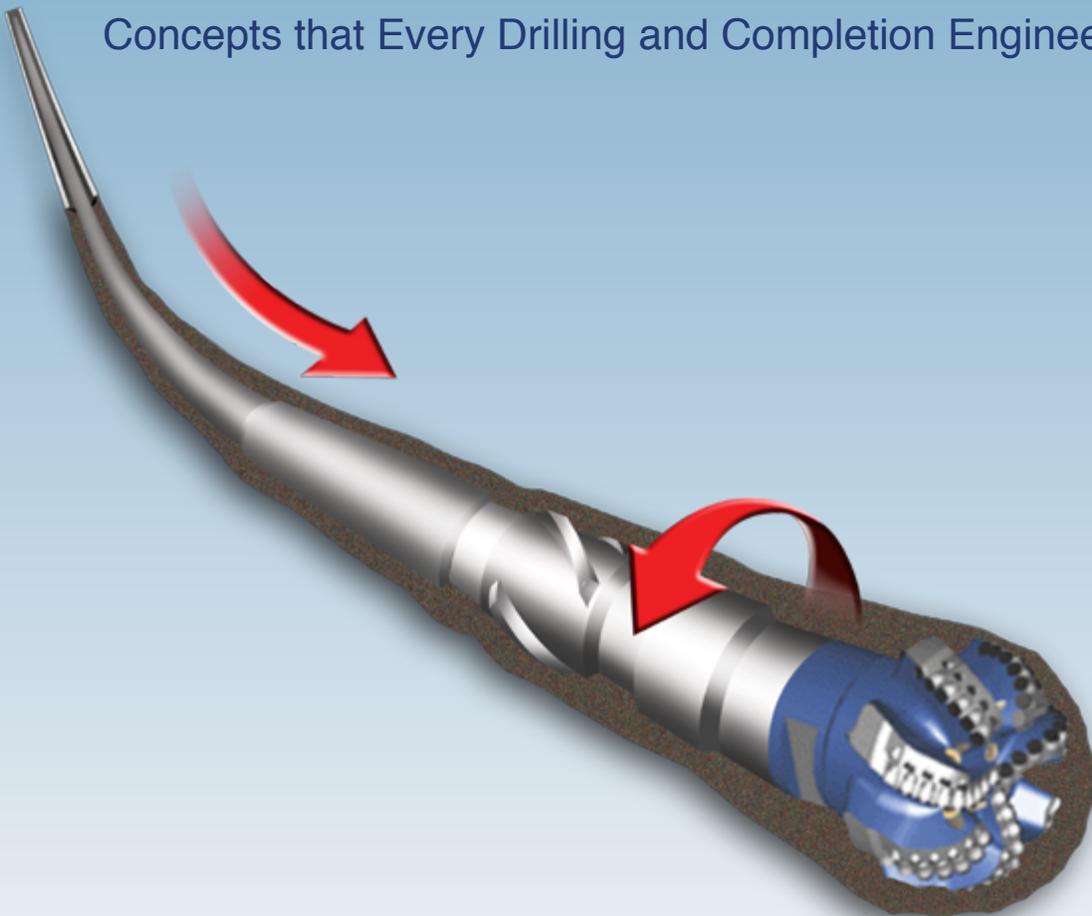


WHITE PAPER

Torque and Drag:

Concepts that Every Drilling and Completion Engineer Should Know



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I. The Problem

With the increase in the difficulty of drilling and completing oil and natural gas wells around the world (Figure 1), the technology required for discovering, accessing and then producing oil and natural gas has developed rapidly. Larger rigs and top drives, double-shouldered connections for drill pipe, new tools and new grades of steel are just a few of the many advancements in technology over the past few decades. Other advancements in technology needed to successfully locate and extract oil and natural gas are advanced software packages that assist with pre-job planning, assimilating and interpreting data and other crucial operational concerns.

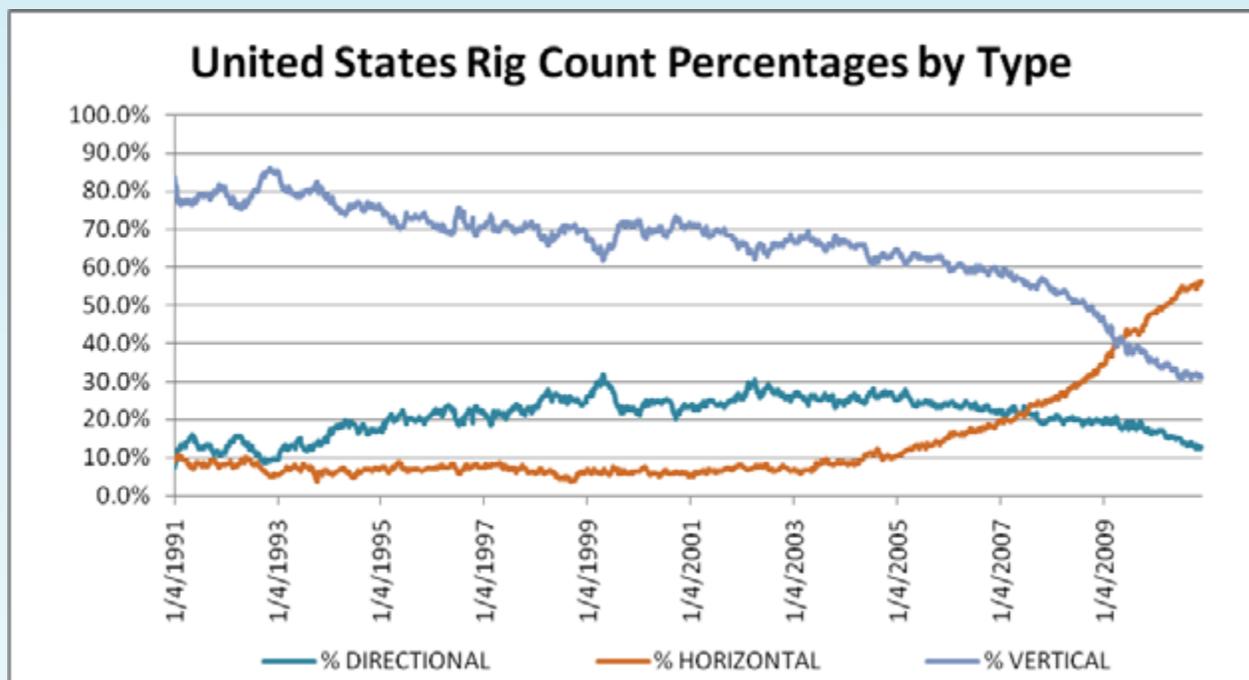


Figure 1: Baker Hughes International Rig Count November 2010

A common statement made of the energy industry is that the technology used to locate, access and produce hydrocarbons is on par with the technology used by NASA to put satellites in orbit and send astronauts to the moon. Drilling and operating tools several miles below the surface of the earth in temperatures exceeding 300 degrees Fahrenheit and pressures in excess of 5,000 psi on a regular basis requires very advanced technology. Wells that have pushed the limits of our current technological capabilities include a well drilled over 40,000 ft deep on the Kola Peninsula in Russia and a shallow ultra-extended reach well in Qatar less than 4,000 ft deep that extended almost 38,000 ft away from the rig (Table 1).

Year	Maximum Departure	Maximum TVD
1975	10,900	31,441
1980	15,082	31,441
1990	24,203	31,441
1995	26,361	31,441
2000	35,197	31,441
2005	35,197	40,230
2009	37,956	40,230

Table 1: Wells by Departure 1975 - 2009 [SPE 139410]

One of the largest challenges while drilling and completing wells is that surface data only provides a partial picture of what is happening downhole (Figure 2).

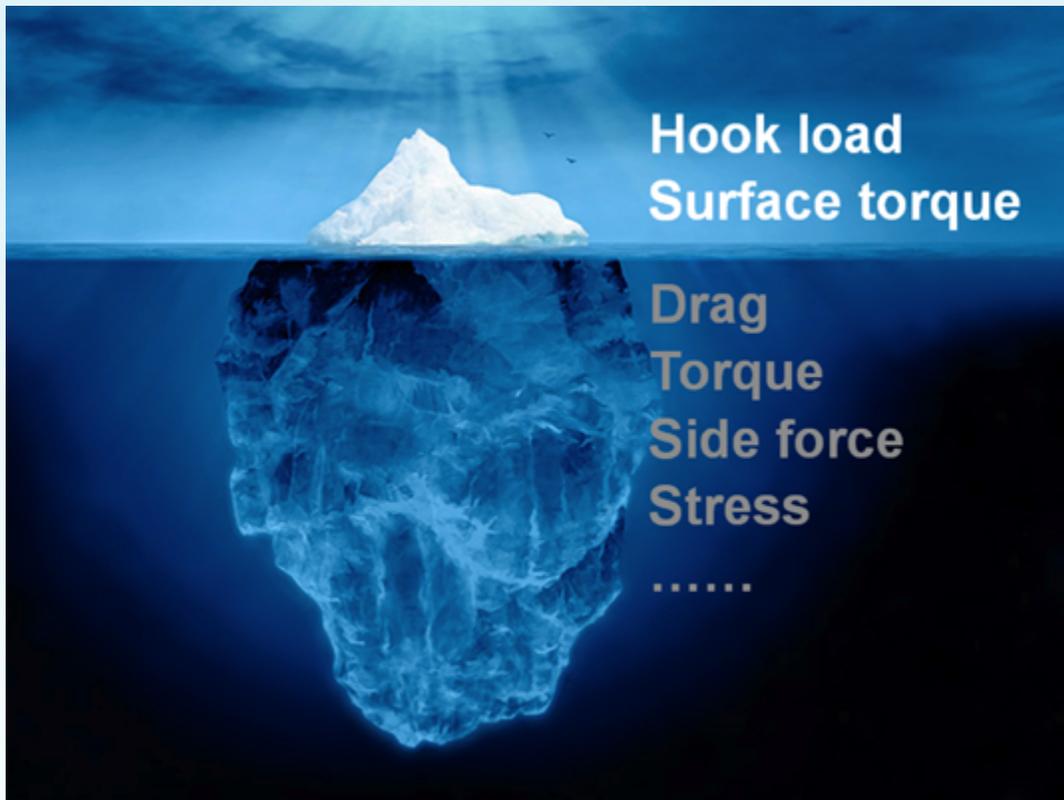


Figure 2: Iceberg Photo Representing Surface Indicators vs. Downhole Forces

Hookloads, surface torque readings and standpipe pressure measurements can indicate problems downhole, but even with these technological advancements, experienced individuals and engineers often have to make educated guesses as to what is happening in the well or with the particular bit or tool being run. Multi-million dollar decisions are commonly made by intelligent men and women using sound engineering principles. The problem is that these decisions are, by necessity, almost exclusively based off of partial data. The partial data used can be termed as surface indicators.

When centralizer salesmen claim their centralizers will reduce the drag running casing or a liner into the hole, how can this be verified? Lubricant companies claim reduction in the coefficient of friction as high as 80-90% within cased hole and specific formations, but is this true? When planning a challenging well or entering a new field, the questions of what size pipe, which type of connection and what size rig are needed to drill to TD. Run casing and complete the well cannot be answered without pre-job planning and the advanced software packages needed to analyze the various scenarios.

Although using offset well data can give excellent indicators, no two wells are the same. Moreover, it is not fiscally feasible to run a string of casing to TD without centralizers, pull it out of the hole and then run the same string into the same wellbore with centralizers. Disputes between operators and service companies often arise when a tool failure occurs. Often times theories are developed based upon the surface indicators available and the condition of tools that are removed from the well. Conclusive evidence to resolve these disputes is often unavailable without modeling software that can give a more accurate picture of what conditions the string was under before, during and after the failure.

II. Proof the Problem Exits

The most publicized problem over the past decade is likely the Gulf of Mexico oil spill that cost the operator many billions of dollars. Less publicized failures happen on a daily basis in the US. Though these problems with wellbores, downhole equipment and rigs often do not cause massive environmental damage, they are a regular part of the risk and business of accessing and producing oil and natural gas. The financial cost is difficult to assess, but settlements in the range of \$50,000 to \$1,000,000 occur fairly often.

Challenges in drilling and completing wells abound in today's oilfield where hydrocarbons are tapped in more and more challenging environments. One well in the Gulf during the previous decade began with an estimated cost of 17 million USD, but spent closer to 90 million USD by the time the final drilling assembly reached TD. This well was exploratory and turned out to be dry, with no hydrocarbons in the trap zone. Another operator in the US successfully drilled a well with a long reach. Two different types of specialty equipment, one on the production liner and one on the drill pipe used to convey the liner, were used to assist with getting the final section of the well cased. Unfortunately the liner landed several hundred feet off bottom.

In IADC/SPE 98969, ExxonMobil discusses an intensive R&D and field validation of various torque reduction methods that were used when drilling the shorter wells amongst an ambitious extended reach well project in the Russian Far East. Notable amongst the results is that lubricant testing in the laboratory under ideal conditions showed up to a 50% reduction in the coefficient of friction versus the use of the base fluid alone, but in the field the actual torque reduction was 5-15%. The engineers involved were also able to determine a significant torque reduction between hardbanded pipe and pipe with worn hardbanding, as the coefficient of friction of the steel was 0.21 and the hardbanding was 0.15.

In SPE 125991 three wells are discussed, of which two had unexpected problems drilling to total depth (TD) and one had unexpected problems completing the well. Well 1 was power limited and the string was torque limited. A new mud system was used which was expected to reduce the torque by 5-10%, but the torque increased by 7% as a result. Well 2 had a severe wellpath and the rig being used could not supply enough torque to finish drilling. The wellpath for well 3 had a small section that was severely off-path. Although the well was drilled to TD, the completion of this well was not possible without specialty tools to assist with drag reduction.

III. The Basic Solution

With the capital risk of moving into a new area to drill, ambitious ERW projects that push the technological envelope and challenges associated with conclusively determining what caused a particular failure during a downhole operation, many types of software are used during pre-job planning, real-time monitoring and post-mortem analysis. Torque and drag (T&D) software is one of the most widely-used types of oilfield engineering analysis packages. With T&D software the risks associated with drilling and completing a well can be assessed and much of the risk can be remediated during pre-job planning. Real-time monitoring of an operation can alert the rig crew to changing well conditions, and post-mortem analysis becomes much more accurate with the ability to understand the forces that various string components were subjected to downhole.

IV. Pre-Job Planning

In terms of pre-job planning, T&D software removes and reduces much of the risk of a drilling program, completions design or specific tool operation. Limits in the length of a horizontal based on specific friction factors can be determined. The ability to get needed weight to a liner-top packer can be evaluated. With the ability to analyze forces downhole, rig equipment specifications for torque and hookload can be predicted.

A short discussion on friction factors is pertinent at this point. A friction factor takes into account the coefficient of friction between the string and the already cemented casing, called the cased hole friction factor (CHFF), the coefficient of friction between the string and the open hole, called the open hole friction factor (OHFF), and a host of other factors. These other factors accounted for by the friction factor include good/poor hole cleaning and micro-tortuosity between survey points.

Because friction factors might vary, a sensitivity graph can be generated to show the degree of risk in OHFFs. Below is a friction factor sensitivity graph displaying a casing run with a set CHFF and OHFFs ranging from 0.1 to 0.35. At a 0.22 CHFF, which is typical for a water-based mud, and an OHFF of 0.1, there is still plenty of available hookload at TD. At an OHFF of 0.23, the available weight by TD drops almost to the block weight of 50,000 lbs. The friction factor of 0.35 is severe enough in this well that it is not possible to drill to TD, even when pushing with the block, which is necessary when the graph shows a hookload below the block weight.

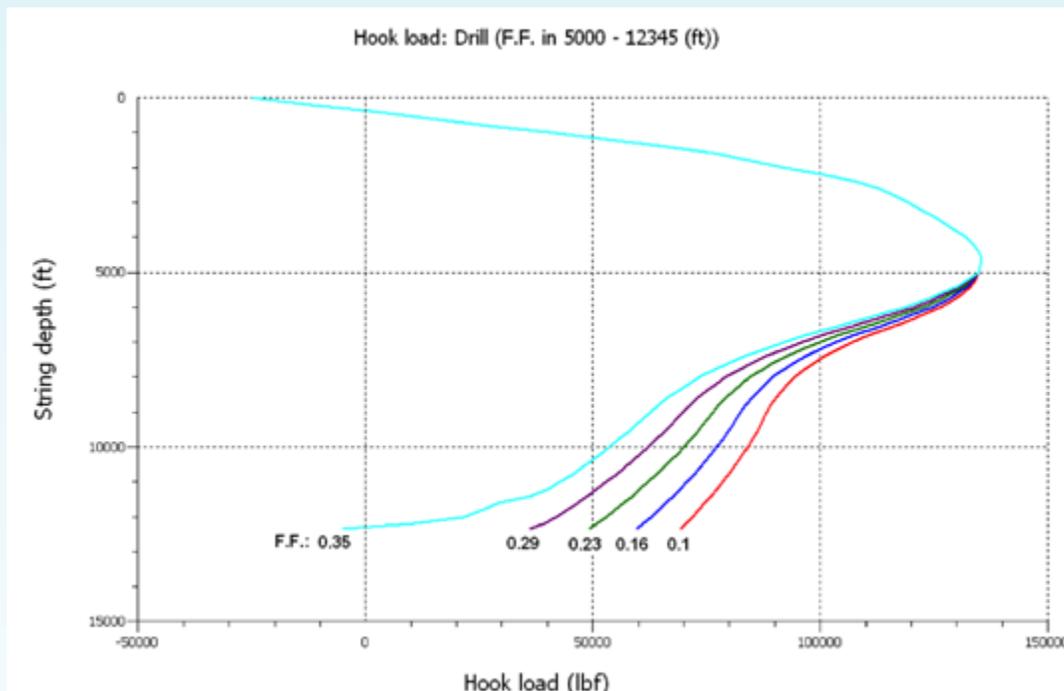


Figure 3: Friction Factor Sensitivity Graph

V. Real-Time Monitoring

Real-time monitoring is also a benefit of using T&D software. Some engineers and technicians take their software programs or hookload graphs onto the rig during drilling operations. As the rig drills deeper, the hookloads can be tracked against the predicted values. If the actual hookloads follow the predicted line for a 0.3 OHFF for a few thousand feet, but then transition to a 0.4 OHFF, something in the well has changed, such as decreased hole cleaning efficiency. This is an opportunity for the rig to change the drilling parameters such as slowing the ROP, or to stop and circulate prior to continuing, before a problem actually occurs.

VI. Post-Mortem Analysis

When a failure occurs there is an inevitable argument between service providers, oil companies and the rig contractor. Was a mistake made while performing the operation? Did a mechanical tool failure occur downhole or was it simply an unforeseen challenge presented by the formation? T&D modeling software can be calibrated to actual hookloads and surface torque values to get an accurate friction factor. Then the software can be used to look at the actual forces that were experienced by different sections of the string downhole when the problem occurred.

For any number of reasons from mitigating risks before a well is spudded, to managing operations as they are performed or looking into the drilling performance or a problem scenario after it has occurred, torque and drag modeling software is an excellent and vital tool for oil and service companies alike. Any company looking to purchase new T&D software should vet the software before making a capital commitment. Since the equations used to model torque and drag have not changed much since their inception into oil and natural gas drilling and completions, this task of evaluating a software provider's evidence of proper calculations should be fairly straight forward.

VII. Our Solution

Once a software’s basic calculations for torque and drag have been evaluated, the question is which software will provide the best results, ease of use and quality regarding the outputs provided. Although the main calculations are the same for any T&D program on the market, there are philosophical differences on how to account for pipe sag, calculate the density of string components and when to initiate buckling that can affect the results. The ease of a user acclimating to the input screens and entering information will affect how readily those users accept the software and how efficient they are with the modeling. Pegasus Vertex, Inc., a drilling software company, has produced, marketed and supported the **TADPRO** (torque and drag model) software program since 2002, and it has been in use by multiple major oilfield service companies.

The calculations used for the TADPRO software can be found in industry documentation and were compiled with the assistance of PhD research professors. A comparison of these calculations with the industry’s largest competitor in the market can be found in SPE 143623. The torque equation takes into account pipe sag when calculating torque, which is pertinent considering the increase in horizontal drilling in shale plays and the increase in deviated wellbores and ERWs. The density calculation fixes the density and weight, unlike competitive programs that allow the density to fluctuate if the user edits an existing component to create a new component (Table 2), which happens often when a specialty tool is needed for a model. The force required to initiate buckling in TADPRO is more conservative than other T&D programs, which has always been the industries preference when approaching potential buckling issues.

Mud Weight	W_A (Software A)	W_A (Software B)
2.08	15.67	16.75
8.5	15.67	18.50
17	15.67	20.82

Table 2: Equivalent Density of String Components - TADPRO (software A) and Software B [SPE 143623]

The user-friendliness of this program is unparalleled in the industry, allowing users to import PDF® files of wellpaths instead of requiring the user to generate a Microsoft Excel® file prior to import. The user-interface is easy to acclimate to and enables users to begin modeling sooner. The auto-generated reports are put together in a Microsoft Word® document that allows editing and the technical support provided is not only fast but also practical and useful.

The graphical outputs of the TADPRO software lead the industries T&D software. 3D graphical video representations of where buckling will occur while drilling and tripping in allow the engineers involved to view where the buckling will initiate (Figure 4), how it will propagate and how severe it will get over the entire run.

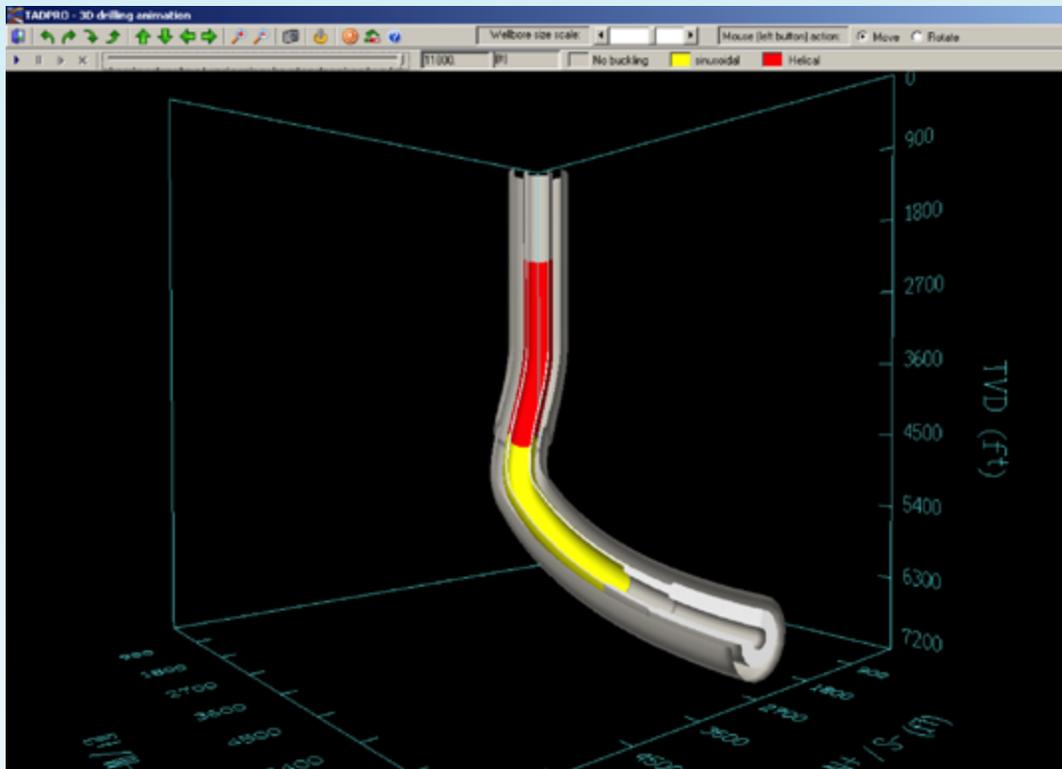


Figure 4: 3D Video Screenshot of Buckling in a String

Another important point to note is that, unlike other software programs, there are two operation lines in TADPRO that allow users to define every parameter. Other software programs are unable to handle computations involving drilling with casing because the drilling line rotates at an RPM value that is too high, overpull applied when jarring up because the upward moving lines either do not allow a force at the bottom of the string or involve rotation, and many other scenarios that are likely to occur in a well. TADPRO provides both versatility and accuracy in its calculations, while also integrating many features that make it easy to use and interpret results.

V. Conclusion

With the uncertainty and cost involved in drilling, running tools and providing services, a good evaluation software is a necessary part of any oilfield company's toolbox. No one would walk across a busy street with their eyes closed, nor should anyone send a tool or bit downhole without a clear view of what forces it might encounter.

For more information, visit the TADPRO website to look at more of the features the software provides, download a brochure or obtain a quote: www.pvisoftware.com/TADPRO.html

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