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Proceeding algorithms for difficult trees as the basis for expert system to increase sawmen' safety on post-disaster sites

JACEK BRZÓZKO, JAN SKARŻYŃSKI
Department of Agricultural and Forest Machinery, Warsaw University of Life Sciences – SGGW

Abstract: *Proceeding algorithms for difficult trees as the basis for expert system to increase sawmen' safety on post-disaster sites.* Utilization of systems based on artificial intelligence, including the expert systems, in programming processes of decision taking has become popular in recent years. Their idea involves simulation of the process of taking decisions by the man-expert, who acquired his knowledge through many years' activity in a given field. Such systems are based, apart from inference machine, on wide knowledge bases containing the facts, principles and rules of proceeding. Assumption of the authors is creating of expert system that aids the process of sawmen' training to work under post-disaster conditions. The way to that objective is identification and determination of most important threads in timber harvesting of particularly difficult trees, determination of the safe methods for their removing, and expressing of these methods in the form of rules that can be applied in taking decision process of expert system. Several algorithms of proceeding in the process of save timber harvesting from very difficult trees are presented in this paper.

Key words: expert system, post-disaster timber harvesting, blow-over, breakage

INTRODUCTION

Usability of electronic computing technique extends more and more the fields of its application. Nowadays, it is difficult to find the technical or medical field without equipment controlled with decision algorithms. Utilization of systems based on artificial intelligence, including the expert systems, in programming processes of decision taking has become very popular in recent years. Their idea involves simulation of the process of taking decisions by the man-expert, who acquired his knowledge through many years' activity in a given field. It is characteristic that such systems use, apart from the inference machine, also wide knowledge bases containing the facts, principles and rules of taking decisions based on their analysis, contrary to traditional decision taking systems that usually use simple algorithms. The inference machine is then a module that uses the knowledge base. Recently, more and more often there are used, so-called, framework expert systems, i.e. programs with designed inference module and empty base of knowledge. It is then possible to introduce the rules of a given knowledge field to the module. The rules are usually the logic sentences that determine some implications towards creating new facts resulting in solution of the problem. Therefore, development of a suitable knowledge base is the ground for designing of expert system to realize the complex process of taking decisions.

In the case of timber harvesting from forest post-disaster sites, the most important problem has been securing safety of workers. Application of machine harvesting practically excluded heavy injuries at work, however, under Polish conditions this system of timber harvesting is used only in the case of large disasters of wide territorial range. If disaster affects a small region or numerous sites situated big distance apart, application of harvester as a safe method of timber harvesting may not be justified [Nurek 2006, 2013]. In such cases the post-disaster wood is usually harvested in manual-machine system with the use of internal combustion chain saws. Big diversification of tree damages that occur usually on post-disaster sites calls for high skill and experience of the sawman. Therefore, withdrawal of less experienced sawmen from work on post-disaster areas is quite often [Wójcik and Petrów 2013]. However, in that case they cannot improve their skills under difficult conditions or cannot get such experience. The only way of solving this problem is carrying out a special training of lumbermen to work under damaged tree stands conditions, with the use of stands that assure their safety. Such trainings for sawmen that are realized in Poland at present are based on generally well-known rules of proceeding with the stressed, broken or windfallen trees. However, there is the lack of operation outlines for special cases occurring in various versions and configurations. Development of the expert system will enable to combine general rules of proper work with the special techniques proposed for actual and very difficult cases. Knowledge of appropriate technique for their correction acquire only some few, very experienced lumbermen. The expert system, as a "teach yourself" system, will enable to propose a safe working procedure for cases that cannot be verified experimentally, since the number of possible forms of tree damages is practically unlimited.

The authors aim at creating of expert system that will assist in the process of lumbermen training to work under post-disaster conditions, and practically will enable to determine the way of safe cutting of difficult and very difficult trees, independently of their configuration. The way to that objective is identification and determination of most important threads in timber harvesting of particularly difficult trees, determination of the safe methods for their removing, and expressing of these methods in the form of rules that can be applied in taking decision process of expert system.

TIMBER HARVESTING OF DIFFICULT TREES

Timber harvesting on post-disaster areas is more difficult than on undamaged areas. It manifests itself in usually lower productivity, higher costs, greater number of machine break-downs in machine harvesting and greater accident risk during timber harvesting with the use of internal combustion chain saws [Suwała 2004, Brzózko 2007]. The accident risk is bigger, the more specific is post-disaster area [Jewuła 1970, Muszyński and Muszyński 1999]. Despite the lack of detailed data on accidents on post-disaster areas, according to Bartoszczak [2008] the main reason for accidents at work in forestry is incorrect behaviour of the worker (in 2006–2008 above 50% of accident reasons). Such behaviour occurs most often on areas of big variability of conditions and diversification of objects on the area, e.g. post-disaster area. One can meet the areas damaged by wind or snow, with types of tree damages rare even on the post-disaster sites. The reasons for their occurrence can involve specific factors causing the damage (whirlwinds resulting in numerous tree piles and tangles) or habitat factors, e.g. shallow rooting that in combination with substantial tree stand density can cause the blow-overs connected by rooting systems. In the case of timber harvesting with highly productive machines, occurrence of these specific types of tree damages is not a menace to operator's safety. It can only cause the possible risk of machine damage or a decrease in productivity. In the case of timber harvesting with the use of internal combustion chain saws, the situation is more dangerous. Occurrence of such damages as: multiple breakages, blow-overs supported on breakages above and below center of gravity, group blow-overs connected with the root lump, increases the risk of accident at work. This risk is increased by the lack of references caused by individuality of these cases, and the lack of actual procedures in timber harvesting that can assure the work safety. General rules included in manuals and publications, e.g. of Giefing and Korzeniewicz [1998], Olszewski [2000], Suwała [2002], and discussed during trainings for lumbermen are not sufficient in respect of their generality. Peculiarity of post-disaster areas calls for their expansion and adaptation to actual conditions.

Most important general rules for operation proceeding with internal combustion chain saws on the post-disaster areas are included in Industrial safety manual... [2012]; it concerns, among others, the size of working groups, application of appropriate equipment, preparation of site, the necessity to remove stress in a tree prior to beginning of operation, felling of trees only on the previously cleaned site (meeting of this requirement seems to be difficult or impossible in the case of majority of post-disaster areas).

These information constitute a set of general rules that should be observed to maintain safety of work. However, the expert system cannot be based on general rules only. One should work out a set of rules of the lower order concerning the main damages of trees. Peculiarity of post-disaster areas enables to distinguish five fundamental damages of trees: standing trees straight or bent with the crown or without it (type D), torn off fragments of breakages lying on the ground (type L), tangled trees connected to each other with branches; their processing is impossible before their separation (type S), trees broken at various heights, so-called breakages (type Z) and windfallen trees with roots lying freely or supported in various ways, so-called blow-overs (type W). Safe timber harvesting of the two first mentioned damages calls for the knowledge of mentioned general rules (combined with proper technique of work). Type S is a combination of other types of damages; the main proceeding rule is here spreading of such trees to obtain the single tree forms. More difficult is usually removing of trees included in types Z and W.

Selecting of tree fall direction for broken trees (type Z) one should follow the rules of the lower order for a given damage, described in the cited publications, that concern especially the tree fall direction, necessity of application of wedges or direction poles, or e.g. special techniques used under mountain conditions.

The case of blow-overs is similar (type W), where particular attention should be paid to protection of root lump from the fall toward the sawman and to precise analysis of stress distribution in the stem to fit appropriate number, sequence and depth of unloading cuts.

Unfortunately, in the described above rules designed for main damages and particular types occurring commonly there is the lack of references to specially difficult cases that occur rarely, but are the highest threat for lumbermen at their work. Determination of rules for this kind of trees called for empirical investigations.

CONDITIONS AND METHODS OF INVESTIGATIONS

The investigations were carried out during timber harvesting on areas damaged by wind in 2007–2013 in Forest Inspectorates: Osie, Przedbórz, Koszęcin, Legnica, Starogard Gdański and Wipsowo. More detailed description of research conditions is presented in Table 1. During investigations the work of sawmen on real post-disaster sites was recorded. Recording of work allowed for later multiple reproduction and analysis of particular stages.

Timber harvesting was carried out by the sawmen of substantial experience (min. 3 years of employment), who have been working previously on post-disaster areas. Behaviour of the tree during its processing that was identical with behaviour predicted by the sawman (and described by him before beginning work) was accepted as a main criterion of sufficient skill of the sawman. Analysis of video materials was executed by a set of experts consisted of 4 instructors of timber harvesting with many years' experience. The following aspects of work were assessed:

TABLE 1. Specification of investigations conditions

Forest Inspectorate/ /RDLP	Osie/ /Toruń	Przedbórz/ /Radom	Koszęcin/ /Katowice	Legnica/ /Wrocław	Starogard Gdański/ /Gdańsk	Wipsowo/ /Olsztyn
Forest district	Zajęczy Kąt	Reczków	Cieszowa, Kalina	Mierzowice	Orle	Cisy
Section	342	152, 229	232, 22	77,78	189	164
Date od disaster	11.05.2007	20.07.2007	15.08.2008	23.07.2009	11.06.2010	12.07.2011
Size of disaster [ha]	1	3200	730	3000	220	600
Date of investigations	15–16. 05.2007	8–12. 10.2007	3–5. 11.2008	19–23. 10.2009	1–4. 10.2010	8–12. 08.2011
Number of sawmen / / recorded trees	1/46	2/143	2/87	2/211	1/38	1/102
Age /species of harvested trees	45–82/ /So, Br	77–102/ /So, Br, Db	58–110/ /So, Br, Db	48–130/ /So, Db, Br	55–75/ /So, Św, Br	45–87/ /Św, So, Db

Br – birch, Db – oak, So – pine, Św – spruce.

- approaching and carrying out of felling on the safe side of tree,
- correctness of maintaining sequence of kerfs,
- behaviour of sawman in specific situations, i.e. seizing of guide in the kerf, very soft and flexible ground, difficult to predict health condition of tree or distribution of its internal stresses and others,
- maintaining of all mentioned above general safety rules related to work technique for all types of tree damages.

In investigations under specially difficult conditions, where the sawman could not be accompanied by a person making records in respect to his safety, an unmanned aerial vehicle (drone) with mounted video camera was used. The drone could stay in mid-air and allowed for recording of sawman's work and observations on the ground-based station situated at safe distance from the work site.

ANALYSIS OF SELECTED CASES OF PARTICULARLY DIFFICULT TYPES OF TREE DAMAGES

Basing on carried out investigations, observations and analyses there were determined the rules of safe removing of particularly difficult trees that occurred on the investigated sites as single cases and made difficulties to sawmen working there. No descriptions of techniques of such trees removal can be found in available references. The selected and interesting examples of damaged trees are presented below. Main rule of work under such conditions is necessity of timber harvesting by at least two-person teams; the second person continuously observes behaviour of damaged tree, while the first person performs all essential operations on the tree. This rule is a requisite condition for beginning work on trees with such damages.

The first case are gate multiple breakages (Fig. 1), usually supported above center of gravity on other trees, with the trunk broken at several places.

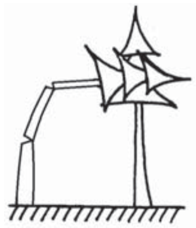

FIGURE 1. Gate multiple breakage supported high

In cutting and felling of this type breakage one should rigorously use the cable equipment. The tree should be thrown in direction perpendicular to direction determined by broken parts of the bolt. A cable should be fixed on broken tree, possibly high, it should be strongly tightened; one should attempt to tear off the broken part of bolt. If it is impossible, upon completion of all kerfs and after walking away of lumberman at a safe distance, the gate breakage should be thrown by stretching the cable. This procedure in the form of algorithm based on implication rules as the part of knowledge base is presented in Figure 2.

Split breakages occur in two varieties: split at the butt end (Fig. 3) or top end (Fig. 4).

In the case of breakage split at butt end, the cable should be fixed on part 2

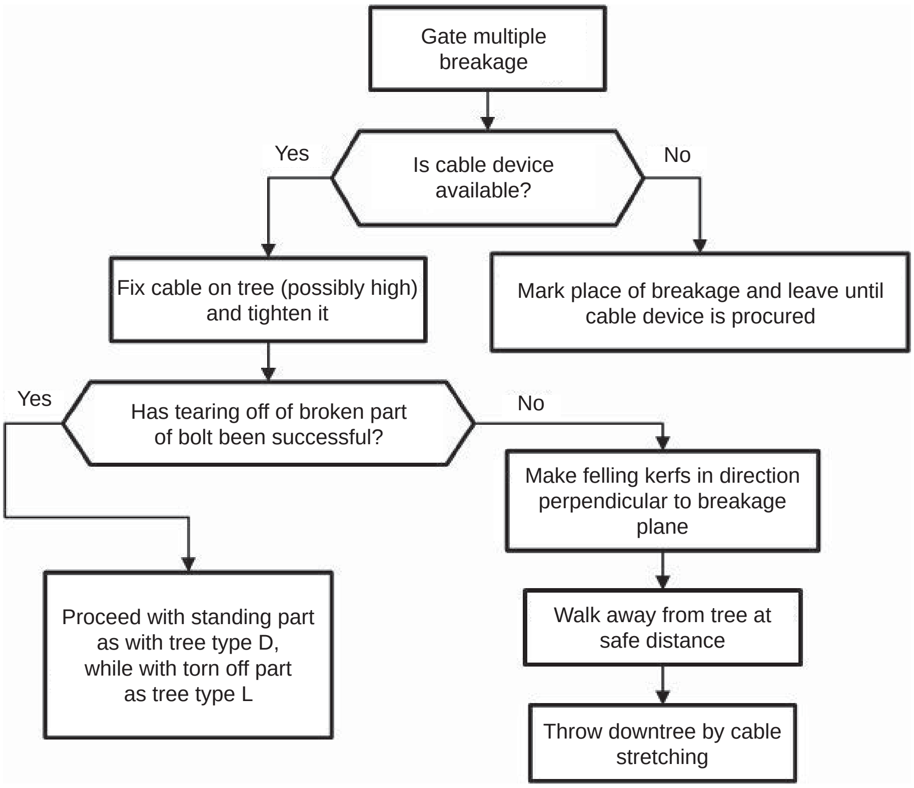

FIGURE 2. Block diagram of algorithm for removing gate multiple breakage

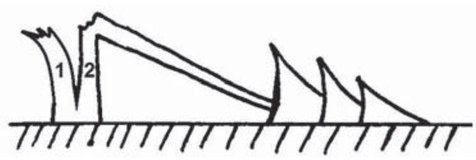

FIGURE 3. Breakage split at butt end

of broken tree, possibly high, and strongly tightened; during releasing of cable one should watch the broken part of bolt. If broken part of tree doesn't fall on the ground, then (if split reaches beneath the operator's shoulders), the part 1 of trunk should be cut separately, similarly to breakage without the top. Part 2 of tree is cut similarly to breakage with crown supported on the ground. If the trunk crack ends high, one should cut the entire tree similarly to breakage with crown supported on the ground, binding the trunk with a band or cable with tensioner. An appropriate algorithm for this case is presented in Figure 5.

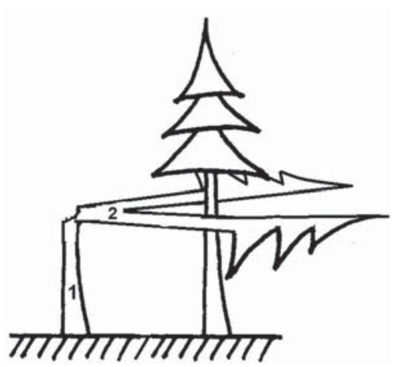

FIGURE 4. Gate breakage split at crown

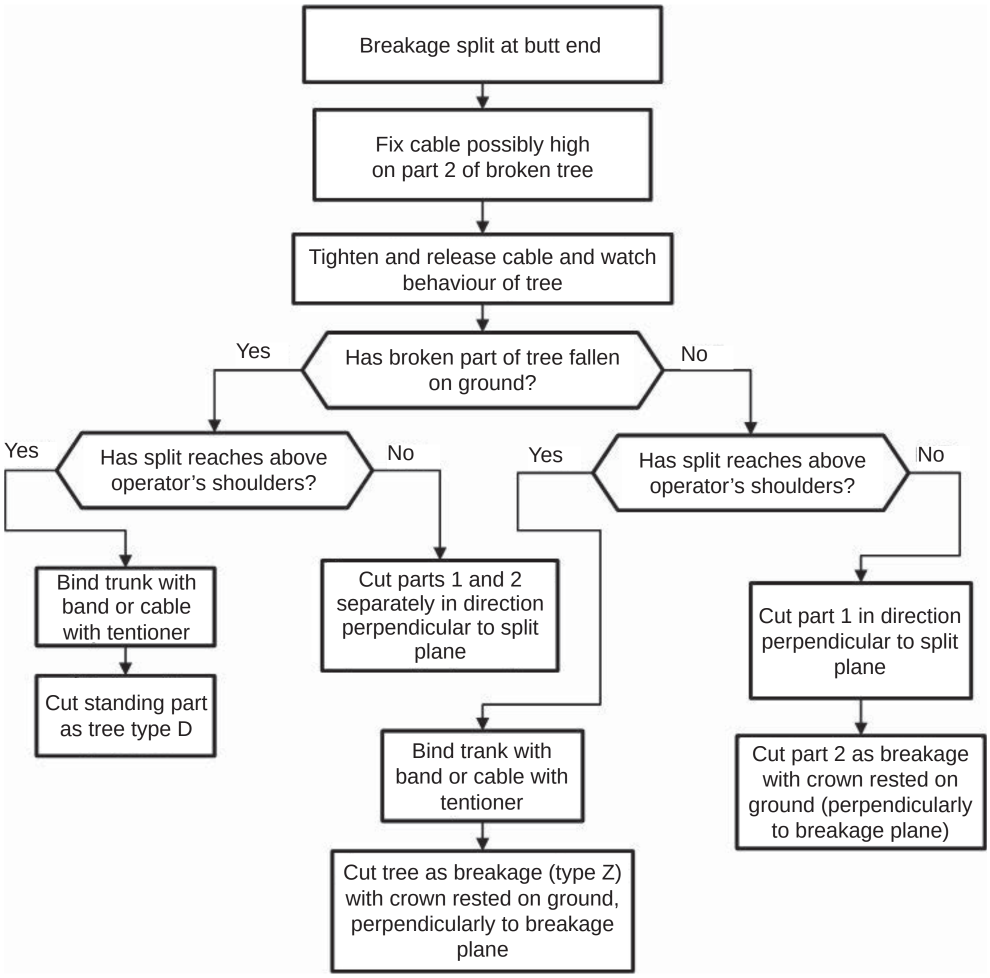

FIGURE 5. Block diagram of algorithm for removing breakage split at butt end

In cutting and felling of breakage split at crown (Fig. 4) one should rigorously use the cable equipment. The tree should be thrown in direction perpendicular to direction determined by center of the split. A cable should be fixed on the tree 1, possibly high, it should be strongly tightened and released; one should watch the broken part of bolt 2. If it is impossible, upon completion of all kerfs and after walking away of lumberman at a safe distance. If the broken part of tree does not fall on the ground, remaining the fixed cable one should make all kerfs and walk away at safe distance, then throw gate breakage by stretching the cable. A suitable algorithm is presented in Figure 6.

Suspended trees jammed at big height or torn off fully from the rootstock and entangled between trunks of other standing trees (Fig. 7).

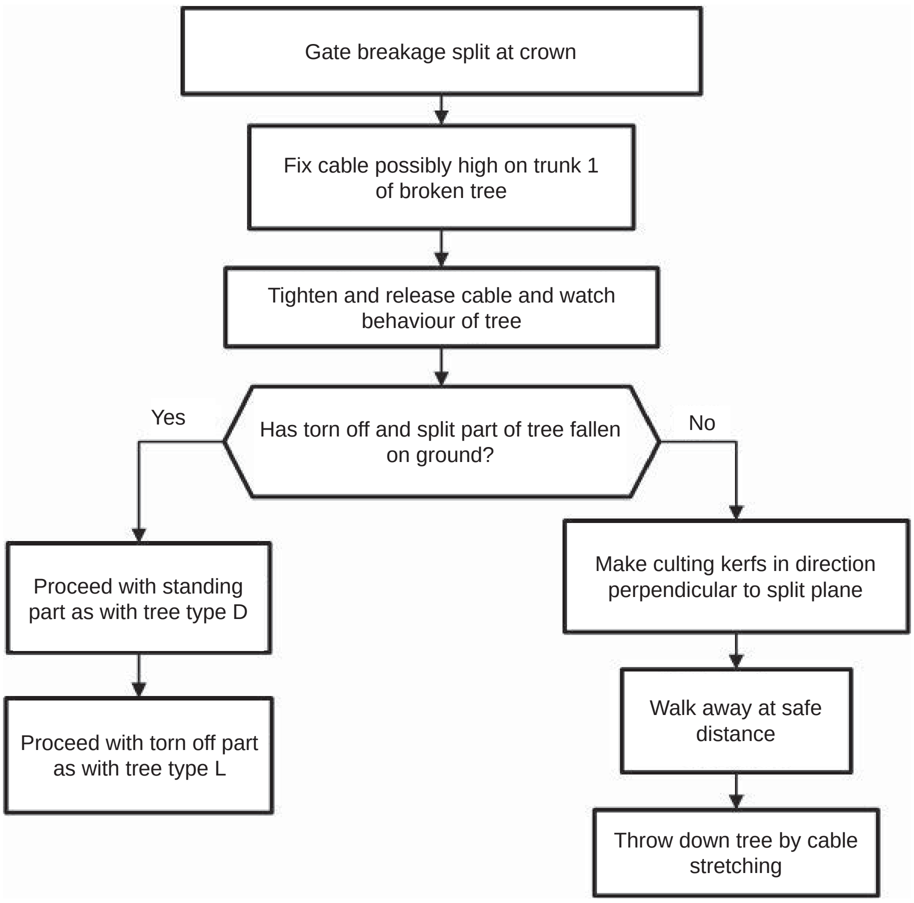

FIGURE 6. Block diagram of algorithm for removing gate breakage split at crown

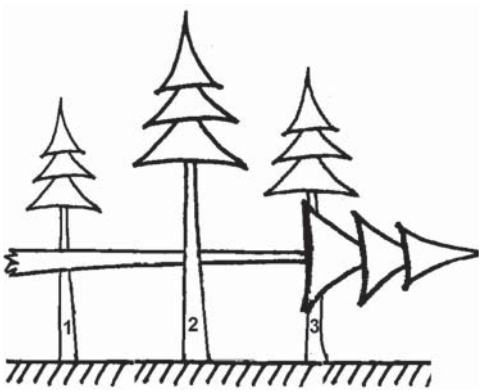

FIGURE 7. Jammed part of full breakage at big height

The way for releasing such suspended tree is supporting its butt end to protect it against out-of-control sliding down as well as cutting of standing tree 1. If it is impossible (e.g. when the tree is hanging at big height), one should attempt to reproach the cable on the suspended tree, as near as possible to tree 3. Then, one should pull away the top of suspended tree from standing tree 3, removing the stress in it. If the suspended tree does not fall down, the tree 3 should be cut down. After releasing the cable, the suspended tree will fall down autonomously. However, in that case the sawman will have to make the cutting kerf on tree 3, standing directly under the stressed hanging tree. It is extremely dangerous situation. The decision algorithm proposed for such case is presented in Figure 8.

Their number is practically unlimited; therefore, only application of a self-teaching system enables to propose the possibly safe technique for removing trees other, than included in knowledge base. Possibility of continuous supplementing the base with new cases is the biggest advantage of the proposed system.

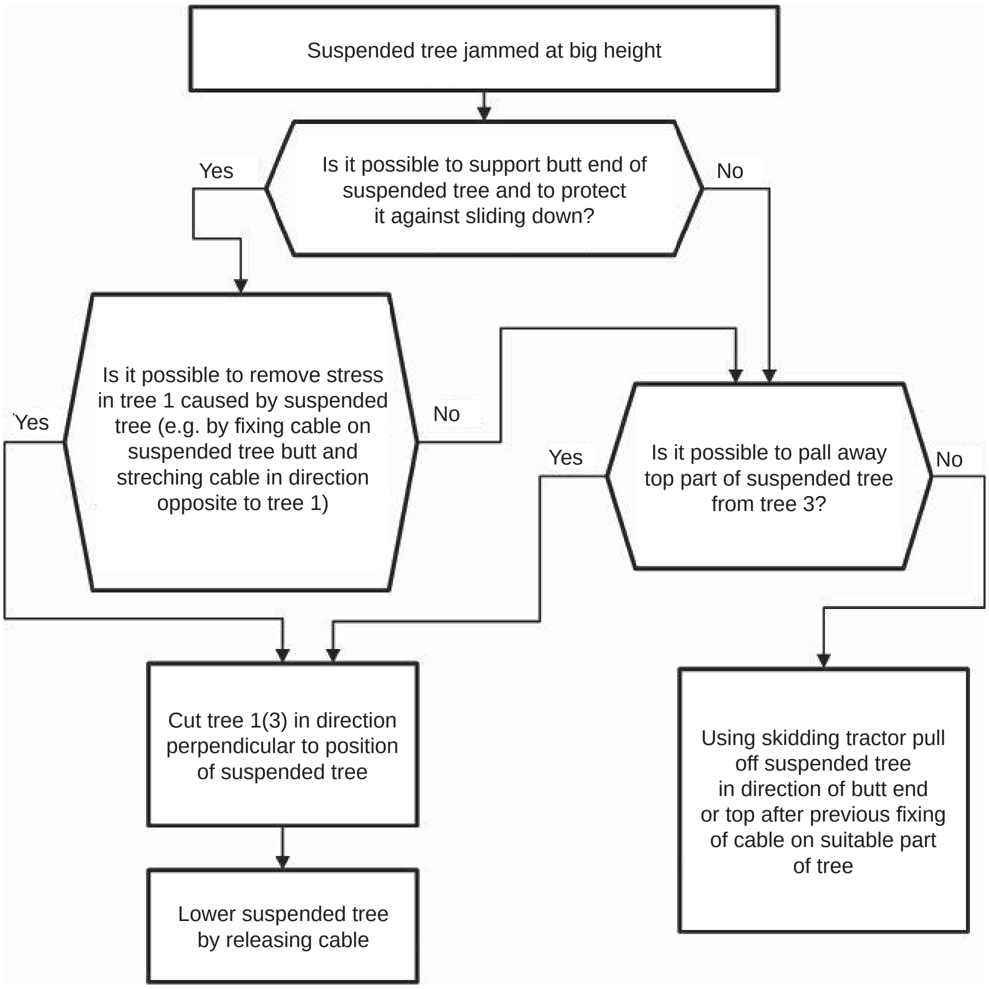

FIGURE 8. Block diagram of algorithm for removing tree jammed at big height

SUMMARY

Of course, the four described cases do not represent all existing variants of tree damages that occur on post-disaster sites.

One should also stress, that in every presented case the application of timber harvesting machines (if possible) should be rigorously recommended. However, the project authors assumed the least advantageous variant, taking into consideration only availability of internal combustion chain saw with essential equipment of sawman and auxiliary hand device in the form of a cable puller.

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Streszczenie: *Algorytmy postępowania z drzewami trudnymi jako podstawa systemu ekspertowego zwiększenia bezpieczeństwa pilarzy na terenach poklęskowych.* Coraz częściej wykorzystuje się do programowania procesów podejmowania decyzji systemy oparte na sztucznej inteligencji, a wśród nich systemy ekspertowe. Ideą ich jest symulowanie procesu podejmowania decyzji przez człowieka-eksperta, który swoją wiedzę zdobył poprzez wieloletnią działalność w danej dziedzinie. Podstawą takich systemów oprócz maszyny wnioskującej są obszerne bazy wiedzy zawierające fakty, prawa oraz reguły postępowania. Założeniem autorów jest stworzenie systemu ekspertowego wspomagającego proces szkolenia drwali do pracy w warunkach poklęskowych. Drogą osiągnięcia tego celu jest identyfikacja i określenie najważniejszych zagrożeń powstających przy pozyskiwaniu drewna z drzew szczególnie trudnych, określenie bezpiecznego sposobu ich uprzątania oraz wyrażenie tego sposobu w postaci reguł dających zastosować się w procesie decyzyjnym systemu ekspertowego. W artykule podano kilka przykładów algorytmów przedstawiających bezpieczny sposób pozyskiwania drewna z drzew bardzo trudnych oraz przedstawiono technikę ich uprzątania w formie opisowej. Możliwość ciągłego uzupełniania bazy o nowe przypadki jest największą zaletą proponowanego systemu.

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Authors' address:
Jacek Brzózko, Jan Skarżyński
Katedra Maszyn Rolniczych i Leśnych SGGW
02-787 Warszawa, ul. Nowoursynowska 164
Poland
e-mail: jacek_brzozko@sggw.pl;
jan_skarzynski@sggw.pl