exists. Worldwide reserves of PGM are estimated by the U.S. Geological Survey (USGS) in 2013 to be present to 95% in South Africa, 1.6% in Russia, and the remaining 2.8% in the rest of the world underlining the strong dependence on Africa's supply. Due to the presence of permafrost soil in Russia and deep mines in Africa, the processing of the ore is cost intensive. A peak in demand cannot easily be compensated, for instance in the case of Russia, because their PGMs are produced as a by-product of nickel. Russia would have to increase their production of nickel, leading to a higher supply, and thus to a lower price for their main product (nickel), to increase the PGM production [13].

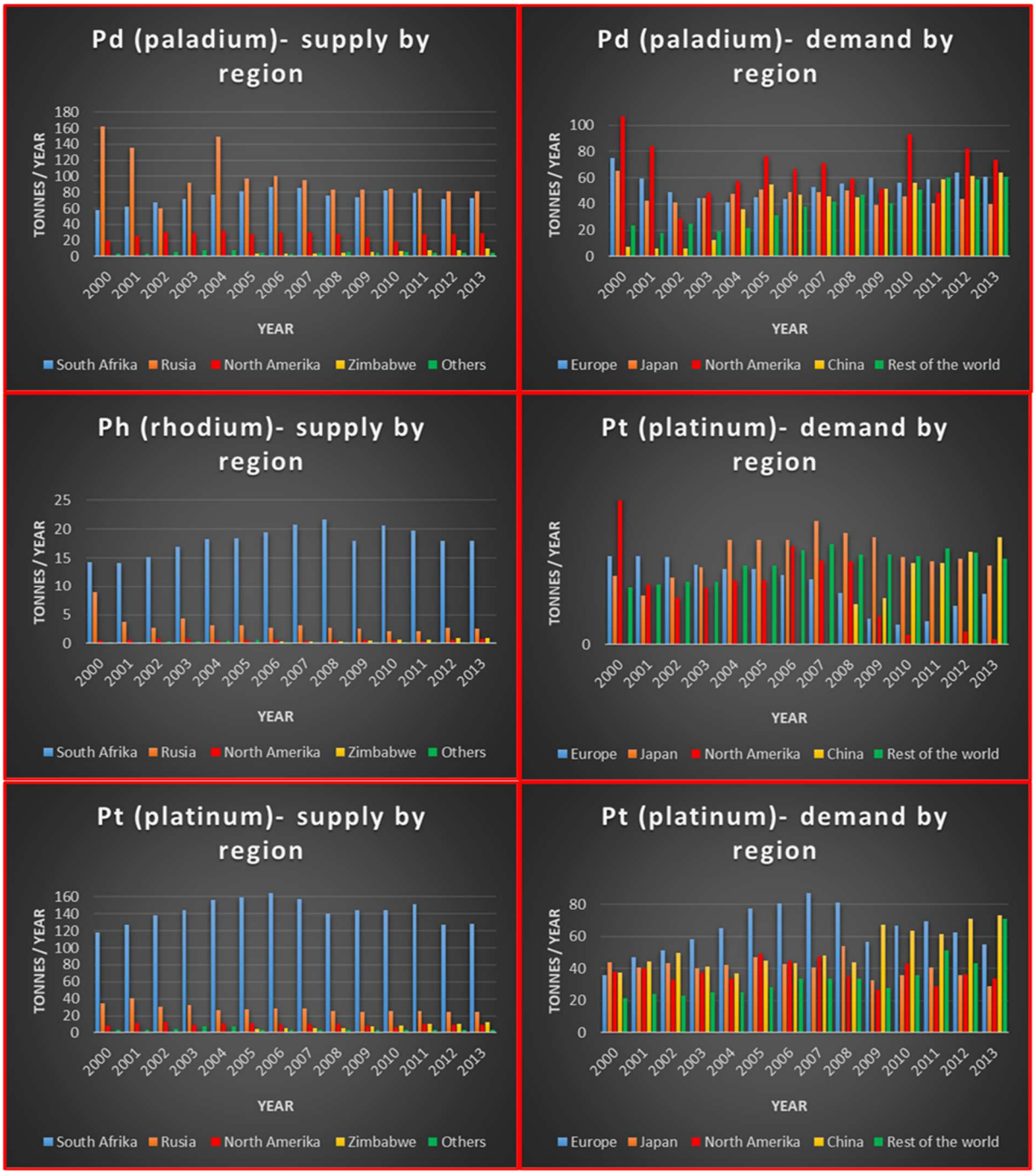


Figure 5 Platinum, palladium, and rhodium supply (a) and demand (b) by region and their development since 2000 Data source [13]

A somewhat similar case, even more drastic, can be found around rare-earth elements. The element cerium is of interest in this context due to its utilization in the wash coats of catalysts. By 2005, China accounted for 96% of global rare earth production, including more than 99% of heavy rare earth oxides. In 2008, the production of rare-earth elements peaked, accounting for 97%4 of global production. Slowly, the rest of the world is trying to open new resources to become more independent, but the chemistry is complex, and the rest of the world will have its main impact on light rare earths, like cerium, and not on the heavy ones, where a strong dependence will remain.

A second reason for price peaks is the fact that, as shown in Figure 5, the main utilization area of platinum and palladium as well as cerium and rhodium is the automotive industry in form of catalytic converters. Statistical data show that around 55% of palladium and platinum are used in automotive catalysts (40%

of Pt and 67% of Pd), which makes it clear why the supply is strongly dependent on the automotive market [12].

5 Results and discussion

Initially, uncontrolled oxidation and reduction catalysts were used in mixture preparation equipment without electronic control. The advent of electronics brought with it a more precise regulation of the composition of the mixture with the advent of a three-way oxidation-reduction catalyst. The catalyst with a ceramic support used mainly due to the low price is in decline. Today, a metal-supported catalyst is increasingly preferred.

With the ever-tightening legislation on emission limits and the position of the automotive industry, there is a growing interest in new catalysts, and so is the consumption of platinum, palladium and radio. Due to the yield of these metals obtained by recycling catalysts, it is economically advantageous to thus obtain platinum metals from spent catalysts. These represent a significant secondary source of precious metals.

Within Central Europe and the European area, in connection with the creation of this article, it was not possible to find a suitable database that would specify the purchase and consequence of the recycling of car catalytic converters from ordinary users. The Slovak Republic and its statistical office do not keep a database on the purchase of catalysts. This fact is slightly worrying about the environment. On the positive side, there is a company on the world market that has developed the Eco Cat application, where the application, with its 20,000 different catalysts that have been inventoried and awarded so far, is an ever-growing database that is fast becoming the search standard for the industry. The Ecotrade Group has been a recognized leader in the ecological and ethical recycling of catalysts in Asia for more than 15 years, using state-of-the-art recycling technologies and a huge network of industrial partners.

Hydrometallurgical and pyrometallurgical methods are used among the existing methods of recovering noble metals from depleted catalysts.

There is currently an effort to develop new methods for recycling and separating precious metals.

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